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Europäische Telemetriekonferenz mit Ausstellung

European Telemetry Conference with Exhibition

27. – 30 .05. 2002 / Garmisch-Partenkirchen, Kongreßhaus
Germany

Veranstaltet von:	**Arbeitskreis Telemetrie e.V.**
organized by:	***German Society of Telemetering***

in Zusammenarbeit mit
in cooperation with

- **Deutsche Gesellschaft für Luft- u. Raumfahrt e.V. Lilienthal – Oberth e.V. (DGLR) Fachausschuß 6.1 "Telemetrie"**
- **Technische Universität München Lehrstuhl für Flugantriebe**
- **International Foundation for Telemetering (IFT)**
- **International Society on Biotelemetry (ISOB)**
- **Société des Électriciens, des Électroniciens et des Radioélectriciens (SEE), Section 17**

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INTRODUCTION

The EUROPEAN TELEMETRY CONFERENCE etc 2002 will be held in form of a Congress with Exhibition for Telemetry,Test Instrumentation and Telecontrol in Garmisch-Partenkirchen, Germany, from May 27 to 30, 2002. The event will be organized by the German Society of Telemetering [Arbeitskreis Telemetrie e.V./ DGLR-section 6.1"Telemetrie"] and will inform the experts on innovations and the latest state of the art in this field.
The international character of the etc 2002 again is stated by a large number of lecturers and participants from european and overseas countries. The papers will be presented in english language, according to the internationality of the event.Due to the number of conference contributions it is necessary to held parallel meetings.
Along etc 2002 the Annual Plenary Meeting of the European Telemetering Standardization Committee [ETSC] with delegates of Germany, France, Great Britain and TSCC/USA will take place. In addition questions of the future availability of frequencies for telemetering purposes are discussed in a meeting of the International Group of Telemetry Practioners [ICTS]

Together with etc2002 the Symposium "Aircraft Integrated Monitoring Systems" AIMS2002 will take place as in the years 1998 and 2000.
Participants of etc 2002 and AIMS 2002 are free to attend the presentations of both events as well as to visit the common exhibition.

A CD, which contains all presentations of etc 2002 and AIMS 2002 as well as the presentations of etc 2000/AIMS 2000 and ETTC 2001 which was held in Marseille, further a part of the exhibitors catalogue, will be added to this Proceedings Volume.Due to the fact, that all contributions have been established by means of computerized text- and graphic processing, many authors made use of coloured pictures and diagrams in their papers. Because of cost reasons the Proceedings Volume could not be printed in colour, the CD is a great supplement serving to show the coloured graphics on the screen of a computer monitor.
The German Society of Telemetering as organizer of the etc 2002 will further endeavour itself in discussions with the participants of the conference, as well as in dialogue with other national and international organisations, e.g. the "International Foundation for Telemetering [IFT]" in the USA, the "Société des Electriciens,des Electroniciens et des Radioelectriciens [SEE],section 17" in France, the "International Society on Biotelemetry [ISOB]" and the "Low Power Radio Association [LPRA]" in England, in order to recognize trends and developments in the field of Telemetry, Test Instrumentation and Telecontrol and to take this into account in future events.
The joint exhibition gives an extensive overview of the latest developments in technology and on the great variety of hardware and software for instrumentation, installation and systems concerning Telemetry, Test Instrumentation and Telecontrol. 70 manufacturers and organisations are exhibiting on 60 booths.
On behalf of the Arbeitskreis Telemetrie e.V. I say thanks to all who worked in the organisation of etc 2002 / AIMS 2002, as well as to all lecturers and exhibitors contributing to the success of the event.

Hans-Joachim Klewe
Conference Chairman

EINFÜHRUNG

Die EUROPÄISCHE TELEMETRIEKONFERENZ etc 2002 findet vom 27.-30.Mai 2002 als Kongress und Ausstellung für Telemetrie, Versuchsinstrumentierung und Fernwirken in Garmisch-Partenkirchen statt. Die Veranstaltung wird vom Arbeitskreis Telemetrie e.V./ DGLR-Fachausschuß 6.1"Telemetrie" durchgeführt und informiert über Innovationen und den Stand der Technik dieser Fachgebiete.
Wie bei den vorhergehenden Europäischen Telemetriekonferenzen wird auch bei der etc 2002 der internationale Charakter der Veranstaltung durch eine große Zahl von Vortragenden und Teilnehmern aus Europäischen und Überseeischen Ländern belegt. Die Vorträge werden, der Internationalität der Veranstaltung entsprechend, in englischer Sprache gehalten. Die große Zahl der Konferenzbeiträge macht es erforderlich, Parallelsitzungen in den zur Verfügung stehenden Konferenzräumen durchzuführen.. Im Rahmen der etc 2002 findet wie üblich eine Tagung des Europäischen Telemetrie Standardisierungs Komitees [ETSC] mit Teilnehmern aus Deutschland, England, Frankreich sowie Delegierten des TSCC/USA statt.
Weiter tagt die International Group of Telemetry Practioners [ICTS], deren Thema die Sicherstellung von Frequenzen für Telemetrie-Anwendungen ist.

Zusammen mit der etc 2002 findet wie schon in den Jahren 1998 und 2000 das Symposium "Aircraft Integrated Monitoring Systems" AIMS 2002 statt. Den Kongressteilnehmern stehen die Vortragsreihen beider Veranstaltungen offen.

Dem vorliegenden Tagungsband wird wieder eine CD beigefügt, die alle Vortragsreihen der etc 2002/AIMS 2002 als auch der etc 2000/AIMS 2000 sowie die Vorträge der ETTC 2001 (Marseille) und einen Teil des Ausstellungs-Katalogs enthält. Bei den mittels elektronischer Textverarbeitung erstellten Beiträgen haben sehr viele Autoren von der Möglichkeit Gebrauch gemacht, Grafiken und Bilder farbig darzustellen. Da der Tagungsband aus Kostengründen nicht farbig gedruckt werden konnte, stellt die CD eine hervorragende Ergänzung dar, da nunmehr die Farbdarstellungen auf dem Bildschirm erkennbar gemacht werden können.
Der Arbeitskreis Telemetrie e.V. [German Society of Telemetering] als Veranstalter der etc 2002 wird sich im Gespräch mit den Teilnehmern der Konferenz und im Dialog mit anderen nationalen und internationalen Organisationen wie der International Foundation for Telemetering [IFT] in den USA, der Société des Electriciens, des Electroniciens et des Radioelectriciens [SEE] Section 17, der International Society on Biotelemetry [ISOB] sowie der Low Power Radio Association [LPRA] weiterhin bemühen,Trends und Entwicklungen im Bereich der Telemetrie und Fernwirktechnik zu erkennen und bei künftigen Veranstaltungen zu berücksichtigen.
Die mit der Konferenz verbundene Ausstellung gibt einen umfangreichen Überblick über den Stand der Technik und die Vielzahl des Angebots von Hard-und Software bei Geräten, Anlagen und Systemen im Bereich der Telemetrie, der Versuchsinstrumentierung und des Fernwirkens. Mehr als 70 Hersteller und Organisationen stellen auf 62 Ständen aus.
Im Namen der Arbeitskreises Telemetrie e.V. danke ich Allen, die bei der Organisation der etc 2002 mitgewirkt haben, sowie allen Vortragenden und Ausstellern, die zum Erfolg der Veranstaltung beigetragen haben.

Hans-Joachim Klewe
Conference-Chairman

DATA RECORDING AND STORAGE

‘NEW TECHNOLOGY’ DATA RECORDERS
A TECHNOLOGY OVERVIEW

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ABSTRACT

For longer than anyone can remember, the days of the ubiquitous magnetic tape recorder have been numbered. But whenever recording *gurus* have met to consider the medium’s imminent demise, the conclusion has hitherto always been the same. “Yes, tape is definitely on its way out – but maybe not quite yet”.

Just two years ago, at ETC 2000, there were clear indications that ‘new technology’ (disk and solid-state) products were about to challenge tried and tested ‘legacy’ (linear and rotary) tape products - but the evolution was still in its infancy. Few would now doubt however that this change is now well underway – and possibly at a faster rate than many observers might suppose.

The dynamics of this transition are extremely interesting, involving a number of important changes of focus among recorder manufacturers and users alike. For example, while ‘new technology’ products typically offer improved data rates and capacity than their tape-based predecessors, and at lower cost, these attributes are not in themselves enough to guarantee success. Users are looking for much more – ease of integration into existing data capture and analysis environments, more convenient data management and processing, improved dissemination of data to where it is needed, and so on.

This Paper offers a brief overview of the choice of ‘new technology’ solutions now becoming available – in particular, Solid State Recorders, JBODS (just a bunch of disks) and RAIDS (redundant arrays of independent disks). New solutions for airborne, mobile and laboratory data collection, handing, analysis and archiving are discussed, demonstrating that (for once) the migration path has been carefully charted, with industry-standard data interfaces, true computer connectivity (Windows and UNIX) and familiar control techniques.

The Paper concludes that many users with a keen interest in replacing ‘Legacy’ products for whatever reason can now do so with confidence – with little or no disruption to their day-to-day operation. At the same time they can access the important benefits which ‘New Technology’ solutions offer – improved performance, higher capacity, convenient data handling, easy computer connectivity and lower cost.

KEYWORDS

Data, recording, capture, acquisition, storage, RAID, JBOD, magnetic, tape, disk, solid-state, new technology, legacy, STANAG 4575, telemetry.

INTRODUCTION

The term ‘new technology’ is popularly taken to describe recorders which use either solid-state memory or disks as their primary storage medium. In one sense of course the term is a misnomer since these technologies have been around in their own right for many years. Indeed, both have been chipping away at the lower end of the data acquisition spectrum for decades. But in the context of ‘high end’ data capture, solid-state and disk-based recorders are relative newcomers to the scene. Now for the first time the traditional supremacy of magnetic tape in terms of bandwidth and storage capacity is seriously in question.

SOLID-STATE RECORDERS

The fundamental *raison d'être* for solid-state recorders is obvious. With no critical moving parts, a carefully designed recorder might reasonably be expected to out-perform an electro-mechanical device (e.g. tape or disk) under extreme conditions of shock, vibration, temperature and acceleration. Technically speaking, maximum data rates and capacities for solid-state recorders are not an issue since the architecture of the device can be scaled as required. Compared to sophisticated electro-mechanical tape recorders maintenance costs are minimal. An early entrant into the proprietary solid-state recorder market was the Calculex MONSSTR™ family of recorders used primarily for reconnaissance, missile and flight testing applications aboard fighter aircraft and helicopters. Present implementations of MONSSTR™ offer data rates to 1 Gbps and scaleable storage to 415 GB in one or more hot-swappable canisters. A more recent example is S/TAR™ range from L-3 Communications offering data rates to 400 Mbps and capacities to 16 GB (RM-3000) and 100 GB (RM-8000) in a removable cartridge. Both manufacturers prefer the non-volatile FLASH memory technology to the more bulky DRAM devices found in some early examples of solid-state recorder. L-3 Communications has also formed a marketing partnership with Ampex, manufacturer of the widely used 1 inch transverse scan DCRsi™ tape recorders, in order to be able to offer total collection-to-archive system solutions. Under this arrangement, Ampex markets the S/TAR™ as its SSRS™ product.

The relatively high cost of memory compared to tape and disk media is an important factor when considering very high capacity (100+ GB) applications, particularly when a number of cartridges are involved. Although disk and solid-state technologies are at about the same level of maturity, FLASH memory is currently some fifty times more expensive than disk storage. Although the cost per MB of FLASH memory can be expected to improve as 256 Mbit chips displace the existing 64 Mbit devices, many observers expect this differential to remain a significant factor for the foreseeable future. Table 1 includes a representative sampling of proprietary solid-state recorders.

DISK RECORDERS

The evolution of recorders based on hard-disk technology has been astounding. Just a couple of years ago, this approach was little more than a 'promising concept'. But now at least three major manufacturers have introduced one or more disk-based products. Disk recorders come in two flavors; RAID (Redundant Array of Independent Disks) and JBOD (Just a Bunch of Disks). While both use similar high-end computer peripheral hard-drives, it is important to understand the differences between the two approaches. RAID-based recorders generally convert the data input (typically digital, analog, pcm, telecommunications or video data) to a conventional computer file which is written directly to an array of disks according to industry-standard RAID conventions. Although these files may later be converted back to their native format for analysis it is more normal for them to be analyzed directly on a workstation. This means that the traditional problems of getting instrumentation data into a computer format for analysis are largely overcome. Typical of this approach are the Ampex *FAST*disk ™ RAID and the Sypris Data Systems (formerly Metrum-Datatape) Model 80, both of which use RAID-3 level parity. As its name implies, Calculex's SPIDR™ (Smart PCI-based Instrumentation Data Recorder) utilises specially designed analog and digital PCI bus modules which reside within a personal computer. In contrast, JBOD recorders simply commutate a digital bit stream across all the available disks in a continuous, relatively unstructured fashion in order to gain the maximum possible speed advantage. The JBOD technique is a more efficient use of the available disk space since no redundancy is involved. Although implementations differ, JBOD recorders tend to emulate traditional tape recorders so that conversion to a computer file or other data format will generally involve a separate 'extraction' process. Examples of JBOD recorders include the Ampex DDRS™ family, the Avalon AE7000 and Enertec's DS2000 and DS4000 products.

Disk-based recorders (RAID or JBOD) are an attractive proposition on several counts. At the present time, digital data rates as high as 1 Gbps can be supported by as few as eight inexpensive 36 GB hard-disks operating in parallel. That's around 50 MHz of signal bandwidth in analog terms (8-bit sampling), or more than double the capability of the fastest tape recorders currently available. For SIGINT, reconnaissance imaging and similar applications where bandwidth really matters, this is an important gain. It is predicted that the next generation of 72 and 143 GB disk drives now becoming available will support a sustained data recording rate of up to 2 Gbps – or DC to 100 MHz in analog terms. With a suitable multiplexer/demultiplexer this class of system can easily emulate a 14-track analog IRIG legacy recorder, with bandwidth to spare. An example of this approach is Avalon's AE7000 disk recorder which can be integrated either with the company's own 16-channel MUX/DEMUX or a proprietary telemetry multiplexer such as Apogee Labs' MITC-430. An 8 x 36 GB disk configuration has a storage capacity of some 275 GB (2 Terabits) – nearly three times that of the largest ANSI ID-1 tape cartridge, for example. The new generation of 142 GB disk drives will extend this figure to over 1 TeraByte (more than 8 Terabits). The random access element of disk recording has been used to good effect in several recorders where a true read-after-write mode has been implemented. This has the advantage not just of allowing the user to confirm that error-free data is being collected but, much more importantly, offers the possibility of accessing recently acquired signals for immediate examination or analysis without interrupting the recording process in any way. As with solid-state recorders, maintenance costs are minimal.

With some implementations of disk recording now capable of operating reliably in all but the most severe of platform environments, disk recorders in reality share virtually all of the attributes of a solid-state recorder – high recording rates, high storage capacity, random access, a read-after-write capability – but at a significantly lower unit cost. Hard-drives also have a good road map. When disk recorders were first introduced a year or two ago they typically incorporated 9 or 18 GB drives. Already 36 GB drives are the norm, with the promise of 72 GB and 143 GB products becoming available from multiple sources during 2002. Table 2 includes a representative sampling of proprietary disk-based recorders.

APPLICATIONS

But solid-state and disk recorders share one major drawback in that neither offer a direct means of long-term 'permanent' storage. Consequently, transcription to another form of archival medium is invariably required. It is the inventiveness of manufacturers in this particular area where the most important advances have been made. To see how the apparent shortcomings of disk and solid-state storage have been overcome to the practical benefit of the user, it is convenient to discuss several representative applications.

High Environmental Platforms

These typically include; high performance aircraft, strategic/surveillance aircraft, UAV's and most helicopters. Applications include the recording of imagery, COMINT, ELINT, ASW, mission video, avionics and flight test/evaluation data. By definition, the environment is anything but benign, the available space is invariably limited and the crew (if there is one) will generally have little time to worry about the recorder. The opportunity may sometimes exist to downlink critical data during the mission, but more often the recorder has to look after itself. In essence it is vital that all mission data be brought back alive for others to deal with later.

From the survival standpoint, a solid-state recorder appears to start firm favorite, particularly if it is designed to emulate the legacy recorder which it is intended to supersede. In recent years, two classes of tape recorder have dominated the high environmental area – the 1 inch transverse scan DCRsi family from Ampex and the 19 mm helical scan ANSI ID-1 products from Enertec, Sypris Data Systems (Metrum-Datatape) and others. Not surprisingly therefore, Ampex, Calculex and L-3 Communications all offer their solid-state recorders with full DCRsi and/or ID-1 emulation/compatibility. Calculex also offers compatibility with the Sypris' ½-inch tape VLDS/Model 64 family. These products all have removable memory canisters or cartridges which can be inserted into a compatible ground-replay unit at the end of the mission either for direct data analysis or for transcription to a high capacity tape recorder.

But the high environment area is no longer the exclusive preserve of solid-state recorders. Ampex offers its DDRS disk-based family as a lower cost alternative to both its tape and solid-state products. Its DCRsi-compatible DDRS 400 recorder offers 100 GB of disk storage in a compact hermetically sealed cartridge which is capable of operation at high altitude without regard to the effects of moisture and dust. Similarly, Enertec offers a family of disk-based recorders for high environmental electro-optical/IR/SAR reconnaissance imagery, ASW and flight test applications. Although Enertec still sees a long-term future for its conventional ID-1 helical scan tape products it has nevertheless developed the necessary airborne and ground-support elements to permit the smooth flow of imagery, acoustic, digital and video data from sensor to analysis equipment. The larger DS4100 recorder can capture 72 GB of data at up to 240 Mbps).

The interchangeable medium (solid-state cartridge or disk pack) approach just described is generally quite acceptable in a flight test scenario for example where the aircraft may not be flown again for some time, but may cause difficulties under battlefield conditions where the aircraft must be readied for use again in minutes. It is of course possible to rotate several cartridges so that a fresh one is available for each new mission, but the high cost of solid-state memory modules in particular may sometimes render this approach uneconomic. A further complication arises when an aircraft lands at an unfamiliar base where no compatible replay facilities exist. To overcome these problems, NATO Air Group IV TST is working with industry and others to develop a new standard NATO agreement (STANAG 4575). The intent is to define a *generic* download port for any airborne recorder (particularly disk-based and solid-state units) so that any ground station with a compatible port will be able to extract and transcribe the stored data from any compliant recorder, *in situ*. It is expected that STANAG 4575 will define the physical connector, the power requirements, the data and control interface (copper FibreChannel) and the protocol (a sub-set of SCSI-3). This approach of transferring the compatibility issue from the *media* to the *interface* is an important example of how manufacturers and users are taking advantage of the opportunities offered by new technology products to ease the flow of data through the overall data path.

These two complementary routes to compatibility with legacy products means that new technology recorders can generally be integrated directly into an existing data capture, analysis, dissemination and archiving infrastructure with minimal disruption. The clear strategy in the high environmental platform area is for manufacturers to offer new technology products as direct replacements for existing legacy recorders, facilitating this transition with a range of proprietary and/or generic data and control interfaces. This way, a user's investment in existing technical and operational infrastructure (sensors, analysis equipment, software and on-line, near-line and off-line mass storage systems) can still be utilized while at the same time establishing a clear migration path to access the improved capabilities and/or cost advantages of the new solid-state or disk-based products.

Large Platforms and Static Locations.

Away from the high environmental environment, the story takes a different turn. Although there are some obvious differences between large aircraft, ships, submarines and static environments from the data collection point of view, these can nevertheless be considered as a group for this discussion. The more benign 'shirtsleeve' environment of these locations does not generally justify the cost premium associated with a solid-state recorder so the interest here currently is mainly in the capabilities of disk recorders.

But one further and vitally important consideration also comes into play. As with high environmental applications, there are many cases where all recorded data must be transferred from temporary to permanent storage as soon as possible. It is generally essential for example that all COMINT and reconnaissance imagery data be archived so that this material can be accessed again quickly in the future. In other cases, the 'good' data recorded during a mission or test may represent only a small fraction of the total dataset. For example, the calibration and measurement telemetry from a test missile firing may occupy only a few minutes of the day's work. In this situation, the ability to edit and transcribe these short passages to low cost medium immediately after the completion of a test often simplifies the subsequent analysis process considerably. Similarly, in some ELINT applications, the number and duration of 'interesting' contacts during a mission may be small. Here too some immediate editing and sifting will often be an advantage. A subtle but important sub-set of this concept is the ability of operators to review recently recorded data without interrupting the recording process. Disk recorders with a read-while-write capability allow operators to recall possible contacts for more detailed examination – with the added potential for marking the passage of interest for transcription if necessary. There is also a growing need to transmit recently acquired data to another location electronically rather than ship bulky tapes by land, sea or air. A typical example might be where missile telemetry is captured at a remote range but processed at a central analysis facility. Valuable time could be saved if the salient data could be transmitted back to base by secure link after each test.

Not surprisingly, the exact approach taken by the manufacturers of disk recorders tends to be based on their own background and experience. For example, Ampex offers its *FAST*disk recorders as a direct replacement for its DCRsi digital cartridge tape recorder. With data rates of 960 Mbps it comfortably out-performs the 240 Mbps capabilities of the fastest DCRsi recorder, but at a fraction of the cost. So too do the company's 400 Mbps DDRS systems. For easy integration into an existing Ampex UNIX or NT platform or analysis facility, these new units can all transcribe data directly to Ampex's DCRsi and/or DIS mass storage tape recorders and libraries. Sypris Data Systems' PC-based Model 80 RAID recorder is offered as a direct replacement for the company's Model 64 and Buffered VLDS ½-inch cassette tape recorders which are used to record the output of ARMOR data multiplexers in multichannel telemetry applications. Model 80 stores data as computer files on its internal hard drive(s). Files can then be transferred to an archive device, forwarded over a network or replayed using the ARMOR system. The highest data rate is 80 Mbps and the maximum storage capacity is 72 GB.

Avalon has taken a slightly different approach with its AE7000 Disk Recorder. Designed specifically to emulate a tape recorder as closely as possible, this unit is offered with a range of interchangeable analog, digital and telecommunications interfaces. Since Avalon's background is mainly in SIGINT, ASW and telemetry it has elected to concentrate on the high bandwidth and storage capacity features of disk recording. With a maximum native data rate of 1 Gbit/s and a capacity of 2 Terabits (on eight 36 GB hard drives), the company has understandably given a considerable amount of thought to the question of pre-analysis editing and transcription. Three levels of permanent data storage are offered. First, selected passages of recorded data can be transcribed directly to a built-in Exabyte M2 or AIT-2 tape drive for transfer on cassette to a separate analysis workstation. Provided that the data sets are relatively small (as with many telemetry applications, for example), this approach offers an extremely cost effective means of storing and distributing edited passages of data. The second level of permanent storage involves integrating the AE7000 Disk Recorder with an NT4 Workstation running a series of proprietary data management utilities. These allow the user to select passages of recorded data for saving to computer disk or distribution across a network. For long term, unattended monitoring applications, Avalon offers a range of integrated tape library solutions. For legacy applications, the AE7000's normal single channel 20 or 50 MHz analog interface can be replaced with a 16-channel 2 MHz analog interface which is designed specifically to emulate 14-track IRIG recorders. Alternatively, the unit can be interfaced directly to its own 16-channel MUX/DEMUX or a number of 3rd Party telemetry multiplexer/demultiplexers.

SUMMARY

We have seen that 'new technology' recorders offer a number of intrinsic benefits compared with traditional recorders; higher data rates, higher capacities, excellent recording fidelity, durability, ease of data handling, relatively low capital cost and near-zero maintenance. Indeed, in terms of data rate and capacity the new technologies now actually allow designers to go far beyond the practical limits of tape-based systems without incurring the usual penalties of increased cost and complexity. But these benefits alone are not what have spawned the present interest in new technology solutions. No, this is the result of the way that manufacturers across the board have taken the opportunity to develop real improvements in operational capability while at the same time minimising the risks and disruption normally associated with technological advances.

In the high-environmental area, manufacturers have adopted a 'cut-and-paste' philosophy whereby new solid-state and disk-based products can simply be substituted for legacy recorders, in many cases using directly plug-compatible data and control interfaces. This way, the transition becomes more or less transparent to user, with minimal disruption to their tried and tested data collection, analysis, distribution and archiving infrastructure. But at the same time, the building blocks for future improvements in operational capability are in place – wider bandwidth, improved data integrity, lower maintenance costs, etc. In addition, the potential problems associated with a proliferation of recorders, media and formats are being addressed by a standardisation effort at the *interface* (rather than at the *hardware*) level – offering the possibility of a hitherto undreamed of level of interoperability around the world.

In more benign environments, designers have taken the opportunity to nail the age-old computer interfacing problem once and for all. Instead of having to shoe-horn a traditional data recorder into a computer environment (generally at considerable cost), users of new technology recorders are presented with their data in PC or UNIX formats – perhaps already edited for immediate networking and analysis.

The movement to replace 'legacy' recorders with 'new technology' devices is already well underway. In some cases, particularly where the installed base of 14 and 28-track IRIG recorders is concerned, the need is becoming urgent as critical spares become more difficult to source.

Users with a large investment in current generation large format rotary systems can perhaps afford to take a longer term view since it is anticipated that the availability of these units and their spares is not an issue at present. Nevertheless, many programs would welcome the enhanced capabilities that 'new technology' recorders can offer, not just in terms of raw bandwidth and capacity but also the ease with which data can now be handled and processed. This carrot has been made even more enticing by the way that manufacturers have eased the transition from the old to the new with a low risk cut-and-paste approach to recorder substitution. For the first time ever, perhaps, the next generation of recorders may not be accompanied by a heavy cost penalty or a requirement for substantial levels of NRE. They can be tried and tested within existing environments and implemented without significant disruption to existing systems.

TABLE 1: COMPARISON OF SOLID-STATE RECORDERS

Vendor	Product	Data Rate (max.)	Capacity	Emulation/ Compatibility	Primary Data Interface	Removable Medium
Ampex	SSRS	400 Mbps	8 – 100 GB	DCRsi ID-1	Digital	Yes
Calculex	MONSSTR	1 Gbps	22.7 – 415 GB (scaleable)	DCRsi VLDS ID-1	Digital	Yes
L3 Communications	S/TAR RM-3000	400 Mbps	8 – 16 GB	DCRsi ID-1	Digital	Yes
L3 Communications	S/TAR RM-8000	400 Mbps	8 – 100 GB	DCRsi ID-1	Digital	Yes

TABLE 2: COMPARISON OF DISK RECORDERS

Vendor	Product	Type	Data Rate (max.)	Capacity (max.)	Emulation/ Compatibility	Primary Data Interfaces	Removable Media
Ampex	*FAST*disk	JBOD	960 Mbps	432 GB (12 HDD)	DCRsi DIS	Digital	Yes
Ampex	*FAST*disk RAID	RAID-3	960 Mbps	360 GB (10+2 HDD)	DCRsi DIS	Digital	Yes
Ampex	DDRS	JBOD	480 Mbps	54 – 180 GB	DCRsi	Digital	Yes
Ampex	DDRS 200	JBOD	200 Mbps	50 GB	DCRsi DIS	Digital	Yes
Ampex	DDRS 400	JBOD	400 Mbps	100 GB	DCRsi DIS	Digital	Yes
Avalon	AE7000	JBOD	1 Gbps	275 GB (8 HDD)	-	Digital, Telecomm, Analog (50 MHz)	Yes
Calculex	SPIRD	PC-based	400 Mbps	Media dependent	-	Telemetry	Media dependent
Enertec	DS2100	Single disk	60 Mbps	14 GB	-	Digital, Multi-channel Analog (optional)	Yes
Enertec	DS4100	JBOD	240 Mbps	72 GB	-	Digital, Multi-channel. Analog, Video (optional)	Yes
Sypris Data Systems	Model 80	RAID-3	80 Mbps	27 - 72 GB	Model-64, Buffered VLDS, ARMOR	Digital	Yes

Telemetry Data Recording
Using the Min/Max Algorithm

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Keywords
min/max, oscillograph, recorder, data recording, strip-chart

Abstract

Since their inception, digital strip-chart recorders have efficiently used a min/max algorithm to reproduce a time-varying signal on a moving chart. This method ensures that changes in recording or display speed do not compromise bandwidth or introduce amplitude artifacts. The min/max algorithm also offers the advantage of glitch capture where high speed events can be recorded even when storing samples at a relatively low rate. A recent development in telemetry data recording is to utilize the min/max algorithm to send digitized data directly to the recorder. This technique dramatically reduces the data rates required to supply the recorder and allows the use of the common Ethernet interface as a data bus. Additionally, the use of digital-to-analog converters is eliminated, resulting in significant cost savings.

Introduction

It has been common practice to record time-varying signals by converting the amplitude of the signal to the motion of a pen while moving paper under the pen at a constant speed. The resolution of the time base is determined only by the paper speed while the bandwidth of the recording is determined by the combined characteristics of the amplifier and pen. If the amplifier / pen combination were good but the paper was moved slowly, a fast amplitude event would be recorded as a line with accurate amplitude.

Recording Sampled Waveforms

Modern paper recorders generally require that the signal amplitude be converted to digital values by sampling the signal at a fixed rate. The amplitude axis of such a recorder consists of dots spaced closely together at a constant distance between them. A set of dots is printed each time the paper moves a fixed interval. The paper speed depends on the size of the interval and the number of print cycles per second. A similar process is used to make waveform displays on a CRT.

In the simplest scheme, as each value S(n) is acquired, a dot is printed and the paper is moved one interval. The position of the dot printed is proportional to the amplitude S(n). This implies that the signal sample rate (fs) and the recording rate (fm) are the same. As long as S(n) changes slowly as compared to fs, the result appears to be a continuous recording. Of course, this assumes that the printing intervals are small (approximately 300 dots per inch with a good paper recorder and 100 dots per inch on a good CRT display).

If S(n) changes in amplitude by more then a few dots from S(n-1), the recording looks like a random set of dots and becomes difficult to use. The appearance is improved by drawing lines at each print cycle instead of single points. The line is drawn between S(n) and S(n-1). This is the standard graph approach.

Example 1 of the Appendix provides a simple illustration using a 10 Hz sinusoid sampled at 1200 Hz. If this were a real-time paper recorder with a resolution of 300 dpi and a print rate that matched the sample rate, the chart speed would be approximately 100 mm/sec. The results apply to CRT displays with appropriate changes in the display resolution.

Problems with Under Sampling

In general, a paper recorder or CRT display system has a fixed resolution. Following the previous discussion, this implies that changes in the recording speed require a change in the recording rate (fm). If we are using one sample per print cycle then the signal sample rate (fs) must also change with changes in paper speed (or CRT display speed). This can lead to under sampling of the original signal.

If the original signal has frequency components that exceed fs/2, the recording will suffer from aliasing. Even if the signal has components of only fs/10, there may be amplitude distortion such as incorrect amplitude peaks and attenuated spikes.

Example 2 of the Appendix illustrates the effect of a 500 Hz sinusoid sampled at 1200 Hz. This is fast enough to avoid aliasing but you can see the loss of peak data. If all the peaks had been captured adequately, the graph should be close to a solid band. Example 3 provides a second example where inadequate sampling causes an incorrect amplitude peak.

The Min/Max Algorithm

The Min/Max Algorithm (MMA) provides a method for de-coupling fs from fm so that changes in recording or display speed do not compromise bandwidth or introduce amplitude artifacts. It assumes that the time between each sample (Ts = 1 / fs) is less then the time between recording cycles (Tm = 1 / fm). The ratio of these time periods (r = Tm / Ts) should be greater than 2 but in practice need not be an integer.

The MMA operates by finding the minimum and maximum values of S(n) over each successive recording period (Tm). At the end of the recording period, a line segment is drawn from Smax to Smin and the cycle repeats. In some cases, the appearance of the recording (or display) is improved by initializing both min and max values to the last value of S(n) in the previous recording cycle.

The Appendix of this paper provides an implementation of this algorithm that will be used to study its effects. This specific implementation assumes that the ratio r is always an integer. The input to the algorithm is a sampled waveform, S(n). The output of the algorithm is a version of the original sampled waveform, MM(k), that has been compressed in time but without distortions in amplitude. MM(k) has two values for every r values of S(n). When k is even then MM(k) is a minimum. When k is odd then MM(k) is a maximum. By defining MM(k) in this way, it can be treated as any other sampled waveform.

Examples 4 through 6 of this paper illustrate the effect of the MMA by applying it to each of the waveforms discussed previously. The sinusoids were sampled at 12,000 Hz as compared to the 1200 Hz rate used for the original graphs. The MMA was used to process this data based on an fm of 1200 Hz (r = 10). This means that the time bases for examples 5 and 6 are the same as the time bases on examples 1 and 2 with a total graph time of 1 second (1200 points, fm = 1200 Hz). The 10 Hz sinusoid is unaffected by the MMA because fm is much greater the 10 Hz. The 500 Hz sinusoid, on the other hand, shows significantly improved amplitude after the MMA is used. This makes the point that the MMA has no advantage when fm is significantly greater (x10) than the fastest components of the original signal.

The sinusoids can be described with a continuous function that is equivalent to a real world analog signal that is sampled to create S(n). The third waveform begins as a set of discrete values called Orig that must be re-sampled to create S(n). As a convenience, we assume that the values in Orig are spaced at 1/24000 seconds. This is arbitrary but allows us to relate the results to the other two signals. The graph in example 3 was created by simply re-sampling Orig, in effect, keeping only 1 out of every 20 points. The MMA is able to set r to 20 and use all of the original points to create the graph. The result is an accurate peak of 50.

Applying the MMA to Oscillographic Recording

Consider a digital oscillograph with a print resolution of 12 lines / mm (approximately 300 dpi) and a range of user selectable speeds from 1 mm/s to 100 mm/s. Inputs are analog voltage waveforms from a measurement device or other source. The rate at which new lines must be printed to maintain a constant speed is fm where fm = (mm/s) x 12. If the MMA where not used, the amplitude bandwidth of the resultant recording would vary with the selected speed.

Instead, the analog inputs are sampled at a fixed rate (fs) that is significantly greater then fm. This ensures a reliable bandwidth that is independent of the selected recording speed. Unlike the MathCad algorithm in the appendix, a practical oscillograph must work with r values that are non-integer. In practice this means that some min/max periods contain 1 more sample then others.

Consider the following example:

> An oscillograph has a resolution of 12 lines/mm and an fs of 5000 Hz. At a 50 mm/s recording speed, the min/max frequency (fm) is 600 Hz.` The ratio r is 25/3 (5000/600). This implies that most print cycles will use a min/max pair that is based on 8 samples but that every third cycle will include 9 samples. As r increases, the significance of this diminishes.

Using DACs with Oscillographs

It is ironic that one popular source for the analog waveforms recorded by digital oscillographs is a Digital to Analog Converter (DAC). Historically, this came about because the original oscillographs were purely analog. Systems where waveform information already existed in a digitized form were forced to convert the digitized waveforms to an analog voltage so that they could be recorded on the analog oscillographs. By the time digital oscillographs were available, the use of DACs as a source for oscillographs was standard. At the present time, it is common to have data digitized at the point of measurement, converted to analog again with a DAC, transmitted to the oscillograph as an analog voltage then digitized again by the internal circuitry of the oscillograph.

One step towards improving the situation has been the design of oscillographs that accept directly, the stream of digital data normally intended for the DACs. This significantly reduces cost and maintenance of the system but the protocols that support these transfers are still based on sending individual samples. This often requires a very high data rate between the data source and the oscillograph to avoid the problems associated with undersampling.

Using MMA to Save Transmission Bandwidth

Recently, Astro-Med has developed an oscillograph that accepts min/max pairs directly. This leaves it to the user to implement the MMA. While this increases the effort required to supply data to the oscillograph, it can dramatically reduce the data rates required to supply the recorder. In addition, because the user selects fs, amplitude bandwidth becomes independent of the oscillograph.

Consider the following example:

A system uses 2 bytes to represent the amplitude of each sample (16 bits) and samples the original signal at 10,000 Hz. If 8 channels are being sampled then the total data rate is 160,000 Hz (10,000 x 2 x 8). This stream is to be recorded on an oscillograph with a maximum printing rate of 1200 Hz. If data is sent to the oscillograph as min/max pairs then the transmission rate is only 38,400 Hz (1200 x 2 x 2 x 8).

The Benefits of MMA in Data Acquisition Systems - Glitch Capture
Data acquisition systems are routinely used to acquire and save signal data. In general, a fixed sample rate is used and sampled values are saved sequentially. The advantage to this technique is its simplicity and the fact that there is a wealth of information on processing sampled data after it is collected.

Whenever signals are sampled, care must be taken to limit the signal frequency content to avoid aliasing. This is often done with an analog low pass filter but such an approach suffers from the difficulty of adjusting such a filter to compensate for changes in the sample frequency. In addition, there is often a conflict between the need to view a long period of time and the need to accurately measure the amplitude of high frequency events. To accomplish both goals may require an impractical amount of storage space.

If the MMA is used to process the sampled data S(n), then the primary sample rate, fs, can be fixed at a rate fast enough to measure the amplitude of all anticipated events with sufficient accuracy. The hardware filter is optimized for fs and need not be adjustable. Only the output of the MMA, MM(k), is stored. The min/max rate, fm, is chosen only to provide sufficient time base resolution without concern for amplitude bandwidth which is only dependent on fs. Such a scheme can be referred to as 'glitch capture' because it can see high speed events even when storing samples at a relatively low rate

The price to be paid is a doubling of the storage space required for each time period. This implies that if the required time base resolution is not significantly less then the 1/fs, then the MMA is not appropriate.

Appendix

Note: The Appendix examples are based on a MathCad file designed to illustrate several aspects of the Min/Max Algorithm. The appearance of graphs in this Appendix depend on the method used to reproduce the document. Best results are obtained when a 300 dpi laser printer is used to print directly from the MathCad file. Other means of reproduction may change subtle features of the graphs so they no longer match comments in the text. A MathCad file is available upon request.

Example 1: 10Hz sinusoid sampled at 1200 Hz

$fs := 1200$ Original sampling frequency (Hz)

$fo := 10$ Original signal frequency

$n := 0 .. Origcount - 1$ Index of original samples

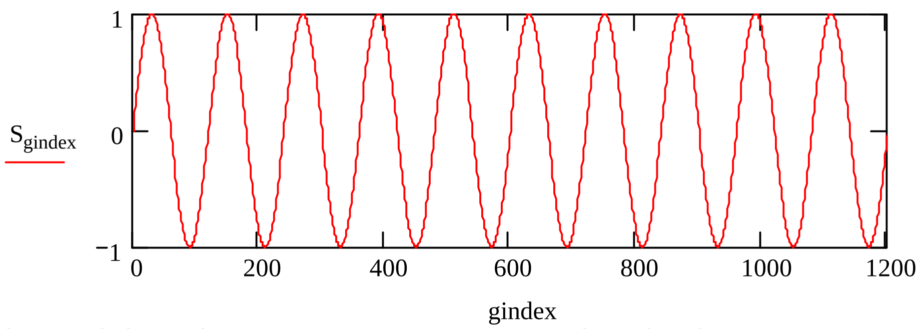
$Origcount := 2000$

$Ts := \frac{1}{fs}$

$S_n := \sin\left(2 \cdot \pi \cdot \frac{fo}{fs} \cdot n\right)$ Equation for original signal

$gindex := 0 .. 1200$ Graph only the first 1200 values of the original signa

$Tgr := 1200 \cdot Ts$



This graph includes 100 samples for a total time (sec) of: $Tgr = 1$

This graph is approx 4 inches long, on a 300 dpi laser, there is about one sample per dot.

Example 2: 500 Hz sinusoid sampled at 1200 Hz

$fs := 1200$ Original sampling frequency (Hz)

$fo := 500$ Original signal frequency

$n := 0 .. Origcount - 1$ Index of original samples

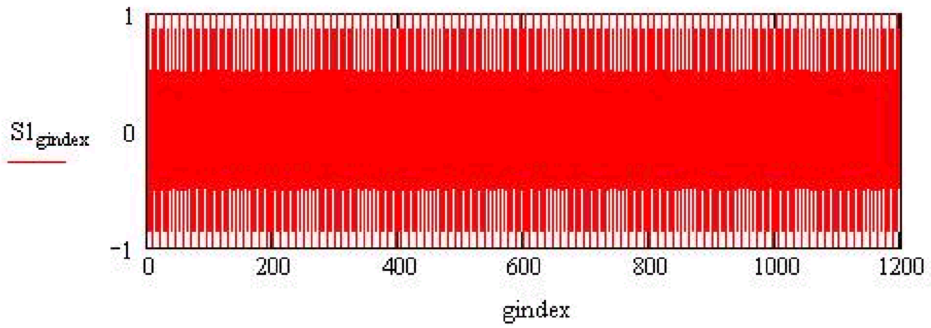
$Origcount := 2000$

$Ts := \frac{1}{fs}$

$S1_n := \sin\left(2 \cdot \pi \cdot \frac{fo}{fs} \cdot n\right)$ Equation for original signal

$gindex := 0 .. 1200$ Graph only the first 1200 values of the original signal

$Tgr := 1200 \cdot Ts$



This graph includes 100 samples for a total time (secs) of: $Tgr = 1$

This graph is approx 4 inches long, on a 300 dpi laser, there is about one sample per dot.

Example 3: Undersampled triangular impulse

S2 is a sampled version of original signal

$Origcount := 24000$

$Spike := 600$

$n := 0 .. Origcount - 1$

$Orig_n := 0$

$n := Spike .. (Spike + 50)$

$Orig_n := n - Spike$

$n := Spike + 50 .. (Spike + 100)$

$Orig_n := 100 - n + Spike$

$Orig_{Spike+50} = 50$ Peak amplitude value in original signal

$RF := 20$ Relative sample rate

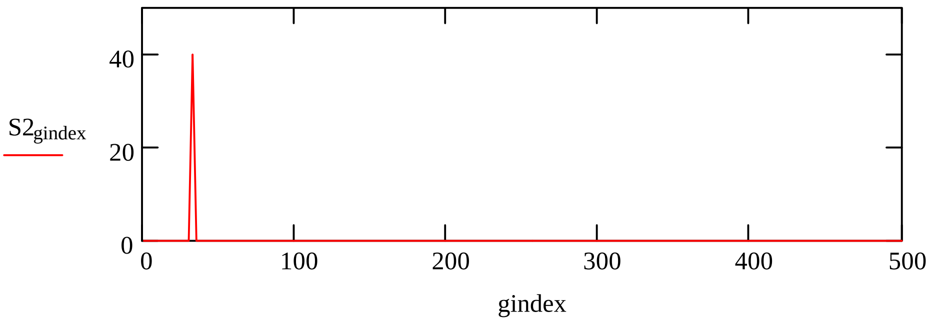
$$n := 0 .. \frac{Origcount}{RF} - RF$$

$S2_n := Orig_{n \cdot RF}$

$gindex := 0 .. 500$

Graph only the first 500 values of the original signal

$Tgr := 100 \cdot Ts$



The peak value of the sampled signal is less then the peak of the original.

Min/Max Algorithm (MMA)

The input to the algorithm is S(n). $\mathrm{Origcount} := 2000$

$r := 10$ Ratio of original sampling frequency to Min/Max frequency

$\mathrm{fm} := \dfrac{\mathrm{fs}}{r}$ Min/Max rate (Hz) *Note: In practice, r must be greater than 2 and constant but need not be an integer.*

$\mathrm{MMcount} := \dfrac{2 \cdot \mathrm{Origcount}}{r}$ Number of min/max pairs derived from number of original samples

$\mathrm{MMcount} = 400$ MM(k) is the set of min/max values

$k := 0 .. \mathrm{MMcount} - 1$

$\mathrm{MM}(k) := 0$ Initialize MM(k) to 0

$k := 0, 2 .. \mathrm{MMcount} - 2$

$$\mathrm{MM}_k := \left| \begin{array}{l} kk \leftarrow k \cdot \dfrac{r}{2} \\ \mathrm{value} \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad \mathrm{value} \leftarrow S_{kk+i} \text{ if } S_{kk+i} < \mathrm{value} \\ \mathrm{value} \end{array} \right.$$

Put Min values at even values of MM index

$k := 1, 3 .. \mathrm{MMcount} - 2$

$$\mathrm{MM}_k := \left| \begin{array}{l} kk \leftarrow k \cdot \dfrac{r}{2} \\ \mathrm{value} \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad \mathrm{value} \leftarrow S_{kk+i} \text{ if } S_{kk+i} > \mathrm{value} \\ \mathrm{value} \end{array} \right.$$

Put Max values at odd values of n

The following examples use the Min/Max Algorithm to graph the waveforms in the previous examples (1, 2 and 3). These examples show how the MMA preserves the bandwidth and accurately maintains peak values.

Example 4: 10Hz sinusoid sampled at 12 KHz using MMA

The input to the algorithm is a S(n), a 10 Hz sinusoid sampled at12,000 Hz.
The output is MM(n), a set of 1200 min/max values.

$fs := 12000 \qquad fo := 10 \qquad Origcount := 20000$

$n := 0 .. Origcount - 1$

$$S_n := \sin\left(2 \cdot \pi \cdot \frac{fo}{fs} \cdot n\right)$$

$r := 10$ Ratio of original sampling frequency to Min/Max frequency

$fm := \frac{fs}{r} \qquad fm = 1200 \qquad MMcount := 2400$

$k := 0 .. MMcount - 1$

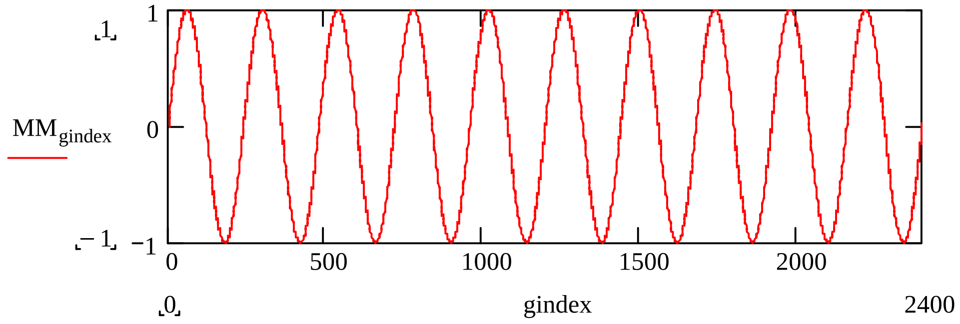
$MM(k) := 0$

$k := 0, 2 .. MMcount - 2$

$$MM_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow S_{kk+i} \text{ if } S_{kk+i} < value \\ value \end{array} \right.$$

$k := 1, 3 .. MMcount - 1$

$$MM_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow S_{kk+i} \text{ if } S_{kk+i} > value \\ value \end{array} \right.$$



Example 5: 500Hz sinusoid sampled at 12 KHz using MMA

The input to the algorithm is S(n), a 500 Hz sinusoid sampled at 12,000 Hz.
The output is MM1(n), a 1200 point set of min/max values.

$fs := 12000 \qquad fo := 500 \qquad Origcount := 20000$

$n := 0 .. Origcount - 1$

$S_n := \sin\left(2 \cdot \pi \cdot \frac{fo}{fs} \cdot n\right)$

$r := 10$ Ratio of original sampling frequency to Min/Max frequency

$fm := \frac{fs}{r} \qquad\qquad MMcount := 2400$

$k := 0 .. MMcount - 1$

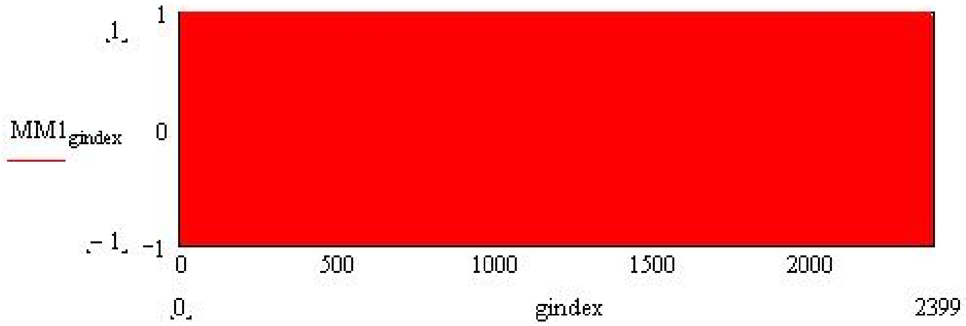
$MM1(k) := 0$

$k := 0, 2 .. MMcount - r$

$$MM1_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow S_{kk+i} \ \text{ if } \ S_{kk+i} < value \\ value \end{array} \right.$$

$k := 1, 3 .. MMcount - r$

$$MM1_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow S_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow S_{kk+i} \ \text{ if } \ S_{kk+i} > value \\ value \end{array} \right.$$



Example 6: Triangular impulse using MMA

The input to the algorithm is an impulse triangle sampled at 24000.
The output is MM2(n), a 1200 point set of min/max values.

$fs := 12000 \qquad fo := 10 \qquad Origcount := 24000$

$r := 20$ Ratio of original sampling frequency to Min/Max frequency

$MMcount := 1200$

$k := 0 .. MMcount - 1$

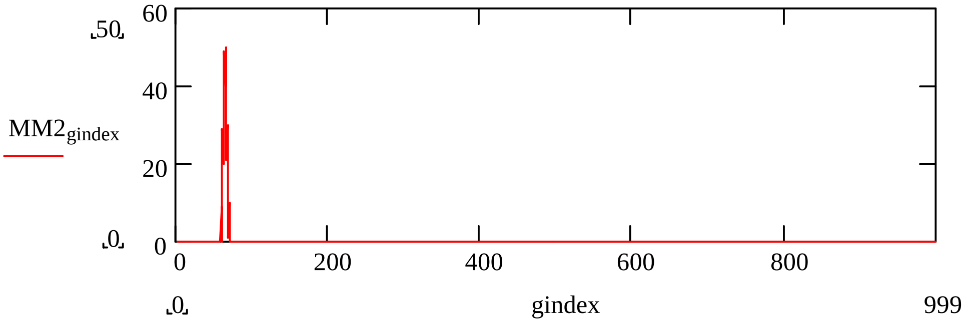
$MM2(k) := 0$

$k := 0, 2 .. MMcount - 2$

$$MM2_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow Orig_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow Orig_{kk+i} \text{ if } Orig_{kk+i} < value \\ value \end{array} \right.$$

$k := 1, 3 .. MMcount - 1$

$$MM2_k := \left| \begin{array}{l} kk \leftarrow k \cdot \frac{r}{2} \\ value \leftarrow Orig_{kk} \\ \text{for } i \in 1 .. r - 1 \\ \quad value \leftarrow Orig_{kk+i} \text{ if } Orig_{kk+i} > value \\ value \end{array} \right.$$



High Speed Data Recording for an Experimental Radar Programme

Chris Duckling (L-3 Communications)
&
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Abstract

As experts in the field of radar test and design, the Instituto Nacional de Tecnica Aeroespacial (INTA) based in Madrid, Spain are developing a new multi-channel Synthetic Aperture Radar (SAR). The new system will be tested onboard a CASA 212 turboprop aircraft. The data rate from the fully developed system is in the range of 1 Gbps and thus beyond the scope of instrumentation recorder systems. Further, the environment far exceeds the capability of unmodified computer storage systems (disks).

L-3 Communications based in Camden, New Jersey USA have produced the S/TAR solid-state recorder designed to routinely cope with high data rates in harsh environments.

This paper describes the challenges of high-speed continuous data recording and the interface to the recorder both onboard the aircraft and on the ground. It also describes the recorder storage process which uses FLASH memory devices with error detection and correction at full data rate. While this application is for a SAR radar recorder, the principles of continuous high data rate recording will be of interest to many other applications.

Introduction

The ability to capture and record large volumes of high-speed data in real time rugged environments has eluded many radar developers. The method of multiplexing channels into a serial stream for recording on a magnetic tape recorder has been used in the past. Helical and transverse scan tape recorders such as the airborne ID-1 (Enertec) and DCRsi (Ampex) have a maximum streaming data rate of 240 Mbps. Other systems have been advertised at twice this data rate, but typically they are designed for ground applications only.

For fast data capture, solid state technologies appeared on the market in the mid 1990’s. While such machines offered previously unobtainable data rates, their storage was often based on small data capacities. They found applications in the replacement of camera systems for high-speed photography and were used for recording short-burst activities such as missile separation from aircraft.

As the capacity of magnetic disk systems expanded, some manufacturers started to offer ruggedised disk-based systems. These have the advantage of being a readily available product with a rapidly growing commercial base. They suffer the inherent problems of rotating devices in airborne environments and configuration control with a fast-changing commercial/domestic-based product is a nightmare. Additionally to obtain high data rates from an inherently slow device requires many parallel devices – although such an approach does yield larger capacities. Where disks fall down in airborne applications is in their built-in-test characteristics that, for example, following an environmental excursion, will send the device off on a recalibration routine without warning and there is no mechanism of terminating such an activity. Additionally they have built-in retry processes when a record or replay error is detected. Both of these activities thus reduce the effective sustainable streaming rate to a number that is well below the quoted rates of these devices.

Returning to Solid State technology, a new generation of high capacity tape-replacement products arrived on the marketplace in the late 1990's using non-volatile FLASH technology [1]. The first generation machines were typically advertised with 240 Mbps streaming data rate and 50GB of capacity – uncannily in the same range as the Ampex DCRsi. L-3 Communications launched its S/TAR Digital Solid State Recorder (DSSR) at the Farnborough Airshow in 1998 with a capacity of up to 48GB and a streaming rate of 400 Mbps on each of two channels. Concurrent replay ability for in-air exploitation of the recorded data was built in as standard.

Since that time, L-3 has enhanced the product to provide up to 4 channels at higher rates with storage capacities of up to 192GB - with double that capacity targeted for 2003. This paper explores an application of that product.

The INTA Radar Recorder Project

In the spring of 2001, INTA started to look for a high-speed recorder for their experimental radar programme. Previous attempts with a magnetic disk based system had demonstrated the weaknesses of the technology and INTA were now looking for a technology that would compliment the robustness of the radar; to fulfil this need they looked to solidstate technology. It was an important concept of their programme that they were aiming to develop a radar system – not a recorder, and thus they wanted a commercial off the shelf (COTS) system that provided high reliability within an airborne environment. Further, the system should require no routine maintenance and the capability to upgrade with new interfaces and additional memory at some future point.

Figure 1. The INTA CASA 212

The platform for the radar and recorder is to be the CASA 212 turboprop operated by INTA. The CASA 212 is an extremely successful multi-purpose medium cargo transport with 460 aircraft delivered to 89 users in 38 countries. It has been adapted for a variety of military missions including Maritime Reconnaissance (MR), Anti-Submarine Warfare (ASW), Search and Rescue (SAR), Electronic Intelligence (ELINT), photoreconnaissance, navigation training, and utility. While space, mass and power were not as critical as many uninhabited fighter jet applications, nobody wants to waste such precious resources and limitations were put within the specification.

The radar is a synthetic aperture radar with multichannel capability. It produces 4 output channels which are multiplexed into two channels with auxiliary data. Each channel is capable of streaming at 480 Mbps, thus giving a combined maximum streaming rate of 960 Mbps.

INTA requested technical details and competitive pricing in the summer of 2001 and awarded a contract to L-3 Communications in November of the same year.

The L-3 Communications S/TAR RM8000R DSSR

Solving INTA's needs was relatively straightforward as L-3 were already under contract to provide a radar recording system to a U.S. based radar manufacturer. This allowed L-3 to conduct a demonstration at the customer's premises in September of 2001 and propose a low risk cost effective solution.

The heart of any DSSR is the management of high data rates with real-time error correction. In a previous paper [1] L-3 has described its process for real-time Reed-Solomon error detection and correction (EDAC). It is important that the EDAC works at full data rate and is always invoked; read-after-write systems when invoked reduce the streaming rate in the presence of errors.

The S/TAR family of recorders uses a common architecture across the entire product range. This architecture is shown in figure 2.

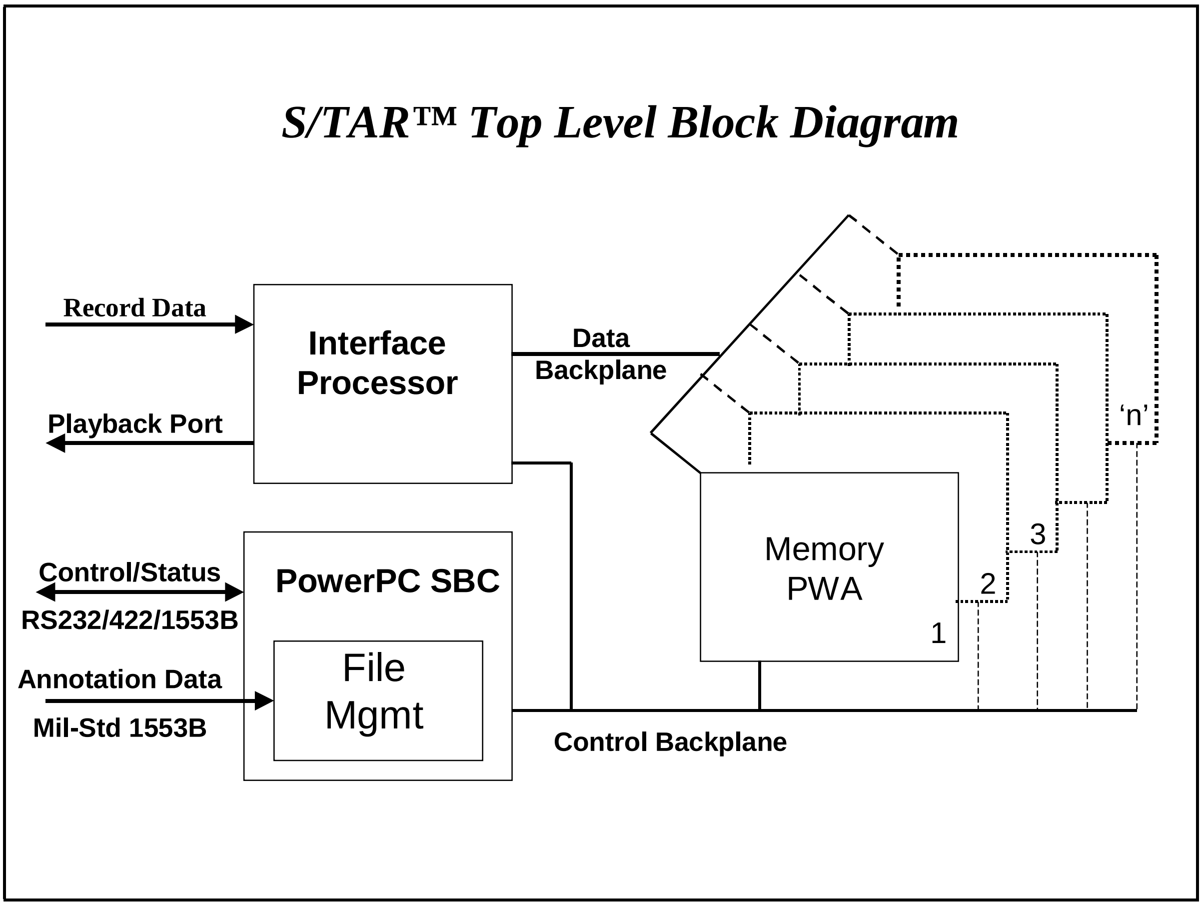

Figure 2. S/TAR top-level architecture

The key to the data rate is the backplane speed, which is 160 Mbytes/sec (40 MHz at 32 bits wide). Channelling the data to that backplane through the EDAC is a non-trivial matter which L-3 has achieved through careful attention to system and timing design. What becomes fundamental is the interface from the recorder to the outside world, in this case the INTA radar system. Earlier DSSRs used ECL logic to manage this interface but ECL is an old and power-hungry technology. Fibre channel offers promise but with the full overhead associated with such technology the data rate is realistically limited to 800 Mbps – too slow for this application. Alternatives to the full overhead of fibre channel could increase the throughput rate but Low Voltage Differential Signalling (LVDS) logic offers a simple hardware interface and greater expandability. A 16 bit wide LVDS interface was agreed upon.

Downloading the data

Once recorded, there needs to be a method of downloading the data for analysis. The RM8000R, as all models in the S/TAR family, has concurrent airborne replay as a standard feature. The INTA requirement did not call for airborne replay but this was considered a desirable feature for the future. Attention thus moved to the method of rapidly and reliably transferring the data from the airborne system to INTA's Sun Solaris workstation. The RM8000R has a removable memory module on which is situated a STANAG 4575 compatible download port. It was agreed to utilise this port for the primary ground download of data.

STANAG 4575 is a newly released NATO standard for downloading data from 'new' technology storage devices. It aims to address the issue of any compliant NATO asset being downloadable onto any NATO compliant ground station, irrespective of the content of the data on that asset. In early 1999 the NATO Advanced Data Storage (NADS) working group comprising NATO, National Governments and Industry representatives was set up to define an interoperable interface. L-3, as an active participant, attended every meeting and chaired one of the sub-committees. The resultant standard, which was authorised for public release in September 2001, uses SCSI 3 protocol over a copper fibre-channel. Just four SCSI commands allow the data in the memory device to be downloaded. The maximum transfer rate is 800 Mbps (the 1 Gbps commonly referred to for fibre channel includes overhead, and the realistic maximum user data rate is around 800 Mbps). This is faster than most workstations can input or process data.

The final system

Figure 3 shows the architecture of the user interfaces for the recorder. The use of COTS PCI Mezzanine Cards (PMCs) for the interfaces reduces the risk and cost of the solution, however careful attention needs to be made concerning power dissipation as this can be a problem from some PCM suppliers.

The record/replay interface module (R/P processor in figure 3) takes up just one slot of the RM8000R's eight slot chassis (see figure 4). The system processor requires another slot leaving 6 slots available for memory modules. Memory modules can be fitted in increments of 16GB and with capacities doubling every 18 months, a full compliment of memory cards will provide almost 400GB of storage in the near future.

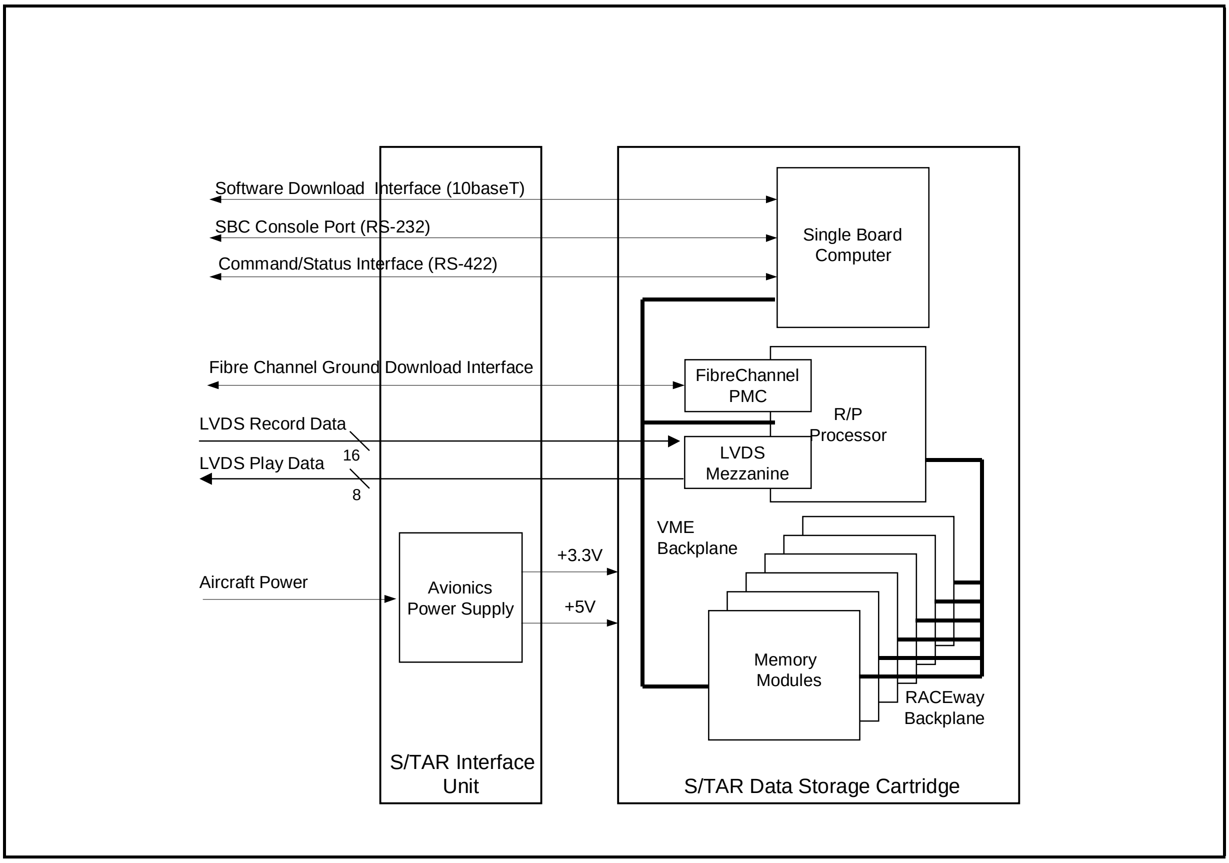

Figure 3. RM8000R high-speed interface architecture

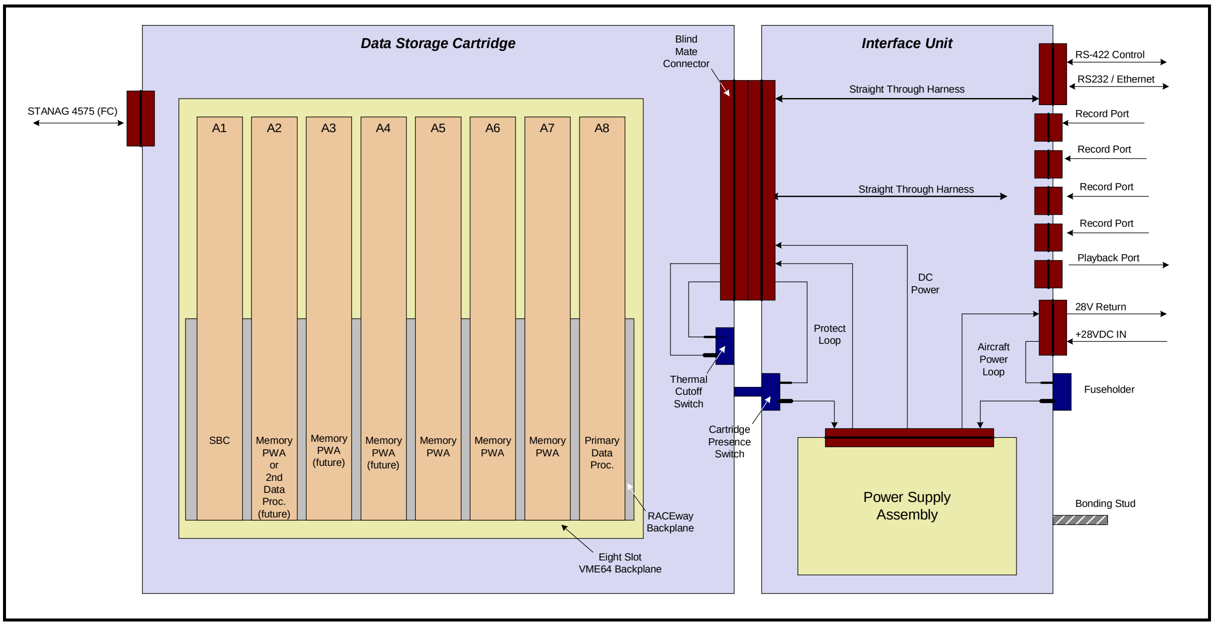

Figure 4. RM-8000R DSSR Physical Partitioning

A further advantage of this architecture is that memory capacity can be added very simply in the field at a later date. Indeed the RM8000R chassis is wired to accept four channels and the INTA solution uses only two. The possibility therefore exists to double the number of channels or take the combined recorder to be a 32 bit wide interface running at an equivalent serial data rate of almost 2 Gbps. With a full compliment of today's technology 32GB modules memory cards this would give a record time at a 2 Gbps streaming rate of 11 minutes! And the power dissipation would still be just over 100 watts with a mass of around 15Kgs.

The L-3 Communications S/TAR RM8000R DSSR

Conclusions

In this short paper it has only been possible to give an outline of the system. However, from an initial need of a high data rate, large capacity recorder for airborne use, INTA and L-3 have worked together to satisfy this requirement. The RM8000R fully meets the customer's needs and with no routine maintenance and an MTBF of 8000 hours will reliably collect data for many years to come - thus providing INTA with a general research instrument into the foreseeable future.

References

[1] Duckling, C., 2000. *Solid State Recorders Gain Ground*: ETC 2000 Conference Proceedings pp48 – 58 (copies available from the author)

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DATA ACQUISITION, PROCESSING AND MONITORING

SDL, a rugged PC data logging and processing system in ATR size using COTS components

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Abstract

This paper describes the design of a sensor data logging system using Commercial Of The Shelf (COTS) components, yet rugged and in standard ATR size. The minimum size is ¼ ATR (57mm). The processing system is 100% hardware and software compatible to the standard PC with an up to 700 MHz PIII performance. For I/O the system integrates two PMC (PCI Mezzanine Card) slots and one PC/104+ socket.

Introduction

The principle of a data recording system is obviously not new. There are many systems on the market – very tiny to very huge and powerful. Very popular are VME- and Compact-PCI based systems or tiny stand-alone units. The more versatile of these systems use a 19’’ enclosure. However, a complete 19’’ system gets quite voluminous and is rather used for central applications.

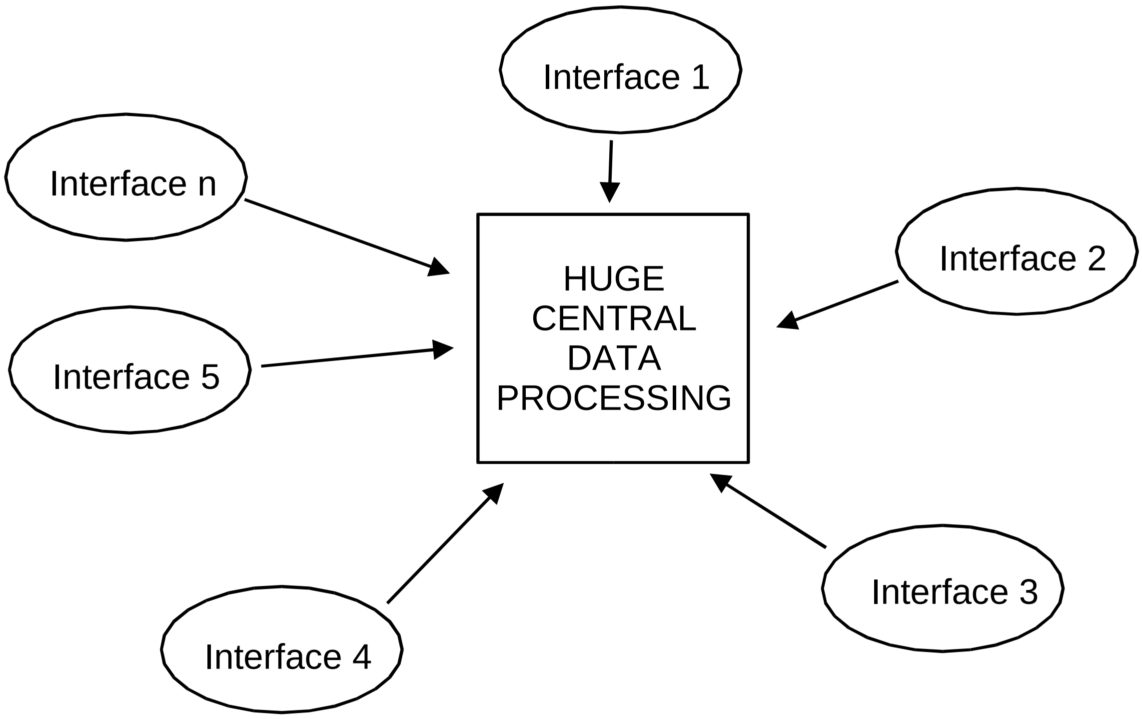

Figure 1, Single Point Data Processing

As interface data rates became higher and EMC (Electro-Magnetic-Compatibility) gets more and more attention, several drawbacks of this topology limited future growth:

- The system is not easily scalable
- Higher Interface frequencies (data rates) need additional tapping hardware
- The total data-rate is limited by single point processing capability

The aggregated bandwidth of newer naval ship designs (using many 100BASE-TX, 100BASE-FX, FDDI, or other high speed serial connections) easily pushes this design to its limits – and beyond.

The solution to overcome these limits is already widely used in the field of high performance computing: Using many smaller computers in parallel – typically one for each interface.

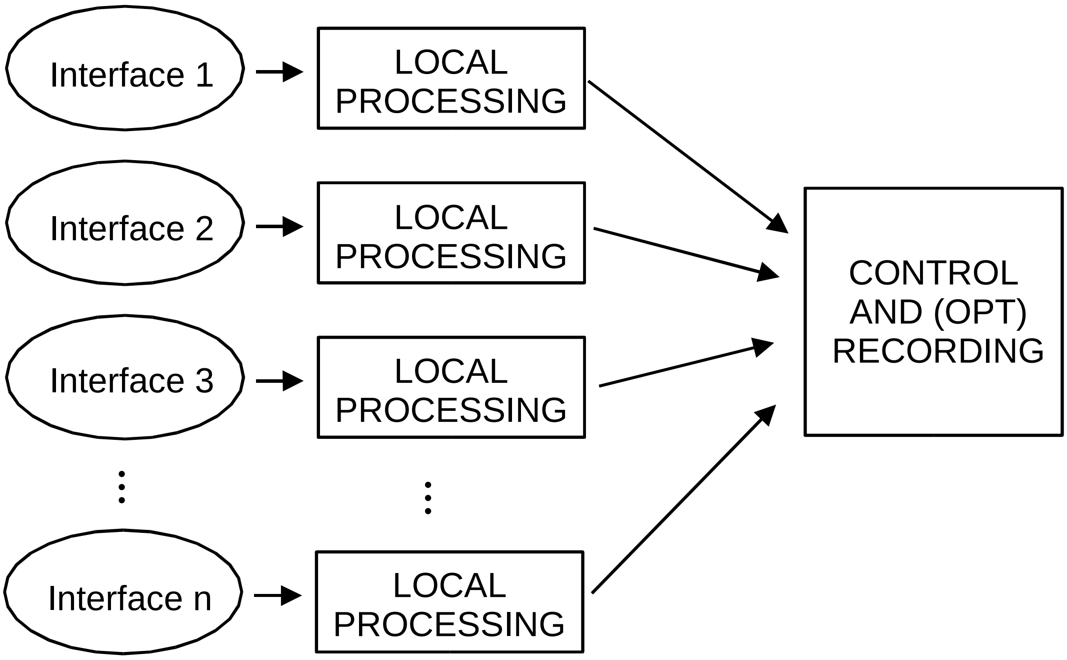

Figure 2, Decentralized Processing

The centralized recording is application dependent, as this may also be done at the individual processing units. However, the processed (filtered) interface data is in most applications of a data rate low enough to be stored into a single hard-disk array.

Where is the beef? This new concept is totally scalable. New Interfaces may be later added at a constant cost per interface – which was not possible using a centralized design. Once an additional interface did not fit into the rack, a whole new rack was necessary. On the other end of the new scalability is the smallest unit now a single local processing module using its internal harddisk for recording.

These local processing modules are a standalone product named SDL (Sensor Data Logger) as a hint to their designed purpose. First units will be delivered April 2002. The original application is recording and analysis of interface signals on naval ships. However, it is also targeted to interface to typical airborne applications, e.g. recording of MIL-STD 1553B and ARINC-429.

During system design several constrains should be met:

- Low cost architecture
- Use of popular platform
- Rugged but small size
- Use of standard I/O modules
- Integration of a 2,5'' hard-disk
- Separate Compact-Flash Boot Medium
- Extensive Built-In-Test Electronics (BITE)
- Easy access for service and software update
- Low-weight modular construction
- EM-shielded design
- Built-in timing circuits to lock to an external time-server

System Overview

The heart of SDL is the ETX based processing board. The ETX-module is a complete embedded PC in the size of 115mm x 95mm, having only four SMD connectors for mounting on a carrier board on its bottom side.

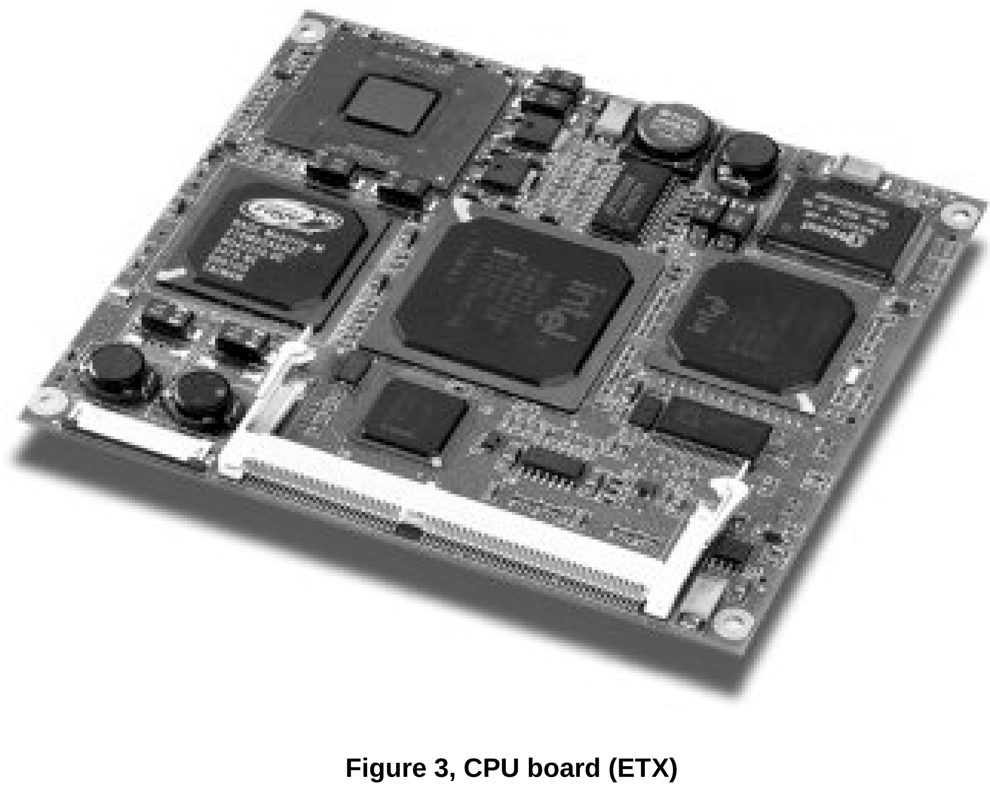

Figure 3, CPU board (ETX)

For thermal conductivity the ETX board is covered with an aluminum plate. This plate has a thermal conduction contact with the enclosure. (See description below for thermal management). The ETX concept was chosen to ensure a rugged (fixable) CPU with no interface connectors, such as keyboard, VGA, or LAN. Usually embedded PC boards have already all connectors on the sides of the PCB (Printed

Circuit Board). However, applications usually require more robust connectors such as of military type. Additionally, having the user I/O connector position already fixed it is nearly impossible to add user I/O modules in the same enclosure.

For the ETX many different PC processor versions exist, ranging from very low power Geode™ (National Semiconductor) up to a mobile Pentium III with 700 MHz (at time of writing). Since it is a standard PC architecture, all usual PC software may be used.

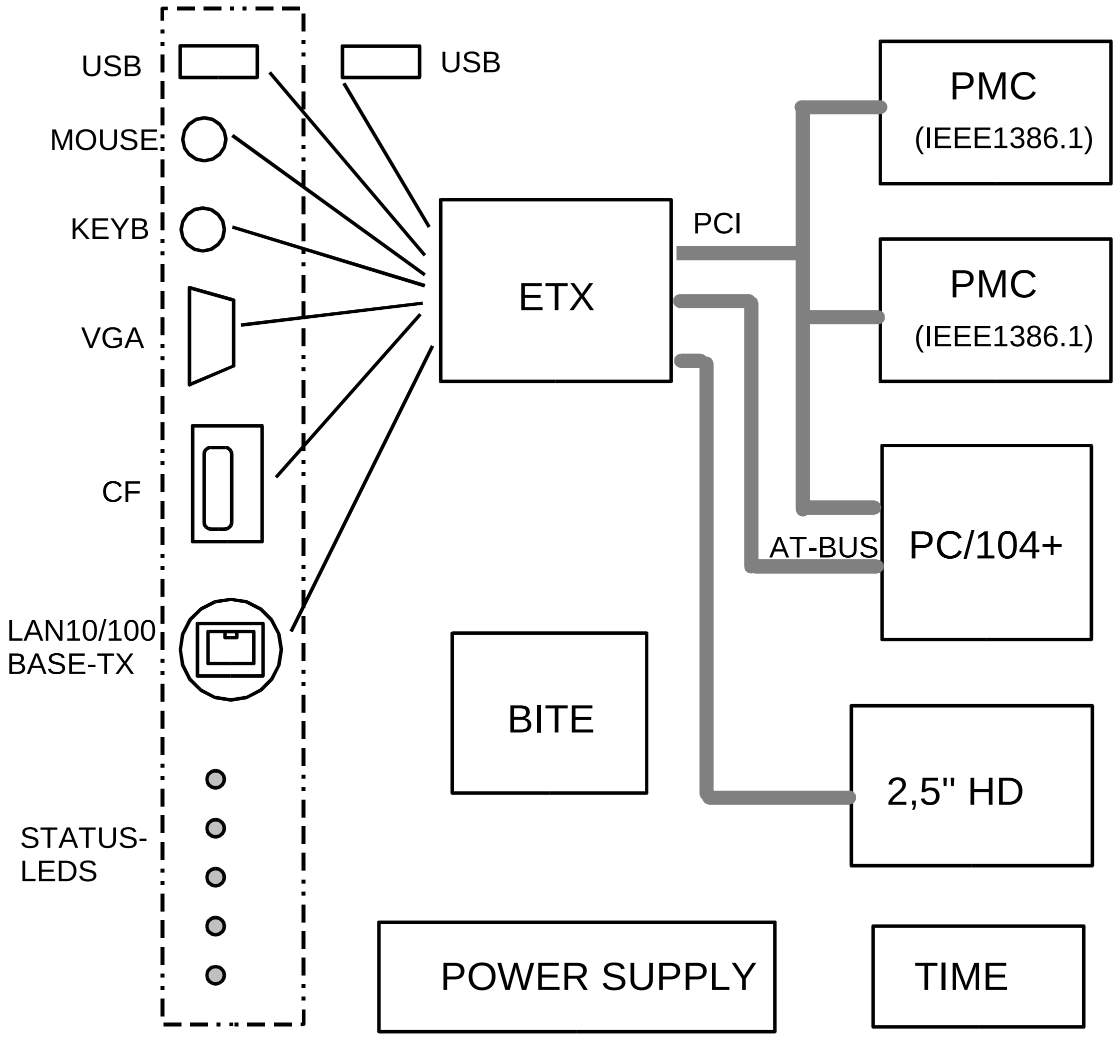

Figure 4, SDL Functional Block Diagram

By its architecture, the SDL is a “Mini”-PC with specialized features. Instead of AT-Bus cards or PCI cards (with connectors not designed to be used in out-of-office use) the system uses PMC and PC/104+ module sockets. Since the system application is gathering of measurement data, a precise local time (VCXO) has been included, which may be trimmed to an external time source. The BITE supervises all on-board functions and signals system health status or any detected problems.

The figure below gives on overview of the module placement inside the SDL box. View is from the right side of the ATR enclosure with side cover removed. The covered areas are the ETX and power supply PCB on the rear side of the PCB.

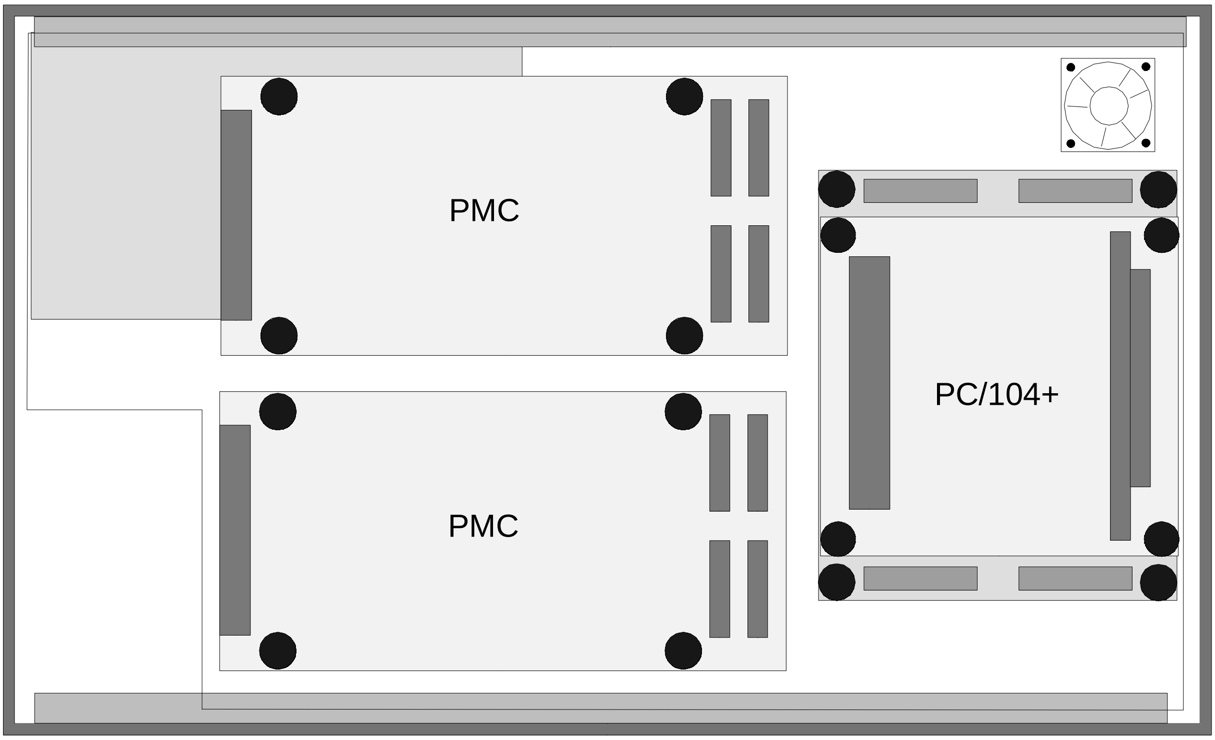

Figure 5, SDL module placement

Enclosure

The enclosure is ATR size. The first boxes are in 1 ATR width, while the constructions are already done for ¼ ATR and ½ ATR. The system uses standardized units:

- Front and rear plate
- Side covers
- Top and bottom covers
- Four profiles
- PCB rails
- Auxiliary parts for fastening, protective cover etc.

Only the front/rear plate and the top/bottom covers must be changed when constructing a different ATR sized enclosure.

All enclosure materials are of aluminum, thus light and rust-free. The surfaces are chromated; the outside surfaces are additionally painted.

One of the key constraints on the enclosure construction was a very good EMC shielding. All cover plates (top, bottom, left and right side) are sealed on all their four sides with an EMC gasket. They are screw fixed at short intervals at the profiles or the front and rear plate.

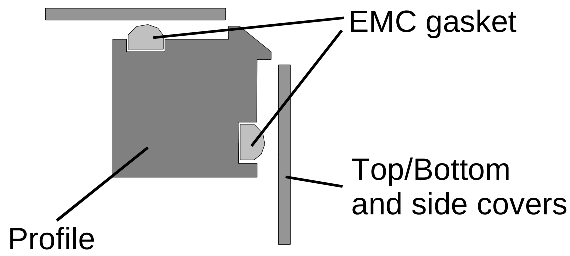

Figure 6, cross view of profile with EMC gaskets

The explosion view below gives an overview of the enclosure parts. The front plate also has a handle and an opening sealed by a protective cover. Behind the cover are the user interfaces accessible, as indicated by the dotted rectangle of Figure 4. This allows easy configuration or system program modifications (e.g. by simply exchanging the compact-flash) while yet having with a closed front door a “simple” box with just the application-interface connectors.

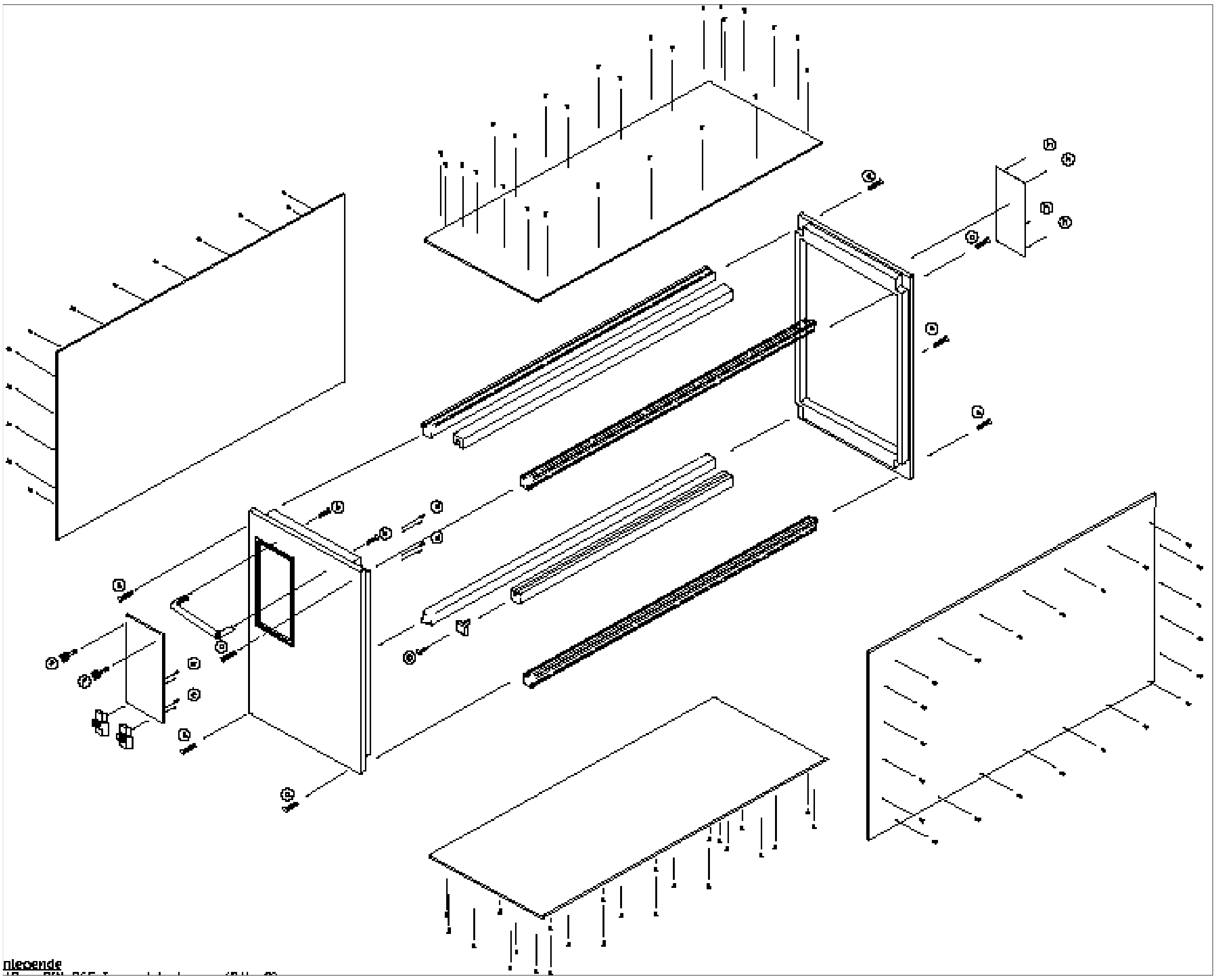

Figure 7, Explosion view of enclosure

Functional Description

The SDL consists of two PCBs: the carrier board, which holds the ETX, the two PMC's and the PC/104+ modules and the power supply, which is mounted piggyback on the carrier. This allows easy adaptation to different power supply inputs when required. Besides being just the carrier for all the modules and the I/O connectors, the carrier board also holds the BITE-circuits and the local oscillator.

BITE

The build-in-test is performed by a programmable FPGA. The circuit monitor runs from the standby power and is thus active at all times. The circuit connects to virtually all relevant interfaces and monitors their activity:

Interface	Supervised signals
Power-supplies	All power supply voltages (even back-up battery) are constantly monitored with an A/D converter. At defined thresholds, warnings and alarms are issued. The supply voltages may be remotely tracked.
Temperature	The temperatures at three different locations are constantly observed: At the main power-supply, at the ETX processor board and near the local oscillator. Programmable actions may be performed at predefined levels, e.g. warnings and auto-shut-down or power-up. The temperature may be remotely tracked.
Compact-Flash	Usually the Compact-Flash is used as boot-medium. The BITE checks for presence and activity of the device.
Hard-disc	The BITE checks for presence and activity.
ETX	Since the ETX board is the PCI arbiter, the BITE observes the PCI bus for proper operation.
PMC	Presence and configuration is checked.
LAN	Link connectivity and activity are monitored.
USB	Overcurrent faults are monitored.
COM-Link	The COM-Link is an RS-422 interface for remote control of the SDL-box. The link-connection and the power-supply for the isolated interface are observed.
Internal fan	Presence and operation.

The BITE result is displayed on front panel LED's, green being all ok, orange a degraded functionality and red a major failure.

PMC

The PMC slots (IEEE 1386.1) allow the use of a wide range of interface boards. They are electrically compatible to the standard PCI bus, but use different connectors that allow to screw-fixing the boards onto the carrier.

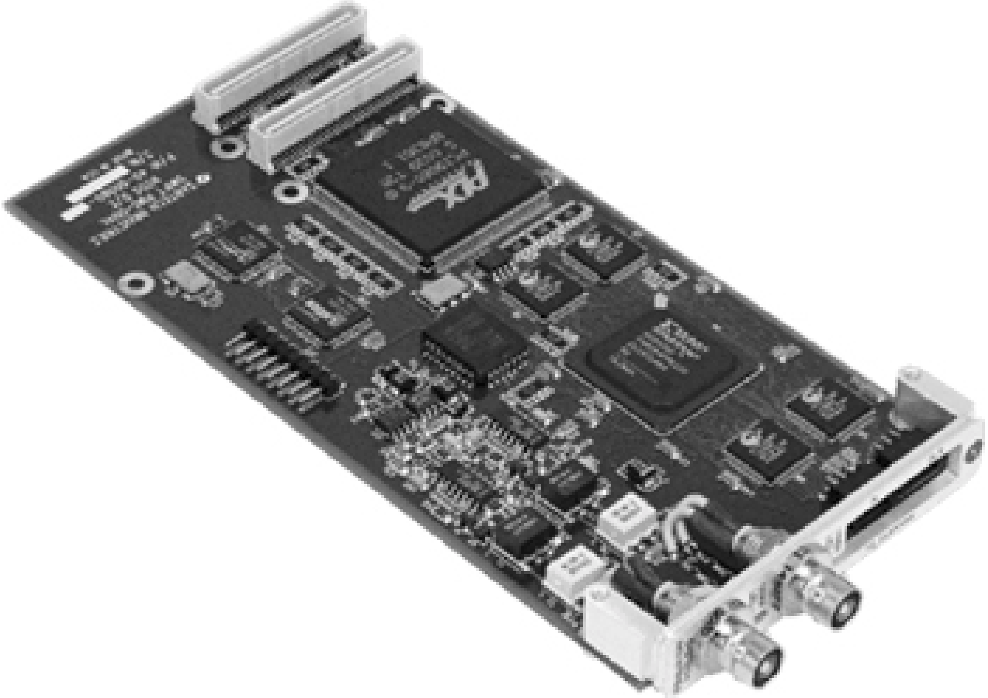

Figure 8, PMC interface board

PC/104+

The carrier board has a full-featured PC/104+ (with PCI extension) interface.

Power

The current Design utilizes a 36-72VDC (nominal 48VDC) Power supply. Since the Power Supply Board is a piggyback board onto the carrier board, the design may be adapted to other power sources, such as 115VAC/400Hz or 28VDC.

The power supply module generates +5V, +3.3V and +/-12V as well as two standby powers of +5V and 3.3V, which are used for BITE and ETX-standby. The carrier board generates a local –5V for the PC/104 using a switched capacitor inverter (no magnetic field induced). All Power-Supply voltages are continuously monitored. The maximum power consumption by the carrier board shall not exceed 50W.

Thermal Management

The DC/DC converters and the ETX module have a thermal conduction to the enclosure using a conductive elastic ceramic[*)] with a thermal conductivity of 1.6 W/mK. Using the components power consumption and conduction area and distance this computes to a temperature rise of 10K for the ETX and DC/DC converters. The PMC and the PC/104 will be cooled using a forced 4 m^3/h airflow inside the enclosure. No external air is ventilated through the box. The internal fan is used only to transport the heat from interface modules to the inside of the enclosure. If special requirements must be met, a specialized cooling technology for the interface boards may be installed. Again, the internal fans activity is constantly monitored by the BITE, measuring fan presence and rotation speed. A beginning fan failure (slow down during end-of-life) gives a warning for required fan replacement maintenance work.

The thermal resistance of the enclosure depends upon several factors, such as air-density (pressure), humidity, external air-flow and enclosure painting. A first test yielded an enclosure temperature rise of +5K at still air at 40W dissipation.

The DC/DC converters have an efficiency of about 80%, which computes to a maximum power input of 61W. Table 1 below shows the maximum consumption of all modules. The system integrator must verify that the total power consumption stays within the limits stated below in order to maintain safe operational temperature conditions.

Module	**Power**
ETX	15W
PMC1	7,5W
PMC2	7,5W
PC/104	15W
Carrier Board	4W
Carrier Board’s sum	49W
+Power supply loss (20%)	12W
=Consumption (Power input)	61W

Table 1, Maximum Power Consumption

*) Chomerics, Inc. type A574

Alternative Concepts

The application requires rugged connectors, such as of military type. This is in contradiction to most ready available industrial solutions, which use small popular connectors not applicable to military use.

Concept	Pro	Contra
PC/104 System Solution	+Ready Available, +Low price	-Difficult to use military connectors -Limited to PC/104 modules, not all interfaces available as PC/104 (e.g. high speed buses) -No extensive BITE
OEM embedded PC	+Ready Available, +Low price	-Difficult to use military connectors -The modules have their connectors at PCB sides, resulting in a large but flat enclosure. -No extensive BITE
19’’ CompactPCI	+Ready Available, +Many suppliers	-Difficult to use military connectors, since boards have their connectors already at front. -No extensive BITE
VME Bus	+Ready Available, +Many suppliers	-Large sized enclosures -High Cost

Conclusion

The proposed concept recommends an ETX CPU with PMC and PC/104+ modules onto a custom made carrier, integrated into a custom made enclosure. The extensive build-in-tests covers all requirements of high-availability system requirements. While having one time design and construction effort, it allows further on the use of a broad range of off-the-shelf interface boards.

A High Performance Reconfigurable Next Generation Data Acquisition System using COTS Products

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ABSTRACT

This paper presents the concepts behind the development of a high-speed data acquisition system for flight test programs. The new system combines the knowledge and experience gained from many years of producing flight test systems with the latest in commercial technology and standards. By utilizing a combination of COTS hardware and custom designed components into a single system, the best combination of performance, cost and adaptability can be offered.

The use of COTS products as the basis for a data acquisition system provides many benefits, including integration of third party products and protection from obsolescence. The use of COTS products allows the engineering design staff to concentrate development efforts on application specific components, rather than components that may already exist. Examples of components where it is more effective to buy than make center on those where technology is constantly evolving, which includes Single Board Computers, Disk and I/O Interfaces and Real-Time Operating Systems.

There are a large number of industry standard buses, such as PCI, USB and Firewire, which are available today, which transfer data at rates much higher than that of any of the proprietary buses that have been previously implemented. Use of an industry standard bus allows for the use of third party modules, and allows a system to be configured in different form factors.

Similarly, a small data acquisition system can be built by integrating application specific FPGA designs with COTS IP Cores, which supply a wide variety of industry standard functions. The design of the system is predicated upon the use of a standard high-speed bus, which is controlled by an IP core that will be common to every module. This implementation reduces the amount of discrete components, ensures design conformance, and allows a signal-conditioning module to be reprogrammed without having to extract it from the system.

KEYWORDS

PCI, FPGA, COTS, IP (Intellectual Property), Ethernet, LAN

INTRODUCTION

Most, if not all, of the airborne data acquisition systems available today are based upon proprietary system architectures that prevent integration of new technologies or Commercial-Off-The-Shelf (COTS) components. The lack of openness in these system architectures has an associated number of negative aspects, including:

- Susceptibility to Parts Obsolescence
- Inability to keep pace with technology
- Reliance on a single vendor

The dominance of PCI as a bus standard and TCP/IP as a networking standard in the desktop market has led in the past years to the introduction of these same technologies into the embedded market. Although there are a number of platforms available, Pentium based CompactPCI and PC/104 (Plus) have become the two predominant platforms.

EMBEDDED COTS PLATFORMS

The Single Board Computers (SBC) in these embedded platforms now have the same capabilities as their desktop counterparts, which include bus interfaces, disk interfaces, network interfaces, keyboard and VGA interfaces, serial ports, USB ports, and memory. In addition, some of the denser processors today include other memory devices (Flash, Disk-on-Chip), and other I/O interfaces such as discrete and A/D or D/A, which allows the boards to be used in a variety of applications.

CompactPCI, as its name suggests, uses the PCI in either 32-bit or 64-bit form, in either 33 or 66 MHz operation, in either a 3U or a 6U form factor. The combination of sizes and speeds allows a system to be built that is tailored to a specific requirement. I/O on CompactPCI boards may be either via the front panel or via the rear connector(s). A single CompactPCI chassis may contain up to twenty slots, with the PCI bus being bridged at eight-slot increments.

Unlike CompactPCI that uses a backplane of predetermined number of slots, PC104 is a stackable system that allows modules to be added or removed as requirements change. Standard PC104 supports the ISA bus, which is normally fast enough to handle inputs such as the1553 and ARINC429 avionics buses. To handle other faster input types, and provide greater processing functionality, the PC104/Plus standards adds the PCI bus. This latter combination allows data to be simultaneously active on both buses, which increases the overall throughput and responsiveness of the system. In a PC104/Plus system, a maximum of five combination modules may be used due to the electrical characteristics of the PCI bus, with the remaining modules being standard (ISA only) PC104. I/O connectors are either on the edge of the board or the board itself, and typically require custom cable(s) that are supplied by the manufacturer.

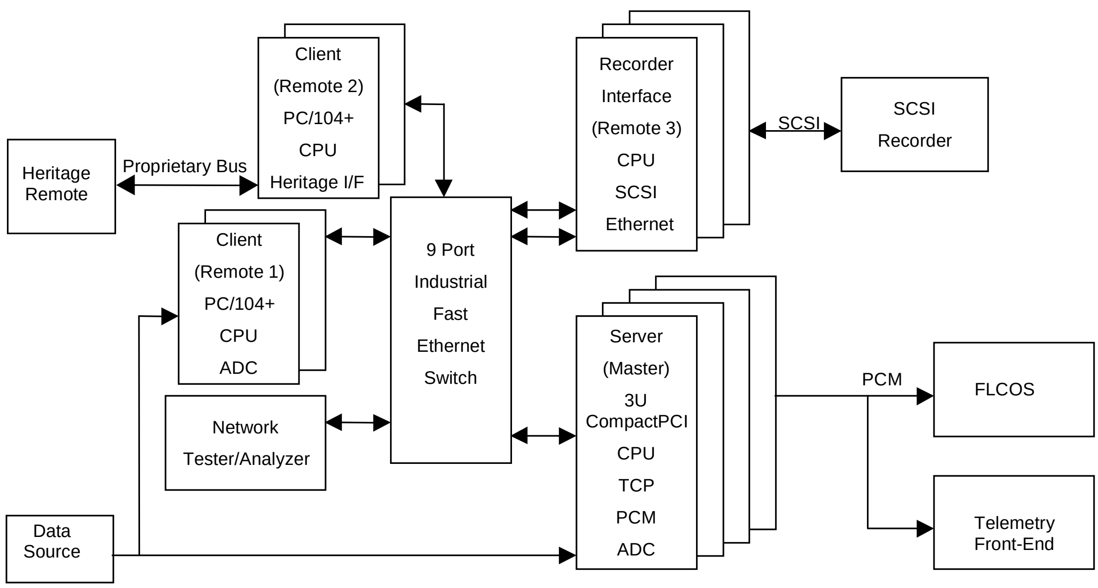
NETWORKING

Ethernet is the standard for connecting computers. As each node of a next generation data acquisition system is a specialized form of computer, the use of Ethernet provides a high-speed industry interface for both setup and acquired data. While 100Mb Ethernet is now widely used in Local-Area-Networks, which also provides backward compatibility for 10Mb devices, 1Gb and even 10Gb networks and devices will soon become available.

Communications between the various nodes is done at the socket level using specific message types, taking into account the development of a standard message protocol that has been performed at the Patuxent River NAWCAD. A socket based application interfaces directly with the desired protocol, typically TCP or UDP at the transport/host-to-host layer. These protocols are responsible for providing the application with specific communication services.

- TCP provides a one-to-one, connection-oriented, reliable communication service. TCP is responsible for the establishment of a TCP connection, the sequencing and acknowledgement of packets, and the recovery of packets lost during transmission.
- UDP provides a one-to-one or one-to-many, connectionless, unreliable communications service. UDP is used when the amount of data to be transferred is small, when the overhead of establishing a TCP connection is not desired, or when the applications or upper-layer protocols provide reliable delivery.

The TCP or UDP protocols are reliant upon the network/internet (IP) layer protocol that is responsible for addressing, packaging and routing functions. TCP is used for initialization or when network utilization is not critical and UDP is used for data packet transfer. The following figure shows a sample data acquisition system that contains a number of components that are interconnected via a local area network.



Sample Network Configuration

An Ethernet switch, rather than a hub, is used to interconnect the various subsystems. A switch provides a number of performance benefits in that it allows each link to communicate at the maximum rate and only transfers data to the destination system(s).

DATA ACQUISITION ARCHITECTURE

While Ethernet's physical interface provides significantly higher bandwidth than that of existing, proprietary system interconnects, the use of networking protocols such as TCP and UDP reduce the amount of available bandwidth. A command-response architecture that uses packets that contain a minimal number of samples dramatically effects bandwidth and effects response time. These negative effects are caused by continuous network arbitration, packet overhead and simply the total number of packets transferred, such that socket based communications should not be used for the standard command-response architecture.

In a networked system architecture, each of the data acquisition nodes is directly downloaded over the network interface with one or more formats/schedules, which are stored on the local non-volatile memory (such as Disk-on-Chip or Flash). The combination of a network interface with large storage allows a large number of formats to be downloaded and stored on each node.

A network data acquisition application will typically open two or more sockets, each dedicated to a specific task or process that must be performed. As a basic example, a remote node would minimally have two processes that would require unique sockets: control (or setup) and data. The benefit of having multiple sockets associated with unique processes is that creates a true multi-threaded environment, which eliminates one process potentially blocking others from executing.

Time correlation between networked nodes can be resolved in a couple of different ways, dependent upon how accurate the correlation must be.

- For highly accurate time correlation between the system nodes, each node will be supplied with its own time code reader that receives time from a common source. The built-in interrupt capability provided by these modules allows each node to trigger an event into the node's processor, thus allowing for synchronization between the subsystems. Selected format information is passed from the master to the other nodes over the control socket on an as need basis, allowing any number of nodes to switch formats during flight.
- For data acquisition systems that require less timing accuracy between nodes, a modified command-response architecture is implemented. In this implementation, the master issues a "start acquisition" broadcast command over a unique socket at the beginning of a specific frame. When a node receives the start command that includes format select information, it will execute its specific schedule.

Each node's schedule contains detailed information as to what (input type, input source) should be sampled and when (time from receipt of start) it should be sampled. Once a node's schedule has been completed, the data collected from the node is tagged and packetized and returned to the master via UDP, which is then responsible for the correlation, assembly and output of the final current frame. The output frame will typically be delayed by one or more minor frames, depending upon the frame characteristics (such as frame length and data rate), to ensure that packets from all nodes are received, correlated and processed.

RECORDER SUPPORT

Many of today's airborne recorders provide interfaces that match the characteristics of the vehicle's physical data sources. The use of a networked data acquisition system, which includes a recorder subsystem that includes a network interface, eliminates the need for additional physical input interfaces and greatly simplifies the recorder configuration.

Data that is transmitted on the data acquisition system network is in a packetized form that is comparable to that recommended in the IRIG 107 specification. The recorder can collect data from the subsystem in one of several ways.

- Data packets between the nodes are transmitted via UDP, which allows multiple listeners to accept packets. In this manner, the recorder can choose data from any combination of sources and record received packets to the storage media.
- The data acquisition architecture allows for multiple masters and nodes executing multiple schedules, dependent upon sampling and frame rates. In this manner, the recorder would issue its own "start command" and then receive data packets that match the desired recording format.
- The master would supply final assembled frame packets directly to the recorder once they have been assembled.

CUSTOM MODULES

While we all like to think that telemetry application is a mainstream application, most COTS data acquisition products are tailored to more general-purpose applications. The implication of this situation is that there are some telemetry/instrumentation-specific functions that would require the development of custom modules:

- PCM Formatter
- Signal Conditioners, because most COTS A/D modules do not provide significant channel density with the full suite of capabilities that are normally required, such as filtering, gains, offsets and simultaneous sampling.
- Heritage System Interfaces, which protect a company's investment in existing deployed data acquisition systems.

These designs would use integrated COTS FPGA devices and associated IP cores that would provide the PCI interface required to connect to the host processor bus. Application specific logic, based upon previous experience and fielded designs, would then be added to complete the new design.

RECONFIGURABILITY

The combined use of networks, standard operating system software, and soft logic allows for various functions within the data acquisition system to be reconfigured without having to remove equipment from the vehicle. In the past, any change in functionality was performed by removing the desired module and/or system from the vehicle and replacing a programmable part, which typically has been (permanently) fastened to the baseboard. The use of large storage devices, including non-volatile RAM, Flash and DOC, now allow new software or FPGA configurations to be permanently downloaded to fix problems, add functions, or completely change the personality of the target component.

DESIGN AND SIZE REDUCTION

Besides adding capability into an industry-standard COTS system, the design and development of new modules serve as a prototype mechanism for developing a miniature system that can be used in space-constrained environments.

Many of the technologies used in the larger platform are available in FPGA IP cores that allow a design to be implemented with a limited number of components, thus reducing the amount of required board space. Once an FPGA design has been verified on the larger form factor, its transfer to the smaller platform becomes simply a matter of re-layout.

Because Single Board Computers in the target miniature form factor are not available, a limited system controller would be developed that would integrate Ethernet, PCI and Microcontroller cores. Unlike the controllers that are general-purpose Pentium based Single Board Computers, the miniature system controller is a dedicated design tailored to the data acquisition application. However, like the larger controllers, the use of soft logic allows for upgrades and patches when required.

CONFIGURATION SOFTWARE

One of the most important aspects of any data acquisition system is the external setup and configuration software package. L3 Communications – Telemetry East has recently developed and released its new VistaTEC application that is responsible for the management of calibration and hardware configuration information, as well as the automatic generation of formats and their associated scheduling.

VistaTEC minimizes the effort and system knowledge required of the user, as it manages all information relating to the data acquisition system and creates formats that are tailored to sampling rates and frame characteristics specified by the user. Any specific hardware restrictions are kept hidden from the user and automatically handled by VistaTEC during the format generation.

The output of VistaTEC is twofold:

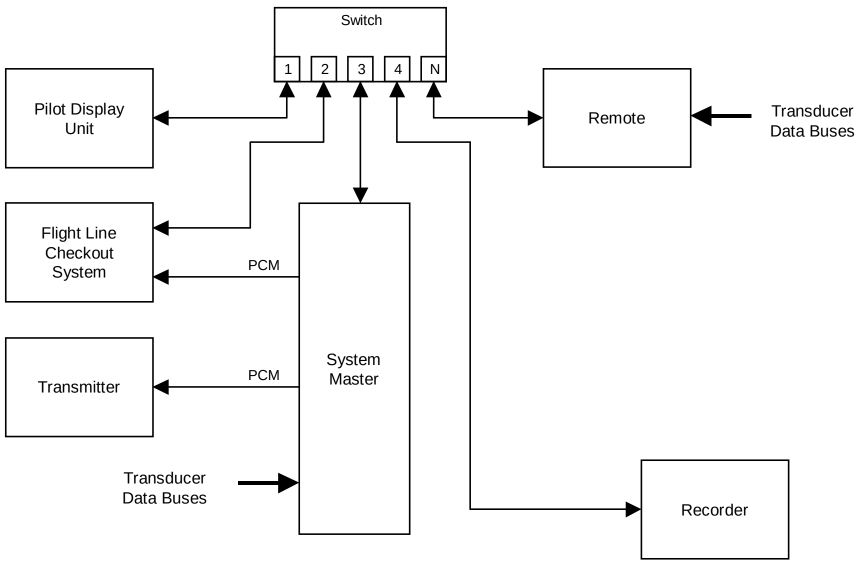
- Airborne Setup Files that are available for immediate download into the data acquisition system
- Database Setup information for a Vista-enabled ground station, which eliminates the user from having to perform any data re-entry for file conversion. [For non-Vista enabled ground stations, VistaTEC can export configuration information in a number of formats, including TMATS (IRIG 106 Chapter 9).]

EXAMPLE CONFIGURATIONS

The following are examples of COTS products in a number of airborne applications, including an airborne data acquisition system. The main item that should be noted is the commonality of hardware and software components between the various system examples.

DATA ACQUISITION SYSTEM

A typical data acquisition system that uses Ethernet as the system interface, as shown in the following diagram, is comprised of many unique components that acquire or produce various types of data. In this example configuration, the data acquisition system consists of a master and a single remote that receives data from a number of transducers and avionics buses. Data output from the remote is received by the system master and merged into the output data streams, which can also be archived by an airborne recording subsystem.

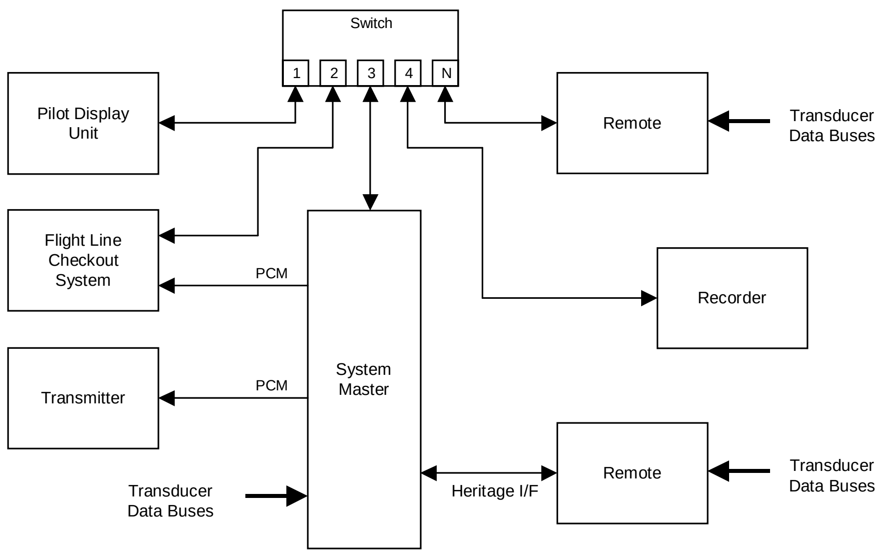


Data Acquisition System Configuration

DATA ACQUISITION SYSTEM WITH HERITAGE SUPPORT

This configuration is almost identical to the first except that it supports a Heritage remote unit that may be already located on the vehicle. Heritage equipment installed in an aircraft, as shown in the following diagram, can be easily integrated into a COTS based system via the development of a customized I/O module that implements the appropriate interface, whether it is 10-Wire, CAIS or some other type. This module would integrate an FPGA device that incorporates a COTS PCI IP core in addition to the heritage interface logic. This implementation, which places most of the design into a single device, highlights some of the benefits of soft logic, including:

- Design Simulation
- Reduced Part Count, which reduces material pricing, debug time, and number of components that could either become obsolete or fail
- Download Capability, allowing patches/upgrades to be done in-system

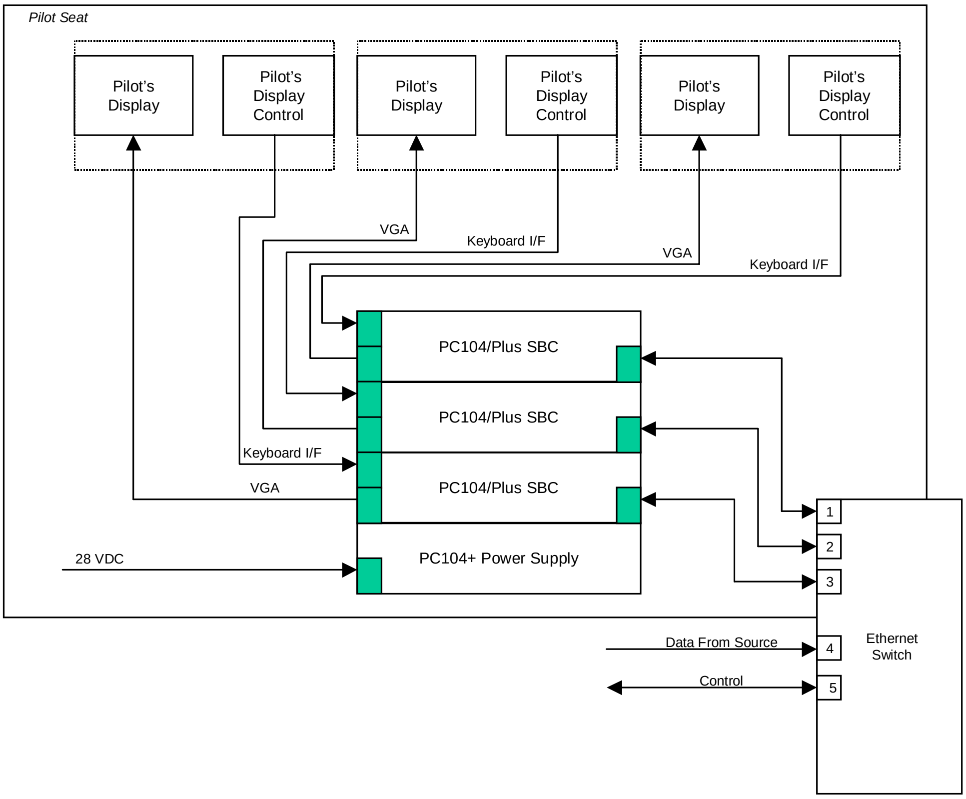


Data Acquisition System Configuration with Heritage Support

COCKPIT DISPLAY PROCESSOR APPLICATION

Many flight test programs now require displays that provide information from the on-board instrumentation equipment. As an example of a Cockpit Display Processor, the next block diagram shows a system that uses multiple PC-104/Plus Single Board Computers to drive multiple VGA displays.

In this configuration, shown in the following diagram, the system is configured as a PC104/Plus stack of processor modules with each processor being completely independent of the others. Each processor is a completely self-contained unit that contains a disk-on-chip to house the operating system and customized software components, as well as supporting the download of user application and/or customized displays.

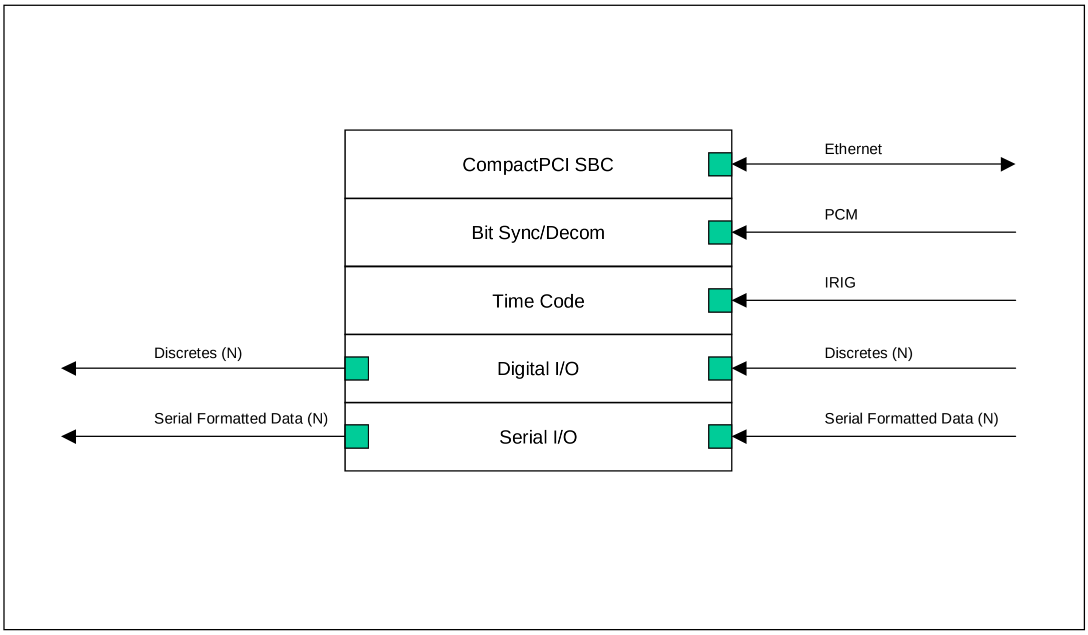


Cockpit Display Application

There is no communication between the processors, as the buses are only used to supply power to the three-processor modules. The stack includes an PC104/Plus power supply in a small system package that is roughly 3"H x 4"W x 4"D, including the connectors. The power supply is configured with filters to allow it to meet MIL-STD-461 requirements. The connectors required by each processor include Ethernet, Serial, Video and Keyboard interface.

AIRBORNE DATA PROCESSOR

In a different configuration such as an Airborne Data Processor, which is shown in the following diagram, the system is configured with a number of I/O interfaces, including PCM, Time, Serial and Discrete, to provide on-board monitoring of the various subsystems located on the aircraft. Results from any processing functions, which include EU conversion or BIT, can be output to the data acquisition system for insertion into the PCM frame that is transmitted to the ground-station monitoring the flight test.



3U CompactPCI Processor Configuration

The Ethernet port is used to receive setup configuration information from a host control computer, and can be used to distribute data to other Ethernet enabled devices, such as a Cockpit Display Processor. The input interfaces are managed by specific software tasks that allow for the monitoring and processing of data from any or all of the sources, while other tasks are responsible for the collection and manipulation of data that is transmitted over the output interfaces

SOFTWARE

Each SBC provides the same functionality that is found in a standard PC, in that it houses all of the same software and hardware components that are resident on an everyday desktop. The primary difference is that each processor typically starts an application that is specific to its functionality on reset or power on.

The operating system is WindowsNT/Embedded with Real-Time enhancements, which are used because they offer a combination of a familiar development environment, standard programming interfaces, and deterministic response from a standard desktop operating system. The use of tools and interfaces that can be run on any Windows platform allows for the development of software without having the target system available. This capability, in itself, saves significantly on the amount of time to test and integrate a unique system configuration.

Software is supplied in one of two forms, depending upon the specific requirements of a customer and the target application.

- Application Programming Interfaces (API) that can be integrated into a customer developed application. These APIs consist of the necessary drivers and libraries that allow a user's program to access the internal system hardware or other data items.
- A fully integrated solution tailored to a customer's specific application. An example of this would be the cockpit display application that would include the integration of a drawing or analysis package to perform the necessary graphics functions.

CONCLUSION

Many concepts and applications have been touched on in this paper, which shows the benefits of using COTS technologies and interfaces within an airborne data acquisition system. While they cannot handle all of the unique requirements of an airborne data acquisition system, they can provide a substantial amount of standard functionality and flexibility at a cost lower than that of the closed proprietary systems that are currently available.

ACKNOWLEDGEMENTS

The author wishes to thank Ed Grozalis for the research that was performed in the development of this paper.

Research on Multi-signals Telemetry Data Acquisition System

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Abstract

As we know, the atrocious environment, strong disturbance and the blackout zone are the features of the reentry telemetry. In order to adapt the requirements of the reentry telemetry acquisition system, an embedding high-speed acquisition system is introduced in this paper.

As various signals have different characters, it is difficult for a telemetry Data Acquisition System to improve the speed of acquisition and increase the number of signals at the same time. This paper introduces a master-slave processors design that consists of two high-speed DSP (TMS320F206) chips, it can make the system realize high-speed picking, storing, editing frame and processing for multi-signals. The whole system can be divided into several different modules according to different functions. Under the control of the master DSP, all of these modules send the acquired data to the master, and the slave DSP can do so by a double-port static RAM, then the master edits the data into frames which will be send to the transmitter.

Key Words

Reentry telemetry data acquisition digital signal processor store

Introduction

The acquisition system can acquire hundreds of vary-slow signals and data by Asynchronous Serial Port at 1200bps easily. The master DSP is mainly in charge of acquiring most signals, processing some signals and editing the data into special frames transmitted at 2Mbps. In order that the master DSP can't be broken by too many interrupts, the slave DSP is used to alleviate the burden of the master. It mainly collects the data that are acquired by interrupts or Asynchronous Serial Port. The other parts of the system are designed in modularization with FPGA (Field Programmable Gate Array) so that it will be easily designed again.

System Description

The whole system is composed of several parts: the master DSP, the slave DSP, the dual-port RAM, the interface circuits and the logic circuit which is integrated within the FPGA. The slave one and some external interface circuits compose another small acquisition system, which exchanges data with the master by the dual-port RAM. The system is depicted as figure 1.

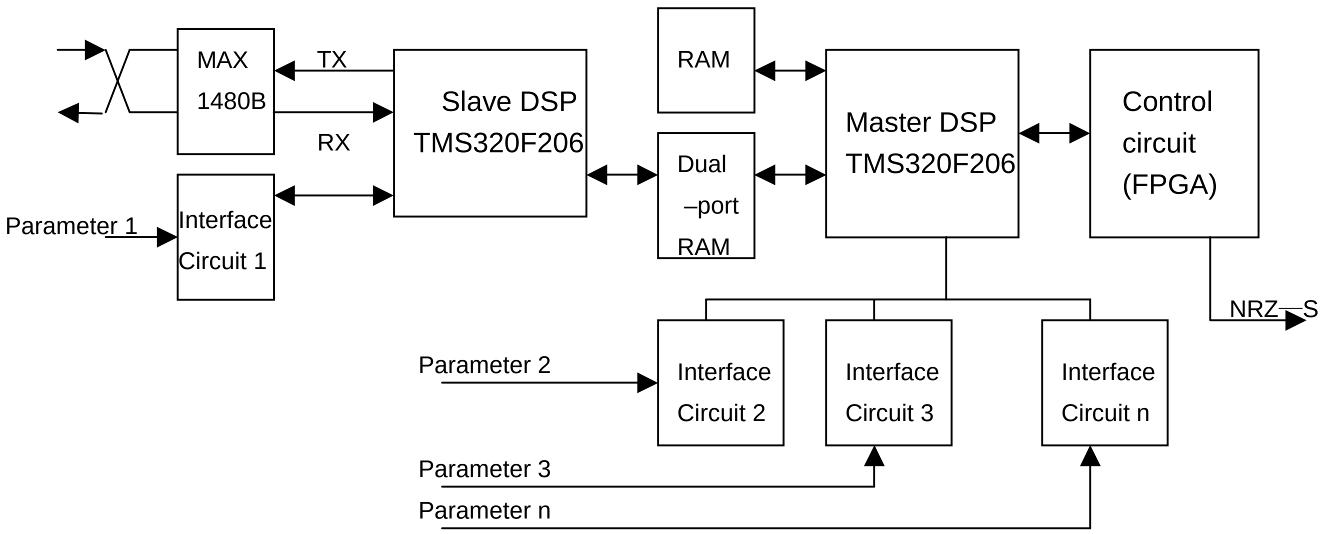

Figure 1 the structure of system

Functions of the system are following:

a. The TMS320F206 Texas Instruments digital signal processor (DSP) is fabricated with static COMS integrated-circuit technology, and the architectural design is based upon that of the TMS320C20X' series optimized for low-power operation. The combination of advanced Harvard architecture, on-chip peripheral, on-chip memory and a highly specialized instruction set is the basis of operational flexibility;

b. The input interface circuits implement the data selection and the communication between internal and external devices;

c. The master DSP takes charge of collecting multi-channel vary-slow signals, storing and processing the acquired data, as well as editing them into regular frames;

d. The slave DSP mainly implements collecting the data transferred by the Asynchronous Serial Port and the parameters that need requests of external interrupts;

e. Dual-port RAM is used to implement the data exchanging between the two DSPs;

f. The pre-processing of the switch signals and the code type transition are implemented by FPGA.

Hardware Design

According to different test parameters, the acquisition system can be divided into several different parts: the power module, the analog signals acquisition module, the digital signals acquisition module, the switch signals pre-processing module, the signals transferred by Asynchronous Serial Port acquisition module and the system control module. Then the detail is as follow:

1. System Control Module

The module is composed of the master-slave DSPs and the peripheral implemented by FPGA. By programming the two DSPs, it can deal with the working schedule of every module and transit the collected data into NRZ-S and send them to the transmitter in the regular telemetry frame.

2. Analog Signals Acquisition Module

The amplitude of tested analog signals includes three kinds: 0~5V, 0~12V, 0~27V. The principle of this module is displayed as figure 2.

Under the control of the master DSP, the A/D device inverts the analog signals into eight-bit digital data.

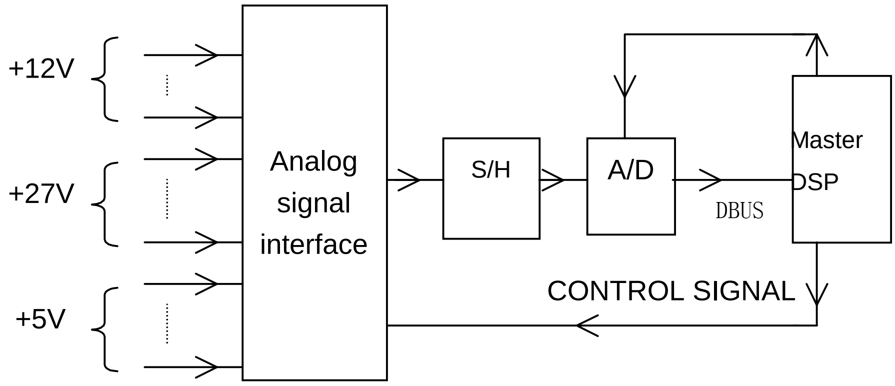

Figure 2 the principle of the analog signals acquisition module

3. Switch Signals Pre-processing Module

Now the telemetry switch signal is brought from relays. Comparing with electro-switch, the dithering must be happened during a relay action (closing and opening). The switch signal isn't ideal when the dithering is transformed into electronic signal. If the dithering can't be got rid of, it will bring some troubles to the acquisition. So the pre-processing module which can get rid of the dithering is necessary. One chip of FPGA can realize the function. The principle figure is displayed as figure 3. The pre-processing module can be divided into three small modules. When it detects the action of the switch signal, module 1 stores the state immediately and then informs module 2 to begin timing. While module 2 times to 3 minutes, it will tell module 1 and module 3 that the action is real and they can store it.

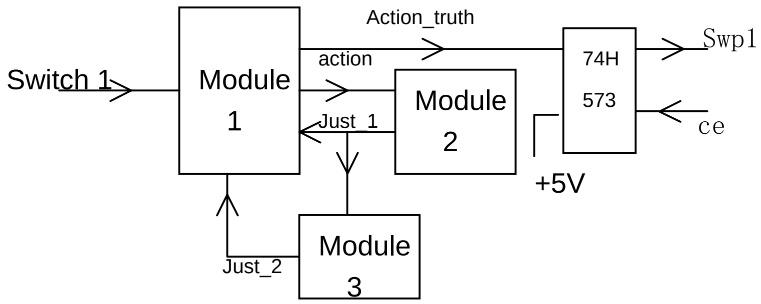

Figure 3 principle of the switch pre-processing module

4. Signals Transferred by Asynchronous Serial Port Acquisition Module

This module is controlled by the slave DSP. The communication between the master DSP and the slave one is implemented by a dual-port RAM. It has two data buses and two address buses. The two sets of buses can visit different store unit at the same time. The figure of communication between the two DSPs is displayed as figure 4. The chip MAX1480B transforms the RS485 lever into TTL lever, and then the signal is collected and processed by the software embedded within the slave. After being processed, it is stored into the dual-port RAM, and waits for being read by the master. In order to avoid the share conflict, the dual-port RAM is divided into two areas (A and B). When the master read data from A area, the slave write data into B area; on the contrary, when the master read data from B area, the slave write data into A area. The alternant read-write method makes the two DSPs can communicates each other in an orderly way.

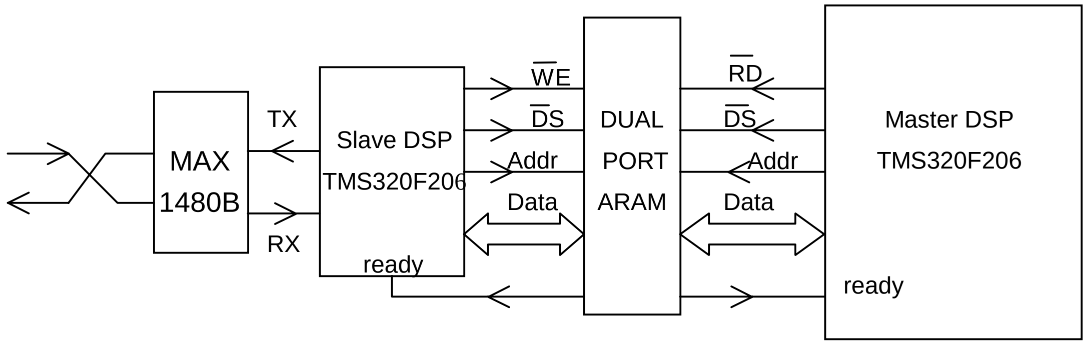

Figure 4 communication between the two DSP

Conclusion

All in all, the design of this system realizes multi-signal telemetry data acquisition, and the modularization design and large programmable logic devices are used to make the system programmable and maintainable, and the system's dependability is also improved at the same time.

Reference

1. Lansun Shen, the principle and appliance of the fast data acquisition system, people's postage publishing company, China,1996
2. Qizong Peng, Yubo Lee, the technique of DSP, Electronic Technology University publishing company, China,1997

THE ANTI-INTERFERENCE ANALYSIS OF PPCM FRAME SYNC-CODE

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1 ABSTRACT

In the reentry telemetry, two super fast signals are often measured, which are called Single Wide Pulse Group (SWPG) and Single Narrow Pulse Group (SNPG) respectively. The results of those measures are of very important value for the reentry telemetry. The Pulse Position Code Modulation (PPCM) code is adopted as the Frame Synchronization Code (FSC) of the two super fast signals. With the noise existing for all time, there certainly exist loss and error pulses after the detector, which will result the loss and error of FSC of the super fast signal encoder. So it is necessary that the loss and error probability of the PPCM FSC is analyzed to understand the anti-interference performance of the PPCM FSC.

In this paper, the error and loss probability of the PPCM FSC is analyzed, and the corresponding probability graph is given, for the existing PPK telemetry system. The results indicate that the performance on anti-interference of the PPCM FSC is powerful, and the error probability is independent of the time interval of the PPCM FSC pulses and only relative to the number of the PPCM FSC pulses and to the number of the error pulses per second after the detector, and the loss probability is also independent of the time interval of the PPCM FSC pulses and only relative to the number of the PPCM FSC pulses and to the performance of the detector such as Signal-to-Noise (SNR) etc, and it is feasible that the PPCM code is used for the FSC of the two super fast signal.

2 THE LOSS PROBABILITY OF THE PPCM FSC

The loss of FSC only takes place while the PPCM FSC comes into the sync section. The n digits PPCM FSC codes are the FSC requested if the number of pulses lost is no more than frame sync error tolerance E. For the super fast signal detector we designed, there are E=0, n=5.

Supposed that the loss probability of every signal pulse is P_{lou} [1]， the digit of PPCM FSC is n, the sync error tolerance is E, then in the sync section the loss probability of the PPCM FSC $P_{ly}(E)$ is

$$P_{ly}(E) = \sum_{e=E+1}^{n} C_n{}^e P_{lou}{}^e (1-P_{lou})^{n-e} \tag{1}$$

where $P_{lou} \approx \frac{1}{\sqrt{2\pi y}} \exp(-y^2/2)$， $y = \frac{A}{\delta_\xi}(1-r)$， δ_ξ is the standard deviation of noise，A is the signal amplitude，r is the amplitude limited relatively。So, when E=0 and n=5，can get

$$P_{ly} = 1 - (1 - P_{lou})^5 \tag{2}$$

Then we can get the results that the loss probability of PPCM FSC increases with the pulse number n up while the P_{lou} being same, and decreases with P_{lou} down for the same n. So the anti-interference performance of the PPCM FSC is relative to not only the selection of the PPCM FSC but also the performance of system operation (Signal-to-Noise S/N etc).

3 THE ERROR PROBABILITY OF THE PPCM FSC

The error of FSC can appear within the signal section and the overlap section. The probability of a or more than a jamming pulse within ΔT or T_w is

$$P(\Delta T) = 1 - \exp(-\upsilon \cdot \Delta T) \tag{3}$$

and

$$P(T_w) = 1 - \exp(-\upsilon \cdot T_w) \tag{4}$$

where $\upsilon = \sqrt{\frac{\pi}{3}\frac{S}{N}} B_{IF} \cdot r \cdot \exp(-r^2 \frac{S}{N})$.

3.1 THE ERROR PROBABILITY OF THE PPCM FSC WITHIN THE SIGNAL SECTION

The error probability of the PPCM FSC within the signal section is relative to the average error pulses number per second υ and to the signal distribution probability, which includes the following two cases.

①The PPCM FSC pulses all are made up of the jamming pulses.

②The PPCM FSC pulses are made up of the jamming pulses and the M signal pulses.

At first, the first case will be analyzed. Supposed that the P is a random jamming pulse within the observing time T, at the same time after the P pulse more than n-2-E jamming pulses occur at the special position and a or more than a jamming pulses take place in the window time T_w at the last sync code position, then the error of the PPCM FSC will occur. So the error probability of the PPCM FSC all formed by the jamming pulses $P_{swwy}(E)$ is

$$P_{swwy}(E) = \sum_{e=0}^{E} T \cdot \upsilon \cdot C_{n-2}^{n-2-e} P(\Delta T)^{n-2-e} (1 - P(\Delta T))^{e} P(T_w) \tag{5}$$

The second, the second case will be discussed. Supposed that there are e pulses lost while the n digits PPCM codes are formed. The e pulses make up of the I lost pulses resulted by the M data pulses (or signal pulses) and the rest e-I pulses which appear the other n-1-M special positions. Then,

when e≤M,

$$I=0,1,2,\ldots\ldots e \tag{6}$$

when e>M,

$$I=0,1,2,\ldots\ldots M \tag{7}$$

The combination with the M data pulses at the n special positions is

$$P_M = C_n^M \tag{8}$$

The probability with the M data pulses losing I digits is

$$P_{MI} = C_M^I P_{lou}{}^I (1 - P_{lou})^{M-I} \tag{9}$$

Within the rest n-1-M special positions, the probability resulted by the (n-1-M)-(e-I) position, whose width is ΔT, is

$$P_1 = C_{n-1-M}^{n-1-M-(e-I)} P(\Delta T)^{n-1-M-(e-I)} (1-P(\Delta T))^{e-I} \tag{10}$$

Then, the error probability formed by the n-e pulses is

$$\overset{M}{P}_{sbwy}(e) = P_M P_{MI} P_1 P(T_w) \tag{11}$$

So, when the sync error tolerance is E, the error probability is

$$\overset{M}{P}_{sbwy}(E) = N_s \sum_{e=0}^{E} \overset{M}{P}_{sbwy}(e) \tag{12}$$

And then, the error probability of the PPCM FSC, which is resulted by the jamming pulses and the data pulses within observing time T, is

$$P_{swy}(E) = \overset{M}{P}_{sbwy}(E) + P_{swwy}(E) \tag{13}$$

Only one word pulse is transmitted for every word in the PPK (Pulse Position Keying) system when the general telemetry datum are transmitted, and the minimum interval between two words is $64\Delta T$. The time width formed by the super fast signal PPCM FSC is always no more than the minimum interval. So M is only equal to 1. Consequently, when E=0 and n=5, the formula (13) can be expressed by

$$P_{swy} = (T \cdot \upsilon + 5N_s(1-P_{lou}))P(\Delta T)^3 P(T_w) \tag{14}$$

3.2 THE ERROR PROBABILITY OF THE PPCM FSC WITHIN THE OVERLAP SECTION

According to the frame characteristic of the PPK system, it is a little probability thing that the PPCM FSC is made up of the several super fast signal FSC pulses and the data pulses. So it is important that the partial PPCM code pulses and the jamming pulses are thought as the reason resulting the error PPCM FSC.

Supposed that PPCM overlaps the encoder window with β identical '1' and λ ingoing '1'. The value of β and λ is given for the SWPG super fast signal regulation code (3,4,5,6), see figure 1. When the PPCM code pulses come into the encoder window in order, the error PPCM will be only formed by the β identical pulses and the jamming pulses. It is not difficult to understand that the probability formula is same in the main as that resulted by the M data pulses and jamming pulses above. Only the β pulses are regular and the M data pulses are random. So, getting rid of the probability coefficient C_n^M from the formula (13), the error probability P_β resulted by the β PPCM

Pulses and jamming pulses with error tolerance E is

$$P_{\beta}(E)=\sum_{e=0}^{E}\sum_{I=0}^{\substack{e(e\le\beta)\\ \beta(e\ge\beta)}}C_{\beta}^{I}P_{lou}{}^{I})(1-P_{lou})^{\beta-I}C_{n-1-\beta}^{e-I}P(\Delta T)^{n-1-\beta-e+I}(1-P_{lou})^{e-I}P(T_{w}) \tag{15}$$

While the PPCM code pulses coming into the encoder window, the judging number of times H is

$$H=D+1 \tag{16}$$

where the D is the code length of the PPCM, which is equal to the number of time ΔT within the width of the PPCM. In the H times judging for the ingoing PPCM, the error probability P_{in} is expressed by

$$P_{in}=\sum_{\beta}N_{\beta}P_{\beta} \tag{17}$$

where the N_{β} is the total number of β for the H times judging. When the PPCM code pulses come out of the window, the same thing will be occur. Supposed that the probability is expressed by P_{out}. Then, get

$$P_{out}=P_{in} \tag{18}$$

Consequently, the error probability $P_{cwy}(E)$ within the overlap section is

$$P_{cwy}(E)=P_{in}+P_{out}=2P_{in} \tag{19}$$

It is not difficult to understand form the figure 1 that the β can only be 0 or 1. When $\lambda=1$, $N_{1}(1)=1$, when $\lambda=2$, $N_{1}(2)=2$, ……, when $\lambda=n-1$, $N_{1}(n-1)=n-1$. So, get

$$N_{1}=1+2+3+\dots+(n-1)=\frac{n(n-1)}{2} \tag{20}$$

$$N_{0}=H-N_{1}=H-\frac{n(n-1)}{2}$$

Then, the error probability of the regular PPCM within the overlap section is

$$P_{cwy}(E)=2((H-\frac{n(n-1)}{2})P_{0}+\frac{n(n-1)}{2}P_{1}) \tag{21}$$

So when the sync error tolerance is E, the formula (21) can be expressed by

$$P_{cwy}(E)=2((H-\frac{n(n-1)}{2})P_{0}(E)+\frac{n(n-1)}{2}P_{1}(E)) \tag{22}$$

3.3 THE ERROR PROBABILITY OF THE PPCM FSC

The error probability of the PPCM FSC within the signal section and the overlap section has been discussed above. But the true error probability should be equal to the addition of the two partial probability, which can be expressed by

$$
\begin{aligned}
P_{wy}(E) &= P_{cwy}(E) + P_{swy}(E) \\
&= [T.v + 2(D + 1 - \frac{n(n-1)}{2})P(\Delta T) + n(n-1)(1-P_{lou})]P(\Delta T)^{n-2} P(T_W) \\
&\quad + C_n^M N_s (1-P_{lou})^M P(\Delta T)^{n-1-M} P(T_W)
\end{aligned} \tag{23}
$$

So, when E=0 and n=5, the formula (23) can be written by

$$
P_{wy} = [T \cdot v + 20 \times P(\Delta T) + 20(1-P_{lou})]P(\Delta T)^3 P(T_W) + 5N_s(1-P_{lou})P(\Delta T)^3 P(T_W) \tag{24}
$$

We can get such a result from the discussion that the error probability $P_{wy}(E)$ is relative to the PPCM pulse digits n, the IF bandwidth of receiver B_{IF}, the signal-to-noise S/N and the limited relatively amplitude r, and not to the characteristic time interval of the PPCM.

Here, there are $T_w = \Delta T$, $T = 20.48\,ms$, $N_s = 64$, B_{IF} =10MHZ for the super fast signal encoder of mine. According to the formula (2) and (24), the figure 2 and the figure 3 can be got.

Only can no data distortion make the transmitting of high precision time meaning. So it is necessary that the probability for no data distortion is discussed, which can be the probability of no error and loss for a data transmitted and can be expressed by

$$
P_{wh} = (1 - P_{lou})(1 - P(\Delta T)) \tag{25}
$$

where ΔT is the average time of a data or a pulse. The figure 4 shows the relation of the probability of no error and no loss and the SNR and the r. From the figure 4, the type of SNR and r can be got when the probability of no error and loss datum is over 99%: $SNR = 16 \sim 17$, $r = 0.5$.

We can find from the figure 2 that the loss probability of the SWPG FSC increases with the r up, and decreases with the SNR up, which is superior to 10^{-4} under the type of SNR and r. At same time we can find from the figure 3 that the error probability of the SWPG FSC decreases with the r and SNR up, which is superior to 10^{-10} under the type of SNR and r.

4 CONCLUSIONS

The error and loss probability of the PPCM FSC are discussed above at the base of coding regular 2 (The n digits pulse at will are thought as the PPCM code pulses transmitted when the interval of time is identical to the special time interval scheduled of the PPCM). Thus the following conclusions can be got.

- Under the PPK system and the code length given and the observing time T, the error probability is independent of the time interval of the PPCM FSC pulses and only relative to the number of the PPCM FSC pulses and the number of the error pulses per second after the detector.
- Under the PPK system and the code length given and the observing time T, the loss probability is also independent of the time interval of the PPCM FSC pulses and only relative to the number of the PPCM FSC pulses and the performance of the detector such as Signal-to-Noise (SNR) etc.
- Under the PPK system and r=0.5 and SNR=16~17db, the loss probability of the SWPG FSC is superior to 10^{-4}, and the error probability superior to 10^{-10}.

5 REFERENCES

1 Mingxun xie, “The Technology for the Reentry Telemetry System”, The Defense Industry Press, 1992.

2 Dajin Lu, “The Random Process and Its Application”, The TsingHua University Press, 1995.

THE ENCODER WINDOW

					λ		β
1001000100001000001							
1001000100001000001	1		1				
1001000100001000001		1		0			
1001000100001000001					1		0
1001000100001000001					2		1
1001000100001000001					2		0
1001000100001000001					2		0
1001000100001000001				2		1	
1001000100001000001				3		1	
1001000100001000001				3		0	
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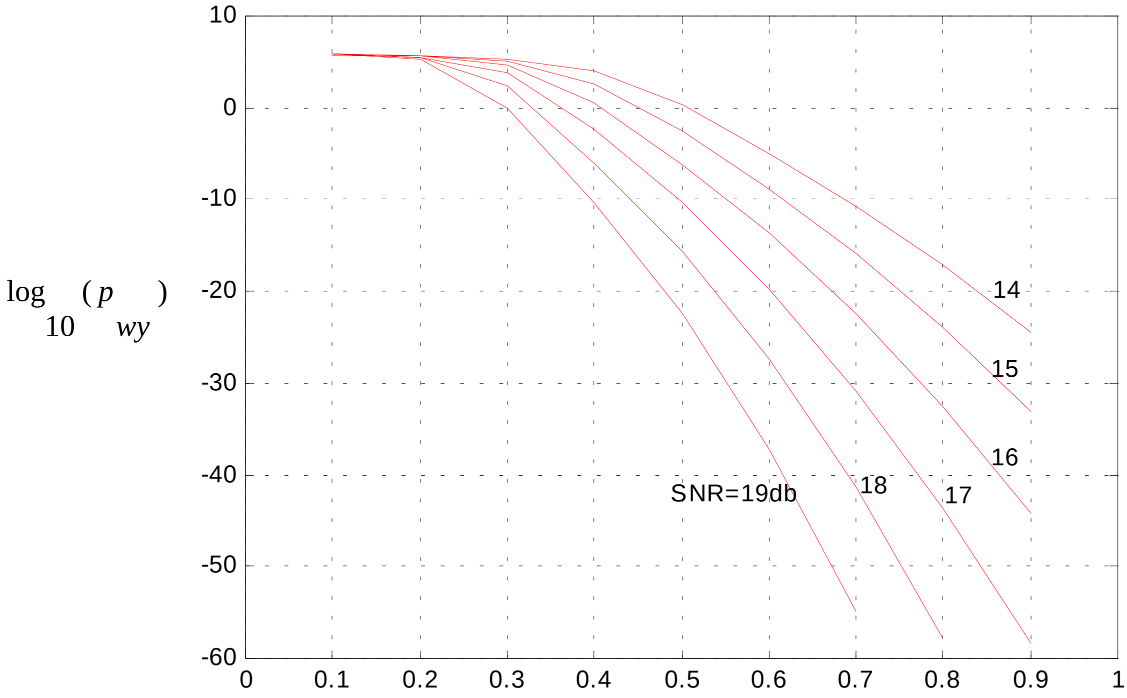

figure 2. The error probability curve

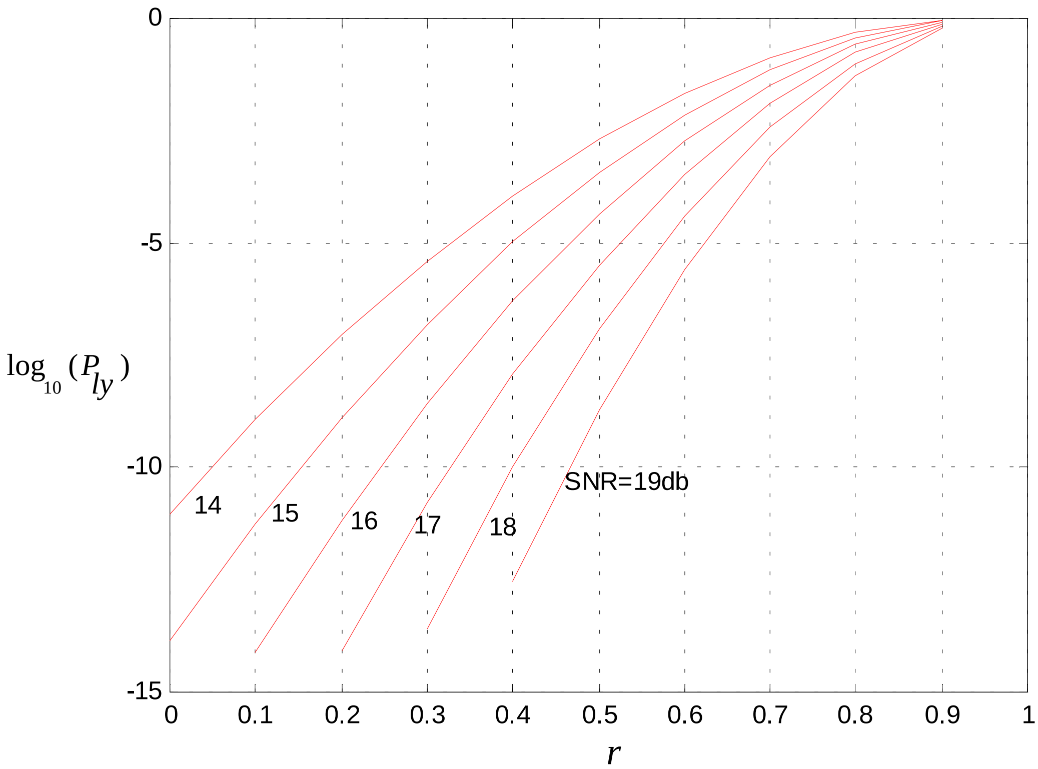

figure 3. The loss probability curve

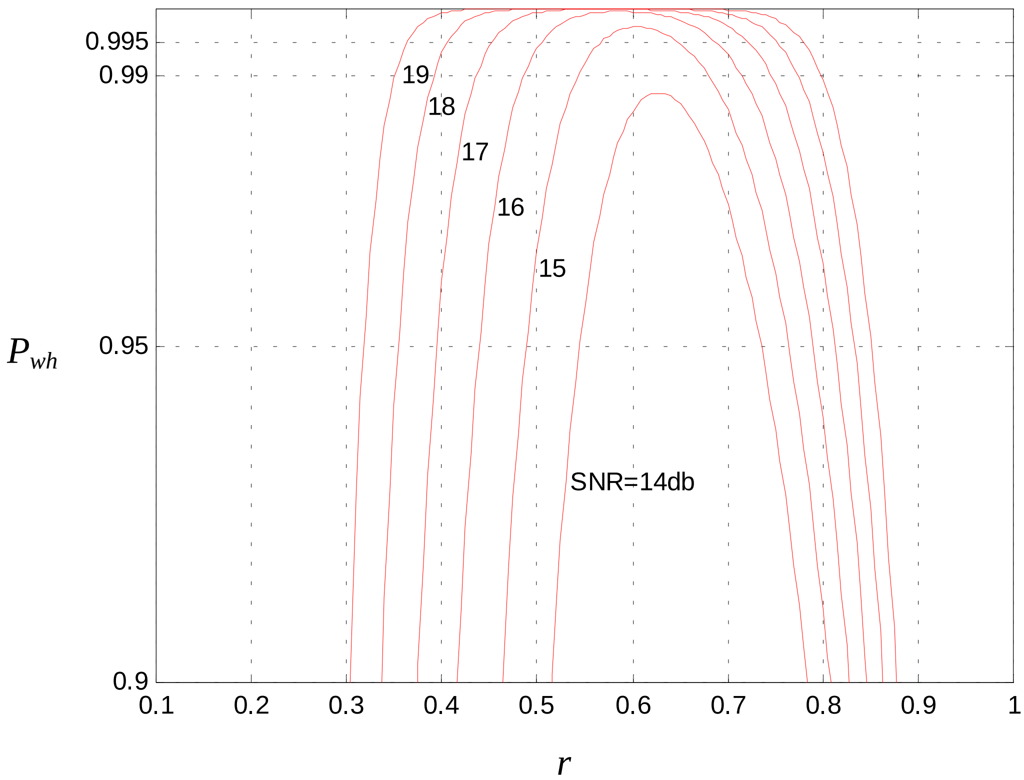

figure 4. The probability of no error and loss datum curve

SPECIFYING A PCMCIA IRIG-106 (Ch. 4) DECOMMUTATOR

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Abstract

There are many applications where an ultra-compact PC (palm-top) is required for quick analysis of PCM data. There are many design issues associated with the design of a PC-Card (PCMCIA) decommutator.

- Is it possible to connect a 20Mbps PCM stream?
- What outputs are required from such a card?
- How many cards can be used?
- Which mode to use (memory or I/O)
- How to program such a card
- How to develop third-party software for analysis of data

This paper discusses some of these issues and the applications for such a card.

Key Words

PCMCIA, PCM Decom, Quick-look

Introduction

The PC-Card (PCMCIA) has been around for about 15 years. Originally a specification for adding memory to portable computers, it has become a de facto standard for the addition of all kinds of peripherals to portables, hand-helds and even desktops (with the addition of an adaptor).

Its common use in compact computers raises the interesting possibility of creating a small, portable, flexible ground-station for in-flight use, or for flight-line testing of an FTI system. Recognizing this, in 1995, ACRA CONTROL produced the world's first PCMCIA format IRIG-106 decom, the SAM/DEC/005. This successful product has since been used in many applications.

With the launch of the SAM/DEC/006, ACRA CONTROL continues and enhances this product. At this point it is worthwhile to step back and look at the kind of features a PC-Card format decoder should have, focusing on its flexibility and power as a flight-line system test tool, and as an in-flight monitoring tool. This paper takes a bottom-up view of the key features required from such a device.

<u>Physical layer</u>

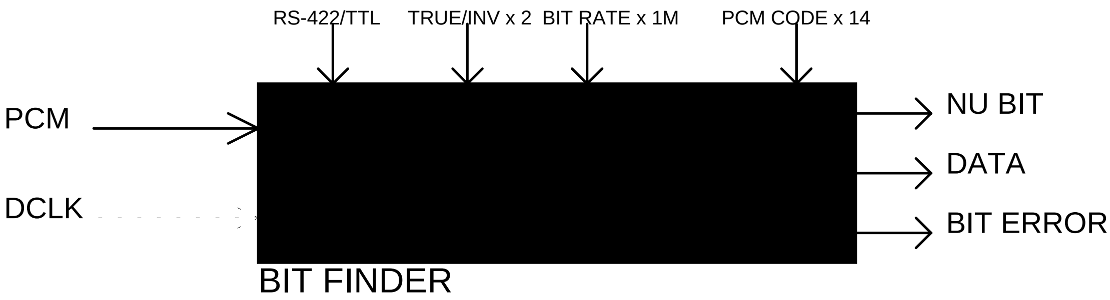

Figure 1 – Bit finder

Bit Rate

In today’s FTI systems there are often multiple streams, intended for multiple destinations, with different bit-rates, frame characteristics and so on. If the decom is to be a useful flight-line test tool it must handle a broad range of bit-rates, from 1kBit right up to 20Mbit/s. This kind of range is possible with careful design, although faster bit-rates (>10Mbit/s) may require a separate clock (such as provided in standard NRZ-L).

At the extreme end of the scale, the bottleneck in data transfer and logging is not the decom, but the physical interconnection of PC-Card interface and disk. Few portables have the power to manage 20Mbit/s incoming and stream it to disk. An extremely useful way of overcoming this limitation is to allow the decom to be configured to store only a subset of the incoming parameters. The non-store parameters are ignored, reducing the effective bit rate to a manageable level. This is often all that is required for test or quick-look applications, and eliminates the need for a separate “test & debug” PCM stream at lower rates.

PCM Codes

The Flight Test Engineer wants to ensure that the system he is looking at is the system that will fly. So he must be able to work with the PCM codes that are preferred by the ground-station personnel. This means that the PC-Card decommutator must be able to handle a wide range of codes. As an example, the SAM/DEC/006 can handle RZ, NRZ-L/S/M, BIØ-L/S/M, DM-M/S, and RNRZ-L x 4.

Protocol layer

Frame Layout

The decom must be able to handle a wide range of frames – from quick & dirty debug frames to large, fully loaded test frames. Further, it must not be limited by requirements like equal-width sub-frames, as many of today's systems use multiple-width sub-frames to optimize bandwidth.

Often, the software available on a portable is not as powerful as that available on a ground-station. For example, the ability to extract a sub-set of a PCM word and display it as a distinct parameter may not be present. The decom can overcome this by permitting the frame to be defined on a word-by-word basis with differing parity, bits-per-word, word order and so on. In addition, a syncword of up to 64 bits (with 64-bit mask) allows a huge range of frames to be handled.

Protocol Tracking

Programmable matches-to-lock and misses-to-loss allows control over the sensitivity of the decom to aberrations in the incoming stream. A surprisingly useful feature is the ability to program a "matches-to-lock" of 1, which means that the decoder locks on as soon as any syncword is detected. This allows even asynchronous "bursts" of IRIG-106-like data to be stored.

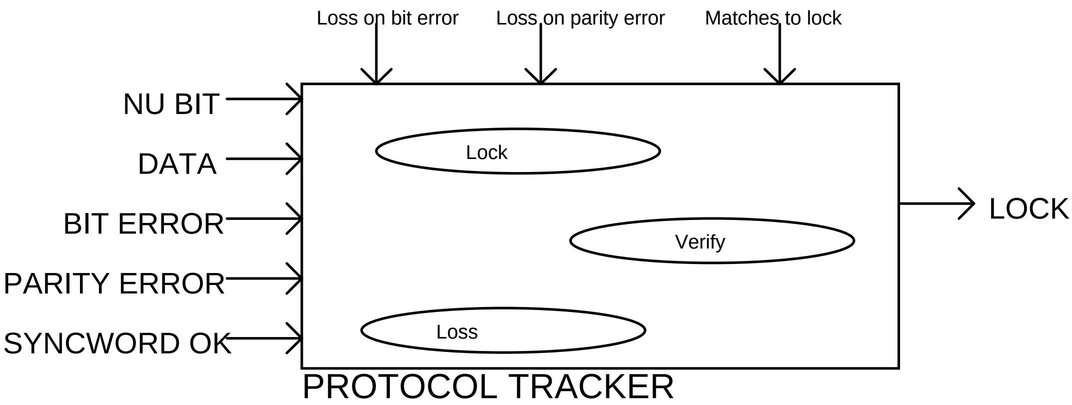

Figure 2 – Protocol Tracker

Synchronization Debug

Many people are familiar with the "it's not in lock" panic when the pressure is on. A modern decom can provide debug assistance for the engineer in this case. The SAM/DEC/006 provides a status word which indicates whether the syncword is present, whether there is a valid clock, whether the number of bits per frame is as expected and so on. Also, the sync word polarity can be set to "both" and each bit can be masked. All the above is useful in identifying where the problem lies.

Data Management

Handling Embedded Data

A common element of many streams is embedded data. This could be a stream of samples from a voice or video encoder, or even an embedded PCM stream. Typically these are handled by some software to extract the embedded data, and then transmit it to an interface card that can send the data to an audio or video playback unit. However, PC-Card is all about compact size and portable systems, so there is no room for extra interface cards.

The SAM/DEC/006 takes a unique and innovative approach to solving this problem. When programming the unit, particular words in the incoming PCM stream can be marked as “embedded”. These are then extracted in hardware and sent to output pins on the decom itself, from where they can be simply wired to the playback device. There is no software required, and no extra complications.

Embedded PCM can be handled just as simply, the embedded output can be looped back to a second SAM/DEC/006 in the same system where it is handled as straightforward PCM without any hardware or software complications.

PCMCIA usually has two type II slots. One of which can be used as a second decom or bit synchronizer.

Handling CVTs

Most decoms convert the incoming serial data to parallel samples stored in a current value table (CVT). Many “ping-pong” between two or more such tables to prevent data overwrite during reading. The PC-Card interface also allows this architecture.

There are two modes of operation for PC-Cards – input/output (I/O) mode with interrupt support, and memory mode. I/O mode has speed and memory space restrictions. It supports the “ping-pong” architecture (using interrupts), however, a more powerful architecture is possible using memory mode. In memory mode, there is access to a large RAM buffer. Depending on frame size, this can be configured to store multiple CVTs. This allows a configurable amount of buffering in the decom itself, an important requirement for working with modern multi-tasking operating systems.

Persistent Storage

The format, protocol and CVT organization can all be stored in EEPROM, so that the decom becomes a stand-alone device that can be swapped between machines without the need for re-configuration.

Software

Plug & Play

The PC-Card represented both a driving force and a challenge for the Plug 'n' play architecture which has appeared in Microsoft operating systems over the last five years. With on board Card Information Services (CIS) a PC-Card decom can configure itself as soon as it is plugged into a new PC. Installing the drivers involves following the on-screen instructions.

Simple Interface

By adopting a very straightforward approach to data recovery from the decom, it is possible to make access to the card completely open. The SAM/DEC/006 ships with DLLs and library support for Visual C++, Visual Basic, LabVIEW, MathLAB and other packages. In addition it is supported by powerful third-party data logging and analysis packages such as Magali from HTS.

Conclusion

A PCMCIA decom and a lap-top or palm-top PC provide an excellent compact part of today's ground support equipment (GSE). However, they must still be able to cope with some of the more daunting aspects of larger ground stations, for example, 20Mbps, multiple PCM codes and embedded PCM output.

They must also have features that allow for fast logging to disk such as store/ no-store select on data and multiple CVTs.

Finally, they must come with DLLs for third-party software packaging.

References

The PCMCIA Developer's Guide, Second edition, Michael T. Mori, W. Dean Welder, Sycard technology, Sunnyvale, CA 94086.

IRIG STANDARD 106-99, Telemetry Standards, January 1999, Prepared by: Telemetry Group, Range Commanders Council. Published by, Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, New Mexico 88002-5110

DEFINING AN OPEN FLIGHT DATA ACQUISITION SYSTEM

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Abstract

As today's flight test data acquisition systems grow more complex, there is a large requirement for open standards that allow COTS equipment from different vendors to be used together. However, there is more to inter-operability than getting the wiring right – it flows through from requirements specification to the gathering of data. This paper discusses the characteristics of an open system at each interface between customer requirements and programming of the DAU:

- Industry standard specifications for data interchange with databases and software packages
- Human readable file formats for Data Acquisition Unit (DAU) setup
- Communications link from ground station equipment to DAU
- Industry standard protocols for interconnection of DAUs
- Intra-DAU backplane specification to allow custom acquisition functionality to be added

Only by providing third-party entry points at all six layers can the goal of an open data acquisition system be achieved.

Open Systems and Interoperability

The term "open system" generally refers to an interface or technology that is controlled by a standards group, is published, and is not specific to a particular vendor. In theory this is good, because users can choose the most suitable equipment for a task from any vendor, with confidence that they can insert it in their system and get it to work with other equipment. In practice, open systems are not always to the benefit of user or vendor. Standards committees are bureaucratic and standards regularly lag behind available technology. Indeed, focusing on open standards and forcing compliance can stifle innovation and exploitation of new technologies.

In fact, an open system in this sense is not necessarily what users require. Users are looking for interoperability first and foremost, the ability to mix and match equipment from different vendors and not encounter endless headaches trying to get them to all work together [1].

What is required are open "gateways" – published interfaces that allow equipment from one vendor to share data and information with equipment from another vendor in a controlled way. This allows innovation and specialization within the (proprietary) vendor's domain, while still guaranteeing freedom of choice for the user.

In the flight test community there is typically a vast range of different types of equipment that are interconnected and/or exchange data involved in any flight test program – in the air, on the ground and in between. From a user perspective the task of getting these systems to inter-operate is crucial to a successful program. But it is not enough to focus on one problem area; for example the physical and data layer tackled by the CAIS initiative. Today's programs are complex and last for so many years that it is almost impossible to identify all the needs for inter-operability at the beginning, each aspect of the system needs to be analyzed and as open a solution as possible found.

The Holy Grail is the "instrumentation network" and there is ongoing development to map out the interfaces that are important to make this network a reality – such as the JDANS program [2]. This focuses on adapting commercial standards to flight test and instrumentation topology requirements (NexGenBus [3]) as well as defining message structures for inter-operable equipment. Other efforts focus on the "big picture" and are trying to get a unified path from user requirement to analyzed data [4a], [4b].

The focus of this paper is specifically on data acquisition (the DAU) and is more short term – what technologies, standards and equipment are available today that are open, and are positioned to take advantage of the developments towards the instrumentation network.

Layers of interoperability

There are five layers of requirements translation from the user specification to samples on the DAU:

Requirements Definition

The user requirements are represented in some form, typically in the form of tables in a database or system definition documents. At this level they are expressed completely in the user domain without reference to any physical implementation of a data acquisition solution.

Instrumentation Definition

At this level, the generic requirements have been refined to reflect specifics about the system; wiring, transducers, topology and so on. Very often this layer reflects proprietary information required by a particular DAU vendor.

Communications Interface

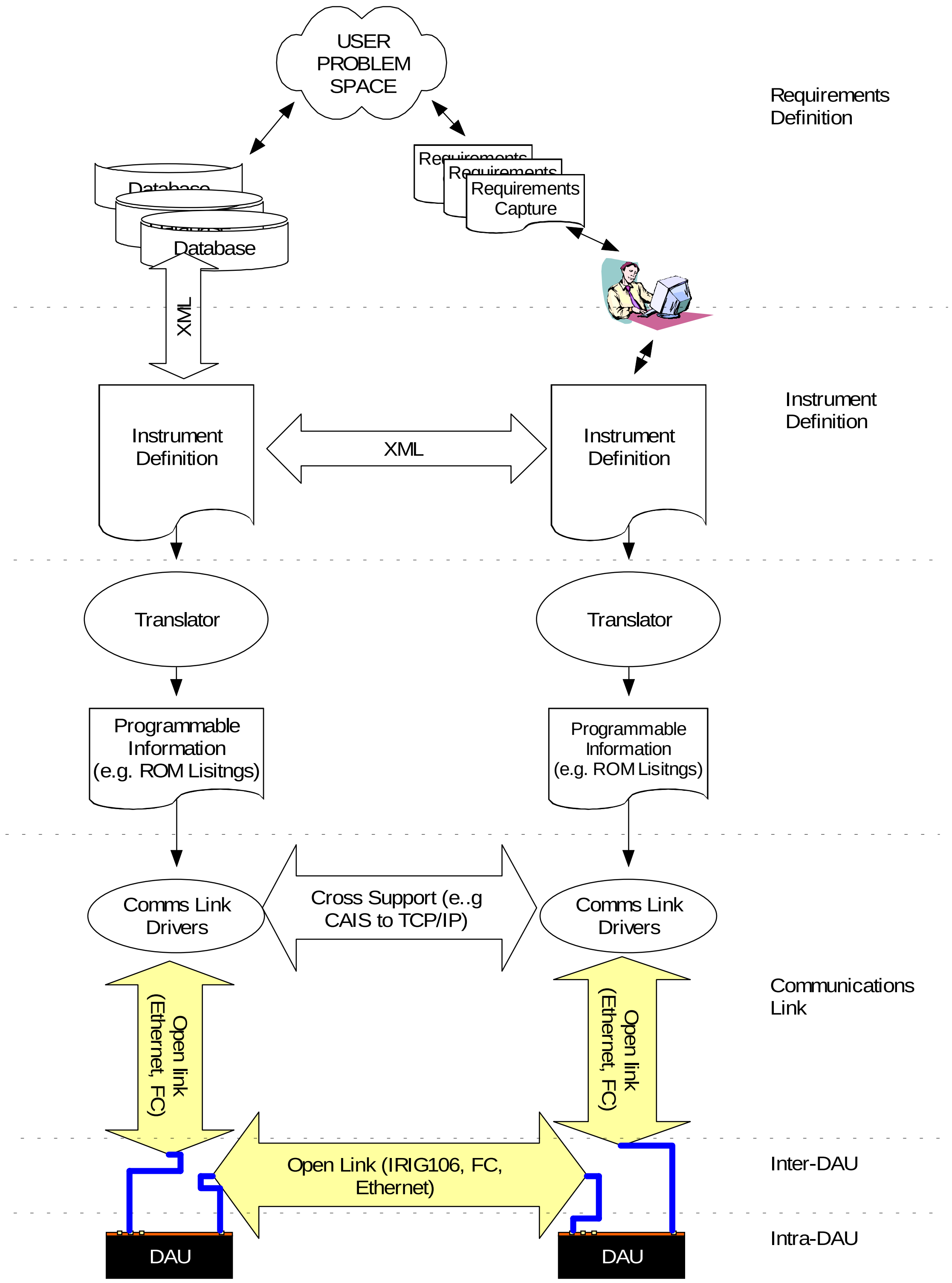
This level translates the setup information from its representation on the ground station as ROM files or setup files, to a form and protocol suitable for transmission to the actual DAU itself.

Inter-DAU communication
In distributed acquisition systems data and synchronization control must pass between different units.

Intra-DAU communication
Within the DAU, sampled data must be transferred from the point of sample to storage or transmission.

To create a system that is open, vendors must try to open interfaces at and between each level to allow inter-operability with other equipment, and users must plan how to leverage these gateways through the life of the project.

In the next section we discuss each of these interfaces in more detail.


USER PROBLEM SPACE
Requirements Definition
Database
Requirements Capture
XML
Instrument Definition
XML
Instrument Definition
Instrument Definition
Translator
Translator
Programmable Information (e.g. ROM Lisitngs)
Programmable Information (e.g. ROM Lisitngs)
Comms Link Drivers
Cross Support (e..g CAIS to TCP/IP)
Comms Link Drivers
Communications Link
Open link (Ethernet, FC)
Open link (Ethernet, FC)
Open Link (IRIG106, FC, Ethernet)
Inter-DAU
Intra-DAU
DAU
DAU

Requirements Definition

Although the details of the equipment and technologies used may vary, the baseline user requirements evolve slowly over time. The number and type of parameters to be sampled goes up, the rates go up, the complexity increases, but overall the end goal is the same so the core task remains the same. Typically, these requirements are stored in databases, often with large amounts of legacy software for parameters management, manipulation, analysis and user input.

The transform of this information into a specific requirements representation is one of the fundamental problems faced in defining an open system. Typically, products from different vendors need to know this information – the DAU needs to know how to encode the data, the ground station needs to know how to decode the data.

Solutions used today include:

- Manually enter the data into software through a GUI (usually supplied by the DAU vendor). This is tedious, expensive and prone to error. It can be assisted by modern GUI standard compliant products, but is ultimately only practical for small installation (a few hundred parameters at most).

- Write software to transform the data into the specific requirement representation. This is the most practical solution, but the cost and complexity of this task is determined almost completely by the nature of the specific requirement representation. Despite attempts to standardize this (TMATS) most vendors use their own (for reasons discussed below). Thus the task of writing and maintaining this software could become onerous unless the equipment supplier has a carefully structured and extensible instrumentation definition.

- Use off-the-shelf tools to transform the data into an international and commercial data interchange standard such as XML. This solution requires that the equipment used supports XML and that vendors are prepared to supply XML schema for the data interchange definition. There is still some software glue required but this offers a genuinely open, commercially led solution to this problem.

Instrumentation definition

At this level the generic user requirements are stated in a language that the DAU can understand. As stated before equipment manufacturers have tended to define their own definition files.

TMATS is an attempt to provide a standards-led open data interchange at this level. It is a well thought out and well structured standard and in many cases is the only option for interchanging certain types of data between manufacturers. However it has limitations: it has a clumsy and non-open way of handling special requirements of equipment manufacturers, it is not human readable making it useless for test auditing or record keeping, it is difficult to extend beyond current technologies. Furthermore, it is specific to the industry – there are few parsers or syntax validators available and they are not free.

Some implementations, such as the XID file used by ACRA CONTROL, try to address these limitations by providing a free-form, easily written Instrumentation Language that is human readable and, more importantly, extensible. The human reading makes it usable as an audit tool – XID files can be stored on CD and used to check or recreate test environments ("was the gain on channel 7 really 1000? Or did someone program 100 by mistake?"). More importantly, it is divided into scoped sections that have version numbers allowing the language to evolve without invalidating files written using previous revisions of the standard.

The powerful, non-proprietary XML standard offers another solution [5]. Here manufacturers need only publish a schema (or XML grammar) that they can accept. The task of generating the Instrumentation definition is greatly simplified by the XML standard and tools that are available from many vendors. One such schema has been proposed to update TMATS to the 21st century [6]. Using XML, interchange between different formats becomes easy to implement – for example ACRA CONTROL freely interchange between XID and XML for instrument definition.

Communications Link

Once the data is in binary form ready for transmission to the equipment, the link becomes important. There are many industry standard options here – RS-232, Ethernet, Fibre-channel, FDDI and so on. Ideally, all equipment should be set up and controlled through one interface. In practice this is not generally possible today.

An example of an attempt to address this issue was the CAIS standard. This was partially successful in that it provided a documented open standard for physical interconnection, as well as the protocols to be used for data transfer. Its failure was that it was very industry specific and thus failed to capitalize on the other benefits of open systems: many vendors and lower costs due to efficiencies of scale. It also failed to take account of the rapid evolution of technology with communications speeds restricted to 10Mbps and the maximum addressable setup ROM on equipment restricted to 64kWords.

Learning from this, the currently active NexGenBus standard adopts an industry led commercial standard (Fibrechannel) and piggy-backs specific requirements for avionics (to handle special needs such as determinism) onto it (FC-AE). While this is undoubtedly necessary for a full avionics bus, there is a danger in this for FTI in that the flight test community could find itself once again asking for very industry specific developments with their associated costs. A better approach for FTI would be to adopt the FC standard without extension and solve the determinism problem in another way.

Apart from fibrechannel, Ethernet is being considered as the communications link for several programs. This uncertainty about which of the many options will emerge as the preferred solution makes selection of an “open” system difficult. The solution is to look beyond the currently available options and into the architecture of the system under consideration to determine if it is capable of adapting rapidly to the ongoing changes in technology.

Interconnection of DAUs

The issue of interconnecting DAUs from different vendors (or even the same vendor) comes down to two issues:

- Inter-DAU control
- Inter-DAU Data transfer

For inter-DAU control, an open system must avoid proprietary timing diagrams and hidden or undocumented protocols. These make debugging difficult and inter-connection of different systems impossible without some “glue” technology. A better solution is to use existing simple, relatively slow, synchronization signals and standard protocols such as IRIG-G251 for transfer of any control information that maybe required.

The transfer of data from DAU to DAU is easier to define in an open way. Options are the well-known IRIG-106 PCM standard, or commercial packetized transfer such as TCP/IP. The industry trend is towards packetization. To capitalize on this trend today’s DAUs should be “protocol neutral”. This can be achieved through an architecture that decouples data acquisition from data transmission, and digitizes data as close to the source as possible for ease of transmission and broadcast.

Although communication links and interconnection of DAUs are treated separately in this paper, in practice there is no technical reason why these two layers cannot be handled by the same technology – that Ethernet for example be used to program DAU’s as well as move data from one to the other.

Intra-DAU

The lowest level of “openness” possible is a published and open specification that allows third parties to design data acquisition or other equipment for direct connection to the DAU.

Although this appears to be desirable, in practice it has some problems: bespoke and specialized development is expensive, inserting equipment from third parties may invalidate the original vendor warranty, vendors may have intellectual property rights tied up in their designs which they are understandably reluctant to release.

Where it is beneficial is in situations where the cost/benefit of a third-party development is worthwhile, where the details of connectivity to equipment cannot be disclosed to a vendor, or where there is concern about a vendor’s ability or willingness to support equipment over the life of the program.

In this case the characteristics to look for are that the equipment uses simple, digital interface techniques that are unlikely to daunt third parties, and that the vendor is willing to support such a development albeit with the protection of non-disclosure agreements or other commercial safeguards.

Conclusion

What this paper has attempted to do is apply a rigorous analysis to what is meant when we use the term “open” systems. In a world where there are customers who need to interconnect equipment from many vendors, and vendors who are dedicated to serving those customers, there is always going to be a tension between “open” and proprietary. However, both sides can be satisfied by a careful definition of the various “gateways” to a proprietary system. These include:

- industry standard data interchange languages such as XML
- published instrument definition language specifications
- adoption of industry standard communications protocols and technologies for the physical interconnection and communication of systems

It is important to avoid FTI specific developments that may lead both users and developers into technological dead-ends.

The long-term efforts are leading us to an instrumentation network where different subsystems coexist happily in a single integrated environment, communicating through open interfaces. In the end, the specifics of the task make a truly open system difficult to achieve, but if the dialog between user and vendor is “open”, then the solution is possible even with systems available off the shelf today.

References

[1] Furness, H. - **Bus or Network - What is Interoperability?** - Control Engineering, February 1993.

[2] http://jdans.navair.navy.mil

[3] S. R Jones, T. DeSelms – **The Use of Commercial Standards in DoD Applications** – ITEA ’99, http://jdans.navair.navy.mil/NexGenBus/Docs/ITEA-99-CommercialStds.pdf

[4a] L. Gardner, J. Garling Jr., A. Berard – **Managing and Acquiring Test Data in the Information Age –** Proceedings SFTE 31st Annual Symposium, Turin, Italy, Sept. 2000

[4b] L. Gardner, C. Jones – **Plug-and-Play Like Data Acquisition –** http://www.edwards.af.mil/itea/Papers99/paper03.doc

[5] Organization for the Advancement of Structured Information Standards (OASIS): http://www.xml.org

[6] B. Downing – **An XML Vocabulary for TMATS –**Proceedings ITC, San Diego, CA Oct. 2000

SIGNAL PROCESSING ABOUT A DISTRIBUTED DATA ACQUISITION SYSTEM

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Abstract

Because modern data acquisition systems use digital backplanes, it is logical for more and more data processing to be done in each Data Acquisition Unit (DAU) or even in each module. The processing related to an analog acquisition module typically takes the form of digital signal conditioning for range adjust, linearization and filtering. Some of the advantages of this are discussed in this paper. The next stage is powerful processing boards within DAUs for data reduction and third-party algorithm development. Once data is being written to and from powerful processing modules an obvious next step is networking and decom-less access to data. This paper discusses some of the issues related to these types of processing.

Key Words

Fatigue, Fast Fourier Transform (FFT), data compression, signal processing, digital signal conditioning

Introduction

As next generation Flight Test Instrumentation (FTI) systems move toward digital technology, they are increasingly required to process data in the Data Acquisition Unit (DAU). This paper looks at the trade-offs to be evaluated in implementing these capabilities. Some examples of the types of processing tasks that are common in FTI and ideally suited to digital processing are:

- Digital signal conditioning
  Provide programmable, accurate filtering, offset, and scaling of incoming analog signals

- Program-specific algorithms
  Derive new parameters from direct measurements

- Fatigue monitoring
  Reduce large quantities of data to a small dataset, which summarizes the current state of the structure

- Networks and cockpit displays
  Format data into packets for real-time transfer and limit check for alarms and displays for pilot and crew

- Data Compression
  Bandwidth for extravehicular transmission may be limited so store all raw data onboard, but only transmit a subset of the information for real-time monitoring

This paper argues that there is no single simple solution to these needs. Sometimes a general-purpose microprocessor or digital signal processor (DSP) is required, and sometimes a simpler state-machine lookup is sufficient. Whichever solution is required, a fully bidirectional digital backplane is essential.

Definition of processing hardware

A DAU often has the primary task of repetitively sampling sensors which transform various physical measurements of the test platform into a form that can be transmitted and recorded, and also monitoring the various buses used for digital communication throughout.

The result of this data acquisition is that digital representations of the monitored channels exist for formatting into an output. Some of this data is in raw form, however, and it may be advantageous to perform some sort of calculation or transformation involving the data to produce another form that is easier to understand first.

Many things may be done to transform the data including scaling into engineering units, compression (e.g. only transmit the difference between the current sample and the last), and derived parameter creation where multiple raw parameters are combined in some way to form a quantity that is not directly measured. An example of a derived parameter is calculating velocity from changes in position measurements.

Each of the examples above are numeric in nature and are benefited by processing hardware that is fast and efficient at these sorts of numeric calculations.

Another aspect of DAU hardware is that it is sometimes desirable for it to interact with the test platform. For example, in order to obtain measurements from an avionics device that is connected to the DAU via a MIL-STD-1553 interface, it may be necessary for the DAU to temporarily act as a bus controller. This application calls for a processor that can both process logical conditions quickly, and one which has well-supported software development resources. This second aspect is often overlooked and may be the more important of the two.

Generic Versus Specialized Processing

A designer has many choices for implementation of processing hardware. These choices include generic solutions which use microprocessors that run programs written for the task at hand, and also hardware whose architecture is tailored to perform a particular calculation (for example, a Fast Fourier Transform (FFT)). Most of the calculations performed by the processing hardware are repetitive and are aimed at either reducing transmission bandwidth or providing real-time information in a special format in addition to the raw data being collected.

In general it is possible to design a generic microprocessor-based solution that is more flexible than the special-purpose hardware approach, but the dedicated hardware is usually simpler and faster. The simplicity of the special purpose hardware also makes it typically more robust.

A good compromise between a general purpose CPU and a specialized circuit design (for example a multiplier) is a lookup table implemented in RAM or ROM. This technique allows the sometimes lengthy calculations to be performed once in a non-realtime environment and then to be accessed quickly and consistently during a flight.

Digital Signal Conditioning

A key principle of digital signal conditioning is to digitize the data efficiently. In other words, have as few components as possible between the incoming signal and the A/D. Each analog component in the chain adds additional error, especially over the operating temperature range.

Older technology A/D devices were simply too large to dedicate a separate A/D for each channel of an analog module and still get a reasonable channel density in a system small enough to be usable for FTI. The alternative was to host the instrumentation amplifier and pre-sample filtering for each channel (using analog filters) on the module, and then pass all signals through a multiplexer prior to a single system-wide A/D. Figure 1 shows this old way of sampling analog signals. Offset adjust is carried out before the A/D, as is all the filtering (therefore 6th order+) and this followed by noisy multiplexers.

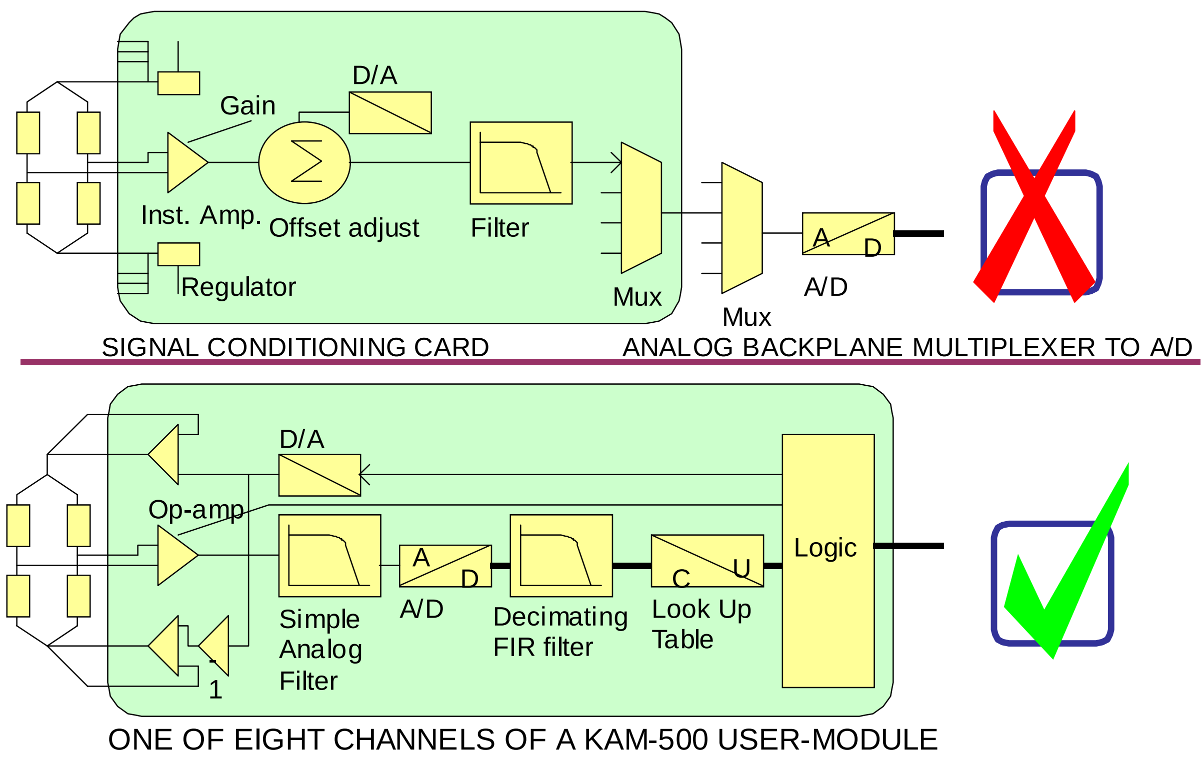

Figure 1 – Two approaches to analog signal acquisition

Figure 1 also shows the modern digital approach which takes advantage of the compact, fast 16-bit A/Ds available today, where the digital filtering and offset adjust is carried out after an A/D device per channel. The multiplexer(s), and offset adjust circuitry are removed and the fixed anti-aliasing filter is much simplified because the A/D samples at many times the desired sample rate and filters the signal digitally.

Some of the significant advantages of digital signal conditioning are: fewer analog components, better pass-band response, less quantization noise, and less drift with time. A detailed treatment of digital filtering is beyond the scope of this paper, but it is interesting to note that the processing required for filtering must be on the module itself and must be scalable to accommodate more/faster channels.

Program-Specific Algorithms

There are many simple algorithms that involve taking a few parameters to produce a single output.

One popular example is Center of Gravity calculations that involve, for example, fuel level readings from several tanks.

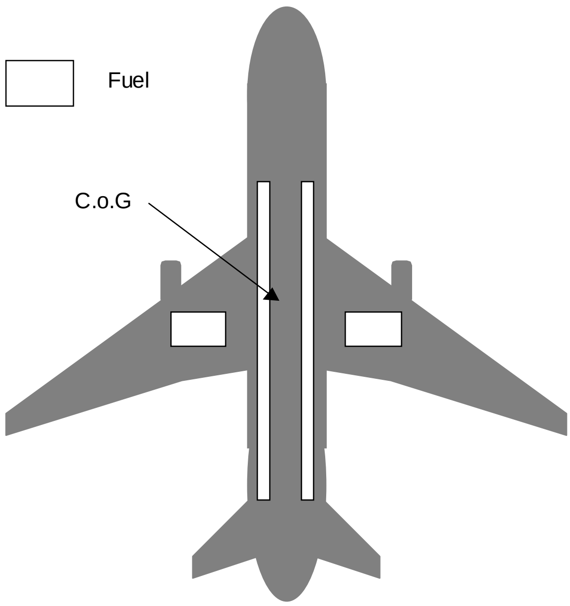

Figure 2 – Center of gravity calculations

Another illustrative example is Engine Thrust. This may involve readings from sensors as diverse as: fuel flow, airspeed, throttle-position and air pressure.

While these algorithms may be required as part of data reduction they may also be useful with respect to onboard real-time display or use.

For the purposes of this paper it is sufficient to note that this type of processing is usually more suited to a generic processor with numeric capability and access to data from many modules. It is also more likely to be suited to microprocessors or signal processors because of the evolving (changing) nature of the algorithms.

Fatigue

Fatigue calculations may not, strictly speaking, be a common request for FTI equipment yet. However the issues involved may be interesting with respect to this paper.

Typically many strain gage readings are taken at high sample rates. The data is then passed (several times!) through a "filter" as illustrated below.

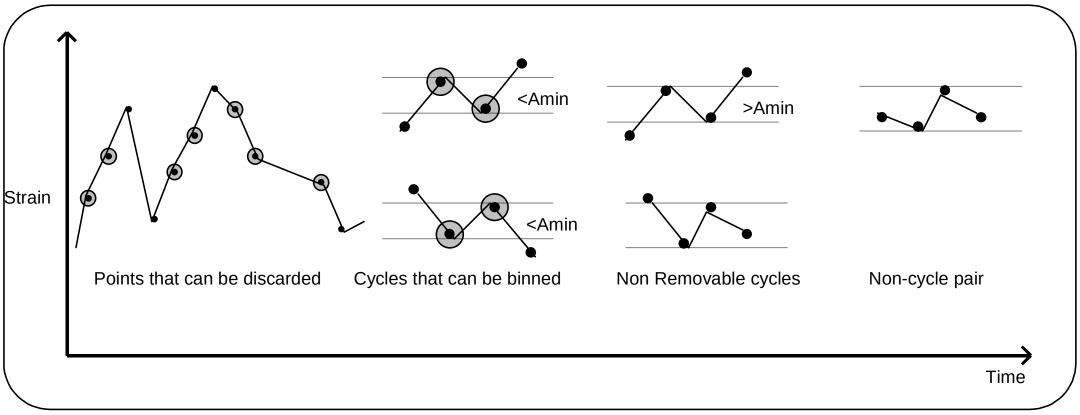

Figure 3 – data passed through a filter

Monotonic points are totally discarded (i.e. not binned or logged). Cycles of amplitude less than a user-programmable constant (Amin) are used to increment a count in one of a large number of bins as shown below.

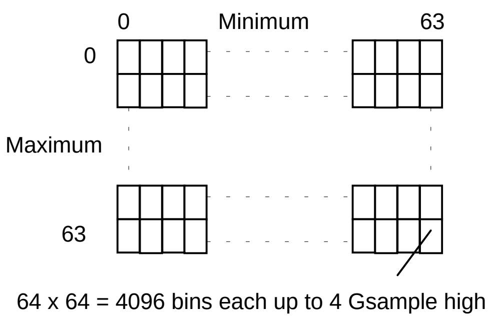

Figure 4 - Bins

The remaining points and their time tags are logged.

For the purposes of this paper (centralized vs. distributed, and logic vs. processors) the following observations can be made:-

The algorithm essentially compares points and cycles with previous points and cycles. While this is second nature to processors they can only do one comparison at a time. A lookup table implementation can do tens or even hundreds at a time. As for centralized vs. distributed, again the answer is probably straightforward. Fatigue analysis involves a lot of data reduction, which can be carried out on each channel individually. To avoid choking the backplane this is best done on the module.

Networked Data Acquisition

An emerging trend in FTI is onboard data networks. This is mainly due to the proliferation of networks in the commercial world and the spread of that technology into the FTI marketplace.

In order to participate in this new scheme, a reformatting of data from the common IRIG Chapter 4 PCM into CCSDS or other packetized structures is required. There are also high-level transfer protocols involved that are widely available in commercial software and ruggedized hardware. This is a case where there is definitely no reason to try and re-invent the wheel. There are even special purpose LAN processors that are capable of surviving the demanding environments of flight test.

One attendant requirement of this type of data conduit is the need to buffer sizable amounts of data. Again, this is not unique to FTI and the problem has been solved in the commercial world and is there for the taking.

As for the program-specific algorithms discussed above, this type of processing is usually more suited to a central unit with access to data from many modules. It is also more likely to be better suited to microprocessors than dedicated logic because of the complexity of the many layers of formatting and flexibility of response required to communicate with other network participants and protocols.

Cockpit Displays

Onboard display of data on a Cockpit Display Unit (CDU) is often much more useful when it is simplified to a “go/no-go” level. Crew tasking is too extensive to require interpretation of raw data to decide when a problem exists. This sort of calculation and alarm/limit checking is another ideally suited application for a processor.

In addition to being able to readily digest the data, many contemporary processors have inbuilt communications interfaces including common parallel busses (e.g. PCI) that allow easy integration with virtually any type of display from the simplest LED indicators to sophisticated 3-D graphics.

The elegance of a digital backplane architecture is highlighted here because there is no impact on the core data collection by the CDU processing. Backplane traffic is simply monitored by the CDU process and data of interest are captured and converted while other data are unimpeded on the journey to onboard bulk storage or encoder modules that format it into packets, PCM, or any other format of interest. Command/response systems are archaic by comparison.

Data Compression

As signal lists and sample rates increase and RF bandwidths do not, the need to evolve data compression algorithms grows.

Solutions such as Continuously Variable Sigma Delta (CVSD) modulation appear to have applications only in audio data. The loss of d.c. accuracy is hardly worthwhile for a 12:1 reduction in data.

Another extreme is to take a large number of samples in an acquisition cycle and then transmit only the maximum and minimum. While this has the advantage of large and constant data reduction, there may well be many “babies thrown out with the bath water”.

A radical approach (only in that it is non-traditional) based on Shannon, involves only transmitting enough data to be able to reconstruct the original signal to within some tolerable error. A typical example of this type of reasoning is shown in Figure 5, where 4096 points (8Kbytes) are passed through an FFT, only those components with amplitude above some (perhaps changing) level are transmitted.

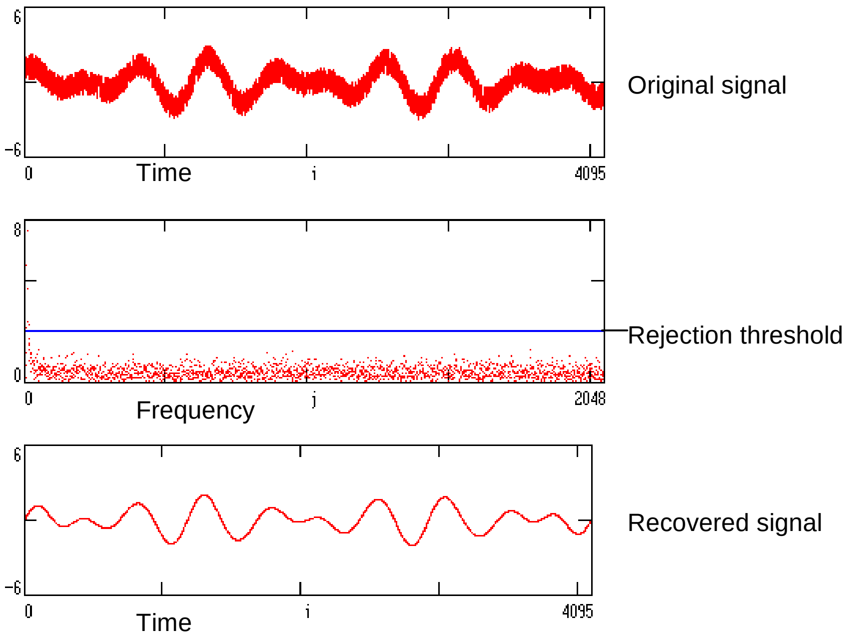

Figure 5 – FFT of signal

In this case six points (6 x 12-bits x amplitude and frequency) were all that was required to reproduce the signal as shown - a 50:1 compression rate.

One problem is that the reduction rate varies unless a rule such as "give me the x largest frequencies" is followed. Another problem is the delay introduced in order to calculate and gather the samples and carry out the FFT.

Rather than an FFT it may be possible to use predictive filters (even an FIR might do). This would have smaller delays but would also be variable in the compression rate obtained.

The type of algorithms discussed above can be implemented in a distributed system with a compression engine in each module of each DAU. However, a central processor would have the advantage of being able to adjust rejection thresholds based on the information levels of other more "important" signals. In other words, signals could be weighted for importance and filtered accordingly. For example, multiple strain gauges on a beam would have one designated as being more "important", so if information is "lost" it is less likely that all information from that structure is lost.

This type of adaptive data reduction would require access to all parameters and would therefore be centralized. Due to the evolving nature of the compression algorithm it is likely that a signal processor would be required, especially for FFTs.

Conclusion

There is no single simple solution to the processing power of the next generation FTI systems. There are issues with respect to brown-outs and coherency. Sometimes a "central" microprocessor or signal processor is required, and sometimes distributed logic cores are needed.

Whichever solution is required a fully bidirectional digital backplane is essential.

References

C. E. Shannon, ”A mathematical theory of communication,'' *Bell System Technical Journal,* vol. 27, pp. 379-423 and 623-656, July and October, 1948.

Discrete-Time Signal Processing
Alan V. Oppenheim, Ronald W. Schafer, John R. Buck
Prentice Hall Publishing

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Visualisation within Test and Evaluation

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Abstract

Synthetic Environments play an important role for QinetiQ, and everyone involved with the test, evaluation, and design of weapon systems. Visualisation displays complex modelling, simulation, and real-world data into a virtual reality format. This paper describes some of the advances that the Test and Evaluation sector of QinetiQ (T&E Ranges) has been involved with, for the testing of complex weapon/defensive systems since we reported on the subject last year [1]. We discuss the use of data visualisation techniques, and a synthetic environment project that will link-up two QinetiQ range facilities, to test future ship support services. We also discuss how we use these techniques to add value, reduce costs, and add to the effectiveness of trials.

Introduction

We refer extensively to the use of Synthetic Environments (SE's) within this paper. Many researchers, papers and publications refer to SE's in different ways. We will define a SE as a system that could be PC based, such as models and simulations running on a PC, or set of PCs, (networked or not), or models integrated with Hardware In The Loop (HITL). This is similar to definitions of SE's elsewhere in literature [2].

Visualisation is a part of the larger SE picture. It is primarily used to combine data from models, and/or output from hardware, and facilitate the ease of understanding of that data. This is particularly time and cost effective if the data sets are large and complex, and difficult to understand. This amount of data is often seen from telemetry on most of today's trials. QinetiQ have used visualisation techniques to plan trials (placement of tracking instrumentation), for after trial reviews, for data extraction, gaining knowledge from data, and mission rehearsal.

The reason why we use SE's, and visualisation can be answered by considering how cost effective they can be. Integrating SE's, and real-world testing can provide significant cost saving benefits. If used correctly they can also provide significant system performance benefits. This is because we can run models and simulations numerous times, at relatively little cost, to see what effects may be had on the system design or configuration. If we also incorporate real-world test data, we can begin to validate the techniques and simulation output that have been used in the SE. This need to Verify, Validate, and Accredit (VV&A) models by combining data sets from real-world trials into the virtual world is now a common occurrence. This provides added confidence in the evidence to support acceptance activities throughout the procurement cycle. A rigorous discussion on VV&A, and so on, is not warranted here because papers dedicated to the subject explain this in more detail [3].

We will discuss some of the visualisation techniques that we have been involved with since last reporting on the subject [1], and how they have helped with the overall test and evaluation process.

What has been achieved so far

To gain a better understanding of large and complex data sets that are produced on many trials, we have found significant benefit in displaying the results in a 3D virtual environment. T&E Ranges have been involved with Commercial Off The Shelf applications (COTS), and developing our own software that provide high-resolution graphical 3D viewers.

Much of the telemetry data that is produced on a trial can be processed into the applications, and a virtual world quickly populated with models of the equipment, targets, and tracking instrumentation. Figure 1 shows a simple textured polygon model of a Type 23 Frigate that has been used in recent data visualisations.

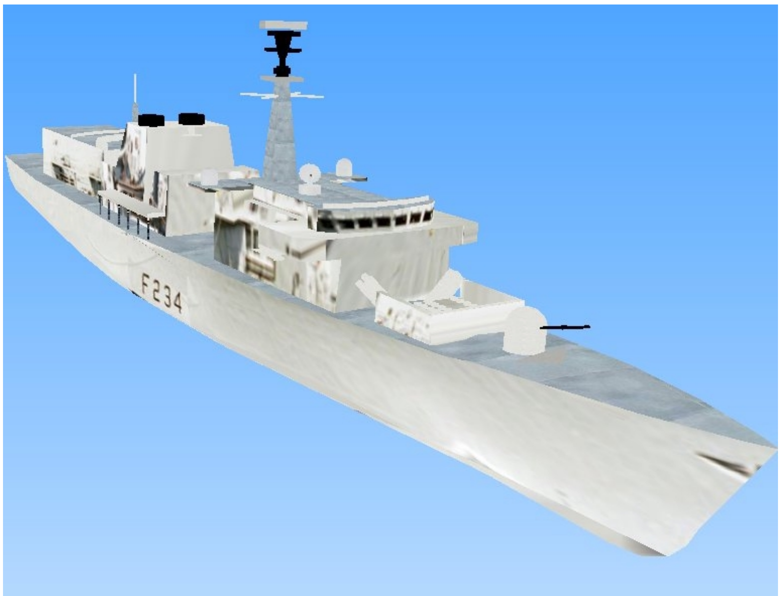

Figure 1

It is also possible to accurately represent world topography using digital terrain. Currently there exist many sources of data for digital terrain; Digital Terrain Elevation Data (DTED) is one format, and digital features (DFAD) is another. The digital terrain can be textured with satellite images, or aerial photographs, to give a photo-realistic appearance. Figure 2 shows a false colour satellite image draped over some digital terrain which highlights this statement.

It is possible to combine the telemetry data of a missile firing, or shell, or any other projectile, and in conjunction with the digital topography of the surrounding area we have generated an accurate virtual world. This has been especially useful for planning trials. The accurate 3D environment enables us to place tracking instrumentation in positions derived from GPS etc, and to establish what the field of view will be for the instrument, sensors, etc (figure 3). We can also use these techniques for examining the potential safety of a trial.

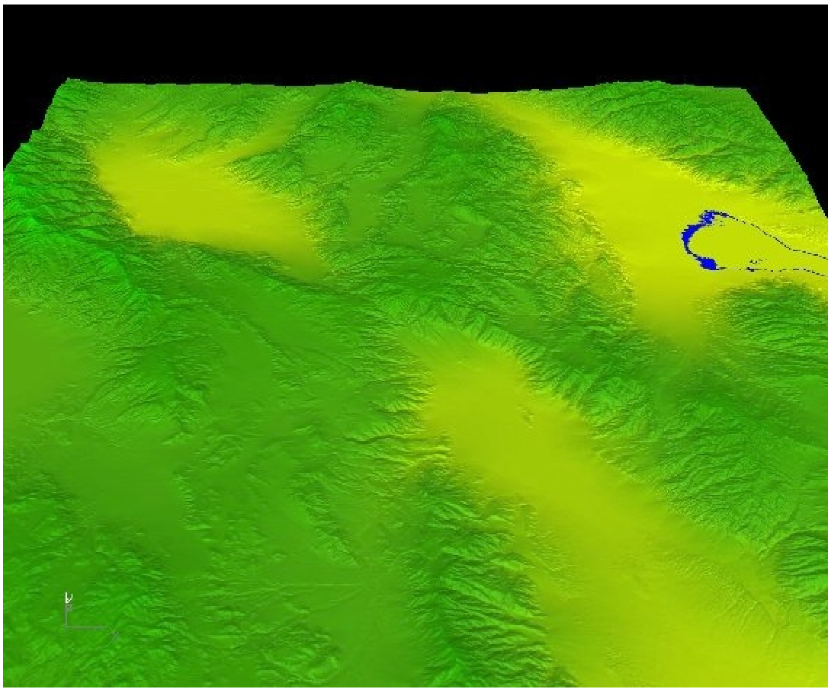

Figure 2

The same 3D scene can be used for after trial reviews. This is often the case; we provide the data in a format that we can give to a customer, to run on a standard COTS PC. The visualisation provides a much simpler picture than a ream of paper, and helps to extract knowledge from data. Figure 4 demonstrates this by showing the projectiles as observed from two different tracking intsruments. The virtual world has been populated with tracks (the green and red lines) showing what the path the projectile took, and then rendered with the raw telemetry data (white text, top-right).

The next stage for the Ranges SE project is to incorporate the live data feeds from telemetry, and integrate more hardware and software models, than has been achieved previously. This is discussed in the following section.

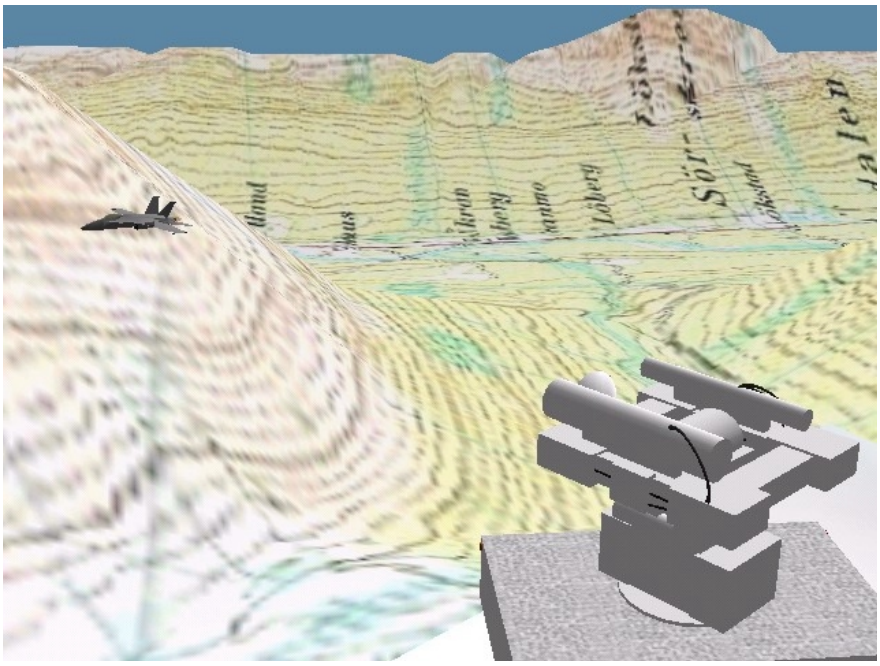

Figure 3

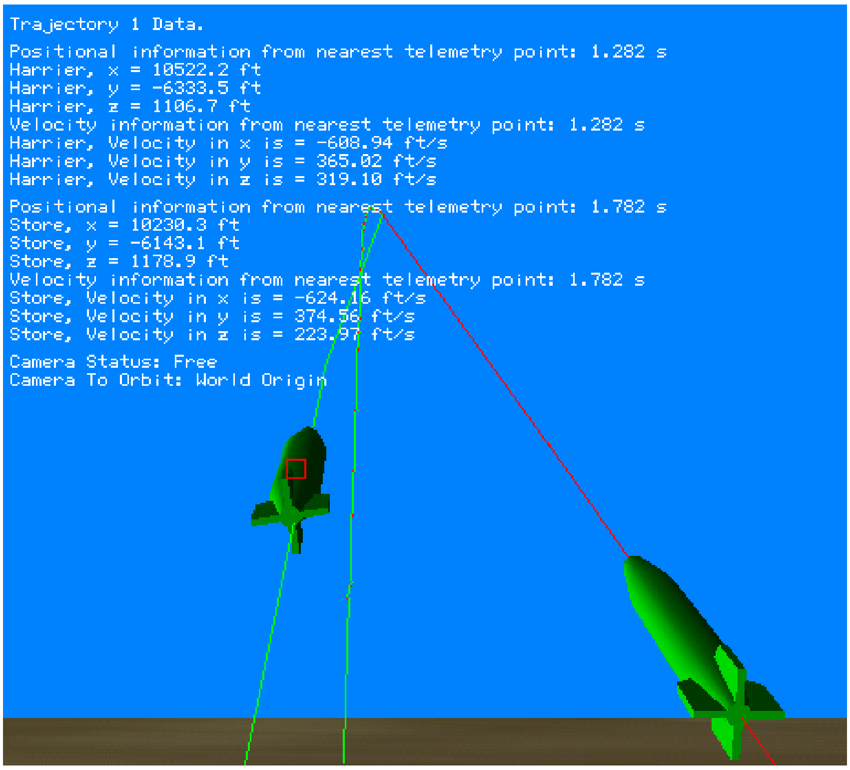

Figure 4

QSET Background

Aberporth, on the West cost of Wales (UK), is one of QinetiQ's principal sites for conducting a range of weapon and defensive tests. Over the past few years the site has acquired a significant amount of telemetry data on anti-ship missile firings.

The Land Based Test Site (LBTS) is one of QinetiQ's shore-based test facilities. The LBTS site offers QinetiQ and the UK MoD (it's main customer), the ability to test integration of new equipment into a modern warship, before the integration takes place on the vessel. Clearly, there are many cost-saving benefits to implementing equipment and/or software in this manner. It is also a lot easier to fix problems in hardware and software in a shore-based facility.

Connecting the two sites using a dedicated ISDN link will provide us with an opportunity to create a HITL SE, with live range assets, data, and the opportunity to test future ship support services. This is explained in detail in the following sections. This link-up is known as the QinetiQ Synthetic Environment Trial (QSET).

The Future Goal of QSET

Aberporth and LBTS are approximately 300 miles distant. This is not an uncommon separation for the majority of our ranges. Clearly, ranges should be in remote and isolated parts of the country.

The future co-operative war-fighting and peacetime operations focus on CEC (Co-operative Engagement Capability), and CEC type scenarios and communications. Because of time and cost constraints it will be impossible (or near impossible) to bring several modern warships (from the same force or multi-national forces) on range and test their systems co-operatively. However, CEC relies on this to counter the most modern weapon systems or tactics from an enemy.

Additionally, CEC capabilities have never been independently tested. How do we know that CEC really offers any advantage? Could CEC tactics, and/or systems provide a data overload to crew? Could it provide a data overload to the display systems, or cause an overload of messages on the combat system or even computationally?

LBTS as discussed above, offers us the chance to test the real systems on a shore-based facility. The site also provides us with a chance to test both allied and hostile tactics. By combining the telemetry and trials equipment at Aberporth, we could bring a real anti-ship missile on range, and fire it at a target within the range. The target can be adjusted to have spectral characteristics appropriate to the vessel we wish to be considered to be under attack.

By communicating the data from the range, over a dedicated link (with an appropriate bit-rate) we can simulate a communication link. It is important to distinguish the context of the word "link" used here. In a CEC type scenario vessels would communicate using something like the Link-11 or Link-16 data links.

These are secure (encrypted), anti-jam resistant data links (Link-16), used in communicating voice (Link-16) and other important bits of tactical information, and help form a CEC type environment (a global picture of all the units participating in the exercise). Because the surveillance pictures from all of the Participating Units (PU) can be communicated to all PU's, this effectively extends the surveillance picture. From this point, Data-Link will refer to Link-16 or Link-11 communications. ISDN-Link will refer to the ISDN communication between the two sites.

Depending on the type of messages sent across the ISDN-Link will depend upon which type of Data-Link we wish to simulate.

Thus far we have begun to generate a significant part of the SE. However, we only have a one-ship environment. The tracking equipment on range will have been set up to know exactly where the missile is being fired from, and, of course, placed in a position to best track the object. A stealthy missile will be enhanced in some way so as to ease tracking (a common occurrence in today's test and evaluation environments). A real ship in the real-world environment will have no such luxury. Clearly we have a problem.

This problem is not too difficult to overcome, and provide a useful CEC type SE environment. Feeding the telemetry data directly into a set of PC's running models of the sensors we wish to simulate, we can generate a perceived view of the missile. This effectively turns the Aberporth systems into a synthetic ship. Clearly, we now have a dual synthetic ship capability.

This synthetic environment is represented in figure 5. To aid the clarity of discussion, the Aberporth range facilities will be represented as synthetic ship A, and LBTS as synthetic ship B.

It is now possible to communicate the perceived view from ship A's perspective (from sensor and viewing angle), to ship B, as would happen (hopefully) in any co-operative environment. Ship B (the LBTS) will, of course, have to generate its own view. Hence, in addition to sending across the ISDN-Link, messages to simulate the Data-Link, we also need to transmit the raw telemetry data, so that Ship B (LBTS) can generate it's perceived view and can feed that data directly into the hardware systems, such as the combat system.

Ship B would also communicate any relevant data back to Ship A, across the ISDN-Link, to close the loop.

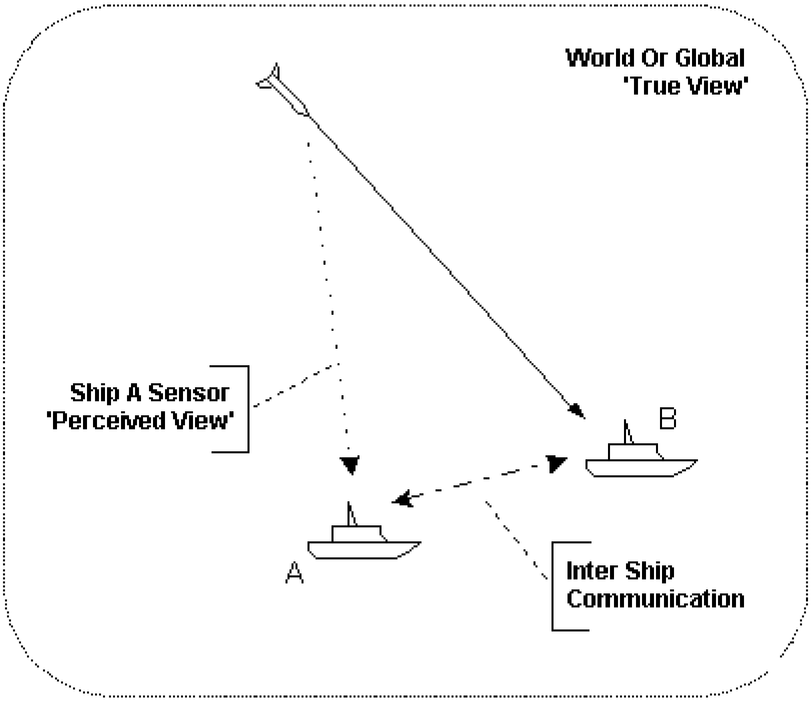

Figure 5

Because the systems at Aberporth (ship A) will be COTS PC's processing the tracking data, it will be possible to configure them with the most up-to-date sensor models. We could cost effectively test how well the sensors will work, and tactics in a CEC environment. Changing the focus on one sensor system to another will not be difficult, as the PC software would simply load up another model, and then repeat the scenario. LBTS would then offer the chance to test how the actual ship hardware and combat systems would respond to Ship A's perceived view, and how they would respond to the threat information from the Aberporth range.

It is not important weather this threat information is transmitted live, in real-time, or whether the data archives are accessed to transmit the information down the link in post-real-time to the LBTS facilities. Either can be achieved, and neither require significant infrastructure change.

<u>Conclusions</u>

This paper, in conjunction with the paper published last year, has demonstrated the benefits of using visualisation techniques to understanding large quantities of data, for planning trials, for after trial reviews, and adding to the safety of a trial.

We have discussed the principals behind linking range assets, to simulate synthetic surface vessels, and how we can incorporate live threat information in real-time. However, we are of course not limited to just threats. We have discussed how a modular approach to this SE will help in the future of CEC type scenarios and tactics, testing the equipment, and adding value to the T&E process.

The possibilities for testing scenarios and tactics are almost endless, because of the ability to bring the latest threats onto range, track them with the most advanced tracking instrumentation, and apply the most up-to-date sensor models to provide the all-important perceived views. It is a simple task on the ISDN link to introduce significant latency issues, and observe what effect this may have on the crew and tactics, or even the combat systems.

References

1. Thorpe, Richard N., Visualisation Within Test and Evaluation, ETTC proceedings 2001, p7.
2. Weeks, Richard; Tomlinson, Barry; Journal of Defence Science, Vol. 3, No. 3.
3. Mugridge, Christopher, J., Verification and Validation within Modelling and Simulation, DERA Internal report 1999.

UNIVERSAL INTEGRATED SIGNAL CONDITIONING FOR DATA ACQUISITION SYSTEM

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ABSTRACT

IN-SNEC, a world leader in telemetry systems and equipments, has developed a universal integrated signal conditioning design to be integrated in its data acquisition systems for various applications :

- Launchers : design used for ARIANE 5 telemetry and functional data acquisition units
- Aircraft : design used in TMA 2000 data acquisition system for commercial and military aircraft
- Missile : configurable version of the design integrated in the CMA 2000 telemetry encoder

The aim of the universal signal conditioning is to handle all the existing sensors currently used for aerospace applications, without need of external added circuits. User has only to plug the sensors to the data acquisition unit and he gets a telemetry flow according to industry standards such as IRIG106 or CCSDS.
Universal signal conditioning includes a voltage or current sources with sufficient power to polarize the sensor, variable gain amplifier and anti-aliasing filter. Then the signal from the sensor is digitized and all the added signal processing is digital. All acquisition modules includes large FPGA and possibly powerful DSP for programmable or configurable digital signal processing such as filtering (Bessel, Butterworth or more with high order), slipping mean to improve accuracy, and user defined routines.

Universal signal conditioning is fully programmable using Management & Control computer of the data acquisition system. When the user download the configuration file of the data acquisition unit, he is able to define the gain, offsets, voltage and current value with high precision. He also defined the bandwidth and which digital filter he wants to use from library.
On Aircraft data acquisition unit, he can also design its own processing routines in C language and download them into the Universal Signal Conditioner.
It can be special filtering, threshold and event detection, spectrum analysis or any relevant processing that helps the flight test engineers during the trial.
Thus They are able to get in real time processed data for critical flights (such as flutter trials), and take the right decision at the right moment to prevent safety and get the very best from their trials.

Keywords : data acquisition, signal conditioning, on-board telemetry encoder, sensor interface,

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TEST RANGES, GROUND STATIONS

Telemetry Facility capability enhancements at the UK's Hebrides Range

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Abstract

Historically under the jurisdiction of Royal Artillery the Hebrides Range, together with the United Kingdom's principal air, land, and sea test and evaluation organisations, had by 1998 been brought together into a single UK Ministry of Defence executive agency, the Defence Evaluation and Research Agency (DERA). More recently, under the UK government's proposals for a public private partnership, the test and evaluation business vested in the DERA transferred to a newly formed organisation – QinetiQ.

This paper describes the integration of the Hebrides facilities into the DERA, and reviews the Range capabilities necessary to accommodate the planned test and evaluation trials associated with the acquisition of the Eurofighter Typhoon aeroplane and the integration of its advanced medium range air to air missiles.

The limitations of the inherited telemetry capability, including factors affecting Range interoperability and data interchange, are outlined together with the organisation's ongoing effort to harmonise Facility management, trials, and other operational procedures.

An overview of the ensuing Hebrides Range capability enhancements is presented.

Keywords

Telemetry, Hebrides, capability enhancement, interoperability

Introduction

In 1995 the UK Ministry of Defence's (MOD) principal research, development, test and evaluation establishments were amalgamated into a single MOD agency, the Defence Evaluation and Research Agency (DERA). The DERA, western Europe's largest research, development, test and evaluation organisation, operated as an 'executive agency' or 'trading fund' creating a genuine commercial customer supplier relationship between the Agency and its customers (primarily the UK MOD) [1]

It was not until 1998 that the Hebrides Range, historically under the jurisdiction of the Royal Artillery, was transferred to the T&E Ranges Sector of the DERA. The major UK T&E Ranges were now under one umbrella, with a central headquarters co-located with the Agency's aircraft test and evaluation centre at Boscombe Down, Wiltshire.

In the past the majority of the UK's guided weapons development trials had been conducted at the instrumented Range at Aberporth utilising the air space over Cardigan Bay. It was apparent however, that to comprehensively test and evaluate the next generation of military aircraft, with their longer range weapon systems, the Hebrides

Range with its larger available Range danger area (see figure 1) offered significant benefits.

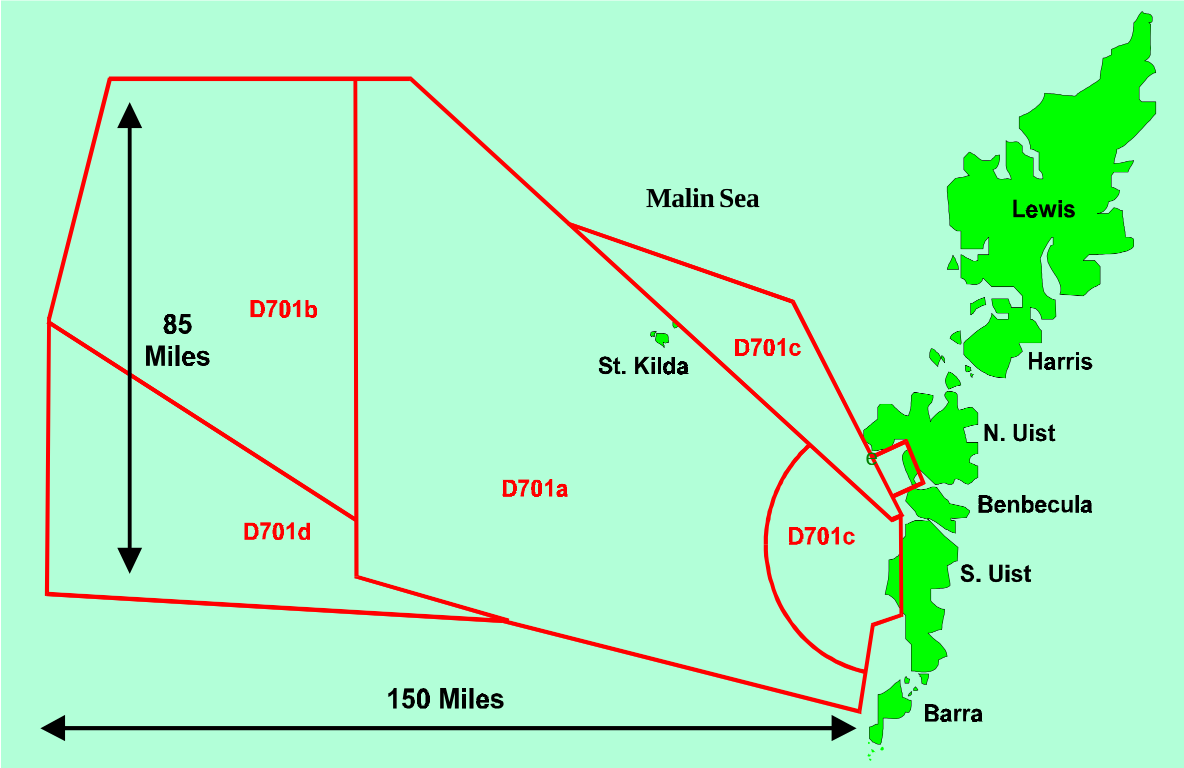

Figure 1 – UK Hebrides Range

The Hebrides Range comprises an ‘inner’ Range, used extensively for ground based air defence missile firing practice camps, and an instrumented ‘deep’ Range with facilities located at a Range Control Building on South Uist and on the small remote island of St.Kilda.

The existing telemetry capability at the Hebrides Range was described in detail in a previous paper [2] and is not replicated herein.

A pan Range Telemetry Facility

The T&E Ranges Sector organisation is predicated on providing its customers with impartial, independent, high quality, test and evaluation services established upon sound business and project management principles. The Programmes department, facilities, and business groups provide the customer/ project interface, equipment capabilities, and skilled staffing resources respectively.

The Sector comprises several facility cost centres some (including telemetry, radar tracking, EO tracking, data analysis) designated “pan Range”*. I.e. they are charged with delivering their bespoke specialist services at several Range sites or in the case of movable systems elsewhere in the UK or overseas.*

This pan Range Facility grouping provides several benefits including:

- Provides customer business channels with dedicated programme management
- Ensures a cohesive technical strategy
- Assures Range interoperability and data interchange
- Maximises the utilisation of assets and specialist technical staff
- Aligns staff development and training to business needs
- Reduces the full economic cost of service delivery

A small team of specialist staff with the ability to configure, operate, maintain, and develop the capability to meet constantly changing customer requirements are assigned to the Telemetry Facility. The retention of this core of expertise, and its extension to the Hebrides, is vital to the successful delivery of the customer trials programme. The Facility management strategy addresses the issues of operating within the QinetiQ commercial business environment and focuses on the prerequisite for seamless Range interoperability as the customer T&E programmes roam between the different Ranges [3]

Given the above, the Sector management plan incorporated the phased integration of the Hebrides Range and its facilities into the existing Sector business model. During the transition period the Hebrides Range would take on the DERA business management and accounting systems.

Harmonisation project

Given DERA s predecessor organisations had such diverse origins it was predictable that many different working methods would exist at the different Ranges. These differences also encompassed trials documentation formats, Range systems and associated operational procedures, data formats and even the names assigned to key posts or functions. Common practice, and equipment to a large extent, existed at Aberporth, Larkhill, and West Freugh (all once Royal Aircraft Establishment sites) but given the necessity for the customer base to operate seamlessly across numerous sites the general situation was deemed unsatisfactory and hindered the transition to a more coherent T&E organisation.

This unacceptable state of affairs, particularly concerning the lack of common data formats appertaining to Range data products, was confirmed at a data standards workshop hosted by DERA at Salisbury in July 1999. At this forum invited internal and external customers presented details of their experiences of handling trials data acquired from several T&E Ranges sites. It was clearly evident that the harmonisation of processes, data formats, frequency assignments etc was critical to achieving a fully integrated Ranges organisation capable of satisfying customer expectations.

A formal project was initiated to investigate and implement ways of harmonising and improving the variety of dissimilar work practices and procedures that had evolved across the Ranges.

The *harmonisation project* was broken down into a number of working groups, each led by a task manager. The groups were:

- Instrumentation & data analysis
- Programmes
- Range Operations and trials control
- Trials safety, and health safety and environment
- Quality assurance
- Human resources

The project was largely customer focused and sought to deliver the following benefits:

- Better quality of service to the customer
- Cost benefit to the customer
- Customer deals with single, common entity
- More strategic use of assets and people that will result in improved utilisation and greater efficiency
- Creation of a single T&E working environment across all the Ranges

Confining ourselves to the Telemetry Facility area, a number of harmonisation issues needed to be addressed – some are detailed in table 1 by way of example.

Topic	Impacts	Proposed action
Trials documentation	Customer has to prepare customised trials documentation, safety submission, telemetry observers brief etc	Introduce common formats and customer interface to single Programmes point of contact
Management accounting	Pricing anomalies across sites, visibility of cost drivers, in-service support contract arrangements	Corporate and Facility systems & procedures extended to Hebrides
Customer data deliverables	Inconsistent formats, branding, QA	Resolve by use of single post trial Telemetry replay Facility
Instrumentation recording	IRIG 7 track IRIG 28 track IRIG 14 track IRIG M64/ARMOR Heim D20	N/A only used at Aberporth N/A only used at Aberporth Formulate common config'n N/A only used at Aberporth N/A Only used at Aberporth
Telemetry systems validation/ performance evaluation	Interoperability, test methods, staff training, support costs	Use common simulator/ BERTS, general TME etc
Telemetry receiving systems	In service support, maintenance costs, asset management, QA procedures etc	Rationalise asset base. Use of common COTS equipment if possible.
Telemetry Processing	Interoperability with QinetiQ sites and contractors, staff training, support costs	Use common COTS hardware/ software
Staff training	Competencies, knowledge base	Create competency database, manage staff development
Management/ Quality procedures	Dissimilar procedures, staff training/ deployment flexibility	Review and harmonise where appropriate. Site specific procedures annotated thus.

Table 1

Two areas were perceived as 'priority' to the Facility's Aberporth and Hebrides operations. These were the interface with the Programmes department (the customer project interface) and the data deliverables of the Facility (in terms of data reduction processes, physical & logical data formats, and quality assurance). Both impacted on the Facility customer directly.

Other topics although important, were not outwardly visible and could be addressed in slower time. For example, the internal '*operational and maintenance'* and '*quality management'* procedures that underpinned the ISO9001 certification of the Ranges would need to be scoped, with the ultimate aim of migration to a common set of procedures. The harmonisation process would also identify those procedures which for one reason or another were infeasible to combine.

Aside of the formal harmonisation project, resolving harmonisation issues and hence realising interoperability between the Aberporth and Hebrides sites, was seen as essential to achieving customer satisfaction, given that the two telemetry capabilities would have common customers; often with plans to conduct a series of identical telemetry trials at both locations.

Fully integrating the Aberporth and Hebrides Telemetry facilities, aligning staff competencies and executing common Facility business and quality management systems were altruistic harmonisation goals.

Firstly, to ensure customer telemetry data deliverables were consistent in terms of media, formats and data processing techniques, all post trial telemetry data handling was routed through the existing Telemetry replay capability at Aberporth. 'Replay' having the capability and resources to handle legacy PAM applications [4] utilising bespoke hardware and software as well as generic commercial off the shelf systems for ongoing PCM applications. It was not economically viable to duplicate the Facility's extensive inventory of 'replay assets' and media archive library at the Hebrides; also necessitating the training of additional personnel on legacy systems and techniques.

Allied to this the *inherited* telemetry data acquisition and processing system was replaced with a L3 Communications model 550. *[The 550 hardware / software also providing direct interoperability / data interchange with QinetiQ's Aberporth and Boscombe Down telemetry facilities and several of the UK defence contractors engaged on current MOD materiel acquisition projects.]*

Operating as a single Facility cost centre offered the prospect of improved efficiency through intelligent resource management as well as a benefit from operating common financial and management information systems. For example combining local in-service support contracts simplified internal administration and delivered savings in external maintenance and support costs.

In seeking to harmonise processes, improvements were sought and best practice identified. An example of this was the equipment fault reporting procedure used by the Hebrides Systems group which was subsequently adopted by the pan Range Telemetry Facility.

As many of the internal Facility procedures and staff competency requirements are systems dependent, rationalising assets and introducing commonality through Industry standards and common equipment variants also featured within the Facility plan. The impending upgrade of the Hebrides Range instrumentation and infrastructure, including the telemetry capability, would provide an opportunity to further assist the harmonisation process.

Telemetry Standards

The benefits of standardisation are firmly established and exemplified within the telemetry community by such bodies as the American Range Commanders Council (RCC), the Telemetry Standards Co-ordinating Committee, and the European Telemetry Standards Committee.

Most of the telemetry equipment used within UK T&E Ranges is commercial off the shelf and largely conforms to the standards of the RCC Inter Range Instrumentation Group (IRIG). Although most applications call for IRIG 106 compliant capability, requirements to service both the French CE-83 and the early British 465/4650 telemetry standards[4] remain.

However, even the use of commercial off the shelf IRIG compatible equipment does not guarantee interoperability; precise configuration and process control being essential to achieving this. It was soon apparent that equipment considered alike on first inspection of the pooled Facility inventory was in fact far from identical; the inventory failing to capture the detailed configuration information necessary to assure interoperability.

For example, the ubiquitous IRIG 14 track analogue instrumentation tape recorder is used at several T&E Ranges sites. It was soon apparent that the track allocation of the direct record and FM channel electronics used by the Aberporth and Hebrides facilities, on their otherwise common 14 track wideband recorders, was different. This resulted in the inability to interchange data (trials tapes) between the two sites without incessant re-configuration and calibration of recording systems.

A similar scenario existed with the inventory of telemetry receivers given the generous selection of plug-in tuner, video filter, and other options. In the case of the recorders, mandating a common hardware configuration and harmonised signal channel assignment promptly surmounted the problem.

The QinetiQ corporate internal communications network (intranet) provided a platform for building an improved asset management database (readily accessible across the organisation) with detailed hardware and software configuration and other useful information.

Hebrides Range equipment and integration programme

One major project typifying the genre of the ‘next generation’ platform likely to benefit from the utility of the Hebrides ‘deep’ Range was the ‘Eurofighter Typhoon’ aircraft venture. The Eurofighter (figure 2) is being developed by Germany, Italy, Spain, and the UK to fulfil airforce requirements for a next generation combat aircraft [5]. In the UK the aerospace company BAE Systems is responsible for the development T&E trials of the aircraft from their flight test aerodrome at Warton, Lancashire.

Figure 2 - Eurofighter testing at Boscombe Down

Although some of the elementary Eurofighter test and evaluation trials would be conducted at the Aberporth Range, airspace limitations constrained its use. An examination of the test and evaluation requirements for the Eurofighter (equipped with the advanced medium range air to air missile (AMRAAM)) confirmed that use of the Hebrides Range would be necessary to achieve all the specified test points.

However, a “gap analysis” of the existing capability[2] with respect to the project T&E trials requirements, confirmed that further capital investment in the Range infrastructure, particularly the instrumentation, would be necessary.

In direct support of the MOD Eurofighter programme DERA launched the Range equipment and integration programme (REIP) to manage a circa €40M Range upgrade project.

The Range equipment and integration programme will through three discrete projects

- Provide the Range with two transportable BAE Systems RIR779 precision G band (5.4-5.9GHz) instrumentation tracking radars to enhance the tracking capability provided by the existing I band radars; also providing a G band transponder tracking capability. [the RIR779 has similar performance and is operationally compatible with the AN/FPS16 and AN/MPS39 (multiple object tracking radar) radar variants used at Aberporth].

- Provide, through a contract with Alenia Marconi Systems, a significant upgrade to the trials control system and its safety related software to produce a comprehensive control facility through which trials control, recording, and analysis can take place with enhanced safety.

- Upgrade the instrumentation and associated infrastructure to include: telemetry, flight termination system, communication systems, communications recorders, trials sequencing equipment. Several contractors underpin this hybrid project.

The procurement and integration of the new systems compelled project managers to re-appraise key issues such as Ranges interoperability, commonality of equipment, systems safety integrity, as well as staff competencies and training needs. In support of the REIP, internal project management and technical expertise was assembled from several QinetiQ establishments including Aberporth, Hebrides, and the Systems and Software Engineering Centre at Malvern.

REIP enhancements to the existing telemetry capability included the replacement of the telemetry antennae on St.Kilda with three L3-EMP 2.4 metre dual D/E band auto-tracking antennas, equipped with wide beam acquisition aids and versatile PC based antenna control units.

Provision is made for independent and simultaneous local (at St.Kilda) and remote (from the RCB via a microwave link) control of the telemetry antennas, receivers, combiners, bit synchronisers and instrumentation recorder, using a newly installed PC based IEEE-488 telemetry control system running customised control and monitoring software with a graphical user interface for ease of operation.

Telemetry is received and recorded locally and then transmitted in real time via a microwave link to the RCB for storage, decommutation and display. Initially the provision of real time telemetry to BAE Warton via a satellite link was postulated, but the solution settled upon entailed the deployment and integration of BAeS / project mobile ground assets at the Range control building – see figure 3.

Maximum Telemetry Requirements for EFA Trials Scenario

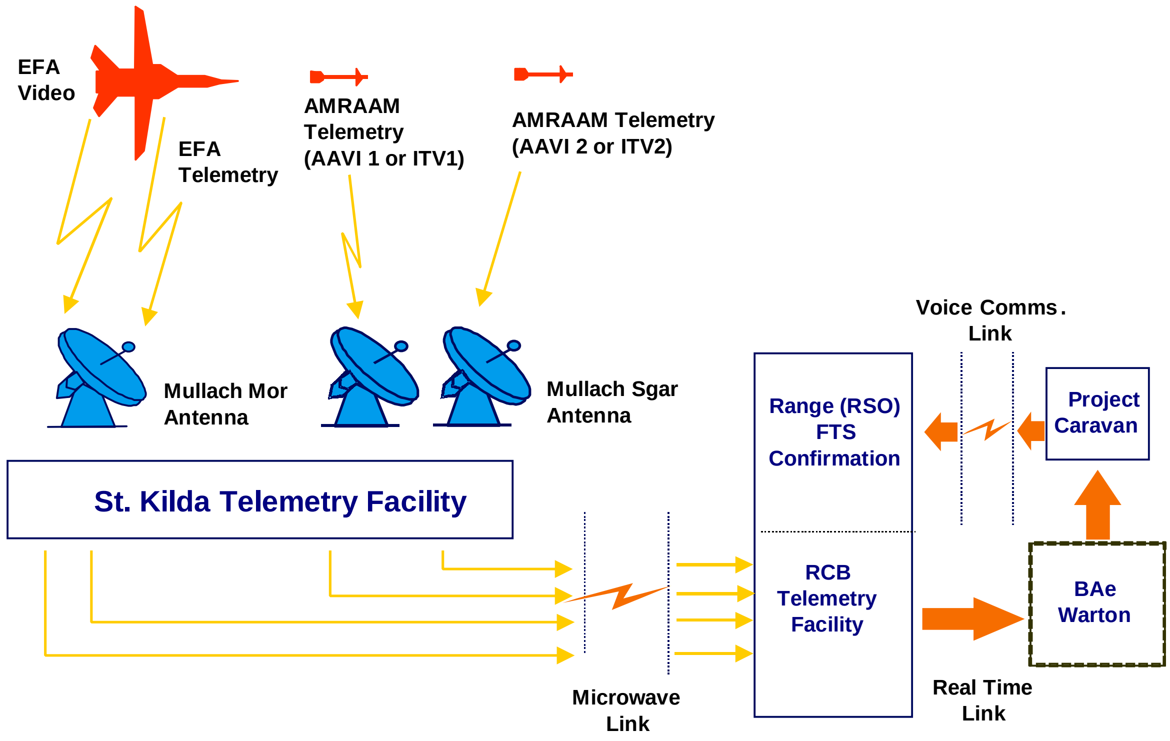

Figure 3 – T&E Ranges Telemetry Facility layout

To cater for other applications with higher data rate PCM telemetry channels the Hebrides Range telemetry facility was engineered to permit the straightforward installation of wideband telemetry receiving and high-density digital recording equipment relocated from Aberporth.

Conclusions

The assimilation of the Hebrides Range into the DERA has created an integrated UK test and evaluation capability in the 'air' environment. The ongoing harmonisation of systems and working practices across the Sector has resulted in improved operational efficiency and a consistent customer interface.

Having successfully conducted initial Eurofighter trials, following the recent enhancements to the capability, the Hebrides Range can now claim to be one of Europe's foremost T&E facilities.

In July 2001, in accordance with government proposals to create a new 'public private partnership', DERA was split into two organisations, the Defence Science and Technology Laboratory (DSTL) and QinetiQ Ltd. DSTL remains part of the MOD and continues to handle the most sensitive areas of research. QinetiQ, presently a wholly government owned company, has the remit to cultivate its commercial business and exploit its technology base. The T&E facilities that were under DERA's guardianship are now managed by QinetiQ [6].

Disclaimer

Any views expressed or implied are those of the author and do not necessarily represent those of QinetiQ, MOD or any other UK government department

References

1. Integration and operation of T&E Ranges in a trading environment - C. Rigden, ITEA symposium, London 1998

2. Control of a remote receiving station and data processing at RA Range Hebrides - D.MacKenzie, R. Fielding, ITC procs 1994

3. Range Telemetry – the next decade - S.W. Lyons, R.G. Davies, ETTC procs 1999

4. Real-time visualisation of target telemetry - P.G. Brown, T.O. Hesford, ETC procs 2000

5. www.eurofighter.com

6. www.QinetiQ.com

ADVANCED RANGE TELEMETRY
Project Update

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ABSTRACT

Real-time aircraft and missile test telemetry (TM) data requirements have grown exponentially. This is primarily due to increased technical complexity of weapon systems and military air vehicles. As the complexity grows, more real-time flight test data is required to maintain today's level of test safety and efficiency. In addition, the electromagnetic spectrum allocated to aeronautical flight test has decreased over the past few years and continues to be threatened by the commercial telecommunications industry.

The DoD test and training community must satisfy customer needs for higher throughput and improved reliability of real-time TM data, in a limited spectrum environment, to avoid creating a bottleneck in the weapons systems acquisition process.

Advanced Range Telemetry is a program to improve the efficiency, reliability, and utility of aeronautical telemetry TM systems for United States DoD test and training ranges. The program is sponsored by the Office of Secretary of Defense and funded through the Central Test and Evaluation Investment Program.

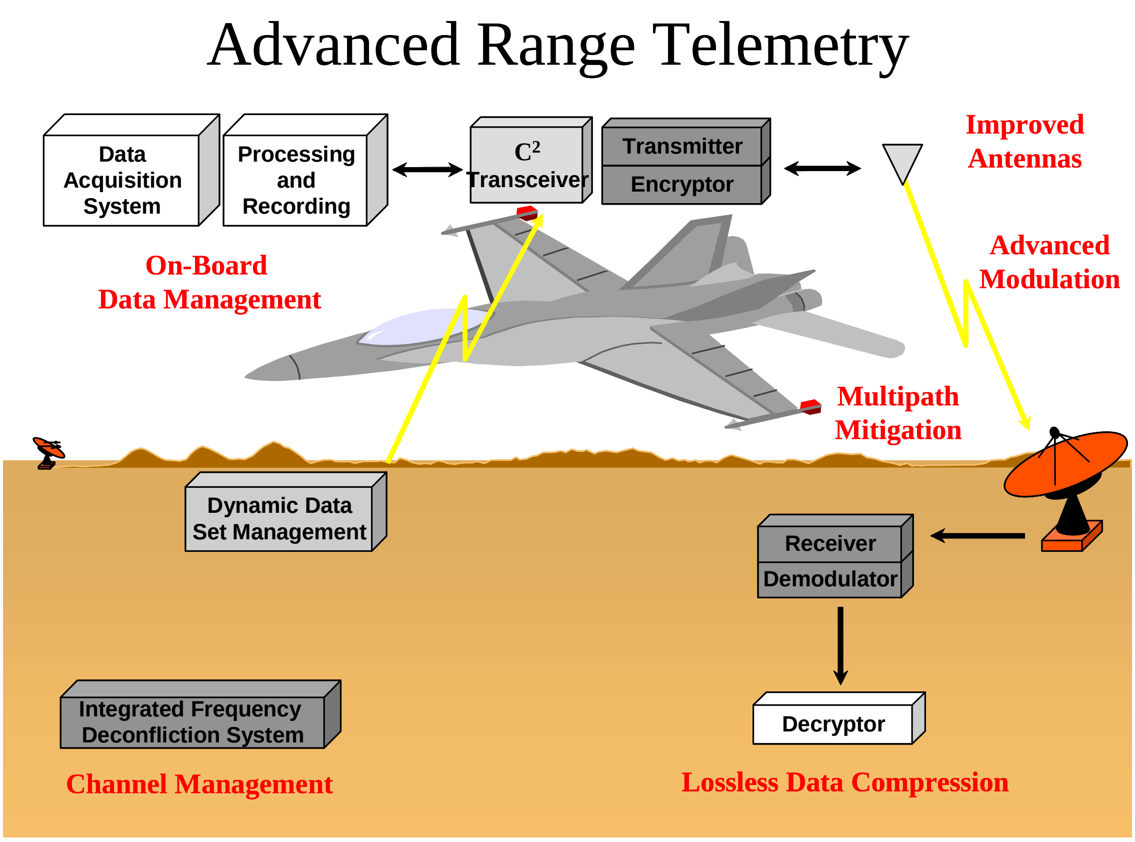
KEY WORDS

Telemetry, Modulation, Feher Quadrature Phase Shift Keying, Data Compression, Spectral Efficiency

INTRODUCTION

Due to expansion of real-time telemetry data analysis requirements and the limited spectral assets available, test ranges are being demanded to do more with less. Future telemetry systems must satisfy customer needs for higher throughput and improved reliability of real-time data to avoid creating a telemetry bottleneck in the end-to-end data flow. The ARTM project provides for the development of technology and standards to improve the efficiency and utilization of the radio frequency telemetry spectrum. This will be accomplished by investigating and developing telemetry technologies such as higher order modulation techniques, optimizing and compression of data streams, improving open air bit error rate performance, improved antenna designs, better frequency deconfliction tools, and the development of on-board data processing systems. An overview of the ART concept is shown in Figure 1. The major benefit of ARTM is the improvement in the capability and capacity of Department of Defense test ranges. These improvements will directly result in the avoidance of increased cost and schedule due to the limited amount of spectrum or unreliable telemetry data links. Other additional key benefits of ARTM will be commonality, interoperability, and standardization. Through this cooperative effort, test ranges will improve the overall test infrastructure – providing a baseline that is economical to establish, operate and maintain.

Figure 1 – Advanced Range Telemetry System Overview



Tier I Modulation (FQPSK-B)

In September of 1999, the ARTM project awarded three separate contracts to multiple vendors for FQPSK-B telemetry hardware. Two of the contracts were to develop FQPSK-B demodulators and one contract was for the development of FQPSK-B telemetry transmitters. The current status of developments under these contracts is as follows:

- FQPSK-B Demodulators
    - L-3 Microdyne has delivered two prototypes with IEEE-488 updates pending.
    - RF Networks has delivered two prototypes and is currently delivering production units on a large multi-range order.
    - In August of 2001, new contracts to both Microdyne and RF Networks were awarded to provide increased user flexibility options for the demodulatos.
- Transmitter Delivery
    - Herley-Vega has experienced multiple problems during the development of the FQPSK-B transmitters. Most of the difficulty stems from the close proximity of the power amplifier portion of the transmitters and the high speed digital logic used in the modulation scheme. Numerous units in various configurations have been tested with detailed comments and suggestions provided to the factory.

The ARTM project also purchased two commercially-available Aydin (L-3 Telemetry East) FQPSK transmitters. These transmitters were not built to the same specifications as the ARTM-sponsored Herley transmitters. Subsequent testing of the Aydin transmitters revealed that they would not meet the ARTM performance requirements.

TIER II Modulation (Multi-h CPM)

In 1999, a Small Business Innovative Research (SBIR) contract was awarded to NOVA Engineering for the development of multi-h CPM modulation technique and hardware. NOVA has currently delivered one prototype three-mode transmitter (PCM/FM, SOQPSK, and multi-h CPM modes) and two three-mode trellis demodulators. The trellis demodulator has been demonstrated in CPM and SOQPSK modes at 21.96 Mbps and at 10.98 Mbps in FM mode.

The project has performed one flight test in September of 2001 with FQPSK-B and CPM at 9.0 Mbps transmitting simultaneously. Preliminary results show FQPSK-B did perform slightly better. Lab testing of the demodulator with a telemetry channel emulator has revealed possible areas where the unit may be “tweaked” for better performance. A follow-on effort to develop “production representative” hardware is in work. The projected delivery is in the Fall of 2002.

Equalization

NASA/JPL equalizer simulation work has been completed and the decision to proceed with prototype hardware development has been made. The prototype hardware will enable real-time testing and additional simulation for further validation of improvement due to equalization. Initially there was an Intellectual Property hurdle with the VHDL supplier (Amphion), but that has been resolved with the government owning it.

On-Board Data Management

A wireless Asynchronous Transfer Mode (ATM) demonstration was successfully performed at the International Test and Evaluation Association (ITEA) workshop in Ridgecrest CA in May of 2001. The demonstration showed the use of ATM over a telemetry link utilizing an ATM switch. The transmission was uni-directional with no back channel (best effort). Differing data sources (video, data, and voice) were multiplexed prior to transmission. The question of "Where to go from here?" remains to be answered.

Joint NASA/DoD "Standardized Bandwidth Efficient Communications" Project

A joint effort between NASA and DoD hopes to provide enabling network-based technologies for future test communication architecture. NASA-Dryden is currently building concept demonstration and software. The Linux Data Acquisition and Distribution System (LDADS) is a small generic data acquisition node that will allow researchers to explore the feasibility of the Linux operating system and emerging interoperability tools such as Java and Extensible Markup Language (XML) as a platform for distributed computing, sensor webs, and intelligent distributed control applications. Successful demonstration of this risk-mitigating research can be leveraged to benefit a variety of terrestrial-fixed, terrestrial-mobile, and airborne wired and wireless applications.

L-Band/GPS Compatibility

The ARTM project initiated a study, with support from the Johns Hopkins University Applied Physics Laboratory (JHU/APL), to determine the extent of interference problems associated with simultaneous L-Band/GPS operation. The purpose of the report generated from this study is to provide observations and recommendations, supported by analysis and experimental data, of how best to implement L band telemetry systems aboard aircraft that utilize GPS. The final report should be delivered in June of 2002.

Diversity Experiments

Dedicated diversity testing experiment test flights utilizing the ARTM mobile receive station have been initiated. Both frequency and spatial diversity experiments will be conducted. Experiments to date have been extremely limited due to T-39 aircraft availability. A prototype hardware implementation of a Diversity Branch Selector (DBS) has been initiated this year by the ARTM project. The DBS is a baseband signal processing unit that will provide post detection diversity branch selection as an alternative to diversity branch combining in receiving stations used for point-to-point air-to-ground data telemetry.

Advanced Antennas

A Phase II SBIR contract for directional airborne telemetry antennas was awarded in 2001. The technology utilizes a wide-band, conformal, circularly polarized micro-strip antenna that has a steerable radiation pattern utilizing on-board GPS position information. The Phase II effort is scheduled for completion in April 2003.

Channel Management

Phase I of the Integrated Frequency Deconfliction System (IFDS) became operational in July of 2000. This phase provides a web-based platform for frequency deconfliction within individual frequency control regions. Phase II, which became operational in July of 2001, provides tools for frequency deconfliction between the various regions. Phase III, which started in August of 2001, will provide "smart" frequency deconfliction with interference analysis based upon equipment and terrain characteristics. Phase III is scheduled for completion in May of 2002.

Data Compression

Early ARTM data compression Phase I & II SBIR work showed promising results. However, later results revealed that the improvements gained by the lossless data compression techniques may not be sufficient to justify the high cost of implementation. The latest ARTM data compression initiative involves the investigation of the Universal Source Encoding System (USES) lossless compression algorithm developed by the NASA Goddard Space Flight Center. The investigation will look at the possible adaptation of the USES to aeronautical flight test data.

Defense Science and Technology (S&T) Initiative

In November of 2001, a Program Research and Development Announcement (PRDA) for spectrum augmentation was published seeking proposals from both government and industry sources for the purpose of developing, demonstrating, and evaluating the technology components and capabilities necessary to enable augmentation of the telemetry spectrum into the super-high frequency range of 3-30GHz. Advances are required in seven key technical areas:

- Spectrally efficient bandwidth techniques at super-high frequencies
- Solid state technology for high power (5-10W) telemetry transmitters
- Advanced (Narrow or variable beamwidth directional) antennas
- Effects of Doppler shift on receiver tracking for coherent receivers
- Channel Characterization
- Mitigation techniques for atmospheric attenuation
- Techniques for overcoming adverse channel effects

Contract awards from the PRDA proposals are expected in April of 2002.

ACKNOWLEDGEMENTS

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Best Source Selection

How to Make Sure Your Telemetry Systems and Personnel are Using the Correct Signal Sources in Real Time

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Introduction

Test ranges that use multiple sources of input data streams from various signal sources face the dilemma of determining which data source is the most reliable while conducting the test. Test ranges often have multiple antennas monitoring the vehicle during the test flight. Range personnel must determine which source of data is the most reliable in order to provide test engineers with real-time data at all times during the flight. This document describes the environment, issues and systems used in a typical monitoring system with multiple sources of input data. It also provides a solution to a very common problem:

- ✓ How can we insure that the input stream from the best data source is being chosen while the test is underway with the least amount of delay and loss of data?

The Best Source Selector (BSS) products from Acroamatics have been developed with input directly from Test Range Engineers across the United States. Recently, it has been deployed at Pt. Mugu Naval Weapons Center and at Barking Sands Missile Test range in Hawaii. Trials are under way at several other missile test ranges in the United States, as word of this new solution has filtered out from our highly successful installations.

The Best Source Dilemma

Test ranges typically are set up to cover large areas of territory and utilize multiple receiving systems such as antennas to capture telemetry data from the vehicle under test. The vehicle itself is moving at very high speeds and can also be maneuvering during the test in order to check guidance systems, stress, speed, handling and control. The vehicles have airborne telemetry equipment installed that is continuously transmitting data in all directions. The antennas are arranged so that most of the area in the path of the vehicle can be covered in order to maximize control and data capture. Since the actual data itself is critical to the success of the test, range personnel are keenly interested in making sure that ground station equipment is ready to receive the data. As the vehicle moves through the flight zone, the signal strength changes relative to a single antenna. Due to the high speed of the vehicles and limitations on the area covered by a single antenna, range personnel must switch from one source of data to another in order to insure capture. This is especially true for range safety personnel since real-time data capture and display is critical to controlling the aircraft.

A traditional solution to this problem has been to capture the same data multiple times during the test and then return to these files once the test has been completed, edit out duplicate data, delete corrupted data and then merge the files into one data stream. Of course, this cannot be done in real time and involves storage issues and post-analysis of the data. This is a very time-consuming and costly strategy.

Another method has been to manually switch the signal sources based upon visual displays, readouts or LED's on the equipment at the ground station. Personnel then must be ready to check multiple signal sources, determine which one is the most reliable and then signal to switch over to the desired signal source, as the vehicle is moving at MACH II or greater. Since tests may last hours, this involves dedicating personnel to this mind-numbing task, a definite waste of personnel. In addition, this is not as easy as it sounds and involves a human factor of uncertainty, what happens when a mistake is made or when the handover takes too much time? Human response times vary with each event or decision. Is there a better, more reliable way?

Layout of a Test Range

Let's assume that a typical test range has an array of antennas spread throughout the area of the test. In this case, eight antennas covering 100% of the flight path of the vehicle have been connected to the ground station via landlines. The placement of these antennas has been chosen so that a certain amount of overlap is tolerated between antenna capture areas. When a vehicle passes through the range of one antenna and is headed towards the space of another antenna, data may be received at both antennas. Or, data may be out of range of the next antenna until the very last moment and then suddenly come into range. In both of these cases, the range engineers must be able to tell which signal is the most reliable in order to switch over and capture the data stream. Multiple data sources typically enter a bit synchronizer and then the decommutators. The decommutators then identify the frames, parse the data, process the data, covert to engineering units and finally send the prepared data to the intended destination. This can be sent to a workstation, monitor, storage device or other destination. Since every data stream entering the decommutator is originating from the test vehicle via an antenna or receiver, the data is identical across every stream. But is it really?

Data corruption due to transmission errors, interference, attenuation, gaps in coverage and a host of similar impacts can occur on a single data stream while other data streams are intact and of high quality. The bit synchronizers attempt to lock in on the streams in parallel. As the vehicle moves through the test zones, data corruption issues occur at every receiving end at various times throughout the flight path. Signal strength, quality and duration vary at each bit synchronizer during the test. For instance, bit synchronizer 1 is receiving data from antenna 1 for the first 10 minutes of the flight. All data is of high enough quality to be accepted. Once the vehicle moves into the area of antenna 2, it starts receiving the signal and passes it to bit synchronizer 2. At this time, both antennas are receiving the signals cleanly but as the vehicle moves, the signal is weakening at antenna 1 and strengthening at antenna 2. At some point in time, the range personnel must decide to drop the signal from antenna 1 and lock in on antenna 2.

The decision making process by range personnel is to view the LED's on the two bit synchronizers, make a determination which one is fading and which one is strengthening, and then switch over. This is repeated throughout the test as the vehicle completes its flight path. Quite literally, this means that someone is making a decision that can have serious repercussions based upon a flickering light. Not exactly high tech is it?

The Acroamatics Solution

Acroamatics has been working closely with missile test ranges for over 30 years. Our line of telemetry products includes bit synchronizers, decommutators and various telemetry systems that enable our customers to act in real time during field tests. After witnessing numerous tests using our own products and working with range personnel, we realized that there was no product available that could manage data source selection and provide the following benefits:

- User Defined Best Source Selection Criteria
- Constant Monitoring
- Fast Decision Making and Implementation
- Easy to Use Graphical Interface and Monitoring
- High Density and Scalability
- Remote Monitoring Capabilities
- Post Analysis Tools

User Defined Best Source Selection Criteria.

Signal strength calculations can open up a huge array of technical issues that may end up complicating the decision making process while adding no real gain in best source selection. Readers can imagine all sorts of ways to determine which signal is strongest but as is usually the case, the simplest methods are usually the most elegant and easy to use. Acroamatics realized that the best determination of signal quality was the ability to lock in on a frame synchronization pattern for a repeated interval. In addition, we know that range personnel usually know which of their antennas is likely to be the strongest. We allow the user to set priorities that look first to pre-arranged antennas or select certain streams in the case of simultaneous locks across multiple streams. This insures that arbitration between signals is handled to avoid flip-flopping. . The BSS provides three Best Source Selection strategies: Burst, Fixed and Adaptive. Each of these three strategies employ different rules for determining the Best Source according to the type of data expected. In all three strategies, the Best Source is selected using three steps: Search, Verify and Lock. The GUI interface allows the user to define criteria within these basic strategies.

Burst Strategy:

This strategy handles variable length frames where the location of the patterns may be different during the test. This complicates the act of locking in on the data since the location of the pattern may be in different places thereby confusing the BSS. Our system allows for this situation and intelligently moves to verify if the pattern is not found in the expected location. In search mode, the unit continually searches the incoming data stream for a frame sync pattern that meets the frame sync error tolerance. Once an acceptable pattern is detected, the unit loads the bits per frame counter and advances from Search directly to Lock (Verify to Lock count set to 0). Upon detecting a sync pattern with errors above the allowable limit at the proper location (depending upon the Slip window and the Bits per Frame settings), the frame synch unit falls back to Verify mode. Various other combinations of events lead to different actions that the BSS has already been designed to handle.

Fixed Strategy:

This is used for tests when the expected quality of the data is normal or of good quality. While in Search mode the unit will search for the defined pattern that meets the error allowance. Once an acceptable pattern is detected, the unit will load the bits per frame counter and switch to Verify. Once in Verify, a pre-set number ranging from 1 to 15 of consecutive good patterns at the right location will tell the unit to switch to Lock. If the unit finds a series of bad patterns (1 to 15), the unit reverts to Search. While in Lock mode, the unit will continue to send data and stay in Lock until the unit finds a pre-set number of consecutive bad patterns thereby losing Lock.

Adaptive Strategy:

This is used when the quality of the data is expected to be poor due to historical data or known issues with the test and environment. In spite of this, the test may still be conducted and the equipment cannot be so selective that none of the data is captured. Again, our system allows for this occurrence and provides the user with a strategy for insuring that the data is captured.

In this strategy, a frame sync pattern is identified using a pre-set error tolerance level. Once a candidate is found, the bits per frame counter is loaded and the number of detected errors in the candidate frame sync patter is stored for comparison with the following possible frame synch pattern. The frame sync unit will remain in Search for one frame and, if a sync pattern with less errors than the current detected error count is found, it will start all over again using that as the new location. If it is found at the expected location, the unit will advance to Verify and then Lock.

Constant Monitoring

The BSS continuously monitors every data stream 200 times a second. Every 0.005 seconds, the pre-programmed lock in strategy searches, verifies and attempts to lock in on every single data stream entering the system. It monitors the status of the chosen source and only changes when the strategy for Best Source selection forces a move. The other data streams in the system are continuously monitored even if they are not currently the Best Source.

Fast Decision Making and Implementation

Once the system locks onto the signal, the signal is then selected and all data from that source will be passed. The previous data source will be dropped and the new source will be forwarded in 5 mille seconds.

In order to avoid having the system flip flop between equally strong signals, the BSS has been designed to stay on the selected signal until frame synchronization is no longer possible.

Easy to Use, Graphical Display and Monitoring Capabilities.

Acroamatics built a powerful user interface with intuitive displays that allows for easy manipulation, control, setup and display of the system in real time. Upon initialization of the BSS, a Windows style GUI pops up that allows for complete control, setup and manipulation of the data streams on a stream-by-stream basis. Easy to use pop-up windows allow the user to select default parameters and add custom parameters to any of the values controlling the BSS. A sample screen shot of the interface shows how status on each data source is selected and controlled. Details on the operation of the interface can be read in our GUI Interface Users Guide that is available on-line at our web site.

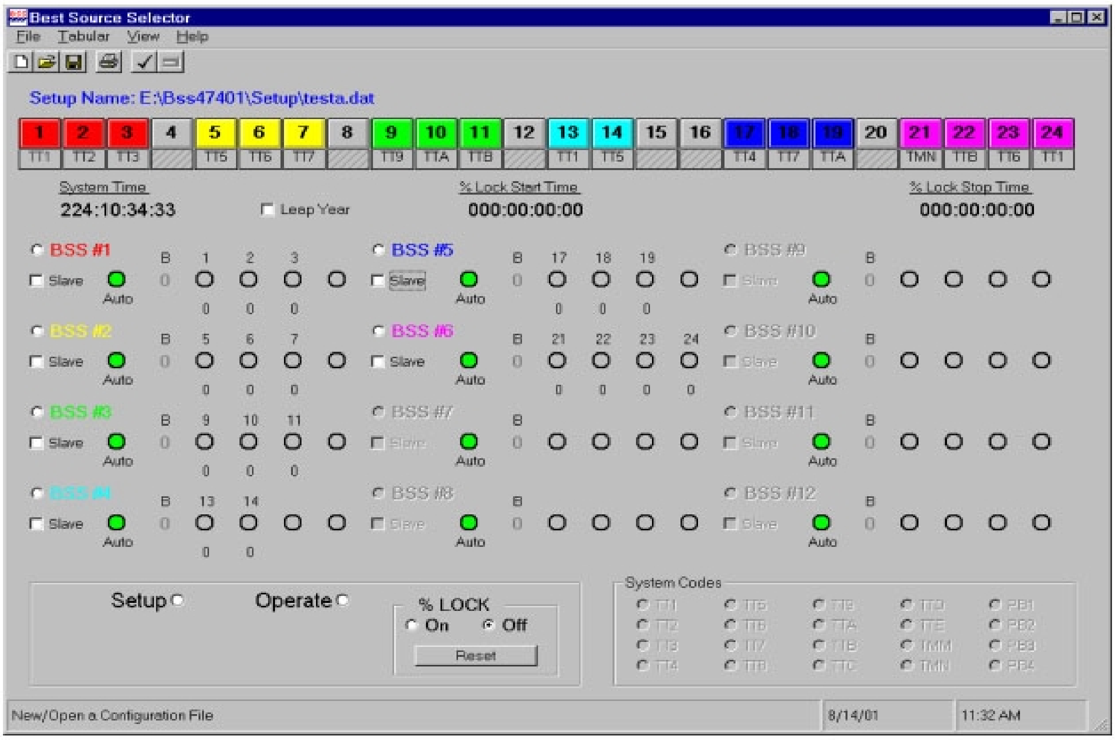

Figure 1 - Main Screen

In addition the BSS includes disk drives for storage of up to 100 installation scripts or set up configurations for easy retrieval. Unique naming of each set up configuration is allowed to make it easy to load the correct set up. All set up configurations and screen displays can be sent to a printer for easy viewing.

High Density and Scalability.

Since most test range sites have multiple antennas, the system must be able to support a flexible number of data sources and scale upwards easily and economically. The BSS connects to each bit synchronizer via a co-ax cable and can scale from 8 to 24 data streams.

The BSS comes in a 12.5” chassis and incorporates a 6-slot PCI back plane. We are able to support up to 24 data streams in one rack-mounted system. The basic system includes a main processor card and a format simulator mezzanine that is standard on all systems. Each additional 8 streams are supported by one Model 650 8 Stream Frame Synchronizer card occupying one slot. The user can add capability by adding additional 8 stream Model 650 PCM Frame Synchronizers up to a total of three Model 650’s in one system. Each BSS system is pre-configured to support all possible 24 data sources and has hardware to support IRIB B time, remote displays, hard drives and LAN connections

Post Analysis

Users need to have access to the data for post-analysis and determine what happened during the test. The BSS has a connector that supports IRIG Time B to be input into the system to provide universal time. One of the most important issues is time stamping Best Source transitions in a log file for future reference. This allows the engineers to correlate events across multiple streams for post analysis.

Remote Monitoring Capabilities

While the BSS system itself has a complete built-in display, users may have a need for test engineers to monitor the status of the system while located in remote offices, labs or areas that can be quite far from the BSS. The BSS can support up to 6 lines for remote display that can be connected via RS-232 connectors. These displays are rack mounted, 3.5” high and contain a series of LED’s arranged in a way that allows for easy viewing of the data streams. These systems can be located up to a maximum of 500 feet from the BSS giving the user tremendous latitude and flexibility during the test. The entire bank of LED’s is controlled through the GUI to allow for custom mapping of information to LED’s on a per channel basis. The individual lock status of each frame synchronizer is displayed along with channel groupings of each data stream. The user can clearly see exactly what each signal source is doing and which one is currently in lock.

Conclusion

The Best Source Selector system is a valuable tool for the test range team. It allows the team to focus on other matters during the flight tests and leave the determinations to a very intelligent device. It provides the test engineers with a reliable means of capturing data during the test and does away with time-consuming post-analysis of multiple files searching for good data. The range safety officers will appreciate the added benefit of insuring that all data is being captured in real time. This product will not only save time, money and hours at the computer, it will do so at a fraction of the cost of current methods.

For more information on this product and other Acroamatics Telemetry Products, visit our web site: www.acroamatics.com. A downloadable version of the GUI Interface Manual for the BSS is available on the site. You will also find a Windows NT based demo that takes you through the interface using random numbers to simulate a real test. It can be downloaded via our web site.

Highrate Data Acquisition System for Earth Observation Satellites

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Abstract

In this contribution will be informed about the technical requirements for an operational data acquisition system for EO-satellites with data rates up to 300 Mbps. On the basis of the link budget the influence of all most important ground station parameter will be discussed in respect of the received data quality.
It will be reported about results in data acquisition from ERS-2 (105 Mbps), LANDSAT-7 (150 Mbps), IRS-1c/1d (86 Mbps and 43 Mbps) and PRIRODA-MOMS (66 Mbps).
Also expected future requirements will be considered.

Introduction

Remote sensing is a well known application of space research to monitor great areas more or less continously – for instance wildlife parks, agricultural regions, towns, oceans... During the last years the resolution (geometric, spectral, radiometric) of the EO-mission was increased continously, more and more data are transmitted to earth and more and more bandwidth was used for these transmissions. But also the EO-missions with lower resolution have a high importance because in these cases normally the high swath-width enables a short repetition rate which is necessary for some applications.

Figure 1: ERS-2 observed area at a satellite pass (flight direction from North to south)

In case of the LANDSAT-7 satellite and its instrument ETM+, which has a resolution on earth of 7 m in the PAN-channel, the repetion rate is 16 days. To assess this value it must be considered that clouds often influence the application of remote sensing products from optical instruments – or make it even impossible.

Therefore the systematic data acquisition (instrument is only pointed nadir), which was a standard for many years, will not used for very high resolution observations. For instance IKONOS (EO-satellite, resolution on earth up to 1 m) has the possibility to tilt the instrument and by this method also to achieve repetition rates of 1 or 2 days – which is important for instance to analyze actual disasters.
Table 1 shows some examples of different EO-missions and their transmission rates:

satellite	**sensor**	**Geometric resolution**	**Swath width**	**Repetition rate**	**Data rate**
IRS-P3	WIFS	180 m	800 km	3 days	5 Mbps
LANDSAT-7	ETM+ / PAN	15 m	185 km	16 days	150 Mbps
IRS-1c / 1d	PAN	7m	70 km	48 days	85 Mbps
IKONOS		Up to 1m			

Table 1: some actual EO-missions

For the data transmission of the highrate EO-data the frequency range 8.025 – 8.400 GHz is foreseen. The figure 2 shows that nearly the whole frequency band is necessary to transmit the broadband signal at its standard modulation QPSK. The technical limit is aproximately at 300 Mbps for QPSK modulation.

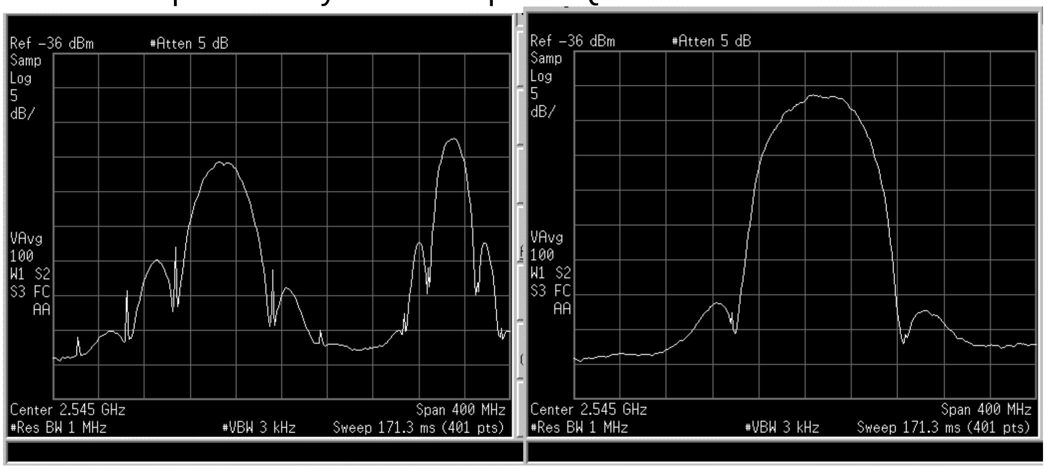


Figure 2: X-band spectrums of EO-satellites (frequency span 400 MHz)
Left: IST-1d with PAN-transmission (85 Mbps) and LISS-transmission (42 Mbps) , right: LANDSAT-7 with ETM+-transmission (150 Mbps)

But all EO-data has not only to be received with high quality (high reliability, small biterror-rate), they have to be processed, quicklook-data and catalogue-data have to be extracted for the user interface and data products have to be distributed to the users.
Also for the data processing a very efficient equipment is important – in every case great data volumes have to be considered. For instance for 2 passes LANDSAT-7 (ETM+) with 8 minutes data transmission time, there has to be archived 6.6 Terra-byte rawdata every year. Not only the actual data are of great interest, but also older data out of the archive are important for reference purposes.

Transmission Requirements

The main transmission requirement is in every case that the groundstation acquires the EO-data nearly completely (> 98 – 99%) and with the agreed quality (BER < 10exp-7). The link budget is used for the analysis of the link and to determine the operational margin.

Table 2 „ENVISAT X-Band Transmission“ gives an overview about the linkbudget for the ENVISAT acquisition by a 7.3m antenna at the DLR ground station Neustrelitz. There are 3 transmission frequency possible (8.1 GHz, 8.2 GHz and 8.3 GHz) and each can be modulated by 50 Mbps BPSK or 100 Mbps QPSK.
Basis of the linkbudget is the spacecraft-EIRP (effective isotropic radiated power), which includes the onboard antenna gain for data transmission to the groundstation at a worst case, which is normally the 5 degree Elevation of the groundstation antenna. In this case the satellite has a range of 2784km from the groundstation and this corresponds at the frequency range to path losses from –179.5 dB up to – 179.7 dB. Additionally the polarization loss, the atmospheric loss and the tracking loss have to be considered. The atmospheric loss for 28 C and 70% relative huminity is –0.69 dB and in case of rain the rain loss has to be added, for instance –1.13 dB for rain 4 mm/hr at 5 degr. Elevation /1/. In remote sensing applications normally extreme weather conditions are not considered in the link budget, so that for these events aditional margin neccessary or in the other case at bad weather conditions the service cannot be done in the planned quality at low elevation angles.
By the ground station the link budget is influenced primary by the tracking loss, the sensitivity of the groundstation (G/T) and the demodulator implementation loss. If these values are known the actual Eb/No (Energy of bit-to-noise density ratio) can be determined. It is one of the most frequently used parameters in digital communication sytems. It enables a comparison of systems with different data rates and a comparison of the performance of various modulations and coding systems. According picture 3 there is an Eb/No of 11.3 dB necessary to get a biterrorrate of <10exp-7 for QPSK-modulation and the result of the link budget is, that in this case there is a margin of 4.5 ... 4.7 dB, which seems to be sufficient for an stable and operational data acquisition.

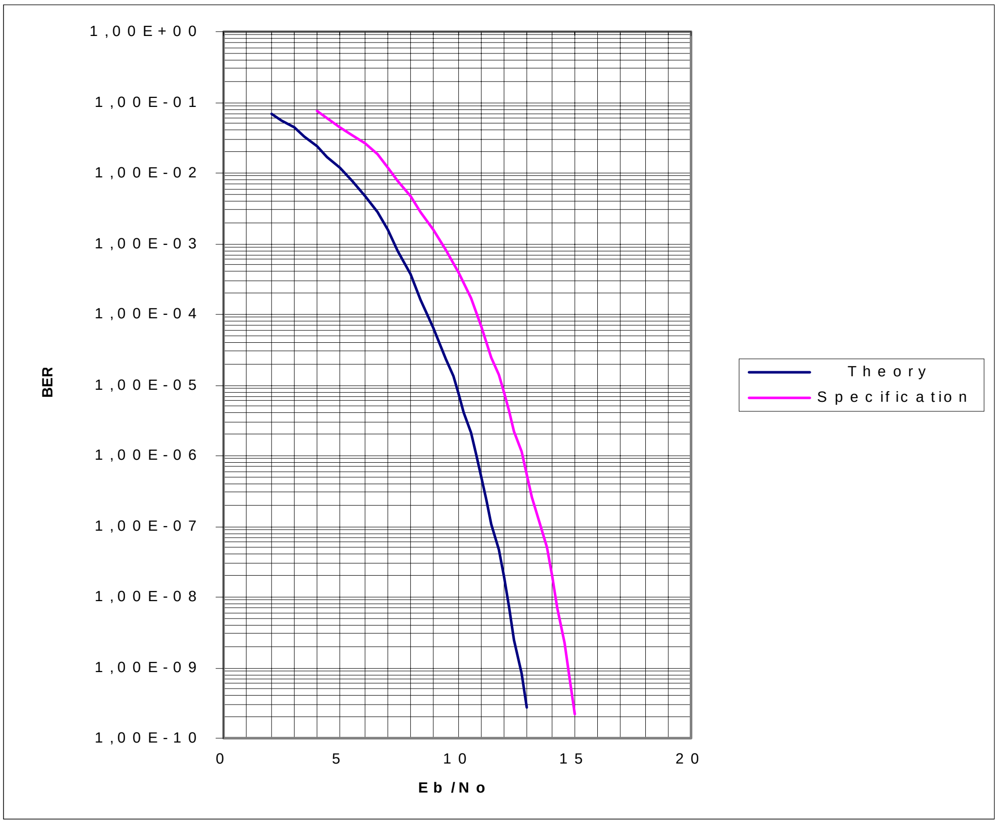


Figure 3: Bit error probability as a function of Eb/No for BPSK and QPSK modulation

Table 2 : ENVISAT X-Band-Transmission

Linkbudget for the NSG-7.3m-antennas

ENVISAT	
Mean altitude	799.79 km, near circular
Transmission frequencies	8.1 GHz, 8.2GHz, 8.3GHz
Polarization	RHC
Data rate	100 Mbps
Modulation	QPSK, scrambled data (PRN), differential coding
EIRP (for 5 deg Elevation)	16.9 dBW
Reference Document	ENVISAT Satellite to National & Foreign Ground Stations, Interface Control Document, Issue 2.2, 05.04.00

Ground Station	
Antenna Diameter	7.3 m
G/T	31 dB (for 8.0 – 8.4 GHz)
Tracking loss	0,2 dB
Demodulation implementation loss	2 dB

Link Budget:

		8.1 GHz (MERIS)	**8.2 GHz** (ASAR)	**8.3 GHz**
Spacecraft EIRP	**dBW**	**19.6**	**19.6**	**19.6**
Slant Range (at 5 deg Elevation)	km	2784	2784	2784
Path Loss	dB	-179.5	-179.6	-179.7
Polarization Loss	dB	-0.2	-0.2	-0.2
Atmosphere Loss	dB	-1.3	-1.3	-1.3
Tracking Loss	dB	-0.2	-0.2	-0.2
Propagation Loss	**dB**	**-181.2**	**-181.3**	**-181.4**
Flux at Groundstation	dBW	-161.6	-161.7	-161.8
G/T Groundstation	dB/K	31	31	31
Received RF-Power	**dBW/K**	**-130.6**	**-130.7**	**-130.8**
Boltzmann Constant k	dBWs/K	-228.6	-228.6	-228.6
Received S/N Dens. Ratio	**dBHz**	**98.0**	**97.9**	**97.8**
Demodulator Implementation Loss	dB	2	2	2
Datarate (100 Mbps)	dB	80	80	80
Bitenergy (Eb/No)	**dB**	**16.0**	**15.9**	**15.8**
Requ. Eb/No (BER:10exp-7)	dB	11.3	11.3	11.3
Margin	**dB**	**4.7**	**4.6**	**4.5**

Tracking Loss

One value, which has to be considered in the link budget is the tracking loss. There are two cases to distinguish:

- the pointing accuracy at low elevation angles
- the dynamic behaviour of the servo system and the pedestal for tracking the satellite at high elevation angles (85 – 90 degr.)

Two variants of tracking are very popular:

- **Program track** – the antenna is tracked by an computer on the basis of the precalculated orbit. In case of inaccurate orbit data it can cause great tracking losses.
- **Autotrack** -measures the tracking error in the horizontal and vertical plane and on this basis the antenna tracking is carried out with high accuracy and low tracking loss.

The normal procedure is that the satellite pass starts in the program track up to the reception of the satellite signal and now the antenna switches automatically in the autotrack-mode, for tracking the satellite with maximum accuracy.
The X-band-antennas at the ground station Neustrelitz are equipped with programtrack and autotrack capability and additionally there is a third axils (tilt) which decreases the dynamic requirements at very high elevation angles, so that there ar no tracking problems at very high elevation angles. For this configuration a tracking loss of < 0.2 dB can be achieved in every case.

Antenna system G/T

The system Figure of Merit G/T (antenna gain / system noise temperature) is a value of the sensitivity of the groundstation. It has th be measured in defined intervalls. The method which is used at the Neustrelitz ground station is to calculate the G/T out of the ratio of the noise level at the sun to the noise level of the cold sky (y-factor) using the following expression:

$$G/T = (8 \pi k L K1 / F1 \lambda^2) (Y - 1)$$

π : 3.1415
k : Boltzmann's constant = 1.38 * 10exp-23 watts $Hz^{-1} K^{-1}$
L: Aperture correction factor
F1: Solar flux at test frequency
Y : Solar y factor (numeric)
λ : Wavelength at test frequency (meters)
K1 : Correction factor for atmospheric attenuation

Normally the result is 31.5 dB/K – 32 dB/K G/T at X-band-frequencies. In the other case the problem (LNA, connectors, high VSWR,...) has to be identified and to solved.

Demodulator implementation loss

On the basis of the measured Eb/No the theoretical value for an minimal biterror rate can be estimated. This theoretical value and additionally a specified value, which considers already a demodulator implementation loss of

2 dB, are shown in figure 3. There are at least the following contributions to the demodulator loss:

- quality of modulation
- transmitter output filter
- quality of demodulation
- post demodulation filter loss
- quality of bit synchronization

The standard value for the demodulator implementation loss is 2 dB and it can be kept by commercial groundstation components. But by increasing the QPSK data rate in the X-band-frequency range (bandwidth 375 MHz), stronger transmitter output filtering is required. Therefore special phase pattern corrections are already sometimes integrated in the demodulator to decrease the additional degradation effect by the filtered modulation spectrum. This effect has to be considered by special measurements at the spacecraft before the launch or/and by similar filters at the output of the groundstation testmodulator. It is the standard equipment at the groundstation for testing the whole acquisition chain and to measure the demodulation implementation loss at the groundstation.

Groundstation Requirements

Data acquisition at the groundstation is a technical service. Primary the customers are interested to get the data reliably and continously, which high quality and by low costs. Additionally there is a great flexibility necessary to be able to start new services or to modify procedures to the customer needs.
All data acquisitions can be done by a multimission groundstation, which has a trained stuff for an complete service at all technical systems and which has redundant systems to overcome technical problems and conflicts. A conflict marks that there are not enaugh acquisition systems available to receive all scheduled transmissions at the same time.
A great advantage of a multimission groundstation is that the technical equipment and the operators can be shared to different missions and that the costs per satellite pass is lower as for a monomission groundstation at a quite lower technical risk.
At the groundstaion Neustrelitz at time data from the following satellites are received operational: LANDSAT-7, ENVISAT (after the commissioning phase) ERS-2, IRS-1c/1d, IRS-P3, CHAMP, GRACE-1/2, BIRD, CORONAS-F. In 2002 there are planned 7000 – 8000 acquisitions on site.

Monomission Groundstation Architecture

Figure 4 shows a simplified block diagram of a typical monomission groundstation.
A groundstation controller is used for antenna tracking, for remote control of all system components and to enable system tests (BER-tests) automatically.
Some years ago the normal solution was to store the serial data stream on magnetic tapes. Today a powerful signal synchronization in realtime is

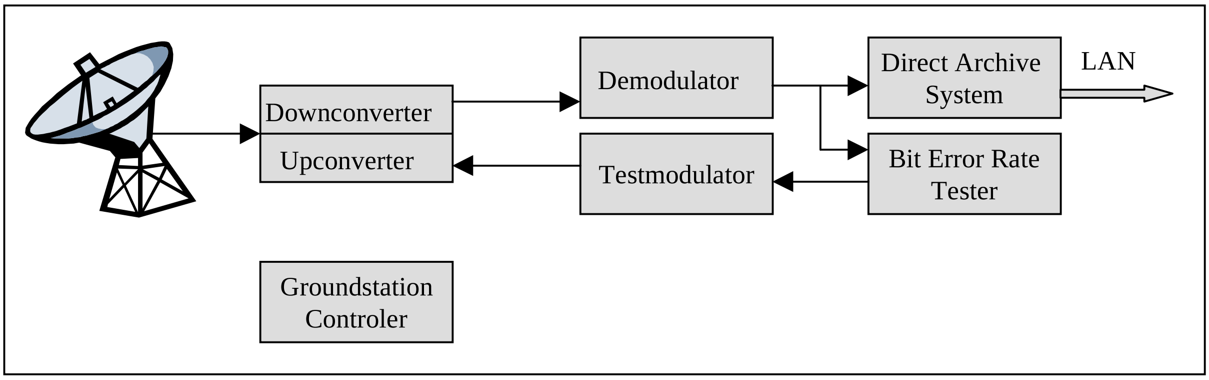


Figure 4: Simplified block diagram of a typical monomission ground station

normally used together with a workstation to store the data on hard disk (RAID) and to provide the operator with realtime information (browse image, status...) about the actual data acquisition.Up to next satellite pass the received data can be processed (generation of metadata and browse data for the user interface...) and transmitted to the archive by LAN or stored on computer compatible tape (DLT). Special software to plan the acquisition, for generation of the acquisition reports as well as the necessary hardware for redundance and for special measurements as well as for the display of the actual received signal spectrum (spectrum analyzer) ar not considered in this simple overview.

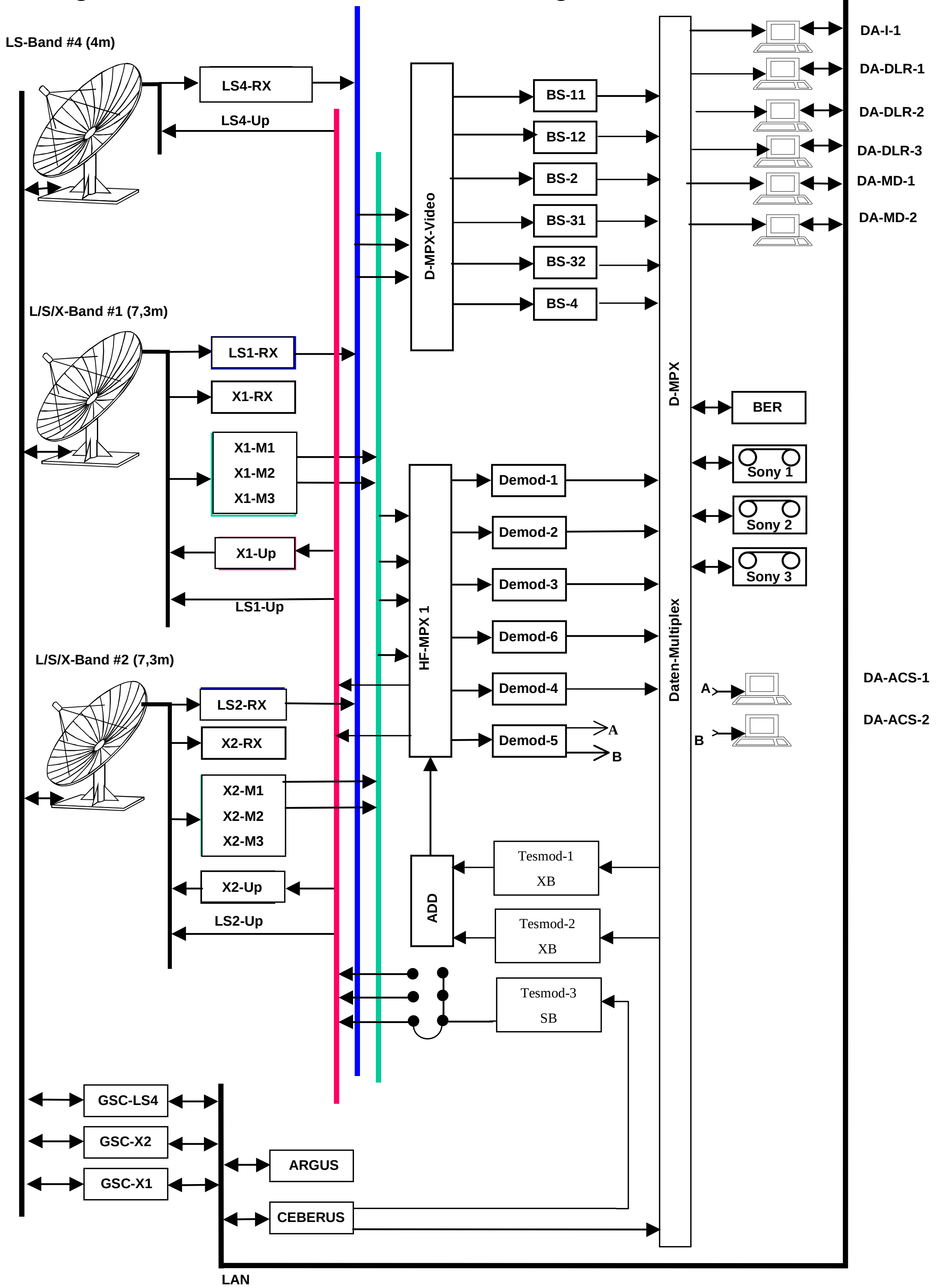
Multimission Groundstation Architecture

At the multimission groundstation data acquisition from different satellites can be done in parallel, if there are are some antennna systems available. The arrangement of the systems can be done in different manners. At the DLR groundstation in Neustrelitz all antennas, all demodulators and all systems for data recording (SONY tape recorders and the mission specific direct archive systems) as well as the needed measurement devices are operated in a common groundstation system (figure 5) . The system will be configured – according the actual data acquisitions – by switching devices:

- IF-switches (12 x 12) „HF-MPX1“ for switching the highrate-IF (720 MHz) to the demodulators/bitsynchronizers
- Video-switches (8 x 8) „D-MPX-Video“ to switch the demodulated low-rate-data at the programmable bitsynchronizers (BS-2, BS-31..)
- Data-switches (32 x 32)“D-MPX“ for switching the serial data streams (ECL, clock & data) at the systems for data recording (tape recorders, DAS)

All data acquisitions have to be configured before the satellite pass and then they are running nearly automatically. The operator supervises all activities and handles only directly, if problems are recognized.
According figure 5 three antennas can be received in paralles by the three antennas. Therefore the operator uses three groundstation controlers „GSC“ (antenna configuration and tracking), three spectrum analyzers (signal level and spectrum) and the station control system „ARGUS“ (graphic display for

Figure 5: Architecture of the DLR multimission groundstation Neustrelitz



actual scheduled acquisitions, logging of all status information, matrix and tape control...)
Because at the multimission groundstation many devices have to be configured via remote control (RS-232, IEEE-488;LAN), it makes great problems if this fails. Also sidelobe-tracking is possible, if the satellite transmitter is switched on at higher elevation angles and the orbit data don't have the needed accuracy. In these cases the operator has to identify and to solve the problem. On the other hand this multimission groundstation has a lot of redundant equipment, so that as an backup the data can be stored also at tape recorders (SONY) or in case a demodulator or an other device failes it can be switched to the redundance. In the past a high reliability (approx. 99 %) was reached by the multimission groundstation and the needed manpower could be shared to different satellite missions.

Expected Future Requirements on data acquisition from EO satellites

The data transmission from the satellite to the groundstation at X-band-frequencies (8025 – 8400 MHz) is limited to datarates up to approx. 300 Mbps for QPSK-modulation. But also in the future the datarates of EO-missions will increase and therefore two solutions are under developement:

- to use a more bandwidth efficient modulation
- to use the K_a-band frequencies 25.5 – 27 GHz for earth exploration satellite (EES) service , space to earth /4/

At the 2nd ESA Workshop on Tracking, Telemetry and Command Systems for Space Application it was reported about an X-Band Highrate 8PSK Modem for Earth observation satellites /3/ at the doubled data rate of 600 Mbps.
In the future also K_a-Band frequencies will be used for highrate transmissions up to the Gbps-range. At time there is no groundstation network available therefore.

Summary

EO-satellites transmit highrate data to the groundstations on Earth. The main requirements were analyzed and the architecture of the DLR groundstation Neustrelitz was described.

References

/1/ LANDSAT-7 TO INTERNATIONAL GROUND STATION (IGS) INTERFACE CONTROL DOCUMENT
Goddard Space Flight Center, Greenbelt, Maryland, USA; April 2000, Rev. D

/2/ ENVISAT Satellite to National & Foreign Ground Station; Interface Control Document,
ESA ; Ref: PO-ID-ESA-SY-1003

/3/ J. Oster, N. Cartier, J. M. Mateus

X-Band High Rate 8PSK MODEM for Earth Observation Satellite Data Down-link
Proceedings of the 2nd. ESA Workshop on Tracking, Telemetry and Command Systems for Space Applications
ESA/ESTEC, Noordwijk, The Netherlands, October 2001

/4/ Y. Wong, M. Burns, J. Brase
NASA K_a-Band Developments and Capabilities for TT&C Support to Near-Earth-Spacecraft
Proceedings of the 2nd. ESA Workshop on Tracking, Telemetry and Command Systems for Space Applications
ESA/ESTEC, Noordwijk, The Netherlands, October 2001

/5/ J. Schwarz, H. Maass, H.-D. Bettac
Data reception of small satellites in a multimission scenario
Acta Astronautica; vol.46, Nos. 2-6, pp.221-228; 2000

/6/ H. Damerow, J. Richter
The Software Scope between Operatorsa and Complex Ground Station Equipment in a Mulitmission Scenario
European Telemetry Conference ETC 2000, Garmisch Partenkirchen

/7/ H. Damerow, J. Schwarz
Satellite Data Reception System at a Multimission Ground Station
3rd. IAA Symposium an small Satellites for Earth Observation, 2000
Berlin

REENGINEERING A TRADITONAL SPACECRAFT CONTROL CENTER

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Abstract

Deutsche Telekom is operating various communication satellites since 1989. The SCC (spacecraft control center) is located near Frankfurt / Germany. The entire system is designed of a network of antennas, RF and baseband equipment. The computer software packages are running on a network of different computers.

As a result of increased maintenance effort the old baseband system needed to be replaced. The computer system is also effected, mainly to the M&C changes. The plan was to design the modified system in a way to minimize the operation effort in costs and human intervention aspects.

This paper explain the successful project of reengineering an old spacecraft control center (SCC). It is will be shown how a fifteen year old hardware and software design was replaced by a modern concept.

The new software controls every aspect of spacecraft- and ground station control. The Monitor and Control System (M&C) is a database driven design (FRAMTEC, from CAM Germany).

Key Words

Satellite Control Center, Reengineering, Baseband and Real - Time Data Processing

Introduction

The old SCC was designed in 1985 to provide the following functions:

(1) Real-time and nonstop operation for up to four satellites
(2) Ku-Band telemetry, telecommand and Ranging for these satellites
(3) Network connections the GSOC (German Space Operation Center) ground station at Weilheim (S-, Ku-Band)
(4) Computer-based system for remote monitoring and control of the whole SCC equipment
(5) Attitude and orbit determination and prediction (integrated Flight Dynamic System)
(6) High reliability and availability of the SCC equipment (system availability design 99.95%)
(7) Ease of operations, automatic control of routine functions for both SCC and satellite control.

Most of equipment manufacturers does not exist anymore and the maintenance costs increased dramatically. Hardware and software components had to be replaced by a modern system.

The Old Ground Control System

The Satellite Control Center of Deutsche Telekom is build by several subsystems:

(1) main and emergency control room
(2) the station computers including the Twisted Pair Ethernet LAN
(3) the Analysis and Offline System
(4) the Flight Dynamic System (FDS)
(5) the baseband equipment installed in the central building
(6) the antenna buildings with RF-equipment and the antennas.
(7) the remote ground stations at DLR sites

The system configuration of the Satellite Control Center is shown in figure 1:

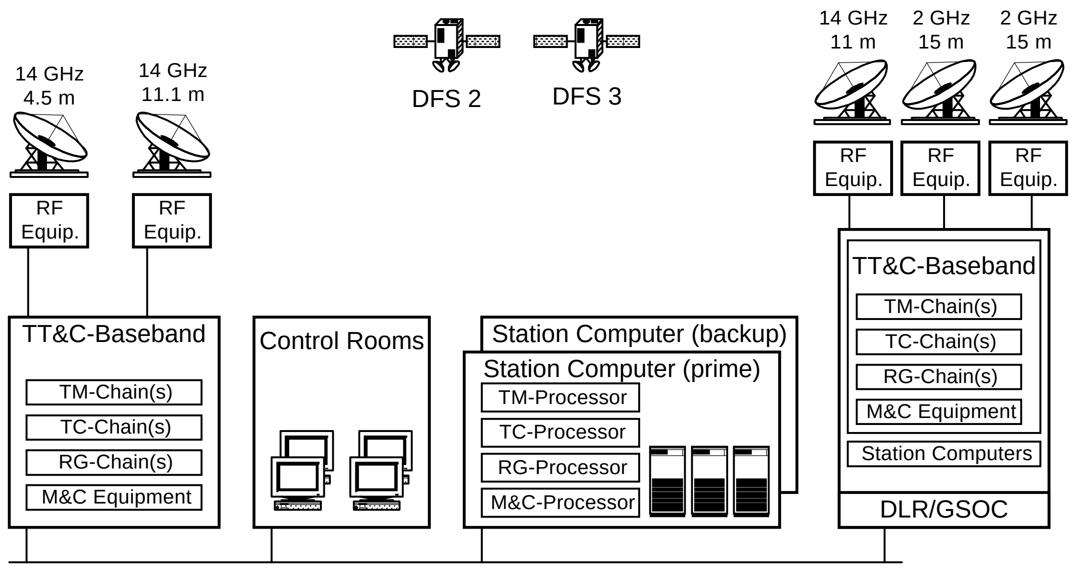

Figure 1: System overview

Computer Systems Hardware Design and Networking

The computer systems are midsize cluster system and workstations running OpenVMS on Compaq hardware. The FDS uses hardware from Hewlett Packard. The workstations process and display real-time data. Figure 2 shows the layout of the computer systems.

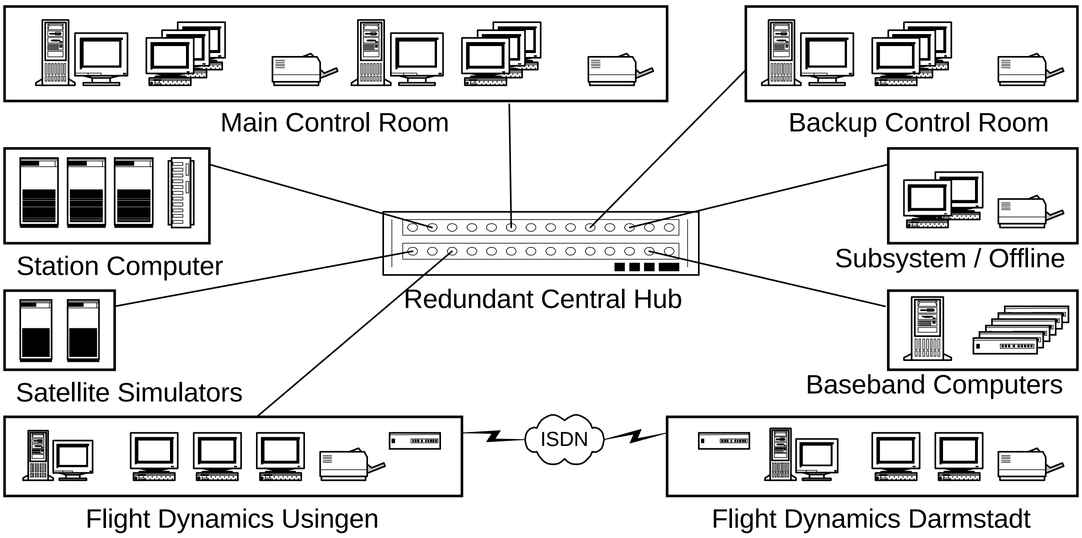

Figure 2. Diagram of computer systems

Data communications links are used between Telekom SCC, DLR GSOC (German Space Operation Center) and the DLR Weilheim ground station. The Wide Area Network (WAN) is build with ISDN (Integrated Services Digital Network) and leased lines.

Baseband Equipment, RF Equipment and Antennas

The old baseband equipment is situated in the main station building. For each main function telemetry, telecomand and ranging the hardware is organized in chains:

(1) Telemetry (TM) Equipment six chains. Each TM-chain had a 70 MHz Receiver, a PSK-Demodulator, a Bit-Synchronizer, a PCM-Preprocessor and a front-end processor.
(2) Telecommand (TC) Equipment six chains. Each TC-chain had a front-end Processor, a TC-Controller, a PSK-Modulator and a 70 MHz Phase Modulator.
(3) Ranging (RNG) Equipment two ranging systems. The ranging systems are interfaced to the LAN via front-end Processors.
(4) The Time-and Frequency System was based on a rubidium frequency standard .
(5) The front-end Processors (FEP) combined several functions: converting, time-tagging and sending the real-time data from the baseband via the LAN to the main computers and to monitor and control the devices in the associated chains. The front-end processors are PDP-11 computers (running RSX 11 M) from DEC.
(6) The two Monitor and Control Processors (MCP) the equipment inside the antenna building (e.g. ACUs, amplifiers), collect all monitoring data from the baseband and sent only new information to the station computer.

(7) The RF equipment is situated in a remote antenna building. Each of the four high frequency groups includes up-/down-converters, high power amplifiers, low noise amplifiers and ranging converters.
(8) The sizes of the two TT&C antennas are 4.5m and 11m.

Problems (Challenges)

Throughout the last six years the problems with spare parts supply increased . These complications led to the decision to exchange the old hardware, except RF equipment and antennas.
At first in 1996 the entire VAX/VMS computer hardware was replaced by Compaq Alpha/AXP computers with OpenVMS. At second the old baseband equipment was replaced by a modern COTS solution. Several suppliers from around the world were asked to provide components.

As cost drivers for the new system were identified:

(1) Not widely known European (ESA) TM, TC and RNG standards from the early eighties
(2) Interfacing with existing real-time system (e.g. RF equipment) and control center software which should not be impacted (e.g. TM and TC processing software)
(3) New HMI development

The New System

As main contractor CAM (Gilching, Germany) was selected. The new baseband hardware and the new M&C software are based on a COTS/MOTS solution. These are the new subsystems:

(1) three baseband units
(2) a switch matrix
(3) a time and frequency system
(4) two interface computers to the existing RF equipment
(5) interface software to the existing real-time system (TM / TC / RNG)
(6) M&C system with an integrated modern Human Machine Interface (HMI)

The three baseband units are COTS products with Windows NT. Two new PCs were added to control the RF equipment and antennas. The existing antennas and RF equipment remains all unchanged. A new switch matrix has been integrated. For the new time and frequency system (TFS) a redundant GPS receiver was selected. The time synchronisation of all computers was simplified by a GPS based Network time server.

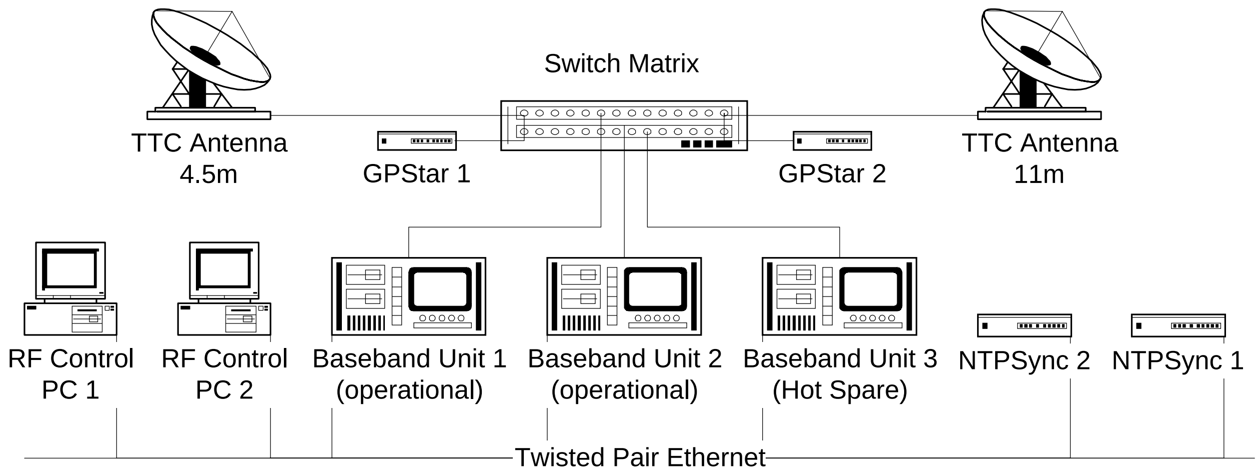

Figure 3: The new baseband system

Maintenance Aspects

There are no user serviceable parts inside the new hardware. The maintenance and repair activities are reduced to identify and replace faulty boards and send them to the manufacturer for repairing.

The highly integrated equipment reduces the dramatically. From seventy single boxes in eight racks to ten boxes in three racks. (single units: TM: 30, TC: 18; RNG: 14; TFS: 4; Control Processors: 4; switch-matrixes: 2).

Software Design

The entire operation software for the SCC is installed on various computers. This software is divided into parts on the main cluster computers (routing, archiving, logging, etc.), parts on the workstations (TM / TC) and parts on various PCs (HMI, for visualization purposes).

The heart of the system is the cluster software . The incoming data are time-tagged, stored and than routed to the other systems. The core operational software provides functionality for TC, RNG, M&C and data archiving. The graphical HMI is running on workstations. A fixed system configuration does not exist If required, each software package (except the HMI, running only on the PCs) can run on each workstation. An additional dedicated workstation servers as an emergency system. The goal of the project was to leave the real-time processing software unchanged, i.e. only modify the interfaces to the new baseband elements and to replace the complete M&C system.

The New Monitor and Control System

The M&C system was completely replaced. The new baseband system, the new TFS, the existing untouched RF equipment and the monitoring of the entire computer system has been integrated.
The actual spacecraft operation is performed at the SCC from the control rooms by two operators. The operators monitor and control the complete data flow throughout the

system from antenna to the SCC. The M&C of the ground station is divided into subsystems and devices as follows:

(1) Antennas, antenna control units, High frequency groups (at Usingen and Weilheim)
(2) Switching matrixes
(3) Baseband equipment: Telemetry chains, Telecommand chains, Ranging chains
(4) Time and frequency system
(5) Computer systems

The M&C information hierarchical organized in four different levels:

(1) Level 4: system level referring to the overall ground configuration and status (highest level)
(2) Level 3: satellite level referring to configuration and
(3) Level 2: chain level referring to subsystem status and function
(4) Level 1: low device level referring to basic parameters and to bits and bytes (lowest level)

These levels are mapped to the ground station monitoring and control functions. The whole ground system can be operated using a few mouse-clicks on the graphical Windows NT screens.

Actual Project Requirements for the M&C System

These are the project requirements which have to be fulfilled by the M&C system:

(1) Reduction of time and costs for implementation; this is an implicit requirement resulting from the number of deliverable items and the time remaining for the development itself.
(2) Increase the functionality; e.g. such as parameter history, trend limits, direct replay of telemetry etc..
(3) Make use of proven software, i.e. to avoid as far as possible the development of new project specific software components.
(4) Modern Human-Machine-Interfacing including line- and symbol plots for representation the current state of the monitored / controlled domain also in a graphical manner.
(5) Quick and easy configuration by the users themselves; this point reflects not only the implementation of derived parameters and the (re-)definition of complex structured data packets but also modification of the display views.
(6) TM, TC and M&C shall be used in identical manner. This is a logical consequence, since processing of monitor data is nearly the same as processing telemetry data and the generation / transmission of control information to the ground station is also nearly the same as commanding a space craft with the exception that “keep alive messaging” is in general not necessary for M&C systems.

FRAMTEC

The monitor and control software is based on a COTS product named FRAMTEC (Framework for Advanced Monitoring, Telemetry and Control). This software is used by different agencies such as DLR Oberpaffenhofen, Germany and EUMETSAT Darmstadt, Germany.

FRAMTEC was selected because of its high flexibility of the decommutation and the parameter processing rules. A further reason was all interfaces to other components within the Telekom SCC environment have been available.

FRAMTEC is a core system for processing telemetry and monitoring data and for generation of control information, e.g. for the configuration of the baseband units. This tool was developed between CAM and DLR (Deutsche Forschungsanstalt für Luft- und Raumfahrt) which is a Joint Venture partner with Deutsche Telekom.. The development accumulate the experience gained in a wide range of commercial, scientific and manned space missions.

The fundamental idea of FRAMTEC is the user can configure applications easily and fully almost without software modifications. The processing rules of the parameters and the layout of the data packets are described within the process database. Even the recognition of incoming data packets can be handled within the process database.

The standard processing of parameters can be defined in a straight forward manner: A wide range of standard process functions for bit/byte extraction, transformation into the engineering unit, limit checking, adaptive processing, event generation, etc. are available.

The performance of special processing, e.g. processing of derived parameters, is simplified by using the build-in interpreter functionality. A C/C++ like source code is written directly into the process database. This code is pre compiled during the database load operation and executed in real-time by the integrated virtual machine. Additional user hooks are available to link user-written functions directly to the application – if necessary.

For the definition and handling the data packets complete functionality is available, such as processing fixed positions or processing multiplexed positions with reference to multiplexed tables. The definition of sub-frames is supported to avoid multiple definition of the same parts of data packets or to interpret the contents of an incoming data packet or part of it dynamically according to the values and states of other parameters.

Control packets to be transmitted as configuration information are specified within the process database in a comparable manner. Functionality for administrations of control packets (modifying, sending, loading form disk, saving to disk) is implemeted. The transmission of control packets is performed on operator request or after detection of specific events.

This flexibility allow the definition of vehicle and equipment independent decommutation and parameter processing rules in a quick and comfortable manner. The representation of parameter values as well as modification and transmission of control information is performed using a modern, Windows-based, human-machine-interface (HMI).

Components of FRAMTEC

It can be seen by the name “framework”, FRAMTEC consists not only of a single program performing the related operations but it consists of multiple components / products working together to satisfy all the relevant requirements in a modern, comfortable and safe manner. The figure below shows the relationships between these components. Figure 4 shows the FRAMTEC components:

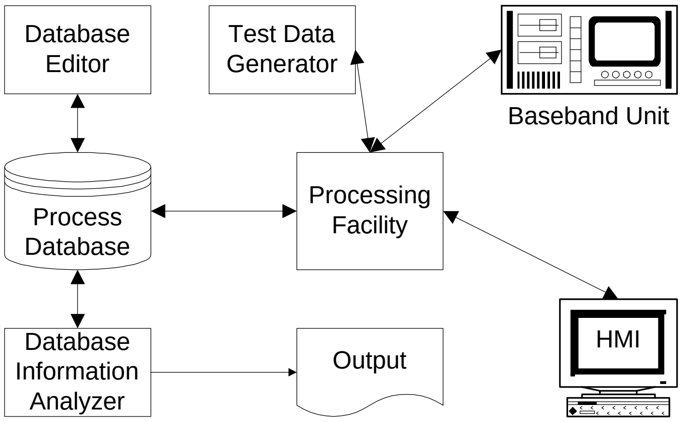

Figure 4: Components of FRAMTEC

The process database contains all information about the processing information as well as the information about control packets structures. The process database is maintained by the FRAMTEC Data Base Editor (FDBE) and loaded into the processing facility during the startup phase. This tool (FDBE) is based on the commercial product MS ACCESS.

Before loading a new or modified process database into an operational system, it is essential to perform various checks and analyzes to detect any faults.

The processing facility is the on-line core of FRAMTEC – received monitor data packets are identified and related to the description within the process database processed, i.e. the parameter information - originally a sequence of bits - is gained, converted into engineering units (volts, temperatures, etc.) and visualized to the operator using the integrated HMI. Operator inputs are processed and the appropriate action is executed; this includes the modification / construction of control information and sending them to the related equipment.
Many M&C systems have to be configured without direct connection to the related hardware facilities because they are not yet available or otherwise in use. As result there are only limited possibilities to perform tests with the original equipment. For this reason test-data can be replayed or generated to perform tests previous to connect to the operational equipment. The usage of this tool reduces the time for integration and test.

The modern Windows-based HMI (in multiple instances) provides display information (in alphanumerical and graphical) to the operating personnel and to receive inputs to configure the system. The archive provides data of the latest history, e.g. in form of line-plots, even if the HMI was currently started. The definition of the display masks is not part of the application itself. The views can be configured without modifying the software by the user. Once the HMI is connected to the processing facility via TCP/IP M&C can be performed on-site and from remote.

Monitoring and Control Philosophy

The ground segment display formats represent the ground station in a hierarchical structure.

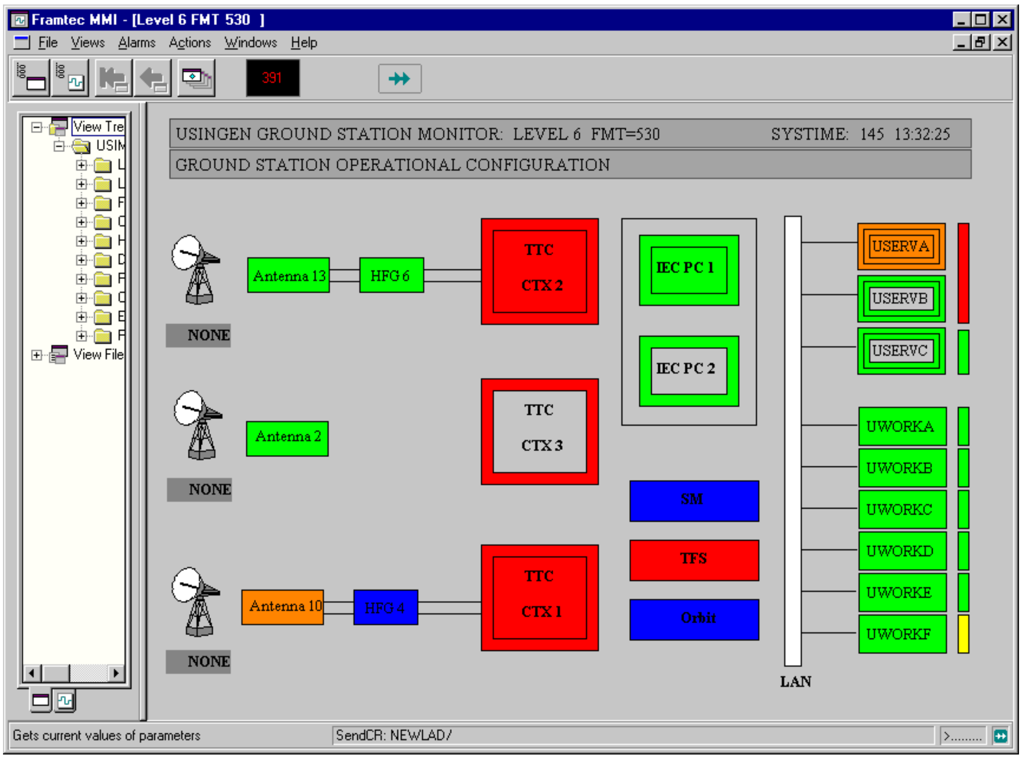

Figure 4. Typical display “system overview” (in emergency state)

The status of any system, subsystem or device is represented by color coded graphical symbols:

(1) Green: fully operational
(2) Yellow: soft-limits reached, but still operational
(3) Red: hard-limits reached , not operational
(4) Orange: device is switched to local or a task of a computer is crashed
(5) Blue: communication alert

This representation allows the operator or subsystem engineer to select the desired information from top to bottom or vice versa. The higher level monitoring display formats contain relevant information, the lower level display formats show the details. The monitoring display formats are driven by the referenced monitoring parameters and derived parameters according to the display format descriptions. The following figures show typical ground station system monitoring screens.

Reengineering Aspects

The complete integration and testing has to be performed during normal operation of the existing satellites – minimizing disturbance of these operations as far as possible. The project was structured into various phases:

Phase 1: Integration of TM and TC processing using the existing S/C specific software components as far as possible – only the interfaces to the baseband equipment have been changed
Phase 2: Integration of the new PCs controlling the existing RF equipment
Phase 3: Integration of the new time and frequency system
Phase 4: Integration of the new overall M&C system

There was one major restriction: it must be always possible to switch back to the old system in case of any anomalies to continue the save operation of the spacecrafts. This was achieved by:

(1) Joint testing the single components – ever under the premises to reduce the impacts for the normal S/C operations, i.e. test could only be performed during restricted time intervals, after an exactly planning of these test and successfully performed “pretests”.
(2) The switching of telemetry and telecommand processing was achieved by patching a few cables in the main building
(3) The integration of the both PCs controlling the RF equipment was more complicated: The existing RF equipment is controlled via an IEC bus and only one controller can act as master at a time. For this reason specific switches had been integrated into the system, to switch the four IEC busses from the old to the new system and vice versa.

With this mechanism it was always possible to switch between the new and the old environment and to operate the S/C in safe manner.

As mentioned, the hand-over of the new system has been performed in single phases and each one after intensive testing the new components. A great advantage was that all the tests concerning any operational behavior have been performed together by both parties.

Due to the high flexibility of FRAMTEC and the easy manner to modify the behavior of the processing and generation of control information this projects could be completed successfully.

Conclusion

The reengineering process was successful. All through the project it was shown that FRAMTEC was able to fulfill the requirements. The hardware was delivered in late September 2000. The acceptance test was successful performed in March 2001. The use of a COTS product reduced substantially the project development time.

FRAMTEC offers a wide flexibility not only for space related missions but also for nearly every application which needs high performance parameter processing without writing new code for any new application.

LOW BUDGET SATELLITE COMMUNICATION GROUND STATION FOR PACKET DATA TRANSMISSION

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ABSTRACT

Under the cooperation program between Indonesia and R.F. Germany (LAPAN and DLR), low budget satellite communication ground station for packet data transmission is being developed. The ground station is based on specification of the many operating amateur satellites in orbit at the moment. The purpose of the cooperation project is to gain hand-on experiences on satellite operation as the first step toward more professional system in the future for LAPAN. The ground station is capable of tracking satellites, doing store and forward communication with Up Link 9.6 Kbps and down link 9.6 and 38.4 Kbps, and receiving satellites' telemetry data. The ground station comprises of VHF, UHF and S-band antennas, one VHF/UHF transceiver, one terminal node controller, two modems, two computers, an antenna mounting, two LNA, an S-band to VHF down converter and a switching unit. Since the location of LAPAN ground station is out of town and the communication infrastructure is not in place yet, terrestrial packet radio with modem speed of 153 kbps is also developed to provide file transfer and internet access. The terrestrial system comprises of a pair of TNC, transceiver, modem, and computer. The overall cost for the station is less than 10.000 Euro where the antenna system alone contributes about half of it.

Explanation of the two figures below:

Figure 1. The concept LAPAN satellite communication.
It shows an overview about the system concept consisting of:

- The ground station facility in Rancabungur,
  - The satellite communication ground station
  - Terrestrial link station
- User satellite station (e.g. non-real-time volcano activity monitoring)

Figure 2. LAPAN satellite communication ground station in Rancabungur.
It shows a detail system consisting of:

- The antenna system
  - VHF transmitting antenna
  - UHF transmitting and receiving antenna
  - S-band receiving antenna
- Front-end system
  - HPA High Power transmitting Amplifier (VHF/UHF)
  - LNA Low Noise amplifier (UHF and S-band)
  - Down Converter S-band to VHF
- Transceiver
  - Dual band all mode transceiver with IFD to receive higher speed data
- Switching Unit
  - I/O data switching and unit control
- TNC and Modem
  - Terminal Node Controllers and Modems for data communication with several choices of speed
- Station computer
  - System monitoring and control
  - Data processing and communication
  - Tracking system

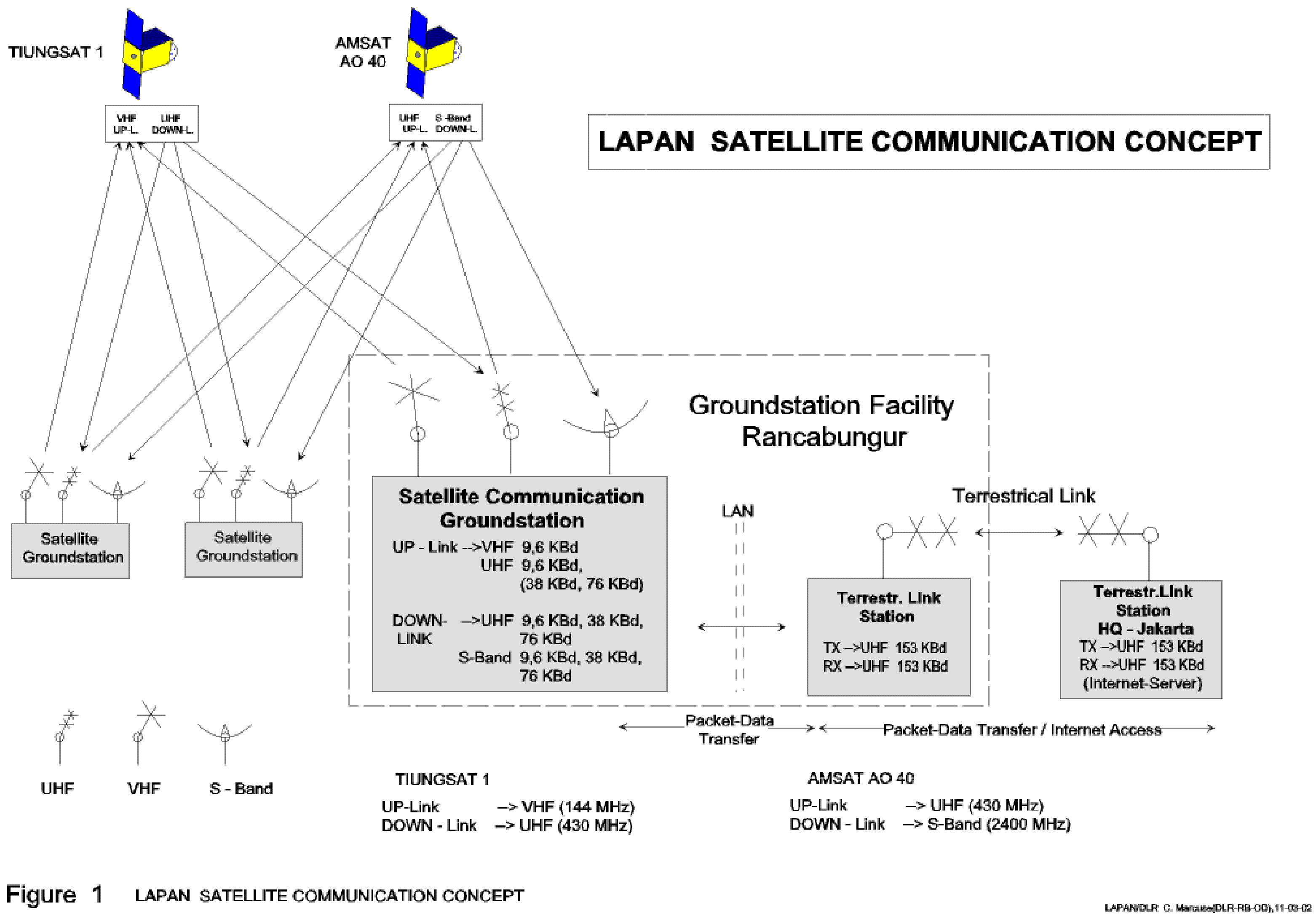

Figure 1 LAPAN SATELLITE COMMUNICATION CONCEPT

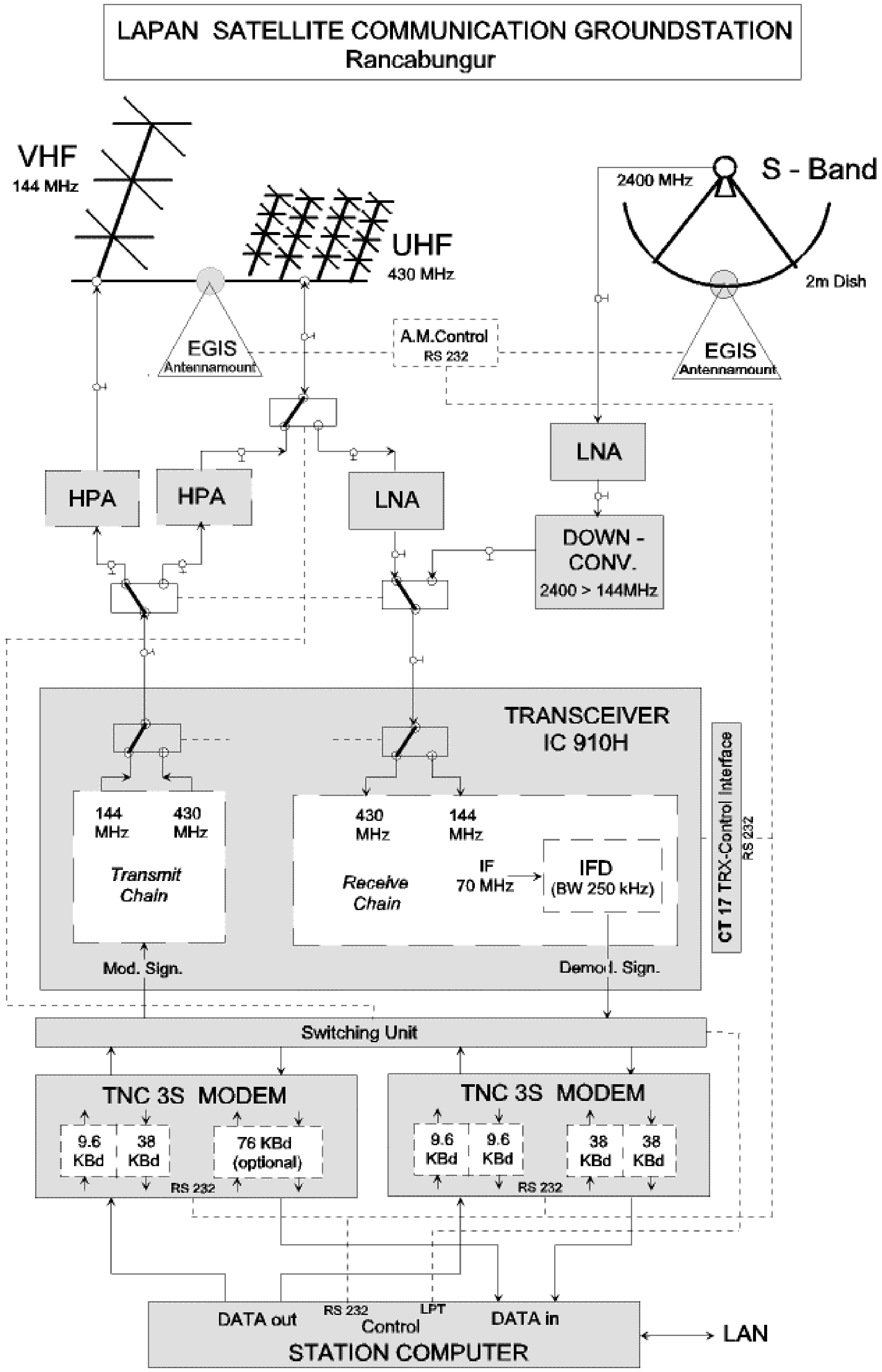

Figure 2 LAPAN SATELLITE COMMUNICATION GROUNDSTATION

LAPAN/DLR C. Marcuse(DLR-RB-OD),11-03-02

TELEMETRY SYSTEMS

Positioning with Telemetry System

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ABSTRACT

Generally speaking, if we need to get the position of a flying object, we can select radar GPS and theodolite etc. All of these equipments have been widely used in proving range, flight-test of plane, and satellite launching. The conditions of using these equipments are very clear against professional. But under some circumstances, all of these methods may be not convenient. For example, the flying object is beyondthehorizon. Sometimes, the telemetry system can be selected to locate the position of a flying object, a plane or another object. In this paper, one of projects will be designed and discussed, and the positioning precision will be simply analyzed. This paper will be consisted by the following main parts: Introduction, System Composing, System Positioning Principle, Positioning Precision Analyzing and Conclusion.

KEY WORDS

Telemetry system, Positioning

Introduction

Positioning technology with telemetry system is very important under special circumstances. To the flying object (Plane, rocket, missile and other flying objects), telemetry system is a necessary tool for testing their interior parameters. So, telemetry is a necessary method in these flight-test. In the meantime, we need radar, theoderlite or other methods to locate the position of the object. The costs of radar and theodolite are very high, but the precision of these equipments is high that we have known. But, on the other hand, if the precision could be used for actual requirement, we could locate the position by using telemetry system.
In this paper, we will analyze the positioning precision with telemetry positioning system, and the factors that affect the positioning precisions. As a conclusion, it will be indicated how to improve the location precision by reasonably set the ground telemetry station or improve other test condition. Those designers of test system could reference all of the analysis.

System Composing

The system configuration is shown in Fig1. The units in the broken line, including PN code producer modulator, could be put in the telemetry object. In this paper, the units in the broken line would be designed and analyzed as function units of the ground telemetry station. If the parts in the broken line had been put in the telemetry object, the analyzing about precision and error would be more complex. In this paper, the second situation would not be analyzed to thrift the length.

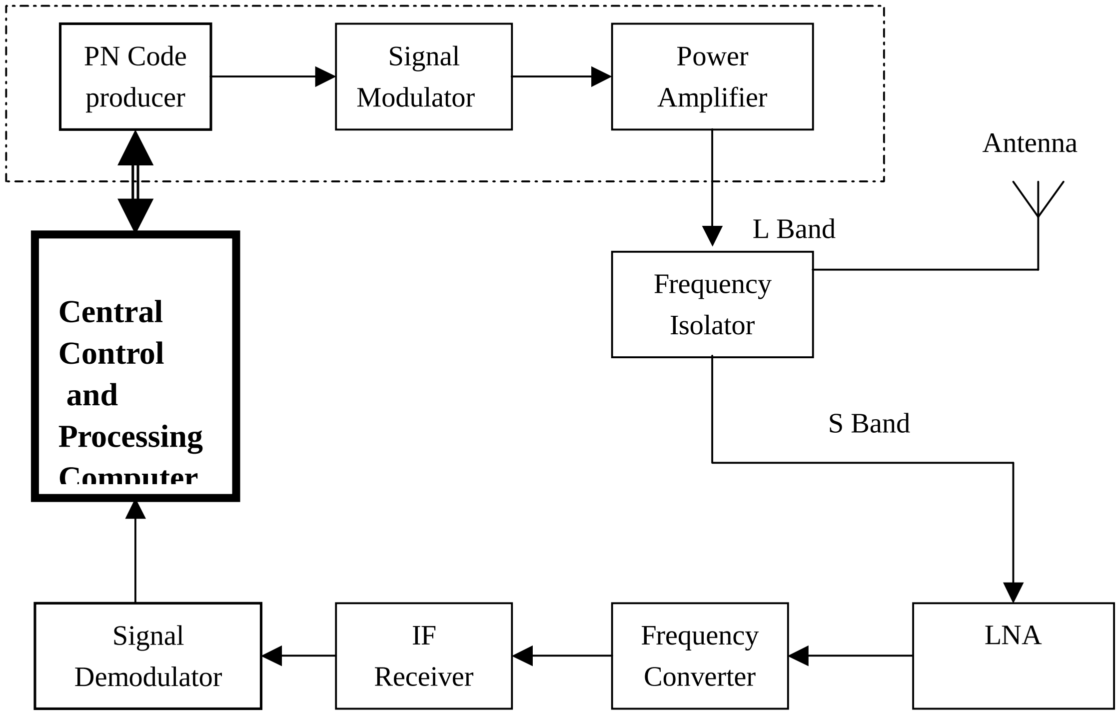


Figure 1. System Configuration

As shown in Fig 1. All of the units in broken line rectangle perform the up-line channel. The others could be considered as the down-line channel. The method of signal modulation could be BPSK. Accordingly, the demodulator must be designed for PSK format. Central Control and Processing Computer would do the object position calculation. At the same time, it would take the jobs to control all of these units, in order to make them work in phase.

System Positioning Principle

The distance measure, between the object and telemetry station, is based on PN Code methods. The PN code Producer generates PN code as shown in Fig 1. The BPSK modulating format would be adopted for base-Band modulation. The radio modulation is L Band, in order to isolating from received S-Band telemetry signals. The telemetry object would translate the L-Band PN Code modulating signals to S-Band, and mix it with S-Band Guide Frequency, then send it back to the ground telemetry station through object telemetry transmitter. PN Code is a complex code that is composed by Code1 and Code2, the length of code1 is 255 bit, and code2 is 511 bit. PN Code rate is 1 MHz.

To comprehend the detailed description about positioning principle with PN code, we can reference radar and data communication books. It will not be described detailed in this paper.

Positioning Precision Analyzing

In the project we have designed, the telemetry system can only give the survey coordinate of the object: R, A, E. Here, R is the slant range between the object and the ground telemetry station; A is the relative azimuth from the object to the ground telemetry station, E is the elevation from the object to the ground telemetry station. According to these parameters and their error we could get the object coordinate in the survey coordinate system. If it is necessary, we can convert its coordinate to geocentric coordinate system. These would be analyzed in the following. The relationship between RAE and orthogonal coordinate is shown with Fig 2 in survey coordinate system.

In Fig 2. the elevation angle is calculated based horizontal plane. The azimuth angle is based the real north direction. Both of the horizontal plane and azimuth “0” angle have been measured before test. In this paper, we consider the values are utterly correct.

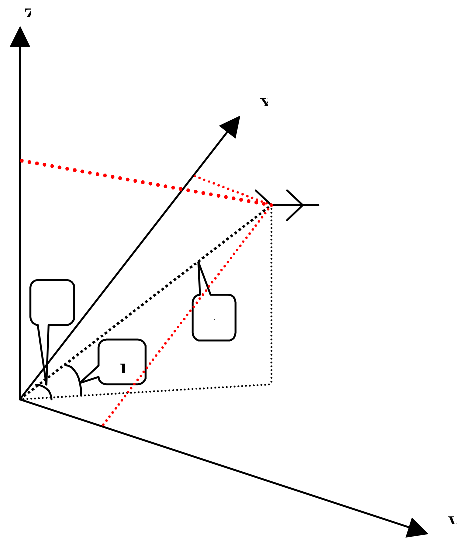


Figure 2. Relationship between RAE and

The coordinates parameters x y and z for specifying the location of the telemetry object could be determined as following. Reference the Fig 2.

x=RcosEcosA

y=RcosEsinA

z=RsinE

According to the propagation error formula. x,y and z match the criteria of differentiation. Making them thaler outspreaded, we could get the following approximate conclusions.

$$\Delta x \approx \frac{\partial x}{\partial R}\Delta R + \frac{\partial x}{\partial A}\Delta A + \frac{\partial x}{\partial E}\Delta E$$

$$\Delta y \approx \frac{\partial y}{\partial R}\Delta R + \frac{\partial y}{\partial A}\Delta A + \frac{\partial y}{\partial E}\Delta E$$

$$\Delta z \approx \frac{\partial z}{\partial R}\Delta R + \frac{\partial z}{\partial A}\Delta A + \frac{\partial z}{\partial E}\Delta E$$

Take the quadratic deviation of each variable above.

$$\sigma^2{}_x = \left(\frac{\partial x}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial x}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial x}{\partial E}\right)^2 \sigma^2{}_E + \frac{\partial x}{\partial R}\frac{\partial x}{\partial A}\rho_{RA}\sigma_R\sigma_A + \frac{\partial x}{\partial R}\frac{\partial x}{\partial E}\rho_{RE}\sigma_R\sigma_E + \frac{\partial x}{\partial A}\frac{\partial x}{\partial E}\rho_{AE}\sigma_A\sigma_E$$

$$\sigma^2{}_y = \left(\frac{\partial y}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial y}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial y}{\partial E}\right)^2 \sigma^2{}_E + \frac{\partial y}{\partial R}\frac{\partial y}{\partial A}\rho_{RA}\sigma_R\sigma_A + \frac{\partial y}{\partial R}\frac{\partial y}{\partial E}\rho_{RE}\sigma_R\sigma_E + \frac{\partial y}{\partial A}\frac{\partial y}{\partial E}\rho_{AE}\sigma_A\sigma_E$$

$$\sigma^2{}_z = \left(\frac{\partial z}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial z}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial z}{\partial E}\right)^2 \sigma^2{}_E + \frac{\partial z}{\partial R}\frac{\partial z}{\partial A}\rho_{RA}\sigma_R\sigma_A + \frac{\partial z}{\partial R}\frac{\partial z}{\partial E}\rho_{RE}\sigma_R\sigma_E + \frac{\partial z}{\partial A}\frac{\partial z}{\partial E}\rho_{AE}\sigma_A\sigma_E$$

In this paper, we assume that R, A and E is isolated from each other. $\rho_{RA}=\rho_{RE}=\rho_{AE}=0$. therefore:

$$\sigma_x = \sqrt{\left(\frac{\partial x}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial x}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial x}{\partial E}\right)^2 \sigma^2{}_E} = \sqrt{(\mathrm{cosEcosA})^2\sigma^2{}_R + (R\sin A\cos E)^2\sigma^2{}_A + (R\sin E\cos A)^2\sigma^2{}_E}$$

$$\sigma_y = \sqrt{\left(\frac{\partial y}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial y}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial y}{\partial E}\right)^2 \sigma^2{}_E} = \sqrt{(\mathrm{cosEsinA})^2\sigma^2{}_R + (R\cos A\cos E)^2\sigma^2{}_A + (R\sin E\sin A)^2\sigma^2{}_E}$$

$$\sigma_z = \sqrt{\left(\frac{\partial z}{\partial R}\right)^2 \sigma^2{}_R + \left(\frac{\partial z}{\partial A}\right)^2 \sigma^2{}_A + \left(\frac{\partial z}{\partial E}\right)^2 \sigma^2{}_E} = \sqrt{(\mathrm{sinE})^2\sigma^2{}_R + (R\cos E)^2\sigma^2{}_E}$$

The precision of distance measure σ_R could be described as following.

$$\sigma_R = c \bullet T_c\left[\frac{B_n}{2C/N_0}\left(1+\frac{2B_e}{C/N_0}\right)\right]^{1/2}$$

Where,

C is the velocity of light.

C/N_0 is the Ratio carrier wave-to-noise (SNR). C/N_0=45dbHz.

B_n is the equivalent Single Side Band Width, B_n=0.06KHz.

B_e is the Band Width of the Correlator, B_e=31KHz.

T_c= is Code width. T_c=0.25μs.

According these parameters described above, we could obtain $\sigma_R \approx 4$m.

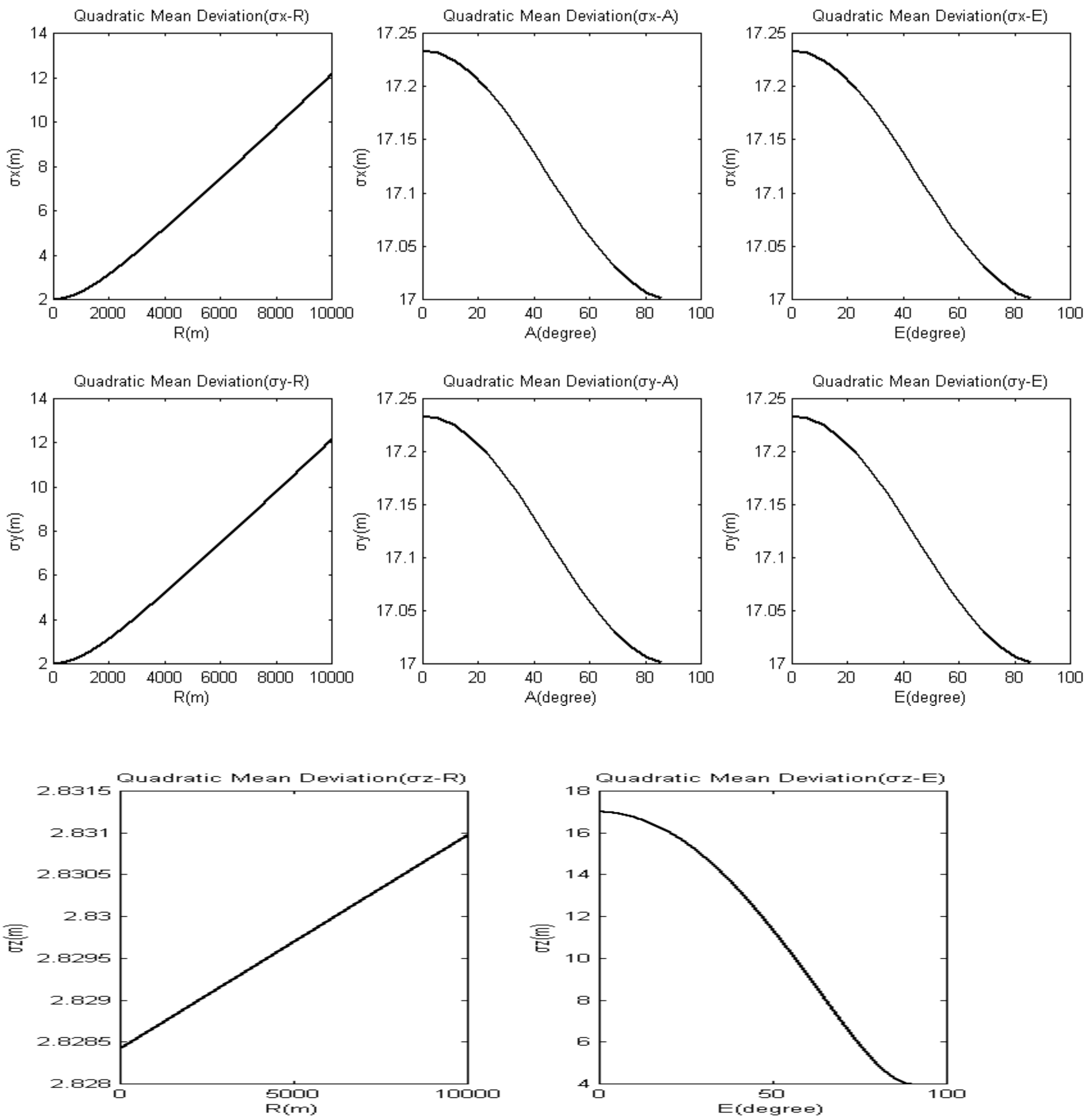
It is assumed that the beam width of the antenna is $\theta_{0.5}=1.9°$. The total azimuth error is 0.1°(1.7mrad); the total elevation error is 0.1°(1.7mrad) (we do not take the effects of multipath into account when the elevation angle is less than certain degree).So, we can get the approximate relationship of the coordinate variables, they are described below.

$$\sigma_x = \sqrt{16(\mathrm{cosEcosA})^2 + 0.0017^2((R\sin A\cos E)^2 + (R\sin E\cos A)^2)}$$

$$\sigma_y = \sqrt{16(\mathrm{cosEsinA})^2 + 0.0017^2((R\cos A\cos E)^2 + (R\sin E\sin A)^2)}$$

$$\sigma_z = \sqrt{16(\mathrm{sinE})^2 + 0.0017^2(R\cos E)^2}$$

The deviation curves have been drawn in the following. Thy describe the following relationship: σ_x-R, σ_x-A, σ_x-E, σ_y-R, σ_y-A, σ_y-E, σ_z-R, σ_z-E.



In this paper, it will not be detailedly analyzed about these curves.

Conclusion

As described as the quadratic mean deviation formula and the deviation curve, the positioning precision is related with distance, elevation and azimuth of the object. When the distance is longer than certain values. The deviation could be represented in approximate straight line. But the deviation related with the azimuth and elevation is bounded function.

All of the values in this paper are designed against a mission. If you need a telemetry system based the theory, all of the values must be changed according to some the conditions.

References

1. Applied Error Theory and Data Processing, Sha Dingguo, Beijing University of Technology.
2. Active and Passive Position Location Technology Using Single or Multi Station. Sun ZhongKang

Prospect of Telemetry Technology in China

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Abstract: It is inspiring to look back the progress of telemetry technology in China in 20th century, especially the achievements in the last decade. What telemetry technology should be emphasized in the new century? In authors' opinion, space data system, low elevation tracking technology, trajectory measurement, and multi-target integration measurement should be the emphasis of the telemetry technology development in the future.
Keyword: Telemetry, Technology, Development, Prospect

1 Review

It is inspiring to look back the progress of telemetry technology in China in 20th century, especially the achievements in the last decade.

In China the telemetry technology started at the late of 1950s. There are 4 stages: technology introducing stage, starting stage, improvement stage, and development stage.

Technique introducing stage was the period when the first space test site was established in 1950s. At that time equipment were introduced from other countries, which included mobile and fixed telemetry system..

Starting stage began at the middle of 1960s. Chinese telemetry engineers improved the design of introduced mechanic commutator by studying the theory and practicing. They enlarged the number of telemetry measured parameters from 26 to 52, and that was applied successfully in flying tests.

Improvement stage is the period from designing large capacity telemetry systems at the middle of the 1960s to applying S-band telemetry system at the middle of the 1960s. During this time, based on the requirement of Chinese space test, China has independently researched and manufactured many telemetry systems, which including large capacity telemetry system, medium or low speed auto-tracking telemetry system, mobile integration telemetry system, fixed station and other kinds of stations derived from them, and the waiting mode telemetry system which was specific for re-entry spacecraft.

Under Chinese reform and open policy, the development of telemetry technology has made breakthrough at the fourth stage named the development stage. The new requirements in this stage are mainly shown in the following two aspects.

1. High bit rate, multi data stream

The telemetry systems in the former three stages are single data stream system, which means one ground station equipment can only receive and demodulate at one frequency point at one time, but new task requirements the equipment has the ability to receive and demodulate data at two frequency points. In other word, the equipment has. two data stream. The data bit rate has increased to 7 times of the third stage equipments.

2. Standard S-band RF and recommended modulation system

The RF band and modulation system of the former three generations are not recommended by IRIG telemetry standard, so when we design the new telemetry system, we use S-band and PCM-FM modulation system, which conform to the international standards.

2. Prospect

In order to keep up with the international advanced technology and to meet the requirements of spacecraft, the following aspects need to be emphasized in the new century:

2.1 Space data system

To turn existing S-band network of tracking and telecommunication to a real international space data system, we shall upgrade them to be compatible with CCSDS. With the re-configurable technology, it is possible to change the functions and protocols of a system by changing the software and not changing the hardware configuration. Now this kind of technique is mature in world, for example the France IN-SNEC company provides CORTEX^{NT} system which is an integrated baseband equipment including telemetry, telecommand and ranging function, CCSDS service cards of US TSI company, and 4428 card of SBS company. The current S-band unified system (USB) can be reconstructed by replacing current IF receiver and video component by these integrated baseband equipment or by connecting the current system to a CCSDS parallel branch which uses switch.to change the function. The figure 1 demonstrates the reconstruction diagram .

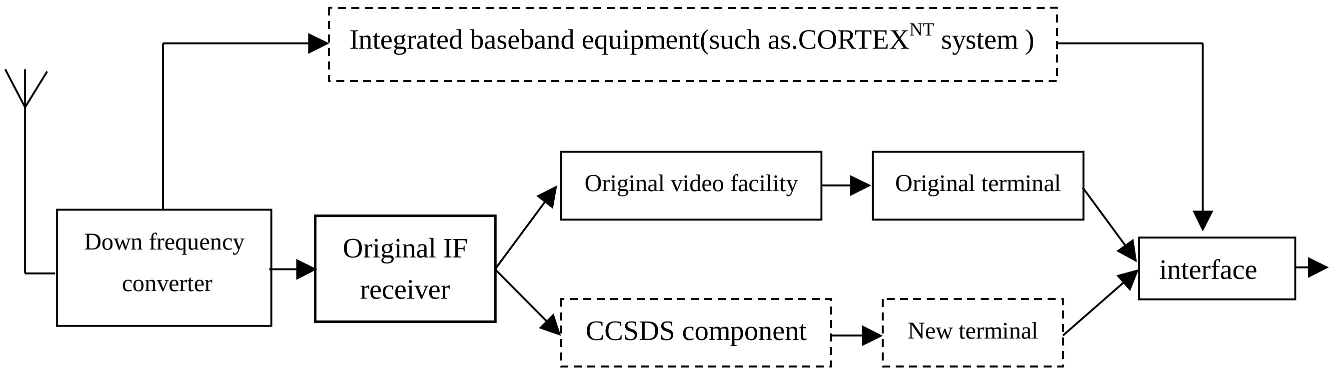

Figure-1 S-band USB Reconstruction Diagram

2.2 Low Elevation Tracking Technique

Because of the voyage of spacecraft becoming longer, the measuring span becoming larger, a new question of measuring equipment tracking——low elevation angle tracking technique is needed. Our former tracking measuring equipments have some good experiences to solve this kind of problem. However the solutions of these problems are individual cases that are fit for specific situation and specific application, and we have not concluded theory rule and can not give generic solution. So the authors hope that the TT&C equipment manufacturers do some fundamental research on low elevation angle tracking technique. In order to find out the reasons why it is difficult to track low elevation angle objects, such as the features of multi-path effect, we hope, through systemic investigation and experiments, find out the methods to overcome the problem of wave fading, phase shift, frequency shift and etc, so we can solve the problems of low elevation angle tracking radically. In order to develop the fundamental research of low elevation angle track technique, we must have some basic conditions, for example the multi-path signal simulator which makes it is possible to do some trials and analysis of multi-path affection quantitatively. This type of equipments have already existed, such as TSS-2000 signal simulator produced by Microdyne Company in USA, which can generate two signals with different frequency, different gain and different phase , and the frequency difference is up to 100 KHz while the difference of phase is up to 360 degree and of gain is up to 50 dB. Additionally it is reasonable using GPS positioning data as a real-time guide to solve the low elevation angle tracking problems.

2.3 Trajectory Measuring

Traditional trajectory measuring equipments include optical measuring equipment and radar. In recent years, more and more aircrafts use GPS/GLONASS and corresponding ground equipment to measure exterior trajectory. The reason why GPS/GLONASS is adopted in trajectory measuring for flight vehicle is high accuracy, full climate, and low cost comparing with conventional methods. At present, there are three typical schemes, which include airborne receiver scheme, airborne converter scheme and airborne difference scheme. They are applied to different occasions and own individual features. The airborne receiver scheme computes the time and position data on the flying object, while the airborne converter scheme only converts and retransmits RF signals, leaves the computation of time and position data to ground equipments. On the basis of the airborne converter scheme, the airborne difference scheme revises the position data using the real time onboard position data based on the ground basic reference station. All these three schemes use telemetry channel as their downlink channel. Telemetry, therefore, has its own unique place in trajectory measuring.

2.4 Multi-target Integration Measuring

The traditional multi-target measuring equipments are optic measuring equipment, radar, and multi-frequency telemetry. Recent years, with the development of code-division multiple-access (CDMA) technology, it is becoming an important means to perform multi-target telemetry and exterior trajectory measurement through traditional telemetry channel.

The fundamental principle of multi-target integration measurement is that the spectrum of telemetry signal is spread, spreading sequences are used to perform uni-direction ranging and distinguish different objects, so telemetry and exterior tracking can be performed through one physical channel or one equipment. According to current technology, up to 20 objects’ telemetry and exterior tracking can be implemented,and the position accuracy is up to 5-20m.

The key techniques of multi-target integration measurement are as follows:

1.High accuracy time synchronization among stations

Provided tracking accuracy $\sigma_{X,Y,Z}$<10m, the accuracy of time synchronization among stations σ_t should <12ns. Presently, using GPS can meet this requirement.

2.High accuracy frequency consistency among stations

Since mono-direction multi-station speed measuring system is used, high frequency consistency among stations is required. At present, locking local frequency of each measuring station to the same GPS satellite's frequency, after removing the frequency difference caused by Doppler affection among stations, the frequency accuracy is higher than 10^{11}.

3. Station distribution geometry

Since multi-station distance-difference position system is used, geometry factor influences position accuracy greatly, especially when the object measured is in low altitude, the altitude error will become divergent. So the baseline length between stations should be as long as possible, so as to reduce GDOP values, and to get higher accuracy position value.

4. Fast capture

The multi-target measuring is often used when space shuttle is approaching the purpose positions, the time available for measuring is rather short. Therefore, it is important to implement fast capture of receiver. Generally, the capture time should be less than 0.5s and this is a key technique for multi-target measuring also.

REFERENCES

1. Tan Wenzhi, "From TT&C to OBDH", Journal of Telemetry, Tracking, and Command, Vol. 21.No.2 2000.
2. Chen Yiyuan, "From Satellite Telemetry to On Board Data System", Journal of Telemetry, Tracking, and Command, Vol. 21.No.4 2000
3. Zhang Yongtai, "Multi-path Propagation and Low Elevation Angle Tracking", Journal of Telemetry, Tracking, and Command, Vol. 21.No.2 2000.
4. Instruction Manual Publication No.901-546-08 MODER TSS-2000 SIGNAL. SIMULATOR Microdyne Communication Technologies, Inc

A MULTI STANDARD COMMUNICATION TERMINAL FOR SPACE AND TERRESTRIAL APPLICATIONS : FLEXICOM 290

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Abstract

Today various communication sectors such as deep space, satellite and mobile are converging. This requires to develop a common platform for multi standard applications. The focus of this article is FlexiCom 290, a platform which is based on reconfigurable hardware and allows to select

- Modulation schemes
- Bit synchronization (open and closed) schemes
- Channel coding (hard and soft out) schemes

in an optimum manner for the application.

In the past, the development of such a complex system often required to proceed in three development phases with often three different hardware platforms :

- A demonstration hardware
- A simulator hardware
- The final system

Today these three development phases are encapsulated in a single hardware platform with a core design concept. The nature of the technology allows to MAP the algorithm in a single or multiple DSPs and in embedded DSP cores which are running in parallel in the Virtex-E and Virtex II FPGAs. The Tiger Sharc accelerator instructions for despreading, Viterbi and Turbo Code algorithms allow to test algorithms in a flexible manner. The current work focuses on various soft in soft out channel coding schemes as well as carrier and bit synchronization schemes. This configuration provides a very powerful communication processing system with high flexibility.

Introduction

The FPGA and DSP based hardware allows Navtel Systems to target three phases in a single hardware environment: simulation, IPcore testing and system integration in a single platform. The Plateform is made of two parts IFP4010 and FlexiCom 290. The IFP4010 handles the RF or video part and FlexiCom 290 handles the base band.

1) Platform overview

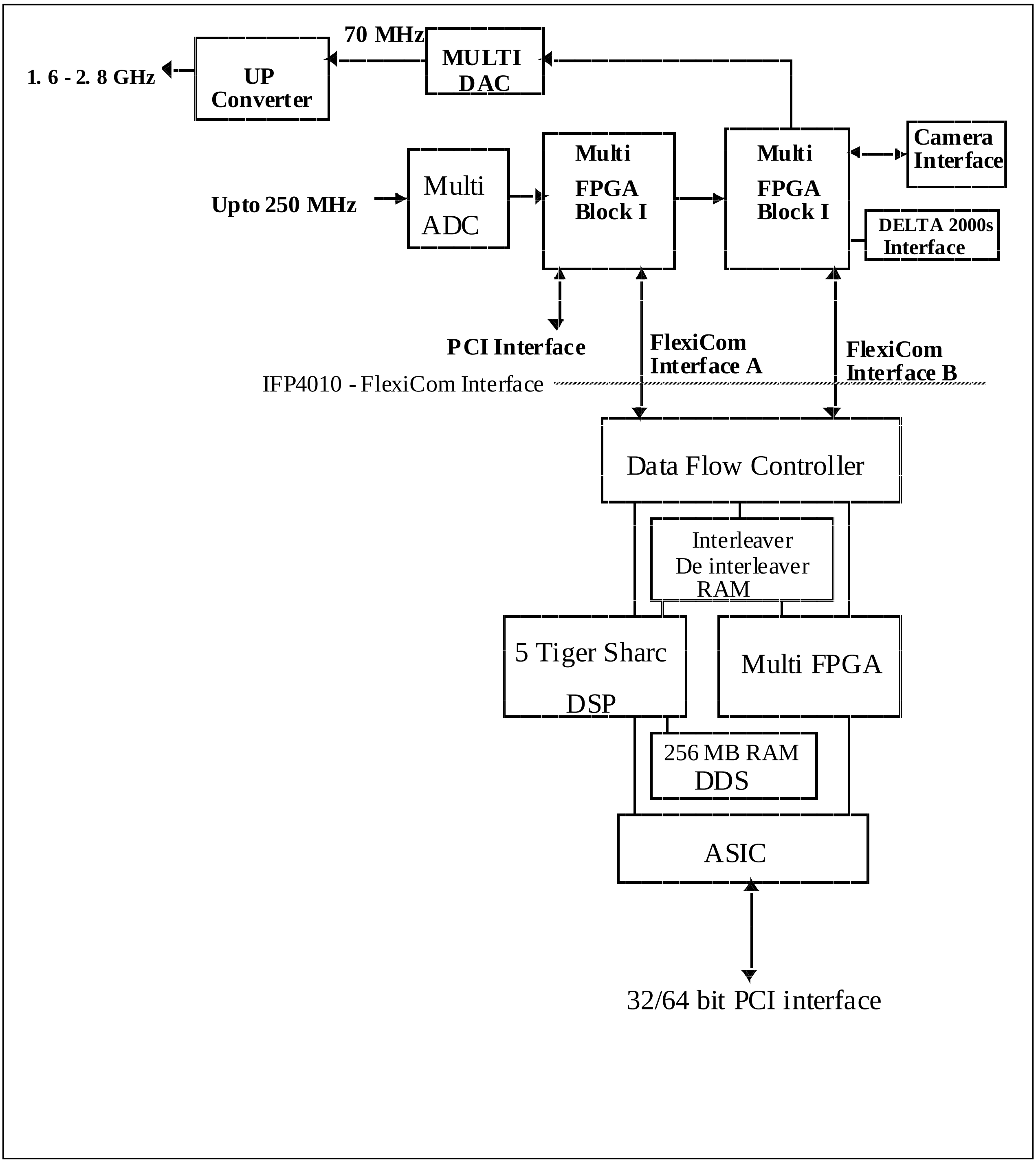
The system is designed to handle transmission and reception. The upper part of the below block consists of:

- ADC block
- DAC block
- Multi FPGA Blocks
- High Speed Camera interface
- Delta 2000S interface (This is another FPGA block which is used in IFP4010 or FlexiCom)

ADC block: two14-bit converters are used for mainly bandpass sampling.

DAC block: two DACs are used for the modulation channel and two DAC are used to display the constellation diagram or EYE diagram display purpose.

Multi FPGA blocks: They are made of Virtex E and Virtex II family FPGAs from Xilinx. These blocks perform spectrum forming filters, decimation/ interpolation, correlation, synchronisation algorithms and error correction. The down converter CIC (cascaded intergrator comb introduced by Hogenauer) filters will be implemented using the Residue Number System (RNS) arithmetic. The current FPGAs consist of large amount of memory blocks which are used to convert the numbers to modular form and vice versa. These large internal memory FPGAs facilitate the implementation of CORDIC modules. The IFP4010 has multiple FPGAs. Due to the complex arithmetic processing requirements, they need to be implemented using a pipeline design in order to achieve the speed.



The bottom part of the block diagram consists of FlexiCom. This is mainly made of four parts:

1. DSP blocks
2. FPGA blocks
3. General RAM
4. Interleaver RAM

FlexiCom accomadates a maximum of 5 DSP Tiger Sharc processors which are loosely or tightly coupled with the FPGA blocks. The DSP processors allow to test the algorithms in “C”, before implementing them in FPGA using VHDL.

2) Simulator mode functionalities

System simulator: It is designed to test modulation and demodulation, synchronization (Open and Closed) as well as the channel Forward error corrector. The system has two loop back levels for the modulation and demodulation test. One is in digital loop back mode and the other is in Intermediate Frequency loop back. This loopback allows to test independently the base band and IF band signal processing modules.

In the channel codec testing (Viterbi, RS or turbo codes), two types of tests are performed: In the Viterbi and RS mode, the data is generated either in the PC or in FlexiCom. The RS interleaver/de interleavers are implemented externally to the FPGA for flexibility. There are two decoder modes for RS: block by block decoding or continous mode decoding.

The TURBO decoder mode uses all the 5 channels for the decoder. The data for the decoder either comes from the PC or from the IFP4010 demodulator configuration. FlexiCom consists of 5 channels, each with DSPs and FPGA and memory. These channels are fed as they become free. This is the way that the system performance is enhanced. The system allows to test various error correction schemes and **L**ow **D**ensity **P**arity **C**heck Codex in a single environment for performance analysis. The future work focuses on interactive decoding based on RNS. The decoder operations can be summarized as follows: decoder types MAP, LOG-MAP and LPDC. The highest complexity is found in the Log- MAP decoder but it requires no division. The other two decoders require division.

3) OFDM implementation

The OFDM is another modulation scheme finding more and more applications in the aircraft testing due to multipath effects in the telemetry channel and spectral efficiency. The system requires a linear amplifier due to multi carriers (the hardware is designed to study peak to average power reduction using coding).

The system design parameters fall into two main categories: number of carrier selection and type of channel coding. The number of carriers required is function of the bit rate, OFDM symbol rate and the delay spread of the system. The type of error correction depends on the application (Viterbi-RS or Turbo codes). The channels coding with its interleavers requires a flexible memory structure but this in turn depends on the selected coding with its block size.
In the receiver, three Tiger Sharc™ DSPs with an associated FPGA block are able to handle an 8K carrier system. The required functions are synchronization, demodulation ,channel estimation and equalization. The reconfigurable nature of the hardware enables it to adapt according to channel conditions, eg. if the channel path of the receiver is good, then the system is able to use a higher modulation scheme. This requires a transreceiver system. FlexiCom290 consists of three receiver channels and one transmission channel in order to handle adaptive modulation schemes.

4) Bit Synchronization

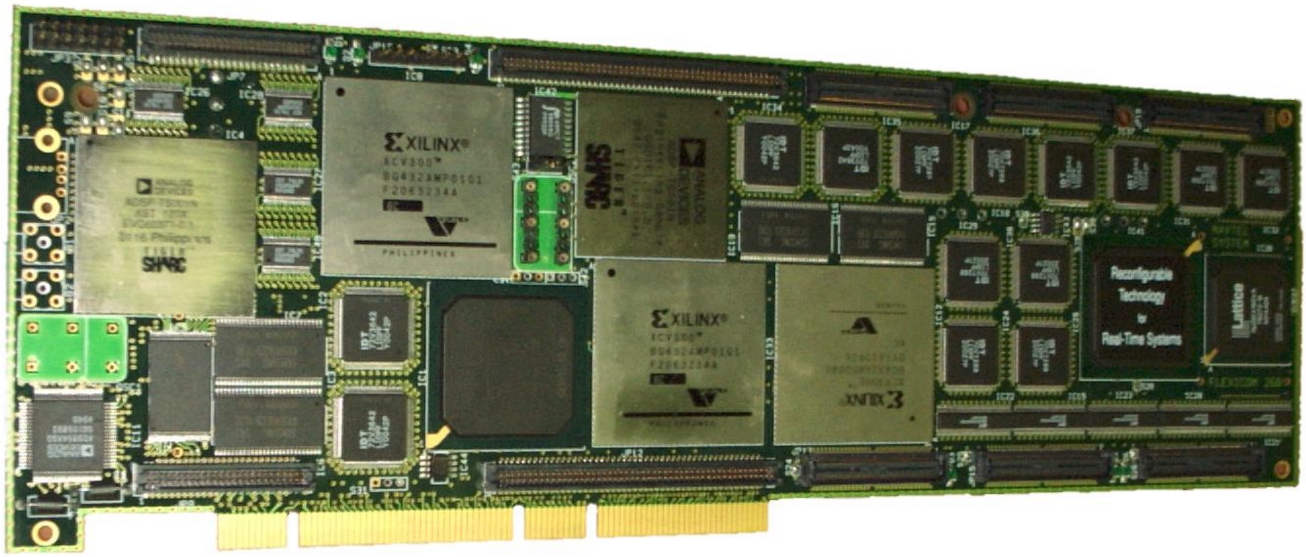
The hardware has been designed to handle closed and open loop synchronization methods. Both structures use on-board MNCO (Modulation Numerical Control Oscillator) . In the case of open loop, the MAP and Gardner's interpolation structures (no common clock between demodulator and bit synchronizer) are both possible. The MAP method requires a large number of match filters. However a reduced number of match filters can be used to make a rough estimation. This estimation is used to shift the MNCO phase and then close the loop. In the case of an interpolation method, one requires two samples from the interpolator block : one is used to strobe the data and the 2nd one is used as the mid-sample. Both samples are used to calculate the error. The calculated error is filtered and used to control the resampler NCO. The error calculation is based on the previous symbol, the current symbol and the mid-symbol. The use of the two interpolator outputs simplify the error calculation. The lead/lag loop filter allows to correct the frequency error. The bit synchronizer block can receive quality information from the error corrector block in order to enhance the performance in closed and open loop modes. Often, the error corrector performance is limited by the bit synchronizer. Under the the bit synchronizer mode, it is possible to enhance the performance of the bit synchronizer using the status information of the error correction block.

5) Conclusion

The reconfigurable hardware based system has allowed the development of all the IP cores required for a Meteosat Second Generation based on a CCSDS - AOS configuration in a flexible manner.

6) Reference

1. E.B. Hogenauer: " An Economical Class of Digital filters for Decimation and Interpolation", IEEE transaction on Acoustics, Speech and Signal processing Vol.34 1986


XILINX
XCV300
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Spacelink^{NGT}
Next Generation Technology TTC & Telemetry/Telecommand Systems

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1 Abstract

This paper describes the design of a Telemetry/ Telecommand system that can be used for many different applications. The system uses System on a Programmable Chip (SOPC) technology and be used to implement true multi-purpose, flexible and high performance TTC TM./TC systems.

2 Introduction

Satellite Services B.V. (SSBV) from The Netherlands, has been focused on TM/TC designs in systems in the widest range possible ever since the establishment of the company in 1985. With TM/TC systems in the field supporting over 15 different satellites; Satellite Services B.V. is continuously developing and improving it's range of products in this area.

In 1999, Satellite Services B.V. started with the development of it's Next Generation Technology TTC & TM/TC systems; making use of the latest technology and aiming to achieve true scalable and inter-operable systems covering all the traditional application areas such as: R&D, payload & Spacecraft AIT, Operations, VSAT's and dedicated User Workstations/Terminals.

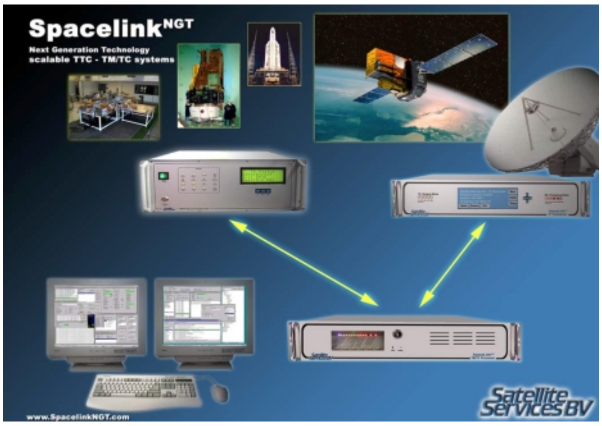
Along with the integration and modular implementation of interfaces at hardware and software (protocol) level and the development of a single-board integrated Intermediate Frequency Transceiver, the full TM/TC baseband processing was targeted for SOPC / single-board implementation.

Together with this, another target of achieving full integration of TM/TC downlink and uplink processing/generation as well as concurrent TM simulation and (echo) TC decoding was given.

A major part of this work was performed under ESA's telecommunications initiative: ARTES (Advanced Research in Telecommunications Systems) with support from the Netherlands Agency for Aerospace Programmes (NIVR).

The result of this and other work is the new SSBV family of TTC and TM/TC products that are now available under the trademark Spacelink^{NGT}.

2 Target Applications



Telemetry and Telecommand systems are required for many phases of a spacecraft project, starting with the first pieces of breadboard hardware all the way through spacecraft development and throughout spacecraft operations.

At its simplest level, TM/TC systems provide a data acquisition and transmission system and the ability to act as a source and sink of serial data. In simulation and/or closed-loop verification systems, also the reversed dataflow is to be supported. In another scenario, special functions to support error injection and BER/FER measurements are required.

The Spacelink[NGT] TM/TC systems must therefore fulfil the desires of users in a variety of scenarios with significantly different requirements, for example:

Spacecraft AIT:

- Extremely flexible TM/TC systems
- Complete control/status over TM and TC (at all layers) including deliberate error insertion
- Low level diagnostics and monitoring to debug and diagnose
- Adaptation to specific modes during pre-flight tests/operations
- Allow for quick changes / expansions
- Support variety of data processing and distribution functions and protocols
- Local and remote mode operation

Spacecraft Operations:

- Extremely High Reliability / Zero Downtime
- Controlled environment/operation
- Tight integration with ground infrastructure
- Normally more strict operational configurations linked to a specific spacecraft
- Focus on remote operation with local mode support
- Support for ranging and link encryption/compression/authentication
- SLE front-end or gateway functionality
- Standardised remote links & protocols to NOC/OCC

VSAT/SatCom Terminals:

- Uni or Bi-Directional Data Communication
- Compact, cost effective
- Integration with receiving equipment
- Embedded Data Processing and Distribution
- Bitrates from kbps to hundreds of Mbps

To fulfil these target application areas three key interfacing points have been defined within the SpaceLinkNGT product range, these include:

- Direct baseband interfaces (e.g. bi-level, SDBL, RS422, LVDS, ECL Data/Clock, I/Q/Clock, Soft Decision I/Q/Clock etc)

- Video interfaces (e.g. sine / square wave modulated signals on a subcarrier, SPL etc)

- 70MHz Intermediate Frequency (e.g. direct carrier modulation / subcarrier modulation, PRN & Tone ranging, Doppler compensation / simulation etc.)

Depending on the application area, a single selection or full support for all the above interfaces can be supported within a single system and as such support a mixture and/or all of the different application areas.

Satellite Services B.V. has designed its systems to support all of the above I/O in a flexible and scalable manner. As a result of this two standard units have been developed which can operate independently:

1. The External Interface Unit (EIU)

2. The Intermediate Frequency Transceiver (IFT)

Both units offer a wide range of I/O and sophisticated monitoring points complemented by local and remote operation. Interfaces to the baseband TM/TC processor (single-board hardware) are supported via direct and isolated interfaces at RS-422, LVDS, ECL and fibre-optic level.

3 The External Interface Unit

To allow usage (mainly) within the AIT domain an External Interface Unit (EIU) was designed. The EIU is an stand-alone modular unit which can host a variety of electrical interfaces that can be used to connect to a spacecraft or CDMU / payload during the development, assembly, integration and test phases up to launch.

The EIU can be placed close to the spacecraft and connected to the remotely located TM/TC processor (or other EGSE) via an optical link or isolated serial link. The EIU also provides galvanic isolation at interface and unit level, thus supporting different grounding schemes without the need for additional isolation.

Internally the EIU is constructed using a mixed-signal backplane that can host digital and analogue interfaces. All interfaces are of the same form-factor (extended Eurocard) and are programmed, controlled and monitored using a standard Serial Control Bus (SCB). Each interface card uses the same backplane connector so that plug-and-play operation and scalable I/O become a reality.

A single card controller functions as the overall control/status master and also provides a remote LAN interface. A backlit LCD screen is present on the front-panel that offers user selected status screens and monitoring point selection.

Another unique feature of the EIU are its integrated monitoring points. A standard monitoring connector (max. 4 signals) is present on the back of the unit to which test and measurement equipment can be connected. Using the local menu on the LCD, a user can then select which of the external and internal signals (analogue and digital) will be routed to the standard monitoring points.

Typical electrical interfaces include:

- Digital I/O (balanced/unbalanced)
- Analogue Video In/ Video Out (single and double ended)
- V11/RS-422/LVDS In/Out
- Digital B/Q-PSK & SPL Modulators
- Digital B/Q-PSK & SPL Demodulators
- Custom interfaces

Due to the complete flexible signal via the analogue/digital TM/TC router connected through the backplane, different signal selection/distribution schemes can be realised, including hot/cold redundancy and multiple output distributions.

In cases of special signal relationships/timing, internal firmware inside the EIU controller, TM/TC router and interface boards can be modified/re-programmed to support this. The standard firmware supports a variety of AIT type set-up's such as hot/cold I/O, EGSE by-pass type port selection , TC enable/active signalling, automatic source selection (active signal & priority based) and NDIU interfacing. In addition standard interfaces for the connection of analogue and/or digital data recorders are available.

Internal I/O loopback/routing to support Built-In-Self-Test (BIST) and TM simulation/echo TC decoding is also supported.

All EIU settings, including signal routing and the programming of the digital modulators & demodulators can be performed on-line under remote software control from the TM/TC baseband controller.

For each standard interface card, FMECA reports are available to demonstrate suitability for direct flight hardware connection.

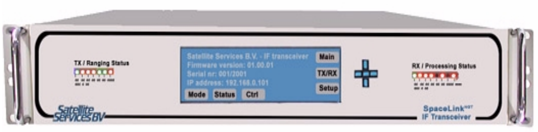
A standard EIU (4U, 19'') provides space for a maximum of 14 interface cards/modems all inserted in the back of the unit. The interface connectors such as BNC, triax and D-types are located directly on the interface card.

For small I/O projects, also mini-EIU implementations, or units with integrated TM/TC baseband processing can be provided.

4 The IF Transceiver Unit

To allow use within the operations, test and point-point telecommunication domains, an integrated IF transceiver has been designed that supports all space<>ground link elements required for an operational ground segment or VSAT/SATCOM terminal.

The IF transceiver supports concurrent operation of an up- and downlink at the same or different IF frequencies (70 MHz or higher). Both up- and downlink modulation/demodulation chains can operate at the same minimum/maximum bit rates. (dual use of equipment to represent both sides of the communication link).



To enable efficient concurrent operation, the standard IF frequency supported is 70 MHz RX TX but the design allows for other IF frequencies (up to 230 MHz) if required.

Each TX / RX chain supports programmable bitrates and digital filters within the range of 1 bps up to 45 Mbps (Q-PSK).

Except for the initial up/down conversion, all filtering, modulation and demodulation functions are performed digitally, thus ensuring efficient and stable operation with a wide degree of (on-line) user programmability.

The IF transceiver supports direct carrier modulation/demodulation as well as subcarrier modulation/demodulation on a modulated carrier in accordance with the ESA modulation and channel coding standards.

The modulation chain is based on an SSBV propriatry, full digital implementation of a B/Q-PSK modulator. In Q-PSK mode separate or combined I & Q signal transmission is supported. For future CDMA applications, gold code modulation can also be supported.

In addition to data modulation/demodulation, the unit also provides ESA standard PRN or tone ranging and Doppler compensation as well as Doppler simulation (applied to all frequencies). All demodulators support hard- and soft-decision outputs. Electrical level interfaces are available as ECL, LVDS, RS-422 or fibre-optic link.

Set-up, Control and Status monitoring is performed via a front-panel LCD/menu and via an Ethernet 10BaseT LAN using TCP/IP sockets, with software available under Microsoft Windows® NT/2000® for direct integration into third party systems.

The internal electronics are implemented using the latest technology and this has resulted in a complete single-board implementation of the transceiver. The overall unit size is therefore limited to 2U, 19''.

All electrical connections as well as digital and analogue (converted) monitoring points are available at the back of the unit. Signal insertion and parallel routing at different levels is also supported to allow easy migration with other RF and T&M equipment.

For future enhancements, the IF transceiver is equipped with two expansion slots and an embedded PC104 based single-board PC controller.

The expansion slots can be used to insert EIU compatible interface cards and an optional fibre-optic modem for connection to the baseband processing equipment. Due to the possibility for software based I/O, low bitrate softradio applications and direct remote frame routing to/from IF level can be implemented.

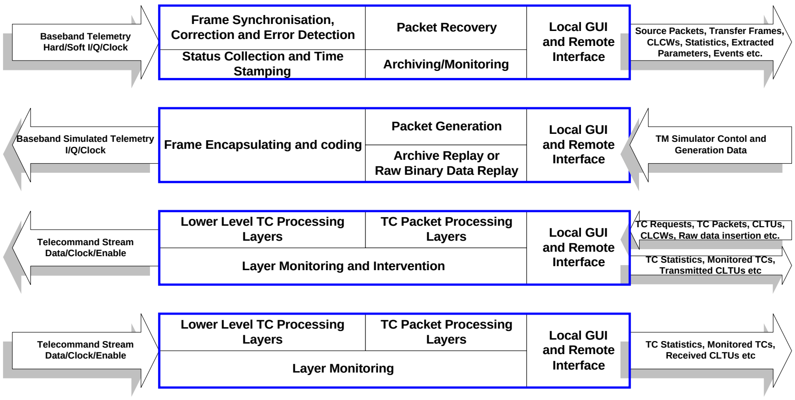
5 The TM/TC Baseband Processing hardware and low level software

The TM/TC baseband processing hardware and low level software uses the latest advances in integrated programmable logic which allows true “System-On-A-Programmable-Chip” (SOPC) solutions.

The core of this system is a in field re-configurable single PCI board. The architecture of this board has been designed to use a modular TM/TC processing chain which can be configured to handle many types of TM/TC standards, together with sufficient facilities for future developments.

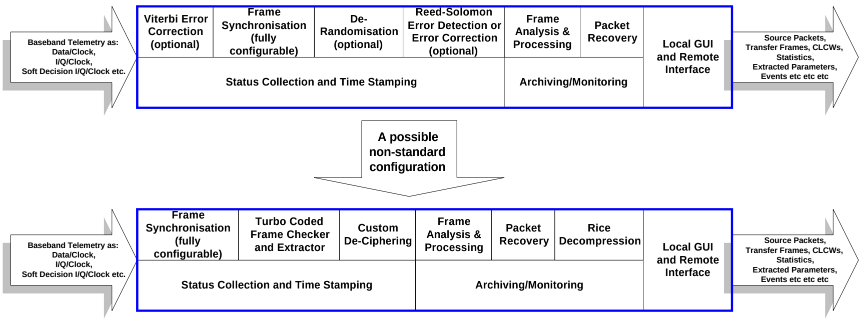
A major feature of the design was to incorporate four concurrent functions within the same board: TM Acquisition, TM Simulation, TC Generation, TC Monitoring and decoding.

An example TM/TC chain configuration is shown below:



A major function of the SOPC architecture is that it allows a single hardware module to be upgraded and modified in the field. Furthermore, the concept of “licensable hardware” allows a user to select a configuration of the hardware and then purchase additional licenses as needed.

For example, a classic ESA/CCSDS TM processing chain together with a possible future spacecraft configuration are shown below:



The same TM acquisition chain can be configured for:

- RS IL depth 1 to 8
- With or without Reed-Solomon support
- With or without Viterbi decoding/correction
- Non-Standard Frame Lengths
- NRZ-M decoding (enable/disable)
- De-Randomization (enable/disable)
- RS error correction
- Reports of corrections (where and was/should be)
- RS error detection without correction
- Reports of erroneous bytes (where and was/should be)

- Optional customer specific De-Ciphering
- Raw Data Acquisition/Dump and Replay
- Etc etc etc.

Low-level software provides access to frame and packet layers plus all statistics, which can be customised to meet customer specific needs

From an Interfacing point of view, the system supports:

- Hard or soft decision data inputs
- Runtime configurable frame synchronisation parameters
- Sync marker
- Don’t Care Mask
- Number of bits to match
- Frame Length
- Configurable Fly wheel Sync
- Coding options include: NRZ-M, Randomization, Convolutional Coding, Reed-Solomon (Turbo coding optional)

For Telecommand processing the system is fully compliant to the CCSDS/ESA Packet TC Standard and includes full COP1 support, CMM modes and PLOP and it is possible to monitor and inject data at all layers of the TC stack including:

- Segments
- Packets
- Frames
- CLTUs
- Raw Stream Access

Performance:
Current systems 1bps to >120 Mbits per second (sustained continuous throughput – not just a burst!) PCM and Non ESA/CCSDS standard formats and coding can also be accommodated.

6 Software Elements

To allow usage of the system within each target application a set of software tools have been development which run within one overall control and monitoring application called the CMS. The CMS is Windows NT™ based that provides the overall System Control, Status, Data Preparation and Monitoring functions and remote (LAN) interfacing functions.

The CMS provides a Graphical User Interface to the local operator from which the complete system can be controlled and monitored. The CMS is implemented in such a way that this software can run on the local Platform Controller as well as from another PC/NT system connected to the TM/TC platform via a LAN.

In this scenario, the system operator does not have to be physically located next to the TM/TC platform, which is particularly useful in cleanroom-checkout situations, Remote Lab Operation and within Ground stations.

From a data processing and routing point of view, the CMS offers integrated TM/TC packet editors, TM/TC packet generators, on-line TM/TC packet viewers (incl. user filters), a CLTU viewer, a transfer frame viewer and the possibility of sending TC packets, Segments and raw CLTUs.

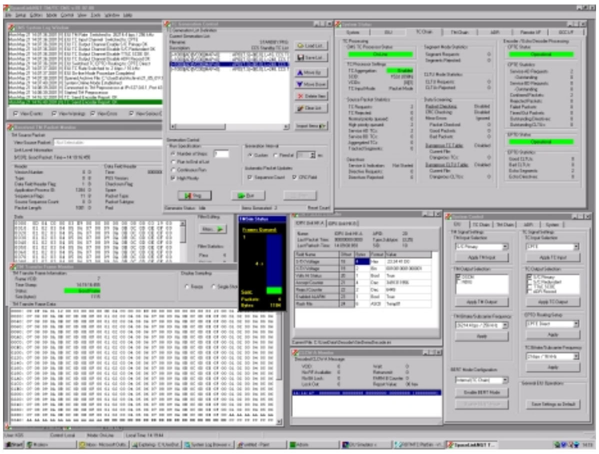
If the echo telecommand decoder function is active, the decoded CLTUs and TC packets can also be monitored in parallel. Within the TC processing chain, a standby TC generation list and dangerous TC filters are supported.

From within the GUI, independent TM and TC status windows are present which provide information on the current configuration and operational status of the TM/TC chains. All main status and data editor/display windows feature on-line and off-line printing to a printer (text & bitmap mode) or to local file(s) in ASCII format.

The CMS automatically maintains an overall system log file and window in which all events are displayed in colour coded ASCII. The log is automatically segmented for size/time or number of lines and placed in an automatic date tagged subdirectory on the local harddisk (or network drive).

The CMS also features an integrated binary archiving module that can be used to store all TM/TC data as well as internal system events for later analysis, replay and re-use in preparation editors. For this purpose a separate tool is provided, the ‘Archive Browser’, which allows for the searching, selection, printing and export of archive data.

For external (LAN/WAN) connectivity, the CMS also features integrated remote system support for a variety of TCP/IP based protocols. Using an optional CMS-API it is also possible to integrate user software and interfaces within the system.



7 Conclusion

The first phase of the SpaceLink^{NGT} developments has proved that it is possible to use the latest SOPC technology to produce a system that is both flexible and performant. It has also been shown that the target application areas although varied can be accommodated by the system.

This makes it possible to re-use the same system during a number of different project phases so thereby achieving significant cost savings.

Frequency allocation for Radio Telemetry in the European Union
- Requirements on non licensed applications -

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Abstract

The professional telemetry is used in remote control, electricity networks, industrial process control and similar high speed communication applications. A wide range of spectrum use for such telemetry applications, is exempt from individual licensing, typically because the power and propagation characteristics of these services is so localised that they do not materially interfere with other spectrum users. With advances in radio technology, there is growing commercial interest in developing products which utilise such licence-exempt spectrum. However, regulatory requirements for placing this kind of equipment on the market and for their use must be fulfilled.

Introduction

The pattern of radio frequency use is continuously evolving taking into account the changes in radio technology. Due to the fact that the frequency allocation management is under national competence, manufacturers of Short Range Device (SRD) equipment should respect the national requirements on radio parameters before placing the equipment on the market. The ERC Recommendation 70-03 sets out the general position on common spectrum allocations for Short Range Devices in Europe, giving an overview on:

- Technical requirements:
  - ETSI-Specifications

- Spectrum requirments:
  - Frequency bands
  - Radiated power or field strength
  - Transmitter antenna source
  - Channel spacing
  - Duty cycle categories

- Administrative requirements
  - Conformity assessment requirements
  - Licensing requirements

- National deviations and restrictions.

Requirements on Telemetry and Telecommand Equipment

The spectrum management requirements on the different categories of SRDs are presented in thirteen annexes of this recommendation. Annex 1 is dealing with requirements on telemetry and telecommand applications. On the basis of *Fig. 1* these technical and administrative requirements should be visualised for the 433-MHz band:

	Frequency Band	Power (Table 2)	Antenna (Table 3)	Channel spacing (Table 4)	Licensing requirement (Table 5)	Approvals (Table 6)	Duty cycle (Table 7)
6	433.050 - 434.790 MHz [1,3]	8 [2]	1 or 2	13	2	1, 2 or 4	3

Fig 1: Technical and administrative requirements

Special tables might be used for interpretation of the codes. Those relevant for the example in Fig. 1 are:

1. column: Relevant for column 7 (if applicable)
2. column: ISM-band; audio and voice should be avoided
3. column: Radiated power: 10 mW erp
4. column: Antenna: integral or external
5. column: Channel spacing: no channel spacing
6. column: Licensing requirement: not required
7. column: Approvals: ERC/DEC/(97)10, CEPT/ERC/REC 01- 06 or R&TTE (in the R&TTE countries)
8. column: < 10%

On account of the expanded use of the 433 MHz band for all kind of applications, even for audio equipment, a duty cycle of < 10% has been introduced. Caused by manufacturers of special SRD applications (radio remote controllers for the winches in the forestry industry, crane controls) there is an ongoing discussion to divide this band in sub-bands with different duty cycles:

- up to 100% within the band 434.20-434.79 MHz
- up to 100% within the band 433.05-434.79 MHz with 1 mW erp without channelisation or with 10 mW erp channelised and base band filtered.

Beside 433 MHz band the range of 868-870 MHz has been established for operation of equipment for telemetry and telecommand purposes. Due to the fact that there are permanent changes in the radio environment caused by new technologies and applications, spectrum allocations must be adapted to these new requirements. At the moment most applications are conventionally narrow band applications which require a high duty cycle. General trend is the further development of the existing applications with particular focus on wider bands, increased power levels and duty cycles, use of techniques e.g. FHSS, DSSS, dynamic channel allocation and frequency agility with 'listen before talk'. The currently available bands within 868-870 MHz are, however, not wide enough for FHSS. Discussions with the aim to allow 25 mW with 100 kHz channels in an FHSS environment within the band 863-870 MHz are going on.

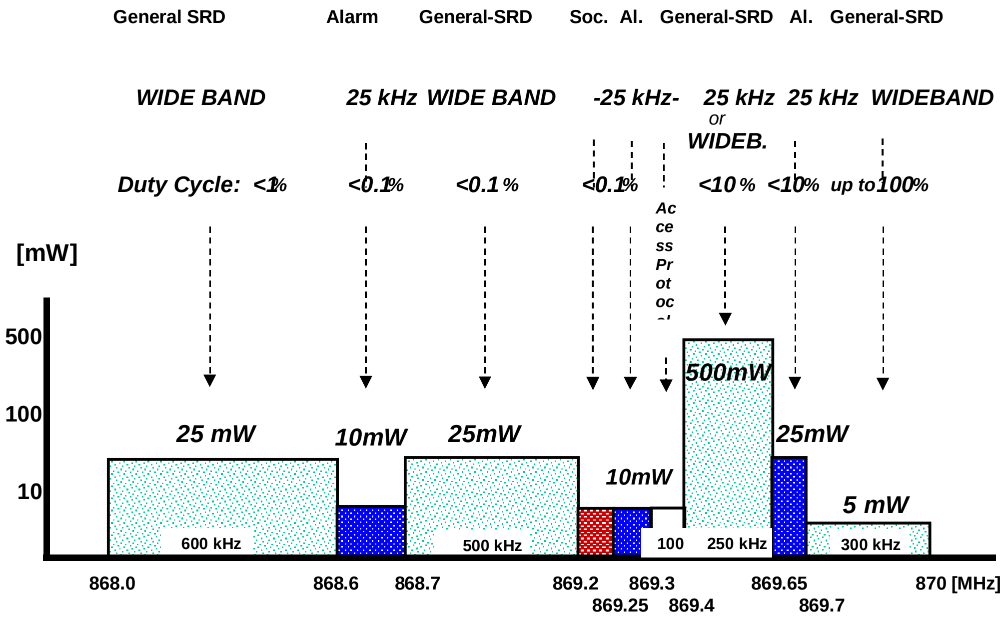

Fig 2: Subdivision of the 868-870 MHz-Band

Administrative Requirements

According to the R&TTE-Directive radio equipment have to meet the following essential requirements:

- Protection of the health and the safety of the user including the LVD requirements with no voltage limits applying
- Protection requirements with respect to electromagnetic compatibility
- The effective use of the allocated spectrum and orbital resources

Harmonised standards for the demonstration of all these requirements have been developed. So manufacturers for telecommand and telecontrol equipment are able to show the conformity of their equipment even to annex III of the R&TTE-Directive.
Concerning the used frequency two equipment classes have been established: Equipment which may be put into service throughout the whole Community (class 1) and equipment which may only be put into service in certain geographical areas (class 2). The latter will be marked with an alert symbol in addition to the CE mark. Most SRD applications are class 2. The only frequency band used for telecommand and telecontrol equipment which is defined class 1 is the 433.050 - 434.790 MHz-band with a duty cycle of < 10%. For all other equipment frequency notifications in each member state are required.

Conclusion

The transnational nature of many radio signals, allied to the global nature of many radio-using services, makes international co-operation in radio frequency planning essential to avoid harmful interference. The ongoing harmonisation process for Short Range Devices is demonstrated on ERC-Recommendation 70-03. Ongoing frequency harmonisation and the implementation of the R&TTE-Directive give industry the benefits of a shorter time-to-market without leading to customers frustration.

References

[1] ERC Recommendation 70-03 relating to the use of Short Range Devices (SRD) including Appendixes and Annexes at August 2001

[2] Directive 99/5/EC of the European Parliament and the Council of 9 March 1999. Brussels: Official Journal of the European Communities L 91, 7 April 1999.

Telemetry Reception and Commanding with a Low-Cost Ground Station for the Small Satellite BIRD

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Abstract

An increasing demand for low-cost ground stations, which can receive images from operational environmental satellites as well as from dedicated small satellites such as BIRD (Bi-spectral Infra-Red Detection) can be observed in the current decade. In the latter case, the motivation of using such low-cost ground stations can be to reduce the overall projects cost or to test new technologies. The objectives of the Experimental Ground Station (EGS), which was developed in the frame of the small satellite project BIRD are:

- Investigation and demonstration of direct user reception of regional data from earth observing satellites with a "low-cost" ground station
- Analysis of autonomous activity capabilities, including high level image processing and alarm generation, such as new fire detection algorithms
- Experimental tests for mission operations (commanding)

The basic idea is to give the user only regional limited data, for which a ground station with a small size antenna can be sufficient. Thus the data volume to be received can be reduced.

Many local authorities, such as agriculture or fire combat departments for example, needs only regional limited data. The basic idea of the EGS is therefore, to analyze the capabilities and limits of a low-cost ground station, which outputs only the data, which is needed by the local end-user. The antenna size of such a Station can be small, which is one of the important cost drivers.

The low-cost aspect of the system leads to a design, which incorporates the extensive use of existing commercial-of-the-shelf (COTS) hard- and software. Standard PC's are used for antenna control, data reception and processing as well as for commanding. In order to have a compact size and an easy transportable system, part of the baseband hardware is built into the PC.

The software for the data reception is not only storing the data on a local disk but also processes and displays the online telemetry. Payload data can be processed with separate tools, which uses algorithms developed by DLR. The software for the uplink of telecommands allows also to send software files to the satellite, which can be used to update the on-board software or to support the classification algorithm.

The current status and first results of the work will be presented in the presentation.

1. Introduction

The development of a low-cost ground station within the frame of the BIRD project is a contribution to various efforts to decrease the total cost of small satellite projects and shortened access time to satellite data. The rapid development of new technologies in the area of information and communication suggest to make extensive use of "commercial of-the-shelf" (COTS) products for satellite ground station applications. Depending on the actual application, this approach may be more or less succesfull in real world. For the purposes of the Experimental Ground Station, a concept, containing the right mix of COTS and self made components has been found to be promising.

2. Objectives

The objectives of the experimental station can be summarized as follows:

- Investigate and demonstrate direct user reception of regional data from earth observing satellites with a "low-cost" ground station (**Figure 1**)
- Analysis of autonomous activity capabilities
- Investigation on possibilities of experimental mission operations together with the German Space Operations Center (GSOC)

From the overall system point of view, the ground segment of a satellite project is as important as the space segment. When calculating the total cost, one has to consider the requirements of the ground segment utilization concept carefully. Cost reduction may be achieved, if data reception and commanding can be done by small, low-cost ground stations, if reliable operation can be ensured by means of robust technology and appropriate personal use. The motivation behind the objectives was to find out the capabilities and limits of such a low-cost station in conjunction with the small satellite BIRD. Thus the results might contribute to improve today's technologies.

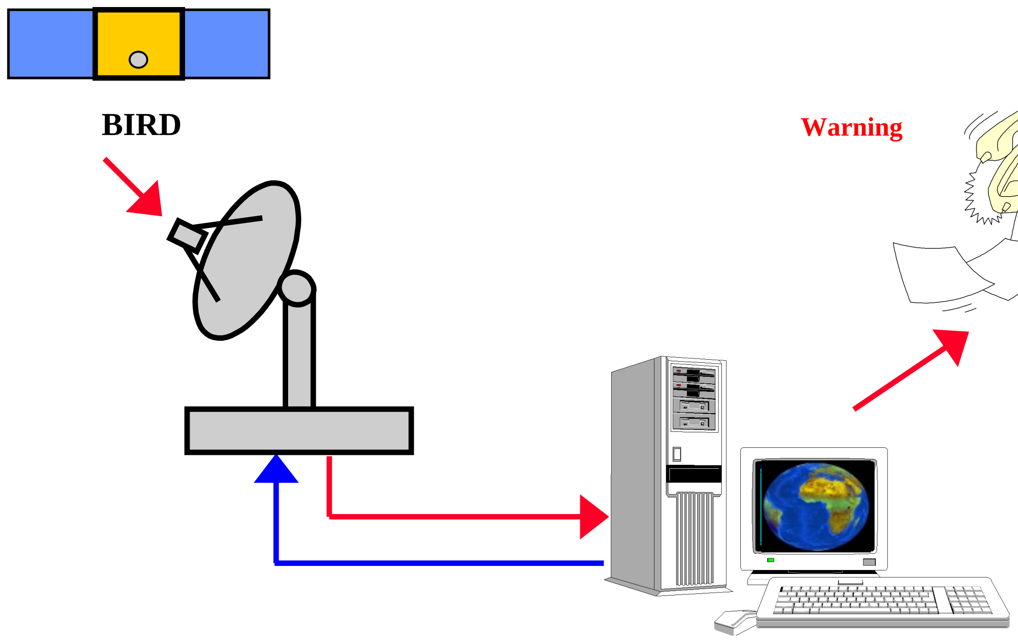

Figure 1: Direct user reception of regional data from earth observing satellites

3. System Characteristics

The main constraint of the system, which has been derived from the first objective, is a high minimum elevation angle (e.g. 30°) for the downlink and the use of COTS products to keep the cost low. **Figure 2** shows the standard coverage area of a 5° minimum elevation and the coverage of 30° minimum elevation for the EGS.

The basic concept of the Experimental Ground Station is to use different modules for different tasks, which can be developed or acquired depending on the actual requirement. The list of top level modules can be summarized as follows:

Hardware:
- Antenna & pedestal
- RF system containing feed, LNA, receiver, transmitter, bit- and frame synchronizer
- Command signal encoder

Software:
- Antenna tracking
- Telemetry reception
- Telemetry processing
- Command generation

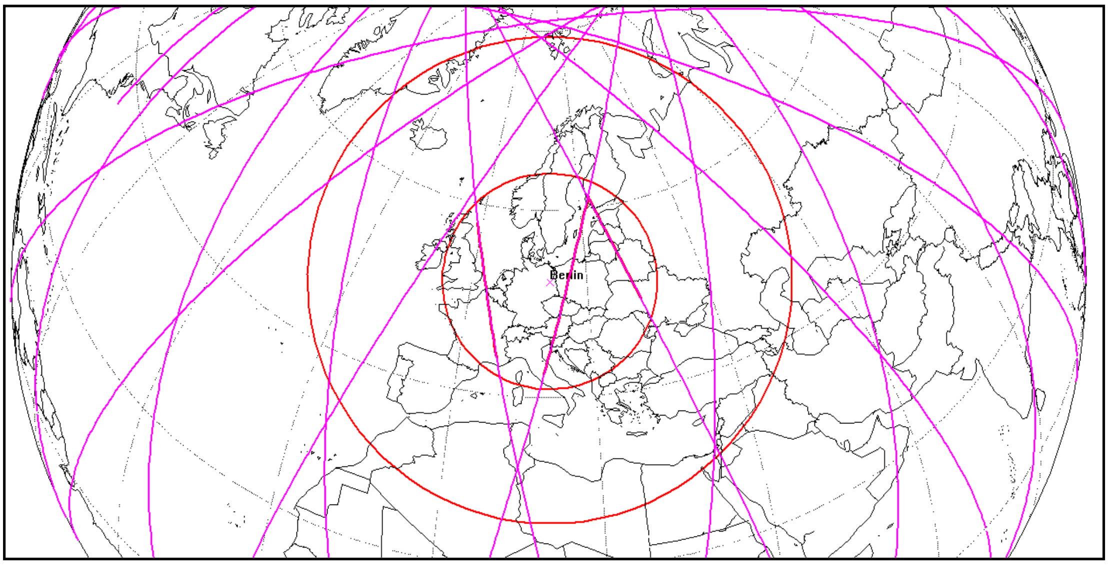

Figure 2: Standard coverage area of a 5° minimum elevation and the coverage of 30° minimum elevation of the EGS

Some parts of the hardware components can directly be used from COTS products. Especially the antenna pedestal, which drives the 2.4 m parabolic dish, is suitable for different satellites working at S-Band frequencies. Almost all other hardware components of the data reception and command system must be adapted for BIRD requirements. The alternative way to use very flexible components (e.g. selectable filter, modulation, etc) increases the cost to much higher levels. After an analysis of different aspects of the ground station requirements such as

- Cost
- Flexibility of the hardware components
- Flexibility of the software components

- Degree of autonomy
- Complexity of Integration and operation
- Compatibility with other stations (e.g. GSOC and Neustrelitz for BIRD)
- Transportability
- Support and warranty conditions
- Availability

a company was selected to deliver most of the hardware, except for the command encoder.

3.1. Overall Characteristics

The main design characteristics of the station can be summarized as follows:

- Receiving capability of science data and telemetry up to 2,2 Mbit/s at a min. Elevation angle of 30°
- Small antenna size of 2,4 m for up- and downlink with 32 dB Gain and 4° half power beamwidth at 2.2 GHz
- System G/T of 9-12 dB/K
- Program track
- BPSK demodulation for downlink, GMSK modulation for uplink
- Compact design
- Uplink capability for experimental purposes with a GMSK modulator and 10 W HPA at S-Band
- Different software modules for various tasks

3.2. Hardware

The maximum downlink bitrate of the system is 2.2 Mbit/s. A special interest was to place as many components as possible within a standard PC. This compact solution makes the system more transportable.

The EGS will be capable of receiving scientific data and housekeeping's from the satellite at a minimum elevation angle of 30 degrees with a BER of 10E-06 at 2.2 Mbit/s. The downlink bitrate of the satellite can be switched to a reduced rate. In this case the telemetry can be received from lower elevation angles.

The antenna system consist of a parabolic aluminum reflector of 2.4 m diameter and an integrated diplexing feed/LNA/downconverter front-end for reception and transmission at S-band. The antenna is mounted on a pedestal for program track of the satellite. No radom will be used, thus some wind speed constraints must be taken into account for the operation of the antenna.

The BPSK receiver and the integrated bit & frame synchronizer cards are integrated into the PC. Time synchronization and location determination of the station are done by reception of GPS data, which is one of the criteria's for independent operation. An dual RS-422 I/O card, integrated additionally into the PC, functions as an interface to the GPS antenna & receiver on one channel. This interface is also used to communicate with the antenna control electronics, which is located inside the pedestal, approximately 20 m away from the control room.

A special GMSK modulator for uplink functions (ISA bus card), may be integrated also in this PC. As an alternative the uplink functions can be done by a second (transmit only) PC. The computers are connected to a LAN for data communication and archiving. All hardware settings can be done by the software, which runs under the Windows NT operating system.

As the EGS has not the main responsibility for mission operations, there is no redundancy but redundant units can be added to the system easily if needed. Defective components must be replaced in case of failure. **Figure 3** shows the antenna and the control room.

3.3. Software

The EGS software has a modular structure and runs under the Windows NT operating system. Part of the COTS software (e.g. pass prediction and planing, antenna control, GPS) can be used without modification. Modifications and additions, which are related to the BIRD project, are made stepwise as necessary in separate modules. The software functions of the EGS can be separated into four groups, which are listed below.

- Antenna control
- Data reception
- Telecommanding
- Data processing

The functions of these groups can be divided to the items listed in the **Table 1** below.

Antenna control	**Data reception**	**Telecommanding**	**Data processing**
Program-track of the antenna	Reception and storage of telemetry	Maintain the database for telecommands	Data storage and
Management of Schedules for data reception and antenna tracking	On-line display of housekeeping data	Input, validation, formatting and transmission of telecommands	“Near-Online” Generation of high level thematic data products
On-screen display of satellite track and schedule information’s	Generation of alarms and messages for out of limit parameters	Verification of reception	Generation of messages as a result of fire detection
Automatic update of system time using GPS	Generation of quick-look files	Communicate with GSOC for the coordination of command files	
Automatic update of orbital elements data (TLE) via internet			

Table 1: List of software functions

Figure 3: Station antenna and control room of the EGS

Antenna Control

Antenna control in program track mode, including scheduling and system time update via GPS is done by off-the-shelf software. Two line elements can be updated from Internet sources or a file, supported by the user.

In case of BIRD, a special feature, which is part of the BIRD technological experiment, can be used to update the two line elements (TLE). The Onboard Navigation System of BIRD generates and transmits TLE’s, using the onboard GPS receiver along with other relevant information’s to the ground station. The benefit of using this data is, that it is most up-to-date, highly accurate and requires no network connection. Thus, using this technique, it would be possible to operate the antenna, even in very remote areas, where no network infrastructure is available.

Telemetry Reception and processing

BIRD telemetry is organized in CCSDS packets, which contains satellite status information and experiment data. **Figure 4** gives an overview of the overall data flow within the experimental ground station. The receive part consists of two main parts. One part is to store and process the experiment data offline. The other path is the online display of satellite status information. These two basic paths are shown in **Figure 5**.

Figure 6 shows a sample of the telemetry status display at the end of the telemetry chain. This path of the software is fully operational and has also been used as part of the electrical ground support equipment during the development and test phase of BIRD. Telemetry is received by this client from a server (“Telemetry Processing”), which is connected to the data acquisition system (“Data Reception”). All necessary information regarding telemetry formatting and out of limit checking is provided by a Microsoft Access database file. An additional configurable tool for message generation informs by means of SMS, pager or e-mail, selected persons in case of out of limit conditions are captured by the telemetry system.

The offline path of the telemetry chain contains modules to process the image data. Software modules for the generation of images and fire data from the infrared sensors are already available and in use but more work has to be done in order to further reduce the human interaction.

Telecommanding

Command generation is based on a telecommand database, which is identical for both the GSOC command system and the EGS. The software of the EGS command system accesses directly the database for validation of commands. The system is able to let the operator edit or load predefined command sequences and send the formatted stream to the telecommand server, which formats and sends the data to the modulator.

The satellite telemetry stream contains different forms of command verification information, which are displayed to the operator online, by the telemetry display client. Because both the display of online telemetry and the command tool are designed as client applications, the operator principally does not have to be physically at the ground station control room (see **Figure 7**). The Graphical User Interface of the command tool is shown in **Figure 8**.

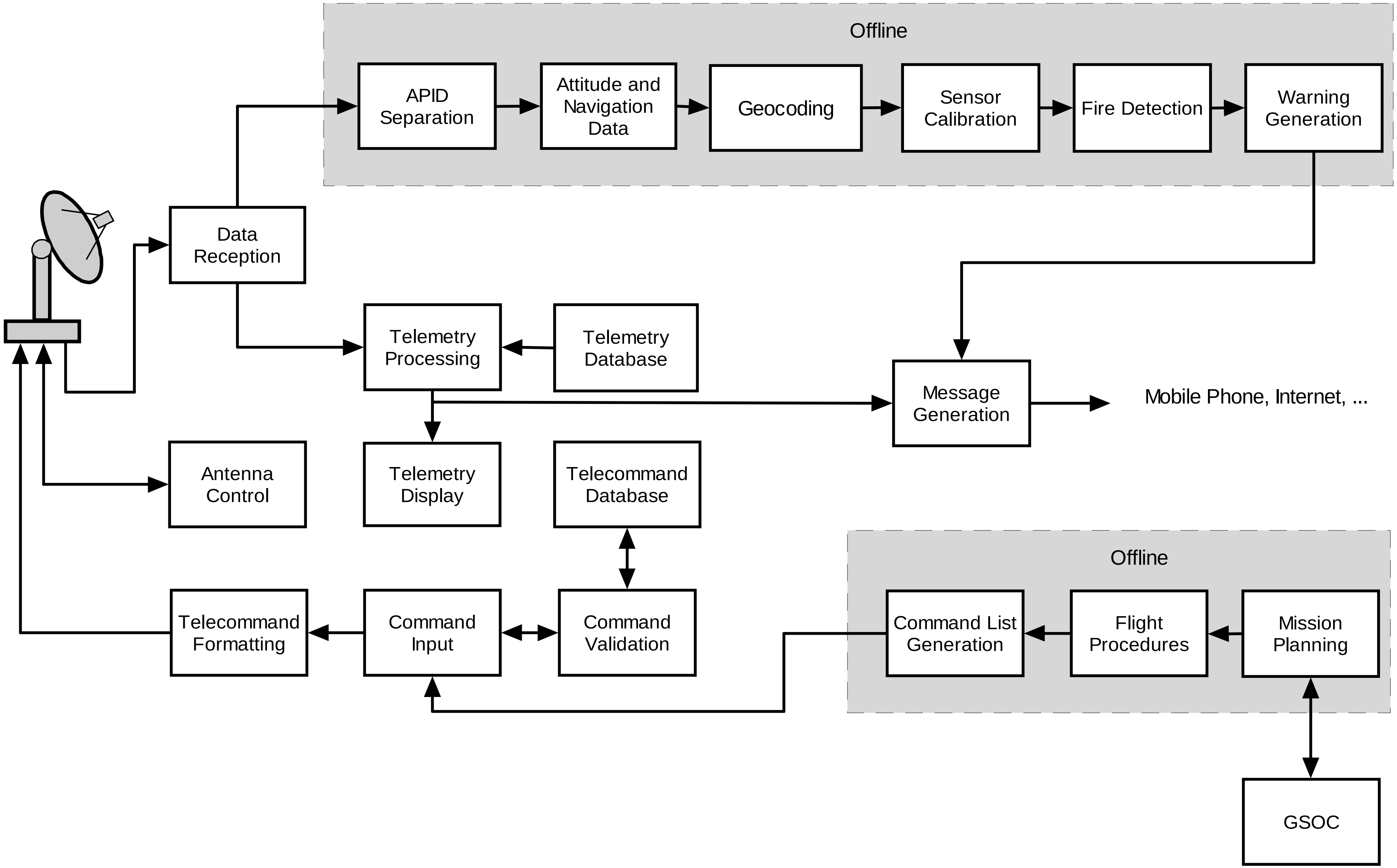

Figure 4: Overview of EGS software functions

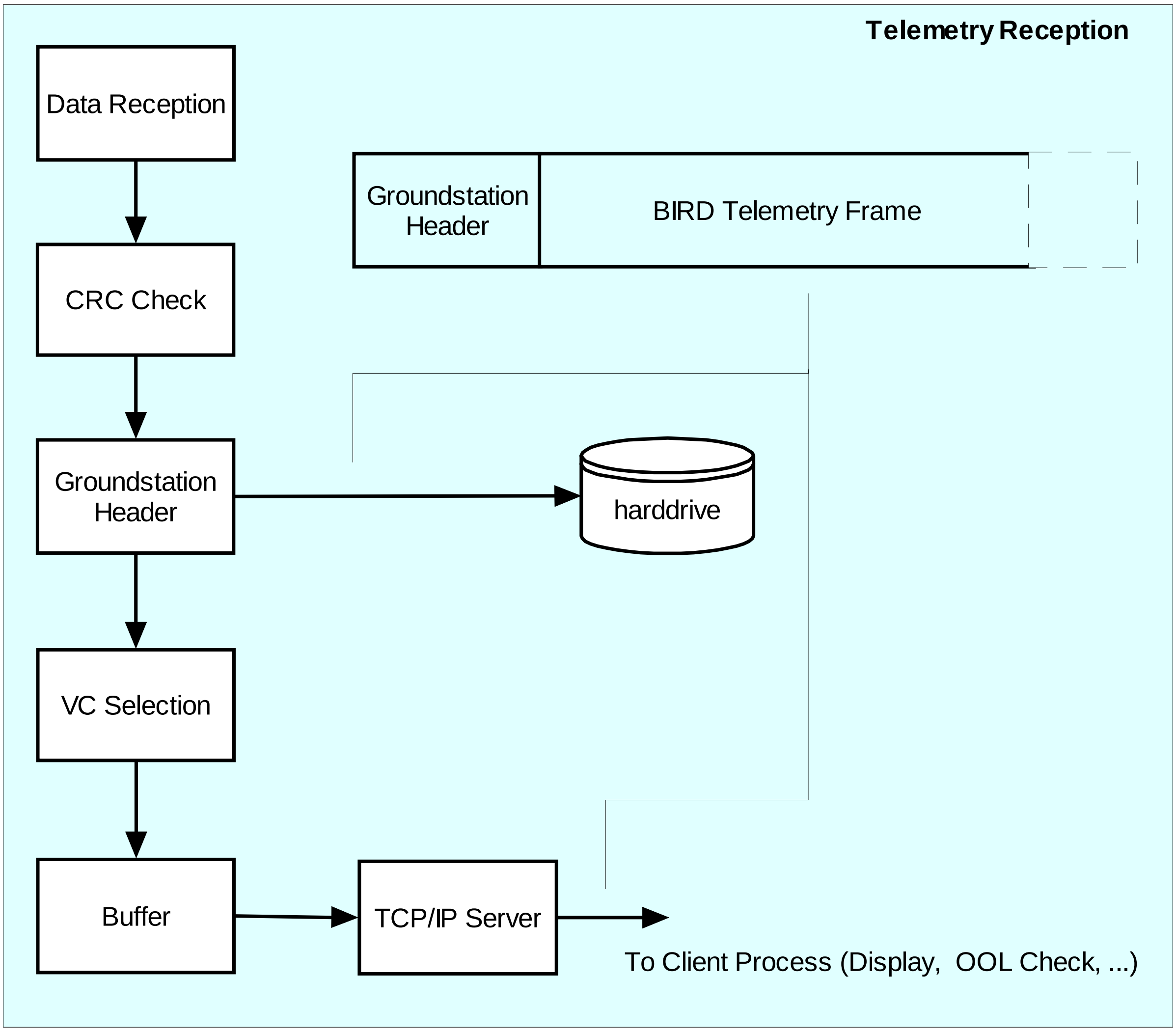

Figure 5: Telemetry processing at data reception

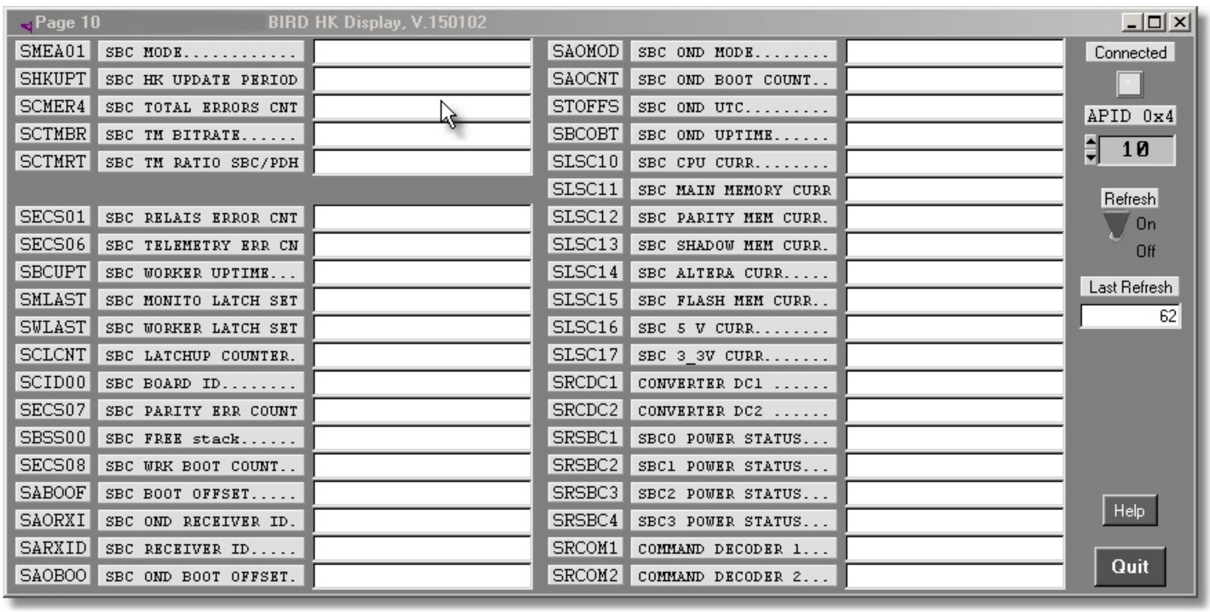

Figure 6: Sample telemetry display page

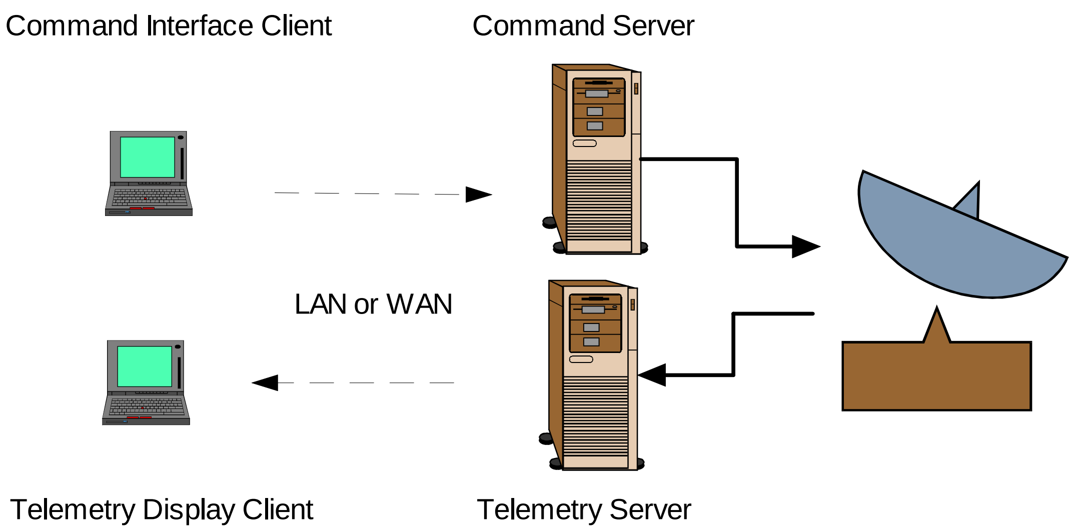

Figure 7: Distributed architecture of telemetry and command tools

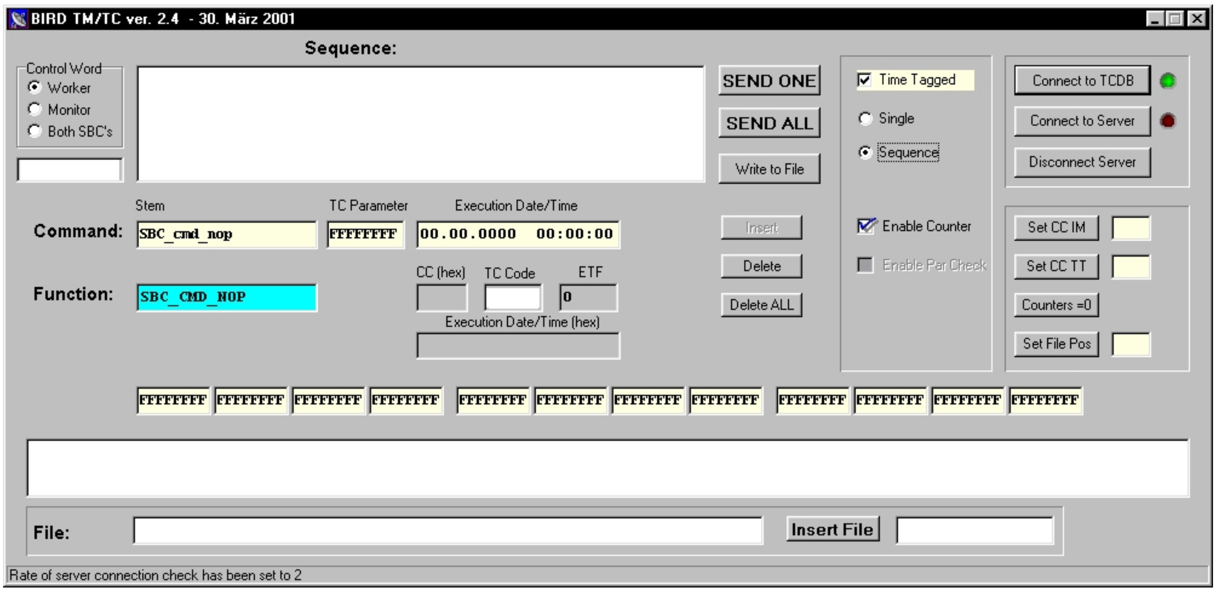

Figure 8: Graphical User Interface of the command tool

Utilities

The operation of the EGS is supported by a number of other software tools to check and visualize satellite telemetry offline and to support command checking and validation. One example for these “small” tools is the “BIRD AOS & TLE updater” (**Figure 9**) for BIRD AOS and TLE files, which (amongst other functions) updates two line elements either from satellite telemetry or from a selectable source over the network and shows the upcoming AOS data for selectable stations.

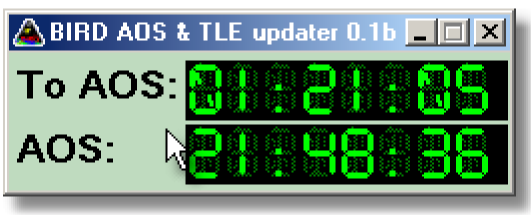

Figure 9: Graphical User Interface of AOS & TLE updater

3. Conclusion

The development of the experimental ground station for the BIRD satellite is a contribution to the efforts aimed to reduce the overall cost for space applications in the field of data reception from earth observing satellites and mission operations. The success of this development can help the realization of projects with limited budget but very useful and focused objectives, especially in locations with less economical strength.

Currently the main software functions of the software is successfully tested with both the BIRD satellite in orbit and the engineering model on ground. Due to outstanding hardware components of the experimental ground station, real data is currently received and kindly supported by the main ground station in Neustrelitz of DLR to the telemetry processor and clients in Berlin Adlershof, utilizing the compatible server port.

In-flight experience with the telemetry system of BIRD shows no difficulties both for satellite status and experiment data.

4. Reference

[1] Madeline J. Butler, Dorothy C. Perkins, & Lawrence B. Zeigenfuss: Renaissance: A Revolutionary Approach For Providing Low-Cost Ground Data Systems, Proceedings of the Fourth International Symposium on Space Mission Operations and Ground Data Systems September 16 - 20, 1996 at Munich, Germany

[2] Kayal, H: An Experimental Low-Cost Ground Station for the Small Satellite Prokect BIRD, Acta Astronautica Vol. 46, Nos. 2-6, pp. 213-220, 2000, Elsevier Science Limited

[3] Gill, E. & Montenbruck, O.: The BIRD Satellite Mission as a Milestone towards GPS-based autonomous Navigation, ION GPS 2000, September 19-22, 2000, Salt Lake City, UT

TELEMETRY ANTENNAS

The Design of a Novel Axial Mode Helical Antenna with Dual Reflectors

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Abstract

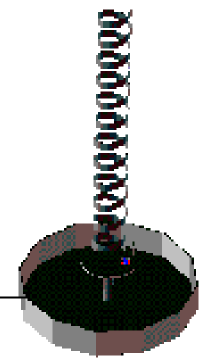
In this paper, a novel axial mode helical antenna is forwarded. Via experimental and stimulant studies, Its performance versus large reflector dimension and space between two reflectors is analyzed, and optimum design dimension is gained. working principle is analyzed. At last, its promising perspective used as element is demonstrated via 2×4 array, and the array can be used as telemetry receiving antenna.

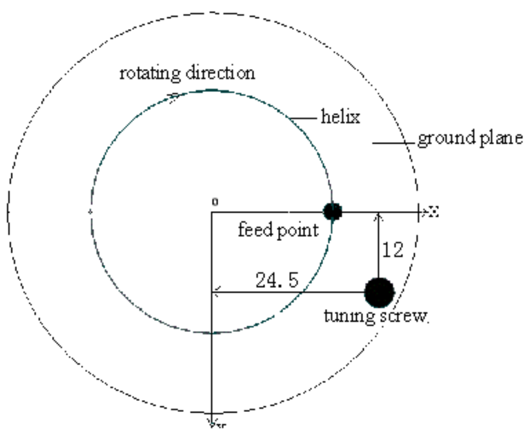
Introduction

Helical antenna has many excellent properties such as small size, lightweight, broad band and good circular polarization. But when turns of conventional helical antenna are more than 10, its gain can not be increased evidently, and it radiating efficiency is not very high, so method to improve helical antenna′s radiating efficiency is significant. As we have known, when the ground plane of general helix becomes smaller and smaller, its backfired radiation will become more and more. In this paper, a new form of helical antenna on base of this is brought forward, and its performances are verified.

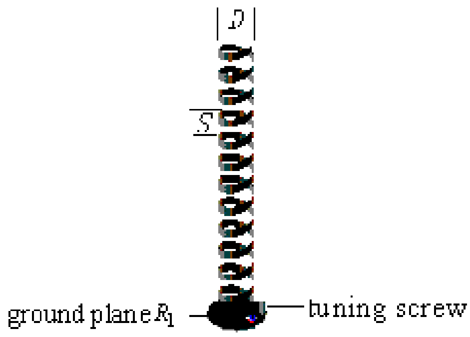
Antenna configuration

The structure of novel helical antenna is shown in Fig.1(a), it has an additional large reflector with $\lambda_0/4$ high edge ring. The position of the tuning screw is shown in Fig.1(b). a conventional helical antenna shown in Fig.1(c),





(a) drawing of novel helical antenna (b) sketch of the position of tuning screw



(c) drawing of conventional helical antenna

Fig.1 drawings of helical antenna

Where: S = spacing between turns

D = diameter of helix

R_1 = diameter of small reflector

R_2 = diameter of large reflector

To guarantee axial mode for both antennas, $D = 0.286\lambda_0$, $S = 0.227\lambda_0$ and $\alpha = 14^0$ are chosen[1]. As for the input impedance of helical antenna, there is no exact solution for it in theory at present. In practice, we regard it as a pure resistor and can estimate it by following formula.

$$Z_{in} = R \approx 140\frac{C}{\lambda} \qquad (1)$$

Due to $C = \pi D \approx \lambda$, $Z_{in} = 140\ \Omega$. So a tuning screw placed near the feed point inducts a parasitic impedance match 50 Ω coaxial cable.

Optimal design parameter

We all know that when diameter of R_1 is smaller than that of helix, it will radiate in bi- direction of axis[2]. If a larger reflector with edge ring is added behind the smaller one and placed in a suitable place. The back-forward radiated wave will be reflected to reverse direction and the electromagnetic wave will cohere in phase. This may greatly improve radiating properties of conventional helical antenna.

We can obtain the space between the two reflectors and the diameter of the larger reflector from "equivalent focus" of reflector antenna. The drawing of "equivalent focus" is shown in Fig.2.

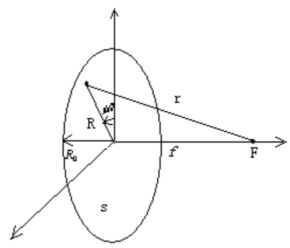


Fig.2 drawings of "equivalent focus"

Where S is the equivalent radiating aperture, F is "the equivalent focus point" and f is "the equivalent focus" . Suppose the electric field distribution on the aperture is equal amplitude, its value is E_0 . When the diameter of the reflector is finite, the electric field E on boresight is given by:

$$E = j\frac{CE_0}{\lambda}\int_0^{2\pi} d\psi \int_0^{R_0} \frac{e^{-jk\sqrt{f^2+R^2}}}{\sqrt{f^2+R^2}} RdR = -CE_0(e^{-jk\sqrt{f^2+R_0^2}} - e^{-jkf}) \quad (1.2)$$

When:

$$\left.\begin{array}{l} kf = 2n\pi \\ k\sqrt{f^2+R_0^2} = (2n+1)\pi \end{array}\right\} n=1 \quad 2 \quad 3\cdots\cdots \quad (1.3)$$

the value of E is maximum.

We can consider helix's geometry center as its phase center. As far as helix with 12 turns, suppose the space between the two reflectors is d then:

$$f = (d + \frac{12\times 0.22}{2})\lambda \quad (1.4)$$

Taking $n = 2$,we can get $d = 0.68\lambda$, $R_0 = R_2 = 2.1\lambda$ from equation(1.3).But we know From paper[3] that geometry center of helix is not its phase center in fact, the position of its phase center changes with frequency and dimension of the reflector[3]. So the final value of $R_2 = 1.5\lambda$ is obtained through experiment. When $R_2 = 1.5\lambda$, we utilize Ansoft HFSS finite element analysis software to simulate novel helical antennas at different values of d. The simulating results are shown in Fig.3 and Tab.1

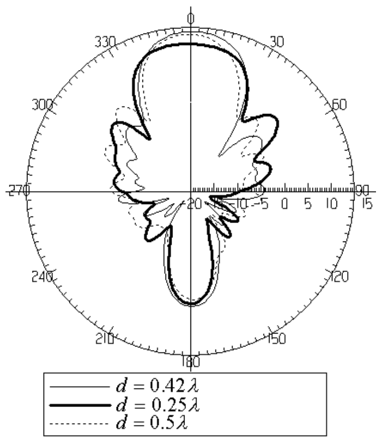


Fig.3 The radiating patterns simulated at different values of d

Tab.1 The specifications of helical antenna with dual reflectors at different values of d

Specifications / Space	Maximum Gain(dB)	Half power beam width(^{0})
$d = 0.25\lambda$	11.49	47
$d = 0.42\lambda$	14.13	36
$d = 0.5\lambda$	13.52	32

From Fig.3 and Tab.1 ,we can draw a conclusion that when $d = 0.42\lambda$ ther antenna's gain and radiating efficiency are highest.

When $n = 12$, $G_1 = 1.5\lambda$, the simulated radiation patterns of novel helical antenna and conventional one are shown in Fig.4.

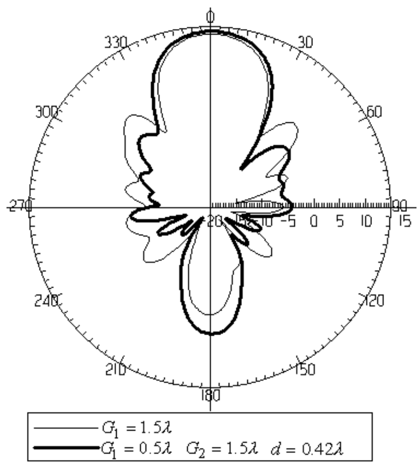
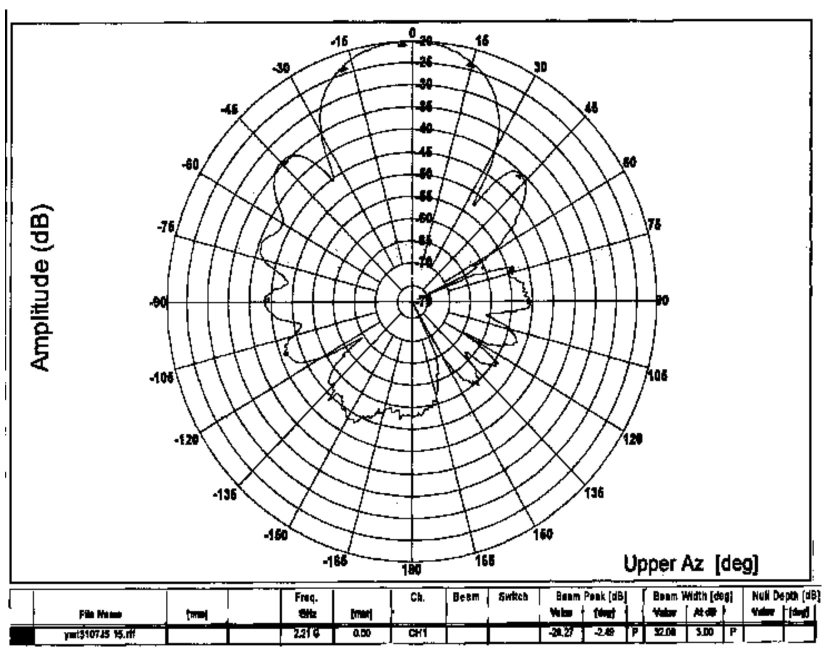


Fig.4 the simulated radiation pattern comparison between novel helical antenna and conventional one

From Fig.4, we can know that the gain of the simulated conventional helical antenna is 13.58dB,half power beam width is 34^0.Thus its radiating efficiency is about 62%. The gain of the simulated novel helical antenna is 14.13dB half power beam width is 36^0,so its radiating efficiency is about 80%. We fabricate a prototype of novel helical antenna by choosing $G_1 = 0.5\lambda$, $d = 0.42\lambda$, $G_2 = 1.5\lambda$. Its measured radiating patterns are shown in Fig.5.



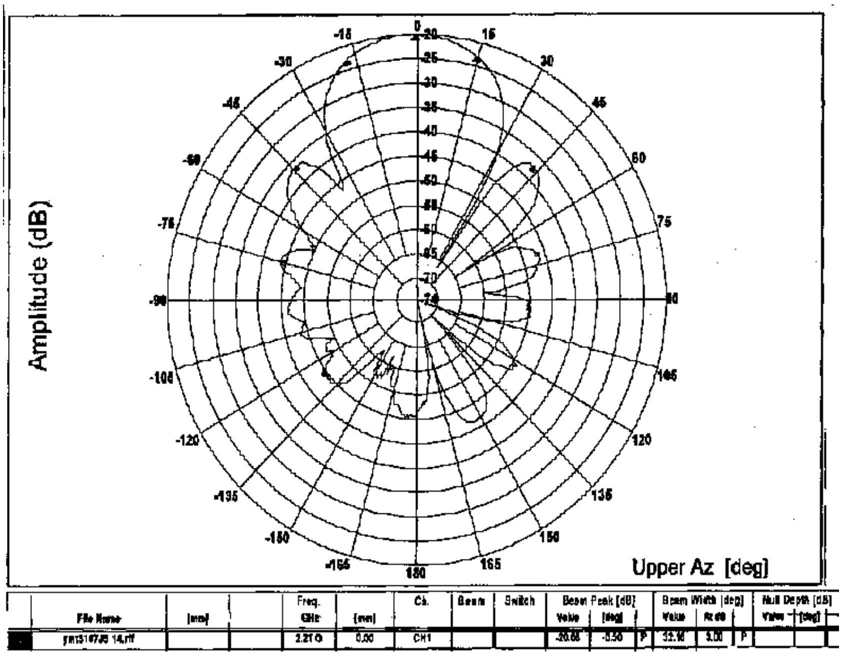


Fig.5 the measured radiation patterns in two main planes

From Fig.5, we can know that the measured gain of the prototype is 15dB its half power beam width is 32^0,thus its radiating efficiency is about 77%. So we can draw a conclusion that radiation efficiency of novel helical antenna is much higher than that of conventional helix and it is much more suitable to be used as radiating element of antenna array. The back radiation could be reflected to the open end. Adjusting the spacing between the two reflectors to a suitable value, the reflected power can be cohered in phase with radiated forward power. So its beam is narrowed, side lobe is suppressed, gain is heightened and efficiency of the antenna is increased.

Antenna array

Because of its high efficiency, the proposed antenna can be employed as array element. We constructed a planar array of $\boxed{\quad}$ elements, shown in Fig.6.

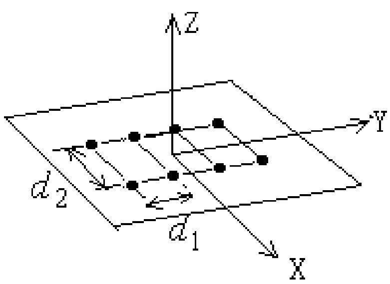


Fig.6 $\boxed{\quad}$ rectangular planar array

When the eight elements are fed in phase with equal amplitude and the distances and between each two elements are adjusted to and respectively, The radiated electromagnetic wave will cohere in phase along the axis of the array. Its feeder system is an eight-armed power divider with total insert loss less than 0.9dB. The gain of the system can reach 23dB.Its beam width is about and its side lobe is below –10dB. Thus gain$\times$beamwidth^2 of the antenna is about .Its radiating patterns in narrow and wide radiation plane are shown in Fig.7 and Fig.8.

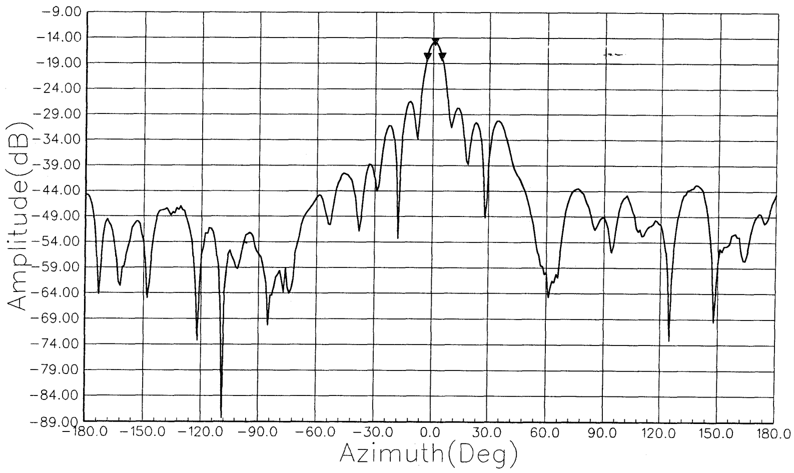


Fig.7 Radiation pattern in the 4-element plane

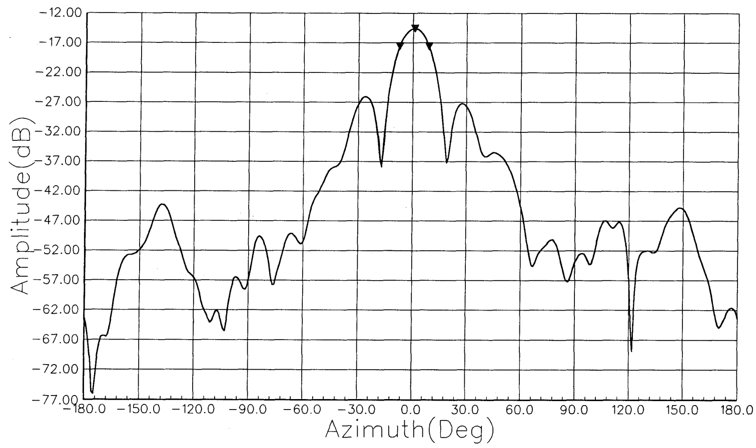


Fig.8 Radiation pattern in the 2-element plane

Conclusion

As for axial mode helical antenna, one kind application is using it as conventional axial mode helical antenna when the ground plane is large. Because of its back-fired characteristics when the ground plane is small, the other application is using it as feed of reflector antenna. The axial mode helical antenna with dual reflectors studied in this paper takes the advantage of above two applications, and we obtain high radiating efficiency. Under the condition of 1.0dB insert loss of feeder system, using it as radiating element of antenna array, we can see that the radiating efficiency of the array can reach 57%. All of these has not been seen to be reported in present papers.

References

HISAMATSU NAKANO. Backfire Radiation from a Monofilar Helix with a Small Ground Plane.

A multi-antennas COFDM system
For Spectrum resource optimisation

An AIRBUS telemetry application

Pierre LEMAHIEU, SAGEM SA – Luc FALGA, AIRBUS FRANCE

Abstract

COFDM is a technique that is naturally suited for propagation environments where multipaths occur. Usually, these multipaths are not controlled, as they are created by signal reflections on various obstacles. But considering COFDM's excellent robustness to such conditions, one can also design a multiple antennas system that would create the same effects. The benefits of this scheme are a better spatial transmission pattern (which is useful for many telemetry applications), and no needs to use different frequencies on each antenna (hence a benefit in spectral efficiency).

It is in this context that the modulation COFDM was chosen by AIRBUS as the trial programs A340 / 600 , A318 , A340 / 500 (6 planes of development). According to specific constraints (size of the aircraft, the speed, the environment ,notion of real time), we shall describe below which were our choices. The notion of spectral efficiency will take all its place for the programs A380 and A400M where needs already expressed (parameters, video) urge us to optimise at most the spectral attributed resources while keeping the quality of current transmission.

Introduction

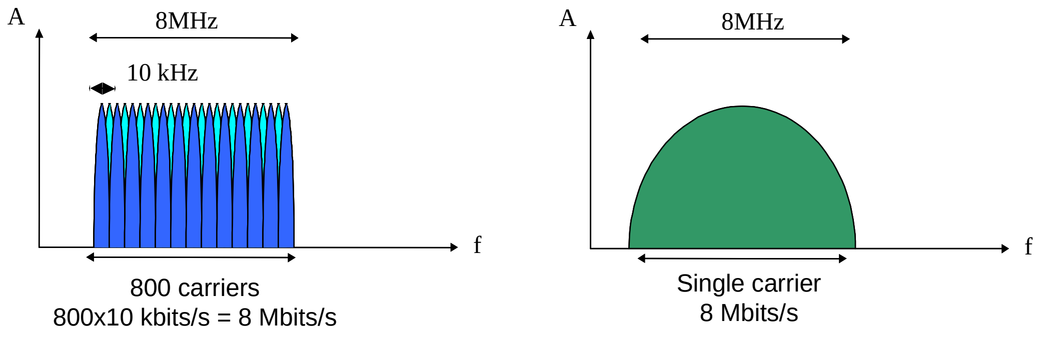
Within the framework of the attempts in flight for the certification of the commercial aircraft, the systems of telemetry are systematically operated. Their use allows to reduce the cycle of the attempts while insuring a maximum safety. To allow an exploitation in real time by the specialists in reception room, the quality of the signal should be optimal, absolved even for certain trial types and the objective is a transmission without error in all the exploited trial phases.
The configurations of transmission are very variable. The distances can be spread out of the close field (attempts "autopilot" or "braking") in more than 300 km in high height (attempts "Performance" or " flight qualities").
The infrastructures of reception, organised by AIRBUS - FRANCE, consist of six stations of reception distributed in the South and the West of France which allow to follow the plane from the South of England until the Italian border.
The beginning of 2001, further to the reorganisation of the national plan of frequency, a new Hertzian space was assigned to us under the shape of 3 canals of 5 MHz separated from 2 MHz in band S (2.7 GHz). This allows us to follow through telemetry three planes simultaneously. This move from the L band to the high S band lead us to make a complete renovation of our transmission and reception equipments. After different attempts, our choice narrowed to a system based on a principle of COFDM modulation supplied by SAGEM-SA and its product : STERN.

A quick review of COFDM principles

The main features of COFDM (Coded Orthogonal Frequency Division Multiplex) are the following :

- The data to be transmitted are split over a large amount of subcarriers (say Nu subcarriers), which could be considered as Nu independent channels. Every subcarrier is modulated at a low rate, and therefore occupies a very small bandwidth.
- The subcarriers can overlap thanks to a special mathematical property known as orthogonality. This rule insures that there won't be any frequency interference between consecutive "channels" in the receiver. This also provides an excellent spectral efficiency.
- In the transmitter, some Coding (redundancy) is introduced before the data are split over the Nu channels. In the receiver, this redundancy is exploited to benefit from multipaths.

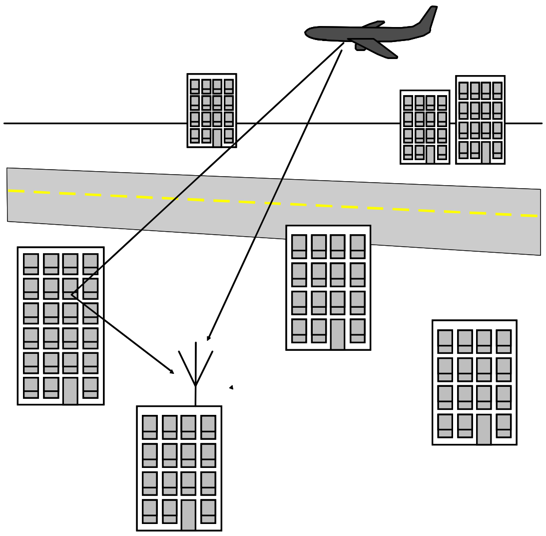
The following figure compares the COFDM spectrum (800 subcarriers modulated in parallel with an individual data rate of 10kbits/s) with a classical single carrier spectrum (1 single carrier modulated with a data rate of 8 Mbits/s). Note that the two signals convey exactly the same amount of data, using an equivalent bandwidth.

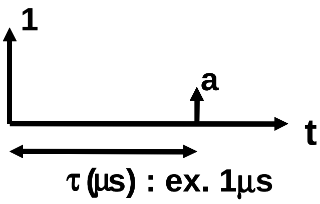


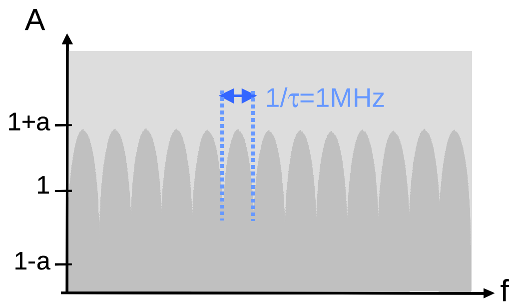
COFDM & Multipaths

Multipaths occur when the receiver gets multiple signals from the transmitter. These multiple signals are created by the radio propagation environment, when obstacles reflect the original signal and create some "echoes" : a reflected signal that has a longer path to the receiver is delayed in time, and if the path length difference is 'r', then the delay will be $\tau = r/c$ where $c = 3.10^8$ m/s.

The next figure gives an example where the receiver recovers the original signal (with a normalized amplitude '1') and an echo, delayed of τ=1μs and with an amplitude 'a'. If we consider the effect of this transmission environment in frequency, we see that it introduces some local amplifications ('1+a') and local attenuations ('1-a') in the spectrum. The frequency space between two local amplifications (or conversely two local attenuations) is $1/\tau$, hence 1MHz in this example.

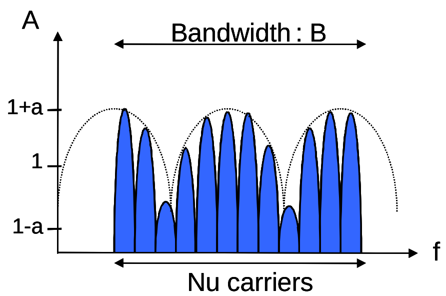




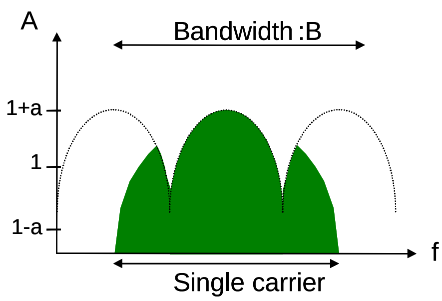


The consequence of such a propagation environment on the transmitted signal is shown below :

COFDM :
Local attenuations
and amplifications.
No distortion



Single-carrier systems :
Distorted Spectrum



In the single-carrier case, the spectrum is distorted by the channel. There is no way to transmit a high data rate binary flow (requiring several MHz of bandwidth) in such a channel without suffering from this distortion. Equalizers can be used to try to invert the channel response, but they are very difficult to design for high data rates in the presence of long echoes.

In the COFDM case, the overall spectrum suffers from the same shaping as the single carrier spectrum. But the difference here is that this overall spectrum is in fact the sum of many subcarriers spectrums. A subcarrier takes up a 10kHz bandwidth, which is 100 times smaller than the space between two local attenuations. Therefore, every subcarrier (or channel) can be considered as suffering only from an amplification or attenuation, but with no distortion. An equalizer will therefore not be necessary.

Still, the subchannels which are attenuated exhibit a lower S/B than expected in a gaussian channel. On the other hand, the amplified subchannels benefit from a higher S/B. Without any coding, this situation could be terrible for the system's performance.

With a bandwidth of 8 MHz and a radio channel with $1/\tau$=1MHz, 8 subchannels could be completely attenuated (if a=1), and the best BER one could then expect would be of $8*0.5/800 = 5.10^{-3}$, whatever the received power on the other subcarriers. The coding (redundancy) which is introduced in the transmitter stages is therefore essential, and is exploited at the reception. Indeed, the decoder is capable of using the redundant information on the high S/B subchannels to recover the information lost on the low S/B channels. In fact, the amplified channels really play a key role and they more than compensate for the attenuated channels.

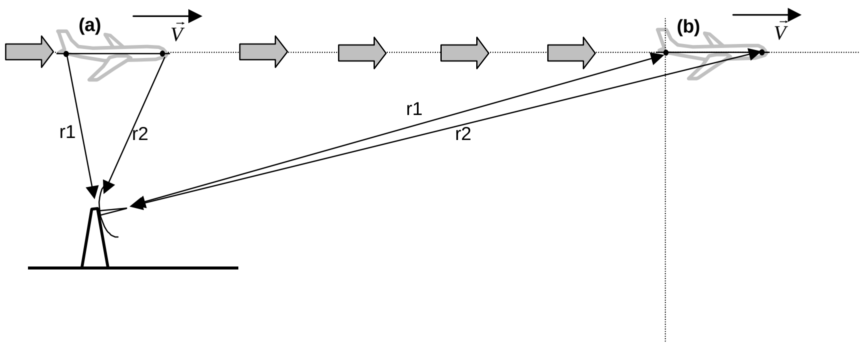
Thanks to all these special features, compared to all modulation schemes, COFDM exhibits today the best robustness to outdoor multipaths environments where long echoes occur.

A COFDM product by SAGEM SA : STERN

COFDM also offers many parameters that can be tuned to optimise robustness over long echoes, carrier speed, attenuation, spectral efficiency, etc. SAGEM SA largely exploited this feature in its STERN system to make it able to cope with any kind of environment with a single product : all in all, more than 500 parameters combinations are possible. STERN has been commercialised for 4 years, and its applications range from Electronic News Gathering to Airborne Surveillance Systems, and also Telemetry systems, with all kind of links (ground/ground, ground/air, air/air, sea/ground,…). Last but certainly not least, the system's ability to take advantage from multipaths enables the use of omni-directionnal antennas instead of directional antennas, which dramatically loosens the installation and costs constraints. Initially designed with a 8MHz bandwidth, STERN was first adapted to meet AIRBUS constraints of a 4 MHz bandwidth.

Multiple antennas configuration

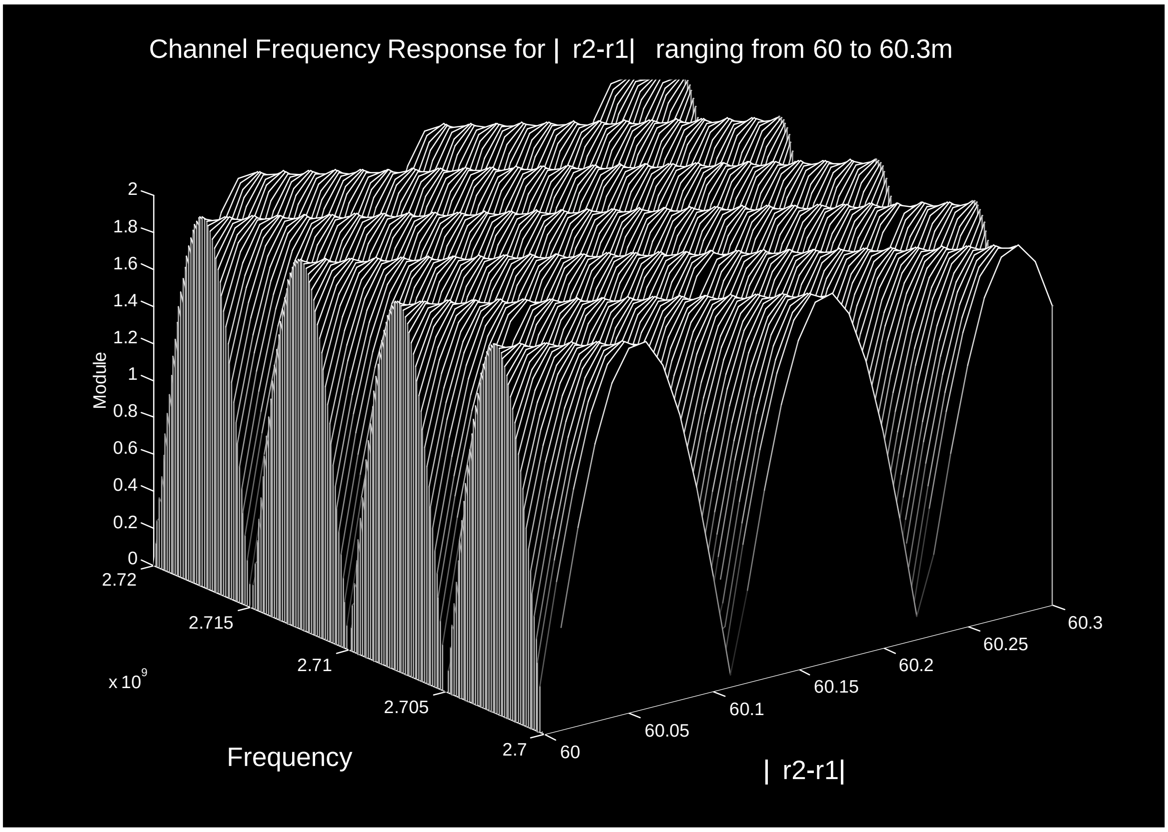
In telemetry applications, the use of multiple antennas can significantly improve the spatial radio coverage of a monitored system. Then, whatever the system's attitude, the receiver should be able to receive a signal. The AIRBUS plane was equipped in such a way with a front antenna and a back antenna, approximately separated by 60m.

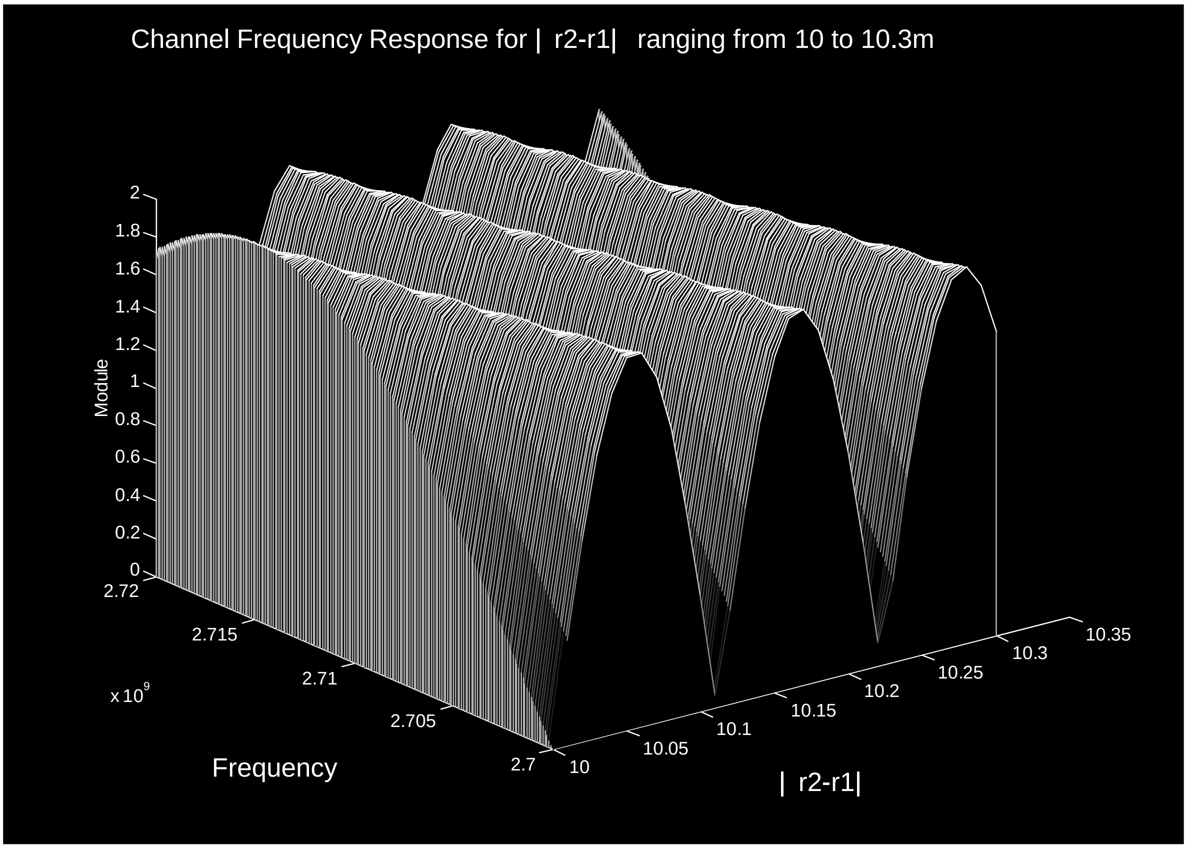


From a radio propagation point of view, the resulting situation is analogue to the multipaths phenomenon : the receiver gets two signals, similar but delayed in time, and with a specific phase and amplitude. When the plane looks sideways from the receiver (a), | r2-r1| can be very small : the echo can be delayed of just tens of nanoseconds. When the plane is flying away from the receiver, | r2-r1| can reach its maximum value of 60m. The echo would then extend to approximately 200ns (| r2-r1| / c, with $c=3.10^8$ m/s).

The following figures describe the influence of the | r2-r1| value on the channel frequency response. As expected, large values of | r2-r1| create a channel where the frequency space between two local attenuations decreases, leading to situations where a 4MHz signal spectrum would be guaranteed to suffer from local attenuations but also benefit from local amplifications. The STERN system is perfectly suited for such cases and would cope with them with no particular problem.

On the other hand, small values of | r2-r1| may lead to situations where a 4 MHz spectrum signal could be only attenuated. There is no more COFDM effect there, as no stronger channel can help to recover the information lost on weaker channels, and this would quite certainly introduce a high final BER.

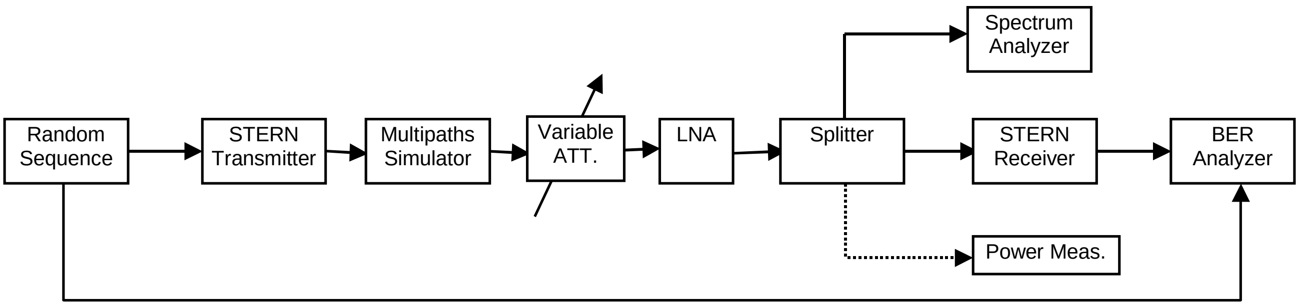




Multiple antennas Experiments

As the test planes could suffer from such effects during their flight, AIRBUS asked SAGEM SA to conduct some experiments with its STERN system and a realtime multipaths simulator, to analyse the consequence of such conditions on the BER.

The test bench is shown below.



These simulations included :

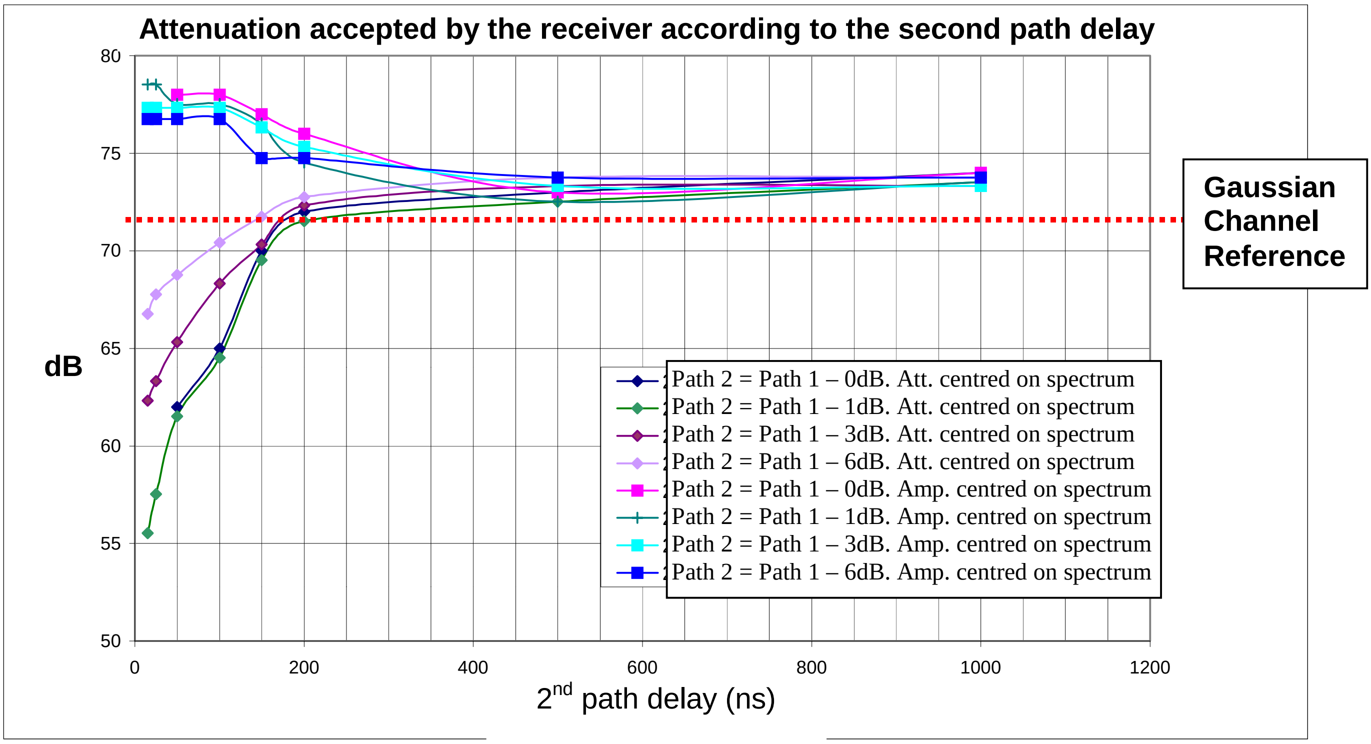
- Static configurations where the multipaths were set as to create a local attenuation or amplification just centred on the spectrum, and where their amplitude and delay were modified. Two, three or four paths were used (Cases with more than two paths may be encountered when the two transmitted signals are also reflected on the ground and reach the receiver as other echoes).

- Dynamic configurations with various amplitudes, delays, and Doppler values. Again, Two, three or four paths were used.

The following figure give some of the results in a static two paths case. It gives the attenuation that is acceptable by the receiver with an output BER equal to zero over 15 seconds (at 3 Mbits/s). Note that the actual input power of the LNA was –27dBm when the attenuator was set to 0dB (The Receiver sensitivity is equal to -99dBm in the Gaussian case).

In this static case, short multipaths (t2-t1<200ns, or r2-r1<60m) can be either quite beneficial or very detrimental : they increase the received power when they come in phase, and do the opposite when they come out of phase. As there is no way to control the individual phase in practical situations, this multipaths configuration is rather risky : there is a potential loss of approximately 20dB over the Gaussian case when the signals are out of phase.

On the contrary, when t2-t1>200ns, the situation is **always better than the gaussian case**. Hence multipaths can be seen as a benefit to the transmission (up to a 2-3 dB gain !).

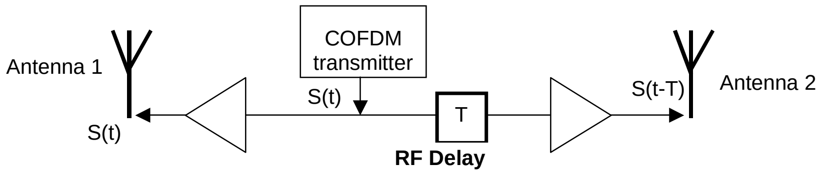


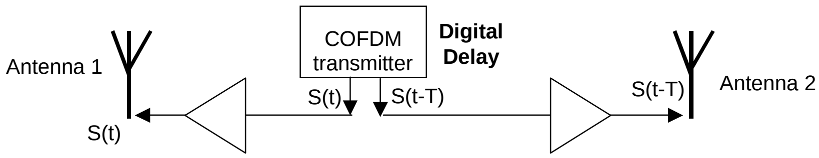
These results confirm that, if long echoes are handled very easily by the STERN system, shorter echoes (<200ns) may cause some problems. With no particular constraints, there are COFDM solutions to this problem, using more bandwidth (for example, 802.11a commercial wireless-LAN systems use a COFDM scheme with a 16 MHz bandwidth). But the STERN system's bandwidth had to be limited to 4MHz in the AIRBUS application because of legal constraints.

Another solution can then be considered. As the performance of the system is much better with long echoes, the idea is to transform the short echo into a long echo (say around 1µs).

This can be done quite easily. Two possible solutions are :

- the use of a RF delay insertion device (of 1µs) inserted at the output of the transmitter (useful for the systems already installed),
- the use of a specific COFDM transmitter with a digital delay of 1µs on a separate output (more integrated solution).





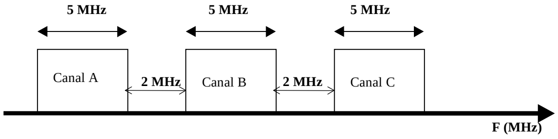
Using this idea, it is now possible to insure transmissions with a global benefit up to 2-3 dB over the gaussian case, as the echo will never be shorter than 1µs.

Apart from this performance gain, the other benefit of this scheme is also that the same frequency can be used on the different transmit antennas, as there is no ripple in the overall radiation pattern created by the two antennas.

On a global system point of view, moving from a multiple antennas system (where different frequencies were required for each antenna) to a COFDM scheme on a single frequency can be considered as an overall bandwidth efficiency multiplied by the numbers of antennas.

Constraints and choice of AIRBUS

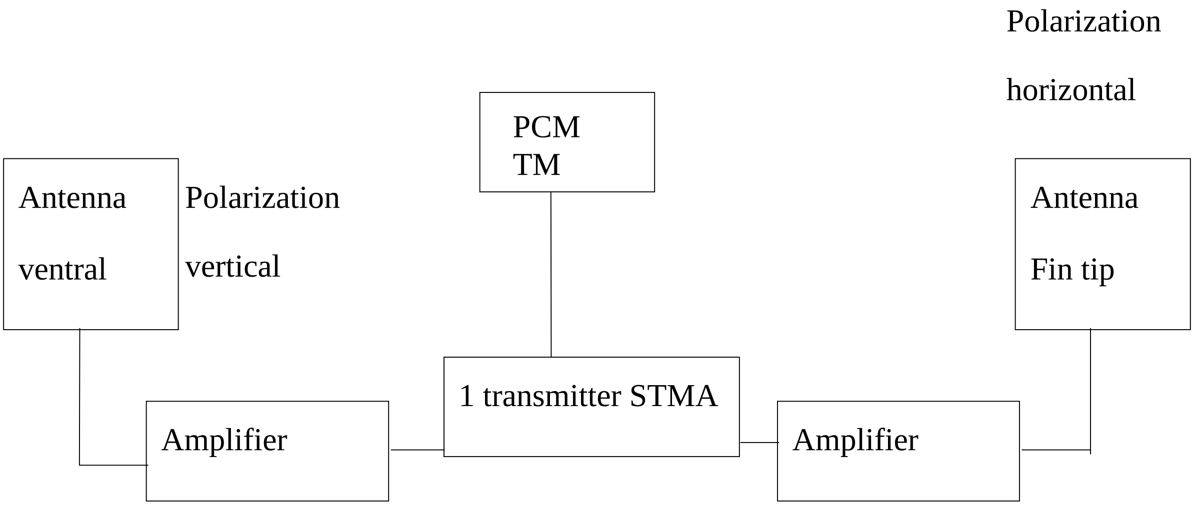
An official announcement attributes us 3 channels of 5 MHz spaced out by 2 MHz.



Modulation COFDM DQPSK

The original STERN system was developed by SAGEM SA in purposes of transmission of high data rates (up to 12 Mbits/s). It worked with a 8 MHz bandwidth. In view of very weak period between this allocation and the application for the program A340 / 600 (6 months), it was considered less risky technically to divide by 2 the band of the STERN to give birth to the “STMA”, which is a STERN with a 4 MHz bandwidth. Indeed, the passed on and exploited "useful" data rate stayed in 852 kbits/s to remain compatible with the existing systems (data base, constitution of message, extraction of the parameters, software of exploitation). The rest of the message (total data bit rate = 3 Mbits/s)is occupied by bits of "completion".

The following Synoptic describes the on-board installation. It consists of a transmitter and two amplifiers, each connected to one antenna.



The antenna situated in the fin tip transmits with an horizontal polarisation. The antenna situated under the fuselage transmits with a vertical polarisation. This combination of polarisation was organised to avoid interference in the space. Nevertheless, the fact of emitting on the same frequency by using two antennas provoke normally cancellations of signals at the level of the antennae of reception. Simply the fact of using the modulation

COFDM places the first signal received as a direct route, the second as a route having undergone a reflection, the receiver STMA can adapt of this fact.

The current mode STMA allows us "useful" debits of 2.86 Mbits/s in 4.49 Mbits/. Different field trials of the STERN system (in 1999,2000) had allowed us to characterise precisely the propagation channel to define the characteristics of the appropriate STMA modes :

- Number of subcarriers : 224 or 448. A lower number limits the robustness to echoes, a superior number reduces the space between carriers and is more sensitive to Doppler spread.
- Time Interleaving : 4 COFDM frames (160ms). This interleaving allows to break a burst of errors and to distribute it in the time domain to improve the efficiency of the error correcting codes. The superior limit of the interleaving is given by the maximal delay tolerated by the user (300ms in our case, to keep the notion of "real time" for the exploitation of the data).
- Rate of coding: 7/8; ¾; 2/3; ½. This rate concerns only the VITERBI code. A REED-SOLOMON code of fixed length (188-204) is also implemented. The codes we are using are ½ and 2/3.
- Maximal speed of the plane : It is directly bound to the frequency space between subcarriers. At present, a mode conceived for a speed of the mobile of 300 km/h gives whole satisfaction.
- The resistance to multipaths : This notion is essential within the framework of our follow-ups telemetry in close field. It is directly bound to the length of the guard interval of the COFDM's symbol and allows to fight against the echoes of distribution. It was to notice that the length of these echoes could reach 12 µs. At present, the used mode allows to absorb echoes of 28 µs (8.4 km)

The possible maximal data rate is a function of the choice among these different parameters (can go up to 6 Mbits/s for 4 MHz spectrum).

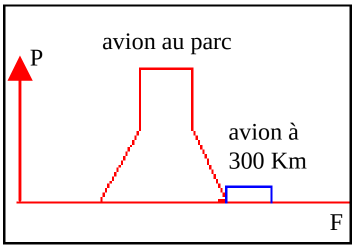
Operating results

At the time of current, 8 planes of development are endowed with systems STMA to pass on the data . These means allowed a real-time exploitation of 1170 hours during year 2001avec a remarkable quality of transmission in every case.

The programming of a STMA mode is always the same, whatever is the type of flight followed On the other hand, the conditions of progress of a trial flight can be very changeable. During the same flight, the plane can make a succession of laps in airport environment consisted of hangars with metallic structure (conditions convenient to the multipaths) may be brought to go away in limit of reach of our antennas of reception (2 m of diameter). The power of emission, (2*15W) assures a balance of connection with a margin of 20 dB and allows a almost not measurable reported BER ($< 10^{-9}$)

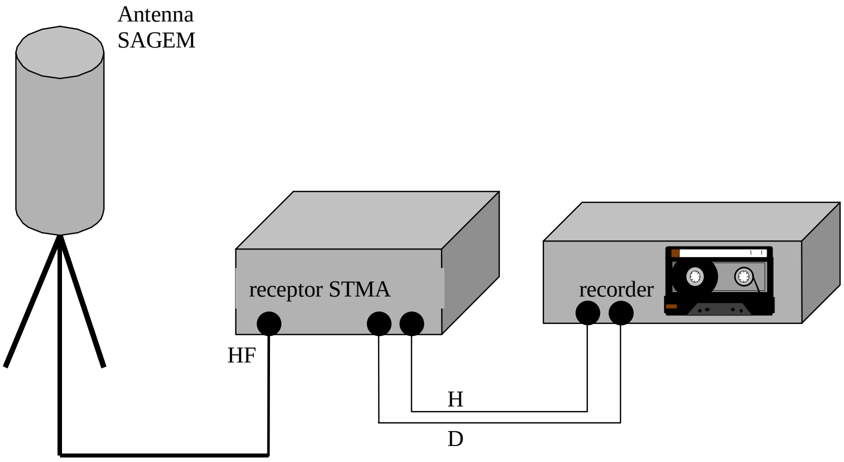
The size of trial planes constitutes an important parameter in our case. The distance between the two antennas varies from 31 m for the A318 t 80m for A340 / 600. Moreover, the position of the transmitter in the plane is variable according to the programs (in front, in the middle or behind) creating more or less important temporal asymmetry between both ways (from 20 to 150 ns).

The quality of the transmitted spectrum is also an essential parameter. It is essential for the radiated power out of the assigned band ("spectrum shoulders") to be weak enough to avoid problems of cohabitation with our Hertzian neighbours. But it is also necessary to avoid any disturbance inside band within the framework of the follow-up of two planes on two neighbouring canals.



Particular Trials

The use of the STMA allowed us to fulfil specific missions on remote sites, by using light means of reception. The employment of an antenna 4 panels with right circular polarisation equipped with filter and with preamplifiers authorised a telemetry reception. Its gain of 8 dB and its opening of 360 ° in azimuth and +/-20 ° in site allows a reach of 50km @ 2.7 GHz.



On the Lounge of the BOURGET in 2001, we were asked to pass on an image of the cockpit during the demonstration in flight of l'A340 / 600. This image was emitted without the slightest error with a bit rate of 3.5 Mbits / s in the format MPEG2.

The same means were settled to MORON (Spain) for a campaign of certification in external noise for the A340 / 600. Microphones are implanted around a ground and measure the sound level provoked by the passage of the tested plane. The characteristics of these passages are exactly defined at first and the exploitation of the data passed on by telemetry allow the validation or not of the point.

Also, the follow-up and the recording of the first flight of the A318 in Hamburg was able to be achieved by the use of the same equipment.

Foreseen evolutions

If at first, these new means simply substituted themselves for the ancient in term of passed on data rate, it will be there quite different for the programs A380 and A400M. New needs have raised with the increase of the number of telemetry parameters (multiplication by 2), of their cadence, as well as a will to pass on video image.
In every case, the possible data rates offered by a transmission channel of 4 MHz do not allow to answer it. The systems will thus be optimised for a band of 5 MHz by proposing an increase of data rate (from 3.5 Mbits/s to 5.3 Mbits/s) . This allows to keep a quality of equivalent connection. Furthermore, a decision was made to implement an uplink remote control, which should allow to change the type of transmit parameters during the flight. Indeed, some parameters are useful only during certain parts of the flight and passed on pointlessly the rest of the time. The fact of being able to change these configurations in the course of flight also constitutes in a sense an earning in term of spectral efficiency.

Conclusion

The COFDM modulation already demonstrated many of its advantages in terms of considerable improvements on the quality of the telemetry link in zones where multipaths occurred. The global system spectral efficiency, further improved by the use of multiple antennas combined with COFDM, should now help us to optimise the Hertzian space so that we can give answers to the new needs expressed for the A380 program.

Analysis and Matching of Small Loop Antennas for MicroRadio Transmitters

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Introduction

Small loop antennas outperform small dipole and small monopole antennas when they are operated in close proximity to carnal bodies such as mammals. [1]

A small loop antenna is defined as a conducting loop with a perimeter of less than 15% of the transmit wavelength. Loops are often etched directly onto the printed circuit board for simplicity and cost. Figure 1 is an equivalent circuit model of a small loop.

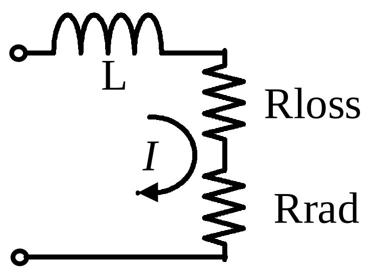


Figure 1. Equivalent Circuit of a Small Loop Antenna.

Calculating Loop Inductance

Grover [2] provides a compact general formula for the inductance of a single turn loop:

$$L = \frac{\mu}{2\pi} \cdot l \cdot \ln\left(\frac{4 \cdot A}{l \cdot \phi}\right) \qquad (1)$$

A is the loop area, *l* is the loop perimeter and ϕ is the wire diameter. Dimensions are in meters and $\mu = 4\pi \cdot 10^{-7}$.

Calculating Loop Radiation Resistance

Fujimoto [3] provides the formula for radiation resistance of a small single-turn loop:

$$Rrad = 31{,}171\ \frac{A^2}{\lambda^4} \qquad (2)$$

A is the loop area and λ is the wavelength, in meters.

Calculating Loop Loss Resistance

Johnson [4] provides a formula for the high frequency resistance of copper wire:

$$Rloss = 8.3 \cdot 10^{-8}\ \frac{l}{\phi} \sqrt{f} \qquad (3)$$

l is the loop perimeter and ϕ is the wire diameter in meters. *f* is frequency in Hertz.

Calculating Efficiency

Current flowing through Rrad is converted to radiated RF power. Current flowing through Rloss is converted to heat. We may therefore write the efficiency of the loop as:

$$Efficiency = \frac{Rrad}{Rrad + Rloss} \qquad (4)$$

Numerical Example

A small rectangular loop antenna has dimensions of 20mm x 30mm. The wire diameter is 1mm. The frequency is 173MHz. Using the above formulas, we calculate the following:

Inductance	63.6nH
Radiation Resistance	0.0028Ω
Loss Resistance	0.11Ω
Efficiency	2.5%

Table 1. Equivalent Circuit of a 20mm x 30mm x 1mm Loop Antenna at 173MHz.

We note from our calculations that 97.5% of the RF energy supplied to the antenna will be converted to heat and we conclude that small loop antennas may be inefficient. We also note from the equation for radiation resistance that if we double the loop area, the radiation resistance and therefore the efficiency is (almost) quadrupled.

Matching Milli-Ohms to Kilo-Ohms

We have seen that small loop antennas have high reactance and low resistance. We may cancel the inductive reactance with a series capacitor, but the low resistance, in the milliohm range, must somehow be translated to the kilo-ohm range to extract maximum power from CMOS radio frequency integrated circuit transmitters.

Transformer Matching Approach

Figure 2 shows one approach to the resistance matching problem. A second, smaller coupling loop is placed in close proximity to the loop antenna. The two loops act as a loosely coupled transformer. We designate the smaller coupling loop as the primary winding Lp and the loop antenna as the secondary winding Ls.

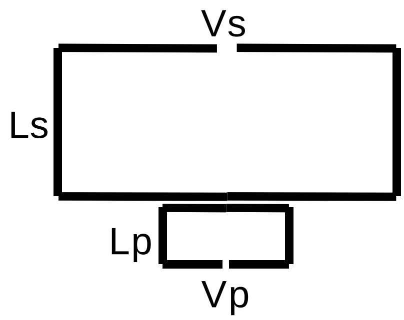


Figure 2. Small Loop Antenna Ls with Coupling Loop Lp.

Primary and Secondary Winding Inductances

The self-inductance of a transformer's primary winding is determined by leaving the secondary winding open circuit while measuring inductance on the primary side. From Figure 3 we note that the self-inductance of the primary winding will therefore only be determined by the inductance of the primary loop, Lp, and we may use equation (1) to calculate it.

Likewise, the self-inductance of a transformer's secondary winding is determined by leaving the primary winding open circuit. From Figure 3 we note that the self-inductance of the primary winding will be the inductance of the secondary loop, Ls, and we may use equation (1) to calculate it.

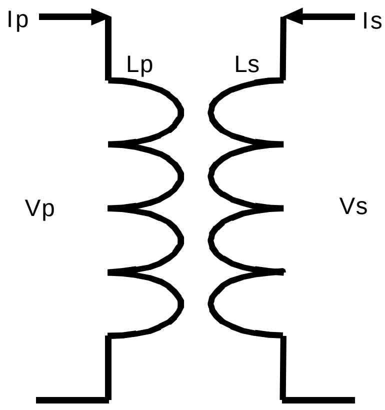


Figure 3. Transformer Model of Two Magnetically Coupled Loops

Transformer Transfer Inductance

The transfer inductance or mutual inductance M of a transformer determines the open-circuit voltage over the secondary winding due to current flowing in the primary. Similarly, mutual inductance determines open-circuit voltage in the primary due to current flow in the secondary. To fully describe the effect of primary, secondary and transfer inductance, we write the basic transformer voltage and current equations as

$$Vp = j\omega\, Lp\, Ip + j\omega\, M\, Is \qquad (5)$$

$$Vs = j\omega\, Ls\, Is + j\omega\, M\, Ip \qquad (6)$$

We note from equation (1) that the primary voltage consists of two parts: A local voltage part $j\omega \cdot Lp \cdot Ip$ and a transfer voltage part $j\omega \cdot M \cdot Is$. The local voltage contribution is due to primary current and primary inductance. The transfer voltage part is due to current in the secondary and transfer inductance M.

Equations (5) and (6) fully describe the general impedance transforming characteristics of any lossless transformer. After some manipulation, we find the secondary-to-primary resistance transformation of a transformer to be given by

$$R_{PRIMARY} = (\omega M)^2 \cdot \frac{1}{R_{SECONDARY}} \qquad (7)$$

Examining equation (7), we find that the low resistance of the loop antenna, which is in fact $R_{SECONDARY}$, is first inverted and then multiplied by $(\omega M)^2$. Therefore if we can control $(\omega M)^2$ we can also control the required impedance transformation.

Calculating Transfer Inductance

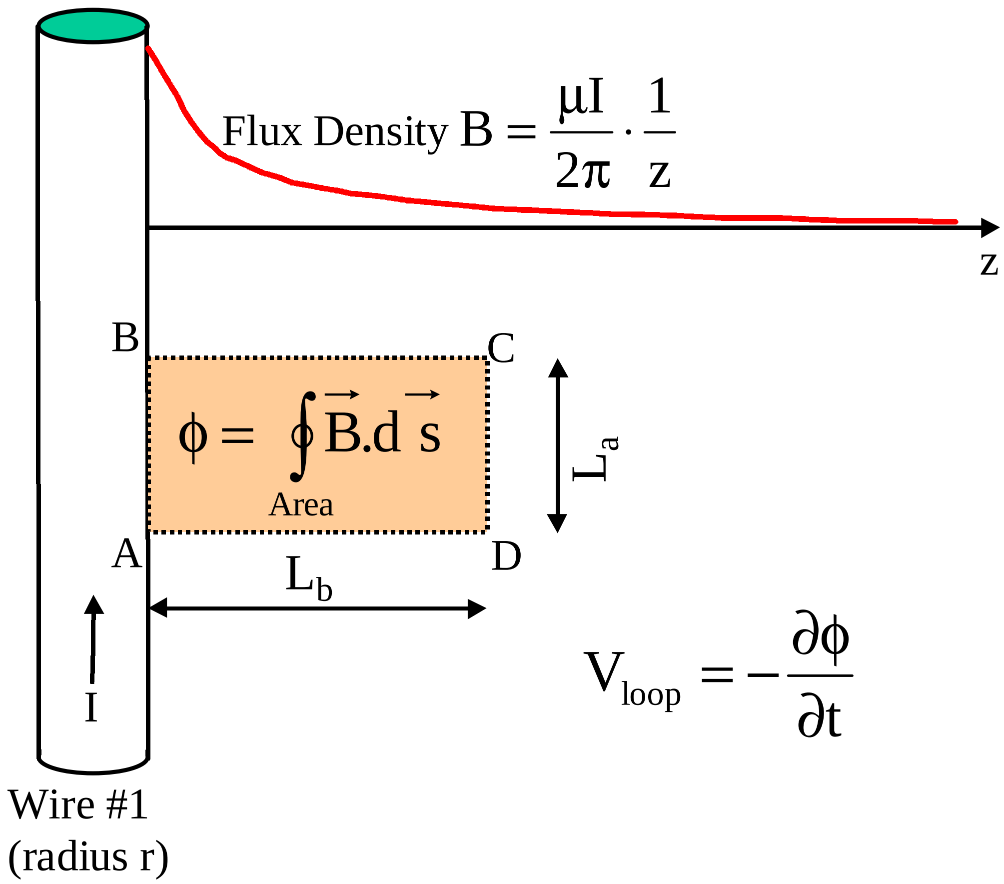


Figure 4. Voltage around a Finite Loop near a Current Carrying Wire.

Using Ampere's law we simply state the flux density **B** for an infinite wire as

$$B = \frac{\mu I}{2\pi} \cdot \frac{1}{z} \tag{8}$$

Where $\mu = 4\pi \cdot 10^{-7}$, z is the distance from the wire in meters and I the current in Amperes.

Referring to Figure 4, we now integrate flux density **B** over the loop area ABCD to find total flux enclosed by loop ABCD. Note that loop segment AB is at r, the radius of the current carrying wire.

$$\phi = \frac{\mu I}{2\pi} \cdot \int_{r}^{L_b + r} L_a \cdot \frac{1}{z}\, dz = \frac{\mu I L_a}{2\pi} \cdot \ln\left(1 + \frac{L_b}{r}\right) \tag{9}$$

Finally we find transfer voltage through the rate of change in the flux ϕ

$$V = -\frac{\partial \phi}{\partial t} = j\omega I \frac{\mu}{2\pi} \cdot La \cdot \ln\left(1 + \frac{L_b}{r}\right) \tag{10}$$

From (10) we may conclude that the transfer inductance between an infinitely long round wire of radius r and a small loop is exactly given by

$$M = \frac{\mu}{2\pi} \cdot La \cdot \ln\left(1 + \frac{L_b}{r}\right) \tag{11}$$

This is a useful result when a large loop and small loop are in close proximity, because the side of the large loop will model an infinitely long wire with reasonable accuracy. This provides us with a simple expression for equation (7), and we are therefore able to find primary loop dimensions needed for the impedance transformation between low loop resistance and the kilo-ohms needed to match to CMOS RFICs.

Conclusion

We have used a loosely coupled coplanar transformer to match a small loop antenna to the kilo-ohms impedances required by CMOS radio frequency integrated circuits. As with any transformer, we find that the resistance transformation is primarily driven by $(\omega M)^2$ where M is the transfer inductance, also known as mutual inductance. Finally, armed with a simple approximation for mutual inductance, we find that we have all the tools to achieve impedance matching and analysis of small loop antennas.

References

[1] K. Fujimoto and J.R. James, Mobile Antenna Systems Second Edition Artech House 2001 ISBN 1-58053-007-9

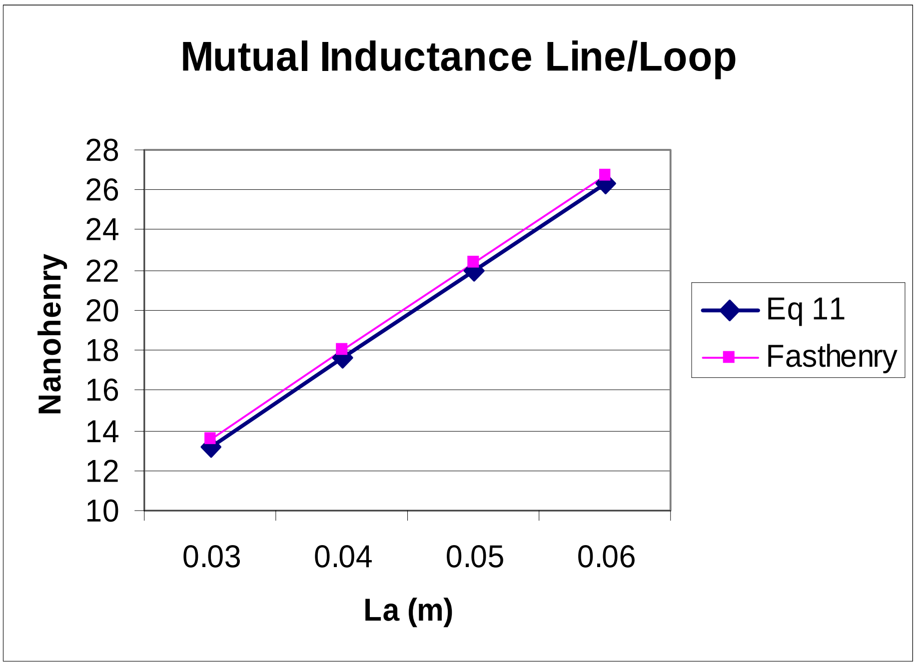
[2] Frederick W. Grover, Inductance Calculations Working Formulas and Tables Dover Publications Inc. 1946

[3] K. Fujimoto, A. Henderson, K. Hirasawa and J.R. James, Small Antennas Research Studies Press LTD 1987 ISBN 0 86380 048 3 (Research Studies Press) ISBN 0 471 91413 4 (John Wiley & Sons Inc)

[4] Howard Johnson, High Speed Digital Design: A Handbook of Black Magic Olympic Technology Group ISBN 0-13-395724-1

Appendix 1.

Figure 5 shows M calculated by the field solver Fasthenry and by equation 11. Wire diameter is was 1mm and Lb was 4mm. La was varied from 30mm to 60 mm.



FLIGHT TEST INSTRUMENTATION

The Instrumentation Unit incorporated in the ASRAAM Telemetered Operational Missile Variant

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Abstract

This paper describes the system design of the Instrumentation Unit (IU) incorporated in the ASRAAM Telemetered Operational Missile (TOM) to enable the assessment of missile performance in development and production. The IU together with a body tube, Antennas and Break Up Unit (BUU) is a self-contained unit designed to replace the Warhead in an Operational Missile (OM) to create a TOM.

The IU is responsible for the collation of data from within the missile, formatting the data into a PCM stream which is then transmitted to a telemetry ground station via an r.f. data link.

The IU contains a Flight Termination Receiver (FTR) which provides signals to the BUU which enables destruction of the missile on various pre-defined conditions or on command. It also contains a Transponder, which enhances missile-tracking performance, by transmitting a unique response when interrogated by the ground radar.

Various standards of IU with different characteristics have been developed for TOMs, to enable operation at different trials range facilities throughout the world.

Introduction

ASRAAM is an Advanced Short Range Air to Air Missile developed by MBDA UK. Its key features are an infra-red imaging Seeker, a multi microprocessor Electronics and Power Unit (EPU), an active infra-red Fuze and four independent control surfaces. The Seeker employs a focal plane array detector of 128 x 128 pixels. The missile is approximately 2.9 metres long and 166mm diameter and is rail launched from a wide variety of aircraft. Missile development proving trials were conducted principally at Eglin Air Force Base (AFB) in Florida. Missile firings have also been carried out at White Sands Missile Range, China Lake and Patuxent River in the US, Aberporth and Hebrides in the UK, Woomera in Australia and at Salte Di Quirra range in Sardinia. For all these trials the Warhead section was replaced with a purpose designed and built IU which provided the principal functions of telemetry, radar transponder and flight termination.

Description of Instrumentation Unit

The IU is responsible for the collation and encryption of the missile analogue data, Seeker image data, digital missile data and fuze status data into a PCM data stream which is then transmitted to a telemetry ground station via an r.f. data link. The IU is operational both before and after missile launch. The IU also provides signals from the FTR to the BUU which enables destruction of the missile on various pre-defined conditions or on command. A Transponder is included, which enhances missile-tracking performance, by transmitting a unique response when interrogated by the ground radar.

The IU interfaces electrically with Electronics and Power Unit (EPU – 'the missile computer'), and its telemetry facility is a PCM/FM system operating in the NATO E-band. Trials site encryption key codes (keys, variable) can be loaded via an external connector, in the missile skin.

Various standards of IU with different characteristics have been developed for TOMs, to enable operation at different trials range facilities throughout the world. For example, IUs have operated in telemetry missiles at the US Eglin AFB and White Sands Missile Range in the lower E-band and operated in missiles in the upper E-band at the UK Aberporth and Hebrides trial sites.

The major functional blocks comprising the IU and the Break-Up Unit (BUU) shown in Figure 1 are; Telemetry System which includes an encryption facility and associated antenna, Transponder System and associated antenna, Flight Termination System with associated antenna and Power Supply System.

Figure 1 - Instrumentation Unit block diagram

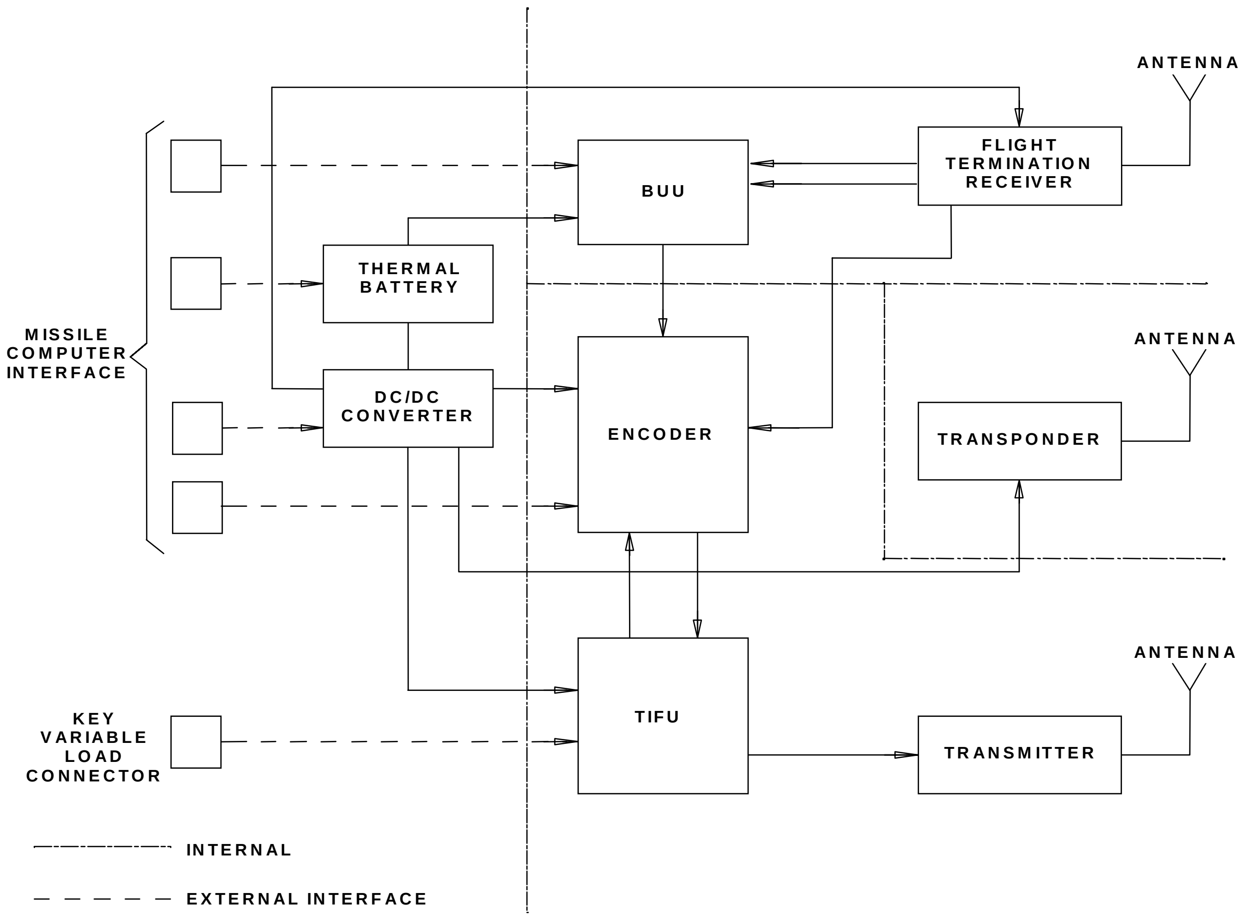
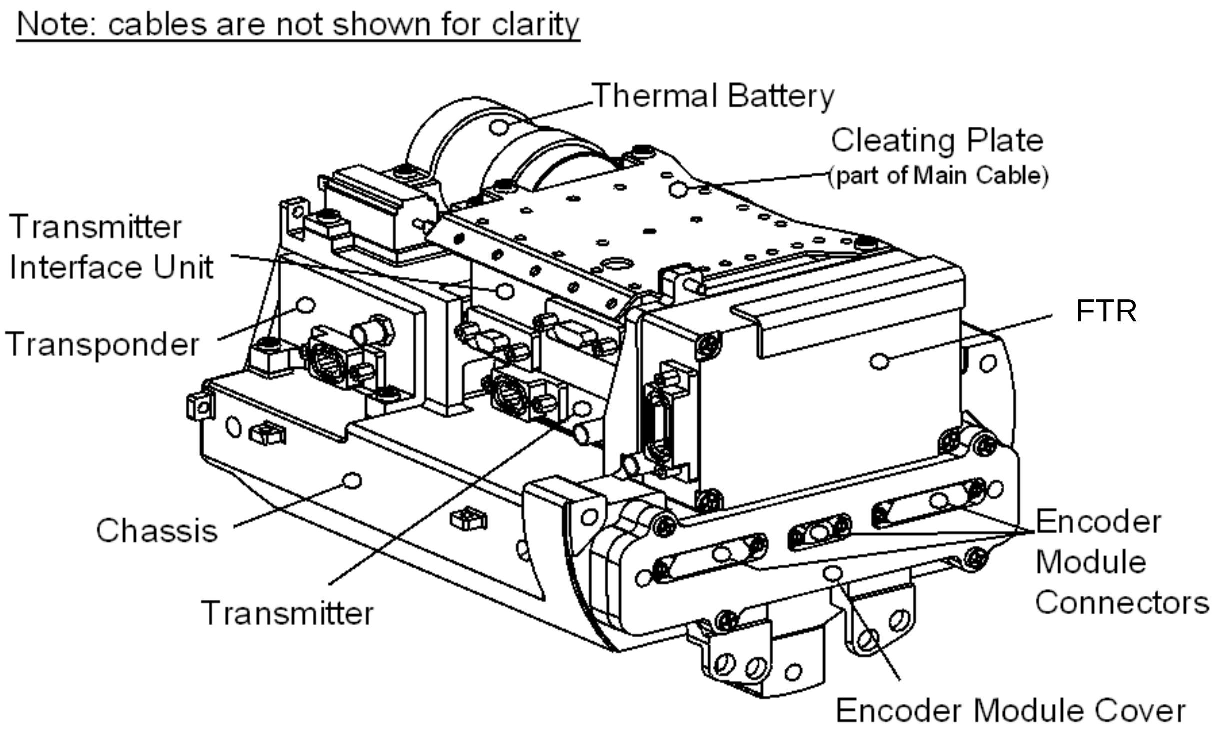


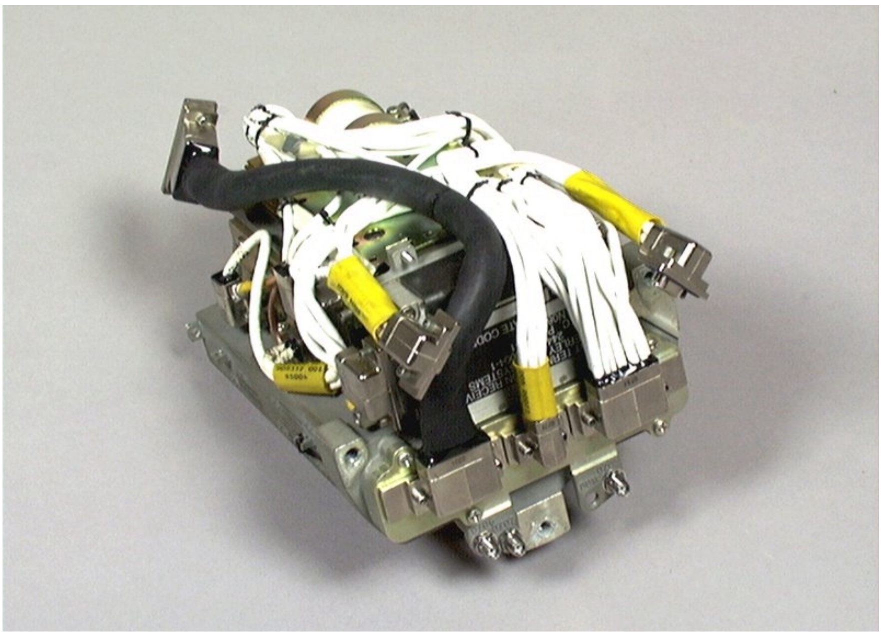
Figure 2 shows a schematic view of the mechanical configuration of the IU depicting the major component parts.

Figure 2 - Instrumentation Unit schematic drawing



A photograph of the IU assembly is shown below in Figure 3 and the unit is approximately 160mm in diameter and 240mm long in dimension.

Figure 3 – Photograph of Instrumentation Unit



Initialisation

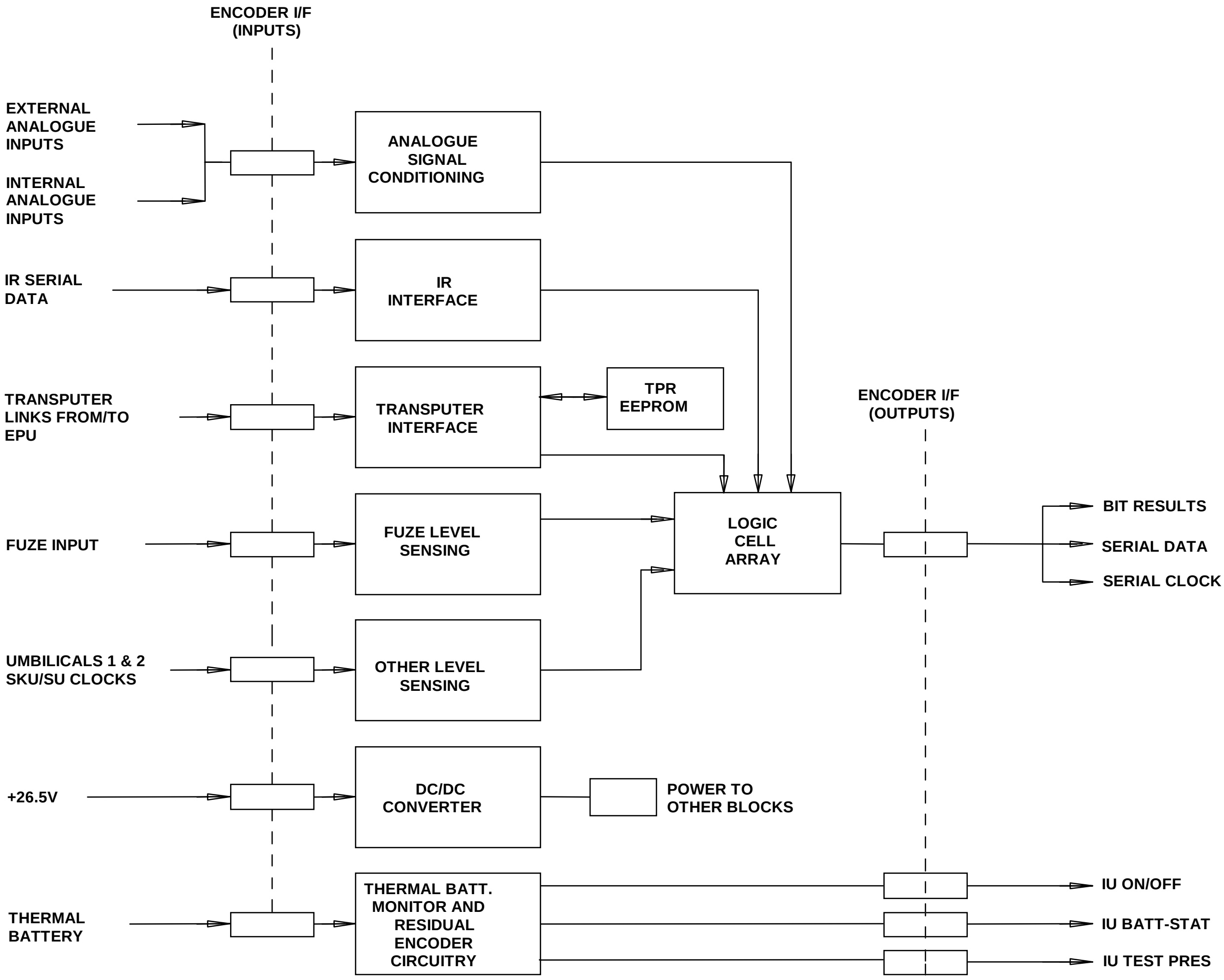
Before the missile is launched from the aircraft, the IU functions can be enabled/disabled via an IU On/Off signal selected at the aircraft 'TELE RF ON/OFF' switch and passed to the IU via the missile Analogue Umbilical. Throughout the system states; pre-launch, launch and free flight, the status of the IU thermal battery is monitored. The IU Thermal Battery is ignited by a pulse signal from the parent aircraft when the missile fire button is pressed and the missile is to be launched.

Telemetry System

The Telemetry System comprises of the Encoder Module, the Transmitter Interface Unit (TIFU) and the Telemetry Transmitter with associated Antenna. A description of the telemetry system components are given below;

Encoder Module
A schematic of the functions of the Encoder are shown in Figure 4.

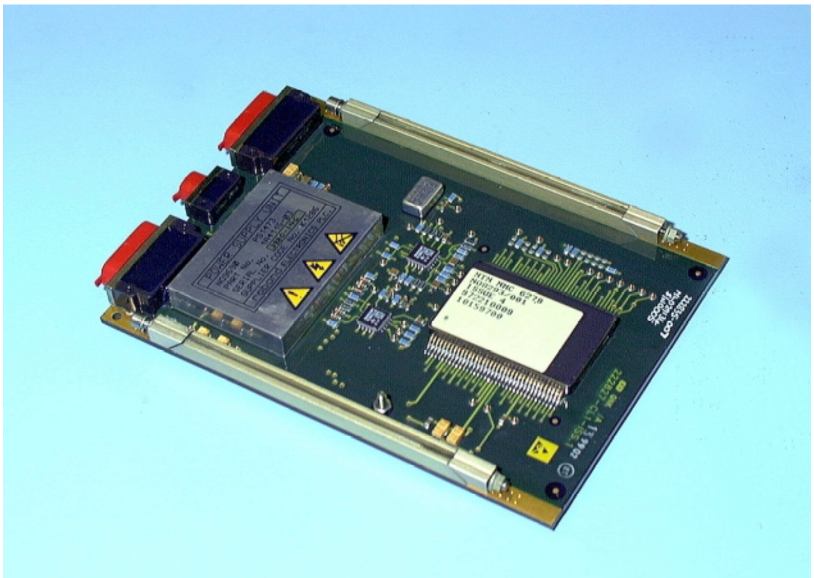
Figure 4 - Encoder block diagram



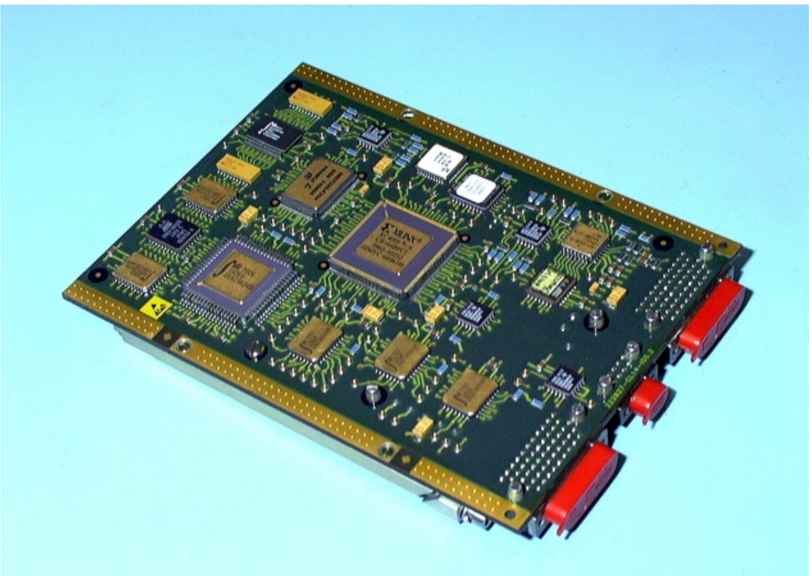
The Encoder thermally constrained circuit board of dimensions 165mm x 120mm x 23mm utilises surface mount component technology and is illustrated in Figure 5.

Figure 5 – Photographs of either side of the Encoder Module

Top Side



Under Side



The board is located within an electromagnetically sealed enclosure and consists of a number of separate interface circuits providing data to a Logic Cell Array (LCA) which in turn formats the data into the telemetry frame. The Encoder accepts data from other missile subsystems in one of the following formats; discrete signals such as the proximity fuze output, serial digital links such as the four RS422 links with the missile EPU and the link with the Seeker and analogue signals in a variety of signal levels and formats.

The Encoder processes all this data into a clock and PCM data stream outputs, both in RS422 format. It also performs a built in test function the result of which is included in the output data.

A comparator on the Encoder board senses the level of the discrete inputs (Fuze output, umbilical breaks, Seeker and Sensor clocks). The output is sampled and the results placed into bit locations within the ‘Fuze byte word’.

As the missile EPU consists of an array of Inmos Transputers, there is a corresponding transputer in the IU. A principal feature of the Transputer is that each processor has four serial links thus enabling arrays of processors to be constructed. Four of these links provide the data exchange between the EPU and the IU. Each link carries message based data at a rate of 10Mbit/s. The IU processor strips off the message headers and writes the remaining data to one of three blocks of dual port RAM. In the event that a complete frame of data is not available at the start of a telemetry frame output, the transputer data part of the frame will be packed with the value AA_h and a flag will be set in the subframe ID word.

To enable the design to function without a synchronous clock input, the output telemetry frame rate exceeds the input frame rate. The dual port RAM forms the link between the two different rates. Processed data frames are written into the three memory blocks sequentially. Access to each frame is controlled by semaphore logic incorporated in the dual port RAM. Before writing a frame into a memory block, the transputer sets the corresponding semaphore flag thus prohibiting access from the other side. The incoming frame is then written (after data selection and compaction) and finally the semaphore flag is reset.

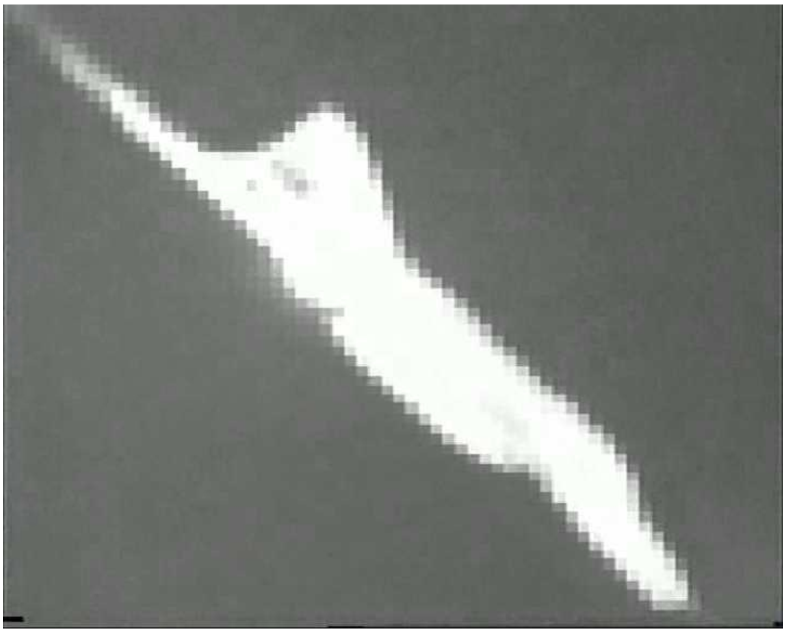
The LCA reads the frames in the same sequence but will only access a frame when the corresponding flag is reset. This indicates that the transputer has written a complete frame.

The function of the Seeker interface is to receive complete frames of seeker infra-red data and reduce the data to an amount which can be accommodated by the system. Due to bandwidth limitations of 10Mbit/s only every other frame of Seeker data is telemetered. The Seeker infra-red data is received over a ‘Taxi’ link (a proprietary high frequency serial device produced by AMD) operating at 120Mbit/s. An AM7969 Taxi Receiver configured in 10 bit data 2 bit control mode is used to decode the serial data. Parallel data is output from the receiver at 10Mword/s regardless of the input rate which is nominally 10Mword/s.

The infra-red image data, where each pixel comprises 2 bytes of data, is formatted into blocks with three blocks making up the infra-red data part of the telemetry subframe. Due to telemetry data limitations, only a circular area of the 128 x 128 array and only every other frame of data is telemetered. In the event that a complete frame of data is not available then the entire infra-red data part of the next two major frames will be filled with packing data AA_h.

Figure 6 shows an example of an infra-red image obtained from processing telemetry trials data.

Figure 6 – Infra-red image obtained from telemetry data



To overcome the need for a synchronous clock input, the telemetry output frame rate exceeds the input rate. The link between the infra-red interface and the LCA is formed by 3 FIFOs. Frames are written into the FIFOs in a cyclic manner with each FIFO being reset before writing commences. Frames are read by the LCA in the same sequence with access being controlled by the state of the flag on the FIFO being accessed.

The analogue interface accepts 36 data inputs from various sources in the missile. These are filtered, sampled and digitised at a rate appropriate to the characteristics of the data. The LCA initiates the analogue to digital conversion after selecting the channel to be sampled.

The primary function of the Frame Formatting Logic is to interface to and gather data from the interfaces defined above and format that data into the required sub-frame format. The data is then converted into an NRZ-L serial bit stream and output together with a synchronous clock.

The LCA also performs a Built in Test to a functional block level and produces a 625kHz clock for use by the DC/DC converter to minimise the impact of any switching noise.

The Frame Formatting Logic has been implemented using a Xylinx Logic Cell Array operating at 40MHz input clock rate. The LCA is configured t operate in ‘Master’ mode and therefore, at power up, uploads its internal configuration from a 32 x 8 EPROM. The frame format contains the usual subframe identification counter and a 24 bit frame synchronisation code.

The total telemetry data capacity is allocated approximately in the following proportions:-

Seeker - 60%, Electronics Unit - 35%, Analogue data - 2%, Discrete data – 2% and Frame synchronisation – 1%.

The Encoder output is an NRZ-L PCM data stream at a rate of 10Mbits/s in accordance with IRIG 106.

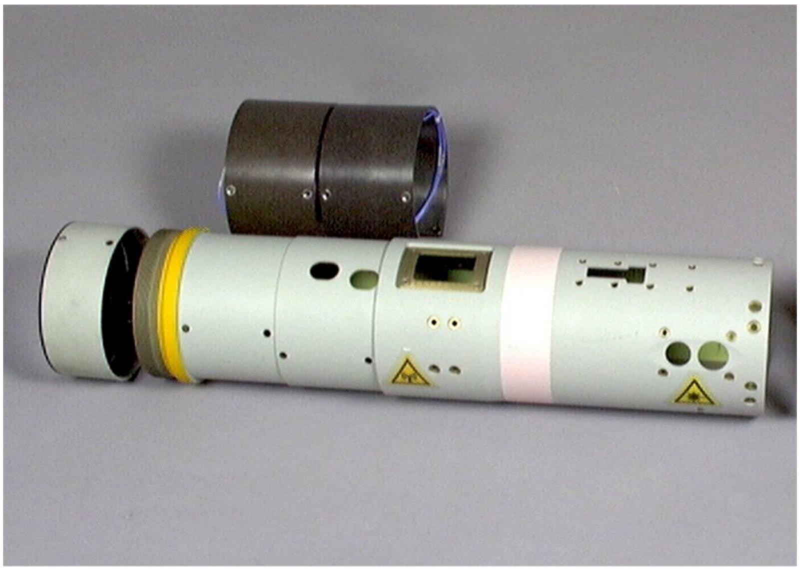
Transmitter Interface Unit (TIFU)
The TIFU, sometimes known as an Interface Support Module (ISM), of dimensions 83mm x 44mm x 36mm is secured to the Encoder casting enclosure. The TIFU is an L3 Telemetry East model ISM-900 which provides the functions of data/clock buffering and filtering, power isolation, pre-modulation filtering of the 10Mbits/s data for transmission, key variable loading and power supply for the embedded encryption device. The TIFU encrypts the telemetry data prior to transmission.

Telemetry Transmitter
The Telemetry Transmitter of dimensions 64mm x 51mm x 17mm is secured to the Encoder casting enclosure. The FM Transmitter is a L3 Conic model CTS-905 which operates at a frequency between 2200MHz and 2400MHz, pre-set at the manufacturer prior to delivery. The minimum output power is 5Watts.

Four standards of Transmitter with different frequencies have been used to accommodate the facilities at various trial sites, two in lower E-Band and the other two in upper E-Band.

Telemetry Antenna
The telemetry and transponder antennas are combined into the same circumferential physical structure, located in a recess in the outer skin of the missile's body tube. Figure 7 shows the antenna sets used and the missile structure.

Figure 7 – Photograph of Telemetry/Transponder Antenna, FTR Antenna and the missile body tube structure



The telemetry/transponder wrap-around conformal antenna is recessed to preserve the missile's aerodynamic profile and the antenna surface is covered with an ablative heat shield.

The telemetry antenna has a number of linearly polarised radiating elements rendering nearly omnidirectional coverage with a typical gain of –3dBi. The telemetry antenna is compatible with the range ground station, as it is receives both left and right hand circular polarisation.

Two standards of telemetry antenna are used for the various missile build variants, one for operating in the lower E-Band and the other for upper E-Band use.

Transponder System

The Transponder System comprises of the Transponder and associated antenna. A description of the two transponder system components are given below;

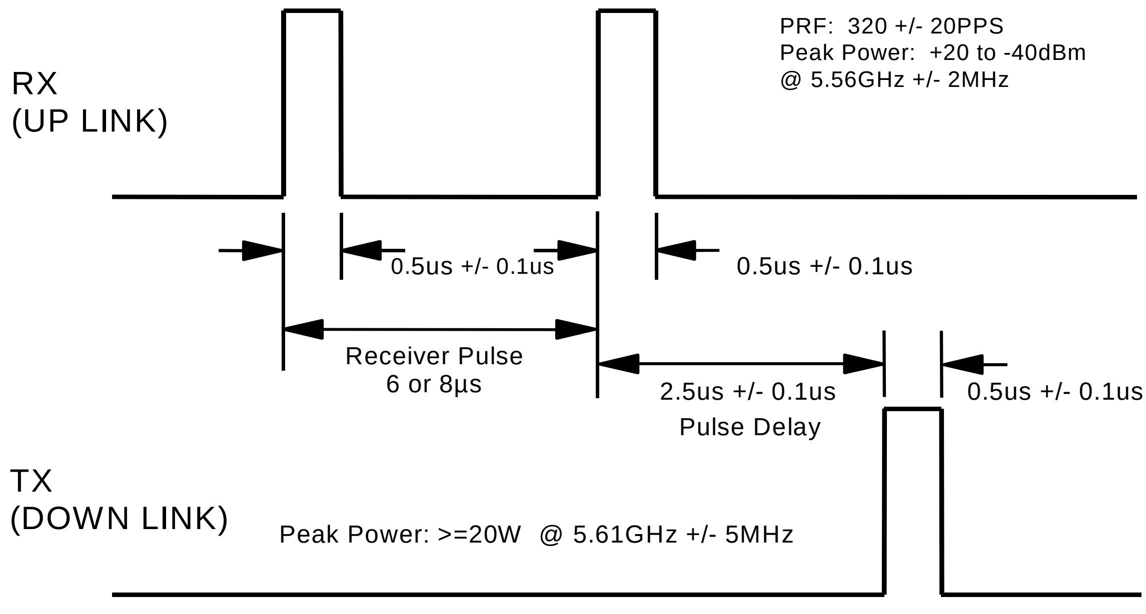
Transponder

The Transponder of dimensions 103mm x 57mm x 32mm is secured to the Encoder casting enclosure. The Transponder is a Herley Industries HSST20C-1 which has a minimum peak power output of 20Watts and a receiver sensitivity of –40dBm.

The function of the Transponder is to generate a return response when interrogated by the range instrumentation radar. This allows the radar to check that it is tracking the correct missile.

The fundamental Transponder characteristics are given in Figure 8.

Figure 8 - Fundamental Transponder Characteristics



The Transponder operates in the NATO G-band with the up and down link frequencies between 5.5GHz and 5.7GHz , and in order that it can distinguish between random inputs, and specific radars that are tracking it, a double-pulse interrogation mode is used. The spacing between the leading edges of the two pulses forming the pair is the receiver pulse code. The pulse code for the various IU standards is either 6µs or 8µs. Each Transponder system will only respond to a specific pulse code, and on receipt, will respond by transmitting a single-pulse return.

Transponder Antenna

The transponder antenna is combined with the telemetry antenna as previously described. The antenna operates in the NATO G-band and has adequate bandwidth to cater for the up and down link frequencies. The transponder antenna consists of an array of linearly polarised radiating elements orientated at 45° to the missile's longitudinal axis in order to preserve both horizontal and vertical polarisation. The antenna provides nearly omnidirectional coverage with a typical gain of –6dBi and is compatible with the range tracking radar antenna, which is vertically polarised.

Flight Termination System

The Flight Termination System (FTS) consists of a Flight Termination Receiver with associated antenna, and a Break-Up System comprised of a Break-Up Control Unit (BUCU) and break-up Linear Cutting Charge (LCC).

Destruction by the FTS is initiated by the following:

Receipt of the Command Destruct signal.

Output of the override self-destruct timer.

Loss of the Flight Termination System (tone A) for longer than the specified dropout time.

Loss of either power supplies (IU or EPU thermal battery).

Flight Termination Receiver

The Flight Termination Receiver (FTR) of dimensions 84mm x 56mm x 24mm is secured to the Encoder casting enclosure. The FTR is a Herley Industries model HFTR120, which operates in the NATO B-band and utilises the standard IRIG three-channel decoding system. The received r.f. signal is decoded into a combination of the three audio tones, and the logical combination of simultaneous tones determines the output from the FTR to the BUU.

The tone combination and logic is in accordance with IRIG RCC 313-94 and that typically used is shown in Figure 9.

Figure 9 - IU Flight Termination Receiver switching tones

TONE (STATUS)			RESULTS
A	B	C	
ON	OFF	OFF	STANDBY
ON	OFF	OFF - ON	ARM
ON	OFF – ON	ON - OFF	TERMINATE
OFF			TERMINATE produced after 1.5 or 4 sec

FTR Antenna

The FTR antenna is a circumferential aerial, located in a recess in the outer skin of the missile's body tube section. The FTR wrap-around conformal antenna is recessed to preserve the missile's aerodynamic profile and the antenna surface is covered with an ablative heat shield.

The linearly polarised FTR antenna operates in the NATO B-band and has provides nearly omnidirectional coverage with a typical gain of –8dBi. The FTR antenna is compatible with the range ground station which transmits either left or right hand circular polarisation, depending on the specific trials sites facilities.

Power Supply System

During air-carriage, the primary source of power to the IU is the aircraft +28 V supply, modified for use by the IU dc to dc converter.

During free flight, the IU is capable of operating from the output of the +28 V IU thermal battery (type ATL), which is manufactured by MSB. At the same time, the +56 V EPU thermal battery will be available as a backup supply to the BUU.

Conclusion

The IU has operated successfully at numerous trial sites in the United States, United Kingdom, Italy and Australia providing significant amounts of invaluable data for missile performance analysis and model validation. It has achieved an operating range in excess of 100km. Production of the ‘In-Service’ variants of the IU has started, provided to the customer either in Telemetered Operational Missiles or as modification kits.

Abbreviations

AFB	Air Force Base
ASRAAM	Advanced Short Range Air to Air Missile
BUU	Break Up Unit
EPU	Electronics and Power Unit
FIFO	First In First Out
FM	Frequency Modulation
FTR	Flight Termination Receiver
FTS	Flight Termination System
IRIG	Inter-Range Instrumentation Group
ISM	Interface Support Module
IU	Instrumentation Unit
LCA	Logic Cell Array
LCC	Linear Cutting Charge
NRZ-L	Non Return to Zero - Level
OM	Operational Missile
PCM	Pulse Code Modulation
RAM	Random Access Memeory
RCC	Range Commanders Council
r.f.	radio frequency
TIFU	Transmitter Interface Unit
TOM	Telemetered Operational Missile

A WEB-ORIENTED APPROACH TO DATA DISTRIBUTION AND WORK COLLABORATION IN A FLIGHT-TEST ENVIRONMENT

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Abstract

To survive in the new economy, companies are looking beyond the four walls of traditional organizational boundaries. Information systems and business processes are being replaced by web-enabled solutions to achieve seamless integration with systems and processes of their customers, business partners and suppliers, some of them living in another countries, miles away.

The challenge now is to take established legacy systems and integrate them into an e-business strategy to make information more accessible to its final consumers. In this process, old applications are extended or replaced by new ones that can be accessed from a browser anywhere in the world.

Behind these web-applications, there is a relational database that consolidates data from various sources, achieving more consistency and availability than the original databases.

This paper describes how a young flight test organization could benefit from this technology, creating new means of communication and collaboration and improving its internal processes. Some benefits of this approach, such as flight test data distribution among multiple test sites and work collaboration of multi-national teams in the development process of a new aircraft, will be covered in some detail, as well as some key architectural aspects involved in the implementation of web-oriented information distribution systems.

Keywords

Flight-testing, Internet, World Wide Web, Information Distribution.

Introduction

Web applications are the latest incarnation of the so-called “3-Tier Architecture”, which introduced three entities in application design:

- “Front-End Tier”: also called “Presentation Layer”, it is the user environment, including the Graphics User Interface (GUI).
- “Middle Tier”: also called “Business Logic Layer”, contains the business logic in the form of components that ensure that the data flow represents the everyday business tasks, guaranteeing that sets of operations are executed atomically across multiple data servers.
- “Back-End Tier”: also called “Data Services Layer”, ensures that data is available to all applications, all the time and without inconsistencies.

These three logical tiers do not mean three physical tiers, they can be distributed in many different ways to provide best performance and management capabilities.

In a traditional web application, the “front-end tier” runs what it is called “Internet browser” as Netscape Navigator or Microsoft Internet Explorer, which process HTML (“Hypertext Markup Language”) pages and script code. The “middle tier” can be a web server as Microsoft IIS with server extensions, as ASP or ColdFusion that interacts with PowerBuilder, Java beans or COM components. The “back-end tier” can be unstructured data as a mail server or a RDBMS (“Relational Database Management System”) as Oracle or Sybase. A single application can access many types of data providers and the integration is provided by the “middle tier”.

The protocol between the “front-end” and “middle tiers” is traditionally HTTP (“Hypertext Transfer Protocol”), but other protocols as FTP (“File Transfer Protocol”) are also supported.

There is a large amount of web-oriented software development tools available today, therefore, it seems natural that programmers do take a look into these tools seeking greater performance in developing and deploying software and, as will be shown here, many times it makes perfectly sense to choose these tools to fulfill software system requirements instead of traditional compiled programming language tools.

Flight Test Data Distribution

Flight testing in general produces a fairly large amount of data. Each test flight can produce millions of samples per hour that need to be filtered, plotted and analyzed. Traditional software applications built to perform these tasks are mostly “client-server”, another application design in which a user workstation running specialized software reads data stored in a server accessible via a network. Performance constraints in this design are normally network related: the available bandwidth needs to accommodate as much traffic as possible to provide a good response time on the user’s side. Sites running this type of “client-server” application for elaborating flight test data tend to be small, connecting users in the order of hundreds to multiple servers (Figure 1).

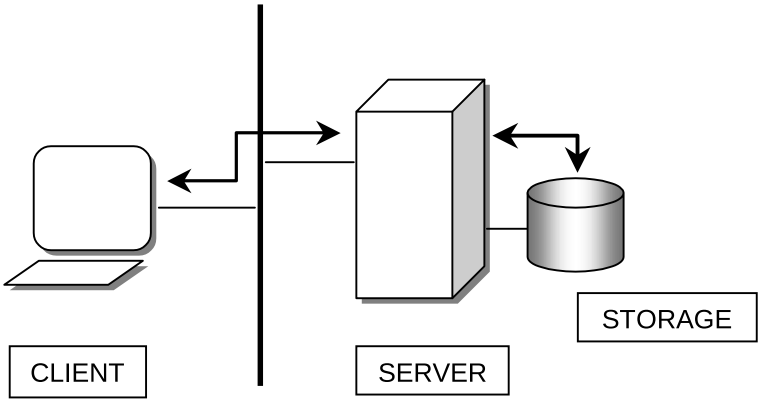

Figure 1 - Client-Server Application Design

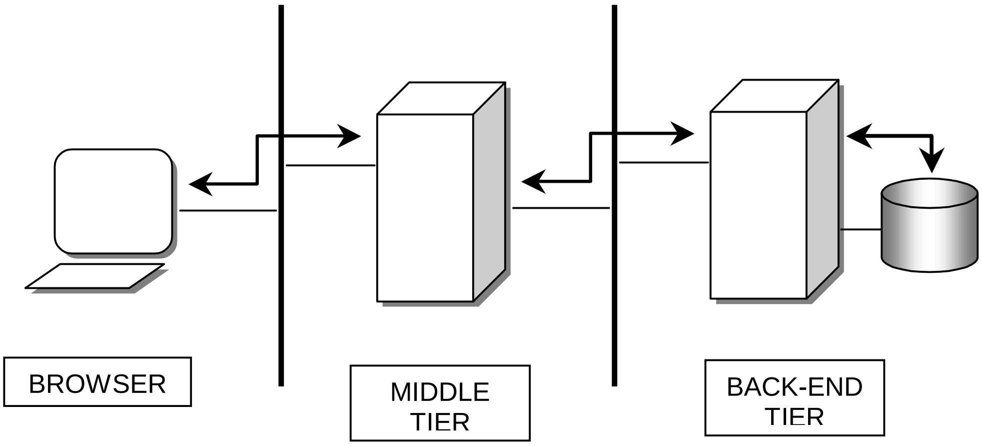

Figure 2 - 3-Tier Application Design

It is not uncommon that flight tests are performed in multiple test sites. In this case, it might be necessary to provide some kind of network connection between the sites, allowing the "client-server" application to run unchanged when a user in one site needs to access data stored in another. Network bandwidth will again play an important role, and the cost of it may be also significant when a third party provides this type of service. If we consider the fact that potential users may not belong to the same organization, it becomes more evident that a "client-server" application may not be suitable for integrating multiple, eventually heterogeneous test sites seamlessly.

"3-Tier" applications, in particular web-oriented ones, tend to use a different approach when they need to manipulate large amounts of data. In a web application, users send requests to the "middle tier" server, which in turn accesses the appropriate service in he "back-end tier" (Figure 2). User requests tend to be small in terms of quantity of bytes of data, an HTML page for instance.

The results from the “back-end” server may vary, but due to the fact that the assumed network bandwidth to the user is very limited (as limited as a phone line can be), it tends to be small as well. Therefore, services available in “back-end” servers are designed to elaborate as much as possible the results of user requests before sending them back to the users.

A hypothetical “Data Scan Service” designed to extract the minimum and maximum values of a particular flight test data item, for instance, “Left Engine Power Level”, within a specified time interval may scan thousands or even millions of data samples in a large binary file before producing a small data pair. In this case, the amount of data transferred from the user to the “back-end” server and back to the user is insignificant.

A sample web application that can access the “Data Scan Service” could be built very quickly to work as follows (Figure 3):

1. A user opens up an “Internet browser” in his computer and establishes a HTTP communication with a known “middle tier” server in the network;
2. The “middle tier” server queries the “back-end tier” server and sends a HTML page back to the user describing what services are available;
3. The user receives the HTML page, modifies it requesting the “Data Scan Service” and sends it back to the “middle tier” server;
4. The “middle tier” server reads the modified HTML page, detects the user request for the service, queries the “back-end” server for available flight test data items and time intervals, builds a new HTML page containing the returned information and sends it back to the user;
5. The user in turn modifies this new HTML page entering a particular data item and time interval and sends it back to the “middle tier” server;
6. The “middle tier” server receives the modified HTML page, check for inconsistencies and sends a message to the “back-end” server requesting the “Data Scan Service” passing the user entered information as parameters;
7. The “back-end” server starts the service, waits until it completes and sends the results back to the “middle tier” server;
8. The “middle tier” server receives the message, builds another HTML page with the results provided by the service and sends it to the user.

A side effect of this design is the complexities of the actual data location and organization can be transferred from the user interface to the “middle-tier” server. This facilitates integration of heterogeneous sites without users having knowledge of where or in which format data is available. In such a case, a user request could be automatically routed to a server located in another site through a private or public network (Figure 4). Furthermore, adding, moving or replacing servers, or data among servers at the “back-end tier” can be done without interference in the user environment.

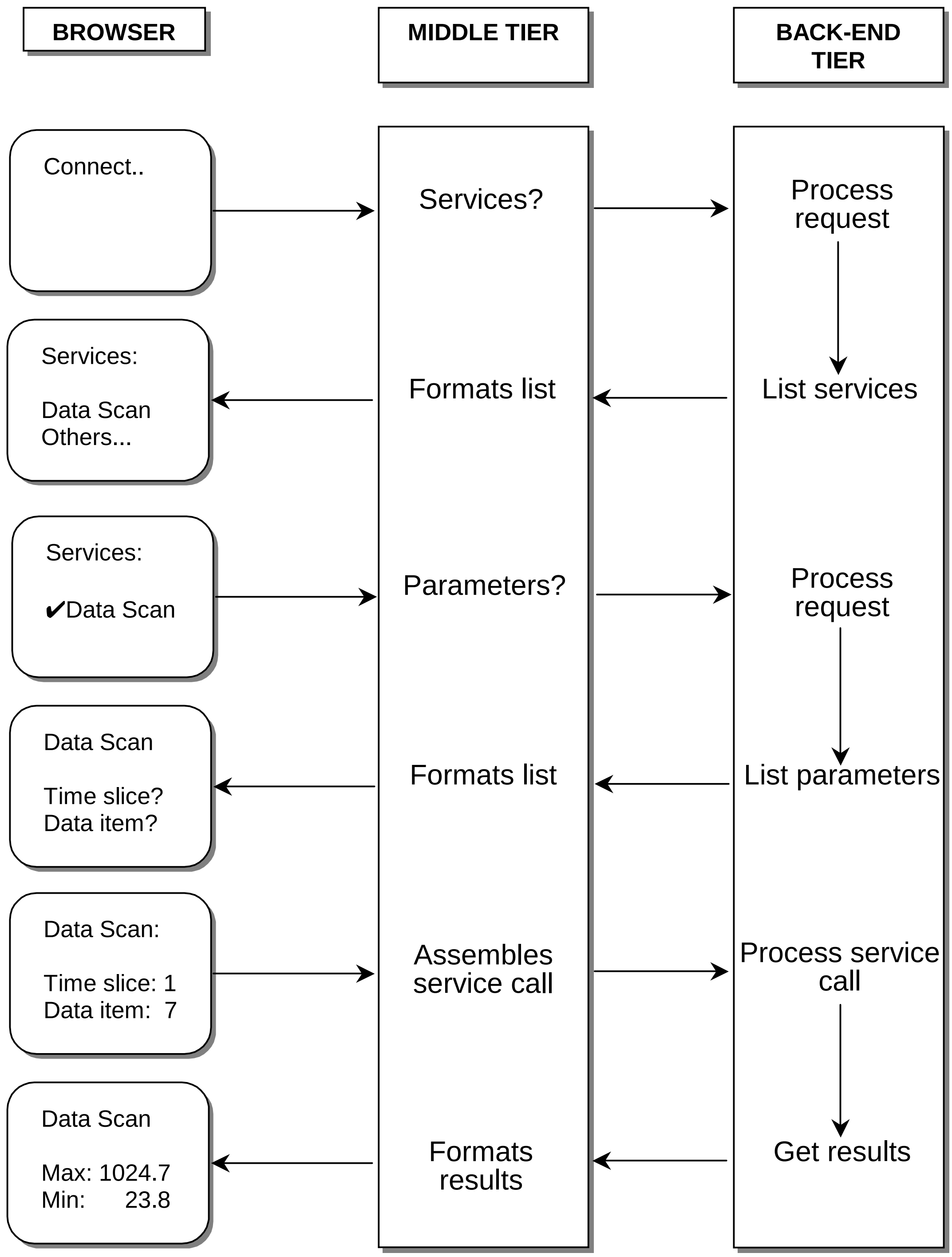

Figure 3 - Sample application flow (processing test data)

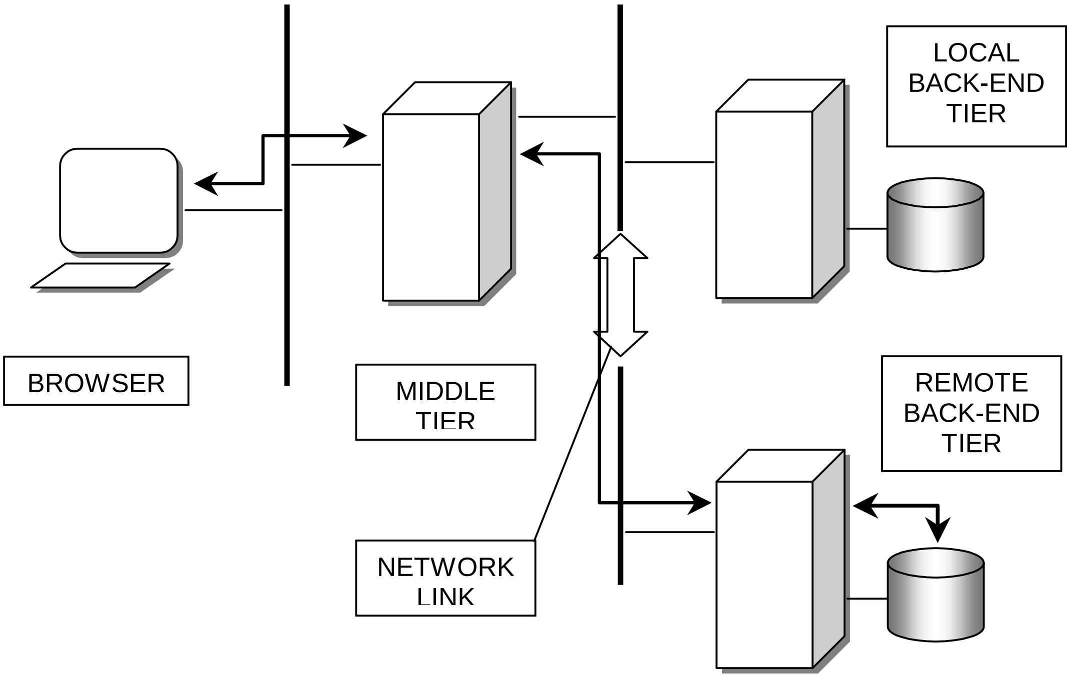

Figure 4 - Accessing local and remote sites

Work Collaboration

Obtaining the Type Certification for a newly developed aircraft is a very long and expensive process. It requires from the company building the new aircraft submitting documents for approval by the Certification Authority describing how it will demonstrate each and every certification requirement specified for that particular aircraft type. In a usual way, documents are drafted and revised and sent back and forth by mail or e-mail. Since Certification Authorities and aircraft companies do not need to be located near each other, this document approval cycle can take several weeks or months, panel meetings need to be scheduled, and so on.

Assuming a hypothetical document format that has a “draft area” and a “comment area”, a sample application for revision of Certification Documents could work as follows (Figure 5):

1. On the Certification Authority side, the designated person opens up an “Internet browser” in his computer and establishes a HTTP communication with a known “middle-tier” server using a Uniform Resource Locator (URL) string;
2. The “middle-tier” server builds a HTML page exposing two operations: “GET”, for getting a document for revision, “PUT”, for returning a revised document, and sends it back to the CA person;
3. The CA person modifies the HTML page selecting “GET” and send it back to the “middle-tier” server;

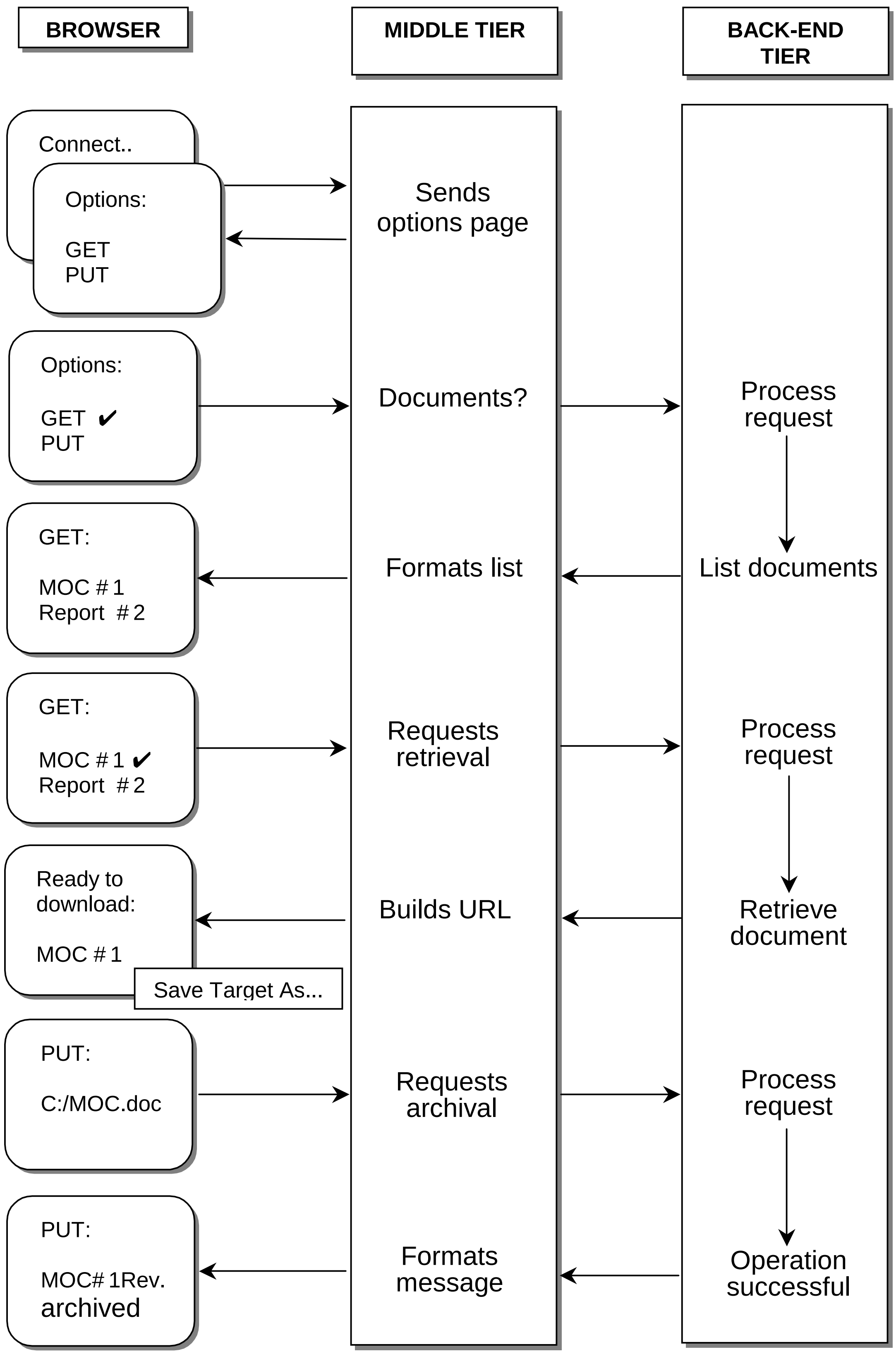

Figure 5 - Sample application flow (document revision)

4. The “middle-tier” receives the modified HTML page, detects that a “GET” is desired, queries the “back-end” server and sends a new HTML page back to the CA person containing a list of documents available for revision;
5. The CA person receives the new HTML page, modifies it selecting which document to revise and sends it back to the “middle-tier” server;
6. The “middle-tier” server reads the modified HTML page, detects the desired document reference, retrieves it from the “back-end” server copying it to a local directory, builds a new HTML page containing instructions for download (a new URL) and sends it back to the CA person;
7. The CA person in turn uses the mouse to right-click on the new URL in this new HTML page, selects “Save Target As...” and downloads the document to a local directory;
8. After reading and revising the document filling up the “comment area”, the CA person starts a similar procedure for “PUT”, where by the revised document is transmitted via HTTP protocol to the “middle-tier” server;
9. Upon receiving the revised document, the “middle-tier” server send it to the “back-end” server for register and archival, builds a new HTML page confirming a successful operation and sends it back to the CA person.

This application flow, as presented here, does not cover any information security aspects, although is this particular case they might be quite relevant.

Pros and Cons

Some aspects in the “3-Tier Architecture” should be seen as positive factors driving initiatives toward its implementation. Flight test organizations should take these factors into account in its investment planning for development and implementation of software systems destined to serve the daily operational routine:

1. At the end-user level, it is an advantage for both user and system programmer not to be concerned with updating software at each and every desktop computer. “Internet Browsers” are the only one tool required and they are available from many different sources for many different operating systems at no cost. It is also an advantage for the system programmer not to be concerned with the design of the protocol connecting the “front-end tier” and the “middle tier”. HTTP is solid and is backed up by the high instances of the Internet Protocol caretakers.
2. At “middle tier ” level, it is an advantage to be able to choose from different implementations from different sources for processing HTML pages and multiple scripting languages. It can go from small atomic executable files to complex routines written in Java programming language. “Middle tier” servers can work as a “cluster”, providing features such as automatically load-balancing user connections among two or more available computers, while presenting users a single virtual point of connection.

3. At the “back-end tier”, it is an advantage not to handle user connections directly, preserving the integrity of the most sensitive systems from a misbehaved application. For implementations where the “back-end tier” is a relational database server, there is also plenty of software components available for directing “Structure Query Language” (SQL) formatted requests from the “middle tier” to the “back-end tier”.
4. A web-oriented application can run unchanged in a restricted network, such as the one internal to any organization, or in a public network, such as the one we use to call “the Internet”, provided that data security issues are properly addressed.

When compared to traditional “Client-Server Architecture”, other less positive aspects should be also considered:

1. “Internet Browsers” are getting more sophisticated everyday, but they are not built to match applications coded using compiled language, such as traditional “client” applications. With a “Browser”, much of the flexibility provided when the programmer has full control over the displayed screen is lost. Some flexibility can be achieved by using JavaScript at the client or server side but this increases the complexity of the application and requires more skilled programmers.
2. Applications designed for the Web are transaction oriented, therefore programmers need to re-think how they code engineering applications.
3. There are important differences in how different browsers render the same HTML page or interprets the same script. The development team must be aware of these differences, and a “standard browser” must be chosen, if possible.
4. Since most of the existing support software for developing web-oriented applications is based on industry or “de-facto” standards, programmers are limited to what these standards provide. On the other hand, development time can be saved if these standards are used properly.
5. Flight test organizations that choose to write their own customized data analysis tool, specially if complex graphic features are a requirement, should consider separating test data analysis from test data gathering software.

Conclusion

It is common to see flight test organizations heavily investing in software development. Each one has developed its own particular way of dealing with its daily flight-test routine, therefore software tools that uniquely address particular requirements are seldom available on the market.

The popularization of the “Internet” and the “World Wide Web” created a very good business opportunity for software companies and a large number of tools and features were produced and sold. Architectural aspects also started playing an important role, and the “3-Tier” approach once restricted to transactional environments, such those developed on top of large relational databases, gained ground on all web-oriented applications.

All of this make web-oriented tools and applications hard to ignore by any software system designer, and those dedicated to make flight testing more efficient are no exceptions. Those in the process of choosing a new development track for future flight test data and information distribution systems [1] should carefully examine the possibilities offered by a web-oriented software system design.

References

[1] Sergio D. Penna, Felipe E. Fernandez - *Conceptual Design Of An Integrated Operating Environment For Flight-testing*, ETC Proceedings, 2000

The Telemetry Attributes Transfer Standard (TMATS): Reducing the Cost of Flight Test

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Abstract

Rapid growth in the aerospace industry coupled with more complex technologies and shrinking program budgets continues to challenge the flight test community to be more effective in their testing and to achieve the most testing for the funds expended. This often means that programs are required to test at multiple locations to receive the maximum benefit from each test mission. This is especially true for many programs today, where weapons systems such as the Joint Strike Fighter in the US and the EuroFighter in Europe are designed for use in multiple environments and have components developed by multiple manufacturers. Operation in these disparate testing environments has a significant cost impact on the setup, configuration, and test planning for these complex programs. The focus of this paper is on the practical use of the TMATS standard, which was specifically designed to enhance transportability and interoperability for Ground Station and Airborne Systems, in reducing the cost of testing. It will describe what TMATS is, present a Set of Software Tools specifically designed around TMATS, and provide practical examples of how it is currently used in the Flight Test Community.

Introduction

Since Pulse Code Modulation (PCM) became the primary means of aircraft and missile telemetry in the late 1960's virtually every test program has gone through some degree of trauma getting the ground station decommutators to lock up and properly decode the data and subsequently provide it to ancillary real-time monitoring and recording systems. Some of these were very easy while others took weeks and even months of intense effort and associated cost. In the early days getting data to strip charts in real-time and to digital tape for post flight processing was most of the task. As applications software began to produce much more detailed results from the down linked data (derived variables, limit checks, alarms, spectral plots, real-time flutter analysis, etc.) the number of people and processes depending on accurate data grew rapidly; as did the cost. Real-time processing also meant that calibrations (for converting counts or percent band-edge to Engineering Units) had to be ingested, not just format descriptions.

To further exacerbate the increase in data requirements, each test facility and telemetry vendor had its unique and usually proprietary methods of building setup databases to load and operate their ground station equipment. This meant that to move from one test environment to another required additional weeks or months worth of effort to prepare for testing. Further, virtually every major weapons platform manufacturer developed their own calibration and format description "file" structure and “their own’ means to convey calibration and format information to the ground station.

As bad as the telemetry people felt the problem was, the Program Managers, Flight Test Directors and Test Center's top management knew the larger picture dwarfed the ground station problem. The impact involved much greater financial as well as program survival concerns. These additional program costs ranged in the hundreds-of-thousands-of-dollars due to project delays at the test centers in preparation of new test programs.

By the late 1980's it became clear that the solution to preventing program delays and to avoiding costly manpower-intensive programming effort redundantly for each and every test project was to standardize on the ***"interface"*** between the instrumentation groups and the ground stations rather than the data formats or the hardware involved. Such a standardized interface could be extremely valuable to every major test project if they could go to any ground station and load the same calibrations and format descriptions with confidence that it would work, that the data would be correct and that it could be done literally overnight. To Program Managers it would be a breakthrough in freedom to locate the test work wherever necessary and minimize cost and risk. This valuable enabler of test efficiency was chosen and planned by the Range Commanders Council (RCC) and was called the Telemetry Attributes Transfer Standard (TMATS).

What is TMATS?

As with standards in other industries, the standards developed by the Telemetry Group of the Inter-Range Instrumentation Group (IRIG) of the RCC are designed to provide a standard platform for the development, implementation, and utilization of telemetry systems by the user and vendor community.

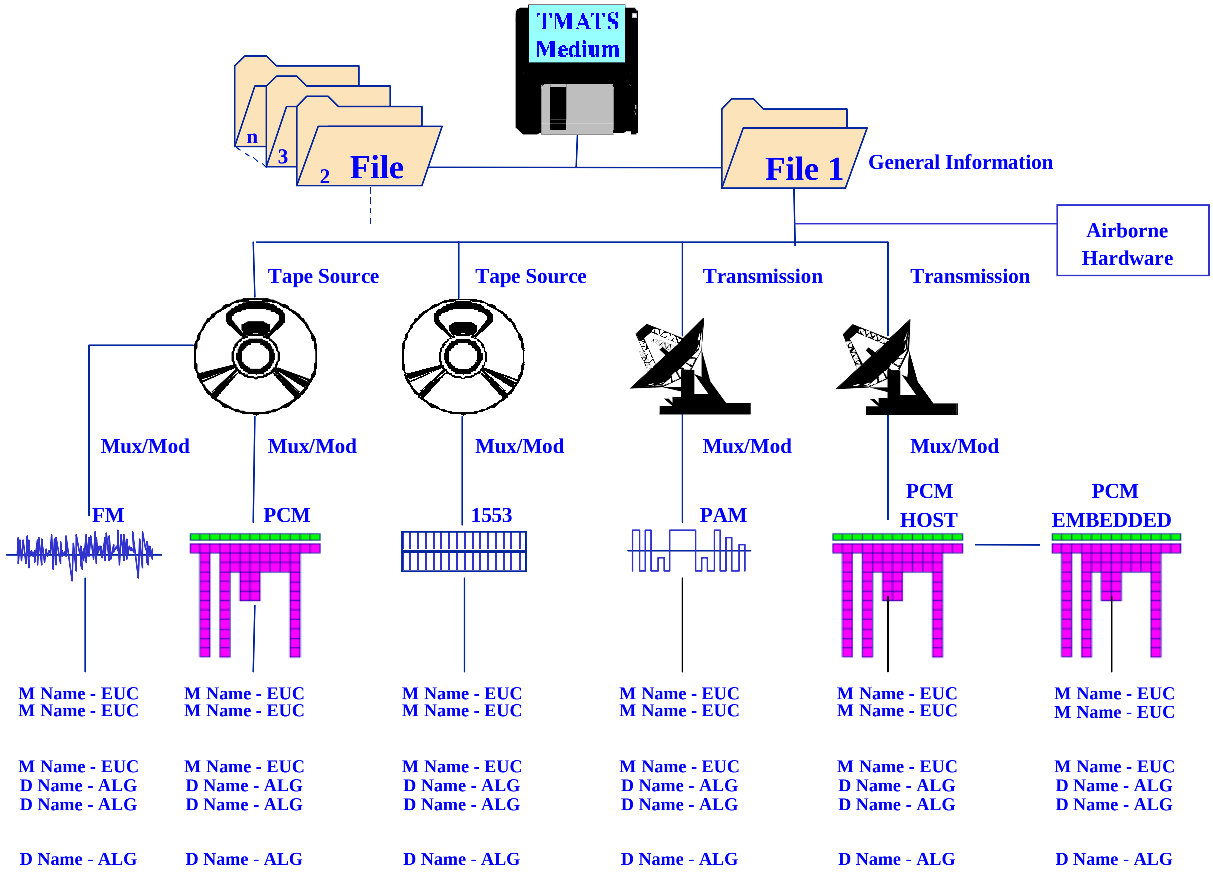
In early 1993 the IRIG introduced the TMATS which was published in IRIG 106-93 as Chapter 9 (updated in 1996, 1999, and 2001). This long needed standardization was designed to provide a common thread through which test programs could move from one test range to another without a significant amount of re-work in the setup environment and its associated cost.

As described in Chapter 9, the purpose of TMATS is *“... to provide a common format for the transfer of information between the user and a test range or between ranges. This format will minimize the ‘station unique’ activities that are necessary to support any test item. In addition, it is intended to relieve the labor intensive process currently required to reformat the information by providing the information on computer compatible media, thus reducing errors and requiring less preparation time for test support.”* [1]

The attributes defined by TMATS (shown pictorially in Figure 1) are those parameters required by the receiving/processing system to acquire, process and display the telemetry data received from a test item or source. Each attribute is represented by a unique code name and associated data (syntax).

A TMATS file may contain multiple definitions for various configurations. A TMATS file is structured similarly to a hierarchical database allowing a user to extract the necessary information for a particular configuration.

This information consists of all of the parameter definitions, locations in the PCM stream, calibration information, transmission and downlink information, RF frequencies, tape information, for Frequency Modulation (FM), PCM, Embedded Asynchronous PCM, Chapter 8 PCM (1553), and Pulse Amplitude Modulation (PAM) data sources.



Telemetry Attributes Transfer Standard

These telemetry attributes are divided into the following groupings:

Attribute Group	Description
General Information	Defines various top-level program definitions and defines each data source used within this TMATS file.
Transmission Attributes	Describes each RF link that was defined in the General Information Section.
Tape Source Attributes	Describes each tape data source defined in the General Information Section.
Multiplex/Modulation Attributes	Defines each FM/FM, FM/PM, or PM/PM multiplex characteristic. For analog measurement, this section defines a link to the Data Conversion Section.
PCM Format Attributes	Defines the format and various characteristics of a PCM data stream. This definition includes subframe and embedded format descriptions.
PCM Measurement Attributes	Defines and describes each PCM measurand to the system. This definition includes the measurand location(s) and measurement names.
1553 Bus Data Attributes	Defines each 1553 data stream by defining the various messages and their locations.
PAM Attributes	Definition of the Pulse-Amplitude Modulation system. This includes PAM format characteristics and measurement attributes.

Attribute Group	Description
Data Conversion Attributes	Defines the various conversions that are to be applied to defined measurements.
Airborne Hardware Attributes	This section was recently added to the TMATS specification (5 May 1995). It defines the specific configuration of airborne instrumentation hardware in use on the vehicle under test.

The primary considerations for using TMATS are represented in the following:

- A single TMATS file contains the entire description of a test system from onboard transducers through data converted to engineering units as one "database" of definitions and descriptions. By incorporating TMATS, projects can be easily transported between different hardware and software platforms and test ranges.
- TMATS has gained significant support throughout the flight test community in the last several years.
- TMATS, like any other "setup file", can be difficult to read/maintain/edit without additional tools. Although TMATS is a text file, it can be quite large for even the most modest PCM definitions. In order to create or edit a TMATS file manually the user must be intimately familiar with the TMATS "keywords" and syntax. This is a job not well suited for the everyday word processor, since the simplest error could result in an invalid definition.
- Most telemetry vendors are now offering TMATS support for their ground systems either directly or through a third party. In addition, commercial-off-the-shelf (COTS) developers are offering tools to maintain TMATS structured data files. Windows based COTS software tools (Such as Spiral's Open Telemetry Interactive Setup - OTIS) are available to allow users to create, edit and maintain TMATS files in a simple, easy to use environment. With these COTS applications the TMATS structure becomes invisible to the user and is replaced with a friendlier graphical format, allowing the user to visualize the various data formats in the TMATS file and focus on its use in the test and evaluation and/or research environment.

Of What Use Is TMATS?

Depending upon your role in flight test, the use of TMATS has different advantages:

Test Ranges - As a range systems user, TMATS provides the ability to support new programs coming from other ranges or test facilities with a minimal amount of tedious setup work by importing the majority of the mission definition in the TMATS format. This allows the range to support more programs in the same time frame by minimizing the preparation time necessary for each new program.

Test Programs - As a Program Manager, you can move testing from internal to external test facilities with minimal cost using TMATS allowing for a more cost effective and robust test program.

Telemetry System Upgrades – When it becomes necessary to competitively procure a new Ground System, the migration from your existing system is made much simpler when TMATS is used as the transition mechanism.

Operations - Used as the primary interface between telemetry instrumentation and the ground station, TMATS will simplify the setup environment for operators.

User's with Multiple Vendors - For facilities with multiple vendor products in use, TMATS provides a common setup environment which, when coupled with translators to convert from TMATS to unique vendor formats, will also simplify the number of setup environments the operations staff will need to learn.

Shrinking Budgets - With budgets shrinking, the use of TMATS helps to reduce the Test Program Life Cycle Costs thereby allowing budgets to be spent on testing, not test facility preparation.

<u>Tools to Support TMATS</u>

Spiral's OTIS family of software tools was developed in 1994. The OTIS family represents a complete set of tools designed specifically to support the TMATS from the OTIS-9 Graphical User Interface for viewing, editing, and creating TMATS files to Translators to convert from TMATS to unique vendor formats and Bridges to convert from unique vendor formats to TMATS.

OTIS-9 TMATS Editor - The OTIS-9 graphical user interface (GUI) module is the foundation of the OTIS product family. It provides support for the hierarchical TMATS structure including all of the standard's defined attribute groups. When importing a TMATS file, OTIS-9 presents the user with an easy to read and understand windowed display (Figure 2) of the information contained in the file.

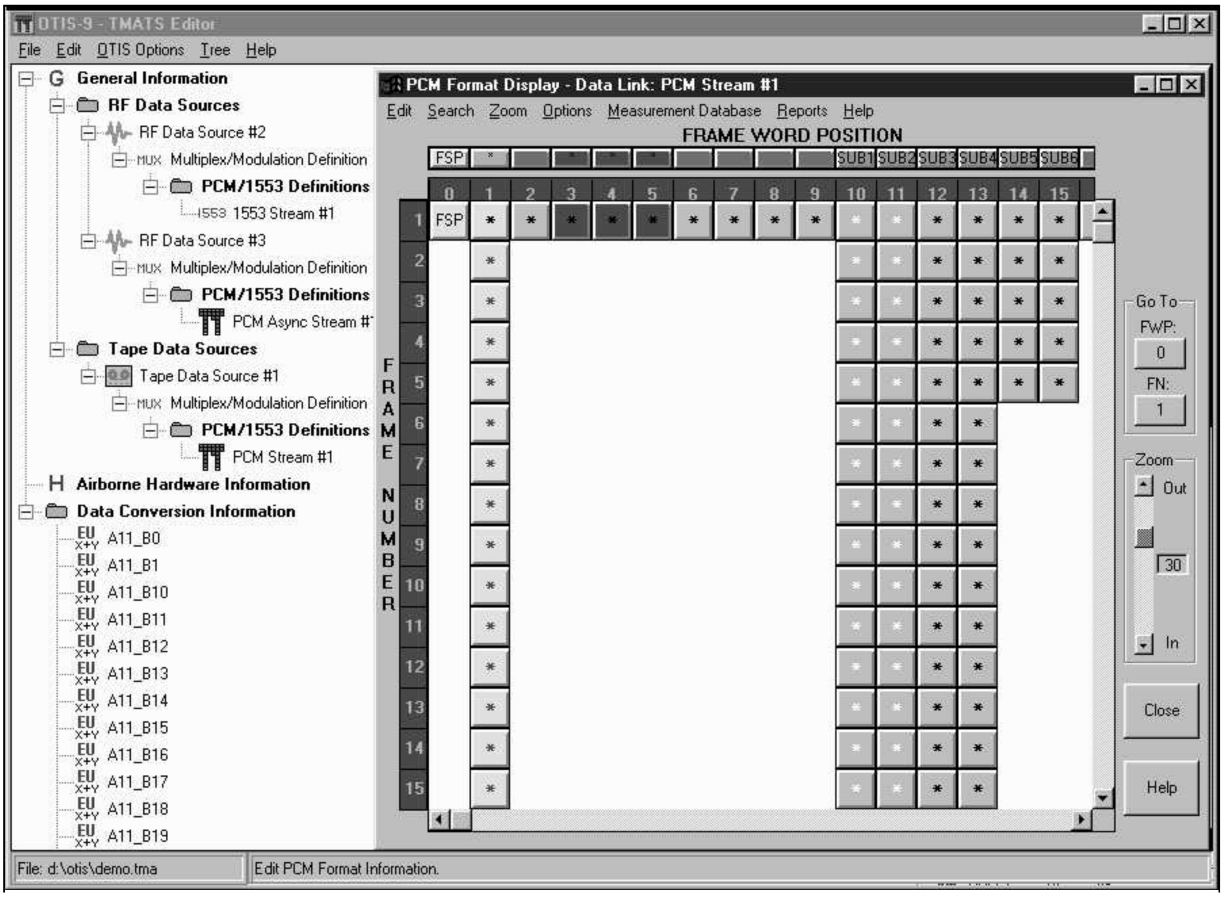


Figure 2 - OTIS PCM Format Display from TMATS Definition

At this point the user may modify these attributes using a simple “fill-in-the-blank” and “pull-down-menu” interface. Once modification has been completed, the user may save the new TMATS file from the OTIS-9 file menu. Of course, telemetry attributes may be defined from scratch using this GUI and saved as a standard TMATS file.

In addition to supporting the viewing and editing of a TMATS file; the OTIS-9 editor provides several features to assist the instrumentation engineer/technician in preparing a PCM format from scratch. One of these features is the ability to import a database of measurement information into an OTIS measurement database.

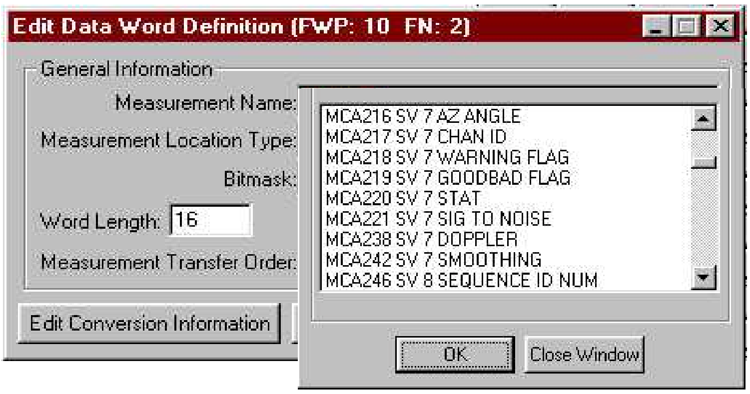


Figure 3 - Selecting Data Words from OTIS Database

As shown in Figure 3, the user may then select from a menu of measurements to place in a PCM slot within the format.

This database contains all of the information pertaining to this measurement including Name, Description, Word Length, Most Significant Bit (MSB) – Least Significant Bit (LSB) Word Orientation, Engineering Units Conversion Algorithm, Alarm Conditions, and Transducer Characteristics.

Another feature of OTIS-9 that is focused on assisting the instrumentation engineering/technician in preparing accurate calibrations for transfer to the ground station is depicted in Figure 4.

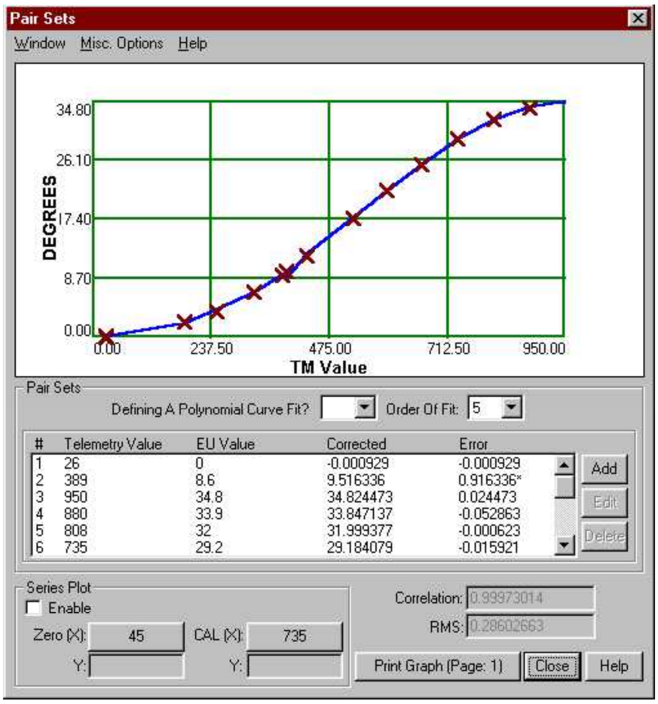


Figure 4 - Deriving Calibrations from Raw Data

This feature allows instrumentation personnel to enter raw calibration date into the software to prepare the most accurate engineering units fit. This includes the ability to:

- Graph Engineering Units (EU) against actual Calibration Data.
- Select the Order of the EU Fit desired.
- Correlation Coefficient and RMS Calculations are presented to determine the accuracy of the fit.
- Identify Zero Calibration Points
- Print a Graph Report once the Calibration is Satisfactory.
- Select Coefficients, Pair Sets, or Pair Sets with Calibrations for output to the TMATS file.

OTIS Translator Modules – The OTIS Translator Modules represent the heart of the interoperability and portability possible with TMATS. Each of these modules is specifically designed to translate from the standard TMATS file structure to a format that is compatible with a specific telemetry vendor's internal format. Each OTIS Translator Module supports the unique capabilities and requirements of the vendor's format. For instance, a specific vendor may have a particular method of performing engineering unit conversion or derived parameter calculations. The OTIS translator module fully supports these vendor-specific methods.

OTIS Bridge Modules – The OTIS Bridge Modules represent another significant portion of the interoperability and portability possible with TMATS. Each of these modules is specifically designed to translate from a specific telemetry vendor's internal format to the standard TMATS file structure. The Bridge Module essentially performs the reverse function of a Translator. This is the utility that takes vendor-specific setup structures and converts them into a valid TMATS file. As with the Translators, Bridge Modules are also vendor-specific, since the format of each vendor's setup structure is unique.

OTIS Custom Conversion Modules - These modules are similar to the OTIS Translator and Bridge modules in that they provide the customer with the ability to import and export TMATS files from/to their unique database systems. However, each of these modules will be unique to the specific customer's needs. Spiral has developed these modules for several customers who wished to incorporate TMATS into their overall support capability including: Boeing FA-18E/F Mux Catalog; TRW; Orbital Sciences Corporation, and Eglin Air Force Base.

Figure 5 depicts the current TMATS support provided by OTIS representing virtually every major telemetry vendor in the industry.

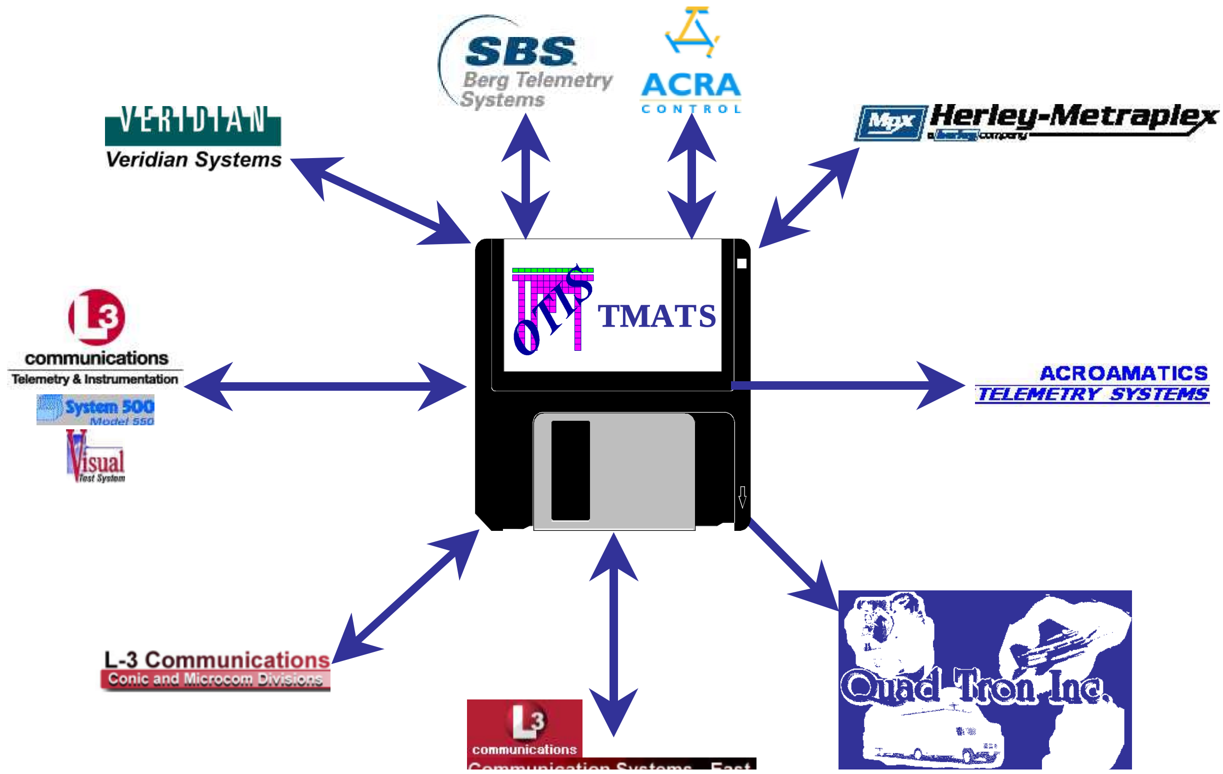


Figure 5 – OTIS TMATS Vendor Support

Potential Cost Savings Using TMATS

Approximately 80% of the project preparation time and expense at a typical test facility ground station is involved in ingesting calibration data and measurement and format descriptions, debugging the ground station equipment loads and responding to changes in this information throughout the life cycle of the test program. Typical Test Center ground station effort estimates are in terms of six (6) to eight (8) man-hours per flight for repetitive real-time test flights while project preparation (entry of calibrations and format descriptions, modifications and debugging) are in man-weeks for the smallest projects and several man-months for the larger projects.

While it is **NOT** accurate to expect that TMATS users will eliminate all manual entry or all system-unique modifications, it **IS** accurate to expect that the manual entry and system unique changes can be reduced to a minor effort representing only a small portion of the total effort necessary to prepare for a mission. The use of TMATS also becomes a significant force multiplier in that so much more can be accomplished for a test program per flight, per month, per year, and per test block, when nearly all of the system load is accomplished using a world-wide standard from a simple universal media such as a diskette or a file transferred over a network.

Where is TMATS Being Used Today?

The following represents some of the test facilities around the world that are currently using the TMATS standard in the telemetry processing environment:

- Naval Air Warfare Center – Aircraft Division at Patuxent River, Maryland. It is noteworthy that every test flight on the F-18 E/F full-scale development program (well over 2000) utilized this TMATS mechanism. Many of these involved overnight instrumentation or calibration changes.
- Air Force Flight Test Center at Edwards Air Force Base, California
- National Aeronautics and Space Administration’s Dryden Flight Research Center at Edwards, California
- Naval Air Warfare Center – Weapons Division at China Lake, California
- National Aeronautics and Space Administration’s Langley Research Center at Hampton, Virginia
- Orbital Sciences Corporation – X-34 Program
- White Sands Missile Range at White Sands, New Mexico
- Eglin Air Force Base Florida
- Boeing St. Louis
- Lockheed Martin Ft. Worth, Texas (F-16 Program)
- Denel Aviation, South Africa
- Royal Australian Military
- Sandia National Laboratories, New Mexico

Conclusions

Since its inception in the early 1990s, TMATS has gained popularity and overcome the skepticism from both the telemetry vendor and user communities. This is largely due to TMATS' ability to significantly reduce the time necessary to bring a new program to test readiness.

It should be noted that a standard interface between instrumentation groups and ground stations is extremely valuable not just for ease of use and portability among ground processing stations but also for commonality, report generation, calibration archiving and pre-flight checkout for instrumentation personnel. All of these things contribute to lower risk, less cost and less chance of program delay to the ultimate customer -- the test project.

References

[1] "Telemetry Standards", IRIG Standard 106, May 1996, Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range.

Acknowledgements

The author would like to acknowledge the support of Mr. Bill Rymer in the preparation of this paper. Mr. Rymer is the retired head of the Patuxent River, Maryland, Telemetry Division and Real-time Telemetry Processing System (RTPS) Team. He was awarded the Pioneer Award in Telemetry by the International Foundation for Telemetering in 1997 and was Vice Chair of the Telemetry Standards Coordinating Committee of the IFT.

Abbreviations

COTS	Commercial-Off-The-Shelf
EU	Engineering Units
FM	Frequency Modulation
GUI	Graphical User Interface
IFT	International Foundation for Telemetering
IRIG	Inter-Range Instrumentation Group
LSB	Least Significant Bit
MSB	Most Significant Bit
PAM	Pulse Amplitude Modulation
PCM	Pulse Code Modulation
RCC	Range Commanders Council
RTPS	Real-Time Telemetry Processing System
TMATS	Telemetry Attributes Transfer Standard
US	United States

APPLYING RULES FOR ISOCHRONOUS SAMPLING WITHIN ACQUISITION CYCLES TO ALL LEVELS OF FTI SYSTEM DEFINITION

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Abstract

This paper examines two rules for data acquisition that have advantages for today's Flight Test Instrumentation (FTI) systems where:

- Data is acquired from physically separate test equipment
- Deterministic (IRIG-106 (Ch. 4)) and non-deterministic networks co-exist
- Data Acquisition Units (DAUs) from multiple vendors are required
- Signal lists and sampling rates change rapidly
- A time-coherent sampling strategy (even for smart sensors) is required

These rules may aid not only in the selection of the data acquisition equipment but also the definition of the sampling, transmission, storage and analysis strategies.

Key Words

Isochronous, acquisition-cycle, time-tagging, packet-definition, IRIG-G251, smart sensors.

Introduction

There are many questions asked of FTI vendors today:

Can you supply a 1553, CAIS, NexGenBus, smart sensor controller? ✓
Have you a plan for FC, Firewire, FDDI, 1Gb Ethernet, 1553++, Loadnet? ✓
Have you thought about non-deterministic networks? ✓
Can you send packets of data to a certain Solid State Recorder (SSR)? ✓
Can you guarantee simultaneous sampling? ✓
Have you thought about packet structures and how they may be handled? ✓
Can I change my mind later about any of the above? ✓

Many FTI vendors are content to tick these boxes; and explain later the coherency issues and the problems of stale, skipped and lost packets. This paper argues that there exist some core axioms about which an FTI system must be designed. Obeying these axioms supplies a rigorous solution to these challenges rather than simply ticks in boxes.

This paper outlines some of these rules and illustrates some of the problems these rules solve.

The Generic Problem

Data is gathered from many sources:
- Analog to digital converters (strain, accel., video, synchros, and so on)
- Bus controllers (smart sensors, 1553, 429, CAIS and so on)
- Bus monitors (too many to mention)

Subsets of this data are being sent to many sinks
- A few to a cockpit display (VGA, 1553, 429 and so on)
- A few to a telemetry link (perhaps in packets and hence to a network)
- A lot to a recorder (e.g. SSR via FC-AE or 1Gb Ethernet or whatever)

How do we correlate, with respect to time, the data from the various sources? Furthermore how do we present the data to the various sinks in well-defined, succinct packets across networks with limited determinism?

Next, this paper takes an informal look at some old rules by which FTI programs were defined. This is followed by some new rules and a discussion of how some of the challenges outlined above are met.

The Old Rules for Solving These Problems

I) TAG EVERYTHING - With time, stale, skipped and empty (at least)!
How else can data from the controller gathering data via MIL-STD-1553 be correlated with respect to the data gathered from the smart sensor belt and the myriad A/Ds about the system?

II) AVOID COMMERCIAL BUSSES - There be dragons!
There was a time when MIL-STD-1553 was a better choice than Ethernet, mainly because the latter did not exist, but even when it did, it was not much faster and had "determinism issues". With 1Gb Ethernet is this still the case?

There was a time when we could only dream of "Decomless" telemetry. Again mainly because the commercial world was not sending large packets of data via telephony in real-time? Is this still the case?

III) FORCE "SIMULTANEOUS SAMPLING MODES" - Whatever that is?
In those cases where parameters must be sampled "simultaneously" the FTI vendor must jump through some ill-defined hoops and support a "broadcast" sample command. We won't talk about what that means for parameters at different sampling rates or why we just don't do this for all parameters.

IV) DEFINE DATA PACKETS IN DETAIL - Don't trust the FTI vendor!
How do we specify that all parameters be sent to the recorder and which subset to send to the telemetry link? One problem with old FTI systems is that a small change like adding a new parameter or changing the sampling rate of an existing parameter often meant a big change to the sampling sequence and hence time delays and so on.

The New Rules for Solving These Problems

I) Define an **acquisition cycle** time during which all parameters everywhere that are **potentially** of interest are sampled at least once.

II) Insist that all parameters everywhere be sampled at the start of the acquisition cycle and at even time-intervals thereafter.

These rules are deceptively tricky to understand and implement but are equally deceptively powerful once implemented completely. They describe an isochronous sampling system (Iso = same, chrono = time).

This goes beyond the mere synchronicity of a PCM stream or the type of "simultaneous sampling" boasted of by certain command-response busses. Before looking at the design elements of such a system let's first look at some situations where these rules may provide clarity.

Commercial Networks – Beyond MIL-STD-1553

Many ground stations today use networks to share telemetry data among multiple ground stations. As these networks get faster and the chip-sets associated with them get smaller it seems the next step may be to think of the Data Acquisition Systems (DAUs) from which the data was originally gathered as network nodes.

There are a few commercial busses under consideration by the avionics community: FDDI, Firewire, ATM, 1Gb Ethernet, and FC-AE to name but a few. It is also worth mentioning that considerable effort is being spent on faster, "enhanced", usually optic-fiber versions of MIL-STD-1553.

Deciding between the various options is not trivial. There are financial, mechanical and packet delivery time trade-offs. Once a network is chosen the learning curve is just beginning; for example:

- Fiber-channel (FC) is a commercial network standard
  - They want a very fast SCSI bus.
- FC-AE is an Avionics Environment group within FC
  - They want a very fast avionics bus (MIL-STD-1553+)
- NexGenBus is yet another group with an FTI focus
  - They want a very fast CAIS type bus

This paper does not advocate one bus over another. All the busses discussed above can operate comfortably in an environment of isochronous DAUs. In particular, it may be that in environments where more than one network is used then the DAUs *must* be isochronous.

This paper argues that, whatever network or flavor of network is chosen, if each DAU node is isochronous then at least the data collection or sampling is completely deterministic - even if the transfer of that data is not. Now the problem of determinism is purely on the receiver (ground station) side.

Figure 1 shows multiple DAUs operating isochronously (the mechanics of this are discussed later). Each is gathering data packets during each acquisition cycle. The network however transfers these packets in a way that first might appear as anathema to an FTI engineer - the DAUs can be read out of sequence and at varying intervals of time.

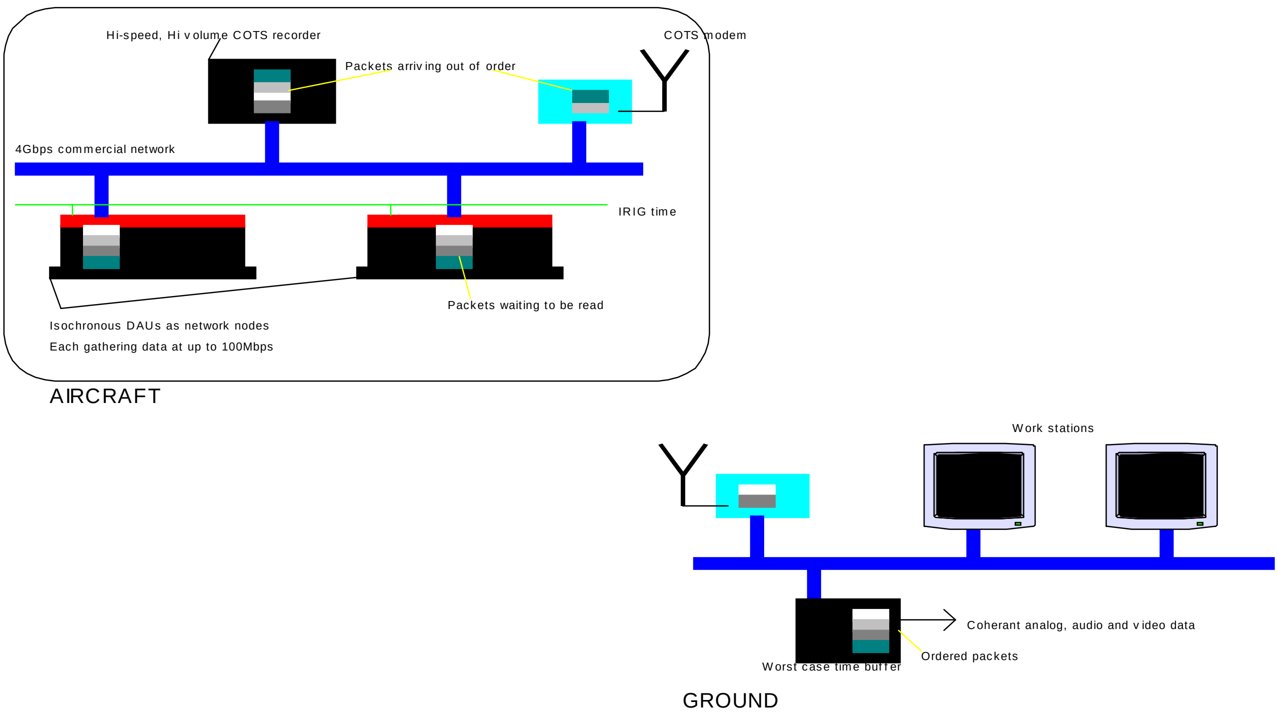

Figure 1 - Commercial networks – Beyond MIL-STD-1553

All is not lost! Remember all the data is sampled isochronously within, for example, ±100ns. The large (super-set) packets going to the recorder can be sorted in time later. Also it may be that the even though the order in which the smaller (sub-set) packets are transmitted to the ground may change, the worst-case delay may be within some acceptable window, for example 300ms. In this case the design task on the ground becomes one of building a 300ms buffer on the ground - if a packet is received within 10ms; delay it by 290ms. For this to work each packet must have a time tag - axiomatic for an isochronous DAU network.

Packet Definition

It may not be obvious that isochronous systems have advantages with respect to packet definition. In particular once the two core axioms of isochronous operation are understood then significantly less communication is required when discussing topics such as:

- Sub-packets
  For example, a parameter sampled at 20kHz to an on-board recorder is also sent at a much slower rate to the ground and at an even slower rate to a cockpit meter. Which samples are sent where?
  Another request often made is - only send "interesting data" - if data is reduced, the structure of the new packet must be defined (or must it?).
- Time tagging
  Wouldn't it be great if one time tag tagged all parameters?
- Packet structure
  What information is needed in a packet?

Below there are two packets of data acquired during one acquisition cycle. One packet is going to a solid-state recorder and another, smaller one, is going somewhere else. The first element in each file is the packet identifier, the second is the packet's time tag. Each row after that contains samples of a particular signal.

```
P1234
2002 03 27 23 59 5999 9999
0001   0002   0003   0004   0005   0006   0007   0008   0009   000A
1001   1002
2001   2002   2003   2004   2005   2006
3001   3002   3003   3004   3005
4001   4002   4003   4000   4005
```

First (super-set) packet

```
P1234
2002 03 27 23 59 5999 9999
0001   0006
1001   1002
2001   2004
3001   3002   3003   3004   3005
4001
```

Second (sub-set) packet

In an isochronous acquisition system there is a lot of information in these packets.

The **packet identifier** points to a header packet that need only be sent occasionally. This packet contains information on the acquisition cycle time and signal names, ranges, units, delays and so on for each row.

The **time tag** (Tc0) is the precise time that all the samples in the first column of the packet were sampled. If the acquisition cycle length is Ta and there are only two samples in a row then the second sample was taken at exactly Tc0 + Ta/2 and so on.

Some observations:
a) It may be worth considering having the packet identifier and time-tag incorporated into any file name associated with the packet, as it would make sorting easier.

b) One time tag tags everything - while this greatly reduces the tag information that must be transmitted it also means that even if the sampling rate changes or extra signals are added the engineers analyzing the data need not care.

c) Defining data reduction subsets becomes axiomatic. Each set must contain the first sample and all samples must be evenly spaced in time. For example see the third row of each packet.

d) In the first packet the parameter in row 5 is sampled at 50Hz and row 6 at 60Hz. Time correlation of these signals is straightforward. Remember the first sample of each row was taken at the same time.

e) In the first packet the parameter in row 7 is also sampled at 60Hz, that means every sample in row 6 was taken at precisely the same time, as those in row 7.

Bus Controllers

FTI equipment is often the glue between high-speed busses used to transport all FTI data and slower sub-system busses such as MIL-STD-1553, ARINC-429, CAIS, smart sensor arrays or legacy 10-wire interfaces.

These sub-systems are typically command-response type architectures not designed for isochronous operation. However they can be adapted to co-exist in such an environment with immediate advantages with respect to time-tagging and coherency.

Figure 2 shows multiple bus controllers gathering data about their respective busses. For completeness data from an analog channel is being sampled along with data from an external analog multiplexer or scanner.

The analog signal is sampled at the start of the acquisition cycle and at equal intervals of time thereafter. The first sample is stored in address X of a current value table (CVT) the second in address Y and so on. So far so good - this would be expected from an isochronous channel. However in real life systems there must be an anti-aliasing filter and all filters have delays. So even though the A/D sampled the signal at the start of the acquisition cycle there is a fixed delay that must be noted.

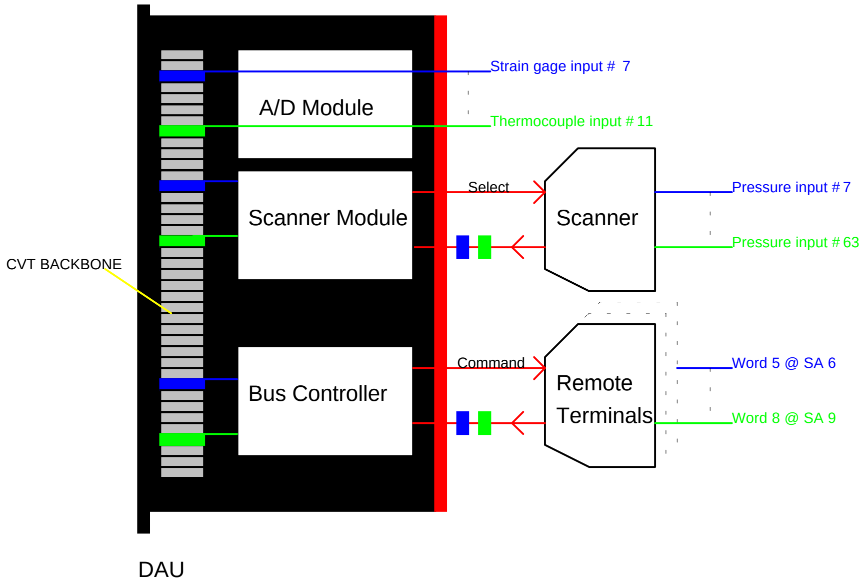

Figure 2 - Different modules in an isochronous environment

The external multiplexer at first seems to violate the rule of sampling all parameters at the same time - this cannot be done with a multiplexer. However think of each channel of the multiplexer as being sampled after a fixed delay. Design the multiplexer controller to step through a sequence of channels at the start of the acquisition cycle and at equal intervals of time thereafter. The first sample from channel 1 is stored in CVT address A, the second sample from channel 1 in B and so on.

This concept (delays + sequences + equal sample intervals) is then extended to the case of the bus controllers. At the start of the acquisition cycle the MIL-STD-1553 controller requests data from a given remote terminal and sub-address and each data word is stored in a specific address in a CVT.

All this data from a myriad of analog channels and busses is stored coherently in a CVT, a snap-shot of which at the end of the acquisition cycle forms a super-set of all the data packets for that DAU. Even if the sampling sequence changes radically on one module, the other modules do not change, providing the acquisition cycle has remained the same.

With multiple data banks these packets can be stored for as long as it takes the network(s) to read the packets.

Furthermore, all these acquisition modules need not be in the same DAU providing all the DAUs are operating isochronously. It is very important to note that only the bus controllers were affected by the move to isochronicity - none of the remote terminals had to be redesigned. One hidden advantage of isochronous systems is that if they work once, they work always because everything that happens, happens always.
The next section discusses some of the design implications in designing an isochronous distributed data acquisition system.

Making DAUs Isochronous

At first glance it may appear that a simple broadcast at the start of an acquisition cycle to all DAUs is all that is required to make multiple DAUs operate isochronously. However even with 3ppm oscillators this would require a broadcast every 30ms to guarantee jitter of less than ±100ns. This may be an excessive overhead on many networks. By the way, 100ns jitter is not an unreasonable tolerance for oversampling digital filtering systems.

So an indication of the start of an acquisition cycle, and a regular metronome beat would be ideal. Also it may be desirable to have different sampling strategies or modes or formats. For example CAIS has program, verify and acquisition modes. Also, it may not be possible to always sample everything that might possibly be of interest in every stage of the flight - for this reason IRIG-106 Ch.4 supports format switching.

One solution to all three problems has been around the FTI world for decades. IRIG time can be connected to all DAUs with control function bits indicating the end/start of an acquisition cycle and the format to use during the next acquisition cycle.

The downside of this solution is, at worst, an additional single twisted pair looped to each DAU. The advantage however is that all DAUs are now gathering data coherently even across multiple airframes.

Remember that it is only bus controllers that are affected - not remote terminals. Also it is only network sources that are affected - not the sinks. In other words, the DAUs are affected - not the recorders. For example, a COTS SSR that supports an acceptable flavor of FC-AE (for example) need not be modified to gather data from multiple DAUs. However, each DAU must have enough buffer space to handle any lack of determinism in the network.

The final section looks at the various decisions that must be made in choosing an acquisition cycle length.

Some Thoughts on the Acquisition Cycle

Imagine an FTI system with multiple PCM streams, some CAIS equipment and a MIL-STD-1553 controller talking to a cockpit display.

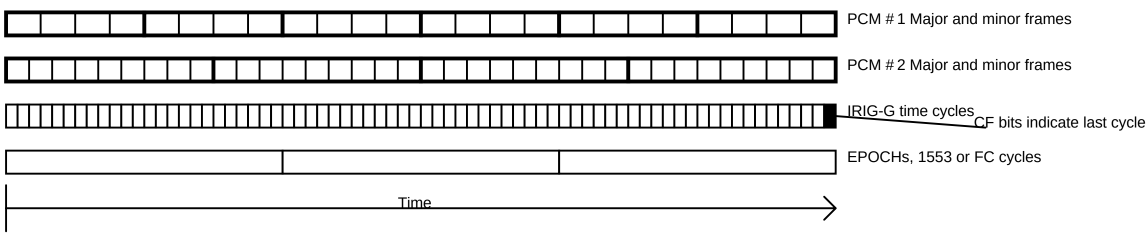

Figure 3 - An acquisition cycle and various sub-cycles

PCM streams are often defined using power-of-two rules such as 512 words per minor-frame, 128 minor-frames per major-frame and 8 major-frames per second.

Fifty cycles per second are often found in MIL-STD-1553 busses. With these two criteria alone, 500ms may be the optimum choice for acquisition cycle (500ms = 4 major-frames and 25 MIL-STD-1553 cycles). By the way, some smart sensor systems talk of EPOCHs - another word for acquisition cycle - that may also have to be factored into the choice of acquisition cycle length.

If 500ms is chosen then IRIG-G time (10ms/cycle) would be a better choice than IRIG-B (1s/cycle).

If the data packets are too big then the delay in gathering the data might be unacceptable (for example audio to ground). Also with a large file losing a small proportion of the file means losing a lot. Finally larger acquisition cycles mean that the recovery time from a power brown-out is longer.

On the other hand if the packets are too small then the protocol overheads (e.g. packet headers or file names) may be excessive, also sampling rates may be pushed too high.

Conclusion

Forcing various elements of an FTI system to operate isochronously with respect to IRIG time requires some investment from each vendor, some training of program groups and may require a twisted pair to the controller of whatever network or bus is used to gather data.

However, when adhered to, these simple rules provide many advantages with respect to interoperability, network independence, future-proofing and packetization.

References

Fibre Channel: Replacement for MIL-STD-1553 & Next Generation Military Data Bus, Wilf Sullivan, Product Manager-Systems & Software, DY 4 Systems Inc.

COMMON AIRBORNE INSTRUMENTATION SYSTEM; A FRESH LOOK

Thomas Grace, Systems Engineer

Naval Air Systems Team

ABSTRACT

The US Government originally funded the development of the Common Airborne Instrumentation System (CAIS) to address industry-wide compatibility, maintenance, and commonality issues. Although initially targeted for US Department of Defense (DoD) programs, CAIS is also being used throughout the world in many commercial applications. This paper provides a fresh look at the evolution of the CAIS concept starting with some historical background of the CAIS Program, an overview of the CAIS System Architecture and recent trends in the use of "Commercial Off The Shelf (COTS)" products and technology.

KEY WORDS

Common Airborne Instrumentation System (CAIS), Commercial CAIS Products, Commercial Off The Shelf (COTS), Data Acquisition Unit (DAU), Department of Defense (DoD), Flight Test Instrumentation, PC-104, Pulse Code Modulation (PCM), Telemetry.

CAIS PROGRAM OVERVIEW

Introduction

The Common Airborne Instrumentation System (CAIS) was funded by the United States Department of Defense (DoD), through a tri-service program office, located within the Test Article Preparation Department at the Naval Air Warfare Center. The purpose of CAIS is to facilitate commonality of flight test instrumentation between aircraft types and interoperability between DoD test facilities. CAIS was designed to support a broad range of airborne applications -- from a small test program requiring a few parameters to a full-scale major weapon system test program -- while remaining independent of any test platform.

Background

The Army, Air Force, and Navy have traditionally developed new airborne instrumentation systems for each new major weapon system. This led to a proliferation of instrumentation systems across the services. This proliferation is further amplified by the requirements of each test platform within the services. Each of the Major Range and Test Facilities maintain and support a wide variety of instrumentation systems for varying test platforms. Historically, these systems have had limited spares and minimal commonality. Reutilization of these systems in other programs has been minimal, making the cost of ownership high.

In order to increase supportability, interoperability, and reduce cost, the Office of Secretary of Defense directed the development of CAIS. Successful use of CAIS by the F-22 and F/A-18E/F test programs has led to growing support for CAIS. The CAIS program evolved from development of a core set of hardware to the establishment of a DoD instrumentation bus standard. This was driven by policy changes within the DoD and eventually led to a change in the CAIS acquisition strategy. Industry acceptance of the CAIS bus interface standard has improved supportability, reduced cost and enabled test facilities to leverage from each other's investments while increasing options available to CAIS users.

CAIS has changed the way DoD and major aircraft manufacturers develop and procure instrumentation systems for major weapon system acquisitions. Rather than develop a new instrumentation system, the CAIS bus interface standard enables integration of COTS with much of DoD's existing instrumentation hardware to meet performance requirements at the lowest cost.

CAIS STANDARDS AND PLANS

The CAIS Program Office developed several documents to help facilitate the commercialization of CAIS. These documents are briefly described in the next several paragraphs.

Bus Standard

The CAIS Bus Interface Standard was written to provide a single document for equipment designers to ensure interoperability among units on the CAIS bus. The standard establishes the requirements for digital command/response, time division multiplexing techniques for a single CAIS bus. The interface standard encompasses the physical, electrical, and protocol aspects of the CAIS bus. However, it is not the intent of the standard to provide operational details for any unit.

Test Plans

The CAIS test plans were developed to ensure interoperability among vendor items that operate over the CAIS bus. Currently there are two validation test plans - one for data acquisition units and one for CAIS bus controllers. These general test plans deal only with functions that are described in the CAIS bus interface standard. These plans do not specify tests that check the integrity of data within the subsystem to the bus, nor does it attempt to address the system test requirements.

Configuration Identification

One of the features of CAIS is the ability to perform a configuration match test. This allows the ground support equipment to interrogate all DAU addresses in the system to ascertain the configuration of the system and identify what DAU addresses are in use and by which DAU type. Therefore, each DAU type and sub-unit type must have a unique identification (ID) value.

PRACTICAL CHALLENGES AND CAIS SOLUTIONS

The Instrumentation Engineer faces a wide range of challenges in their day-to-day work. Equipment compatibility issues, data systems being maintained beyond their service life, difficulties to expand system capability and cost control are but a few of the practical, every-day problems. Even worse, it seems that the right tool is seldom available to make the overall job easier.

The CAIS System has evolved to address many of these issues through the use of an "Open System Architecture" and the insertion of the latest commercial technology and software products. A few examples will be used to illustrate the point.

Example #1: The "Old Ground Station"

Existing (old) systems are big, expensive to use, limited in performance, and often are being used beyond their maximum service life. New CAIS systems are small, fast, cheap, and powerful. Since they are PC-based, they are easily expandable with both software and hardware add-ons with virtually limitless growth potential.

Example #2: System Pre-flight Checkout

Existing (old) systems are large, complex, tedious to use, have significant learning cures, sparse documentation, power hungry, and often are lacking performance. New CAIS pre-flight checkout systems are based on portable computer equipment (laptop), with powerful software and hardware features, integrated setup, programming and diagnostic tools, quick-look data capable, data archive to disk capable and low cost.

Example #3: Vehicle Anomaly Investigation

Existing (old) systems must be physically brought out to the vehicle, have significant cabling and wiring requirements, require cooling and protection from the elements, are labor intensive, and are costly to maintain. New CAIS diagnostic tools are available in laptop configurations that can be brought out to the vehicle or used within the vehicle, have resources to perform real-time diagnostics and data validation, contain CAIS bus emulators to validate system performance and connectivity, don't require that primary aircraft instrumentation be brought on-line, and do not rely on traditional telemetry or ground instrumentation equipment.

CAIS SYSTEM EVOLUTION

The primary reason for the current advances within the CAIS System is the use of a proven "Open System Architecture." A set of "core" products forms the backbone of the system, while measurement-specific products can be added to the system as required. Normally this kind of architecture results in compatibility problems and difficulty during system integration. However, the CAIS architecture prevents these problems since it is based on the same kind of architecture used in the commercial sector to allow PC computers to easily work with peripheral hardware and network connections that are manufactured by different companies. A new breed of "Commercial CAIS Products" is now emerging, not unlike the wide range of commercial products and software available to support the PC computer.

The concept to incorporate products and software developed in the commercial sector has resulted in significant cost reduction, improved lead times, and significantly better performance. We have found that, in many cases, commercially developed items surpass equivalent military products in terms of price, performance, and reliability.

In addition, the evolving CAIS concept has enabled existing CAIS users to expand their in-place systems using standard, low-cost commercial add-on products. Airframe manufacturers, vendors and DoD test ranges are now rethinking how the evolving CAIS concept can provide greater flexibility, increased capability and reduced cost.

CAIS SYSTEM ARCHITECTURE

System Configuration

CAIS is a time division multiplexed digital data acquisition system whose basic implementation consists of distributed data acquisition units interconnected via the CAIS bus. The system controller orchestrates the operation of the system and provides scalability of the system with additional CAIS buses. A CAIS distributed system allows for the wiring of numerous sensing elements to be routed over a short distance, while the wiring of the system interconnection requires four-wires to be routed over a much longer distance.

The CAIS bus is a full-duplex communications network interconnecting a CAIS Bus Controller with Data Acquisition Units (DAUs). The CAIS bus is a star/daisy-chain hybrid configuration. The bus carries commands from the CAIS bus controller to the various DAUs and returns the collected data to the CAIS bus controller for output. The command/response bus provides the open architecture feature of a CAIS interconnected system.

The CAIS bus in its most elemental configuration is shown in the figure below. The data bus functions synchronously in a command/response fashion and transmission occurs in a full-duplex manner by means of a command bus and a reply bus. CAIS is a deterministic bus that provides coherent data based on the sample timing from the placement in the format. The information flow on the data bus is comprised of broadcast commands that set the operating mode of the Data Acquisition Units (DAUs), and DAU commands that request DAU specific actions. Therefore, all data on the reply bus is the result of DAU commands from the bus controller. In addition, the bus can be used to communicate with other system elements such as cockpit displays, recorders. This enables a single-point access to a wide range of system information, as well as allowing the system to monitor critical data such as pilot switch activity, pilot mission screen settings, and telemetry recorder status. Note that the CAIS bus not only operates as an instrumentation bus, but as a vehicle-wide communications bus.

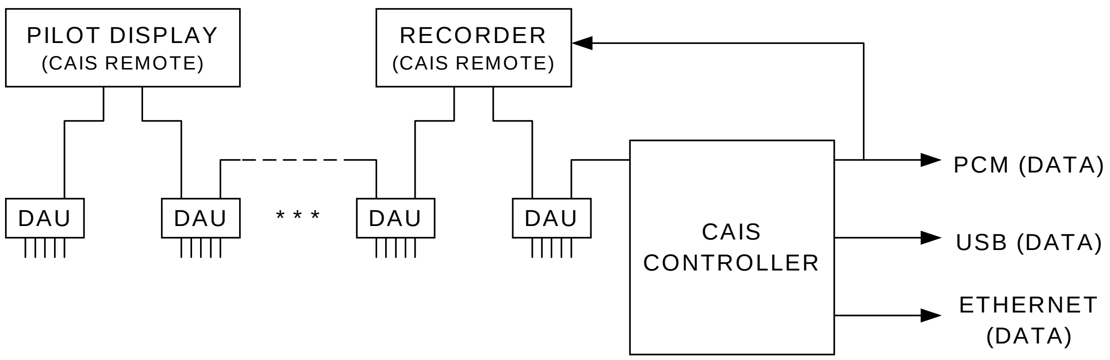

Figure 1: Simple CAIS Configuration

A CAIS system can be configured with a single bus controller that controls a single bus or a system controller that controls multiple CAIS buses as depicted in the figure below. The bus/system controller orchestrates the collection and output of data from the system, regardless of data type. A typical controller synchronizes the data output with the commands issued across the CAIS bus(es). Each CAIS bus can handle up to 5Mbps of data; however, the system throughput can be greatly increased and is only limited by the number of CAIS buses within the system. As the system grows it still maintains the deterministic nature of the data acquired over the CAIS bus, including data acquired over several interoperating CAIS buses. CAIS also supports simultaneous sampling of data across all buses.

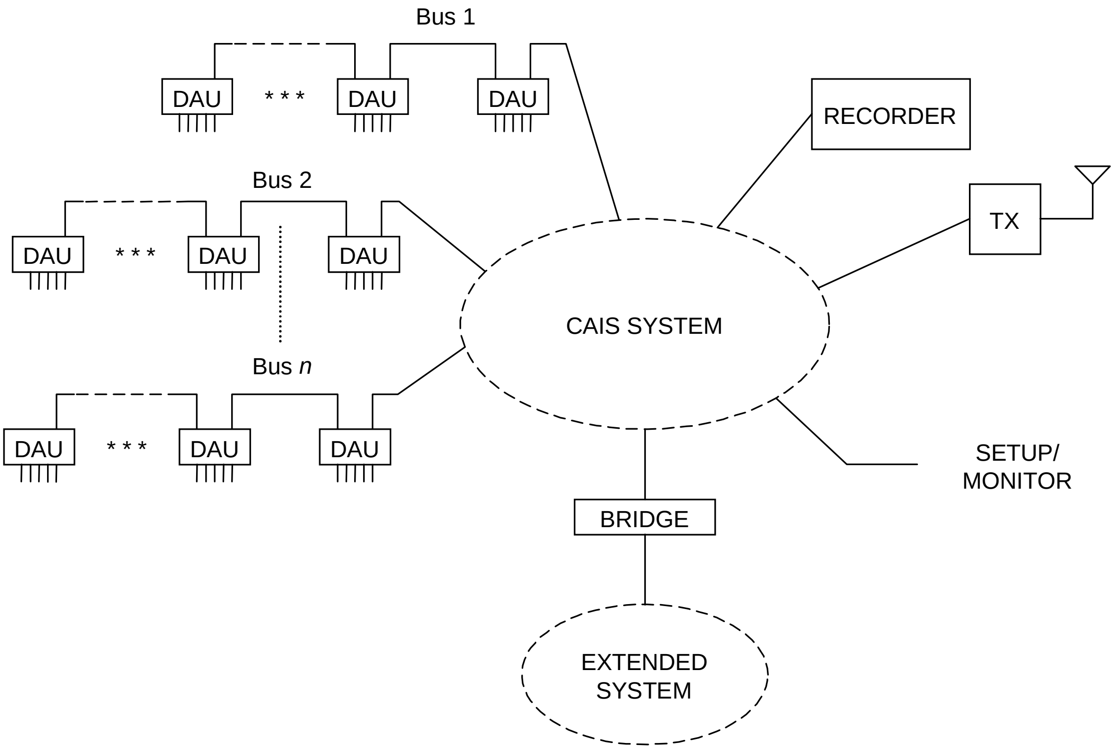

Figure 2: Expandable System Configuration

Measurement Capability and Growth

The CAIS system allows measurement growth through modularity within the individual system elements. The growth can be addressed with the simple addition of a card or module, a remote unit or even additional CAIS buses. Additional interfaces can often be added to system elements without impact to the existing system thereby eliminating the need for retrofits to existing CAIS equipment. The following is a partial list of the kinds of signal inputs and outputs available to the CAIS system:

- Simple Analog (potentiometer, discrete, accelerometers, thermocouples, strain gauge, etc.)
- Differential Transformer (Gyro's, Synchro/Resolver, LDVT/RVDT, etc.)
- Multimedia (Video, Audio, etc.)
- Avionics data (MIL-STD-1553, ARINC-429, etc.)
- Serial data (RS-232/RS-422, Air data transducer, etc.)
- Processing (RMS, Derived parameters, etc.)
- Time and Position (GPS, IRIG, etc.)

- Acoustical (Microphones, Accelerometers, etc.)
- Multiplexed (Pressures, Thermocouples, PCM, etc.)
- Packetized data (Ethernet, USB, Fibre Channel, etc.)
- Display (Analog Indicators, Cockpit Display, etc.)

System Flexibility

The figure below depicts a multifaceted system that demonstrates the wide variety of interfaces that can be accomplished with a CAIS system as well as some of the ongoing technology advancements being used in today's CAIS systems. New communication technologies such as Fibre Channel, inter-bus bridges, and interconnection between standard aircraft bus types and the CAIS bus have resulted in unprecedented system flexibility and improved data throughput. New system elements such as solid state recorders, smart transducers, smart display systems, and enhanced performance data acquisition components have found a natural home within the CAIS environment. Results from the current CAIS generation are truly revolutionary. Future incorporation of wireless technologies and network sensors promises to provide even greater performance improvements and cost reduction in the future.

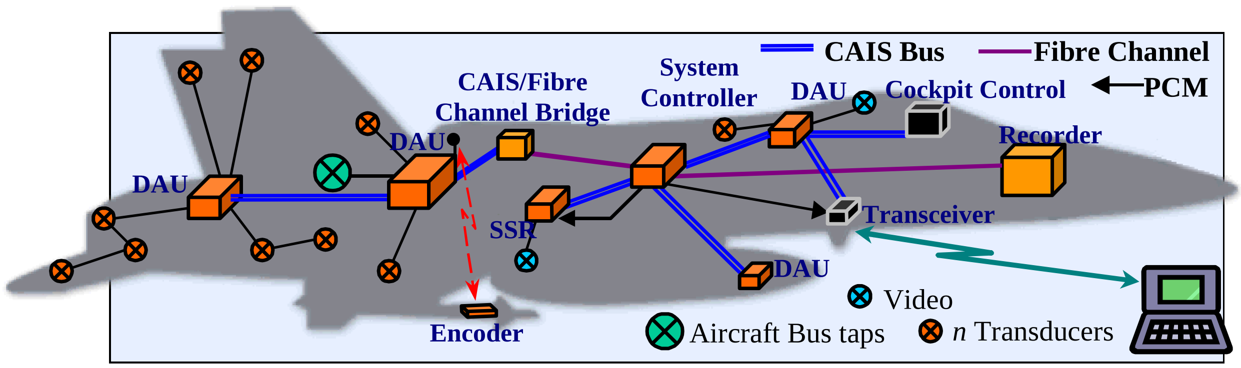

Figure 3: Dynamic System Configuration

CAIS APPLICATION EXAMPLES

Handling New Requirements

CAIS was primarily designed for use in a dynamic flight test environment. It is often used in applications that call for frequent system changes, reconfiguration, channel distribution, and sample reprogramming, which occur sometimes on a daily basis. The user of the CAIS system quickly realizes that the best way to handle these kinds of changes is not by re-inventing the system each time a change is required but to meet the need by adapting the existing system.

CAIS products are modular in nature and can be easily adapted to meet new requirements, in most cases through the simple addition of a card or module. New cards/modules can easily be developed to handle new measurement requirements within the need to retrofit the core chassis. This minimizes the impacts to standard installations in satisfying unique requirements.

The CAIS office is continually monitoring the addition and expansion of the CAIS product family, including specific measurement capabilities within the system. As the list grows, it is being offered to all users for consideration on present and future applications. If you have a requirement, contact the CAIS office. They can give you a list of what is currently available, and what is currently being developed.

Adapting to Installation Challenges

The CAIS DAUs are offered in a wide variety of form factors including 2” x 2” square and 4” x 5” rectangular shapes that are modularly expandable or fixed volume but card configurable. The variety of sizes allows the user to select the unit that best fits the need. These units are typically designed to fit tight applications (i.e. fighter and trainers) as well as larger versions for "general purpose applications" that are not size-limited and typically provide greater channel capacity. The products are generally available in both commercial and industrial temperature ranges and are suitable for use in harsh environmental applications such as a fighter.

Adding System Bandwidth

The CAIS system bandwidth is user-scaleable through the addition of multiple CAIS buses. Each CAIS bus provides 5Mbps of bandwidth. If four CAIS buses are utilized the aggregate bandwidth capability is 20Mbps. In this fashion, multiple CAIS buses can be used to increase the total aggregate bandwidth of the system.

The CAIS system can be configured to provide small networks of individual CAIS buses, each acquiring data from MIL-STD-1553 ("all data" or "selected data"), video, radar, etc., from each network.

The CAIS system is very open ended since multiple buses can be added to provide the necessary system bandwidth. However, in some situations, adding more CAIS buses may not provide the required bandwidth. This may call for the "next level up", involving the incorporation of a high speed multiplexer in order to achieve the necessary system speed.

Testing and Integrating the System

The CAIS architecture gives the user a significant amount of flexibility. The system is easily adaptable to changing requirements, modular in nature, and is non-intrusive. Any node within a CAIS system can be tested independently of others. The bus provides considerable flexibility since the CAIS bus continues to operate even when remote units are powered down. In addition, no splices are required to split any CAIS bus wires since all interconnects are made by standardized connectors that are transformer coupled.

The scalability of the system allows the Instrumentation Engineer to bring the system up in a piecemeal fashion. The system can be incrementally assembled and tested in phases in order to simplify troubleshooting and analysis. Individual system elements such as remote units can be added and tested individually rather than testing the entire system as a whole.

Interoperability

The open system interconnection offered by the CAIS bus enables CAIS units to be integrated into existing instrumentation systems. The CAIS system is interoperable with a wide variety of different vendor hardware, allowing the Instrumentation Engineer to make maximum utilization of existing equipment. This also benefits the user since interoperability allows the use of any vendor's equipment within the instrumentation system that best fits the requirements rather than the best single vendor solution.

CAIS can be easily adapted to work with an existing system through development of a specific Bus Interface Adapter (BIA). This technique can be used to interconnect inventories of heritage equipment. For example, you can turn a PC into an active CAIS remote by putting a commercial PC-104 CAIS bus interface adapter into the computer. Anything occurring on the PC back plane is then available to the CAIS system, including data processed by the computer. In this scenario, the CAIS bus does not just interface with the subsystem but actually converses with the subsystem.

Interoperability can also be as simple as adding a standard BIA card or module to an existing CAIS element. This technique results in immediate interoperability with many common standards such as Ethernet, USB, and other commercial buses.

Support Tools

Many support tools are available to simplify the Instrumentation Engineers' job. In general, these tools are extensions of existing commercial technology, adapted for use in the CAIS environment. They include such things as handheld PCM decommutators (IRIG 106 Chapters 4&8), Palm Pilot Quick-Look, PCMCIA PCM decommutator, bus interface cards, ruggedized potable support units, notebook computer support units, and many more.

The software to control these computer-based tools has been fully integrated with the instrumentation setup software. The result is that information is entered once and is automatically transferred to ground checkout equipment without the need for data re-entry. This combination of tools and software results in an integrated software/hardware environment for end-to-end development of instrumentation configurations and for ground checkout and processing.

Modular Software

Software compatibility is a major issue to the Instrumentation Engineer. Object-oriented software development techniques have become accepted throughout the commercial software development industry over the past several years, and are currently making ingress within the military and commercial flight test markets. CAIS's software system has been specifically designed to exploit the inherent technologies and benefits behind object-oriented software, as well as to simplify the integration of software that has been sourced from several different vendors.

The key software technology leveraged for CAIS is the concept of "Software Components." The idea is that multiple vendors produce software components that work within in a common user environment, just as easily as one would add a new printer to their PC computer. The result is that the end user can select hardware solutions based on capability rather than the limitations on the associated support software.

The advantage of this approach is that it facilitates a spiral development process that rapidly demonstrates the functionality within an application. This enables both vendor and customer to benefit by the early validation of requirements and thereby reduces the risk of missing capabilities and integration difficulties associated with the new functionality. This compels the developer to not limit the choices in component designs and to remain flexible in trading off functionality across components until the components are verified and integrated. The component approach allows customers and vendors to add additional functionality from other component developers as well. This ability to plug-in components offers a significant advantage to the user.

A common software platform for configuring CAIS modules developed by multiple vendors greatly enhances the user options in designing and supporting the instrumentation system. In the near future, a component developer's specification will be published that provides an open environment that enables any CAIS hardware provider to develop software components that will install and operate within a component-manager environment. Individual vendors will deliver CAIS products along with the appropriate software component/driver, vastly simplifying integration and reducing startup costs.

CONCLUSION

CAIS vendors are always evolving their products to keep pace with recent technology opportunities. The use of these technologies in the commercial world has given way to a new paradigm that has provided an affordable means for incorporating those technologies into CAIS systems. This has fueled a new generation of CAIS airborne and ground products.

The implementation of the CAIS architecture in a more network-like fashion has enabled the transition of current and future CAIS systems into the data acquisition network environment. The CAIS architecture maintains the time/data deterministic nature of synchronous time division-multiplexed systems while supporting emerging data packet technologies. These developments increase the value of the CAIS concept and ensure that today's investments will provide benefits well into the future.

New communication technologies such as Fibre Channel, Ethernet, USB, and inter-bus bridges as well as the interconnection between standard aircraft bus types and the CAIS bus have resulted in remarkable system flexibility and improved data throughput. New products such as Solid State Recorders, smart display systems, and enhanced performance data acquisition components have found a natural home within the CAIS environment. Future incorporation of wireless technologies and network sensors promises to provide even greater performance improvements and cost reductions in the future.

Industry acceptance of the CAIS bus standard has enabled DoD's usage of COTS equipment to promote standardization, commonality, and interoperability between Test and Evaluation facilities. The COTS products provide the user with the ability to select the best technical solutions at the lowest cost -- regardless of vendor systems. The commercial CAIS items have enhance and replace instrumentation systems in current platforms and continue to grow into test articles.

DATA NETWORKS AND CODING TECHNIQUES

Test Range Data and Communication Networks: Packetized Telemetry Techniques Bridge the Gap

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Abstract

This paper presents techniques that may be used to connect Telemetry Data Acquisition Sites with remote Data Reduction and Data Analysis sites in real time using a variety of available Data Communication Networks. The current trend at flight test facilities is to reduce the preprocessing and formatting performed at each acquisition site since it is desirable to provide multiple tracking sites of minimal investment and maintenance requirements in order to support longer range and multidisciplinary missions. Then by concentrating on a central flight test processing system, this facility can be leveraged across multiple customers and programs. Converting the raw telemetry signals and associated control and status information to network friendly formats is the central issue. The key concept presented in this paper is to decompose the requirements into a series of data unit conversions that will support a wide variety of protocols and layering.

Introduction

Decentralization of Data Reduction and Data Analysis requires transporting test range data over an ever wider geographical area. For each such expansion, new infrastructures are encountered at the new, formerly unconnected sites. Economic reality and the pace of commercial technology advancement in data communications simply do not permit all users at all sites to adapt standard equipment, software, or transport infrastructure. The solution therefore must embrace layered protocol and modular architecture techniques that economically provide bridges between this diverse equipment while facilitating widespread interoperability.

The problem for the Test Ranges is the unique signals, data structures and acquisition techniques in use that do not directly interconnect to common carrier and commercial data communications equipment. This paper addresses this problem and illustrates how the use of the existing CCSDS Packet Telemetry techniques can be applied to this terrestrial based problem. Techniques for converting PCM, FM/FM, Video, Voice, Time and Pre-Demodulation analog signals into digital data units that can be aggregated into an easily transportable data structure are available. These techniques address common range concerns of maintaining channel-to-channel timing coherency and maintaining acceptable end-to-end system transmission delay. It is the use of layered protocol techniques that facilitates this ability to interconnect Range Data with a variety of commercial network services.

Background

Test Ranges have continued to evolve since the earliest FM multiplex and single PCM stream configurations. Initially, the telemetry acquisition site had the receiver, synchronizers, processor, strip charts and other outputs in one location. Users rolled up paper and carried it home for analysis. Then came real time processing systems with EU converted data displayed in real time and users took a combination of paper and disks home. Next came the ability to combine data sets for cross-correlated depictions of events and attitudes. With these larger systems, it was possible to add data communication interfaces and download the data to contractor sites. Lately, as processing capabilities in VMEbus and Personal Computers increase, this trend continues with reduced costs and greater flexibility.

The reduction/analysis equipment costs for single users are now so low that the deployment costs of analysts to the field are now the dominant concern. The range acquisition sites must also be capable of accommodating an ever-expanding set of signals in terms of bit rates, types, and formats. These last two items are pushing the acquisition sites to evolve to support a “tracking and forwarding” mission. This means simpler, more automated and less costly operations.

Each range and contractor facility has it’s own history of data communications infrastructure evolution. Each facility developed it’s own ‘best solution’ over the years and was based on a prevalent or emerging technology available at the time of initial implementation. Economic realities also play an important part in shaping the facilities equipment and capabilities as available funds must be split between expanding the number and types of services versus upgrading older facilities. One range may use microwave links implementing a T3 network while another uses optical paths at OC3 rates. A newer installation may use ATM with T1, T3 and STS1 paths.

For all these reasons it is not practical to attempt to legislate all users to fit a standard model. The clear analogy to all this is the commercial data communications networks. They have evolved, expanded, and to a large degree provided successful interoperability that is built on the concept of protocol layering. There will not be one single network technology or topology that can be applied equally well to most requirements. This is because of both the technologies to address the requirements per application and the economies imposed if attempting to do so. Rather the hallmarks of a successful implementation would be:

-Heterogeneous

Connect a wide variety of signals, users and networks

-Scalable

Types and numbers of elements change to meet needs of bandwidth and number of interconnects

-Flexible

Once in place, upgrades and extensions require a minimum of replacements

An example follows.

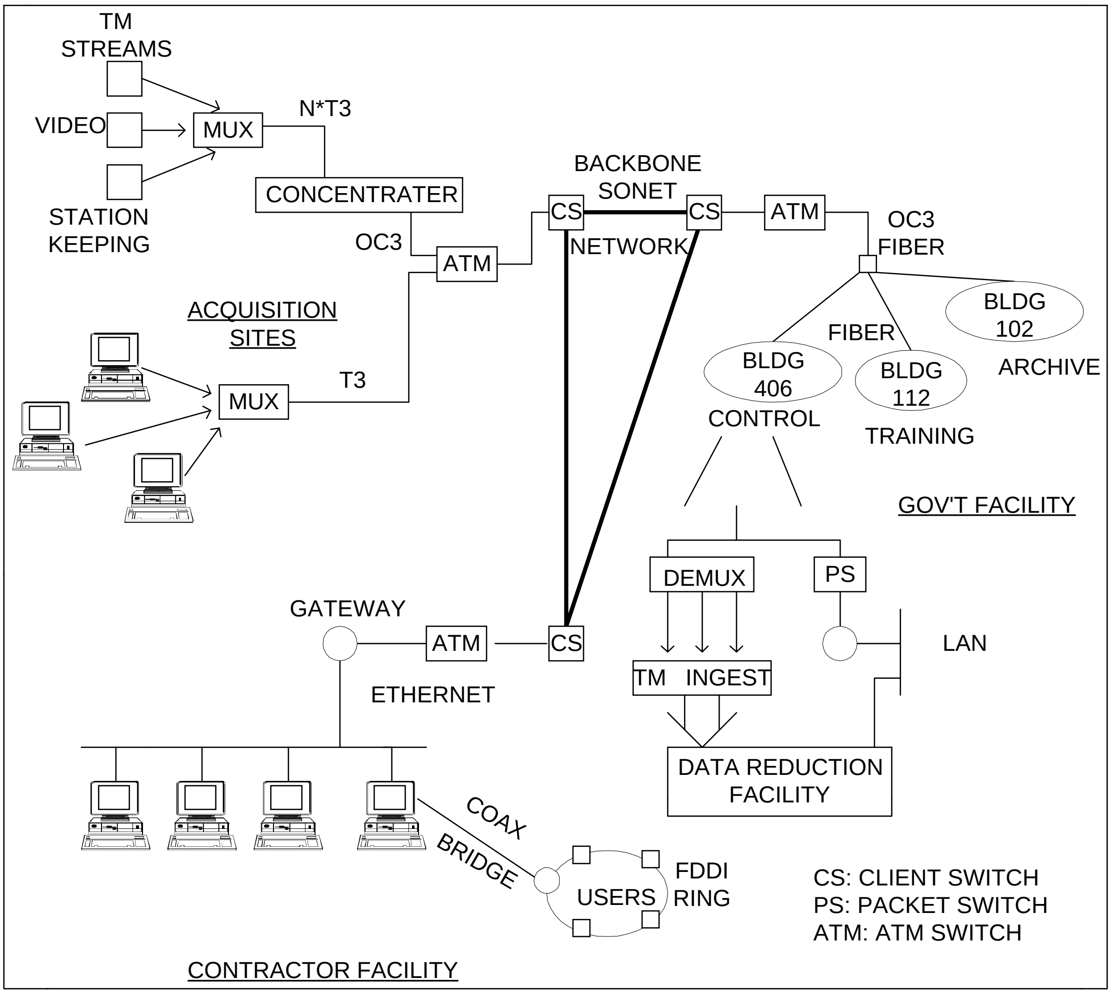

Figure 1 Multilayer Network

Protocol layering is a common technique to simplify designs by dividing them into functional layers, each concerned primarily with one task and defining protocol to perform each layer's tasks. While the terminology derives from networking designs it can be broadly applied to general system designs dealing with data acquisition and delivery. Protocol layering should not be confused with 'top-down' design techniques. Successive layers do not necessarily address more elemental or primitive concepts. Rather, each layer is designed to perform a well-defined function while interfacing directly with only the layer immediately beneath it to provide facilities for use by the layer above it. This means that each layer is **independent of the others** and is therefore **replaceable**.   Within each layer one or more entities may implement its' functionality. For any given application only the layers required need be assembled, which holds the promise of reusability without imposing costs inherent with monolithic solutions that need to address all anticipated requirements.

Scope / Overview

Figure 2 presents the requirement under discussion. The key functions are:

Accept Input Signals
Collect these signals
Aggregate these signals into one multiplexed signal
Transport the Multiplexed signal
Possibly record for fault protection
Recover the original signals
for direct or indirect (via legacy equipment) ingest.

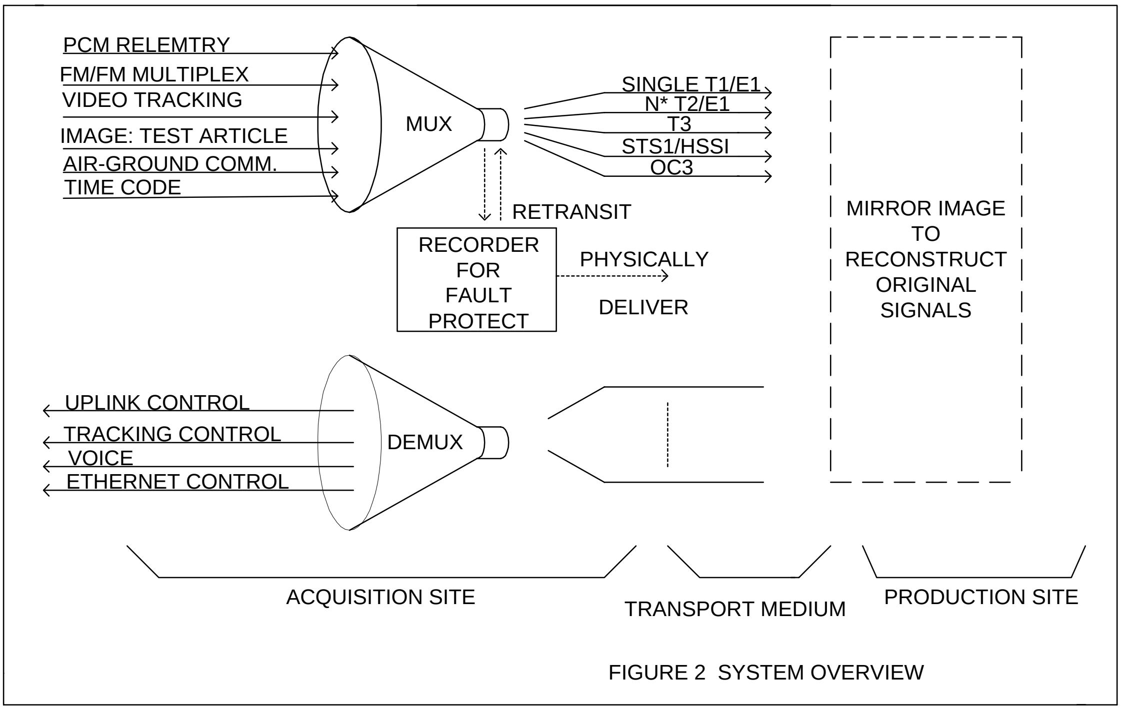

Figure 2 System Overview

This can be implemented as a layered process as shown in Figure 3. At the transmission site, each layer is effectively coupled with it's corresponding mirror function at the receive site by it's Data Unit. In this simple example, the process layer 'virtually' moves the PCM data and clock from the bit synchronizer's output at the tracking site to the frame synchronizer's input at the data reduction site. Note that because the telemetry user has specific needs that are not met in most commercial communications equipment and protocols the use of the CCSDS recommendations for Packet Telemetry[1] can provide a 'bridging' set of layers to connect the PCM data at the top of the stack to any type of network chosen at the bottom. The importance of the test range data handling differences and the techniques to address them are presented in the following sections.

The overall goal is for multiple asynchronous telemetry signals to generate variable length Source Packets that are then multiplexed into a synchronous stream of fixed length Transfer Frames. The Transfer Frames are then treated as payload data and can be inserted into the Network Protocol as required.

The Data Collection layer accepts the signals and converts them into digital sets. PCM data is simply converted into parallel data. Video signals must be digitized and generally compressed to reduce the bandwidth of the resulting signals. JPEG, MPEG and WAVELET techniques each offer significant bandwidth reduction while providing a range of quality, motion and update rate tradeoffs.

Voice (intercom) and tracking station indicators of merit such as AGC and Loop Stress are typically handled by low rate Analog to Digital converters. FM/FM and pre-demodulation type signals however require a high quality Analog to Digital conversion process that can maintain a wide dynamic range and low phase distortion in order to provide the minimum of signal degradation.

Other techniques would include collecting MilStd 1553 and ARINC429 bus data as either captured transfer data or bit by bit bus activity as required and formatting it into a data set. The mirror layer at the receive site is tasked with reconstructing the data sets into the original signals.

Ethernet data is being encountered more frequently for remote control and status operation of automated tracking sites. This data is already in digital form and needs only be buffered.

The Packetizing layer is unconcerned with the type or content of digital data sets, only that it must collect the data and format it into a Source Packet which will provide it's mirror function the ability to reconstruct the data sets. There are two key tasks for this layer. The first is to provide routing information so that once combined with Source Packets from other data inputs, the resulting stream can be correctly connected to the output. The second task is to operate within a unified Sample Interval for all channels so that the digital data sets of multiple channels will be delivered to their Data Reconstruct process in a channel-to-channel time coherent fashion. By establishing a regular Sample Interval, each Source Packet length will vary according to how much data is received during that interval [3]. An extension is to slave the Sample Interval to GPS timing and thus provide data coherency over an extended geographical area [5].

The CCSDS Packet Telemetry Recommendation establishes an excellent framework for this task. It facilitates the transmission of data in a highly automated manner using data structures specifically designed to encapsulate telemetry data and spacecraft related data into a common data transport structure.

The Channel Access Layer is concerned with aggregating the Source Packets of various lengths into one continuous stream of data comprising Transfer Frames. At the beginning of each Sample Interval the variable-length Source Packets from each signal source are sequentially placed into the transfer frames. After all the available Source Packets are transferred, fill packets are inserted to sustain the transfer frame transmission until the start of the next Sample Interval.

These fixed length synchronous frames now provide a single, easy to use data unit for the Network Access Layer. In the case of direct RF and Optical paths the synchronous nature of the data is readily modulated onto the carrier. In the case of data networks, the frames may be placed in a non-synchronized fashion into whatever payload data structure is provided and readily recovered by the mirror function at the receive site. For fault protection recording, the fill data can be removed to reduce the amount of storage required.

The Network Access Layer provides the conversion to the desired communication link and or recording device for fault protection.

Note that each layer operates independent of the higher or lower layers and therefore can be changed, upgraded or expanded without the need to rework the remaining layers. Also note that information in the frame and packet headers allow the data transmission routing and extraction to occur automatically in a standardized, data-independent method.

Multiplexing for Network Considerations

There are three considerations specific to Range data systems that are of lesser importance to the networking world. These are Time Correlation, Delivery Delay, and Synchronous operation.

Users of multistream telemetry systems need to be able to cross correlate events found in different streams. If each signal were to be placed into a simple queue and transferred in the order received as is done in most network hardware, there would be no preservation of the timing that exists between the channels. Instead, by ensuring the source packets are all generated based on a Sample Interval established by the Packetizing Layer the data sets can be realigned prior to reconstruction. This is described as the Buffered Service type [2] and an example of this operation is detailed in the reference[3].

End-to-End delivery delay is of vital interest for Range Safety and closed loop control systems.[4] Data should be transported with a minimum of delay, often restricted to less than 10 milliseconds. This imposes the practical limit on the Sample Interval of 1 millisecond since each layer may require 1 buffer. In practice, end-to-end delays of 5 milliseconds are readily achieved.

In the instances where the data is to be reconstructed it is necessary to ensure the layers sustain the data transfers and the output is a continuous, non-gated reconstruction if channel-to-channel cross correlation is to be supported. By implementing this system whereby all data channels are transported in 1 millisecond Sample Intervals, the reconstruct layer is assured of receiving a constant stream of data and will be able to reconstruct synchronous PCM, FM/FM, Pre-demod and Video signals.

Link Considerations

When the link was a dedicated microwave radio or fiber optical point-to-point connection little attention to the modularity of the system was required. Today, a system may need to change between E1/E3 (T1/T3) links, Sonet & ATM links, and may even include Inverse Muxing. Unchannelized T1 and T3 ‘path emulate’ modes have been successfully used to transmit the Transfer Frames as payload data within the T-carrier’s framing structure. Similar operation with OC3 provides up to 150 Mbps of composite bandwidth. It is important to note that the path emulate mode provides a continuous stream of data like the radio and optical paths. In the ATM world this is referred to as Constant Bandwidth Mode. It would become necessary for the Link Access layer to add additional buffering (and therefore delay) if the link can only provide isochronous data transport.

In some applications the ability to cost effectively scale links above the T1/E1 rate becomes very important. Currently, there are very few options for bonding multiple T1 links together and the cost of T3 circuits are often prohibitive. One networking solution is Inverse Multiplexing over ATM (IMA) but this is only scalable in T1 increments and requires access to ATM facilities. With proper buffering and attention to realignment procedures, the direct use of multiple T1/E1 circuits can be achieved [6]. The combined use of the layering techniques presented in this paper and inverse multiplexing has been successfully reduced to practice.

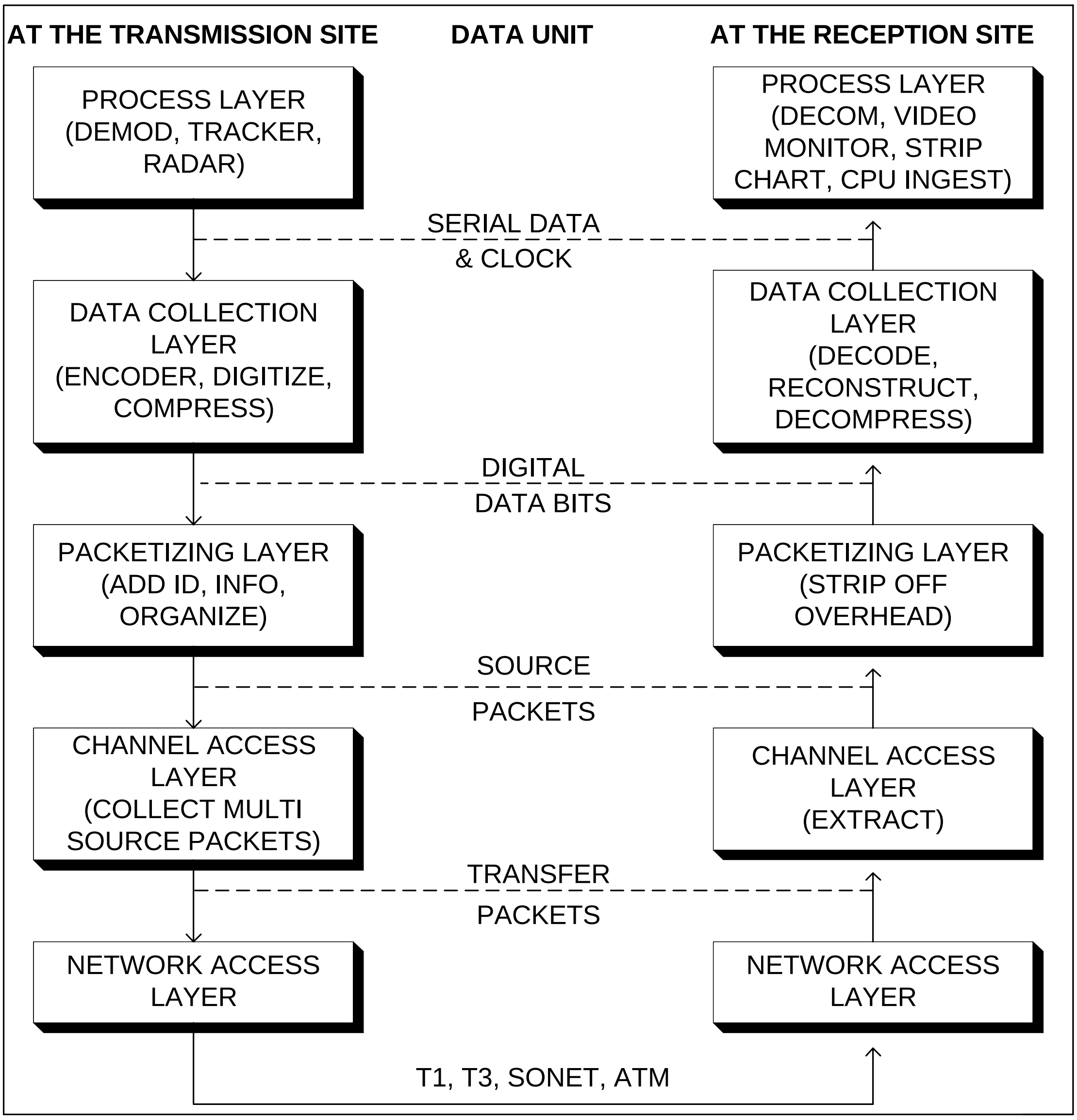

Figure 3 Layering Technique

Economics of Bridging the Gap

When considering the impact of selecting the type and approaches to be taken when implementing a "Range Support Data Network" of any size, economy is reflected in:

Cost to Institute the Network:

- Cost of hardware
- Cost to install
- Cost to bridge legacy systems (or cost to replace them)

Cost of Operation, Maintenance, and Administration:

- Cost of dedicated vs. common carrier networks
- Cost of application-specific vs. consumer/commercial equipment (economy of *market scale* issue)
- Cost of documentation, distribution of configuration per mission (how automatic is operation of the network as a TRANSPORT system?)

Cost of Data Mining

- Value increases to a user as the number of users increase:
    - o Data Reduction and Analysis computing assets can be leveraged across multiple customers and programs
    - o Availability of inter-networking facilities can be less than transporting finished data products

Cost of Scope or Service Integration

- Within a multi-disciplinary architecture, services may be expanded at lower costs
- Within an architecture **designed for change** the unforeseen needs of tomorrow's data sources are more likely to be accommodated

Conclusions

Test Range data types and operations are rapidly changing. Gone are the days of simple PCM streams. Now Packet Telemetry and high rate Image data from multiple target/test sources and multiple tracking sites must also be collected and correlated. The ability to leverage the ever increasing capabilities of network carriers and personal computing equipment plays a direct role in implementing responses to these needs. This paper illustrated the ability to implement a "Range Support Data Network" that can preserve the significant and unique attributes of the test data acquisition techniques required by the flight test community while taking advantage of the virtual connectivity and interoperability with many existing networking implementations. These can work together to provide the user with diverse requirements a network of lower-priced bandwidth.

References

[1] “Packet Telemetry”, CCSDS 102.0-B-4, Blue Book, Consultative Committee for Space Data Systems, November 1995.

[2] “Packet Telemetry Services”, CCSDS 103.0-B-1, Blue Book, Consultative Committee for Space Data Systems, May 1996.

[3] Grebe, D.L., “Multiplexer / Demultiplexer Implementation Using a CCSDS Format”, Proceedings of International Telemetry Conference, 1997, pp. 53-60.

[4] Woolridge, D.S., “Packetized Telemetry Increases Feedback System Response Time in a High Energy Physics Application”, Proceedings of International Telemetry Conference, 1999, pp. 246-250.

[5] Grebe, D.L., “Combining GPS and Packetized Telemetry Concepts to Form a Wide Area Data Multiplex System”, Proceedings of International Telemetry Conference, 1999, pp. 1014-1019.

[6] Urban, J., “The Use of Packetized Telemetry in Inverse T1 Multiplexing”, Proceedings of International Telemetry Conference, 1999, pp. 617-624.

AUTONOMOUS ACQUISITION OF ENVIRONMENTAL DATA IN A GLOBAL NETWORK ENVIRONMENT

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ABSTRACT

This paper presents the results of a feasibility study undertaken by the University of Salzburg (Austria), investigating the autonomous acquisition of environmental data in a global network. A suggested application which is used as the basis of this paper is a volcano monitoring system which would be able to track the activity of a volcano and act as a disaster warning system. The background Volcano observation data required for such a system is covered, before discussing the concepts for sensor data acquisition, storage and processing. A final analysis is then presented of the opportunities for the transmission by packet radio (both terrestrial and satellite).

KEY WORDS

Data Acquisition, Packet Radio (terrestrial and satellite) transmission, Volcano Monitoring,

1 INTRODUCTION

The measurement of environmental data plays a vital role in life nowadays. Examples are rainforest and volcano activity monitoring. Rainforest monitoring can provide very important data to detect the man made changes in the sensitive oecological system in order to rescue it. Volcano activity monitoring can even save the lives of many people, warning them in time before it erupts.

Since 1993, the Department of Scientific Computing at the University of Salzburg (Austria) has been involved in international projects such as

- acquisition of earth magnetic field data in the tropical rainforest of Brazil and transmission in a wide area network (in co operation with INPE Brazil) [Clau93]
- introduction of an Indonesia-wide packet radio network, linking most of the universities and research institutions of Indonesia for the first time (Jasipakta) [Clau93].
- support of a feasibility study of a Multi Mission Equatorial Satellite System (MMES) [Soew99]

For these (and many other) projects there is a requirement for an autonomous, portable data collection unit with packet radio link capabilities, which is able to supply itself with electrical power, to acquire the measurement data and to transmit it into a wide area or global network.

There are about 120 volcanoes in Indonesia, but currently most still lack a portable volcano monitoring and disaster warning system. Thus, this paper presents a feasibility study of volcano monitoring and disaster warning in Indonesia (in the frame of a students' project in co operation with LAPAN, the Directorat Vulkanologi and the Gadja Madha University of Yogyakarta), exploring some opportunities for acquisition and transmission by packet oriented radio transmission.

So what is the system supposed to do? First of all, it should acquire the volcano specific data in real time and store it as raw data for a certain time period. Then, specific monitoring data, e.g. statistical or smooth mean values, minima and maxima, should be provided to volcano scientists by transmission into a terrestrial packet radio or satellite network. Further, if some values exceed fixed limits, a warning mechanism should be started. The final goal would comprise the global availability of specific volcano monitoring data in the internet.

2 VOLCANOLOGIC BACKGROUND INFORMATION

Which kind of data is the system supposed to measure? Data acquisition of volcanologic data in general can be divided into several parts. There is geo-chemical data to be collected as well as geologic and meteorological data:

2.1 GEOCHEMICAL DATA

The “smoke” rising from volcanoes is gas that is naturally released from both active and inactive volcanoes. The rate at which a volcano releases gases into the atmosphere is related to the volume of magma within its magma-reservoir system. Their chemical composition depends on the temperature, and on the stage of volcanic activity. Tab 1 gives an overview of the 10 most important components of the volcanic gas composition [Mcge95] [Sutt92].

Gas	Formula	% mole	Gas	Formula	% mole
Water vapor	H_2O	18,95 – 98,13	Hydrofluoric acid	HF	0,00 – 8.67
Carbon dioxide	CO_2	2,86 – 35,77	Nitrogen	N_2	0,00 – 6,98
Hydrogen	H_2	0,02 – 11,60	Carbon monoxide	CO	0,00 – 3,68
Sulphur dioxide	SO_2	0,74 – 10,86	Oxygen and argon	O_2 + Ar	0,00 – 3,28
Hydrochloric acid	HCl	0,10 – 10,53	Hydrogen sulphide	H_2S	0,03 – 1,66

Tab 1: Volcanic Gas Composition [Purb97]

The concentration of this gas composition varies from one volcano to the next. Typically the most abundant volcanic gas is H_2O vapor, followed by CO_2, H_2, and SO_2. Volcanologists study these gases to improve their understanding of how volcanoes work, and to recognise changes in abundance or composition that might signal the possible reawakening of an inactive volcano or point to a threatening eruption at an already restless volcano. Therefore, chemical sensors are installed in or near volcanic vents and are linked to radio telemetry devices to provide a continuous readout on one or more gases. In doing so, significant short term releases of gas that will usually be missed by occasional sampling, can be detected. Decreasing H_2O and increasing CO_2, SO_2, H_2S, HCl, N_2 concentrations usually precede an eruption, whereas H_2 and O_2 on the other hand do not change significantly. Sometimes several crises exhibit an increase of H_2/H_2S, CO/CO_2 and a decrease of CO_2/H_2O and HCl/H_2O ratios even a few months prior to the eruption. [Mcge95], [Purb97]

2.2 GEOLOGICAL DATA

Most important is Seismicity, since the earliest warning of volcanic unrest usually contributes to earthquakes. Earthquake swarms immediately precedes most volcanic eruptions. Here, the *frequency*, *magnitude*, *location*, and *type of earthquake* are measured for monitoring and forecasting eruptions. The distribution of earthquakes provides information about magma pathways and the structure of volcanoes. Most volcanic related earthquakes are less than a magnitude 2 or 3 and occur less than 10 km beneath a volcano. Sometimes, these tiny earthquakes represent the only indication that a volcano is becoming restless. [Mcnu96], [Url1]

In order to measure the deformation of the volcano surface caused by the pressure of magma moving underground, geodetic networks are set up. Measurements of *horizontal deformation* are made with electronic distance meters (EDMs). *Tilt*, which is the measurement of the slope angle of the volcano's flank, is measured by so called tiltmeters. [Ever93]

Magma movement can also be traced by changes in *electrical conductivity*, in *magnetic field strength*, and in the *force of gravity*. These measurements may even respond to magma movement when no earthquakes or measurable ground movement occurs. [Wrig92]

2.3 METEOROLOGICAL DATA

In order to complete the acquisition system, it will also comprise of the measurement of the following meteorological data: *temperature* (air, ground), *atmospheric pressure*, *humidity*, *amount of rain and snow*, *wind* (speed, direction) and *sun irradiation* .

2.4 HOUSEKEEPING DATA

"Engineering and Housekeeping-Data" is required to supervise the health of the station itself. The acquisition of parameters like *electrical voltages*, *currents*, *power* or *temperatures* needs less bandwidth than the other measurement values. They can be subcommutated into one single multiplex channel. Therefore, a subcommutator with 8 channels may be used. So far, there are 7 different housekeeping values to be transmitted. The eighth channel is a spare one.

3 SYSTEM DESIGN CONSIDERATIONS

How will the system look like? Fig. 1 shows the schematic system overview. The heart of the system consists of a laptop, a data acquisition system (DAS) board, a GPS card, and a packet radio terminal node controller (TNC) with a modem. Market available components are used. The DAS board provides the PC with the raw information of the input channels (see 3.1) The GPS card tells the exact position of the measurement system and synchronises the master clock, which is important for the timestamps. The PC (laptop) receives, processes and stores all the data just gathered (see 3.2). According to a predefined time interval, which by the way depends on the current operating level (see 3.2), the processed data is transmitted via a modem (for example TNC2, which can either be for satellite or terrestrial transmission) (see 3.3). There is also the possibility that the control station sends commands to the system to ask for specific measurement data (as indicated by the broken line):

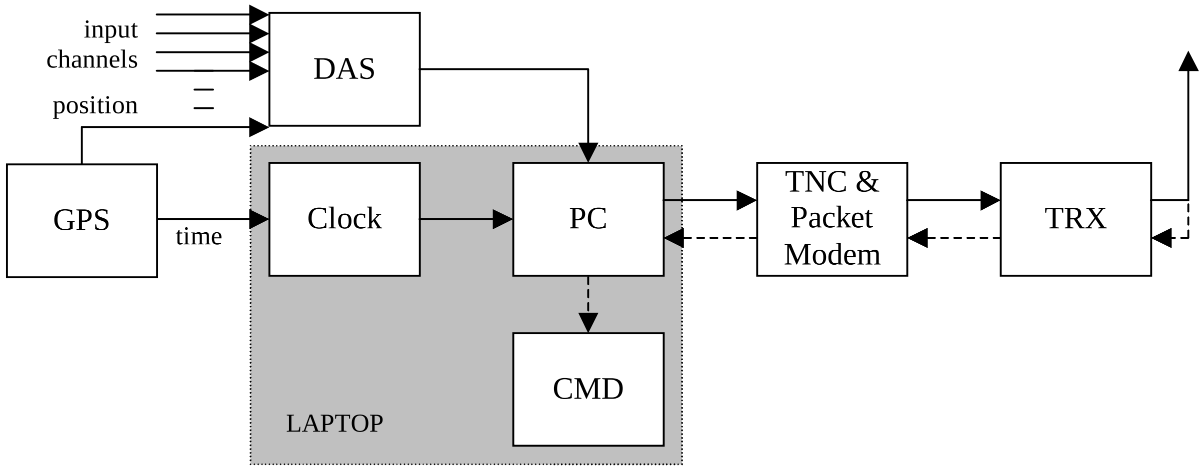

Fig. 1 Schematic systems overview (DAS...Data Acquisition System, CMD...Command, TRX...Transceiver)

3.1 DATA ACQUISITION

Based on the results of chapter two (illustrated in Tab. 2), the monitoring station would require a DAS (Data Acquisition System) with 32 channels.

Category	Measurement Values	Nr. of channels
Geochemistry	H_2O, CO_2, H_2, SO_2, HCl, HF, N_2, CO, O_2 + Ar, H_2S	10
Geologic data	earthquake (frequency, magnitude, location, type), horizontal deformation, tilt, electrical conductivity, magnetic field strength, force of gravity	11
Meteorological data	temperature (air, ground), atmospheric pressure, humidity, amount of rain and snow, wind (speed, direction), sun performance	9
Housekeeping	position, time, temperature, various electrical parameters (U, I, P) (subcommutated into one channel)	1
future use	for future measurement goals or overhead	1

Tab 2. Overview of the 32 input channels of the system

As far as the resolution is concerned, 10 bits are enough for most of these sensors. Since none of them provides information with a higher frequency than 10 Hz (as indicated in [Purb97], [Url2] and [Url3]), this bandwidth is used as a standard.

How much data has to be transmitted per second? In order to calculate this, the sampling rate has to be figured out first. In this example, a Butterworth filter (8th order) is chosen. To get a full profit of the resolution of 10 bits, a sampling rate of 40 Hz is to be taken into account. Now, the number of accumulated bits that have to be stored in a second can be calculated:

*number of channels * resolution * sampling rate = 32 channels * 10 bit * 40 1/s = 12800 bit/s*

Thus, within an hour the system has to transmit

*3600 s * 12800 bit/s = 46080000 bits/h = 5760000 Bytes/h = 5,49 MB/h* which is due to the assumption that all the measured raw data is transmitted. This does not seem to be very efficient. In some cases it doesn't even make sense, like for example to transmit the position of the monitoring station or the temperature which surely won't change much within a second. As a consequence, the data has to be processed before transmission.

3.2 DATA HANDLING AND PROCESSING

As mentioned before, it is not necessary to transmit all the raw information every single second. It seems to be far better to scale the data and then to process it, according to different types of operating levels.

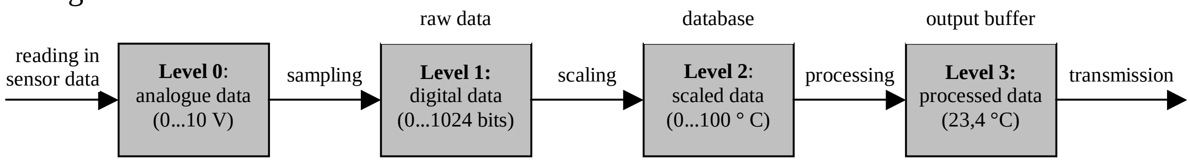

Fig. 2 Data handling

The analogue input coming from the sensors first has to be sampled. The sensors are expected to deliver values within a standard input range (e.g. from 0 to 10 Volts or ± 5 Volts). With a resolution of 10 bits, they will be represented as discrete values between 0 and 1023. This level is called raw data. Then, a scaled measurement ("human readable") value is calculated out of the raw data that accumulates in one second (e.g. value of a temperature sensor in the range of 0 ° C to 100 ° C). The mean value of the 40 values of a sensor per second is calculated and written into the database:

timestamp = id	temperature [° C]	pressure [mbar]	humidity [%]	...	value 32
20010511/161500	25,4	986	84,3	...	...
20010511/161501	25,5	986	84,3	...	...
20010511/161502	25,4	987	84,4	...	...
...	...	...	...	...	...

Tab. 3: Database model: timestamp = id (2 Bytes), 32 values (floats, each 4 Bytes) with some example data

In other words, every second a tuple of 32 values is inserted into the database. The 40 packets of raw data are then thrown away. Every tuple gets a timestamp (2 Bytes), which at the same time is the ID of the database table. The final step is the appliance of one of the following operations:

ab.	Description	ab.	Description
E_m	Average value	σ_E	Variance
E_{eff}	Root mean square value (effective value)	n_{s1}	Number of trespasses of threshold no. 1
E_{max}	Maximum value measured	n_{s2}	Number of trespasses of threshold no. 2
E_{min}	Minimum value measured	n_{s3}	Number of trespasses of threshold no. 3

Tab 4: possible operations for the scaled measurement values and their abbreviations (ab.)

The length of the time period where the operations should be applied may either depend on the operating level in which the system currently runs, or can be requested by a parameter when using the command option.

In the *command option*, the scientist can determine, from which sensor (s)he wants the data and which operation should be applied for a specific time period: (`get_data(start, end, sensor, op)`). When a command is coming in, the measurement values from the chosen `sensor` between `start` and `end` is read out of the database. Then, the specified operation `op` is applied on the data. Finally, the result is written into the output buffer where it waits to be transmitted (see 3.3).

When no commands are sent to the system, it behaves according to the operation level in which it is running (*automatic mode*). That is to say, the operation level determines the time interval in which the scaled data is read out of the database, processed an written to the output buffer. Tab 5 shows a suggestion for operating levels (which, of course, can be altered by the scientist as well). The decision, in which operating level the sensors run, is taken automatically by the system. For critical sensors (like CO_2, SO_2, temperature, ...), the scientist has to define several ranges that correspond to the particular operating levels. :

Operating Level	Description	Data processing every ...	Temperature
P1	Disaster	n = 6 sec	> 90 ° C
P2	Problem	n = 60 sec = 1 min	90 ° C – 70 ° C
P3	Warning	n = 600 sec = 10 min	70 ° C – 50 ° C
P4	Normal	n = 6000 sec = 100 min	< 50 ° C

Tab. 5: different operating levels & an example for measurement ranges (temperature) according to the operating level

Should a measurement value pass such a threshold, the system would change the operating level for this sensor (or for the whole system) automatically.

An other way of determining the operating level of one sensor or of the complete system is provided via the command function. The scientist can change the operating level manually by just telling the system to do so (`set_operating_level(sensor, level)`). According to the operating level, the system now gathers the values that have accumulated in the last `n` seconds, applies the predefined operations for each single sender and puts the results into the output buffer. Here, the results wait to be transmitted by the TNC. This is repeated by the time interval defined in the operating level. In other words, in operating level P4 (normal), the incidental raw data is processed every n = 100 minutes, using the data of the last 100 minutes, and then put into the output buffer. Unless there is any change in the operating level, it repeats doing this every 100 minutes.

How much data would there be accumulated in the output buffer? If we assume that one measurement value (float) needs 4 Bytes, we get

$$32\ channels * 4\ Bytes * 8\ operations = 1024\ B = 1\ KB$$

What happens to the scaled measurement values? They remain in the database for a predefined period, selected by the scientist, for example one week. Then, the last n measurement values will be deleted every n seconds:

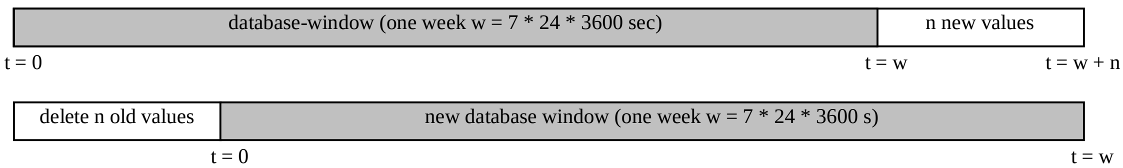

Fig 3: delete last n measurement values every n seconds

How much data has to be stored in the database within this week (*7*24*3600 s*) then?

$$(32 \text{ channels} * 4 \text{ Byte} + 2 \text{ ByteTimestamp}) \text{ B/s} * (7*24*3600)\text{s} = 78624000 \text{ Bytes} = 74{,}98 \text{ MB}$$

3.3 DATA TRANSMISSION

The data transmission is based on packet radio, since the broadcast nature of the radio channel and the ease of transporting and installing a station make this technology very attractive for the collection or dissemination of sensor data in remote areas with a poor infrastructure. As communication protocol, the world wide standard X.25 (or rather AX.25 with an extended address field) is used (see Fig. 4):

flags	address field	control field	PID	data field	FCS	flags
8 bits	112 - 560 bits	8 bits	8 bits	8 - 2048 bits	16 bits	8 bits

Fig 4. The X.25 protocol

As far as the data transmission is concerned, the VHF/UHF range is advisable, because there exist a plenty of efficient low power systems (1 - 10 W) with rather low prices (as a consequence of being the radio amateur level technology). Further this technology exhibits low signal attenuation (caused by vegetation like trees) when transmitted in the VHF/UHF range. The applied modulation technique for bit rates of 9,6 kbps (and higher) is FSK. If aiming for a bit error rate of about 10^{-5}, a Carrier-to-Noise-Ratio of more than 15 dB is required.

There are two types of PR, terrestrial (3.3.1) and satellite based PR networks (3.3.2). When a terrestrial PR network is used, the antenna could be a fixed mounted medium gain directional (Yagi) antenna. In the case of LEO satellite PR networks, fixed mounted cross dipoles (circular polarisation, over a reflector plane) would be applied. [Clau93] [Maye94]

3.3.1 TERRESTRIAL PACKET RADIO NETWORKS

Since acquisition systems of environmental data are often located in areas that lack GSM infrastructure, a packet radio network seems to be attractive. Such an infrastructure with digipeaters is now available in many countries. In Indonesia for example, a packet radio network system called Jasipakta (UHF, 56 kbit/s) was introduced in 1993 [Clau93]. In the case of volcano data collection, the measurement stations are located on elevated points, at the top of the volcano, which means a wide range of propagation. By the way, the data rate mentioned is not the one that can be used by the system. Since an X.25 frame looks like as indicated in Fig. 5, there is also some protocol data to be transmitted. So every 2048 bits are accompanied by (at most 594 bits) overhead. Thus, the maximum efficiency η is calculated

$$\eta = \text{maximum data field / total packet} = 2048 \text{ bits} / (2048 + 594) \text{ bits} = 0{,}775$$

Consequently, the effective net uplink data rate amounts to a value of

$$56 \text{ kbps} * 0{,}775 = 43{,}4 \text{ kbps}$$

According to the calculation in (3.2), there are 1024 Bytes (= 1 kB) in the output buffer that have to be transmitted (in the worst case within 6 s). Thus, the transmission would last for

*(1024 * 8) bits / 43,4 kbps = 0,19 s*

How many stations could be served then (best case)?

Operating level	Transmission every	possible Stations
P1	n = 6 sec	6 s / 0,19 s/station = 31,79 = 31 stations
P2	n = 60 sec = 1 min	60 s / 0,19 s/station = 317,87 = 317 stations
P3	n = 600 sec = 10 min	600 s / 0,19 s/station = 3178,71 = 3178 stations
P4	n = 6000 sec = 100 min	6000 s / 0,19 s/station = 31787,10 = 31780 stations

Tab 6. calculation of possible served stations according to the operating level (terrestrial system)

3.3.2 SATELLITE BASED PACKET RADIO NETWORKS

If data from stations without access to any terrestrial PR network, like a monitoring station in the tropical rainforest of Brazil or a volcano from Indonesia, should be transmitted, the only solution is the use of space based networks. Or, to put it differently, satellites. The available geo-stationary satellites are not recommendable here, since VSAT require high power transceiver or large antenna structures because of the distance to the earth (about 40000 km). Therefore, LEO satellites (circular or elliptic orbit, < 1000 km) are used. In general, there are two different types of LEO satellites, commercial and non-commercial satellites. [Maye94]

The big advantage of *commercial satellites* such as ORBCOMM is that they are visible (available) all the time. The disadvantage is the fact that they are rather expensive; every single byte that is transmitted has to be paid. Furthermore, the provided uplink data rates are not really impressive (see Tab 7).

Satellite	Frequency (uplink)	Data rate (uplink)
ORBCOMM	148.00 – 150,05 MHz	2400 bps (net)
ARGOS	137 MHz	1200 bps (net)

Tab 7: Commercial satellites

According to the calculation in (3.2), there is a size of 1 KB in the output buffer that has to be transmitted (in the worst case within 6 s). When ORBCOMM (net data rate uplink = 2400 bps = 300 Bps) is used, the transmission would last for

1024 Bytes / 300 Bps = 3,41 s

This means that only one station could be run in operating level P1, whereas in operating level P4 1759 stations could be served. (see Tab 8):

Operating level	Transmission every	possible Stations
P1	n = 6 sec	6 s / 3,41 s/station = 1,75 = 1 station
P2	n = 60 sec = 1 min	60 s / 3,41 s/station = 17,59 = 17 stations
P3	n = 600 sec = 10 min	600 s / 3,41 s/station = 175,95 = 175 stations
P4	n = 6000 sec = 100 min	6000 s / 3,41 s/station = 1759,53 = 1759 stations

Tab 8. calculation of possible served stations according to the operating level (commercial satellite PR system)

An alternative would be the use of a *non-commercial satellite* like one or more of the AMSAT, UOSAT series or, further, Indonesia's planned Multi Mission Equatorial Satellite (MMES), likely to be available beyond 2004. The usually used protocol with these satellites is the PACSAT protocol, which was developed by the University of Surrey (Great Britain) [Ward91]. The big advantage of non-commercial satellites lies in the fact that they can be used for free and that they really offer rather high transmission rates (see Tab 9). Therefore, they are ideally suited for the test and evaluation of a prototype system.

Satellite	Frequency (uplink)	Data rate (uplink)
AMSAT - series	144 - 146 MHz and 430 - 440 MHz	1,2 - 9,6 kbps (brutto)
MMES	144 - 148 MHz and 430 - 440 MHz	1,2 - 9,6 kbps (brutto)

Tab 9: Non commercial satellites

The major drawback consists of their non-continuous visibility. They are only visible every 100 minutes for about 5 minutes. That is to say that in automatic mode only operating level P4 (normal) can be applied. Thus, the data collected in 100 minutes would have to be transmitted within the short time span of five minutes. If MMES - PACSAT for example is used, the transmission for one station would take

$$(1024 * 8 \text{ bits}) / (1{,}2 \text{ kbps} * 0{,}775) = 8{,}81 \text{ s}$$

How many stations could be served by MMES - PACSAT within their availability of 5 minutes?

$$300 \text{ s} / (8{,}81 \text{ s/station}) = 34{,}05 = 34 \text{ stations}$$

CONCLUSION

In this paper the results of a feasibility study of a volcano monitoring and disaster warning systems, as an example for a measurement system of environmental data, was presented. Background information on volcano monitoring was provided. Concepts for sensor data acquisition, storage and processing were discussed, along the results providing that the designed system could easily be realised: given that the hardware is available on the market within anticipated budget estimation, and software for the database and drivers are also available. The interfaces between the drivers, database and the output field would however have to be developed.

Finally, different opportunities for the transmission by packet radio (both terrestrial and satellite) were also analysed: Terrestrial PR networks are preferable as they successfully meet the expectations. Commercial satellite networks allow limited operation, especially in high priority mode. Non commercial satellites are only suitable for monitoring (but not for real time) issues.

So far, neither redundancy nor reliability aspects have been covered. The electrical power budget and the influence of environmental conditions (high temperatures, humidity, animals) of the station on the design of the components still have to be analysed.

ACKNOWLEDGMENTS

Prof. Dr. Gerd Mayer, Ines Witte

REFERENCES

[Clau93] Clausen, Dr. H.-D. (1993), "Packet Radio for Sensor Networks" Proceedings of the Packet Radio Workshop INPE – DLR, National Institute of Space Research, Sao Jose dos Campos, Sao Paolo, Brazil

[Ever93] Evert, J.W et al. (1993), "Preventing Volcanic Catastrophe" The U.S. International Volcanic Disaster Assistance Program, Vancouver, USA

[Maye94] Mayer, Dr. Gerd (1994) "The potential of mobile radio networks for real time data transmission", Packet Radio Workshop, INPE – DLR, 17th Nov 1994, National Institute of Space Research, Sao Jose dos Campos, Sao Paolo, Brazil

[Mcge95] Mc Gee, Kenneth et al (1995), "Volcano Hazard Fact Sheet", U.S. Geological Survey, Vancouver, USA

[Mcnu96] McNutt, S.R. (1996), "Seismic Monitoring and Eruption Forecasting of Volcanoes", Springer Verlag Berlin Heidelberg, Germany

[Purb97] Purbawinata, Mas Atje et al. (1997), "Merapi Volcano - A Guide Book", Direktorat Vulkanologi, Vulcanological Survey of Indonesia

[Soew93] Soewarto, H. (1999), "Multi Mission Equatorial Satellite Development Program", Proceedings LAPAN - DLR Workshop on Micro Satellite Development; The Indonesian National Institute of Aeronautics and Space, Indonesia

[Sutt92] Sutton, A.J, et al (1992), "Fundamental volcanic gas study techniques", US Geological Survey, Menlo Park, California, USA

[Url1] Volcano World, (2001), "Volcano Monitoring Techniques", http://volcano.und.nodak.edu/vwdocs/vwlessons/monitors.html, (06.04.2001)

[Url2] RainWise Inc, (2001), "Weather Station Specifications", http://www.rainwise.com, Bar Harbor, Maine, USA (27.04.2001)

[Url3] Toxalert Inc (2001), "Toxalert Sensors data sheets", http://www.toxalert.com, Mound, Minnesota, USA (27.04.2001)

[Ward91] Ward, P. (1991), "Microsatellites for global electronic mail networks" IEE Electronics & Communication Engineering. Journal, pp. 267 - 272, Dec. 1991

[Wrig92] Wright and Pierson (1992), "Living with Volcanoes" The U.S. Geological Survey's Volcano Hazards

NOMENCLATURE

DAS	Data Acquisition System	LAPAN	Lembaga Penerbangan Dan Antariska Nasional
EDM	Electronic Distance Meter	MMES	Multimission Equatorial Satellite
FSK	Frequency Shift Keying	GSM	Global System for Mobile Communication
GPS	Global Positioning System	TNC	Terminal Node Controller
PR	Packet Radio	VSAT	Very Small Aperture Terminal
LEO	Low Earth Orbit	INPE	Instituto Nacional de Pesquisas Espaciais

CCSDS, NASA, IRIG-and US Government Standardization and Developments of Spectrally Efficient FQPSK

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ABSTRACT:

Recent advances of Feher patented QPSK ("FQPSK") technologies [1], described in this presentation*, include 1) IRIG-106 Standardization of FQPSK and commercially available FQPSK products, 2) the National Aeronautics and Space Administration (NASA) experimental results over NASA's ACTS satellite at 300Mb/s, 3) NASA/JPL (NASA Jet Propulsion Laboratory) and NASA/Goddard developed architectures for 1Gb/s rate FQPSK wireless data links and 4) The Aerospace Corporation Recommendations to the U.S. Air Force Satellite Control Network (AFSCN) for the potential use of FQPSK in satellite systems . NASA's efforts include an Application Specific Integrated Circuit (ASIC) and Field Programmable Gate Array (FPGA) hardware to produce designs for high data rate systems. These successful studies, conducted by NASA, of high bit rate technology also coincide with recommendations of FQPSK for standardization within the Space community, specifically the Consultative Committee for Space Data Systems (CCSDS). In addition to the adoption of FQPSK by CCSDS, it has been determined that FQPSK waveforms meet the Space Frequency Coordination Group (SFCG) (Spectral) Mask Specifications and that FQPSK doubles the spectral efficiency of alternative systems. In addition to the coherently demodulated FQPSK systems, for fast acquisition and re-acquisition, performance results of Non-Coherently demodulated FQPSK are also presented.

Fig's. 1 – 3 of this paper show the results of the NASA studies toward high bit rate advances [2] and CCSDS standardization [4,5] of FQPSK. Fig.4, is taken from a study of The Aerospace corporation [6], illustrating that Feher QPSK (FQPSK) has been recommended as one of several candidate waveforms for the US Air Force Satellite Control Network. Fig's 5 – 7 of this paper illustrate the IRIG-106 standardization of FQPSK [8,9]. Fig. 8 provides performance data of FQPSK receiver configurations [10]. Finally, Fig.'s 9 and 10 of this paper provide illustrations of preliminary studies of Non-Coherently demodulated FQPSK [12].

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References:

[1] K. Feher, et al., U.S. Patents: 4,567,602; 4,644,565; 5,491,457; 5,784,402, 6,198,777; and World Intellectual Property Organization, Patent Cooperation Treaty (PCT): WO 00/10272 (International Publication No. SN: PCT/US99/17995) and other pending patents. To access these and or other patents: www.uspto.gov and/or http://ep.espacenet.com/ and/or www.fehertechnologies.com . For Feher patented GMSK for GSM, FK, FQAM and FQPSK technology transfers and licensing information on an equal-opportunity, non-discriminatory basis with uniform terms and at a fair market price, contact Digcom, Inc.; c/o Dr. Kamilo Feher, 44685 Country Club Dr.; El Macero, CA 95618. Tel: 530-753-0738, Fax: 530-753-1788; Email: feherk@yahoo.com.

[2] P. Ghuman, S. Koubek, T. Winkert, A. Gray, N. Lay, T.Y. Yan, “Ultra High Bit Rate (Up to 1Gb/s) Bandwidth Efficient FQPSK All-Digital Modulator/Demodulator Architectures and NASA Implementations,” International Telemetering Conference, ITC/USA, San Diego, CA October 23-26,2000.

[3] K. Feher, *Wireless Digital Communications, Modulation & Spread Spectrum Applications*, Prentice Hall PTR, 1995.

[4] W.L. Martin, “FQPSK Developments Recommended for CCSDS Standardization by NASA JPL”, International Telemetering Conference, ITC/USA, San Diego, CA, October 23-26,2000.

[5] CCSDS 401.0-B BLUE BOOK, Recommendations for Space Data System Standards, Consultative Committee for Space Data Systems, June 2001. http://www.ccsds.org.

[6] T. M. Nguyen, H.H. Nguyen, J. Yoh, D. J. Sklar, T. Eng ,”Bandwidth Efficient Modulation Schemes for Future TT&C Applications”, International Telemetering Conference, ITC/USA, Las Vegas, NV, October 22-25,2001.

[7] IRIG STANDARD 106-01 "Telemetry Standards," Secretariat of Range Commanders Council, U.S. Army, White Sands, NM, February 2001. (Note: for higher bit rates, when better bandwidth efficiency is required, the IRIG 106-01 Telemetry Standard specifies the use of Feher's-patented FQPSK-B. This standard has been approved for public release and distribution is unlimited). Also available at http://jcs.mil/RCC/manuals/106-01/index.html .

[8] C.E. Irving, "Advanced Range Telemetry", International Test & Evaluation Association (ITEA) Workshop Test Instrumentation: New Architectures for a New Era, Lancaster, CA; March 23-26, 1998.

[9] K. Feher, "FQPSK Transceivers Double the Spectral Efficiency of Wireless and Telemetry Systems", *Applied Microwave & Wireless*, June 1998.

[10] M.K. Simon, *Bandwidth-Efficient Digital Modulation with Application to Deep Space Communications*, Monograph 3 of the Deep-Space Communications and Navigation Series (JPL Publication No. 00-17, Deep-Space Communications and Navigation Systems Center of Excellence; Jet Propulsion Laboratory, California Institute of Technology, June 2001. This book is available for download in PDF format. Type http://descanso.jpl.nasa.gov . On the left side of the home page your will see Monograph series. Click on that and it will bring up a list of books currently in the series. This book is listed as monograph #3. This book/monograph contains over 100 pages of material on FQPSK.

[11] J. McCorduck and K. Feher, "Compatibility of Dual Use Standardized FQPSK with Other Data Links and WCDMA", *Applied Microwave & Wireless, April 2001*

[12] H. C. Park, K. Lee, K. Feher, "Non-Coherently Detected FQPSK: Rapid Synchronization and Compatibility with PCM/FM Receivers", International Telemetering Conference, ITC/USA, Las Vegas, NV, October 22-25,2001.

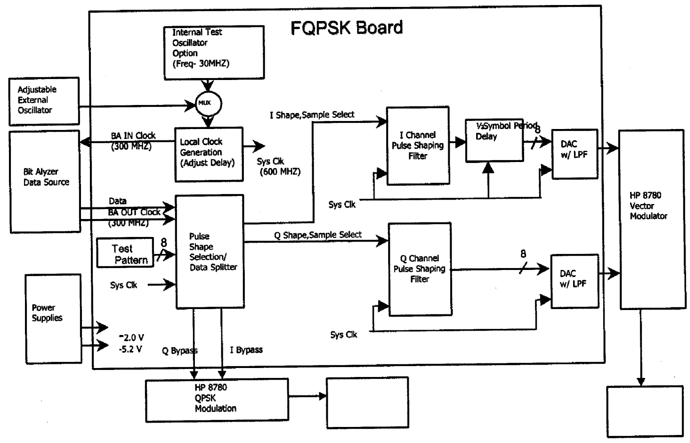


Fig. 1: Test configuration of a NASA/Goddard Space Flight Center FQPSK implementation of Feher-patented FQPSK. This particular modulator was tested over NASA's satellite system at 300 Mb/s. Joint NASA/Goddard and JPL design offer best solutions for 1 Gb/s rate FQPSK [2].

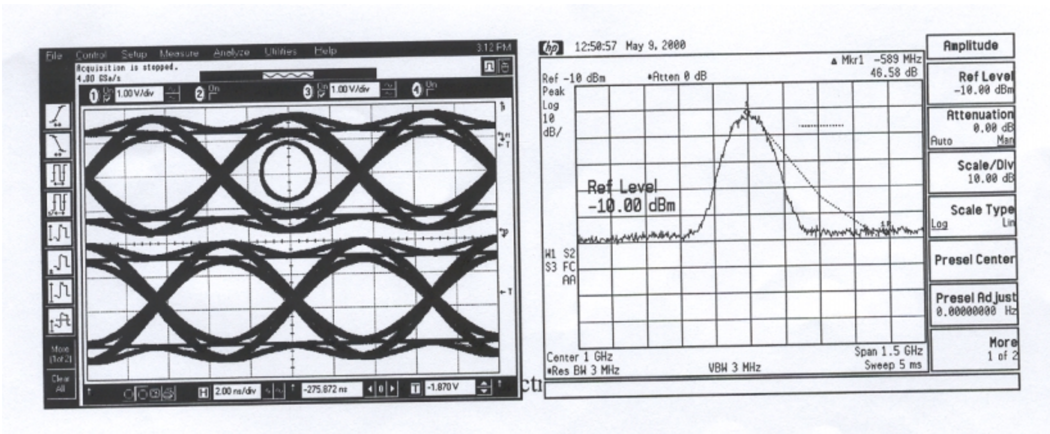


Fig. 2: NASA's FQPSK Eye Diagram and Spectrum measurements operated at 300 Mb/s from the hardware prototype displayed in Fig. 1. Note that the modulator meets the Space Frequency Coordination Group (SFCG) recommended spectral mask for planned high rate missions [2].

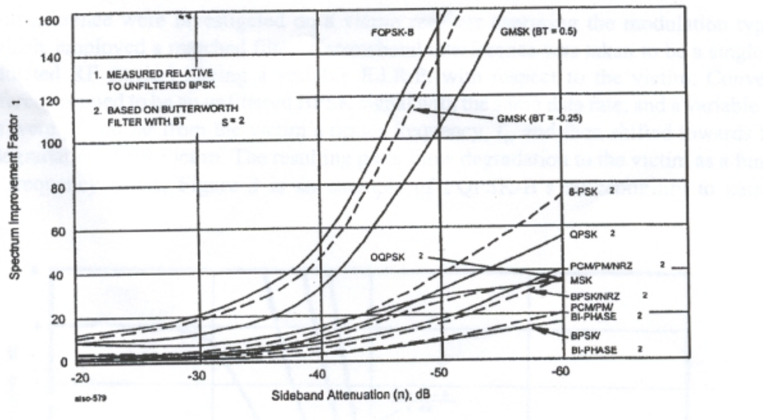
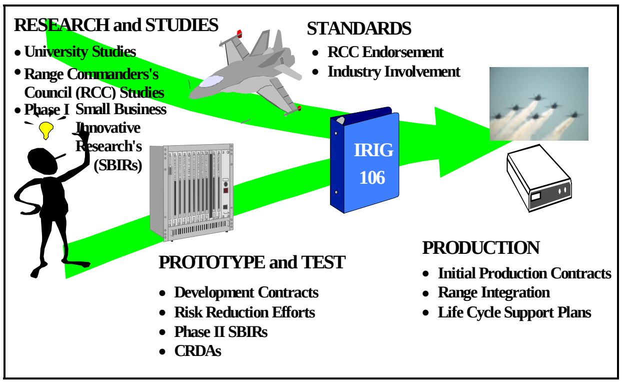


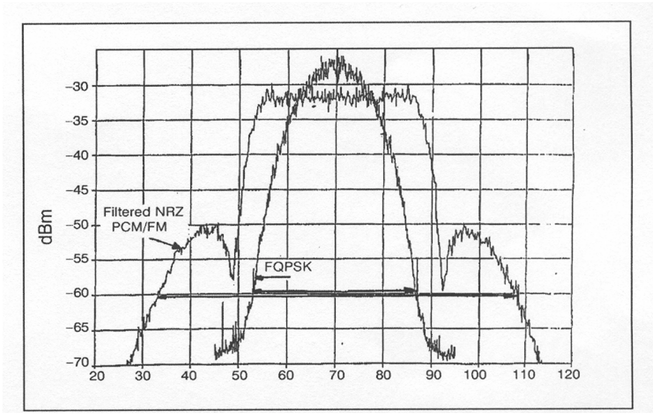
Fig. 3: Spectral efficiencies of various modulation schemes evaluated by NASA/JPL. Note that FQPSK-B displays the best results at 50 dB below the spectral peak. This comparison was performed in an independent study by NASA/JPL to recommend a modulation scheme to the CCSDS [4].

Data Rate	Selected Suite of Modulation Schemes	
	Benign Environments	Stressing Environments
Low Data Rate 5 bps – 4 Kbps	PCM/PSK/PM-Sine, PCM/PM-Bi-Phase, BPSK*, Filtered BPSK*	SS-BPSK/QPSK
Medium Data Rate 4 Kbps – 2 Mbps	Filtered BPSK/QPSK/ OQPSK, GMSK, Feher QPSK	SS-BPSK/QPSK (for lower portion of data rate range)
High Data Rate > 2 Mbps	Filtered QPSK/OQPSK, Feher QPSK, TCM-Filtered-8PSK/16PSK	

Fig. 4: Results of Aerospace Corporation's preliminary study Telemetry Tracking and Command (TT&C) waveforms recommended for the Air Force Satellite Control Network (AFSCN). Note that FQPSK has been recommended for both medium and high bit rate satellite systems. This table was reproduced from a published study conducted by The Aerospace Corporation [6].



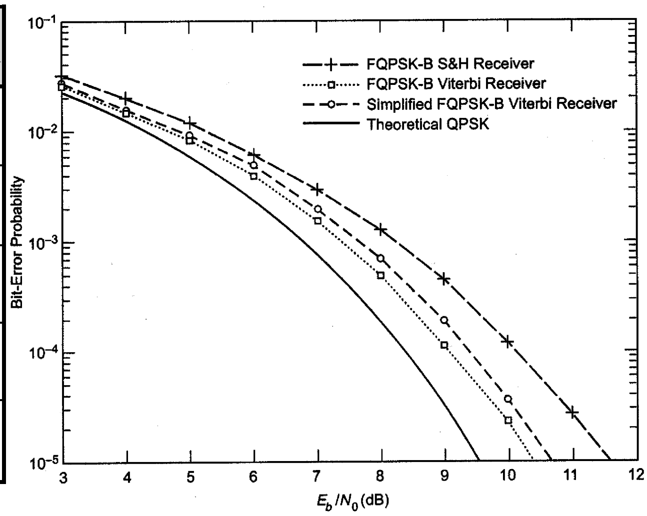
<u>Fig. 5</u>: ARTM's role in the standardization process [8]. Note that all four phases mentioned above have been addressed for FQPSK systems.



<u>Fig. 6:</u> Comparison of PCM/FM and FQPSK in Spectral Efficiency Note that FQPSK only requires half of the spectrum of PCM/FM. This is the result of the prototyping and test phase of the ARTM Acquisition Strategy illustrated in Fig. 5 [9]

Bandwidth	PCM/FM	FQPSK-B	GMSK0.3
99%	1.16	0.78	0.91
99.9%	1.98	0.98	1.13
99.99%	2.4	1.26	1.59
-60 dBc	3.15	1.64	2.02
-65 dBc	3.22	1.75	2.19

<u>Fig. 7:</u> Comparison of Spectral Efficiency for various modulation schemes as conducted by ARTM. Note that FQPSK shows the best results. [8]



<u>Fig.8:</u> BER performance of FQPSK-B B for various receiver configurations configurations. [10. p.165]

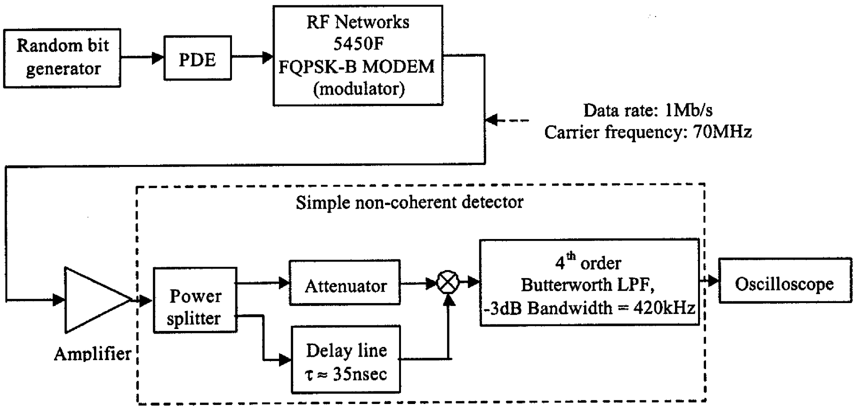


Fig. 9: Implemented non-coherent detector block diagram for non-coherent detector output measurements. This setup reproduced from Mr. Hyung Chul Park's paper [12].

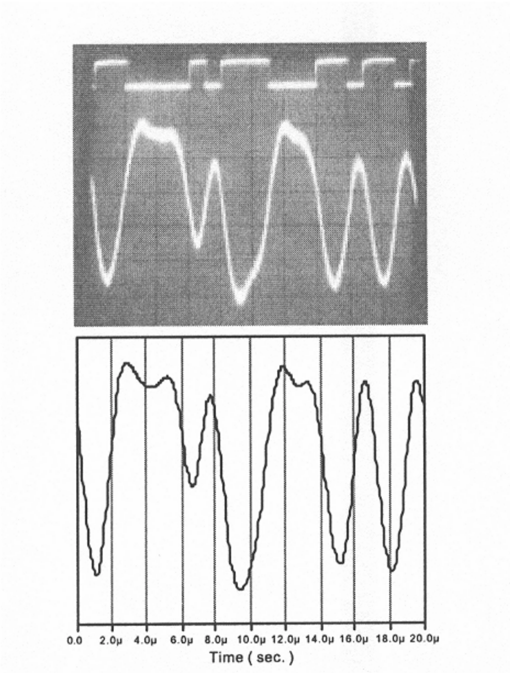


Fig. 10: Measured time patterns (upper) and computer-generated time patterns (lower) of non-coherent detector output. In the measured photos, the horizontal scale is 2μsec/div, upper signal is transmitted NRZ data and lower signal is non-coherent detector output. The data rate is 1Mb/s. Measurement and computer generated time patterns reproduced from Mr. Hyung Chul Park's paper [12].

Advances in Ultra-High Spectrally Efficient FQAM and FK Transceivers

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ABSTRACT:

Initial studies of highly spectral efficient transceiver architectures including utilizing Feher Quadrature Amplitude Modulation (FQAM) and of Feher-Keying (FK) 1) with "Smart" Diversity techniques, 2) Integration with error correcting codes, and 3) Integration with CDMA applications are presented*.

New architectures and coded-modems (CoModem) can increase the spectral efficiency of PCM/FM techniques by "x" times. As a starting point, a two dimensional 2D modulation, known as Feher's patented FQPSK, which approximately doubles the spectral efficiency of PCM/FM (in short "2x") will be used. 3D systems would add more spectral efficiency . Examples of 3D architectures are illustrated in Fig.'s1 – 3 of this paper. NLA trellis coded and/or turbo coded 3D or FQAM, is expected to lead to a spectral efficiency increase in the 4x to 8x range. To the aforementioned 3D modulation systems one more dimension, the "Clock Modulation" (CM) dimension can be added.

Thus, the proposed architectures will include a new family of potentially ultra narrowband 4D modulation systems, designated as Feher Keying or (FK), enhanced VMSK, and CPM-M. Table I of this paper illustrates and summarizes the performance and spectral efficiency (as compared to PCM/FM) of the various proposed architectures. Fig.'s 6 and 7 illustrate the results of preliminary studies of FK Turbo coded M-ary Continuous Phase Modulation (CPM-M), coded Quadrature-Quadrature (Q^2) modulation techniques and CPM-M with Very Minimum Shift Keying (VMSK), i.e. reduced modulation index [from the classical theoretical "minimum m = 0.5" to much smaller values] is suggested [3,4]. This study is also an investigation and optimization of a new generation of highly spectral efficient that will be referred to as "smart" diversity systems, which can operate more efficiently in frequency selective faded systems than conventional diversity systems. Ultra fast Pseudo-Error (PE)-Non-Redundant Error Detection (NRED) circuits and control algorithms are utilized for these systems [1]. In addition to diversity, combinations of the aforementioned architectures with turbo-coding [13 – 18] and CDMA architectures (Fig. 5) will also be presented.

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REFERENCES

1. K. Feher, et al., U.S. Patents: 4,567,602; 4,644,565; 5,491,457; 5,784,402, 6,198,777; and World Intellectual Property Organization, Patent Cooperation Treaty (PCT): WO 00/10272 (International Publication No. SN: PCT/US99/17995) and other pending patents. To access these and or other patents: www.uspto.gov and/or http://ep.espacenet.com/ and/or www.fehertechnologies.com . For Feher patented GMSK for GSM, FK, FQAM and FQPSK technology transfers and licensing information on an equal-opportunity, non-discriminatory basis with uniform terms and at a fair market price, contact Digcom, Inc.; c/o Dr. Kamilo Feher, 44685 Country Club Dr.; El Macero, CA 95618. Tel: 530-753-0738, Fax: 530-753-1788; Email: feherk@yahoo.com.
2. K. Feher, K.Wu, J.C.Y. Huang, D.E. MacNally: "Efficiency Data Transmission Techniques" US Pat. 4,720,839 Issued 1/1988
3. Walker, H. R., High Speed Data Communication System Using Phase Shift Key Coding, U.S. Patent No. 5,185,765; February 9,1993.
4. Walker, H. R., High Speed Binary Data Communication System, U.S. Patent No. 4,742,532; May 3,1988.
5. K. Feher: "Spectral Efficiency of Commercial Wireless and Telemetry Systems Is Doubled with IRIG 106-00 Standardized FQPSK and Is Quadrupled with FQAM,"

Proc. of the International Telemetering Conference, ITC/USA 2000, Vol. XXXVI, Pt. 1, pp. 225-237.

6. Lin, J.S., Feher, K., *"Test and Evaluation of Ultra High Spectral Efficient Feher Keying (FK)"*, International Telemeting Conference (ITC), Las Vegas, NV, October 22-25,2001
7. M. K. Simon*, Bandwidth Efficient Digital Modulation for Deep Space Applications,* JPL DESCANSO Monograph Series, July 2001. This NASA/JPL/Caltech monograph/book can be downloaded at http://descanso.jpl.nasa.gov/. Click on Monograph Series on the left side of the webpage, then click Monograph No. 3.
8. Feher, K., *Wireless Digital Communications, Modulation & Spread Spectrum Applications*, Prentice Hall, 1995.
9. Walker, H. R., *"VPSK and VMSK Modulation Transmit Digital Audio and Video at 15 Bits/Sec/Hz"*, IEEE Transactions on Broadcasting, Vol. 43, (no.1), March 1997.
10. Tien M. Nguyen, Hung H. Nguyen, James Yoh, Dean J. Sklar, and Thomas Eng, "Bandwidth Efficient Modulation Schemes for Future TT&C Applications", International Telemeting Conference (ITC), Las Vegas, NV, October 22-25,2001
11. Zhi Ding and Tuan Nguyen, ``Convergence Study of A Kurtosis Maximization Algorithm for Blind Signal Separation and Antenna Beam forming ", *IEEE Transactions on Signal Processing*, 48(6):1587 -1596, June 2000.
12. Junqiang Shen and Zhi Ding, ``Direct Blind MMSE Channel Equalization Based on Second Order Statistics", *IEEE Transactions on Signal Processing*, SP-48(4): 1015-1022, April 2000.
13. A. Naguib, V. Tarokh V, N. Seshadri, and A. R. Calderbank, ``A Space-Time Coding Modem for High-Data-Rate Wireless Communications," IEEE Journal on Selected Areas in Communications, Vol. 16, No. 8, pp. 1459-1478, Oct. 1998.
14. C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon Limit Error-Correcting Code: Turbo Code," *Proceedings of 1993 IEEE International Conference on Communications (ICC'93)*, Geneva, Switzerland, pp. 1064̃1070, May 1993.
15. M. K. Simon and D. Divsalar, "A Reduced Complexity Highly Power/Bandwidth Efficient Coded FQPSK System with Iterative Decoding," *Proceedings of 2001 International Conference on Communications (ICC 2001)*, Helsinki, Finland, June 2001.
16. C. Wang and D. Sklar, "A Novel Metric Transformation to Improve Performance of the Turbo Coded System with DPSK Modulation in Fading Environments," *Proceedings of Military Communication Conference 2001*, October 2001.
17. C. Wang, "A Bandwidth-Efficient Binary Turbo Coded Waveform Using QAM Signaling," to appear in Proceedings of 2002 IEEE International Conference on Communications, Circuits and Systems (ICCCAS'02), June 2002.
18. C. Wang, "Enhanced Turbo Decoding Metrics for M-ary PSK Signal," submitted to 2002 Global Communication Conference (Globecom'02), December 2002.

Performance(approximate and/or estimated values) Coded Modem (CoModem) Dimensions	PCM/FM 1	FQPSK Enhanced 2 to 3	FQAM-16 With Q^2 variation 2 to 3	FQAM-256 With Q^2 variation 2 to 3	FK with FQAM /CPM-N 2 to **4**
E_b/N_o (dB) for BER=10^{-4} no coding E_b/N_o (dB) for BER=10^{-4} coded	10 4	8.8 2 to 4	15 8	24 12	17 8 to 12
Increase in Spectral Efficiency Relative to PCM/FM Without coding	1x	3x	4x to 5x	8x	>10x

TABLE 1 Estimated spectral efficiency increase ("x" times) relative to PCM /FM, Bit Error Probability (BEP) performance of proposed Coded Modem (CoModem) transceiver research for enhanced performance FQPSK, a new generation of turbo coded and or trellis coded FQAM (having Q^2 variation) and FK (combined with FQAM and or N-ary reduced modulation index CPM) research. These systems are all operated in NLA mode.

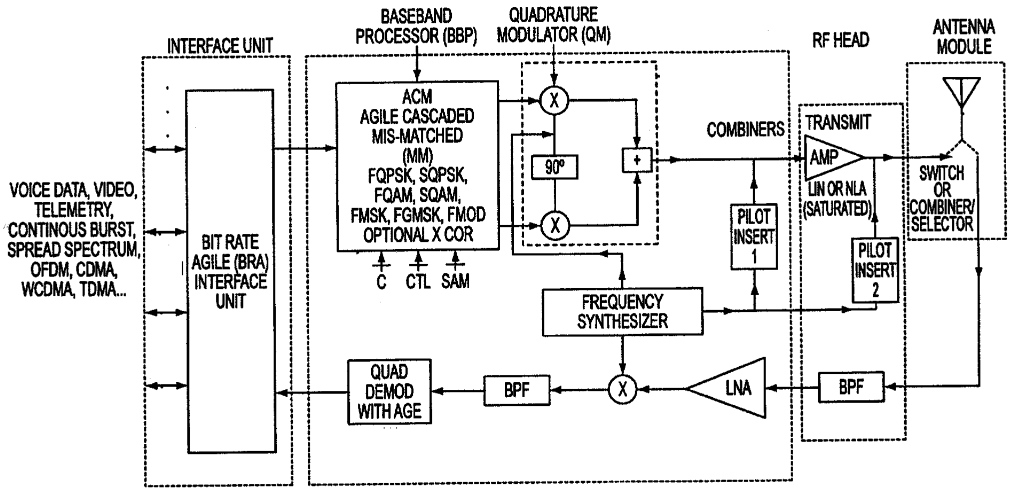

Fig. 1: A bit rate agile architecture of a two dimensional 2D modulation format (if no coding is used) and three dimensional 3D modulation format if Quadrature – Quadrature (Q2) modulation and/or coded modulation (such as trellis or turbo coding) is used [1].

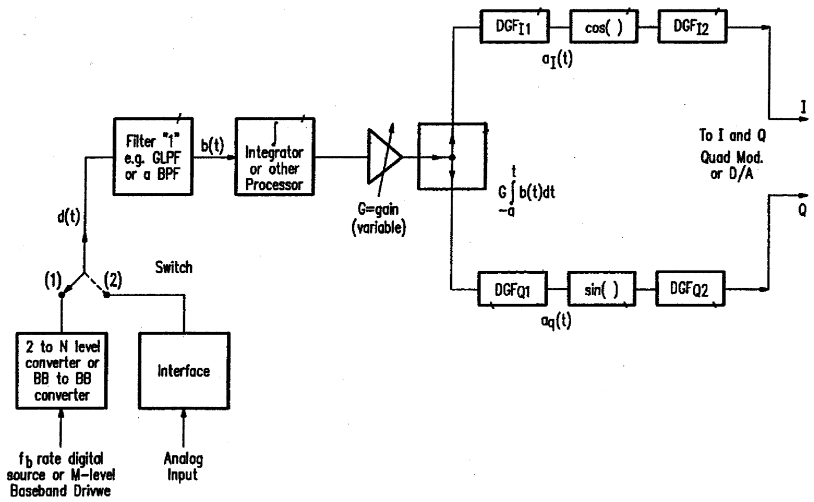

Fig.2: An M-ary CPM (Continuous Phase Modulation) in-phase (I) and quadrature phase (Q) channel architecture with a 2 to N level baseband waveform converter and variable gain for adjustment of the modulation index of this M-ary waveform generator[2,3]. For systems known as Minimum Shift Keying (MSK) the modulation index is m=0.5 , while for the proposed new generation of coded N-level , M-ary CPM systems the modulation index could be substantially smaller than for MSK type of CPM. The term Very Minimum Shift Keying(VMSK) has been used by H. Walker for substantially reduced modulation index – with non-quadrature implementations [1,3,4,9]

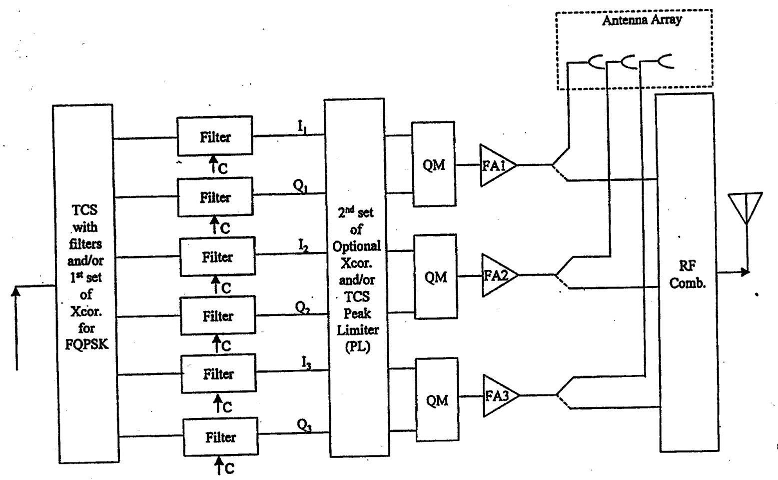

Fig. 3: Antenna Array for “over the air combining” and/or hardware RF Combining implementation of multiple modulated signals is illustrated. This figure illustrates multiple Time Constgrained Response (TCS) waveforms and/or cascaded TCS response and Long Response (LR) (long response refers to the impluse response) filtered cross-correlated baseband signal processors connected to an antenna array and/or RF combiner [1].

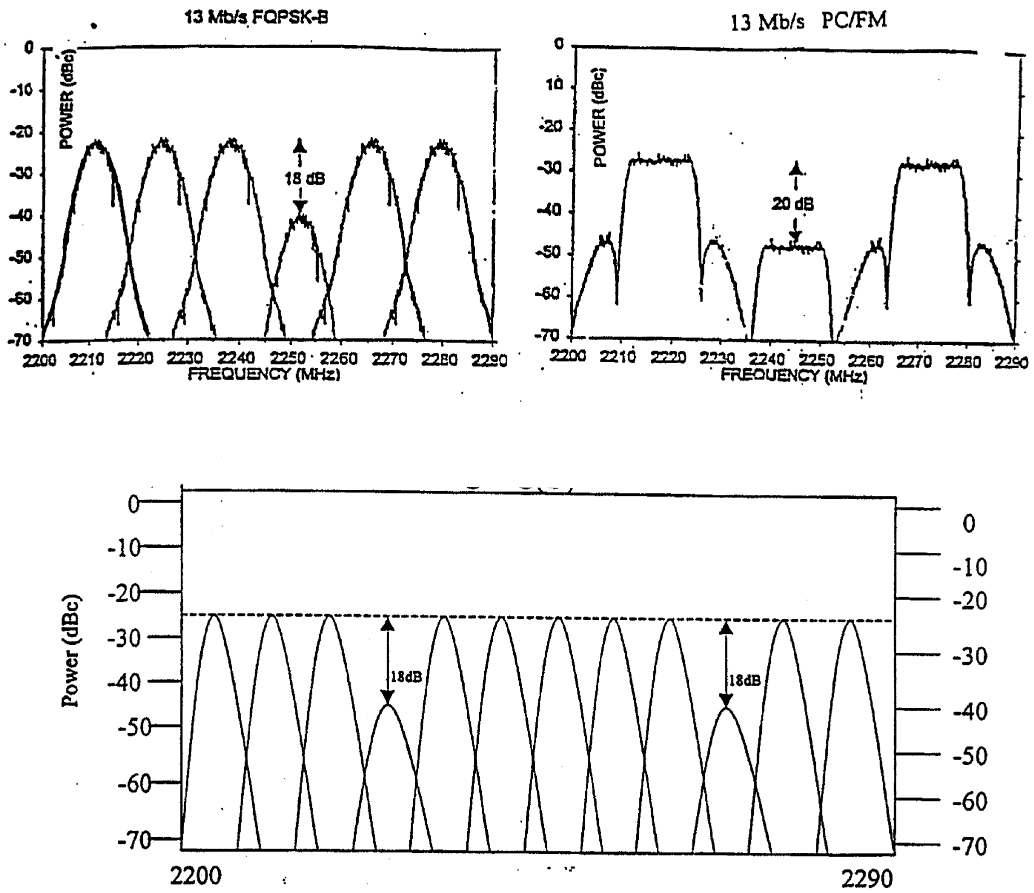

FIG. 4: Shows the Power Spectral Density (PSD) of illustrative data links operated at 13Mb/s rate per link, in the US Government authorized band between 2200 MHz to 2290 MHz. If the spectral efficiency of the IRIG- 106 standardized PCM/FM system (see Fig.- top right) is normalized to one 1x , then the spectral efficiency of IRIG-106/00 standardized FQPSK-B is 2x , i.e. it has two times higher spectral efficiency than PCM/FM.(Fig.top left). The spectral efficiency of FQAM-16 system is 4x (Fig.lower/center). With FQAM–256 the spectral efficiency of PCM/FM would be increased to 8x , i.e. eight times. In all cases power efficient NLA transmitters are assumed [1,5,7,8]

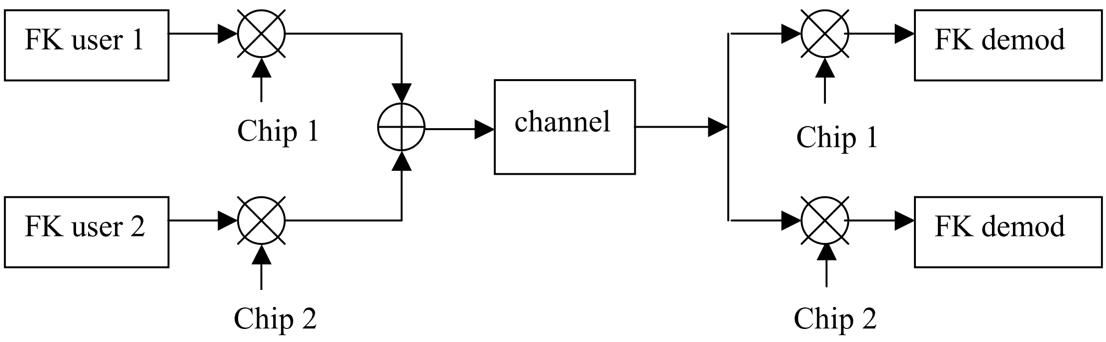

Fig.5: A CDMA and/or W-CDMA integration model of Clock Modulated FK (in CPM mode and or Quadrature Cross-Correlated Implementation is illustrated. This figure is courtesy Prof. Zhi Ding, University of California, Davis.

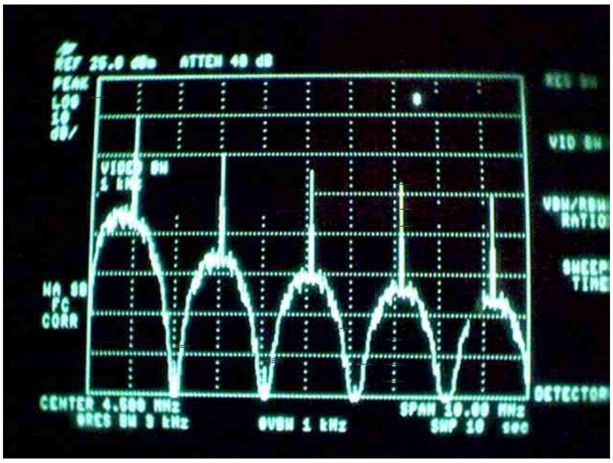

Fig. 6: An experimental Clock Modulated (CM) power spectral density (PSD) of a 1 Mb/s rate "FK-1" system is illustrated (frequency resolution bandwidth 3 kHz; span 10MHz) . Initial theoretical (analytical) and computer simulated results have been in good agreement with the hardware –experimental results [1,6].

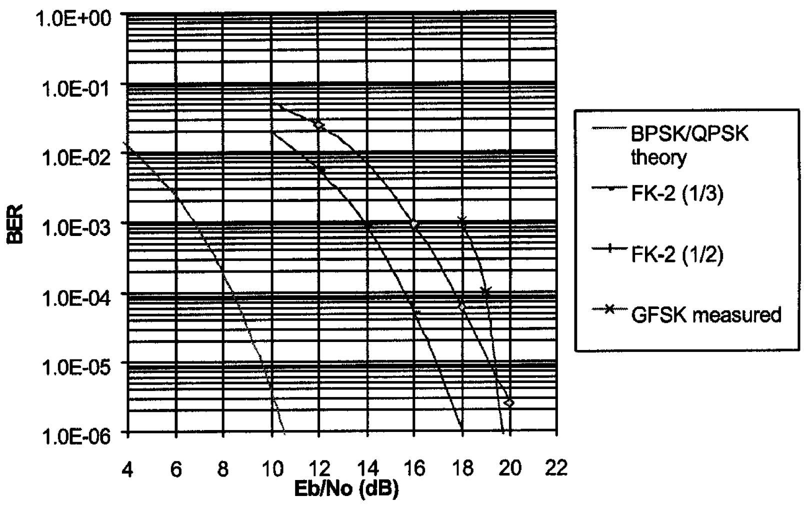

Fig. 7: Preliminary BEP performance of two Clock Modulated (FK-2 and FK-3) signals is illustrated. The results (computer simulation with preliminary hardware) are compared to 1 Mb/s rate theoretical BPSK and QPSK systems and to GFSK systems standardized by the IEEE 802.11 committee for WLAN applications[1,2,6]

Ultra Spectrally Efficient Feher Keying (FK) Developments

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Abstract

Recent developments of a class of ultra spectrally efficient Feher Keying (FK) modulation [1] is presented. The power spectral densities of FK signals could achieve more than 10/b/s/Hz, and can comfortably satisfy the spectral requirements defined in FCC (Federal Communication Commission) part 15 and IEEE 802.11 for both wireless LAN (local area network) frequency hopping spread-spectrum systems and wireless LAN direct sequence spread-spectrum systems. In this paper, FK is demonstrated by hardware to attain a comparable bit error rate (BER) performance to that of standardized wireless LAN specified GFSK while achieving far superior spectral efficiency.

Introduction

Nowadays, spectrum is a limited natural resource for mobile satellite, telemetry, cellular, PCS, and other wireless applications, and the price to obtain the spectrum is very high. The RF spectral efficiency of the systems for four state modulation systems, such as QPSK, DQPSK, SQPSK and FQPSK, is limited to 2 b/s/Hz [1]. An increased number of signaling states increases the required C/N. This leads to more expensive and larger transceivers and perhaps reduced fade margins. For example, an ideal 1024-QAM systems, for a BER=10^{-8}, requires an approximate C/N=40 dB [2]. This is an excessively high C/N requirement for many practical system environments.
In [3] and [4], we presented an ultra spectrally efficient system designated as Feher Keying (FK). This paper will present the advances in Feher Keying studies, including hardware measurement results of Feher Keying bit error rate (BER) Performance.

Description of Feher Keying (FK) Systems

In an FK processor and modulator, specified clock converted and clock shaped signal parameters are generated [1]. These are based on the input data signal patterns and are generated by means of control signals, which are designed in the data input signal interface data signal or clock signal encoder units.

Figure 1 illustrates an embodiment for Feher Keying (FK) modulations by means of shaped clock signals with variable amplitude clock levels. It includes a clock generation processor, two time shifting Signal Clock Generators (SCG), and data interface units for control signals. The clock generator provides clock signal with clock rate equals to, higher or lower than the data rate and is optional. SCG-1 and SCG-2 are two signal clock generators to provide shaped or shifted clock signals to control signal selector switch. The input signal is also fed to data interface input. This unit processes the input data and generates the control signal to selector switch. If the data input is in a high state, then the selector switch selects the shaped clock output from one signal clock generator, while if the data input is in a low state then the control signal selects the output from the other signal clock generator. A comprehensive description and other FK embodiments are disclosed in [1].

A fundamental, truly pioneering original discovery of the FK invention is that the information to be transmitted is contained in the shapes of the clock signals and/or in the different shapes, or differences of the clock signal shapes. In the vast majority of previously described systems the "data" signal elements have been processed, shaped and filtered to reduce the spectrum of the data pattern, while in FK, the "clock" signals is shaped, and the shaped clock is transmitted instead of shaped data.In classical communication theory, the entire cascaded receiver and demodulation filter responses are matched to the characteristics of the modulator and entire cascaded modulator and the RF transmitter filters. For FK, transmitter and receiver filters are intentionally and substantially miss-matched, which leads to simpler implementations than implied by communications matched filter theory and to substantially improved performance for RF power efficient transceivers.

Among various FK signals described in [1], signal patterns with variable amplitude clock levels (CL) and different shaped clock (SC) signals for the one and zero states are highlighted in this paper, and Figure 2 illustrates two of them.

Experimental Hardware Setup of Feher Keying

The experimental hardware setup for generation and measurement of FK signals is shown in Figure 4. Shaped clock signals with different amplitude levels represents ones and zeros. The clock signals are square shaped (FK-1 signals) or sine shaped (FK-2 signals) in our implementation.

To explain how the detector works, let us see the eye diagram of FK-2 signals shown in Figure 3. (The eye diagram of filtered FK-1 signals has similar pattern.) Because FK shapes the clock signals instead of the data signals, the receiver samples twice at (N+0.25)*T_s and (N+0.75)*T_s, where N=1, 2, 3..., instead of N*T_s as in the case of matched filter receiver. The magnitude difference of these two samples is compared with a threshold to make the binary decision. If the magnitude difference is larger than the threshold, we decide the received data is a "1"; otherwise, the decision is a "0.” This is illustrated in Figure 5 (a). To simplify detector design, we can also sample the received signal once per symbol at either (N+0.25)*T_s or (N+0.75)*T_s, where N=1, 2, 3… The magnitude of the sample is compared with a threshold to make the binary decision. The value of this threshold is therefore about one-half of the one in the former two-sample-per-symbol case, as illustrated in Figure 5 (b). In the experimental setup, a delay is introduced such that the sampling moments are chosen to provide best BER performance. With a simple-structured miss-matched receiver like that, we are able to obtain a BER performance that is close to or even better than the ideal BER predicted by matched filter theory.

Characteristics of Two Types of FK signals: FK-1 and FK-2: Analytical , Simulation, and Hardware Measured Results

For FK-1 signals, "0" and "1" states are represented by

$$g_0(t) = \begin{cases} A, & -\frac{T_s}{2} < t \le 0 \\ -A, & 0 < t \le \frac{T_s}{2} \end{cases},$$
$$g_1(t) = N g_0(t)\,, \qquad (1)$$

where $T_s = 1/f_s$, and f_s is the symbol rate.

For FK-2 signals, "0" and "1" states are represented by

$$g_0(t) = -A\sin\left(\frac{2\pi}{T_s}t\right), \quad -\frac{T_s}{2} < t \le \frac{T_s}{2}, \text{ and } g_1(t) = N g_0(t)\,. \qquad (2)$$

In [3], we derived the power spectral density of FK-1 to be:

$$S(f) = \frac{2A^2}{\pi^2}\left\{ (N-1)^2 \frac{f_s}{f^2}\sin^4\left(\frac{f}{2f_s}\pi\right) + (N+1)^2 \sum_{\substack{m=1 \\ m=odd}}^{\infty} \frac{1}{m^2}\delta(f - mf_s) \right\}. \qquad (3)$$

The results show that the PSD of FK-1 contains continuous spectral part and discrete spectral parts. The discrete spectral parts are impulses at odd harmonics of f_s. It can be shown that the percentage power in the first harmonic comparing with the total power is 73% for N = 2 and 65% for N=3.

The power spectral density of FK-2 is also derived in [3] to be:

$$S(f) = A^2\left\{ (N-1)^2 \frac{f_s^{\,3}}{2\pi^2\left(f^2 - f_s^{\,2}\right)^2} \cdot \sin^2\left(\frac{f}{f_s}\pi\right) + \frac{1}{8}(N+1)^2\delta(f - f_s) \right\}. \qquad (4)$$

We note that the PSD of FK-2 contains continuous spectral components and a single impulse at f_s. It can be shown that the percentage power in the first harmonic comparing with the total power is 90% for N = 2 and 80% for N=3.

The discrete spectral components of FK signals make it easy for fast synchronization and noncoherent detection.

According to communications theory [8], the bit error probability for a binary signal assuming matched filter and infinite bandwidth is:

$$BER = Q\left(\sqrt{\frac{d_{12}^2}{2N_0}}\right), \tag{6}$$

where d_{12} is the Euclidean distance of the two signals.

For FK-2 and FK-1, if the amplitude of the big square (sine) signal is 3 times of that of small square (sine) signal, the energy in the big amplitude signal is $E_1 = 9E_b/5$, and the energy in the small amplitude signal is $E_2 = E_b/5$, where E_b is the average bit energy. The Euclidean distance of these two signals is $d_{12}{}^2 = \left(3/\sqrt{5} - 1/\sqrt{5}\right)^2 E_b = 0.8E_b$ instead of $4E_b$ as in BPSK. Thus the BER performance of infinite bandwidth FK (1/3) signals (the amplitude ratio of the two square/sine signal is 1 to 3) is $10 * \log_{10}(4/0.8) = 7$ dB inferior to BPSK if conventional matched filter is used. At BER = 10^{-4}, the E_b/N_o required by the FK (1/3) signals is lower bounded by 15.4 dB with conventional matched filter.

If the amplitude of the big square (sine) signal is 2 times of that of small square (sine) signal, the energy in the big amplitude signal is $E_1 = 8E_b/5$, and the energy in the small amplitude signal is $E_2 = 2E_b/5$. Similar to the analysis in the former paragraph, the Euclidean distance of these two signals is $d_{12}{}^2 = \left(\sqrt{8/5} - \sqrt{2/5}\right)^2 E_b = 0.4E_b$ instead of $4E_b$ as in BPSK. The BER performance of infinite bandwidth FK (1/2) signals (the amplitude ratio of the two square/sine signal is 1 to 2) is $10 * \log_{10}(4/0.4) = 10$ dB inferior to BPSK if conventional matched filter is used. We conclude that at BER=10^{-4}, the E_b/N_o required by the FK (1/2) signals is lower bounded by 18.4 dB with conventional matched filter.

FK-2 gives better performances than FK-1. The analytical results, computer simulation, and hardware measurement results of the power spectral density (PSD) of FK-2 is illustrated in Figure 6. The frequency resolution bandwidth was chosen to be 3 kHz in the measurement.

The analytically derived, computer simulated, and hardware measured power spectral densities for the specific FK signals have similar shapes. We can see that when the frequency resolution bandwidth is increased or decreased by *n* times, the magnitude difference of the discrete spectral components (impulses when expressed in analytical form) and the continuous spectral components will decrease or increase by n times, or $10\log_{10} n$ dB, respectively. Figure 7 shows the Matlab plotted PSD theoretical result of 1Mb/s FK-2 with frequency resolution bandwidth 3 Hz. In Figure 6 (a), the frequency resolution bandwidth is 3 kHz, while in Figure 7, the resolution bandwidth is 1000 times smaller, and thus the magnitude difference of the discrete spectral components and the continuous spectral components is 30 dB. Figure 7 show that, with FK-2, at –60 dB and lower, spectral efficiency of greater than 10/b/s/Hz is achieved at transmitter.

Figure 8 show the PSD of filtered FK-2 signals with resolution bandwidth 3 kHz. FK-2 signals satisfy FCC part 15 frequency mask [10], which requires the power spectrum to be 20 dB down beyond the 1 MHz wide frequency range. The frequency resolution is chosen to be 3 kHz. For frequency resolution bandwidth smaller than 3 kHz, the differences of the discrete components and continuous components of the spectrum of FK-1 and FK-2 signals can be even larger.

The BER performances of quadrature FK systems with miss-matched receiver structure under various situations are computer simulated, and the results are summarized in Figure 9. BER performance of GFSK, which is used in Wireless LAN (IEEE 802.11), is also shown as a comparison. We can see that FK-2 with amplitude ratio 1/3 gives the best result. With specifically designed miss-matched receivers as we have discussed in the former sections, at BER=10^{-4}, FK-2 (1/3) with simple two-threshold detector requires an E_b/N_o of 15.6 dB, approaching the theoretical limit 15.4 dB assuming complex matched filters and infinite bandwidth; and FK-2 (1/2) requires an E_b/N_o of 17.7 dB, better than the theoretical result 18.4 dB assuming complex matched filters and infinite bandwidth. On the other hand, the measured E_b/N_o required by 1Mb/s GFSK (deviation 160 kHz) is 19 dB for BER=10^{-4}. Hardware measured FK-2 (1/3) with simplest one-threshold detector is also shown. We can conclude that, with far superior spectral efficiency than GFSK, FK can achieve comparable or better power efficiency.

Conclusion

We have presented some new developments in a subclass of a new and ultra spectrally efficient Feher Keying, or FK, system. The power spectral densities of filtered FK-1 and FK-2 signals are demonstrated to easily satisfy the frequency requirements defined in FCC part 15 and IEEE 802.11 for wireless LAN, and the spectral efficiency of FK is more than 10/b/s/Hz in transmitter. With hardware measured sub-optimum and miss-matched receiver, FK was found to have comparable or better power efficiency to standardized Wireless LAN GFSK while achieving far superior spectral efficiency. Due to its simple transmitter/receiver structure and fast synchronization capability, FK could be implemented in high bit-rate and bit-rate-agile systems.

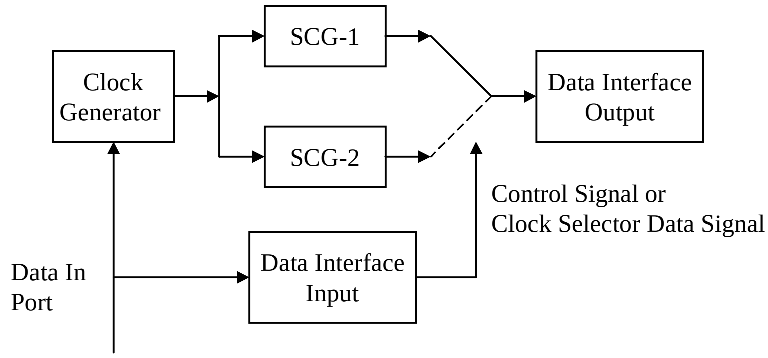


Figure 1. Hardware architecture for one of the Feher Keying (FK) transmitters with variable amplitude clock levels (CL) and different shaped clock (SC) signals for the one and zero states [1].

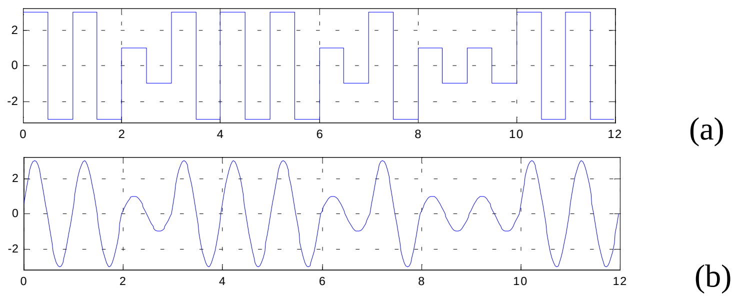


Figure 2. Illustrative FK-1 and FK-2 signal waveform patterns. Information is carried in variable amplitude clock levels. FK-1 signals (a) plotted by Matlab, and (b) demonstrated by hardware. FK-2 signals (c) plotted by Matlab, and (d) demonstrated by hardware. [2]

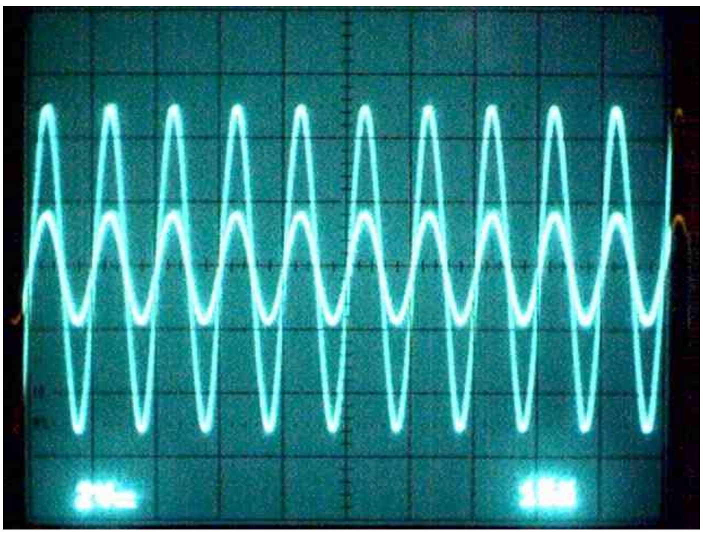


Figure 3. Eye diagram of 1 Mb/s FK-2 (1/3) signals. Filtered FK-1 signals have similar eye diagrams. (a) Hardware demonstrated. [3]

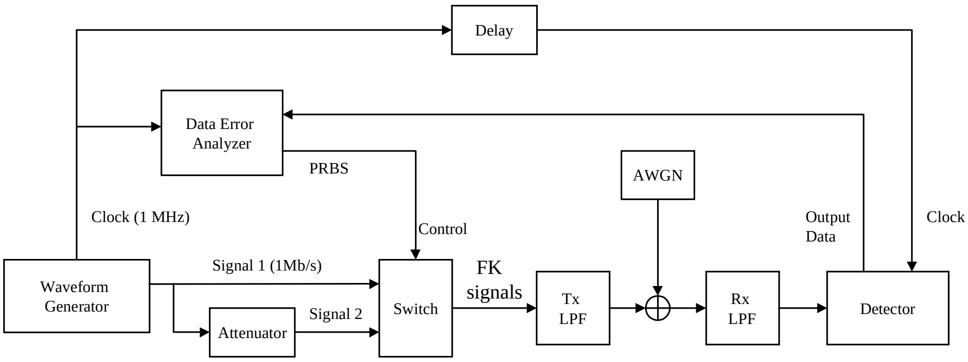
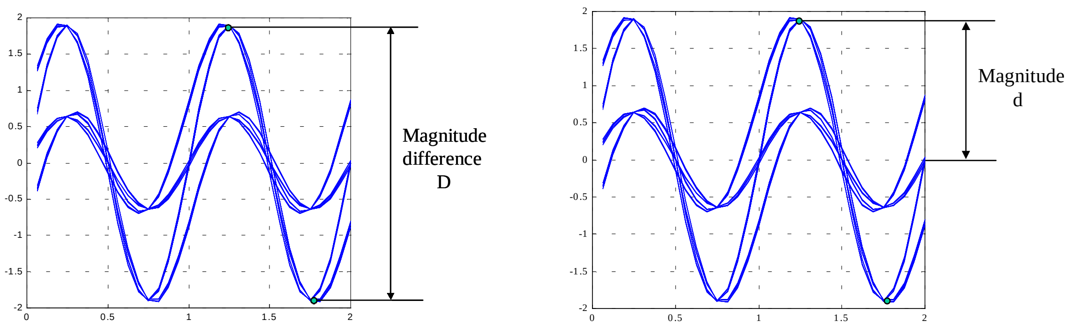
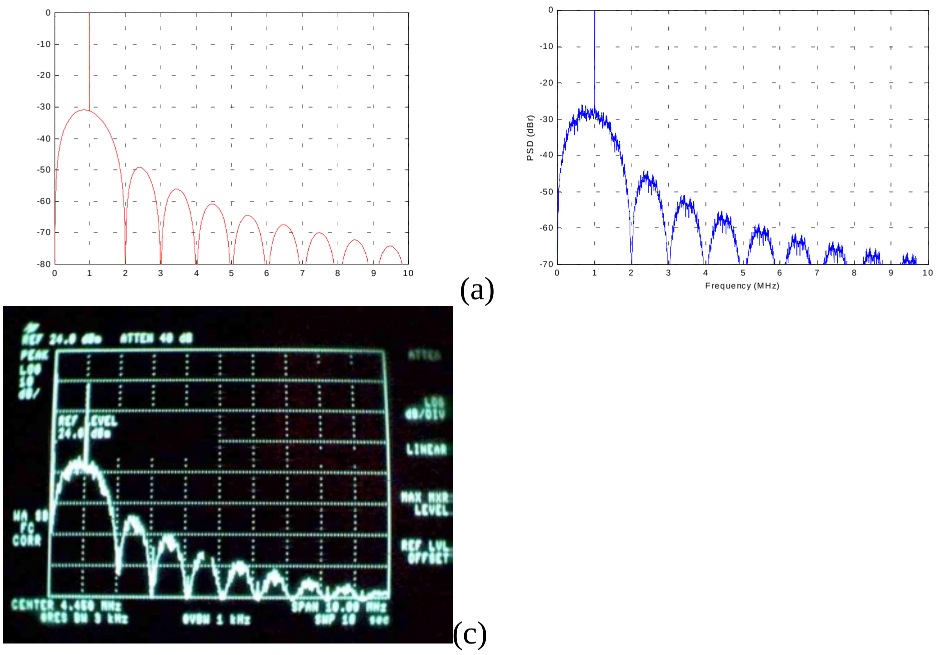


Figure 4. Experimental hardware setup for generation and measurement of FK signals at bit rate 1 Mb/s. [3]



(a) (b)

Figure 5. Eye diagram of received FK-2 1 Mb/s signals. (a) Sampling twice in one bit duration. (b) Sampling once in one bit duration.



(a) (b) (c)

Figure 6. Power spectral density of 1Mb/s FK-2 with frequency resolution bandwidth 3 kHz. (a) Theoretical result, (b) computer simulated result, (c) hardware measured result with video bandwidth 1 kHz and span 10 MHz. [3]

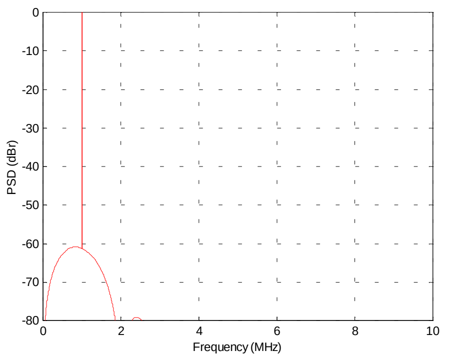
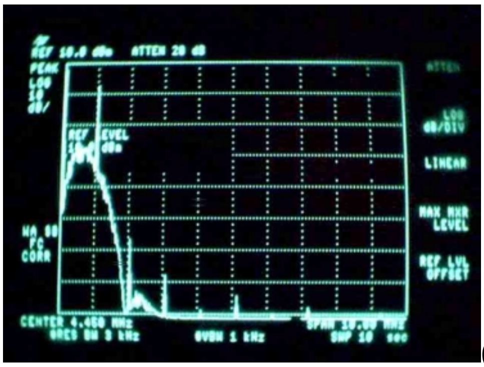
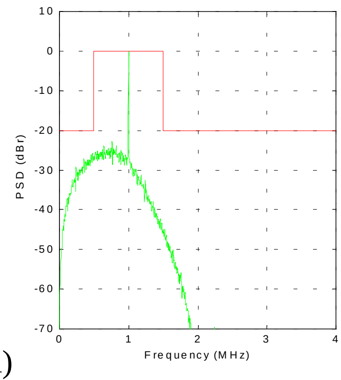
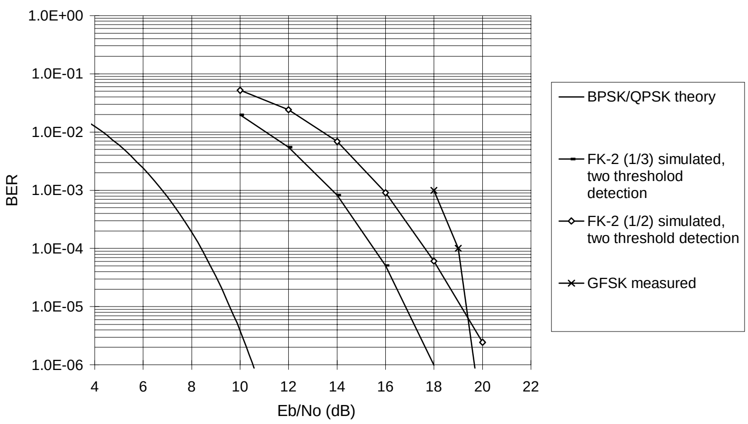


Figure 7. Computer plotted power spectral density theoretical result of 1Mb/s FK-2 with frequency resolution bandwidth 3 Hz.

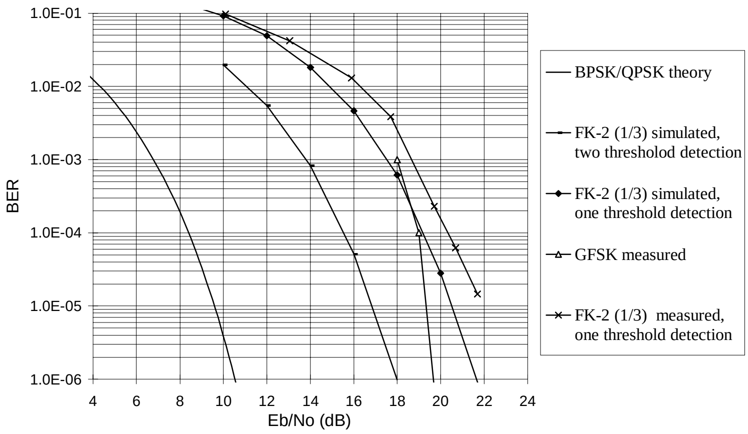

(a)


(b)

Figure 8. Measured PSD of 1Mb/s FK signals after Butterworth 4th order filter, with frequency resolution bandwidth 3 kHz. a) FK-2 measured, b)FK-2 simulated. The power spectral densities of FK systems satisfy the FCC-15 frequency mask for wireless LAN (IEEE 802.11). [3]



(a)



(b)

Figure 9. Simulated BER performance of FK-2, FK-1 and measured BER performance of 1 Mb/s FK-2 with one threshold detection and 1 Mb/s GFSK with 160 kHz deviations. 1/2 and 1/3 means the amplitude ratio of the two shaped clock signals representing 0 and 1 is 1 to 3 and 1 to 2, respectively. 160 kHz deviation is specified in order to meet the FCC-15 and IEEE 802.11 (wireless LAN) spectral efficiency and out of band attenuation requirements

Reference:

[1] K. Feher, et al., U.S. Patents: 4,567,602; 4,644,565; 5,491,457; 5,784,402, 6,198,777; and World Intellectual Property Organization, Patent Cooperation Treaty (PCT): WO 00/10272 (International Publication No. SN: PCT/US99/17995) and other pending patents. To access these and or other patents: www.uspto.gov and/or http://ep.espacenet.com/ and/or www.fehertechnologies.com. For Feher patented GMSK for GSM, FK, FQAM and FQPSK technology transfers and licensing information on an equal-opportunity, non-discriminatory basis with uniform terms and at a fair market price, contact Digcom, Inc.; c/o Dr. Kamilo Feher, 44685 Country Club Dr.; El Macero, CA 95618. Tel: 530-753-0738, Fax: 530-753-1788; Email: feherk@yahoo.com.

[2] K. Feher, “Wireless Digital Communications: Modulation and Spread Spectrum Applications,” Prentice Hall, 1995

[3] J.-S. Lin, K. Feher, “Ultra High Spectral Efficient Feher Keying (FK): Theoretical, Computer Aided Design and Hardware Development,” *European Test and Telemetry Conference 2001*, Marseille, France, June 12-14, 2001

[4] J.-S. Lin, K. Feher, “Test and Evaluation of Ultra High Spectral Efficient Feher Keying (FK),” Proceedings of the *International Telemetry Conference*, Las Vegas, NV, Oct 22-25, 2001

[5] United States Patent 4,742,532 and issued to Walker.

[6] Walker, H.R.:"VPSK and VMSK Modulation Transmit Audio and Video at 15 Bits/Sec/Hz," IEEE Transactions on Broadcast Engineering, January 1997.

[7] Walker, H.R., Stryzak, B., Walker, M.L.:"VMSK Modulation, a Tutorial-Bandwidth Efficiencies of 30bits./Sec./Hz," Proceedings of the Sixth Annual WIRELESS Symposium, Santa Clara, CA, February 9-13, 1998.

[8] Proakis, J. G.: "Digital Communications", McGraw-Hill, Now York, 1995.

[9] Feher, K, "Spectral Efficiency of Commercial Wireless and Telemetry Systems is Doubled With IRIG 106-00 Standardized FQPSK and is Quadrupled with FQAM",

Proceedings of the International Telemetry Conference, Las Vegas, NV, October 23-26, 2000.

[10] Guo, Y., Feher, K.: “A New FQPSK Modem/Radio Architecture for PCS and Mobile Satellite Communications,” IEEE Journal on Selected Areas in Communications, vol. 13, No. 2, February 1995.

Fast Synchronized Noncoherent Detection of Standardized FQPSK and OQPSK

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Abstract
This paper presents noncoherent detection of FQPSK (Feher quadrature phase-shift-keying) and filtered OQPSK (offset quadrature phase-shift-keying) suitable for non-linearly amplified (NLA) communication systems in fast fading or large Doppler spread, and strong phase noise environment. Compared with conventional coherent systems, FQPSK and OQPSK noncoherent systems do not need carrier recovery, and can offer faster synchronization (acquisition) and resynchronization time and reduce frequency selective fading outages for burst operated TDMA (including GSM) and CDMA based wireless communication systems, and could double the system capacity in the case of FQPSK.

Introduction

In mobile or mobile-satellite channels, because of multipath fading, shadowing, large Doppler spread or fast fading ($f_D T_b > 0.01$), strong phase noise, or other reasons, it is difficult, some times impossible, to track the phase of the received signal correctly. Under such situations, coherent detection either cannot be performed, or suffer considerable performance losses; its carrier recovery circuits have long acquisition time, and the receiver experiences high error floor. To resolve these problems, noncoherent detections schemes such as limiter-discriminator detection or differential detection are preferred fading countermeasures, since they have faster synchronization and re-synchronization, and exhibit lower error floors compared to coherent detection, and can reduce burst error and outages for relatively low data rate burst operated CDMA and TDMA (including GSM) systems. A comparison of coherent and noncoherent systems is given in Table 1.

The power spectra of FQPSK and OQPSK are shown in Figure 1. FQPSK-B has been adopted by Telemetry IRIG standard 106-00 [3] and recommended by CCSDS for use in high-speed space data communication systems. Hardware that modulates FQPSK at rates up to 300 Mbps and demodulate at rates up to 600 Mbps has been reported in a joint paper by researchers at NASA/GSFC (Goddard Space Flight Center) and JPL/CalTech [4].

[*] Significant parts of this material are based on the author's reports and remain the property of the authors.
File: 02.02.25 Lin NonCoh FQPSK with Fig. Proc. of the ETC 02 Germany May 02

Non-coherently detected FQPSK and OQPSK could offer double the capacity (in the case of FQPSK), faster synchronization (acquisition) and resynchronization time than coherent detection, and good power efficiency for wireless applications. However, to date, the differential detection of FQPSK is not seen the literature, and the limiter-discriminator detection of FQPSK has not been investigated except the work of the authors and their lab colleagues. Similar situation also holds true for OQPSK. To the authors' knowledge, limiter-discriminator detection of OQPSK has not been reported.

Differential detection of FQPSK and OQPSK

The phase trellises of unfiltered FQPSK (XPSK), filtered FQPSK (FQPSK-B), and filtered OQPSK are illustrated in Figure 2. From them we can see that the possible phases of received XPSK signal at sampling instants, assuming perfect phase alignment and perfect channel, can only be 0°, ±45°, ±135°, ±90°, and 180°, and the phase can only change in certain patterns. Comparison among Figure 2 (a), (b), and (c) shows that the phase characteristics of filtered FQPSK (FQPSK-B) and filtered OQPSK resemble those of XPSK.

The transmitter and receiver structure of differential detection of FQPSK and OQPSK is shown in Figure 3. The eye diagrams of FQPSK and OQPSK signal waveform after differential detector is illustrated in Figure 4. It can be shown that signal $y(t)$ at the output of the low pass filter can be written as

$$\begin{aligned} y(t) &= \frac{1}{2} A(t)A(t-\tau)\cos\Delta\Phi(\tau) \\ &= \frac{1}{2}\left\{A_c(t)A_c(t-\tau) + A_s(t)A_s(t-\tau)\right\}. \end{aligned} \qquad (1)$$

where $A(t)$ is the signal envelope after IF filter, $\Delta\Phi(\tau)$ represents the change over τ of the received signal phase plus the change in phase noise caused by the narrow-band noise, and $A_c(t) = A(t)\cos\Phi(t)$, $A_s(t) = A(t)\sin\Phi(t)$ are the quadrature components of $r_{IF}(t)$.

If we differentially encode the input data in transmitter so that in both I and Q channels, data "1" is mapped to a bit transition, and "0" is mapped to no bit transition, we will have a definite relationship between the NRZ input data sequence, $\Delta\Phi(2T)$, and $y(t)$. The differential encoders are:

$$\begin{aligned} DI_k &= I_{k-1} \oplus DI_{k-1}, \\ DQ_k &= Q_{k-1} \oplus DQ_{k-1}, \end{aligned} \qquad (2)$$

where I_k and Q_k are the data in I and Q channels after serial to parallel conversion, DI_k and DQ_k are the output of the two I and Q channel differential encoders.

If bit-by-bit threshold detection is used, a dc bias *u* has to be added to the threshold detector, and the decision rule is: decide a “1” is transmitted if output of the differential detector d(t) > *u*, and “0” otherwise.

Limiter-Discriminator (LD) Detection of FQPSK and OQPSK

The transmitter structure of limiter-discriminator detected FQPSK and OQPSK systems is the same as the differential detected FQPSK and OQPSK systems shown in Figure 3. The block diagram of the limiter-discriminator detection of FQPSK and OQPSK is illustrated in Figure 5. If the frequency discriminator is modeled by delay-and-multiply method, where the IF FM signal multiplies a replica of itself with a short delay τ and phase shift of 90°, it can be shown that

$$y(t) = \frac{A^2}{2}\sin[\Delta\Phi(t)] \approx \frac{A^2}{2}[\Delta\Phi(t)] = \frac{A^2}{2}\tau\Delta f \,. \qquad (3)$$

where A is the signal envelope after limiter discriminator, and the instantaneous frequency deviation of the signal Δf can be written as

$$\Delta f = \frac{1}{A^2\tau}[A_s(t)A_c(t-\tau) - A_c(t)A_s(t-\tau)], \qquad (4)$$

where $A_c(t) = A\cos\Phi(t)$, and $A_s(t) = A\sin\Phi(t)$.

Figure 6 shows the eye diagrams for XPSK, FQPSK-B, and OQPSK signals after limiter-discriminator. The sampling instants are at *nT*. We see that at sampling instants, the instantaneous angular frequencies of XPSK, FQPSK-B, and OQPSK signals has 3 levels. If a bit-by-bit threshold detector is used after frequency discriminator, according to the differential encoders defined in (2), the decision rule is: decide a “1” if the signal after frequency discriminator is larger than a threshold *v* or smaller than *–v*; decide a “0” otherwise. The signal after frequency discriminator can be followed by an integrate-sample-dump (ISD) post-detection filter to improve the BER performance.

Maximum-likelihood Sequence Estimation (MLSE) with Multi-Bit Correlation and Multi-Bit Viterbi Algorithm (VA)

Because of the cross-correlation of I and Q channels, FQPSK signals (XPSK or FQPSK-B) have intrinsic memory, and Simon et al [1] showed FQPSK could be interpreted as trellis coded modulation (TCM). In addition, filtering and channel distortion also causes ISI. Moreover, the eye diagrams indicate clearly that the signal waveform of FQPSK and filtered OQPSK after differential detection or frequency discriminator detection have memory. To compensate for ISI and make use of the memory, we apply maximum-likelihood sequence estimation (MLSE) that bases its decision on observation of a sequence of received signals over successive signal intervals [5]. Although MLSE such as multi-bit correlation and Viterbi algorithm requires more sophisticated demodulators, they can be implemented with current technology.

The maximum-likelihood sequence estimation (MLSE) detector with multi-bit correlation bases its decision on observation of a sequence of received signals $\mathbf{r} = \{r_1, r_2, ..., r_m\}$ over successive signal intervals, and determines the sequence $\mathbf{s} = \{s_1, s_2, ..., s_m\}$ that maximizes the conditional probability density function $p(\mathbf{r} \mid \mathbf{s})$, or equivalently, minimizes the Euclidean distance metric

$$D(\mathbf{r}, \mathbf{s}) = \sum_{l=1}^{m} (r_l - s_l)^2 \, . \qquad (5)$$

We can divide the received signals into sequences of length *m* and for each sequence estimate the transmitted sequence of length *n*, which can be a number between 1 and *m*.

The multi-bit correlation detector continuously correlates part of the received signal sequence **r**(n) that falls in an m-bit sliding window, as illustrated in Figure 10 (a), with 2^m possible received sequences (sampled FQPSK and OQPSK signals after differential detection or limiter-discriminator and LD-ISD post-detection filter), and picks the signal sequence that results in the maximum correlation or minimum distance metric. From that sequence, decisions are made on what the transmitted data or data sequence is, and the estimated sequence is updated.

With multi-bit Viterbi algorithm we used, the output of the post-detection filter $y(t)$ is sampled and the branch correlation or distance metrics is calculated in the same way as with the multi-bit correlation detector, and the accumulated metrics are used to determine the surviving paths at each state. The multi-bit Viterbi algorithm detector search the trellis of the received FQPSK-B and OQPSK signals and find the most likely path. Figure 10 (b) illustrates the multi-bit Viterbi algorithm.

Computational Results and Discussion

Figure 12 illustrate the BER performances of FQPSK and OQPSK differential detectors and discriminator detectors with bit-by-bit threshold detection, multi-bit correlation, and multi-bit Viterbi algorithm. With multi-bit correlation, the limiter-discriminator detectors of FQPSK-B and OQPSK show 3-5 dB improvement of BER performance over bit-by-bit threshold detection. With multi-bit detector using Viterbi algorithm, the required E_b/N_o for limiter-discriminator detected FQPSK-B at BER=1×10^{-4} is reduced to 12.9 dB, which is a 6.5 dB improvement comparing with bit-by-bit detection; the required E_b/N_o for limiter-discriminator detected OQPSK at a bit error rate of 1×10^{-4} is 11.8 dB, which is a 4.1 dB improvement comparing with bit-by-bit detection. This research assumed Butterworth filters in simulation, since our research lab has hardware Butterworth filters that can be used to verify the computer-simulated results. Therefore, the actual BER performance could be further improved if better filtering is used. The noncoherent techniques we propose could be applied to other offset-keyed modulation systems, for example, spectrum efficient SOQPSK systems.

References

[1] K. Feher, et al., U.S. Patents: 4,567,602; 4,644,565; 5,491,457; 5,784,402, 6,198,777; and World Intellectual Property Organization, Patent Cooperation Treaty (PCT): WO 00/10272 (International Publication No. SN: PCT/US99/17995) and other pending patents. To access these and or other patents: www.uspto.gov and/or http://ep.espacenet.com/ and/or www.fehertechnologies.com. For Feher patented GMSK for GSM, FK, FQAM and FQPSK technology transfers and licensing information on an equal-opportunity, non-discriminatory basis with uniform terms and at a fair market price, contact Digcom, Inc.; c/o Dr. Kamilo Feher, 44685 Country Club Dr.; El Macero, CA 95618. Tel: 530-753-0738, Fax: 530-753-1788; Email: feherk@yahoo.com.

[2] M. K. Simon, *Bandwidth Efficient Digital Modulation for Deep Space Applications*, JPL DESCANSO Monograph Series, July 2001. This NASA/JPL/Caltech monograph/book can be downloaded at http://descanso.jpl.nasa.gov/. Click on Monograph Series on the left side of the web page, then click Monograph No. 3. This book contains a detailed description of FQPSK

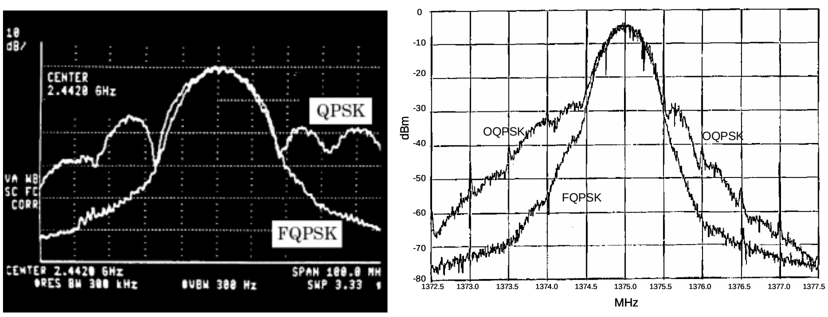
[3] Telemetry Group, Range Commanders Council, Telemetry Standards. IRIG Standard 106-00, Secretariat, Range Commanders Council, U.S. army White Sands Missile Range, New Mexico 88002-5110, January 2000.

[4] P. Ghuman, S. Koubek, T. Winkert, (NASA/GSFC), A. Gray, N. Lay, T. Y. Yan, (JPL/CalTech), "Ultra High Bit Rate (Up to 1GBIT/S) Bandwidth Efficient FQPSK All-Digital Modulator/Demodulator Architectures and NASA Implementations," *Proceedings of the International Telemetry Conference 2000*, San Diego, CA Oct 23-26, 2000

[5] G. D. Forney, "Maximum-likelihood sequence estimation of digital sequences in the presence of intersymbol interference," *IEEE Trans.*, 1972, IT-18, pp. 1096-1117

Communication Systems	Advantage	Disadvantage
Coherent Systems	Good bit error rate (BER) performance in AWGN channels	Has longer synchronization (acquisition) and resynchronization time than noncoherent systems
	More robust in RF drift and frequency selectively faded environment	Has poor performance and exhibit high error floor in large Doppler spread or fast fading ($f_D T_b > 0.01$) environment
Noncoherent Systems	Has faster synchronization (acquisition) and resynchronization time than coherent systems	Performs poorer than coherent systems in frequency selective faded environment
	Performs better than coherent systems in large Doppler spread ($f_D T_b > 0.01$) and strong phase noise environment, can reduce burst error and outage for relatively low data rate CDMA, TDMA, and GSM systems	Adaptive equalization for noncoherent systems is complex

Table 1. Performance comparison of coherent and noncoherent communication systems



(a) (b)

Figure 1. Spectra of NLA (Non-Linearly Amplified) FQPSK and of filtered QPSK and OQPSK after the output of NLA RF amplifier [6]. (a) Hardware measured QPSK and FQPSK spectra (modem designed by Lockheed Martin) over a 2.44 GHz, 1 watt 34 Mb/s system. (b) Hardware measured L-band (1.375 GHz) NLA spectra up to 100 watt optimized OQPSK and FQPSK.

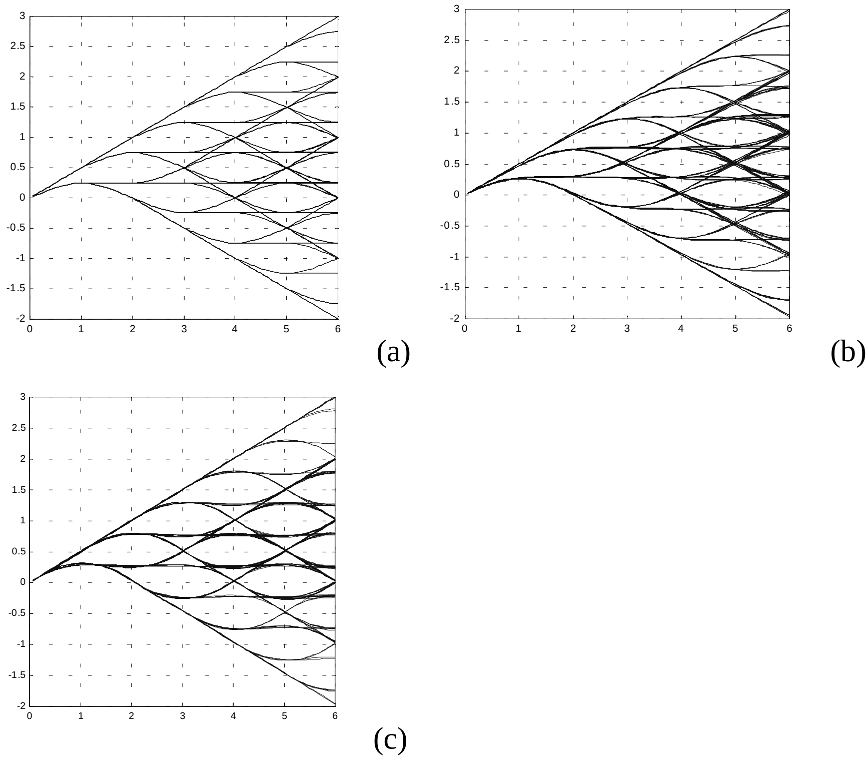


Figure 3. Phase trellis of FQPSK and filtered OQPSK. The unit of the x-axis is bit interval T, while the unit of the y-axis is π radian, or 180°. (a) Phase trellis of XPSK. (b) Phase trellis of FQPSK-B. (c) Phase trellis of filtered OQPSK.

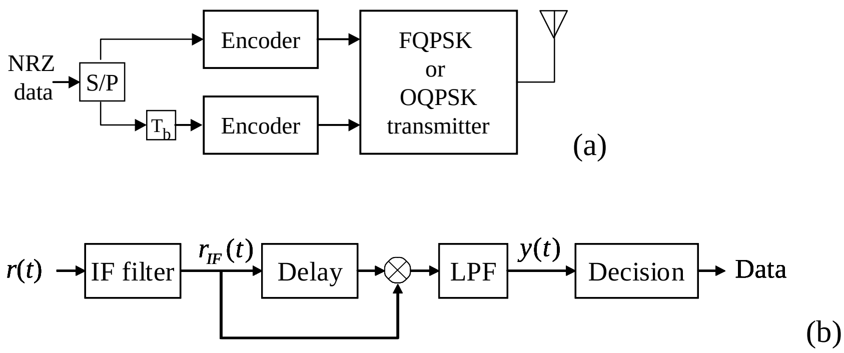


Figure 4. FQPSK and OQPSK noncoherent differential detection block diagram. (a) Transmitter. (b) Receiver.

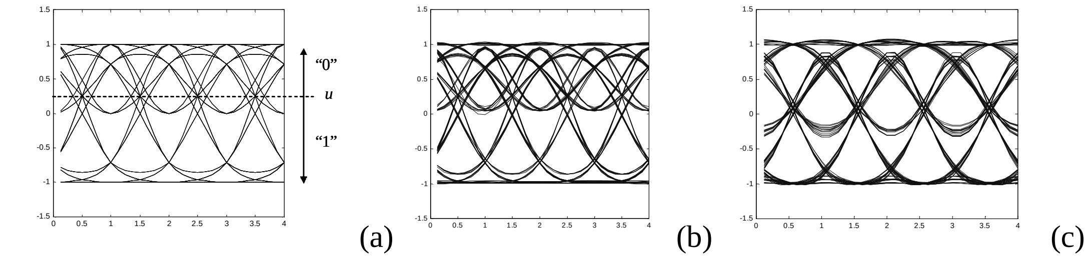


Figure 5. Eye diagram of FQPSK and OQPSK signal waveform after differential detector. The x-axis unit is T, y-axis illustrate the value of 2*y(t) where y(t) is the signal after the post-detection lowpass filter (Equation (5) with τ = 2T). (a) XPSK. The decision rule is also illustrated. (b) FQPSK-B. (c) OQPSK.

Figure 7. Block diagram of limiter-discriminator detection of FQPSK and OQPSK.

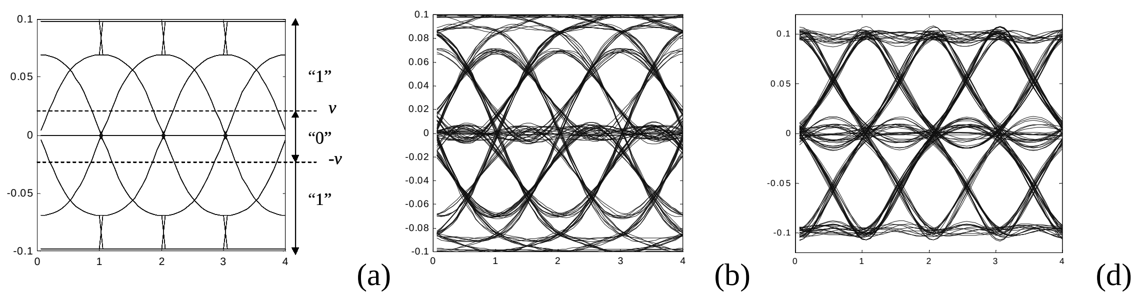
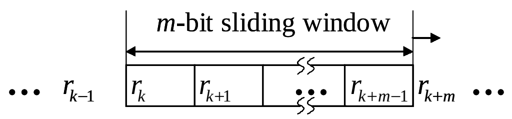


Figure 8. Eye diagrams of instantaneous frequency of FQPSK and OQPSK. Sampling rate of 8 samples per bit is used in the simulation. (a) XPSK. The decision rule is also illustrated. (b) FQPSK-B. (c) Hardware demonstrated FQPSK-B instantaneous frequency eye diagram. (d) Filtered OQPSK.



(a)

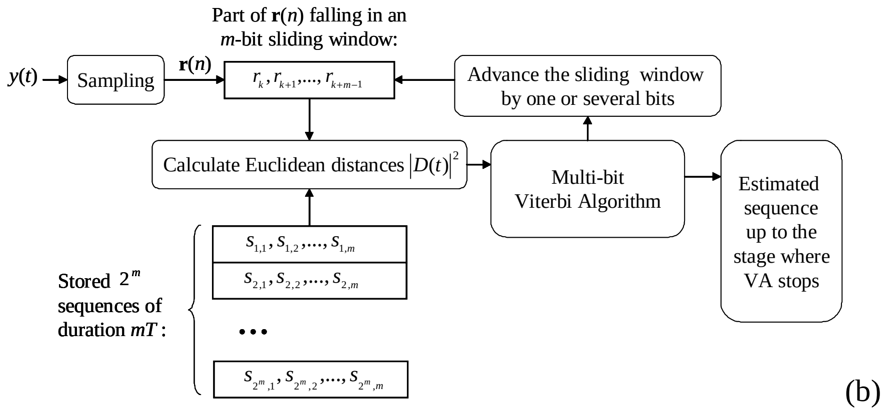


Figure 10. Conceptual block diagram of maximum-likelihood sequence estimation (MLSE) used in noncoherent detection of FQPSK and filtered OQPSK. (a) m-bit sliding window for correlation. (b) Multi-bit Viterbi algorithm detector.

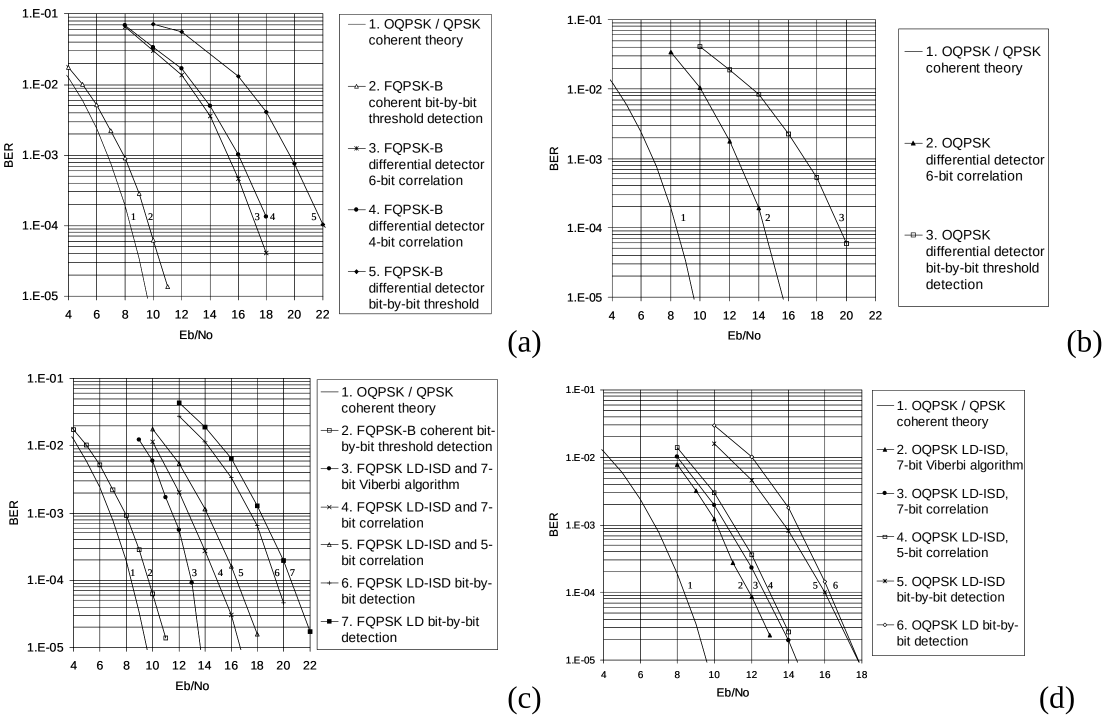


Figure 12. Computer simulated BER performance of non-coherent detection of FQPSK and OQPSK. (a) Differential detected FQPSK, (b) differential detected OQPSK, (c) limiter-discriminator (LD) detected FQPSK, and (d) limiter-discriminator detected OQPSK.

TIMING AND BUS SYSTEMS

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Telemetry Data Encoder with an Embedded GPS Receiver

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Introduction

This paper describes the design of a PCM Encoder with an embedded GPS Receiver module. The GPS Receiver has been integrated into the electronics of the PCM Encoder to provide a seamless tool for the Telemetry Engineer to acquire GPS position and time data with the sensor data acquired from the PCM Encoder. The integration of the PCM Encoder and the GPS receiver simplifies the operation of telemetry systems by combining the initialization and acquisition of GPS Data into a single tool set and hardware platform.

The GPS Receiver is configured to report accurate position and time information to the PCM System during all operable stages of a missile's flight test mission. The mission components includes a pre-flight stage where the missile is transported either under an aircraft wing or in a weapons bay for a period of time prior to flight, followed the launch and flight of the missile when telemetry from the weapon will be acquired for analysis. The PCM Encoder stores the initialization command sequence for the GPS Receiver in Flash Memory and initializes the GPS Receiver when power is applied. The initialization of the GPS receiver from the encoder allows to the GPS receiver to be configured for battery-less operation.

Herley Industries

Herley Industries, Inc. headquartered in Lancaster, PA, is one of the largest telemetry firms in the world. The corporation provides sophisticated electronics, systems, and services to its customers in the United States Department of Defense, National Aeronautical Space Administration, and Aerospace Industry, as well as to non-defense international governments, and the international commercial marketplace.

The PCM Encoder

The PCM Encoder that hosts the GPS Receiver is Herley's PCM880 Product. The PCM880 Encoder architecture is a structure assembled from modular units that integrate an acquisition function to the system bus. Figure 1 is a mechanical drawing of the PCM Encoder designed for this application.

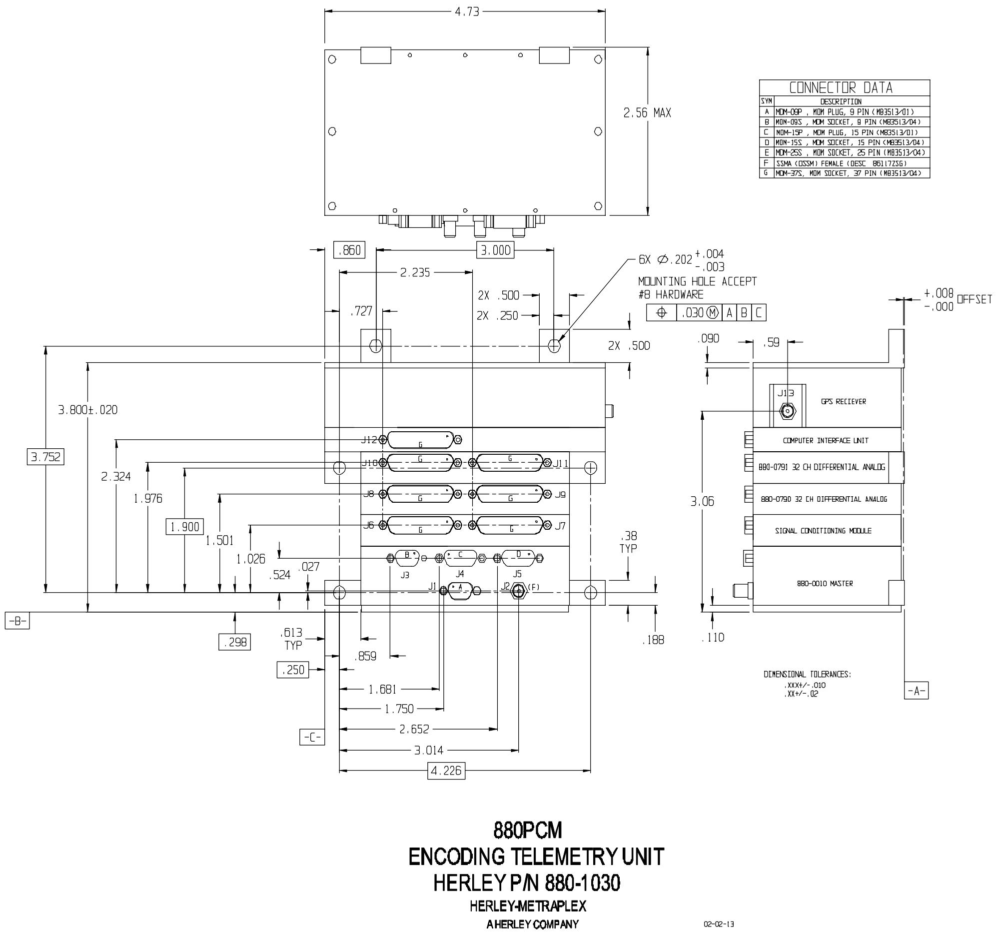

Figure 1: PCM Encoder with Embedded GPS Receiver

The Base Unit of the encoder forms both the electrical and mechanical anchor for the assembly. The PCM Encoder is built by stacking modules onto the base unit. Each module is a printed circuit board assembly mounted onto a 2"x3.5"x.375" aluminum frame. Each module connects the system bus from the lower assembly to the on-board electronics using connector pins on the solder side of the printed circuit board. In addition, the module provides sockets on the component side of the printed circuit board for the next module to be assembled on the stack. Once all modules required to perform the data acquisition function of the unit are assembled, five screws are tightened though the length of the module stack-up to solidify and brace the assembly. The unit's small form factor is designed to operate in high vibration and shock environments of missiles and launch vehicles.

The Base Module of the PCM Encoder is designed to perform the initialization functions of the Unit under microprocessor control. After the unit is initialized, the microprocessor powers down and enables the PCM Encoder sequencing machine to take control of the acquisition process. A PLL synthesized clock allows full programmability of the bit rate from 10 KHz to 10 MHz. The PCM Output Data for the transmitter is conditioned with a synthesized Bessel Filter that follows the programmed bit rate of the unit to produce output data signal characteristics that are compliant with IRIG106-00.

The PCM Encoder has 60 channels of signal conditioning monitoring frequencies, temperatures, voltages, and switch positions throughout the test vehicle. In addition, the PCM Encoder acquires data from a serial interface from the missile's on-board computer, an external GPS Receiver, and an internal GPS Receiver. The signal conditioning section of the encoder has been customized to meet the application requirements in the smallest practical volume.

The GPS Receiver used is the Ashtech Model G12 HDMA Board, (Now Thales Navigation). The G12 HDMA Board is a 12 Channel GPS Receiver Board designed specifically for rugged environmental applications found in missiles, with the additional capability of calculating GPS position while traveling at high rates of speed. The G12 HDMA GPS Receiver Board has a history of applications in aeronautical environments, and the rugged construction of this board makes it suitable for the environments it would be exposed to during the flight mission.

The G12 HDMA GPS Receiver Board connects to a Computer Interface Board that provides serial communication electronics between the Encoder and the GPS receiver. A one kilo-byte FIFO buffer is used to interface the two asynchronous rates between the GPS receiver and the PCM Encoder.

System Design and Ground Isolation

The PCM Encoder is designed with an isolated structural ground for this application. To achieve this goal, a separate DC-DC converter is used to provide power to the GPS Receiver Module. The Structural Ground is referenced to the aluminum case of the PCM Encoder, the return path of the GPS Receiver board, and the return path of the Active GPS antenna. Optical Isolation is used between the GPS receiver and the acquisition electronics in the PCM Encoder. The Block Diagram in Figure 2 details the modular components of the design and the grounding scheme used for this application.

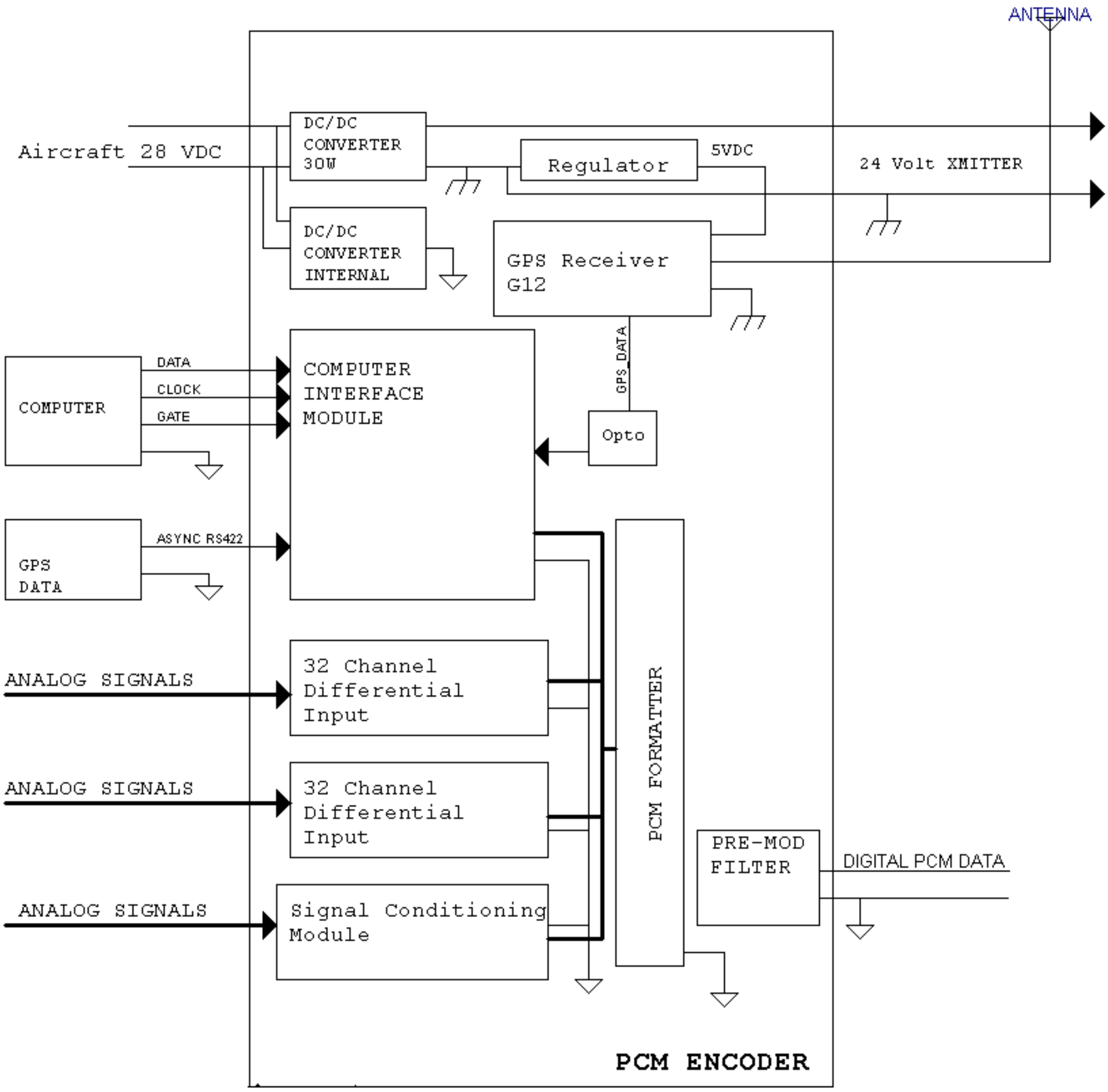

Figure 2: PCM Encoder Block Diagram

Analog Signal Conditioning

The encoder includes sixty channels of customized signal conditioning for this application. The driving requirement for the signal conditioning section of the encoder is the isolation requirements between signal ground, structure ground, and DC Power Return. Sampling rates ranged from 800 sps for the higher frequency measurements to 50 sps for the pseudo-static measurements.

The analog signal inputs are designed to interface to differential input amplifiers and single pole passive filters. The outputs of the pre-conditioning circuits are connected to a standard analog-to-digital multiplexing circuitry used for analog acquisition. The analog inputs are digitized with a high speed, 12 bit Analog to Digital converter and interfaced with the encoder circuitry.

Several channels monitored switch positions throughout the test vehicle. These channels are conditioned with a resistor network that established the unconnected state at an expected DC voltage, and the connected state at a different DC voltage level. The two distinct voltage outputs are converted by the analog to digital converter and encoded as a 10 bit PCM word.

GPS Receiver

The GPS receiver selected for this application is the Thales G12 HDMA Board. This board uses twelve discrete parallel channels for Coarse/Acquisition (C/A) code-phase (psuedo-range) measurements and carrier measurements on the L1 (1575.42 MHz) band. The G12 receives satellite signals using an active L-band antenna. The board can track all GPS satellites specified in the Navstar GPS Space Segment/Navigation User Interfaces, ICD-GPS200, Revision B. All 32 satellites PRN code numbers are programmed into the G12's firmware.

As the GPS receiver acquires lock on each satellite, it records the time and collects almanac and ephemeris data into on-board memory. When the receiver is tracking one satellite, the receiver board gets a time reference from that satellite's clock. When the receiver tracks three satellites, the horizontal position (2D) and velocity of the antenna is computed and the results are time tagged. The receiver calculates three-dimensional position and velocity with the acquisition of data from the fourth satellite.

The receiver can compute up to 20 independent measurements in 50 milli-seconds without interpolation or extrapolation from previous solutions. Position and velocity computations are performed simultaneously using all satellites in view of the receiver. The update rate of the unit is command configurable as either 10 or 20 updates a second. The rate of the output commands is also command configurable from .05 seconds to 999 seconds.

The GPS Receiver is designed with two asynchronous serial output ports. Each port can be individually configured to transmit GPS data. In this design, Port A is used to transmit Real-Time GPS data to the encoder for telemetry through the optical isolation circuits. Port B of the GPS receiver connects connector J12 for the user to directly interface with the GPS board from other equipment for test purposes. This allows the telemetry engineer direct access to the GPS receiver to evaluate the data using OEM provided software.

Performance Specifications

The stand-alone accuracy of the GPS receiver is 3.0 meters Circular Error Probable (CEP) when Position Dilution of Precision (PDOP) is less than 4. The velocity accuracy of the GPS receiver is 0.1 meters per second.

When DGPS techniques are applied using either Real-Time Processing or Post Processing, measurement accuracy improves to 40 cm CEP. To achieve this accuracy, the “Real-Time” data is tele-metered to a ground station, then concurrently the GPS data is packaged and streamed into an RS232 data stream into a workstation executing a software package called PNAV from Thales. The PNAV software will combine the tele-metered GPS data with GPS data from a second ground receiver whose position is known and which is simultaneously acquiring data with the tele-metered system. The PNAV software processes the GPS data from the two receivers to achieve the more accurate DGPS solution.

Time to acquire first position is specified as 45 seconds from a “Cold Start”. If ephemeris data is available in memory, the time to fist fix can be reduced to something between 2 and 11 seconds. Typically, ephemeris data that is older than 10 hours requires the receiver to clear memory and perform a “Cold Start” search.

Environmental performance specifications of the receiver are summarized in Table 1

Table 1: Environmental Performance	
Temperature	-30^{o}C to +70 ^{o}C
Acceleration	23 G’s
Jerk	463 G’s
Vibration	9.8 Grms from 30 Hz to 1000 Hz
Altitude	1100 km
Velocity	to Mach 9

The G12 receiver’s temperature performance is inadequate for this application. The application required operational temperature performance to temperatures below 30 ^{o}C, requiring the use of heaters. The heater elements selected for this application are designed into the unit to create a small oven effect when ambient temperatures drop below a tolerable threshold. A single 2” x 1” heater is embedded into the housing aluminum of the module below and above the receiver printed circuit board. Thermostats sense the ambient temperature and enable current flow to the receiver when the ambient temperature drops below 15 ^{o}C are installed into the module. Current from either the battery (28 Volt Power) or the aircraft (120 Volt, 400 Hz DC) are used to warm the compartment containing the GPS receiver.

Initializing the GPS Receiver

The design of the PCM880 Base Unit is micro-processor controlled. This feature of the PCM880 design facilitates the initiation of a GPS Receiver command sequence from FLASH memory on Power-UP, eliminating the need for battery backed RAM. The Menu shown below in
Figure 3allows the user to specify the initiation command sequence of the GPS receiver. The command sequence is downloaded to Flash memory in the PCM encoder to be issued to the GPS receiver when power is first applied to the unit.

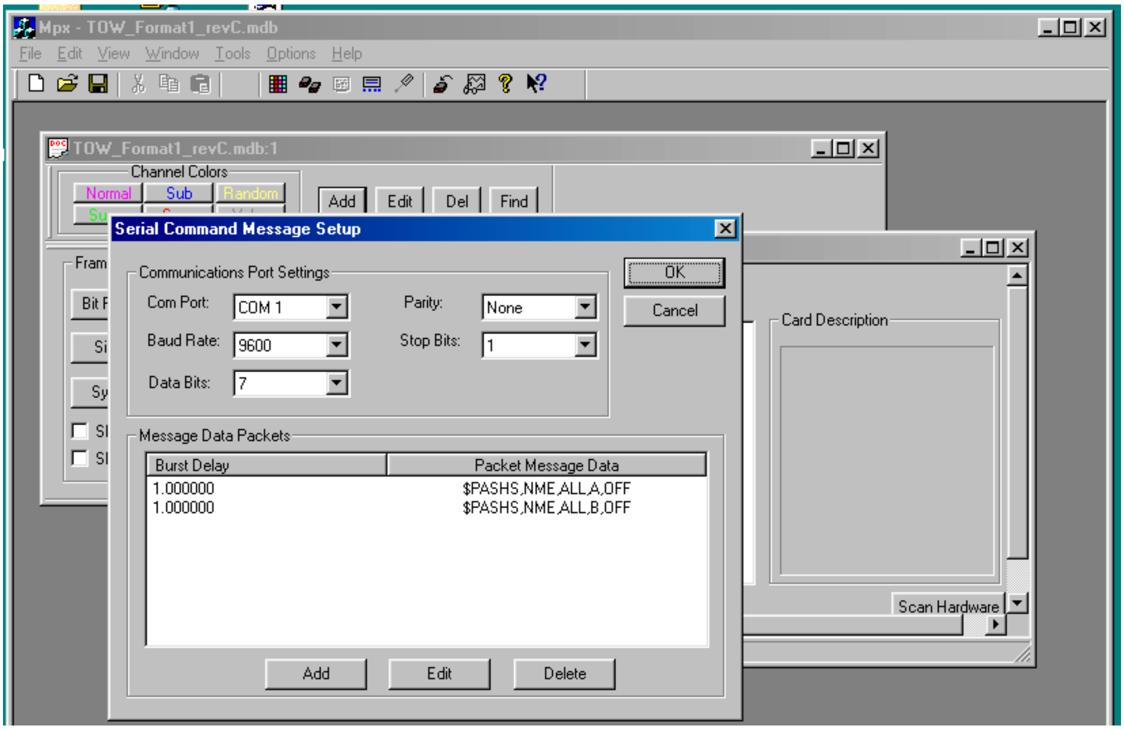

Figure 3: GPS Receiver Initialization Menu

The G12 GPS receiver transmits GPS information using both standard and proprietary formats, ASCII data as well as binary data. The ASCII data is formatted as NMEA 0183 Standard data messages. The G12 GPS receiver has a complete command set that allows the user full control of the GPS data acquisition process. The initiation command sequence in this application is detailed in Table 2.

Table 2: GPS Receiver Initialization

$PASHS,NME,ALL,A,OFF	Turn off all NMEA Text messages for Ports A and B
$PASHS,NME,ALL,B,OFF	
$PASHS,RAW,ALL,A,OFF	Turn off all Raw Binary messages for Ports A and B
$PASHS,RAW,ALL,B,OFF	
$PASHS,RAW,MBN,A,ON	Enable Raw Data output to Port A, Proprietary data structures
$PASHS,RAW,PBN,A,ON	
$PASHS,RAW,SNV,A,ON	
$PASHS,NME,POS,A,ON	Enable NMEA Text Messages for Position and ephemeris on serial ports A and B
$PASHS,NME,SAT,A,ON	
$PASHS,NME,POS,B,ON	
$PASHS,NME,PER,0.5	Configure unit to Transmit NMEA messages once every 500 milli-seconds
$PASHS,RCI,1.0	Configure unit to transmit raw data messages once a second
$PASHS,SPD,A,8	Set Serial Data Baud Rate to 57,600
$PASHS,SPD,B,8	

$PASHS,RAW,MBN,A,ON
This message is transmitted once for each satellite being tracked by the receiver. The message contains raw data values for doppler, carrier phase, satellite PRN number, signal strength, elevation, azimuth, and satellite transmit time.

$PASHS,RAW,PBN,A,ON
This message contains raw position data and includes antenna position and velocity, receiver clock offset, and PDOP.

$PASHS,RAW,SNV,A,ON
This message is transmitted once for each satellite being tracked by the receiver. The message contains raw ephemeris data for each satellite being tracked.

$PASHS,NME,POS,A,ON
This message contains NMEA position data and includes antenna position, velocity, altitude, number of satellites used in computation, and PDOP.

$PASHS,NME,SAT,A,ON
This message is transmitted once for each satellite being tracked by the receiver. This message contains NMEA ephemeris data and contains elevation, azimuth, and signal to noise measurements for each satellite being tracked by the receiver.

GPS Data Acquisition

The GPS data acquisition is done using a UART design followed by a FIFO. The GPS Data encoded into the bit stream takes the form detailed in Figure. The FIFO buffer is over-sampled by the PCM encoder providing an asynchronous data stream containing Real Time GPS data followed by bytes of data that represent the FIFO as being empty.

B9	**B8**	**B7**	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
FB1	FB2	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0

Figure 4: GPS PCM Word

The bits FB1 and FB2 of each GPS PCM word are Flag Bits that describe the state of the GPS data that follows. The post processing software searches the format words assigned for GPS data processing the first two bits of each word. Each PCM word that represents a new GPS data value is streamed from the received PCM format to a separate output that provides processing software the ability to determine a differential GPS position.

B9	B8	B7 – B0: DATA	State
0	0	N/A	Invalid State
0	0	GPS DATA	New Data Word
1	0	2AA HEX	FIFO Empty
1	1	N/A	Invalid State

Table 3: GPS PCM Word Flag & Data Bit Definitions

<u>Time Tagging of Data Acquisition</u>

The G12 GPS receiver also provides a PPS (Pulse Per Second) output. The timing of the Pulse Per Second Output is defined in the receiver specifications as occurring synchronous with GPS time to an accuracy of one microsecond. Using this signal output to feed a counter gives the telemetry encoder the ability to provide time-tagged data based on the GPS receiver.

The GPS receiver outputs a PBN message normally forty milli-seconds after the PPS pulse has occurred. The PBN message contains raw binary data representing GPS Time, antenna velocity, antenna position, receiver clock offset, and PDOP (positional dilution of precision). A counter in the encoder is designed to increment at a 1 MHz rate, and is reset to zero on the occurrence of the PPS output of the GPS receiver. The encoder software provides access to this counter as an encoded parameter in the telemetry data stream. Twenty bits of count data along with the GPS Time message can be used in post processing the telemetry data to get an accurate time stamp of the telemetry data.

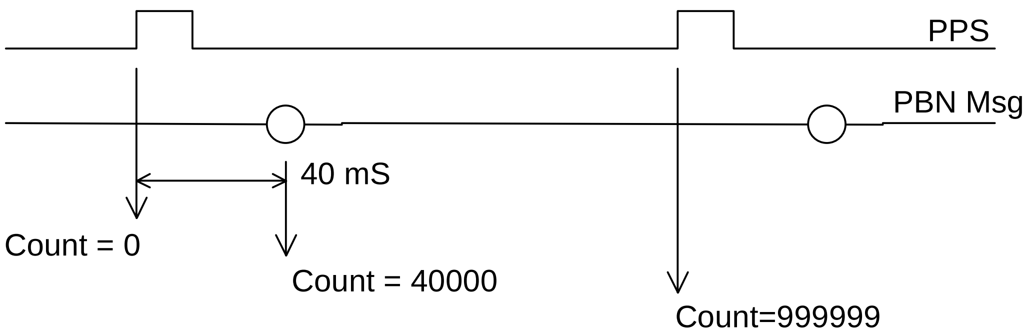

Figure 5: GPS Time Tagging in Encoder

Conclusions

The ability to embed the GPS Receiver function into the Data Acquisition and encoding electronics allows telemetry engineers to maximize real estate in the test vehicle for other functions. With the use of ASICS, DSP processors, and state-of-the-art surface mount electronics, the ability to combine the GPS Receiver data with the Telemetry Encoder is not only practical, it is a natural product evolution. The embedded GPS receiver integrates the Receiver Function into the Data Acquisition package and simplifies the overall system design.

Test of Precise Clock Comparison with Geodetic GPS Receivers

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Abstract

Precise timing is very important for many user applications like navigation, telecommunication, and networking. Common View (CV) time and frequency transfer is a usual way to compare atomic clocks, the sources of precise time. CV is based on simultaneous observations of navigation satellites (e.g. GPS or Galileo in future). The conventional CV time transfer requires specially designed satellite timing receivers, but if a clock comparison is executed in the frequency domain, standard geodetic receivers can be used. In this paper we present the results of DLR CV experiments with geodetic receivers.

In the first experiment we compared the performance of the CV procedure based on geodetic receivers with the performance of that based on timing receivers. In the second experiment we assessed the noise floor of CV procedure based on geodetic receivers using three geodetic receivers installed on the same site and connected to the same reference oscillator.

Introduction

Common View technique is the basic tool for precise clock comparisons between different timing laboratories. Bureau International des Poids et Mesures (BIPM) is responsible for the generation of the international reference time scales TAI and UTC. It has standardized CV procedures and data processing. Each timing laboratory which contributes to TAI should install a satellite timing receiver on its site and operate it according to the schedule provided by BIPM.

Commercial timing receivers (except of Ashtech Z12T) are based on rather old engines with old tracking technologies. On the other hand, a lot of innovations have been implemented in commercial geodetic receivers. Some of them are collocated with the timing ones at timing laboratories that contribute data also to International Service for Geodynamics (IGS).

Therefore, the implementation of geodetic receivers for clock comparisons has been intensively studied (see, e.g. [DEFR-01], [SENI-01]). Two solutions were proposed: combination of a geodetic receiver with a time interval counter and direct use of geodetic receivers for frequency comparisons. We have chosen the latter approach. GPS observations from a permanent GPS/GLONASS monitoring station, operated at DLR-OP (Oberpfaffenhofen), and another two geodetic receivers were used for experiments.

Two experiments were performed to test CV procedure based on geodetic receivers. The calibration aspects were not taken into account because we were interested to investigate the stability of the clock comparison results, i.e. the precision of the method.

1. Clock Comparisons and Common View Technique

Clock comparisons include time transfer and frequency transfer. The first refers to the estimation of the time offset between two clocks and the second to the estimation of frequency offset.
The *time* difference between two clocks is given by [KART-78]

$$x(t) = \frac{\phi_2(t) - \phi_1(t)}{2\pi} \qquad (1)$$

where ϕ stands for the instant phase of an oscillator signal and t for the true time.

The difference x(t) includes two terms, a deterministic and a stochastic one. The deterministic term is usually modelled with a square polynomial

$$x(t) = x_0 + at + \frac{c}{2}t^2 + x_r(t) \qquad (2)$$

Here $\mathbf{x_0}$ is the initial clock offset, **a** frequency offset, **c** linear frequency drift and $\mathbf{x_r}$ noise terms.

A linear model is adopted for the deterministic part of the *frequency* difference of two clocks:

$$y(t) = a + ct + y_r(t) \qquad (3)$$

where $\mathbf{y_r}$ is frequency noise.

Terms $\mathbf{x_0}$, **a**, and **c** be obtained by a simple least-squares fit of measured clock differences [KART-78]. Kalman filtering [KRAE-99] and the method of finite differences [BARN-66] are also used.
Common View allows to measure the time difference between two remote clocks. The procedure is the following: two timing laboratories simultaneously measure the time offsets of their clocks to the clock of the same navigation satellite. These measurements are performed by means of processing navigation signals transmitted by the satellite. In fact, the measured value is the user-to-satellite pseudorange which, unlike the true range, includes satellite and user clock offsets to a reference time scale. The accuracy of properly designed and implemented Common View is about 5-10 ns (1σ) even for transcontinental baselines [HAHN-98].
The time difference between the laboratories is calculated then as

$$x(t) = [t_{sat}(t) - t_1(t)] - [t_{sat}(t) - t_2(t)] \qquad (4)$$

where t_i is local time of laboratory **i.**

Conventional CV requires special satellite timing receivers. To be able to make pseudorange measurements, each satellite receiver establishes the internal time scale using an internal oscillator or an external frequency reference. A timing receiver includes also a time interval counter (TIC) to measure the difference between the estimate of satellite time $t_{rec}(t)+[t_{sat}(t)-t_{rec}(t)]$ (here $t_{rec}(t)$ is the internal receiver time) and the time scale of the siting laboratory. Moreover, the internal delays of the receiver hardware (including antenna and cabling) are calibrated.

A geodetic receiver does not include a TIC. Its internal time is synchronized to the time of the first locked satellite. After each receiver reset the synchronization is re-established, and the receiver time suffers a leap. The offset between the internal time of a geodetic receiver time and the reference time scale of the siting laboratory is unknown, then eq. (4) is transformed to

$$x_g(t)=\lfloor t_{sat}(t)-t_{rec,1}(t)\rfloor-\lfloor t_{sat}(t)-t_{rec,2}(t)\rfloor \qquad (5)$$

where $\mathbf{x_g}$ is the estimate of the difference between the internal time of two geodetic receivers and

$$t_i(t)=t_{rec,i}(t)+\Delta t_{rec,i}(t) \qquad (6)$$

thus,

$$x(t)=x_g(t)+\lfloor \Delta t_{rec,1}(t)-\Delta t_{rec,2}(t)\rfloor \qquad (7)$$

Therefore, the time domain clock comparison with geodetic receivers is ambiguous. However, these ambiguity and 'post-reset' leaps affect only the term $\mathbf{x_0}$ which is cancelled in the frequency domain (see eq. (3)). Consequently, geodetic receivers can be used for clock comparisons in the frequency domain. This possibility was studied recently in [SENI-01] and [DEFR-01]. Unlike [SENI-01], which describes an elaborated Kalman filter for data obtained from the global IGS network, our approach is focused on the modified processing of results of conventional CV. We have used a least-squares fit of CV data to estimate frequency offset and frequency drift between two laboratories involved in a CV experiment (see section 2).

Moreover, no receiver hardware calibration is required to perform a comparison in the frequency domain. The absolute values of receiver and cable delays are not important, they should only be stable over the time of an experiment.

Another problem of the geodetic receiver implementation for clock comparisons was the format of output data. BIPM has defined a special format for GPS/GLONASS Common View data called CGGTTS [BIPMCV] and a processing procedure for pseudorange measurements. The measurement rate is defined to be 1 s. On the other hand, the standard format for the exchange of GPS/GLONASS observation data is RINEX [GURT-01]. RINEX includes only raw pseudorange measurements. The measurement rate is usually 30 seconds as specified by International Service for Geodynamics (IGS). [DEFR-01] has shown that the accuracy of CGGTTS timing data is almost the same for 1 s and 30 s measurement rates. We have developed a RINEX-to-CGGTTS conversion utility similar to that described in [DEFR-01]. This utility was used to process measurement data collected during each presented experiment.

2. Common View with Geodetic GPS Receiver over Long Base-Line

We designed a long-base CV experiment to compare the performance of geodetic and timing GPS receivers. We have used data from IMVP (Institute of Metrology of Space and Time, Mendeleevo), DLR near Munich (designated OPJV) and PTB (Physikalisch-Technische Bundesanstalt at Braunschweig) timing laboratories (see fig. 2-1, table 1).

Equipment	IMVP	PTB	OPJV
Receiver	TTR6	TTR5	Legacy-E
Manufacturer	AOA	AOA	JPS
System	GPS	GPS	GPS/GLONASS
Observables*	C1, L1	C1, L1	C1, P1, P2, L1, L2
Channels	1	1	20
Antenna	std. TTR5	std. TTR5	JPS choke-ring (RegAnt)
Time reference	Cs	active H-maser	Cs

Table 1. Hardware of timing laboratories

** following acronyms are used in the table:*
L1 Carrier-phase measurement using the first carrier frequency
L2 Carrier-phase measurement using the second carrier frequency
C1 Code-phase measurement using civil ranging code on the first carrier
P1 Code-phase measurement using precise ranging code on the first carrier
P2 Code-phase measurement using precise ranging code on the second carrier

We continuously collected GPS observations at OPJV site from MJD 52208 to MJD 52225. Elevation cut-off angle was set to 10 degrees and the observation rate was set to 30 seconds. All satellites in view were tracked. Raw data were converted into RINEX format using a JPS firmware and then converted into CGGTTS format using an in-house developed utility of DLR. CGGTTS timing data from IMVP and PTB were obtained from BIPM public FTP archive.
Fig. 2-2 presents the results of CV for the links IMVP-OPJV, IMVP-PTB and PTB-OPJV (standard deviation is 7.0, 6.8 ns and 4.4 ns respectively). Linear drifts and outliers were removed. The vertical shift on the Y-axis of the plot was introduced intentionally to distinguish different data sets. The results exhibit apparent diurnal variations well-known to CV time transfers (see [WEIS-89]).
The Modified Allan deviation (MDEV) of the CV results is shown in fig. 2-3. The short-term precision was approximately the same for all of the three links. For an averaging time of about 0.5 days the accuracy of PTB-OPJV time transfer is almost one order of magnitude higher than that for the two other links (see fig. 2-2). In our opinion, it is a result of an uncompensated influence of the ionosphere (the distance between DLR and PTB is 5 times shorter than

the two other distances). The accuracy of time transfer became approximately the same for all the three links for an averaging time of 3-5 days. Thus, the performance of the geodetic receiver (JPS Legacy at OPJV) was comparable with that of timing receivers.
We have also estimated the frequency offset between IMVP, PTB and OPJV laboratories. Two links were used: IMVP-OPJV and IMVP-PTB (standard deviations of the frequency offset estimates are 6.3×10^{-14} s/s and 4.5×10^{-14} s/s respectively). The total period of the experiment was split into 1-day spans, then we made linear fits over the CV results of each of the spans to estimate the frequency offsets. Linear fits over these daily frequency offsets provide estimates of the linear frequency drifts (see fig. 2-4). The amount of data for the IMVP-OPJV link was about two times less than that for the IMVP-PTB link because the receivers followed different observation schedules, so the precision of frequency comparisons also differs.

3. On-Site Common View Experiment

We have performed an on-site experiment to estimate the noise floor of CV based on geodetic receivers.

Equipment	OPZ1	OPZ2	OPJV
Receiver	Z12	Z12	Legacy-E
Manufacturer	Ashtech	Ashtech	JPS
System	GPS	GPS	GPS/GLONASS
Observables	C1, P1, P2, L1, L2	C1, P1, P2 L1, L2	C1, P1, P2, L1, L2
Channels	12	12	20
Antenna	navigation, Marine III	Ashtech choke-ring	choke-ring (RegAnt)
Freq. reference	Cs		

Table 2. Hardware of tracking sites

Three geodetic receivers were installed at the DLR site in Oberpfaffenhofen and connected to the same reference clock (Cs HP5071A). All receiver antennas were installed on the roof of the DLR building (see fig. 3-1). Unique IDs were assigned to each antenna-receiver pair (see tab. 2).
We collected GPS data from all the three receivers from MJD 52208 to MJD 52225. The measurement rate was set to 30 seconds, and the cut-off elevation angle was set to 10 degrees. All satellites in view were tracked. No temperature compensation of receivers and antennas was implemented. We converted raw measurements and navigation data into RINEX format and then produced three CGGTTS files, one for each of the receivers. Each CGGTTS file includes timing data for the whole time span of the experiment. No resets of the receivers were done. So no specific leaps of receiver time were observed. Some data were missed because of a PC failure.
CV was performed over the links OPZ1-OPZ2, OPZ1-OPJV, OPZ2-OPJV (see fig. 3-2). Influence of the ionosphere and troposphere errors to CV results was eliminated because the distances between the receiver antennas

were very short, so it was possible to estimate the noise level of CV based on geodetic receivers in this ‘plain’ implementation.
The standard deviation of CV over OPZ1-OPZ2, OPZ1-OPJV and OPZ2-OPJV links is 3.1 ns, 4.0 ns, and 2.3 ns respectively. It reflects the influences of receiver antenna type: OPZ2 and OPJV had choke ring antennas and OPZ1 only the non-precise navigation antenna.
Fig. 3-3 presents MDEV of daily averaged CV results. The implementation of precise antennas appeared to be an important point: it improved the long-term performance of CV by a factor of about 2 (compare the results for OPZ1-OPJV and OPZ2-OPJV links) . Another interesting outcome of the experiment was the mitigation of the influence of a non-precise antenna for OPZ1-OPZ2 link (both OPZ1 and OPZ2 are equipped with Ashtech receivers and antennas). On the other hand, receivers from different firms exhibited different satellite tracking performance (see dashed ovals on fig. 3-2). This effect should be investigated further.
Additionally, the accuracy of a single satellite time CV (SCV) described in [BIPMCV] was compared with the accuracy of multi-satellite CV (MCV) (see fig. 3-4). The SCV procedure deals with observations of only one satellite per epoch. The MCV approach uses the processing technique from [BIPMCV] for all the satellites tracked simultaneously by two laboratories.
The MCV approach improved the short-term accuracy by a factor of about 2.5 (for an averaging time up to 1 day). The accuracy degradation for intervals of $3-6\cdot 10^4$ s has an obscure nature. This effect is also reported in [HAHN-98]. It might be caused by temperature variations of antenna and receiver delays.
Finally, we compared the performance of SCV and MCV with the performance of primary frequency standards, i.e. Cs clock and active H-maser (see fig. 3-5).
After averaging over 3 hours the precision of MCV reached that of the primary Cs standard, and after averaging over 1 day the MCV noise was reduced to the level of an active H-maser. Thus, the short-term noise of CV is much higher than the noise of primary standards, so only the medium- and long-term performance of precise clocks would be assessed correctly.

Conclusion

The results of the experiments have shown that the performance of geodetic receiver based CV is not worse than that of conventional CV. We have also assessed the noise floor of clock comparisons based on geodetic receivers. Periodic affects found in the results of CV should be assigned to environmental variations of receiver and antenna delays.
Future work will concentrate on the elimination of temperature variations of receiver delays and implementation of precise ephemeris and ionospheric parameters. We also plan to use a more sophisticated algorithm of data processing.

List of references

[BARN-66] J. Barnes, Atomic Timekeeping and the Statistics of Precision Signal Generators, Proceedings of IEEE Vol. 54, No. 2, 1966, pp. 207-220

[BIPMCV] Technical Directives for Standardization of GPS Time Receiver Software to be implemented to improve the accuracy of GPS common-view time transfer, Group on GPS Time Transfer Standards, Rapport BIPM 93/6, 1993

[DEFR-01] P. Defraigne et al., Time Transfer to TAI Using Geodetic Receivers, Proceedings of EFTF 2001, pp. 517-521

[GURT-01] W. Gurtner, RINEX: The Receiver Independent Exchange Format Version 2.10, 2001, Web data archives

[HAHN-98] J. Hahn and L. Schmidt, Long Baseline Clock Comparisons with Multi-Channel GPS Time Receivers, Proceedings 5th IEEE SSTA Symposium, Vol. 1, 1998, pp. 92-96

[KRAE-99] R. Kraemer et al., Results in GPS System Time Restitution with Kalman Filters, Proceedings of EFTF/IFCS Joint Meeting, 1999, pp. 255-258

[KART-78] P. Kartaschoff, Frequency and Time, Academic Press, London, 1978

[SENI-01] K. Senior et al., Developing an IGS Time Scale, pre-print for Proceedings of IEEE/EIA IFFC, 2001

[WEIS-89] M. Weiss, Apparent Diurnal Effect in the Global Positioning System, IEEE Transactions on Instrumentation and Measurements, Vol. 38, No. 5, 1989, pp. 991-997

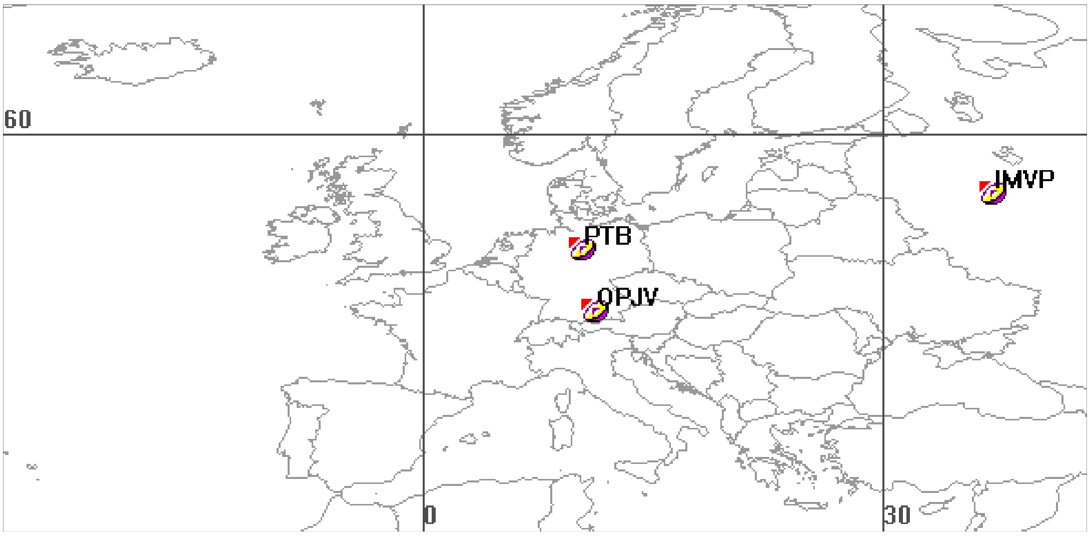

Figure 2-1. Location of time laboratories

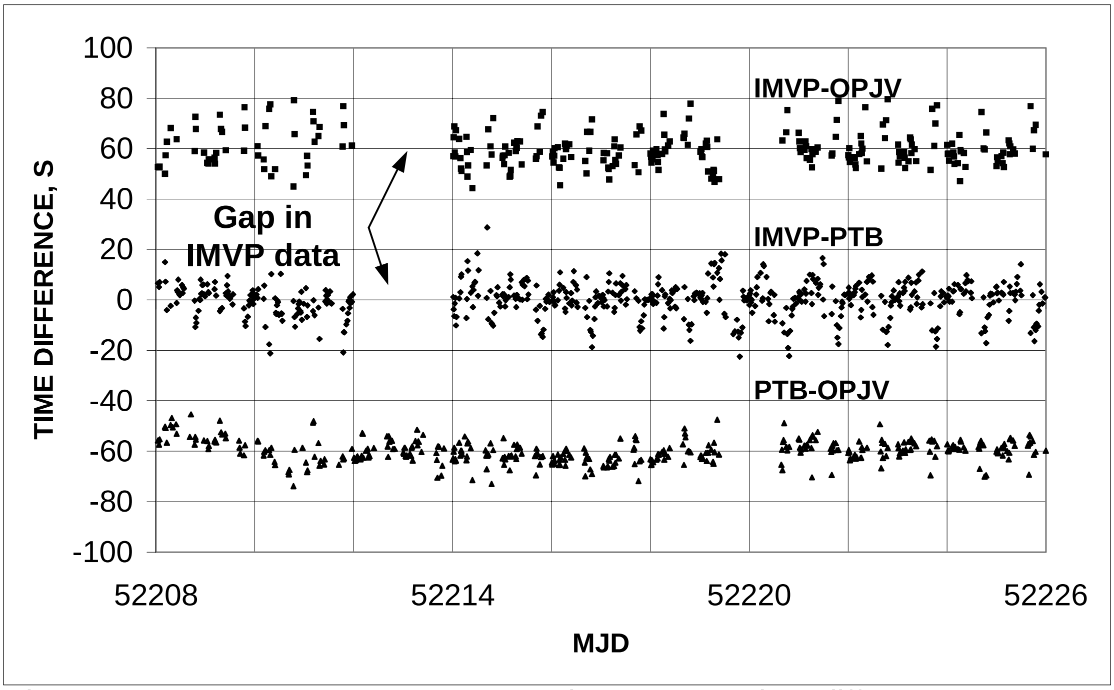

Figure 2-2. IMVP-OPJV, IMVP-PTB and PTB-OPJV time difference.

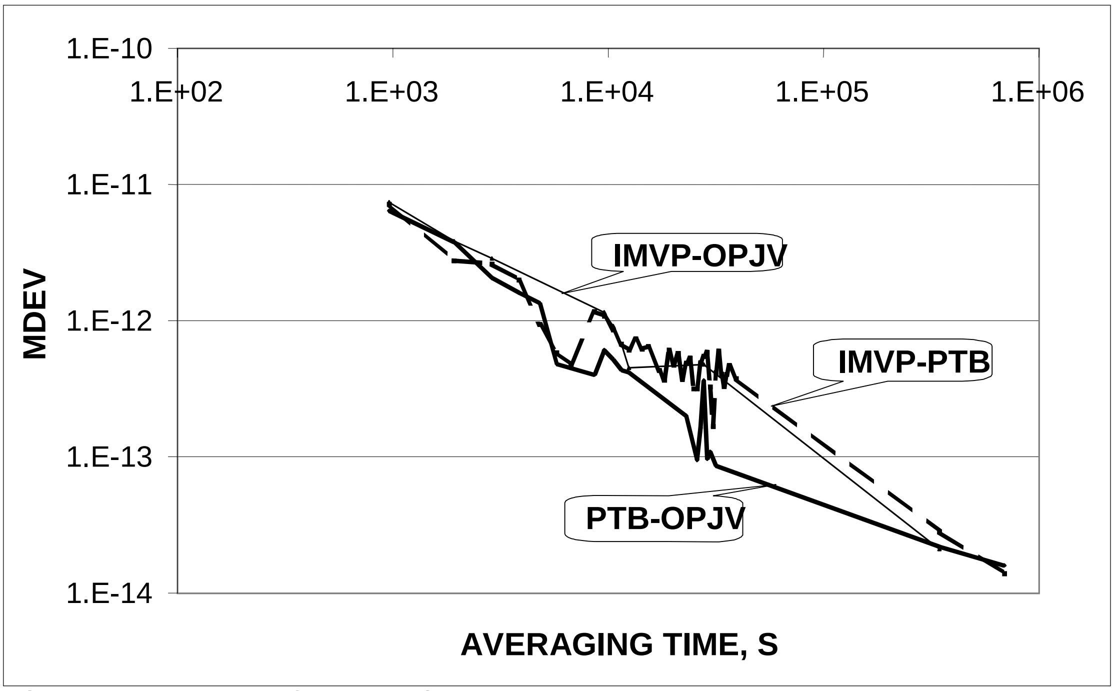

Figure 2-3. MDEV of CV results

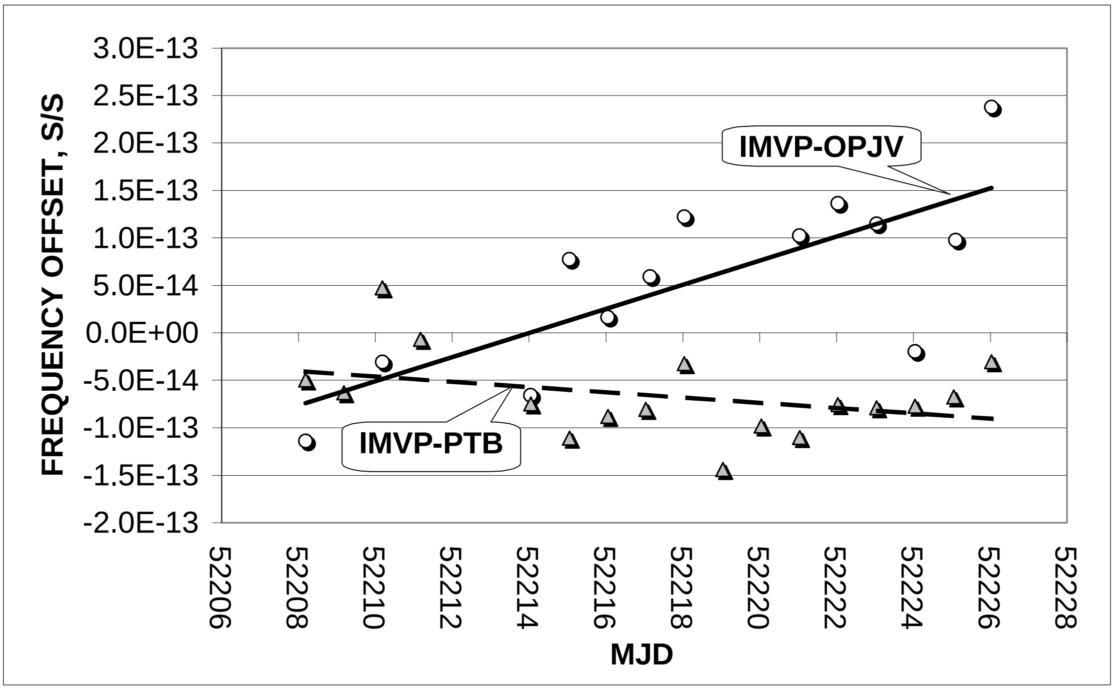

Figure 2-4. IMVP-OPJV and IMVP-PTB frequency offset

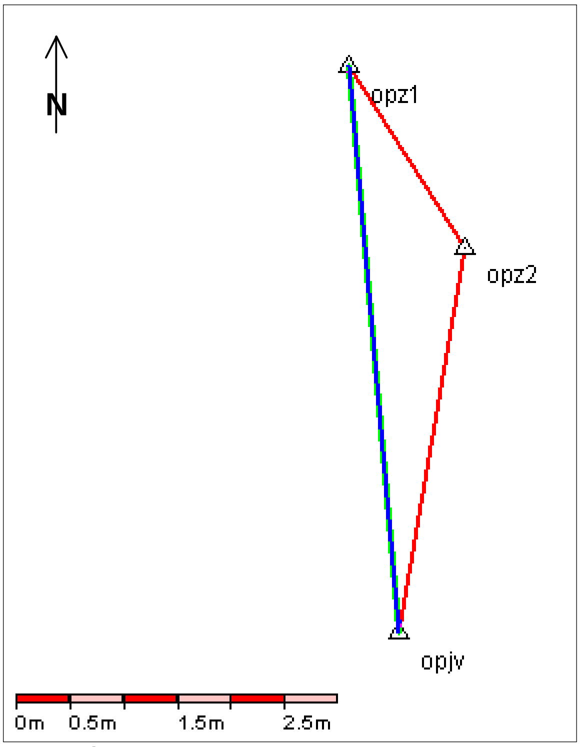

Figure 3-1. Antenna area layout

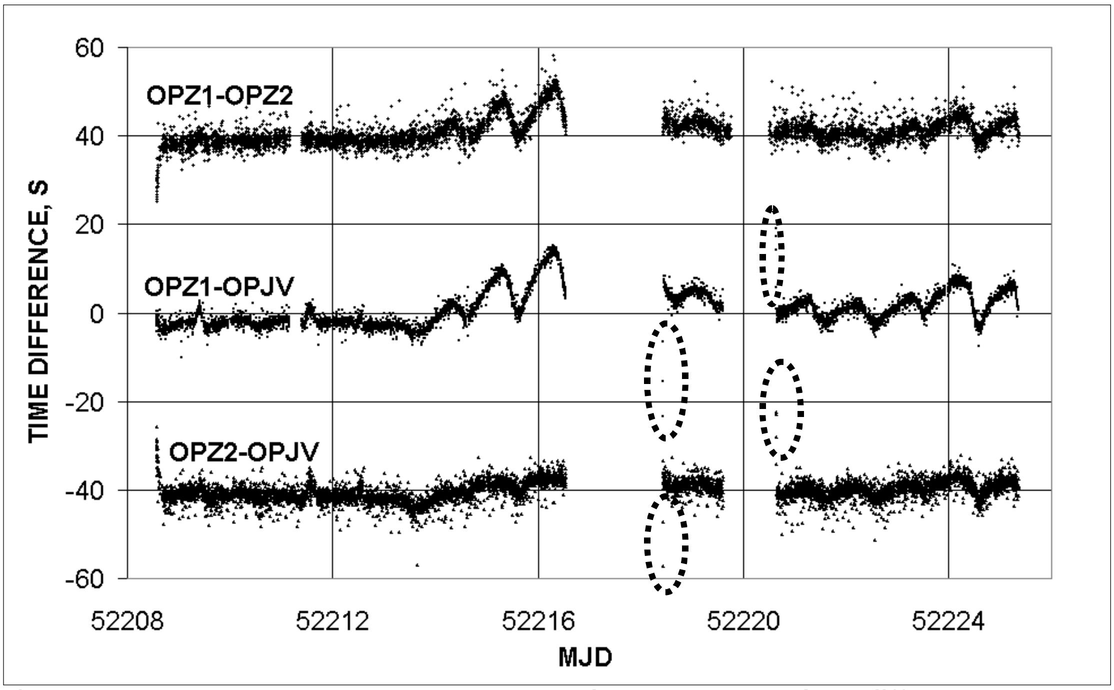

Figure 3-2. OPZ1-OPZ2, OPZ1-OPJV and OPZ2-OPJV time differences

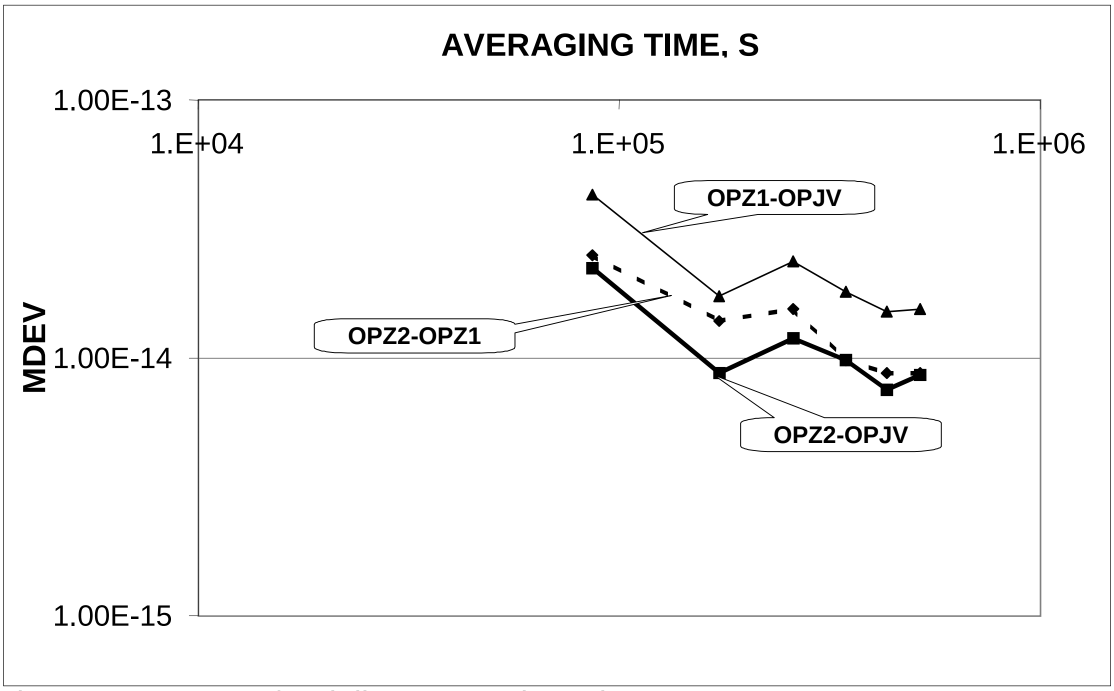

Figure 3-3. MDEV for daily averaged results

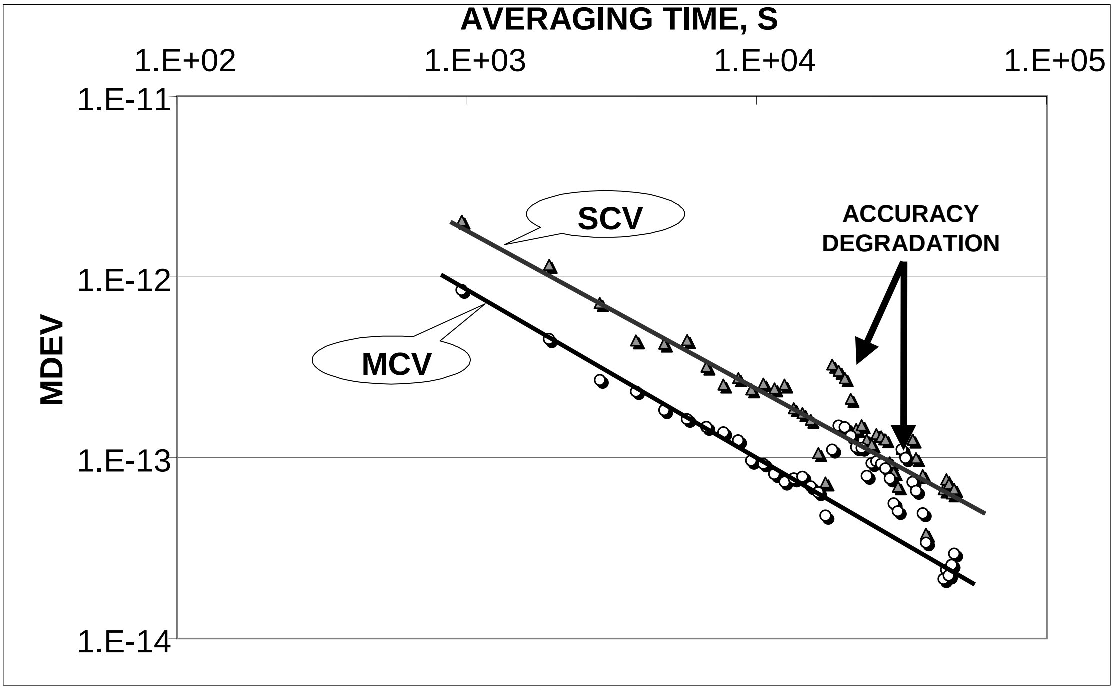

Figure 3-4. Single satellite CV vs. multi-satellite CV (OPZ2-OPJV)

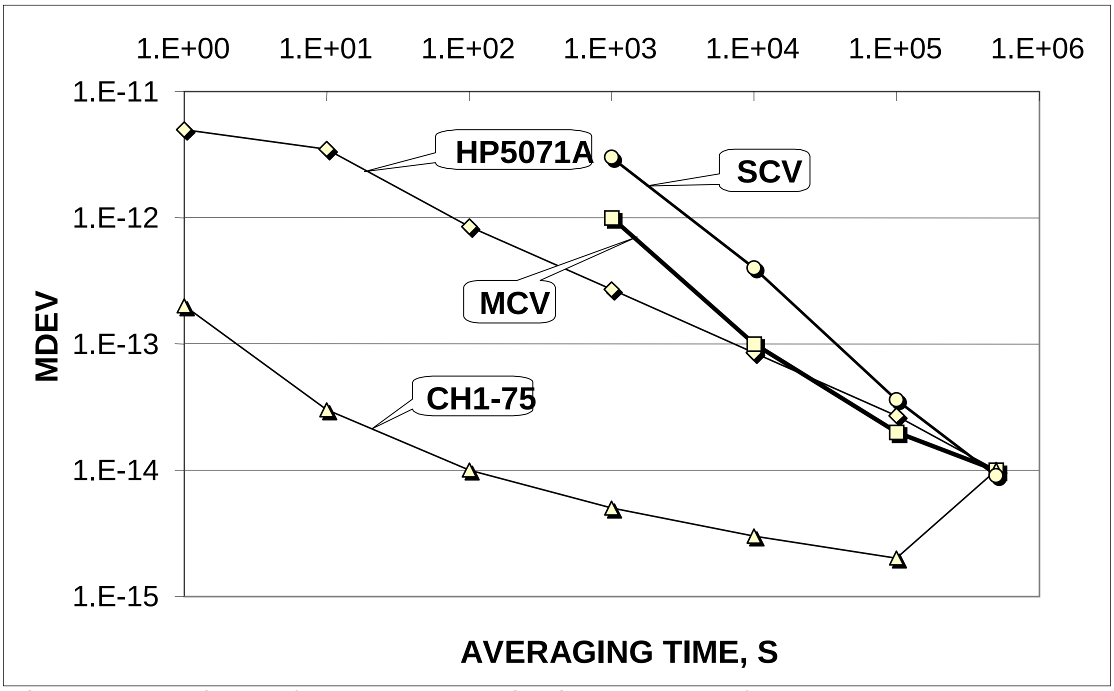

Figure 3-5. Primary frequency standards vs. CV performance

Precise Time and Frequency Standard (PTFS) System

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The Task

The project we had to work for was to design a Precise Timing and Frequency system that should deliver all signals to operate as well as the complete telecommunication as well as the telemetry system of a navy ship. Besides this the station has to be redundant, to able to be synchronized to different external systems like a GPS-receiver or a “flying clock”, represented by a Cesium standard.

Another specification said that the system has to have a maximum timing error of 100 µs if running on its own internal oscillator.

To achieve excellent receiving capabilities for the high data rate telecommunication system the frequency output has to be of very low noise, as well as phase noise as well as harmonic and non-harmonic distortions.

System Overview

The Precise Time and Frequency Standard (PTFS) sub system described below is the resulting solution for the required performance:

Figure 1 shows the front view of the system.

The specifications are:

Free running mode:
30 µs if running unsynchronized within 90 days with primary frequency source
resp. 100 µs of running unsynchronized 30 days with secondary frequency source

Synchronisation:
GPS or flying clock

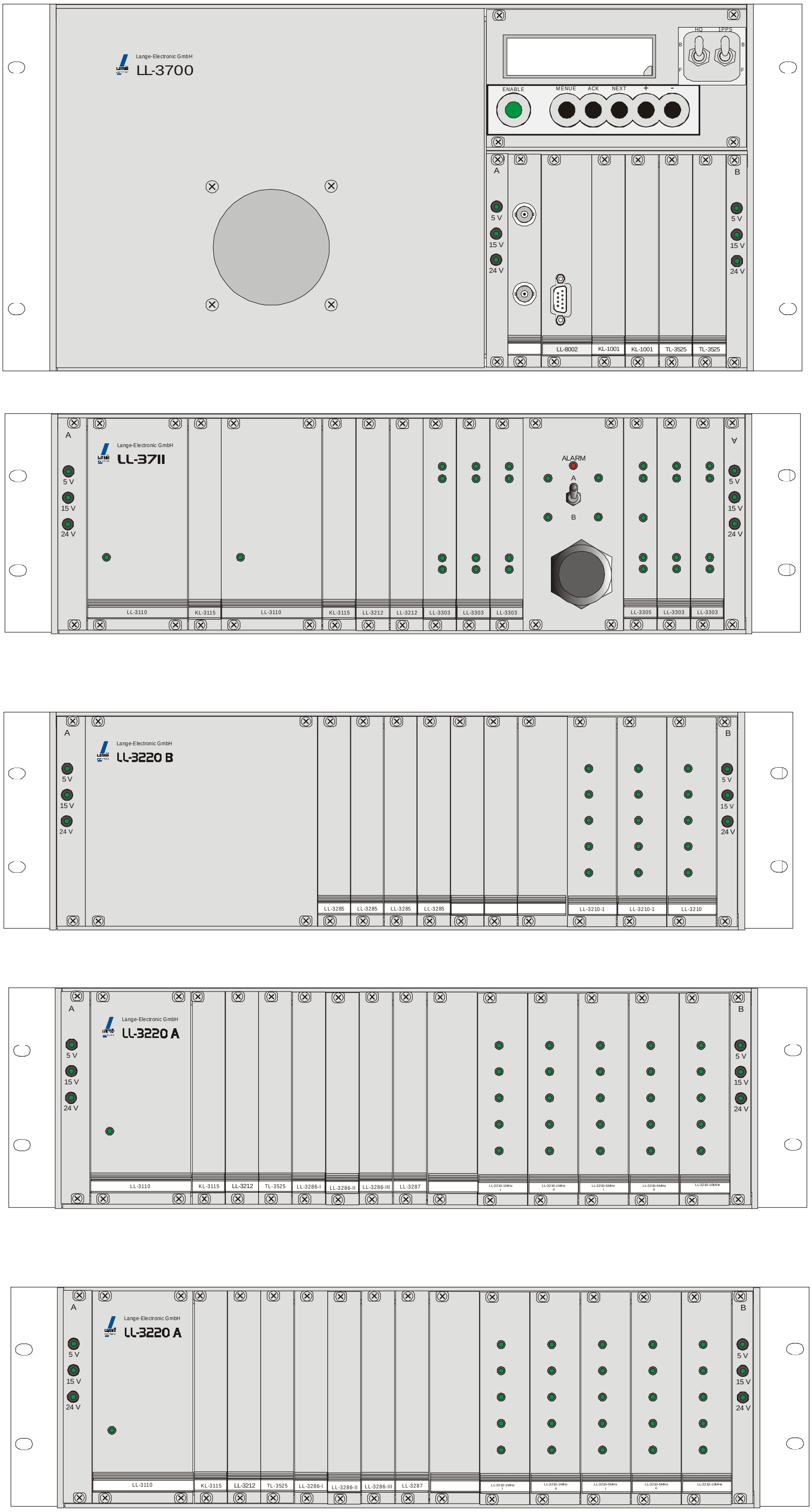

Table 1, System Overview

Frequency outputs:

10 MHz, 5 MHz and 1 MHz, all sine wave

T-1, E-1 as digital outputs

Timing outputs:

1 pps, 1 ppm, HaveQuick, IRIG B, TD-1, TD-2

The complete system comprises of different modules:

- The Primary Frequency Module contains a Cesium Standard as primary and a Rubidium oscillator as secondary frequency standard. The synchronisation and timing boards are also part of this module.
- The Secondary Frequency Module contains two redundant high quality low noise oscillators as “clean-up” units and the alarm and controls circuitries.
- Several distribution modules supply a lot of the a.m. timing and frequency outputs to the outside world

Primary frequency module LL-3700

This unit contains the following modules:

1. Cesium frequency standard
2. Rubidium frequency standard
3. TTL- to HaveQuick /RS485-Converter
4. 1 pps-Synchronisation Board
5. System controller
6. Time code generator with Have Quick sync circuitry
7. Display
8. Front panel control switches

Functionality

The Cesium frequency standard is a fully self-contained unit that is not synchronised to any external frequency or time. This includes a possible phase difference between an external frequency of +- 50 ns. Taking into account that every known frequency source has an unknown phase offset to the “ideal” standard frequency of NIST, PTB or BIPM, this offset can be neglected.

The Rubidium frequency standard is used as back-up and is phase locked to the Cesium unit by the 1 pps-Synchronisation Board, that also synchronises the 1 pps signals derived from the Cesium and Rubidium standards to the 1 pps signal of the external GPS receiver or the external flying clock. This board also outputs the 10 MHz and 1 pps signals to the time code generator boards.

In case of a failure of the Cesium frequency standard the 10 MHz and 1 pps outputs are switched to the Rubidium frequency standard.

Almost all internal timing signals are differential to have a high common mode rejection throughout the complete system.

The Time Code Generator boards synchronise their time code outputs (IRIG B, TD-1, TD-2 and Have Quick) to the Have Quick and 1 pps inputs derived from the external GPS receiver or the flying clock. They also supply 1 pps and 1-ppm outputs. All the outputs of the Time Code Generator Boards have a programmable propagation delay compensation to compensate for all kinds of delays.

The System Controller board links the different modules and supplies the necessary interfaces between the front panel switches, the display and the “inner life” of the unit. It also has an interface to synchronise the units with the 1 pps-signal derived from an external flying clock.

The display is a 2-line vacuum fluorescence display, as used in airborne time code generators. The upper row shows time derived from the Time Code Generator, the lower row shows status information’s.

An acrylic glass shall avoid accidental operation of all front panel switches. The menu pushbuttons require two-finger action to be activated.

The LL-3700 is supplied with redundant DC power from the main Power Supplies in the Mod. LL-3711 and is also supplied by the battery pack. All voltages of the three inputs are switched via diode matrixes to avoid interruptions in case one of the power supplies fails. An external power unit is also available supplying the complete system.

Secondary frequency module LL-3711

This unit contains the following modules:

1. Phase locked oscillator with PLL-board in a Noise Eater configuration
2. Frequency divider
3. T1 and E1 generation board
4. 10 MHz comparator board
5. 5 MHz comparator board
6. 1 MHz comparator board
7. 1 pps comparator board
8. IRIG B comparator board
9. TD-1 comparator board

10. Have Quick comparator board
11. TD-2 switching board
12. 1 ppm switching board
13. Main Controller board
14. Assistant Controller board
15. Redundant power supply

Functionality

The secondary frequency module contains two oven controlled low phase-noise oscillators and the accompanying PLL circuitry to phase lock the noise eater OCXO's to the 10 MHz of the Cesium unit. A frequency divider produces 5 MHz and 1 MHz from the 10 MHz outputs of the oscillators. The configuration cleans the outputs of the Cesium or Rubidium primary standards from noise.

The LL-3711 module also compares and selects the different signals provided by LL-3700 like IRIG B, HaveQuick, TD-1, 1 pps and switches signals like 1 ppm and TD-2. The frequencies produced in this module are also compared and switched to form a redundant system.

Signal distribution modules LL-3220-xx

The distribution units are filled with different distribution boards like:

1. 10 MHz distribution boards
2. 5 MHz distribution boards
3. 1 MHz distribution boards
4. T1 and E1 distribution boards
5. RS 485 distribution board for differential digital signals
6. Digital frequency distribution boards
7. TTL distribution boards for single ended signals
8. High voltage boards to output specific digital levels
9. Analogy output boards for signals like IRIG B

The different distribution units within the system inputs the necessary signals from modules I and II and output the signals usually in a n x 4 mode, like 8 x 1 MHz, 12 x 10 MHz, and 4 ea. of 1 pps, TD-1 and TD-2.

The analogue output boards are equipped with alarm functions to be able to indicate the loss of inputs or outputs and also low signal levels due to shorts in the external cabling.

Frequency outputs:
- 10 MHz, 5 MHz and 1 MHz, all sine wave
- T-1, E-1 as digital outputs

Power supply and Battery Pack

The redundant AC/DC power supply is part of the Secondary Frequency Unit. Each part of the two power supplies is capable of driving the complete system forever. The different boards and modules in the system are supplied with two identical voltages that are combined via a diode matrix. Thus it is warranted that there is always power, even if 1 of the power supplies fails.

An external battery also supplies the Primary Frequency Module and the Secondary Frequency Module.

The battery pack contains 4 batteries, each with 12 VDC and a capacity of 28 Ah. The combination warrants the supply of the primary and secondary frequency modules for 2 hours.

The batteries used are “Powerfit” batteries, which are free of maintenance and very low gazing, have a lifetime of 5 years (depending on temperature) and can be recycled. The loading circuitry and a DC/DC power supply are also contained in the battery pack.

Conclusion

The system was previously designed for a military environment and successfully tested early this year.

ACCURATE TIMING FOR TEST FIELDS

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Abstract

AccuBeat Ltd. has lately developed novel equipment for the dissemination of very high accurate TIME and FREQUENCY for use in test fields and other applications.

The AR-50A/51A Rubidium-GPS Standard provides numerous features in a single box that normally requires the use of several instruments. The unit includes an Atomic Rubidium Frequency Standard and a GPS receiver. It provides very high precision and very low noise frequency output as well as time outputs of 1PPS (1 Pulse Per Second), IRIG B, IRIG A, Time Codes and TLP (Time and Location Serial Protocol for PC or other computers) outputs. The unit accepts 10MHz input, 1PPS input and IRIG B Time code input for frequency and time calibration when GPS is not available. With the absence of GPS reception the unit continues to advance the time with the internal Rubidium Atomic Clock.

The AR-51A is a highly ruggedized unit designed for mobile, ground and airborne platforms meeting very harsh environmental conditions. It also includes a rechargeable back up battery for up to 1-hour operation in the field.

AccuBeat also offers a portable model AR-50A for the dissemination of accurate time and frequency to field units when GPS reception is not available.

The paper describes in detail the above-mentioned equipment and its various applications.

Introduction

The requirement for very high precision time-of-day information for data correlation with time is present in many modern day electronic systems, such as communication systems, data handling systems, missile and spacecraft tracking, and telemetry systems. Numerous scenarios in test fields require data acquisition of remote sensors and time-tagging of the various events, in order to accurately determine the sequence of events, and to differentiate cause and result. In these scenarios highly accurate clocks are required In order to provide absolute timing. Atomic Clocks may provide for the extremely accurate time keeping, while GPS receivers provide for initial time setting. Parallel and serial formatted time codes are used for the time-tagging of the events. Standardization of time codes is necessary to ensure system compatibility among the various ranges of ground tracking networks, spacecraft and missile projects, data reduction and processing facilities, and international cooperative projects.

AccuBeat Ltd. has lately developed novel equipment for the measurement of very high accurate time and frequency for use in test fields and for the other applications described above.

The AR-51A model, Rubidium-GPS Standard, integrates numerous features in a single box that normally require the use of several instruments. The unit includes an Atomic Rubidium Frequency Standard, a GPS receiver and an IRIG B / IRIG A generator and reader. It provides very high precision and very low noise frequency 10MHz output, 1PPS (1 Pulse Per Second) output, IRIG-B and IRIG-A Outputs and TLP code (Time and Location Serial Protocol for PC or other computers) output.

In the following sections we will review the principles of Atomic Frequency Standards, in particular the Rubidium Standard, the principles of the Global Positioning System (GPS), IRIG Time Codes and then present a detailed description of the novel AR-51A model. Thereafter a short description is also presented for a portable model AR-50A.

Atomic Frequency Standards

Atomic Standards' Principles of Operation

Atomic oscillators are based upon emission/absorption of electromagnetic (EM) radiation that occurs in individual free atoms. When an atomic system changes energy from an excited state to a lower energy state, a photon is emitted. The photon frequency ν is given by Planck's Law: $\nu = (E_2 - E_1)/h$, where E_2 and E_1 are the energies of the upper and lower states, respectively, and h is Planck's constant. An atomic frequency standard produces an output signal, the frequency of which is determined by this intrinsic frequency rather than some property of a bulk material (as in quartz oscillators). Atoms that are used are cesium, rubidium, and hydrogen, with transition frequencies of 9.2 GHz, 6.8 GHz, and 1.4 GHz, respectively. Lower output frequencies, typically 5 or 10 MHz, are realized by using either a frequency lock loop (FLL) or a phase lock loop (PLL) and several frequency divide circuits. The frequency of the crystal oscillator (around 5 MHz or 10 MHz) is multiplied, and is either frequency locked or phase locked to the higher atomic frequencies.

In an atomic frequency standard, as shown in Figure 1, a voltage controlled crystal oscillator (VCXO) is locked to the atomic resonator, which is a highly stable frequency reference generated from an atomic transition. The long term stability is determined by the atomic resonator. The short term stability is determined by the crystal oscillator.

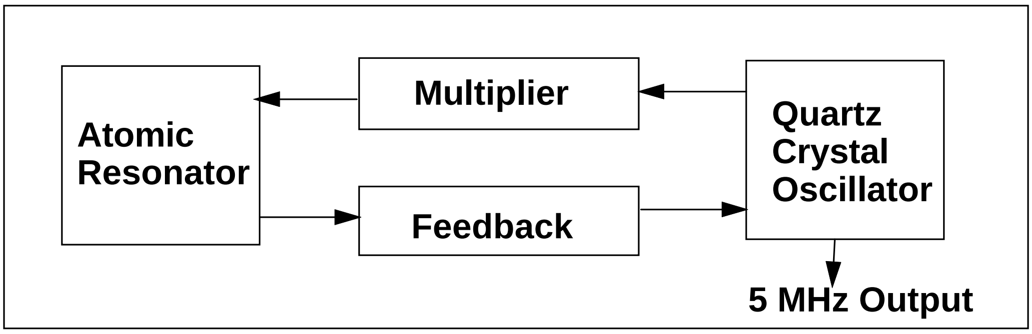


Figure 1: Block Diagram of an Atomic Freq. Std. [1]

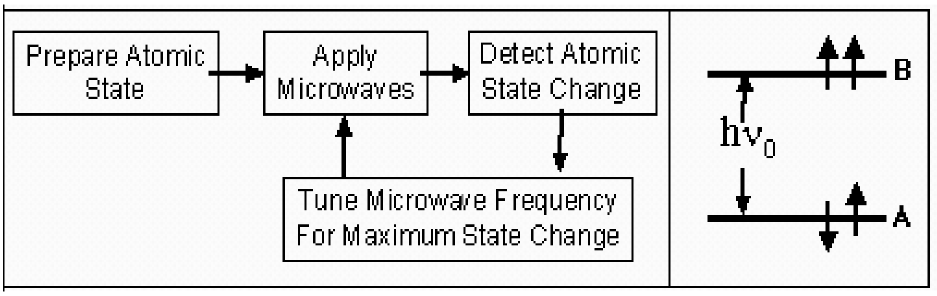


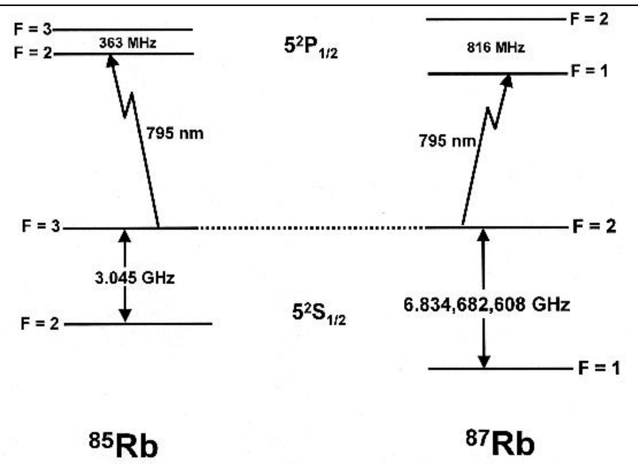
Figure 2: Generalized Atomic Resonator [1]

A generalized atomic resonator is depicted in Figure 2. Under thermal equilibrium (above room temperature), the population in the two energy states (A and B) is nearly equal. Therefore in a natural ensemble of atoms, during energy state transitions, about half the atoms absorb $h\nu$ and half emit $h\nu$; the net effect being zero. A non-thermal distribution is then prepared. That is, one of the states is “selected,” either by optical excitation or by magnetic splitting of the atomic beam into two beams with the two states. Microwave energy is absorbed in the process of converting the selected atoms to the other energy state, e.g., from A to B. Thus, the applied microwave frequency (derived from the VCXO) can be “locked” to the frequency corresponding to the atomic transition.

Rubidium Frequency Standards’ Principles of Operation

Among Atomic Standards, a Rubidium Standard is the smallest, least expensive and commercially available. A general block diagram is shown in Figure 3.

Energy Level Diagram for a Rubidium Atomic Standard



Rubidium Atomic Resonator Schematic Diagram

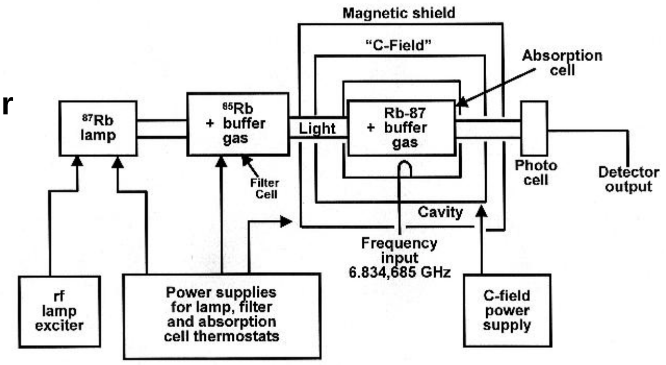


Figure 3: Block Diagram of Rubidium Frequency Standard

The atomic resonance frequency used is 6,834,682,608 Hz.
The RF excited ^{87}Rb lamp emits wavelengths corresponding to both the F=1 and F=2 transitions. The ^{85}Rb filter cell absorbs more of the F=2 transition light. Light which passes through the filter is absorbed by the ^{87}Rb F=1 state. Excited atoms relax to both the F=1 and F=2 states. However, the F=1 states are excited again. The F=2 state is overpopulated. The 6.8 GHz RF input signal converts the F=2 back to the F=1, which provides more atoms to absorb light. Microwave resonance causes increased light absorption, that is, a (< 1%) dip in the light detected by the photocell. Since the microwave frequency is locked to the photocell detection dip, the atomic transition frequency thus controls the microwave frequency, i.e., the frequency of the crystal oscillator.

The Rb Frequency Standard frequency provides frequencies stabilities of parts in 10^{-10} to 10^{-12} with respect to ambient temperature and with respect to time (aging).

For more comprehensive review of accurate frequency sources please see reference [1].

Global Positioning System (GPS)

The following Global Positioning System (GPS) information is obtained from the USNO website [2].

The GPS is a US DoD developed, worldwide, satellite-based radio navigation system. The constellation consists of 28 operational satellites.
GPS provides two levels of service, the Standard Positioning Service (SPS) available to all GPS users, and the Precise Positioning Service (PPS) available only to users authorized by the U.S..
SPS provides a predictable positioning accuracy of 100 meters horizontally and 156 meters vertically and time transfer accuracy to UTC within 340 nanoseconds. The PPS provides higher accuracies.

Selective Availability, Anti-Spoofing

Selective Availability (SA), the denial of full accuracy, is accomplished by manipulating navigation message orbit data (epsilon) and/or satellite clock frequency (dither). Anti-spoofing (A-S) guards against fake transmissions of satellite data by encrypting the P-code to form the Y-code.

Satellite Clocks

Each Block II/IIA satellite contains two Cesium (Cs) and two Rubidium (Rb) atomic clocks. Each Block IIR satellite contains three Rb atomic clocks.

GPS Time

GPS time is given by its Composite Clock (CC), which was implemented on June 17, 1990 at 0000 UT. The CC or "paper" clock consists of all operational Monitor Station and satellite frequency standards.
The GPS epoch is 0000 UT (midnight) on January 6, 1980. GPS time is not adjusted and therefore is offset from UTC by an integer number of seconds, due to the insertion of leap seconds. The number remains constant until the next leap second occurs. This offset is also given in the navigation (NAV) message and the receiver should apply the correction automatically. As of January 1, 1999, GPS time is ahead of UTC by thirteen (13) seconds.
In addition to the leap seconds, there are additional corrections given in the NAV message. The system time, in turn, is referenced to the Master Clock (MC) at the USNO and steered to UTC (USNO) from which system time will not deviate by more than one microsecond (PPS requirement). The exact difference is contained in the NAV message The SPS user can obtain a time transfer accuracy to UTC (USN) within 340 nanoseconds and the PPS user can obtain a time transfer accuracy to UTC (USNO) within 200 ns.

GPS Receivers

A GPS receiver outputs four-dimensional data, which are comprised of location (position) and time. Part of the time signal is a 1 pulse per second (1 PPS) signal that may be considered to be an accurate 1 Hz frequency source. The short term stability of the 1 PPS is not very good due to its relatively high jitter. For example, a jitter of 400 nanoseconds translates into a short-term stability of 4 x 10^{-7} at an averaging time of 1 second, which is rather poor. However, in the long term, the stability of the 1 PPS tracks the excellent stability of the GPS system (which is comprised of atomic clocks located aboard satellites and in ground stations). Thus, one may use a stable “local” oscillator, lock it via a phase lock loop (PLL) to the 1 PPS signal coming from the GPS receiver, and then combine the local oscillator (which has good short term stability) with the excellent long term stability of the GPS receiver.

Time Codes

The need for serial time codes arose in the early days of the missile and space program. During the testing of long-range missiles, data was gathered from different locations, and had to be correlated. These time codes were developed to enable the synchronizing the time at remote locations via a telemetry link or land lines and for the recording time on the same media (typically magnetic tape) as the test data.

Co-recorded time code also enables to perform automatic data location by searching the magnetic tape using the stored time code information.

The basic time information is pulse width coded in either a BCD or binary format. Originally, the Inter-Range Instrumentation Group (IRIG) proposed a series of time code formats which later became the NASA codes. Soon after these, another series called the IRIG Standard Time Code Formats was approved and has become the industry standard.

IRIG Codes are named IRIG A, IRIG B, and so on through IRIG H. The codes differ in the frequency of the amplitude-modulated carrier, which ranges from 100 Hz to 100 KHz, and in the resolution of the time, which may be encoded. Varying numbers of control bits may also be encoded in these time code streams. Time codes may be used either as DC level shifts suitable for direct connection into digital systems or as amplitude-modulated audio tones suitable for recording on to magnetic tape or for transmission over some other band limited medium.

IRIG serial time code formats are defined by IRIG STANDARD 200-95 [3]. .

AccuBeat’s Digital Rubidium Frequency Standards

AccuBeat produces Rubidium Frequency Standards (RFS), models AR-40A and AR-60A. Both models are based upon the same core design. The AR-40A (shown in Figure 4), with dimensions of 77 x 57 x 35.6 mm is the smallest RFS available in the world today, and is intended for commercial applications. The AR-60A (77 x 77 x 39.6 mm) is designed to meet harsh environments, a wide temperature operating range, operation under shock, vibration, and moisture [4].

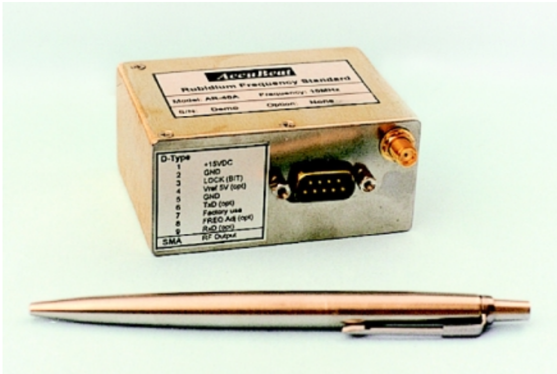


Figure 4: Rb Frequency Standard, Model AR-40A

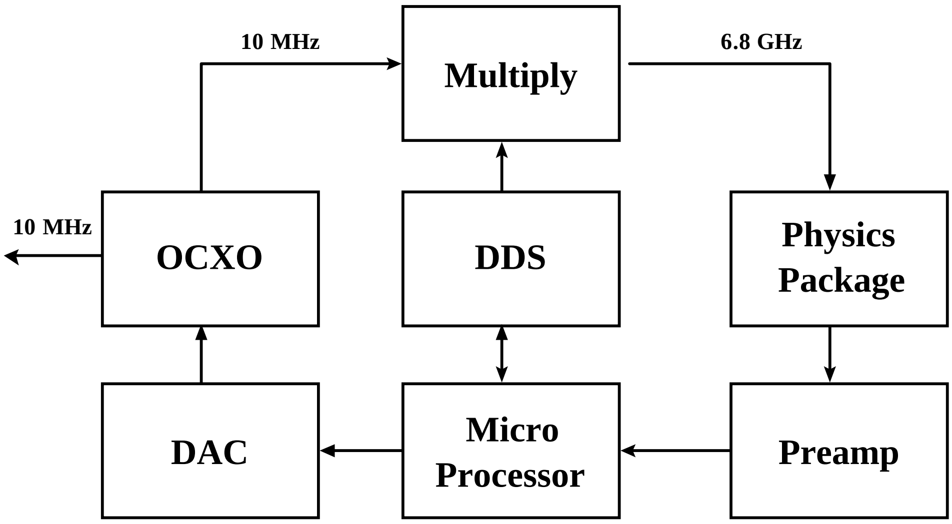


Figure 5: AR-60A FLL Approach

The following is a summary of some of the key performance parameters of the AR-40A/AR-60A:

- Output Frequency: 10 MHz, sine wave
- Spurious: - 90 dBc, $\pm$ 1.5 MHz from carrier
- Long Term Stability (Aging): 5 x 10^{-10}/yr.
- Warm-up: 5 minutes to 5 x 10^{-10}
- Phase Noise:
  -100 dBc/Hz @ 10 Hz, -130 dBc/Hz @ 100 Hz, -150 dBc/Hz @ 1 KHz
- Harmonics: -40 dBc
- Supply: 15 Vdc/0.6A @ steady state
- Stability/Temp: $\pm$2 x 10^{-10}/(-20°C to +75°C) (AR-60A)
- Weight: 250 grams (AR-40A)
- Holdover Mode: When lock is lost, the internal OCXO continues to provide an output frequency.

In the conventional design of a RFS [2], a crystal oscillator is locked at 10 MHz to the rubidium hyperfine transition frequency at 6.8 GHz via a Frequency Lock Loop (FLL). However, the AR-40A and AR-60A, utilize a more advanced scheme where a microprocessor and a direct digital synthesizer (DDS) are embedded in the FLL (as shown in Figure 5), which transforms the FLL into a digital loop.

The scheme used for the software in the microprocessor (pending patent applications) transforms the RFS into a smart clock, improves the sensitivity to external disturbances, and allows for the holdover mode described above. The microprocessor also handles a variety of different functions, thus replacing many of the components required in the conventional design.

For more information regarding AccuBeat's Rubidium Atomic Standards see AccuBeat's website [4].

AR-51A – Rubidium-GPS Clock System

The AR-51A is a compact and ruggedized instrument that combines an ultra-high accurate Rubidium Atomic Frequency Standard (RAFS), AccuBeat model AR-60A, together with a sophisticated GPS receiver to provide an accurate, continuous, non-interruptible and reliable time and frequency. The AR-51A is used by the Israeli Ministry of Defense and the Israel Aircraft Industry.

Figure 6: AR-51A Front View

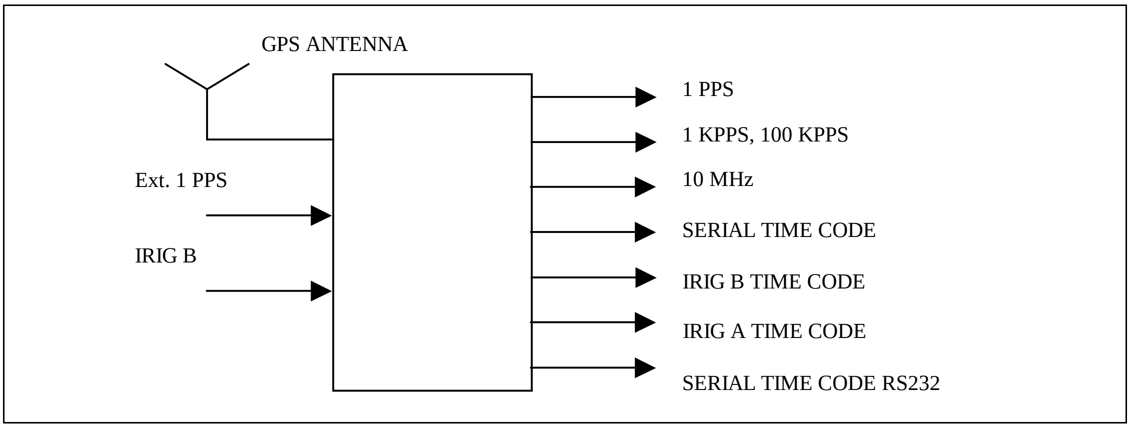


Figure 7: AR-51A Inputs / Outputs

The unit provides 1 Pulse Per Second output (1PPS), IRIG B serial code output, IRIG A serial code output, and serial RS232 output which provides Time, location AND Status Protocol (TLP code). A 10MHz frequency output is derived from the internal RAFS. The unit accepts both 1PPS and IRIG B as external inputs for synchronization.

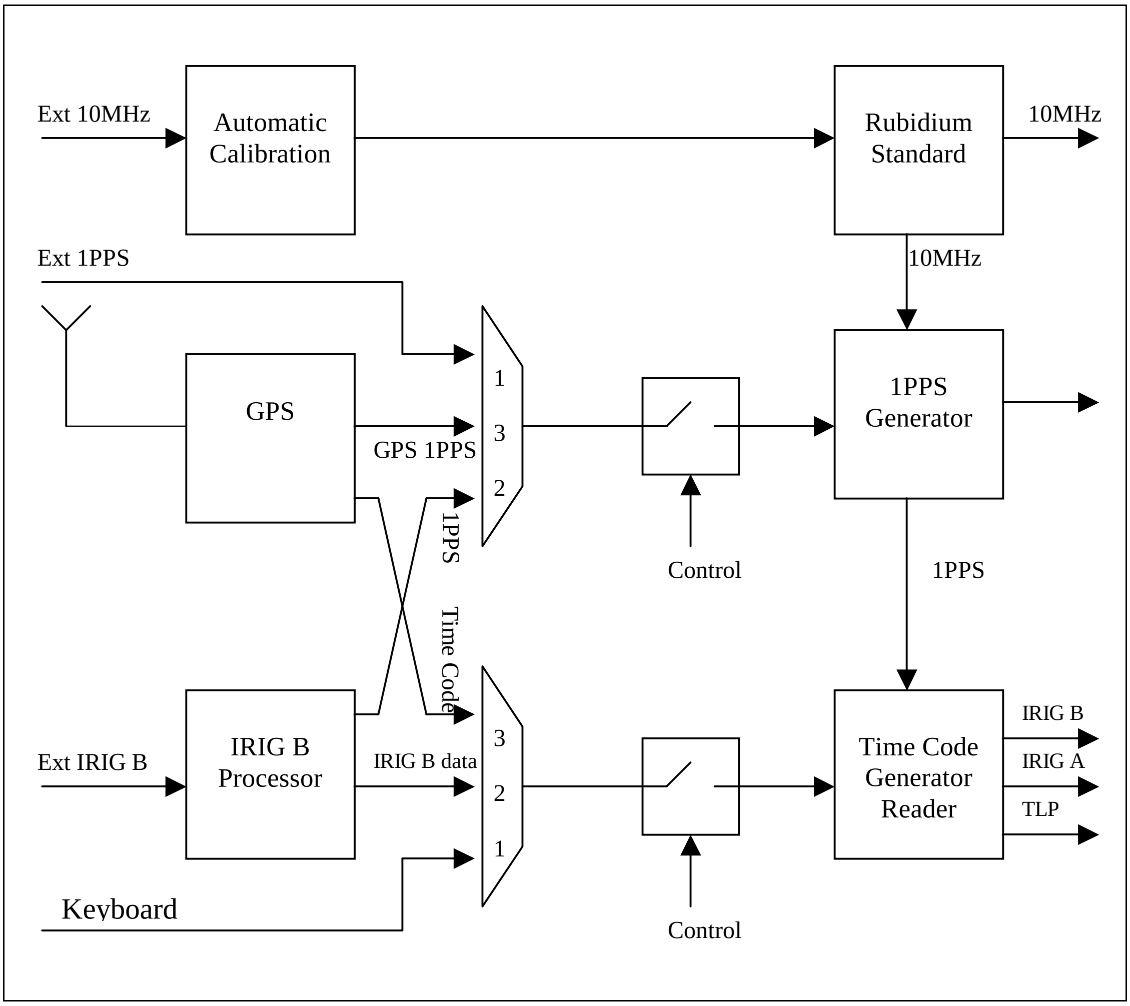


Fig. 8: Detailed Functional Block Diagram of AR-51A

A detailed Functional Block Diagram is shown in Figure 8. In the following paragraphs we describe the principles of operation of the unit.

Initialization

Under normal operation no external inputs (1PPS, IRIG B and 10MHz) are connected and the system uses the GPS 1PPS and Data for initial synchronization. Upon power-on, or upon operator request, the unit synchronizes the 1PPS output rising edge to the 1PPS obtained from the GPS receiver and reads the time and data from the GPS message.

Steady State

After initialization, the system advances the 1PPS and the various time and location codes (IRIG B, IRIG A and TLP) by the RAFS clock. Therefore, other than at initialization, the unit does not rely on GPS reception to output time, date and frequency.

External Time Inputs

When external 1PPS or external IRIGB are connected, the system synchronizes the time and/or reads the data from the external inputs. This however happens again only upon power-on or upon operator request by keyboard (if both external 1PPS and IRIG B are connected the priority is to the external 1PPS). This feature enables the unit to operate with no GPS reception, but to obtain the initial tuning from an external source.

Display and Manual Operation

The display shows the time, date and status of the unit. The keyboard enables the operator to enter the time and date manually and to initiate time, date and frequency calibration from the internal GPS or from the external IRIG B, 1PPS or 10MHz inputs as explained above.

Accuracy

The AR-51A provides time accuracy of < 200ns relative to UTC when GPS signal is available and 5 µsec per 24 hours drift when operated independently. The AR-51A provides very high stability of 1E-11/day and 5E-11/month, and in most cases does not require calibration. However, if required the unit can be automatically calibrated to an external reference, like a Cesium Standard, by a push of a button.

A special option where the frequency of the RAFS is locked to the GPS 1PPS is available as well. With this option there is no need for any calibration whatsoever.

Environmental Conditions

The AR-51A is qualified to operate under severe environmental conditions including wide operating temperature range, vibration, shock, humidity, salt atmosphere and EMI/RFI interference. The unit is designed to operate on various mobile platforms including ground mobile, airborne, helicopters and ship borne, continuously providing very high accuracies.

Summary of AR-51A Performance

Frequency Stability:	1E-11/day, 5E-11/month
Time Accuracy:	200ns relative to UTC, 5µs/24hours
Outputs:	10MHz, IRIG B code, IRIG A code, TLP code, Serial RS422 code
Inputs:	1PPS, IRIG B, 10MHz
Display:	Time, Date, Status, BIT
Power Supply:	28Vdc, 1 hour battery back-up
Environmental:	Wide operating temp. range, vibration, shock, humidity, salt atmosphere, EMI/RFI
Mechanical:	Ruggedized box 210x122x185 mm; can be adapted for 19" rack mounting; can be provided with vibration isolation tray
Reliability:	MTBF 20,000 hrs 30°C ARW
Maintainability:	MTTR – 12 min. A level, 34 min. B level
Built in Tests:	Detects 93% ÷ 97% of all failures

AR-50A – Poratble Rubidium Time and Frequency Standard

The AR-50A model is a portable version of the AR-51A designed for the dissemination of accurate time and frequency to the field unit when GPS is not available. By connecting the AR-50A to another AR-51A one can transmit accurate time and frequency from one unit to another. The AR-50A includes model AR-51A, an AC to DC power-supply, a car cable and a back-up battery for 3 hours of continuous operating. For more information see [4].

References:

1. For review of accurate frequency sources see :

1.1. "Clock Technology", S. Cantor et al, Proceeding of the 55th Annual Meeting, The Institute Of Navigation (ION), 1999.

1.2. "Quartz Crystal Resonators and Oscillators" A tutorial by John R. Vig, US Army Communication-Electronics Command, 2001.

2. Global Positioning System (GPS) information is found in the USNO website: http://tycho.usno.navy.mil/

3. For IRIG STANDARD 200-95 see: www. jcs.mil/RCC/manuals/irig/

4. Visit AccuBeat's website at http://www.accubeat.com.

A340–600: Experience feed back on sensors' field buses

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ABSTRACT

This paper talks about practical experience from installation and use of sensors' field buses on A340–600 flight test aircrafts.

Advantages and drawbacks of such buses use on aircraft test installation are discussed.

1. INTRODUCTION

AIRBUS A340–600 aircraft flight tests gave AIRBUS France Test Integration Centre the opportunity for the first time to install and use sensors' field buses during aircraft flight tests campaign.

There were three applications of such buses:

- engine thrust measurements
- remote acquisitions
- CAN bus spy

2. Engine thrust measurements

For this measurement type, the challenge was to improve the old acquisition system that was made of (see Figure 1):

- pressure measurement points in the engine,
- wired via rubber pipes to pressure sensors and an acquisition system set in the cabin.

The solution adopted consists in (see Figure 2):

- smart pressure sensors placed in the engine,
- wired together on a sensor' field bus (up to 32 sensors connected), managed by

an acquisition system set in the cabin.

Pressure smart sensors sense and digitise pressure phenomenon before delivering them on a field bus (RS485 electrical levels, owner protocol).

This new installation allowed a lot of improvements:

- air leak decrease, which were due among others to pipe lengths ;
- measurement accuracy increase ;
- wiring reduction : just only one electrical twisted pair versus multiple rubber pipes to wire between engine and cabin ;
- easier support (overhaul and installation, periodical automatic calibrations).

Main problems met were due to failing installation (essentially wiring) or sometimes sensor failures.

3. Remote acquisition units

This application has been mainly dictated by the need of wiring reduction between wings and engines / leading edges / fuselage.

Until now sensor outputs were linked point to point to the acquisition system set in cabin. The increasing number of measurements did not allow continuing to do this.

Therefore, AIRBUS France has chosen to install little remote acquisition systems placed near sensors.

Those devices consists in (see Figure 3):

- electronic remote units able to condition and digitise different sensor signals (16 or 32 inputs),
- wired together on a field bus (up to 16 units connected) linked to the main acquisition system set in cabin (up to 100m far).

Since any off the shelf field bus was suitable for this application, a simple field bus has been developed, based on a RS485 compatible link and an owner protocol.

This application demonstrated that:

- remote acquisition systems answer wiring reduction requirements and facilitate wiring installation,
- those are emphasised if units allow catching different sort of sensor signals.

Drawbacks of such an installation are:

- a lot of measurements can be lost if wiring fails,
- remote acquisition systems need to be ruggedized if they may be used in harsh environment places,
- wiring costs can be reduced but total costs may also be considered.

4. CAN bus spy

This application has been required not for connecting sensors together on a CAN field bus (Control Area Network) but for acquisition of data transmitted along CAN buses used by the basic aircraft installation.

It has required to develop one specific system, which should spy information issued on the CAN bus without modifying them (acknowledgement).

Even if this application was not for us a real sensors' field bus one, it has strengthened our opinion about CAN bus, which was considered when we have to choose a field bus for the remote acquisition units application (§ 3).

CAN bus:

- is very sensitive to wires and stubs lengths,
- does not allow high flow rates at long distances,
- is not dedicated to deterministic applications.

5. CONCLUSION

These first experiences with sensors' field buses for aircraft flight tests showed some of the advantages for using such technology, amongst them:

- wiring reduction that facilitates measurement chains installation on the aircraft,
- improved equipment follow-up and easier maintenance,
- sensor automatic calibration due to the digital electronic enclosed in them.

Nevertheless use of such buses requires taking care of:

- having good wiring in order not to lose so much measurements at the same time,
- choosing reliable smart sensors i.e. that don't chat on the bus.

At present, the main problem that should be solved is that there is no standardised field bus on the market. This is costly because acquisition systems require being adapted for each new field bus used.

We hope that IEEE P1451.3 standard currently in development will be the standard that will federate all sensors' field buses.

REFERENCES

[1] IEEE P1451 standards web site :
http://www.ic.ornl.gov/p1451/p1451.html

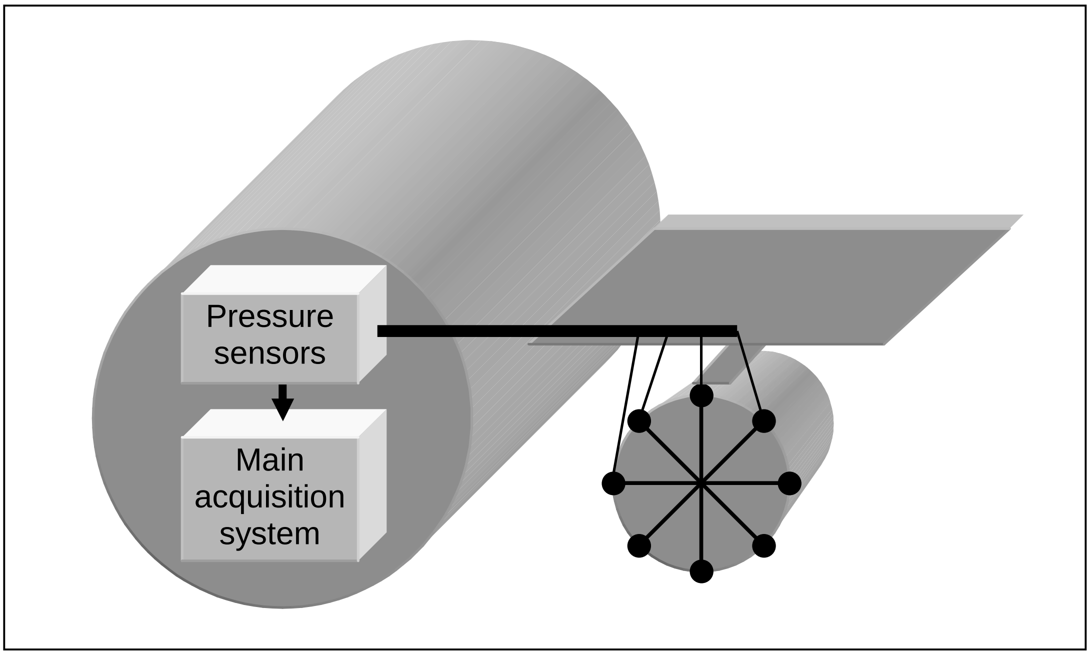

Figure 1: Old thrust measurement installation

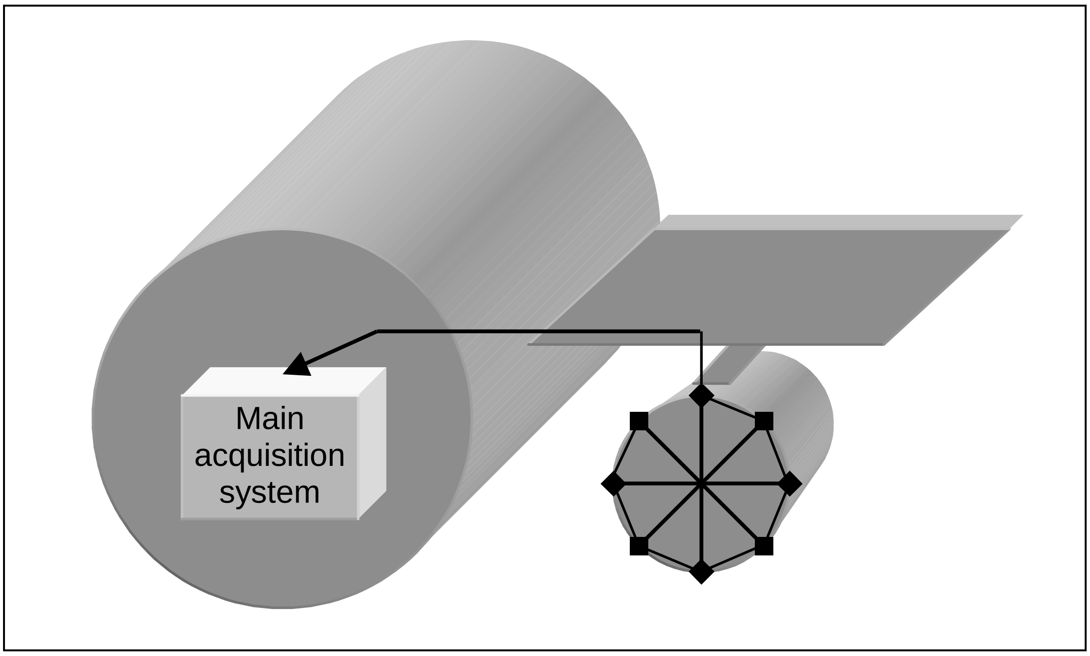

Figure 2: New thrust measurement installation

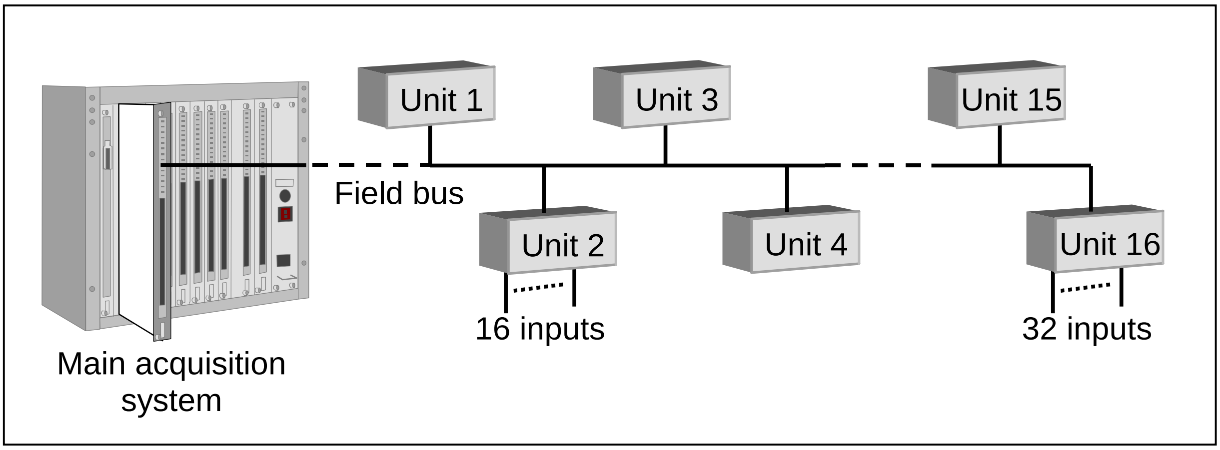

Figure 3: Remote acquisition units' installation

SENSORS AND SENSOR - NETWORKS

Smart transducers and network systems and the proposed IEEE 1451.4 standard

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Abstract

Over the last decade a number of instrument busses and new ways to communicate with transducers have been introduced, but most of these methods have been useful only to small segments of the transducer community. The transducer community recognized the need for a general standard that would make life easier for the transducer community, and began work on the IEEE 1451 series of standards. Furthermore, the availability of off-the-shelf integrated circuits for implementing built-in electronic data sheets in small transducers represents a large step forward. This paper describes the latest development within the IEEE 1451.4 standardization effort and discusses the opportunities and challenges of building systems with Plug and Play transducers, downloading calibration data and exploiting the extended functionality.

Introduction

The ever-increasing capabilities of electronics and computers and the widespread availability of networks can be exploited to make possible the use of large numbers of transducers to measure, characterize and help model many structures. This creates an increasing demand for “bookkeeping” of transducer data with the associated error probabilities. Therefore the drive to get transducers with built-in identification, data (e.g. calibration factors) and even extended functionality has increased sharply over the last few years. The IEEE transducer community, in a concerted effort with NIST, started the work on the 1451.4 standard to fulfil the demands and needs of the changing industry. The main objectives are to:

1. Enable plug and play at the transducer level by providing a common IEEE 1451.4 Transducer communication interface compatible with legacy transducers.

2. Enable and simplify the creation of smart transducers.

3. Facilitate the support of multiple networks.

4. Make a bridge between the legacy transducers and the networked transducers

5. Enable implementation of smart transducers with minimal use of memory

The existing fragmented sensor market is seeking ways to build low-cost smart sensors. Many implementations of mixed-mode (i.e. able to work both in analogue signal transmission mode and in digital communication mode but not simultaneously) smart sensors have been developed, but market acceptance has been slow because of the lack of a standard. A universally-accepted mixed-mode transducer interface standard would not only allow for the development of compliant smart sensors and actuators, it could also lead to lower development costs. Therefore, the objective of this project was to develop a *Mixed-Mode Transducer Interface Standard* that could enable the choice of transducers independent from the choice of networks. This relieves the burden from the manufacturer of supporting a cross product of sensors for multiple networks, and helps to preserve the user's investmentif if it becomes necessary to migrate to a different network standard.

There was previously no defined common digital communication interface standard between mixed-mode transducers and Network Capable Application Processors (NCAPs). Each transducer manufacturer defined its own interface. Consequently transducer manufacturers could not support all of the control networks for which their products might be suitable. It was concluded at a transducer workshops held in 1997 that a common *Mixed-Mode Smart Transducer Interface Standard* be proposed. This common interface allows the transducer manufacturers to more easily support multiple control networks. This standard simplifies the development of networked transducers by defining hardware and software blocks that do not depend on specific control networks. The standard describes the following:

1. An IEEE 1451.4 Transducer containing a Mixed-Mode Interface (MMI) and a Transducer Electronic Data Sheet (TEDS).

2. The MMI which is a two-wire, master-slave, multi-drop, serial connection. MMI requires a single master device to initiate each transaction, with each slave or node according to a defined transaction timing sequence. The MMI uses two wires for power supply, time-shared analog signal and digital data connection.

3. The TEDS, which is fixed and dynamic data, contained in one or more memory nodes on the MMI. (NOTE - Digital interface is not part of TEDS templates).

4. A Template, which is a software object, describes the data structure of TEDS. It is implemented in the Description Language and resides in the Transducer block (T-block).

5. The Description Language which is a scripted and tagged language providing a standard method to describe the functionality of IEEE1451.4 Transducer.

6. A Transducer Block which is a software object describing the IEEE 1451.4 Transducer. It resides in the NCAP, which is the master device (e.g. an instrument or data acquisition system).

The working group has defined the following to facilitate the creation of plug and play systems containing transducers:

1. TEDS data structure. A Description Language to describe the functionality of the transducer.

2. A set of TEDS-templates for various transducers.

3. The Mixed-Mode Interface to access the TEDS.

4. A T-block to access, decode and encode TEDS using the Description Language.

The TEDS residing in the IEEE 1451.4 Transducer, provides self-describing capability. The TEDS contains fields that describe the type, operation, and attributes of one or more transducer elements (sensors or actuators). By requiring that the TEDS be physically associated with the IEEE 1451.4 Transducer, the resulting hardware partition encapsulates the measurement aspects in an IEEE 1451.4 Transducer, while the application-related aspects can reside in the NCAP or alternatively be stored in the TEDS

The IEEE 1451.4 Transducer is a sensor or actuator with typically one addressable device, which here will be referred to as a node, containing TEDS. The digital communication can be used to read the TEDS information and to configure an IEEE 1451.4 Transducer.

The T-block is responsible for communication with the IEEE 1451.4 Transducer. To perform this task external information is required. This information is contained in the Description Language and associated files. The Description Language can be used as an application for communication and configuration. The Description Language does not reside in the IEEE 1451.4 Transducer.

An IEEE 1451.4 protocol is used to separate the time critical part of the communication of the IEEE 1451.4 interface from the T-block. The T-block object located in the NCAP handles the interpretation of the TEDS data for the end user. Further processing of the data may take place both in the NCAP and in other processors in larger systems. The NCAP includes an IEEE 1451.1 object model with an IEEE 1451.4 T-block.

The IEEE 1451.4 Mixed-Mode Interface can be used for control networks and data acquisition in a variety of applications such as portable instruments and data acquisition plug-in cards for PCs.

The standard does not constrain competitive differentiation in areas of quality, feature set and cost, and at the same time offers the opportunity to design to a common interface, which can be used in a wide variety of applications.

Some details of the proposed standard IEEE P1451.4

<u>Foundation</u>

An IEEE 1451.4 Transducer contains a Transducer Electronic Data Sheet (TEDS) and a Mixed-Mode Interface (MMI). The context for the mixed-mode transducer and interface is shown in figure 1. An IEEE 1451.4 Transducer may be used to sense or control multiple physical phenomena. Each phenomenon sensed or controlled shall be associated with a node.

If more than one node is included in an IEEE 1451.4 Transducer, one of the nodes must have a memory block that holds the Node-List. A Node-List contains the IDs of the other nodes.

An IEEE 1451.4 Transducer has no more than one Node-List. If there is only one node inside an IEEE 1451.4 Transducer, there is no Node-List

Each IEEE 1451.4 Transducer is connected to an IEEE 1451.4 Mixed-Mode Interface.

Each Mixed-Mode Interface can have several IEEE 1451.4 Transducers attached provided they are capable of acting in a passive mode.

To communicate with the nodes inside an IEEE 1451.4 Transducer with shared wires, the IEEE 1451.4 Transducer is switched into “IEEE 1451.4 mode". This can be achieved by reversing the polarity. While in “IEEE 1451.4 mode”, the shared lines are used for the digital communication described in this standard and other uses are inhibited. If separate wires are used for the IEEE 1451.4 communication, any other communication can take place simultaneously.

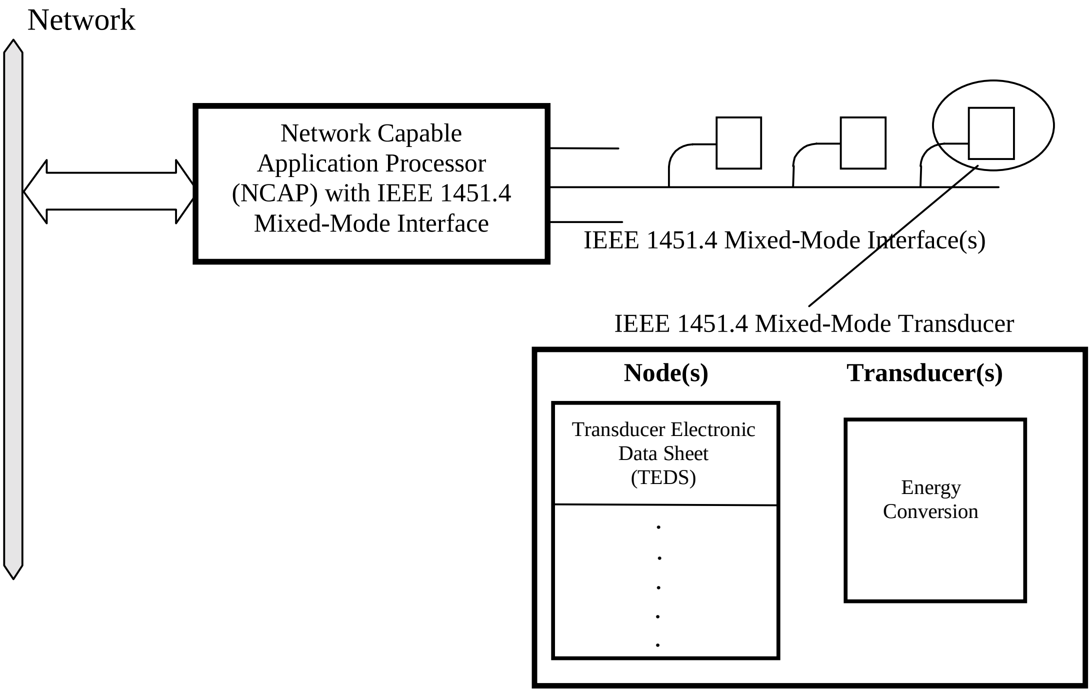

Figure 1. Context for the Mixed-Mode Transducer and Interface

<u>Multiplexing</u>

Multiple IEEE 1451.4 Transducers with switch nodes can be connected in a multi-drop configuration with maximum one of these Transducers in “active” mode and the rest in “passive” mode. The switch nodes can be used to change the functional mode of each IEEE 1451.4 Transducer.

Node-Lists are used to specify which nodes correspond to which IEEE 1451.4 Transducer(s). This is needed if two (or more) nodes are connected to the same IEEE 1451.4 Mixed-Mode Interface. A Node-List is not included if an IEEE 1451.4 Transducer contains only one node. If more nodes are present and no Node-List is found, then each node will be an IEEE 1451.4 Transducer. This permits e.g. a single thermometer node to be an IEEE 1451.4 Transducer. The TEDS must contain information about the type of transducer which is connected, e.g. if it is a sensor or actuator and which physical unit is being measured. If there are more nodes with memory, the memory shall be considered as contiguous, ranked by this list of nodes.

Communication to an IEEE 1451.4 Transducer

Configuration of the IEEE 1451.4 Transducer can be performed by the use of dedicated nodes. The description language contains the information needed to change the configuration.

For example, configuration changes allow:

- Self-test
- Reset of transducer
- Multiplexing between transducers in an IEEE 1451.4 Transducer
- Gain shift in an IEEE P 1451.4 Transducer
- Change of filter settings in an IEEE P 1451.4 Transducer

Communication to several IEEE 1451.4 Transducers on one IEEE 1451.4 interface

Enabling or disabling of the analogue function of the different IEEE 1451.4 Transducers permits several IEEE 1451.4 Transducers to be connected to the same IEEE 1451.4 interface. The Node-List groups the nodes for each IEEE 1451.4 Transducer. This makes multiplexing possible.

The description language

The Description Language described in the standard contains the necessary rules for creating unambiguous Description Files. An interpreter can then handle these and the binary output stored in the transducer. Afterwards the binary content of the transducer can be read and interpreted into the original specifications. A TEDS editor has been created to facilitate these actions. This is however not a part of the standard.

The family of IEEE 1451 standards

The proposed standard defines an interface for mixed-mode transducers (i.e. analog or other transducers with digital output for control and self-describing purposes) as part of the P1451 family of standards (see Figure 3).

It establishes a standard that allows mixed-mode transducers to communicate digital information with an IEEE P1451 compliant object. Both sensors and actuators are supported and the existence of the P1451.4 interface is invisible from the network's viewpoint.

It is the intent that all of the standards in the IEEE 1451 family can be used either as stand-alone or with each other. For example, a “black box” transducer with a P1451.1 object model combined with a P1451.4 compliant transducer is within the definition of the P1451 family specification. The IEEE P1451.4 interface is needed both to allow the use of existing analog transducer wiring, and also for those demanding applications where it is not practical to physically include the network interface (NCAP) with the transducer. Examples of the latter include very small transducers and very harsh operating environments.Each P1451.4-compliant mixed-mode transducer will consist of at least one transducer, the Transducer Electronic Data Sheet (TEDS) and interface logic required to control and transfer data across various existing analog interfaces. The transducer TEDS are minimized and defined such that it contains enough information for the higher level P1451 object.

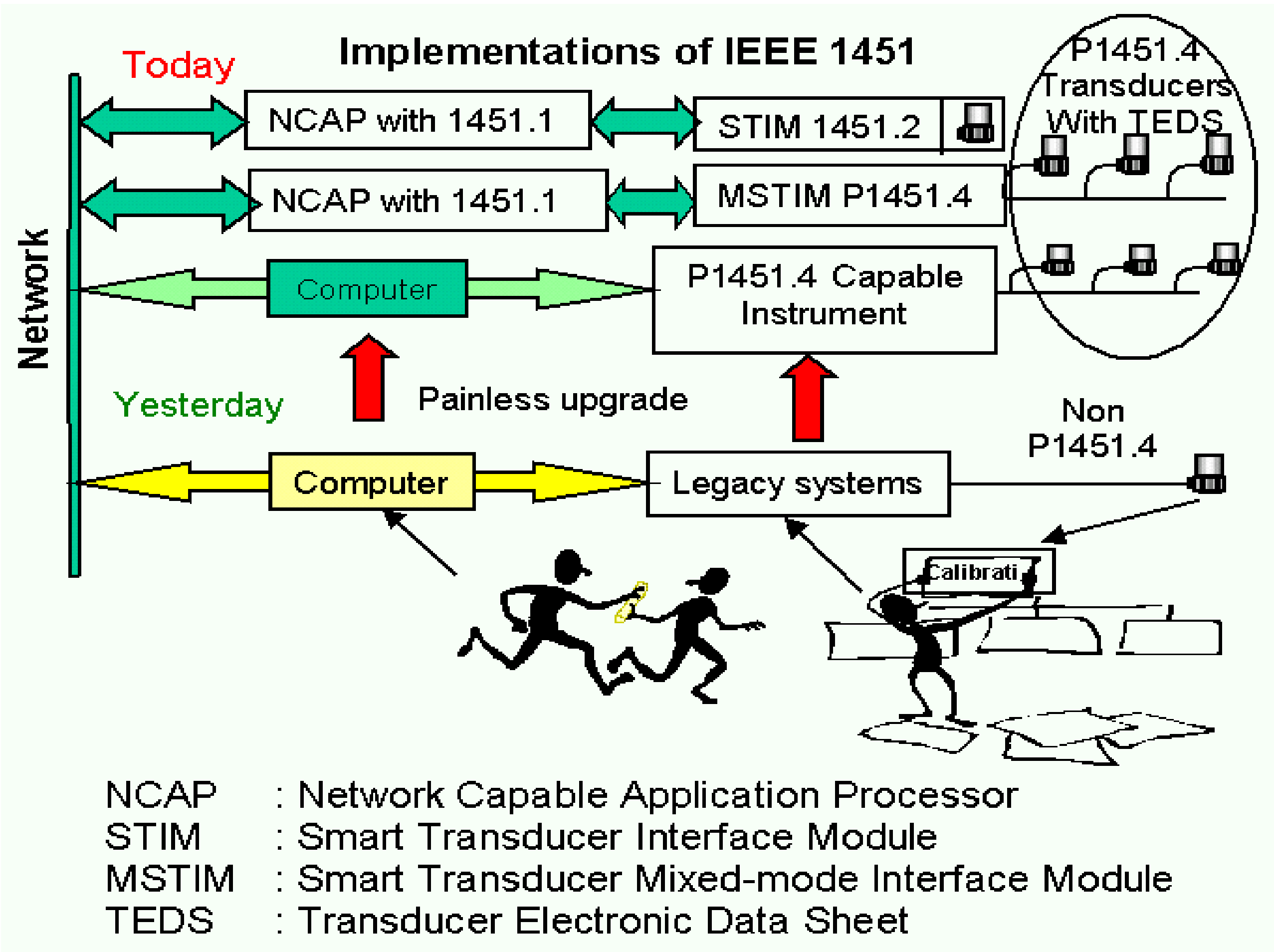

Fig. 2. The P1451 family of standards

The IEEE P1451.4 proposed standard allow analog transducers to communicate digital information with an IEEE P1451 object. The standard defines the protocol and interface. It also defines the format of the transducer TEDS. The standard will not specify the transducer design, signal conditioning, or the specific use of the TEDS. An independent and openly defined standard reduces the risk for potential users, transducer and system manufacturers, and system integrators. This will accelerate the emergence and acceptance of this technology.

Implementation

The two-wire interface demands are set e.g. by the standard co-axial interface used for accelerometers with built-in constant current line drive (i.e. ICP®, DeltaTron®, Isotron® and several others) amplifiers. Once the requirement for a two-wire interface is fulfilled, the implementation in other transducers, where separate wires are available, poses no problems. By using a reversed polarity technology for switching between the normal analogue mode and the digital communication mode, the chosen principles from the MicroLAN™ interface fulfils all the stated needsThis technique enables switching between the analogue and the digital mode, using only two standard diodes. Reversing the polarity performs the switching. The principle in Fig. 3 also shows the simplicity of the receiving

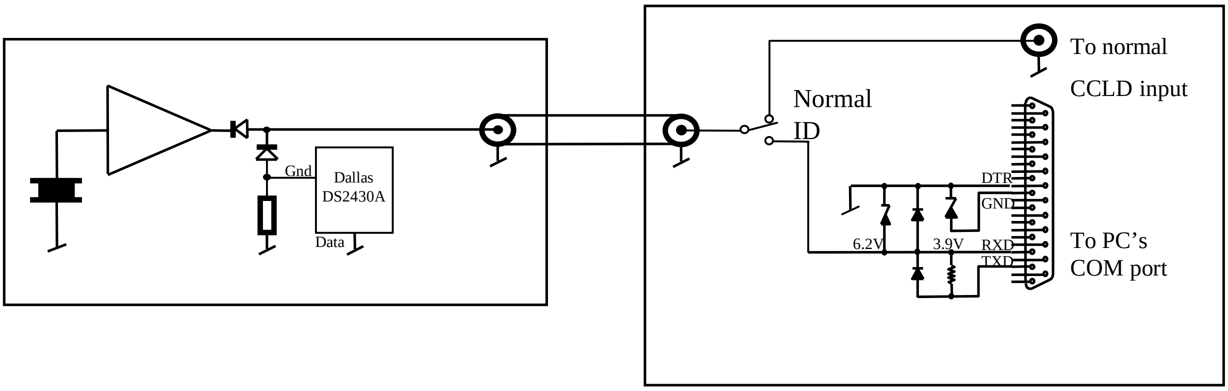

Fig. 3. Principle of implementation of integrated identification with PC support for Constant Current Line Drive (DeltaTron®, Isotron®, ICP® etc.) transducers. Transducer (left) connected via a co-axial cable to interface (right)

device. Primarily an additional supply (here the COM port is used) is needed for supplying the negative voltage for the ID-device. The microcontroller or PC maintains the communication and translation of signals to and from the memory component(s) in the transducer

Benefits of IEEE 1451.4 for the user

In order to describe precisely a given measurement system, all individual components (transducers, preamplifiers, conditioning units, analyzers) including their settings must be known. In multichannel systems in particular, the customer faces a number of problems including long set-up times and validation of the position of the transducers. The implementation of IEEE 1451.4 transducers and systems reduces these problems to a minimum by incorporating essential identification data (such as type and serial number) within the transducer itself in a Transducer Electronic Data Sheet (TEDS) together with calibration data such as sensitivity thus introducing “plug and play” functionality into the system (fig.4).

State of the art products

The standardization and the available memory and communication devices has led to the implementation of a number of products (more than 80 from B&K alone) with functions such as:

<u>Identification</u>
This feature is the main driver for communicating with a transducer. By using the memory very efficiently, practically all relevant information is stored inside the transducer, so the needed data are always at hand. This is practically a duplication of the calibration chart.

<u>Gain adjustment</u>
Transducers often consist of two items. A device to transform the physical properties into an electrical signal(e.g. piezoelectric discs and a seismic mass in an accelerometer) and a conditioning circuit. This transforms the output impedance and the signal level to make the signal of practical use outside the transducer. The dynamic range of this electrical circuit is frequently much smaller than the dynamic range of the physical transducer (for an accelerometer 160 dB are reduced to about 120 dB). This makes a compromise necessary when constructing the transducer. With the new technique, gain switching

inside the transducer has been introduced to obtain the best working condition for the measurement setup.

Multidrop or distributed multiplexing

A charge to DeltaTron® adaptor has been developed with identification in accordance to IEEE P1451.4. It contains TEDS and extended functionality such as dual gain and multidrop facilities. The content of the TEDS is shown in the figure. Multidrop means that several charge to DeltaTron adaptors can be used on the same MicroLAN™ network as a serial, distributed multiplexer. The main application is to allow charge accelerometers (which are analogue transducers) to communicate digital information with an IEEE1451 capable instrument. There are three modes of operation; two gain settings of 1,0 mV/pC and 10,0 mV/pC and an "analogue off" mode which is used to implement the multiplexer function (fig.5).

Analyzer TEDS Support

The B&K PULSE Analyzer is the first analyzer platform to fully support standardized TEDS not only from the initial setup but right through to the analysis result. The system automatically detects the connected transducers, and sets their sensitivities. This ensures the correct conditions are always used when making measurements, thus increasing the confidence in the final data.

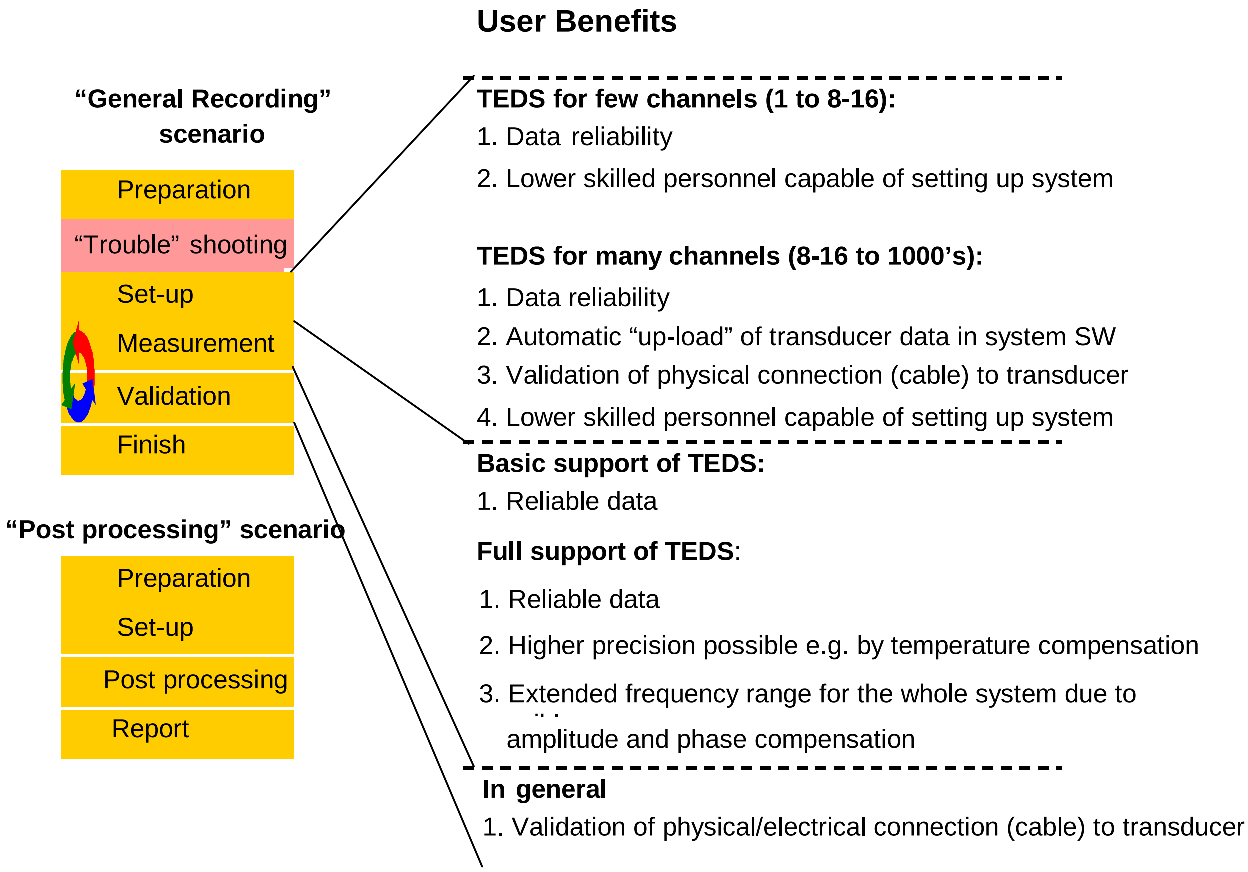

Fig. 4. TEDS impact on the measurement process

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Automated set-up of preamplifiers

The B&K NEXUS range of accelerometer and microphone preamplifiers communicates with the transducers and the received information is used to set up the preamplifier correctly. The data can also be sent on to a controlling computer.

The Endevco Optimal Architecture Sensor Interface System OASIS-2000 is a modular system consisting of a 16 Rack Enclosure that can be fitted with up to 128 channels per rack to provide power, computer control and signal conditioning. One of the input modules is an eight channel card Model 482 that supports IEEE 1451.4 and features automatic transducer identification and user-defined output normalization.

Conclusion

The measurement community is best served with transducers with integrated identification and data. The work in the IEEE group and in the involved companies has in a short time brought Plug and Play to the measurement community and thereby helped the transition to larger systems with more transducers, and simultaneously introduced a new level of quality into the measurements.

The authors would like to take the opportunity to encourage both users and transducer manufacturers alike to participate in the discussions of the standard which is now in the last stage of finalization (for the P1451.4) to ensure that the coming IEEE standard is designed to fit their needs.

References

(1) "A mixed-mode smart transducer interface for sensors and actuators", S.Chen and K.Lee, Sound & Vibration, April 1998

(2) Impact of the proposed IEEE 1451.4 Standard for transducers on future measurement systems. S.Chen, J. Bække, T. Licht, SensorExpo Conference, Anaheim, CA, USA, 2000.

(3) Practical applications of integrated transducer communication, B. Ginn, J. Bække, H. Larsen, B. Kriegbaum, Internoise 1998

(4) Bringing plug and play into multichannel systems using integrated identification, J. Bække, H. Larsen, B. Kriegbaum, B. Ginn, WATTec98, Knoxville, TN, USA.

NOTE:

ICP® is a registered trademark of PCB Piezotronics, Inc.

DeltaTron® is a registered trademark of Brüel & Kjær Sound and Vibration

IsoTron® is a registered trademark of Endevco Corporation

MicroLAN™ is a trademark of Dallas Semiconductor

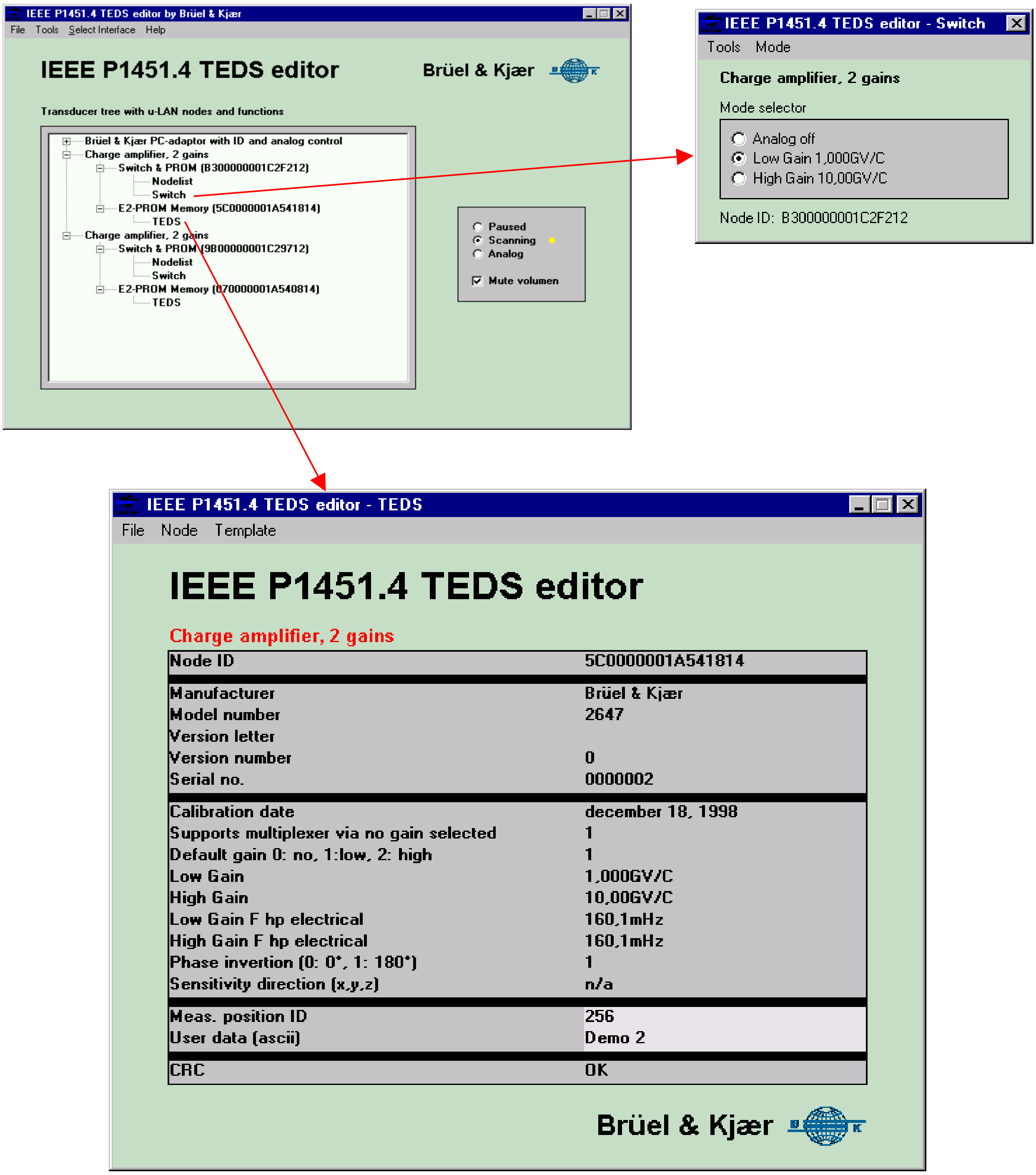

Fig. 6. Example of IEEE P1451.4 TEDS editor for a Charge to DeltaTron converter showing the three main areas of the memory (the "fixed" identification field, the "variable" transducer specific template and the "free" comments field). Top left shows the tree structure of the transducer configuration. Top right: the mode selector.

Tail Rotor Flap Angle Measurements on a BO 105 Windtunnel Model

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Introduction

Tail rotor measurements were required for the project HELIFLOW (Helicopter Flow Interactions), which is a cooperation of DLR (German Aerospace Center), DNW (German-Netherland Windtunnel) and ECD (Eurocopter Germany) supported by the European Union. Within this project tests with a helicopter model of a BO 105 (scale 1:2.5) were conducted in the DNW.
The mission of HELIFLOW was to acquire aerodynamic and flightmechanic data in order to validate mathematical simulation models.

Fig 1: Helicopter model in the windtunnel (DNW)

One of the values to be measured was the flap angle of the tail rotor. It was the first time this angle had to be measured. Because of the high rotation speed of 5000rpm of the tailrotor, a contactless measurement technique was required. Additionally, the dimensions of the sensor needed to be very small since the mounting space of the sensor was limited due to the mechanical construction of the tail rotor.

For this purpose, a Hall sensor from „Micronas Intermetall“ was selected. Besides the size (4x4x1,5mm) this sensor offers the possibility to program its characteristics according to specific measurment requirements.
This paper presents the usage of a Hall sensor for the acquisition of the flap angle from a rotating device.

Flap angle of the tail rotor

The tail rotor of the BO 105 consists of two blades. The blades being mounted on a hinge are variable in pitch (*Fig. 2*). The flap angle is the result of different airstream velocities of the forward (flight direction) and backward (against flight direction) running blade of the rotor at a flight velocity greater zero. This aerodynamic condition results in different lift moments, which again leads to a sine oscillation of the blades. This effect increases at higher flight velocities.

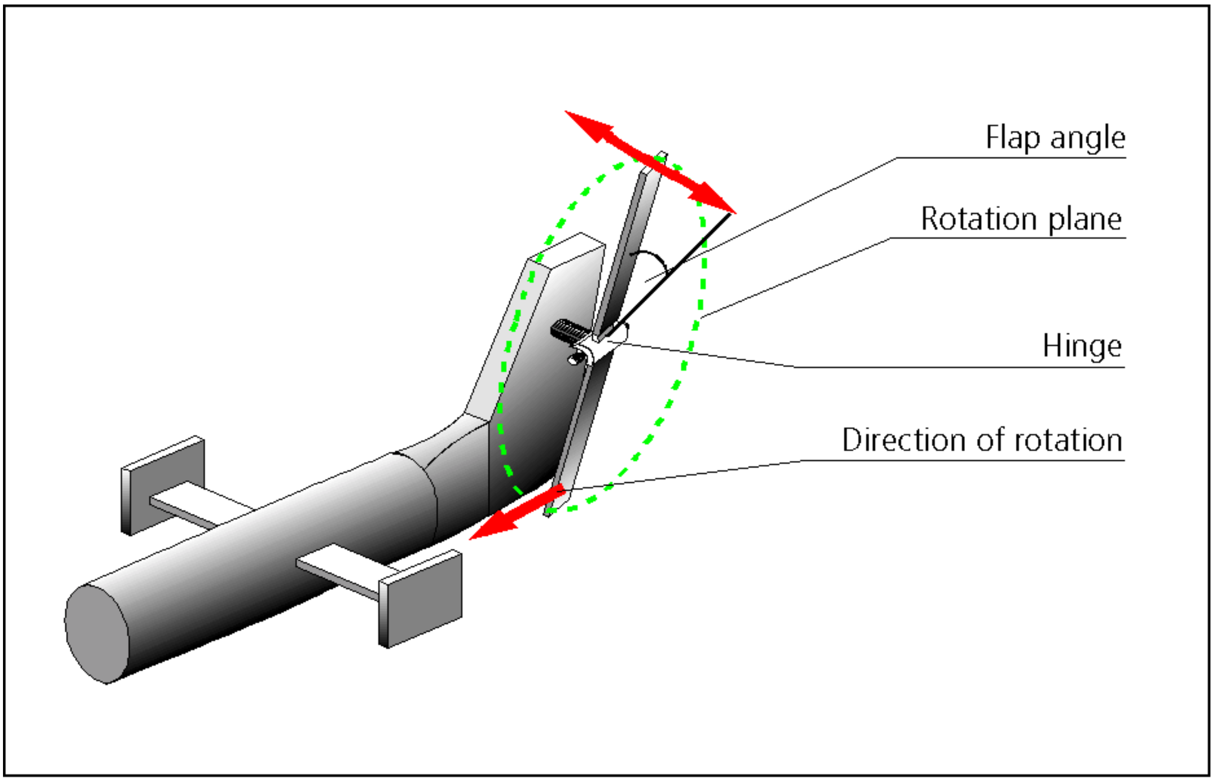

Fig 2: Flap angle on a tail rotor

Sensor

For the measurement of the flap angle the HAL800 sensor from "Micronas Intermetall" was selected. Its mechanism bases on the principles of the HALL effect. The sensor measures a magnetic field and outputs a proportional electrical voltage.

The main advantage of the sensor is its programability. Furthermore an A/D-converter, a D/A-converter, different filters and an EEPROM are integrated. This enables to set and store specific parameters, e.g. the specification of the magnetic material, voltage and filter ranges.

In order to be able to program the sensor an adapterboard with the appropriate software is connected between the sensor and the serial interface of a PC. The adapter board requires a power supply of 15 VDC. This adapterboard communicates with the sensor by a modulation of the supply voltage. The normal operational voltage of the sensor is 5 VDC, which disabled a modification of the parameters.

Pretests in the laboratory

In order to become familiar with the sensor, distance, position and angle measurements were conducted in the laboratory. This was done with a fixed installation of the sensor and by moving several magnetic materials with different dimensions in different directions relative to the sensor (*Fig. 3, 4*). By using the adapterboard during the measurements it was possible to save the A/D-converted output values of the sensor.

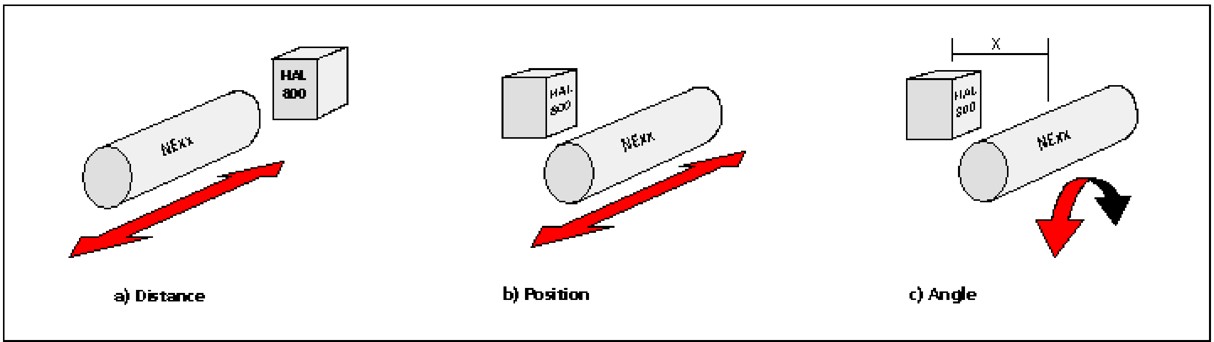

Fig 3: Distance-, position- und angle measurement

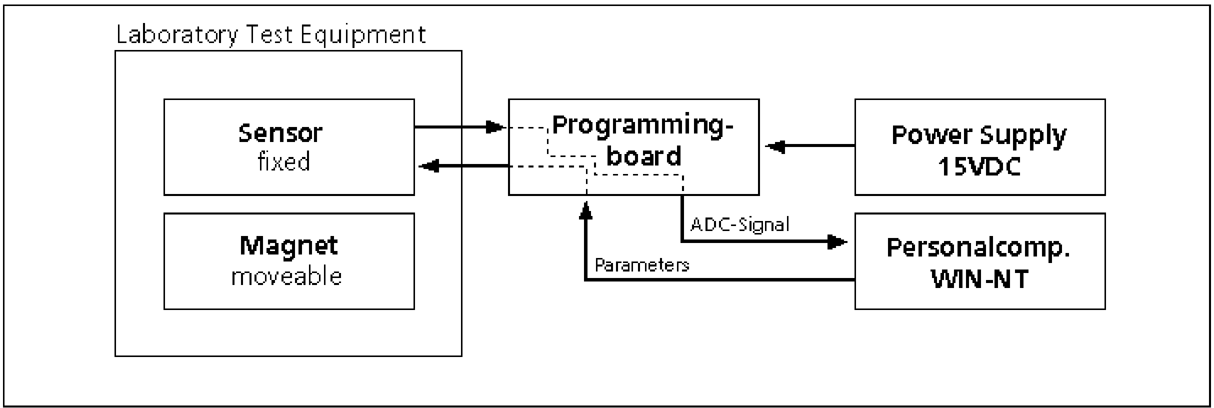

Fig 4: Laboratory test equipment

The measurement of the tail rotor angle needs to be performed within a range of ±8°. *Fig. 5* shows the test results for measurements of the angle using the cylindric magnet (length 10mm, diameter 2mm) which was actually selected for the final measurements in the DNW. Although the measurement shows a non linear behaviour, this doesn't matter since the final acquisition is handled by a digital system which can take care of hysteresis effects (linear changes of a magnetic field normally lead to linear changes of the output voltage of the sensor).

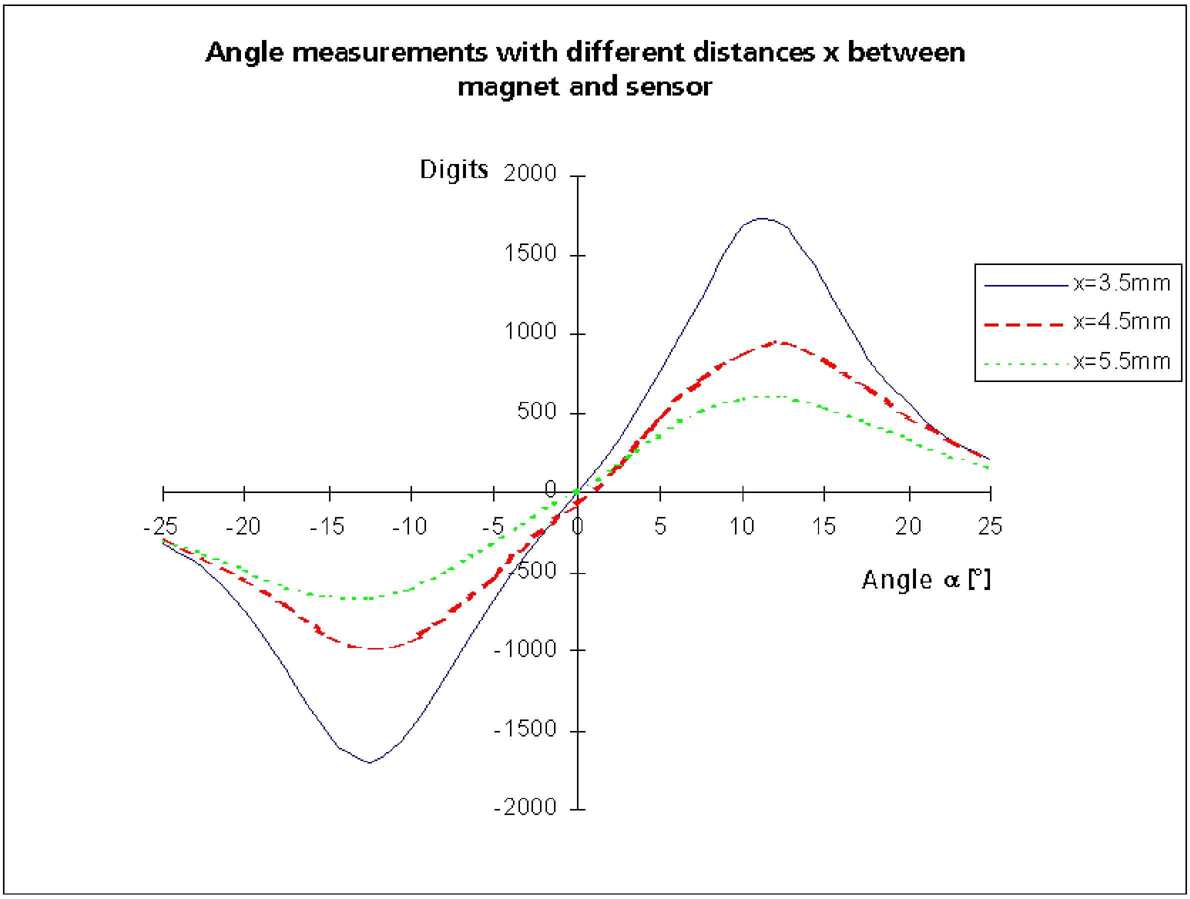

Fig 5: Angle measurements with different distances between sensor and magnet

Integration of the sensor at the model

Due to the mechanical construction of the tail rotor and the small size of the measurement equipment, the sensor and the magnet were installed with a two component glue. The sensor was installed on the fixed side of the hinge, the magnet was installed on its moveable side (*Fig. 6*).

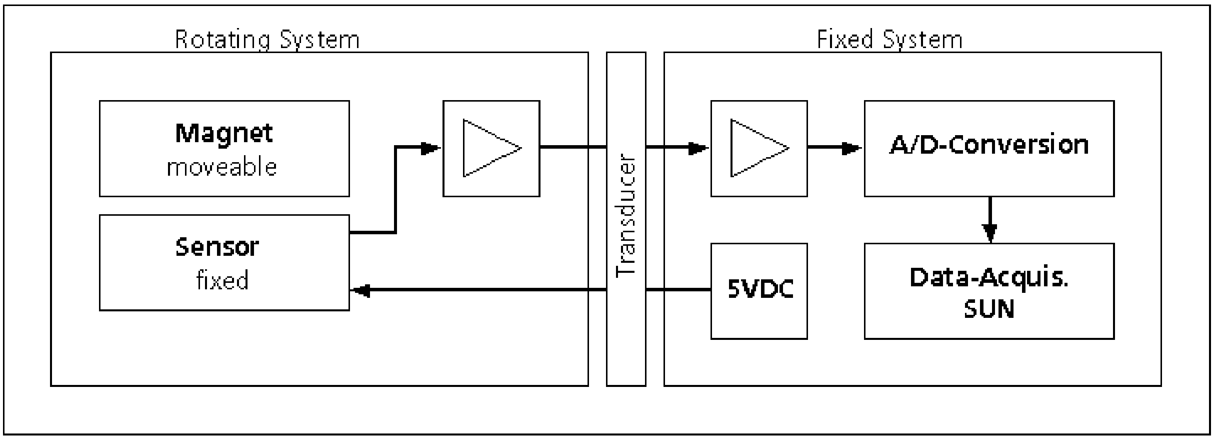

Fig 6: Symbolic view of the tail rotor model system

After the implementation of the flap angle sensor the system was calibrated. As a calibration curve the following 3rd-order polynomial was chosen (*Fig. 7*):

$$\beta(U) = m_3 \cdot U^3 + m_2 \cdot U^2 + m_1 \cdot U + m_0$$

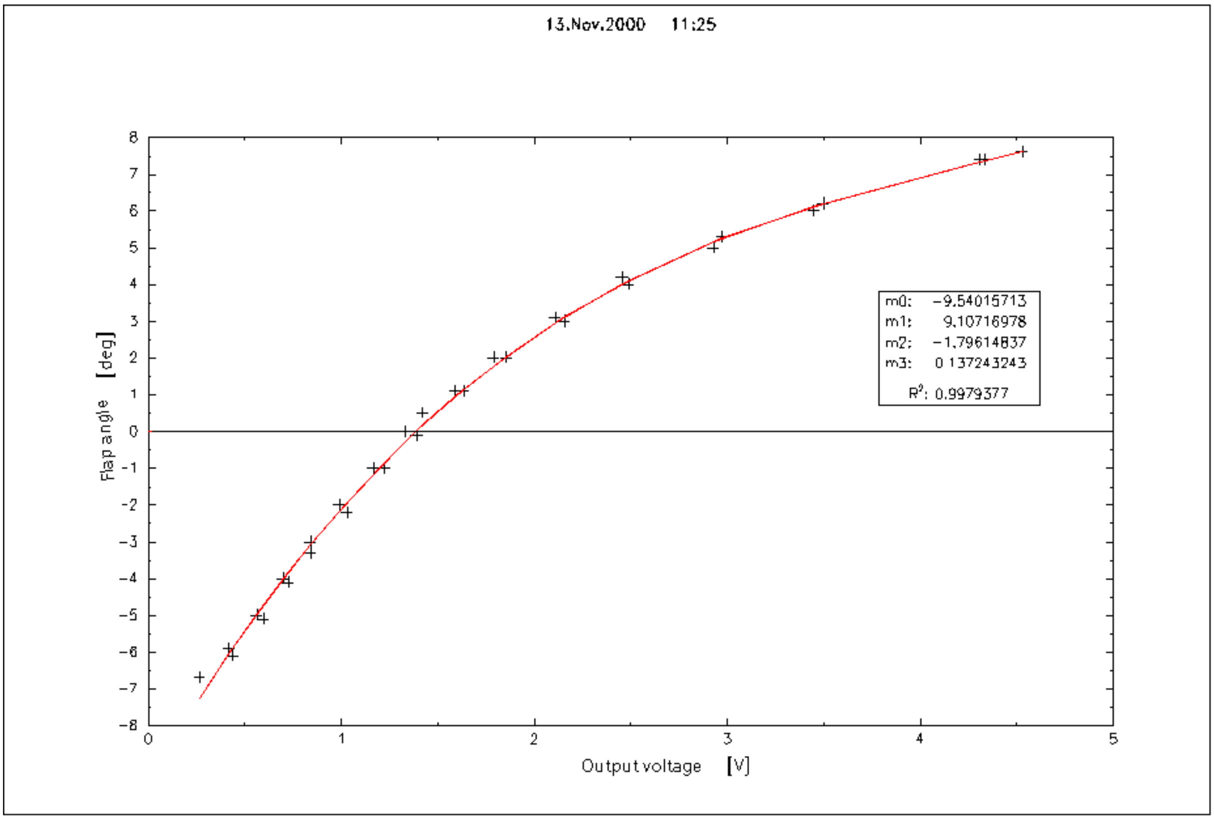

Fig. 7: Calibration of flap angle

The reason for the non-symmetrical curve is the non-symmetrical movement of the magnet out of its center position.

Results

As an example two measurements are shown. The selected flight conditions are Hover (*Fig. 8*) and Levelflight with a flight velocity of v=18m/s at a heading of 18° (*Fig. 9*). The latter means that the x-axes of the helicopter is shifted 18°, a heading of 90° would mean the flight direction is sidewards. Each figure shows the flap angle as a function of the rotor position. An angle of 0° means that the reference blade shows downwards. 32 tail rotor rotations were acquired with 128 samples/rotation.

In Hover (*Fig. 8*), only the airflow of the main rotor and the construction of the fin has an influence on the flap angle. Thus, on both blades the aerodynamic conditions are almost the same, resulting in small flap angles.

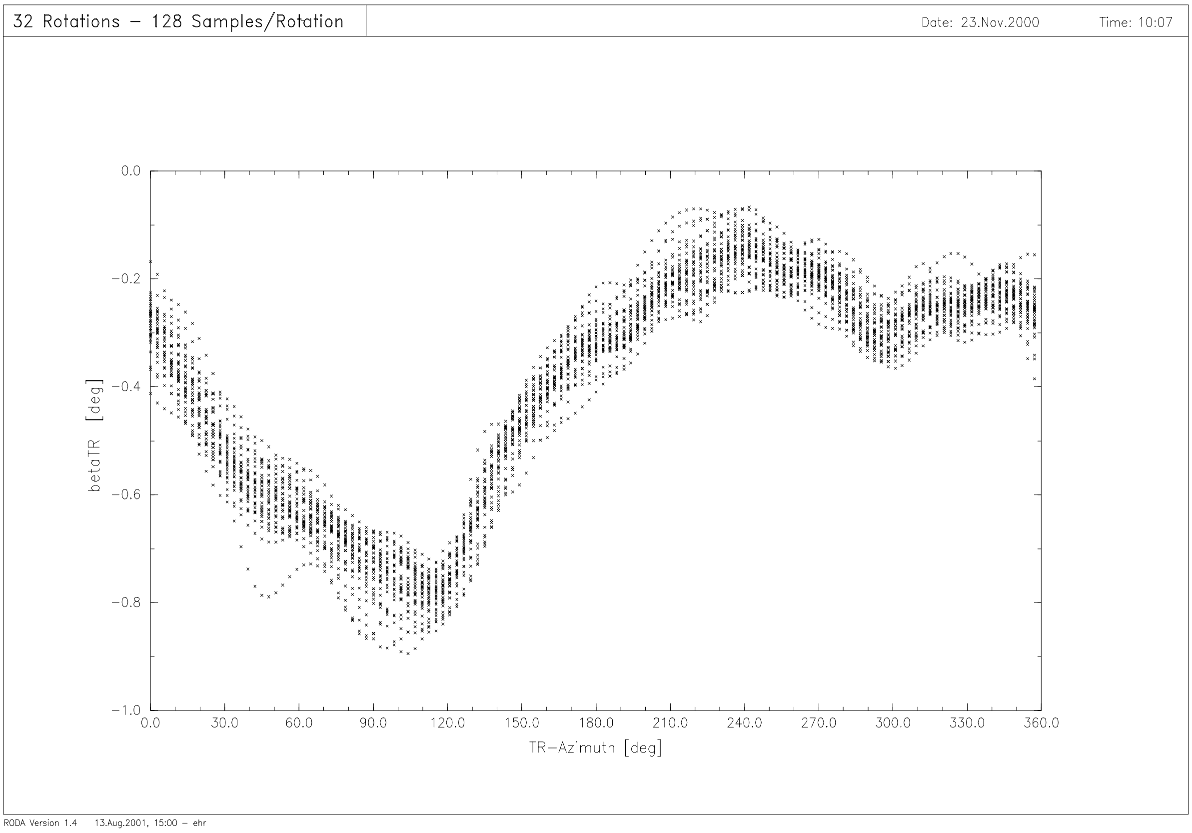

Fig 8: Flap angle at hover

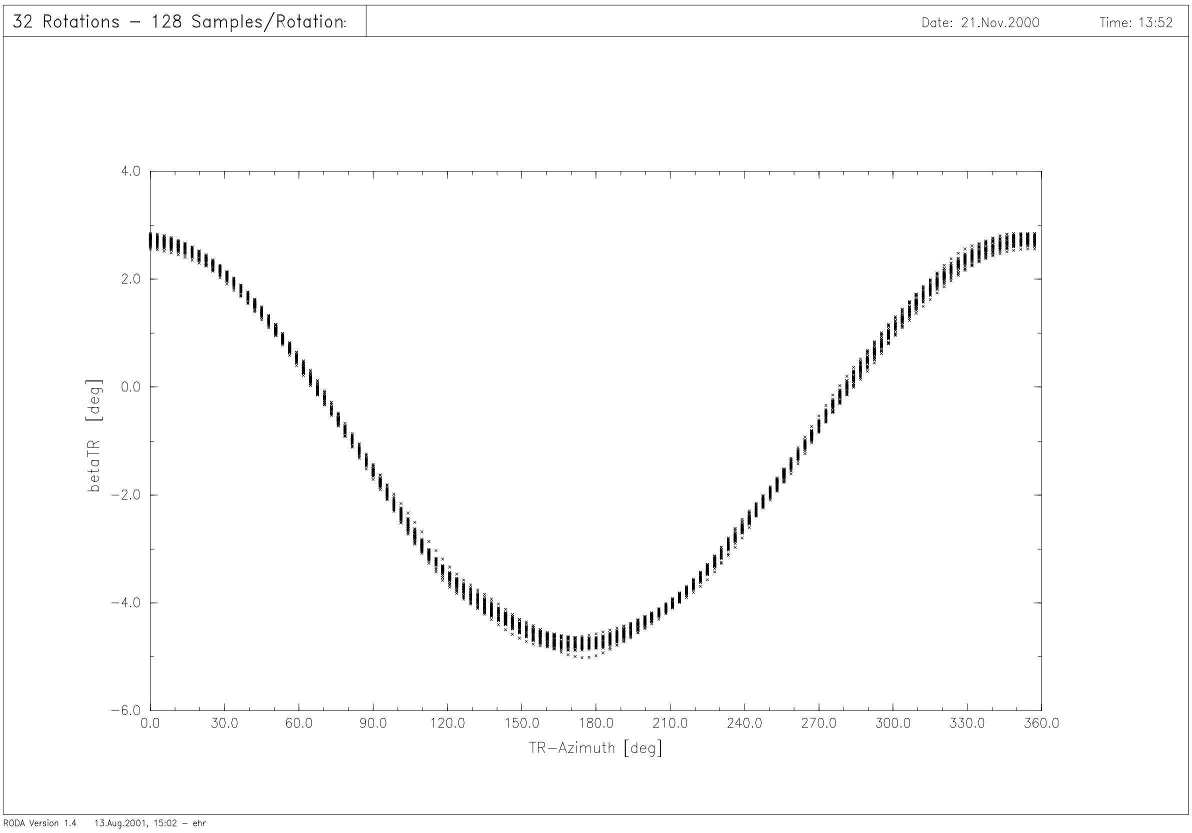

Fig 9: Level flight with v=18m/s

In Level flight (*Fig. 9*) the flap angle is clearly a function of the cosine of the rotor angle. Due to vortexes caused by the main rotor and the flight velocity no constant aerodynamic conditions exist at the tail rotor blades and thus the flap angle varies a little bit with every revolution.

For this Level flight a Fourier Transformation of the flap angle measurement results in a peak at 92Hz which is identical to a rotation speed of the tail rotor of 5520 rpm (*Fig. 10*). This value is equal to the separately measured rotation speed.

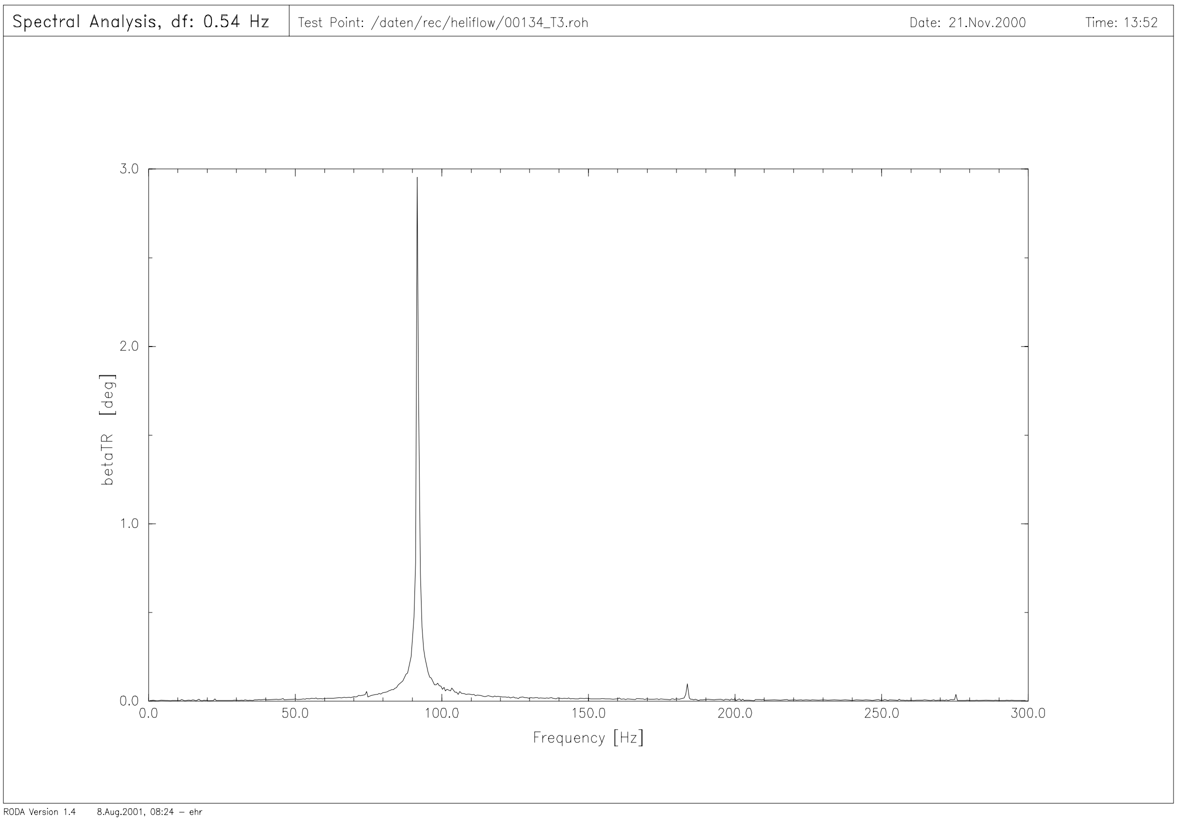

Fig 10: Fourier Transformation of the flap angle measurement from Fig.9

Conclusions

The succesful usage of a Hall sensor for the measurement of the flap angle of a rotor blade was shown. In spite of extremely high vibrations and the high rotation speed of the rotor, the system showed a very robust mechanical and electrical performance.

Smart sensors: Architecture and technological choices for future test installations

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ABSTRACT

From experience acquired with smart sensors and sensors' field buses use during AIRBUS A340–600 and A318 aircraft tests, this paper presents main concepts adopted for architecture and technological choices for future test installations.

1. INTRODUCTION

What are so-called "smart sensors" in the measurement field are sensors which usually deliver the sensed physical phenomenon on a digital output and include in the same box as the sensitive part some computation (i.e. for linearisation, error correction or environmental compensation) and offer built-in test capability.

All field buses that can connect sensors to an acquisition system via a digital link can be called "sensors' field buses".

Smart sensors and sensors' field buses have been installed and used by AIRBUS France Test Integration Centre for the first time during A340–600 aircraft flight tests (see [1]).

Taking into consideration results acquired during this experience and technological evolutions in smart sensors and field buses since these tests started, new solutions have been adopted for future test installations.

They concern two sensor categories:

- pressure sensors,
- accelerometers.

Remote acquisition units' concept developed for A340–600 will be kept and reused on future test installations.

2. Pressure sensors

2.1 A340–600 experience

On AIRBUS A340–600 and A318 flight test installation, smart pressure sensors have been used for engine thrust measurements.

Those measurements represented 15% of the amount of pressure sensors' measurements, those latter representing 25% of the total amount of measurements installed in the aircraft.

Smart pressure sensors were chosen since their features respond to our main requirements:

- accuracy levels
- non linearity and temperature compensation
- operational temperature

and offer a wide array of ranges.

Up to 32 sensors can be connected together on a single bus based on RS485 electrical levels, 9600bps data flow rate and an owner protocol.

These sensors deliver measurements at low sample rate (1 point/second).

Since they gave satisfaction, they will be reused on future test installations for the same measurement types.

2.2 Sensors improvements

In order to answer to higher sample rate (up to 32 points/second) and also bandwidth (up to 500Hz) requirements, pressure sensors with digital and analog outputs have been chosen.

- Digital output is the same type as that presented before, but :
  - protocol has been improved in order to increase transmission efficiency ;
  - data flow rate has been also increased (115kbps) ;
  - number of sensors that can be connected on the bus is limited to 16.
- Analog output is dedicated for high bandwidth measurements that can not be sampled and sent through digital output.

3. Accelerometers

3.1 State of the art

Vibration smart sensors are not yet ready, especially for flight test applications, since required sensor features are strong:

- high bandwidth output,
- light weight for no measurement disturbance,

- use in harsh environment (temperature especially),

and in those conditions either electronic does not yet exist or field bus output is not suitable.

Some solutions are suggested by manufacturers i.e. put sensors' intelligence in one box that is set apart from the transducer itself.

3.2 IEEE P1451.4 standard

For reasons explained before and others, accelerometers with classical analog output will be always used but will be chosen with IEEE P1451.4 functionalities included.

3.2.1 What's that standard?

IEEE P1451.4 is a standard currently under construction that will allow sensors with analog output to get inside and be able to deliver some information.

Those information will be memorised in a Transducer Electronic Data Sheet (TEDS).

Amongst them, we may find:

- general information, i.e. :
  - manufacturer references
  - serial number
  - calibration date
- sensor technical features, i.e. :
  - sensitivity
  - temperature drift coefficient
  - frequency response function type
  - …

The standard main principle is to allow TEDS interrogation without need of specific wiring, which means both analog and digital signals share the same pair.

Sensor switches from analog to digital mode by reversing the line polarity.

3.2.2 Why use this standard?

This standard is interesting for two reasons. It allows to:

- get information on "classical" sensors with analog output without additional wiring ;
- facilitate sensors' management (serial number follow-up, periodical calibration,…). 15% of the total amount of measurements installed in the aircraft are accelerometers.

This will lead also to simplify our accelerometers' measurement chains.

By reading TEDS, the acquisition system will be able to get the real accelerometer sensitivity and hence make the required calculations to correct it.

Therefore, there will be no more need of conditioners between the accelerometer and the acquisition system. Those conditioners required adjustments and association with the accelerometer whose it corrects the sensitivity.

Nevertheless, our future acquisition systems ought to get electronic circuits required to interrogate TEDS and correct sensitivity.

4. Remote acquisition units

Since little remote acquisition units used for AIRBUS A340–600 aircraft flight tests (see [1]) have showed that such systems answer to wiring reduction and remote acquisitions close to sensor requirements, they will be reused on future test installations.

Those devices were also required because the amount of sensors like platinum or thermocouple type K temperature probes, strain gauges to acquire is very important (respectively 25% of the total amount of measurements installed in the aircraft for each) and in contrast with accelerometers (see §3.1) these sensors could not never be smart since the sensing element is the sensor itself and hence could not never include electronic.

Remote acquisition consists in:

- electronic remote units able to condition and digitise different sensors signals (at least 16 inputs),
- wired together on a field bus (up to 16 units connected, RS485 compatible link with owner protocol) linked to the main acquisition system set in cabin (up to 100m far).

Some improvements may be done i.e. for compatibility with the next generation of main acquisition system, but final choice has not been done yet.

5. IEEE P1451.3 standard

IEEE P1451.3 standard will define a digital interface for connecting multiple sensors and actuators. This will be a sort of improved sensors' field bus with additional defined features such TEDS, time synchronisation protocol,…

The aim is to federate all transducer manufacturers round a universal interface standard in order to allow for the development of smart sensors or actuators and lead to lower development costs.

For our applications, IEEE P1451.3 standard will be surely the solution that will come closest to our expectations from a functional point of view.

Since this standard has not been approved yet and hence there are any developed systems using it yet, currently we decided not to use it in our future installations.

6. CONCLUSION

Since last installation test definitions (AIRBUS A340–600 and A318), improvements and technological evolutions in sensors' field allow us today to suggest improvements and novelties for future test installations.

Purposes are: installations simplification, wiring reduction, sensors' management improvement (place in installation, metrological follow-up, built-in test),…

In this way, we hope that IEEE P1451 standards in definition will lead to real and unique standards adopted by all sensor manufacturers community.

REFERENCES

[1] A340-600 : Experience feed back on sensors' field buses

[2] IEEE P1451 standards web site : http://www.ic.ornl.gov/p1451/p1451.html

IEEE P1451.3 A Developing Standard For Networked Transducers

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Abstract

The IEEE p1451.3 standard for networked transducers is designed to provide an interface between transducers and a host processor or a network controller. There are three general types of transducers allowed by the standard, sensors, event sensors and actuators. Attributes can be given to these transducers to modify their behavior. These attributes can be either built into the device and not be changeable by the user or they can be programmable. Data sampling can be handled in three different ways. The simplest mode of data sampling is to let the transducer module control the sample times using an internal clock. Another way to control when the data samples are taken is to use periodic trigger messages to initiate sampling. The final possibility is to use a clock from the bus controller to control the sampling. The physical interface is a single pair of wires. DC power is supplied over this pair of wires along with the signals required for communications and synchronization. The data communications uses a modification of the transmission technique developed by the Home Phoneline Networking Alliance (HomePNA) that has been accepted by the ITU as recommendations G.989.1 and G.989.2. The HomePNA Payload format and link layer requirements are being modified by the IEEE working group to allow for isochronous operation. In addition the proposed standard includes a number of Transducer Electronic Data Sheets (TEDS). These include all of the TEDS from IEEE 1451.2 as well as some additional TEDS that the working group felt was needed. A major difference from the TEDS in IEEE 1451.2 is that all TEDS are defined in either Binary XML or standard XML. The goal is to define a system where a new transducer, from a supplier that has not been used in a system before, could be plugged into an IEEE p1451.3 based system and be used without adding any transducer or manufacturer specific software.

Keywords

Networked Transducers, Transducer Electronic Data Sheets (TEDS), Smart Transducers, Smart Sensors, Transducer Bus Interface Modules (TBIM), Network Capable Application Processor (NCAP), Sensor, Actuator, Event Sensor, Code Division Multiple Access (CDMA)

IEEE 1451 Family of Standards

Most traditional transducer manufacturers are small companies and they have to spend a large development effort interfacing their products to a control network. They have expertise in clever devices to sense or control the physical environment but digital signal processing and networking applications are not their forte. Many will need to hire extra people or consultants to complete these developments. They are willing to make this investment if it allows their products to be used over several control networks but that is usually not the case. To address this issue there are a number of standards that have been developed or are being developed that are sponsored by the TC-9 committee on Sensor Technology of the IEEE Instrumentation and Measurement Society in cooperation with the National Institute of Standards and Technology (NIST) of the United States Department of Commerce. There are two released standards in the IEEE 1451 family, two more in the advanced stages of development, one more is being started and there is one related standard. The related standard is IEEE p1588 covering the synchronization of clocks in a networked environment. The basic block diagram of the IEEE 1451 family is shown in Fig.1. Each system is comprised of a Network Capable Application Processor or NCAP and one or more transducer modules. The three standards in the family that define the different transducer modules each define different devices to support different applications. Each of these standards also define a different interface between the NCAP and the transducer module. However, the general concept is the same. The interface between the NCAP and the network is the same for all of the devices in the family. This allows the transducer manufacturer to concentrate on the transducer and the single interface that is used to support the market that is being targeted by that product. The NCAP can be provided by the transducer manufacturer or a totally different company. Since the NCAP is where the interface is made to the control network the transducer manufacturer does not need to be concerned with that aspect of the system.

The standards define the different interfaces in the system. IEEE Std 1451.1 defines the "Network Protocol Logical Interface" and in the case of IEEE Std 1451.2 the "Transducer Logical Interface." For the standards under development the "Transducer Logical Interface" will need to be defined in the new standards. The "Transducer Hardware Interface" is different for each standard.

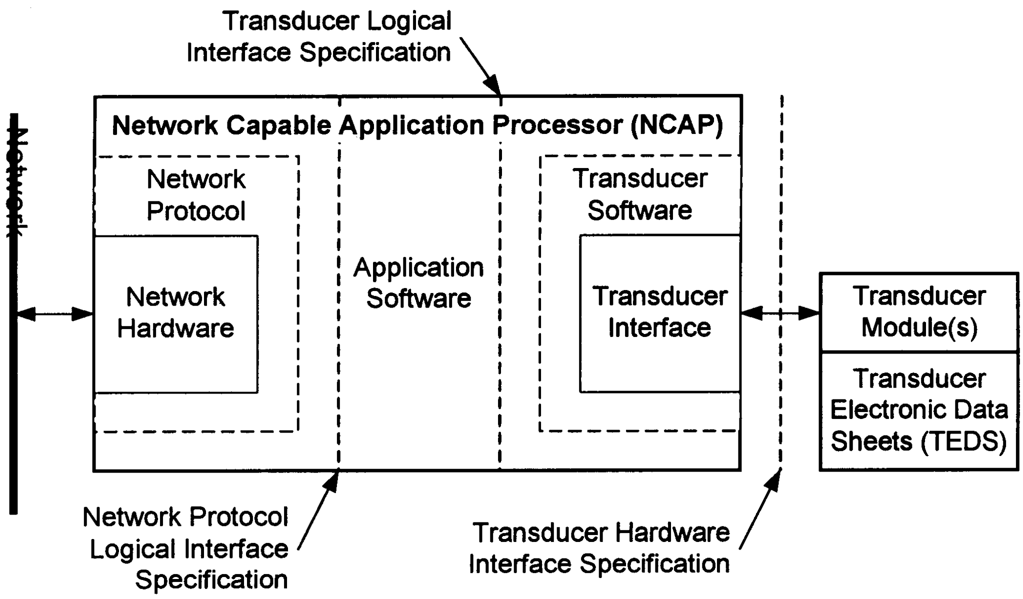

Figure 1 Networked Smart Transducer Model IEEE 1451.1

IEEE 1451.1 Processor Information model

IEEE Std 1451.1-1999 titled “Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Processor Information Model,” is a software standard that provides a standardized software interface between network-capable application processors (NCAPs) to control networks. This standard provides object models for the following: transducer block, function block, and network block along with their underlying structures. The common information model is complimentary, not competitive, to existing object models. This standard does not define individual device algorithms or a specification of what is implemented using the model.

The marketplace has been slow to adopt IEEE 1451.1 for a variety of reasons. The software to implement IEEE 1451.1 is complex and represents a large investment. Until there are IEEE 1451 transducers in the marketplace there is little incentive to develop this software. NIST and Agilent are addressing the availability of this software by developing an open source reference implementation. Both organizations have existing software that is being integrated into a single package for publication. Since the work is being done with out any money changing hands it must be accomplished when people have time to work on it but it should be available in the second half of 2002 or early 2003.

IEEE Std 1451.2-1997 Transducer Module and Interface with TEDS

The first standard in the family to be completed was IEEE Std 1451.2-1997, Standard for a Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communication Protocol and Transducer Electronics Data Sheet (TEDS). The transducer module in this standard is called a Smart Transducer Interface Module or STIM. The hardware interface between the STIM and the NCAP is called the Transducer Independent Interface or TII. The Serial Peripheral Interface (SPI) that is common on many microcontrollers is the basic communications interface. SPI requires three wires. In addition there are five other wires that provide timing, interrupt and presence signals to the TII. The final two wires in this interface provide 5 VDC power to the STIM. One of the most significant developments to come out of IEEE 1451.2 is the Transducer Electronic Data Sheet or TEDS. IEEE 1451.2 TEDS provide a structured way to describe not only the operational characteristics of the STIM but text TEDS to allow the operator to determine the capabilities and characteristics of the STIM without resorting to a paper data sheet. The operational characteristics being supplied in a standard format is intended to allow the NCAP to read these TEDS and set itself up without any unique software for a new model STIM.

A IEEE 1451.2 Smart Transducer Interface Module (STIM) can contain up to 255 different transducers. There are seven different transducer types defined in the standard and a STIM can be composed of any combination of these transducer types. Each transducer can have a different number of bits per word, different sample rates, etc. The ten wire interface design only allows a single STIM to be connected to a TII on an NCAP.

There are eight different TEDS defined in the IEEE 1451.2 standard. Two of them, the Meta-TEDS and the Channel TEDS are required and the other six are optional. IEEE 1451.2 TEDS must stored in the STIM in non-volatile memory. There can be only one Meta-TEDS in a STIM since it describes the STIM as a whole. The Meta-TEDS provides such information as the number of transducers in the STIM and the worst case operating parameters. There is one Channel TEDS for each transducer within a STIM. The Channel TEDS for a transducer gives detailed information about that one channel. This includes such things as the physical units, the bits per word in the A/D or D/A converter and detailed timing characteristics. The optional Calibration TEDS is designed around a single algorithm that can be used to convert data between engineering units and the form required or supplied by the transducer. This will be discussed in more detail later in the paper. The only other TEDS that has a binary format is the Generic Extension TEDS which allows a manufacturer to define a TEDS. The other four TEDS are text-based TEDS that allow the transducer manufacturer to provide descriptive information to the system for display to the operator in multiple languages.

IEEE p1451.3 Transducer Module and Interface with TEDS

IEEE p1451.3 is modeled after IEEE 1451.2 but it uses a different interface to achieve different performance. This necessitates some changes to the contents of the TEDS and the IEEE p1451.3 TEDS are specified to use two forms of the eXtensible Markup Language to take advantage of newer technology. The other major difference between IEEE 1451.2 and IEEE p1451.3 TEDS is that IEEE p1451.3 allows the TEDS to be stored separate from the transducer module. This was required for certain applications that needed to be supported by some members of the working group. It is not necessarily an advantage but it is a difference. The interface between the Transducer Module and the NCAP in IEEE p1451.3 is a true bus instead of a point-to-point interface which allows a user to purchase an NCAP to support several transducer modules instead of the one-to-one relationship required by IEEE 1451.2.

IEEE p1451.3 only provides four transducer types instead of providing seven provided by IEEE 1451.2. In addition to the basic transducer types IEEE p1451.3 defines attributes that can be used to further refine or define the operation characteristics of the transducer. The use of the attributes allows the IEEE p1451.3 to emulate all seven transducer types from IEEE 1451.2 plus several more.

Most of this paper is given over to describing IEEE p1451.3 so we will defer further discussion of that specific standard until later in the paper.

IEEE p1451.4 Transducer Module and Interface with TEDS

IEEE p1451.4 is different from either IEEE 1451.2 or IEEE p1451.3. It was developed to allow TEDS to be added to sensors without any wiring changes in existing plants. The data interface is analog instead of digital. And several different data interfaces are allowed. A single pair of wires can be used to implement this interface if the 4 to 20 ma interface that is common in process control applications is used. The Dallas Semiconductor One Wire network is used for the digital interface. If a 4 to 20 ma interface is used for the data interface, it assumes a given polarity. With this polarity of the constant current the sensor output is placed on the wire as an analog signal. Reversing the polarity of the excitation switches the transducer to the digital mode and the Dallas Semiconductor One Wire protocol is activated. This allows the TEDS to be read. Other data interfaces require additional wires.

The TEDS in IEEE p1451.4 are defining a totally different interface than either IEEE 1451.2 or IEEE p1451.3. In the two other cases the interface was digital but in this case it is describing an analog interface between the transducer module and the NCAP. The Dallas Semiconductor parts that are expected to be used to implement this standard have as little as 256 bits of memory available.

Wireless Transducer Module and Interface with TEDS

The final standard under development uses a wireless interface between the transducer module and the NCAP. At this point it is just a study group that is looking into the possibilities. A Project Authorization Request (PAR) has been submitted to the IEEE requesting that a working group be authorized to define this standard. This standard is expected to define a wireless digital interface between the transducer module and the NCAP. In this regard it will probably be more like IEEE 1451.2 and IEEE p1451.3 than IEEE p1451.4. There are a number of existing wireless interfaces that are under consideration for this interface. These include a couple of possibilities under IEEE 802.15 or IEEE 802.11. Another possibility is to adopt a different propriety standard. The study group is preparing a survey in an effort to get input on the range or wireless applications that the standard will need to support.

IEEE p1588 Standard for Precise Clock Synchronization in Networked Measurement and Control Systems

In order for networked transducers to be practical in many applications the data need to be time tagged before it is placed on a network that will introduce variable delays. The ability to time tag the data will not reduce the requirement for the data to be sampled at a constant interval but it will reduce the requirement for determinism on the network. This has been recognized for some time but the options for achieving this have been limited. There is also a need to synchronize the clocks in the NCAPs to allow for synchronous sampling around the network. These problems are addressed by a standard called IEEE p1588. This standard is being developed around a protocol that was developed and patented at HP Labs (now Agilent) several years ago. Agilent has decided to move this technology into the public domain and is leading a working group in this effort. Other existing network protocols such as NTP, Network Time Protocol, targets large distributed computing systems with millisecond synchronization. Measurement applications need at least microsecond time resolution for many applications and sub-microsecond resolution in some applications. The IEEE p1588 protocol is applicable to systems communicating by local area networks supporting multicast messaging including Ethernet™.

The IEEE p1588 standard draft has been submitted to the IEEE for balloting and the IEEE editor is checking it to assure compliance with IEEE requirements before issuing the ballot.

Installing your IEEE p1451.3 Transducer

Suppose you have just taken delivery of a new IEEE p1451.3 transducer of a type you have never used before. There may be several things that your procedures require that we are going to ignore so the first thing that you will do is take it and plug it into your system. This can be done with the system powered up or powered down. If the new unit is installed with power on there may be a transient impact upon a transmission in progress but there should not be any other impact. This assumes that you have done your homework and that the bus can power another transducer. At this point the NCAP takes over. If we have an NCAP that supports hot-swap then it will periodically go out and broadcast a discover command to determine whether or not any new devices have been added to the bus. The TBIM responds to the discovery command if it has not been assigned an alias. It replies with it's UUID. The NCAP then assigns an eight bit alias to the TBIM using the UUID as the address. After discovery is complete the NCAP will use the assigned alias when addressing the unit. After assigning the alias the NCAP can read the Meta-TEDS. The Meta-TEDS will inform the NCAP of the number of transducers in the TBIM and the worst case operating parameters. The Meta-TEDS also contains information on transducer groupings in the TBIM. A transducer grouping would be utilized to identify any fixed relationships between the transducer channels in the TBIM. This could be as simple as the axis represented in by each accelerometer in a three axis accelerometer. It could also be used to identify virtual actuators that are used to control the set point and hysteresis in an event sensor. After reading the Meta-TEDS the NCAP is now ready to read the Transducer Channel TEDS for each transducer in the TBIM. While the Meta-TEDS provided general operating parameters the TransducerChannel TEDS provides specific information on the characteristics of the specific transducer.

The TransducerChannel TEDS has several blocks of information. The first block informs the system of the physical units and the range of the transducer. It also provides the measurement uncertainty associated with the transducer. The next block of information describes a data set that might be acquired or used by the transducer. This includes the bits per word, the number of samples in a data set and the relationship between samples in a data set. This is followed by the operational timing parameters associated with this specific transducer. Another block describes the relationship between the command to take or apply a sample and when it actually happens. Another section of this TEDS informs the system about the attributes that describe the operational characteristics of the transducer. This is information about the source of the sample clock, whether or not the unit has multiple data buffers and other items of this nature. It also identifies which attributes are programmable allowing the operation of the device to be altered. There is other information in this TEDS but this should give the general idea. Once the Meta-TEDS and the TransducerChannel TEDS have been read the NCAP has all of the information that it needs to operate the transducer except how you want to use it.

The next step is up to the operator. There is another TEDS that is called the commissioning TEDS. You will write this TEDS with the name that the system will use when accessing the TBIM. Once written into the TBIM this information is persistent. The NCAP will maintain a translation table between the system name of the module and the alias that it uses to access it.

There are several other TEDS that may or may not be present in the TBIM. Three of these are classified as “compensation” TEDS. The first of these to be defined is the Calibration TEDS. The calibration TEDS gives the coefficients that are required to convert the raw output of a sensor or sensors into a single Engineering units value using the method described in the standard. Since this method allows for multiple inputs to the conversion process it can be used not only to linearize a sensor output but can do such things as temperature compensate it as well. The Calibration TEDS can also be used for actuators to convert Engineering Units values into the bit pattern required for the actuator. The second of these compensation TEDS is the Transfer Function TEDS. This describes the normalized amplitude response of the transducer to frequency when used with the method described in the standard. The last of the compensation TEDS is the Frequency Response TEDS. This provides information similar to what is provided by the Transfer Function TEDS but the information is in table form instead of being constants for an algorithm. The compensations associated with these TEDS can be performed in the TBIM, in the NCAP or elsewhere in the system. Performing them in the TBIM will only be possible if the TBIM has the necessary logic built in to perform them.

Another class of TEDS is the Text-based TEDS. These TEDS are used to provide information to the operator. All of the TEDS that we have discussed so far have been written in Binary XML. Binary XML allows the TEDS to be smaller than if they were written in text based XML but should be more robust than if they were defined in a structure or table. This class of TEDS provide information in text form. The data itself may be in the TEDS in several different languages so a Binary XML directory is provided at the beginning of each of these TEDS to allow the system to access only the specific language block that is desired. These TEDS can be quite large and require large memories in the TBIM. However, if the manufacturer provided them they can contain all of the information that the user requires to operate the device.

Putting large block of memory inside a TBIM will be possible or desirable in some cases but not all. To get around this limitation the standard allows the TEDS to be “virtual.” A virtual TEDS is one that the manufacturer supplies but that is not installed in non-volatile memory in the TBIM. Just how the manufacturer supplies the virtual TEDS is not called out in the standard but a text-based Location and Title TEDS is specified to allow the manufacturer to install the virtual TEDS on a web-site and to allow them to be accessed over the Internet. If this is how they are supplied it probably behooves the user to copy them into the users system some place to be able to guarantee access to them in the future.

The last TEDS that we need to discuss is the Commands TEDS. If there are things in the TBIM that require setup and the commands to accomplish that setup are not part of the standard command set then the manufacturer will define the required additional commands and describe them in a Command TEDS. This allows the operator access to the necessary commands and with a little common software the ability to execute those commands without changing the users system in most cases. The command TEDS is a text-based TEDS so the commands can be supplied in multiple languages if desired.

Operation of the unit

Now we need to decide just how we are going to operate the unit. The standard allows for two possible modes of operation, Asynchronous and Isochronous. The HomePNA physical layer that was chosen for this standard provides for Ethernet like operation. It uses CSMA and transmits information in packets. Like Ethernet when the bus is heavily loaded collisions will occur limiting the bandwidth that can be achieved unless something is done to avoid this problem.

Asynchronous Operation

The first mode of operation, called the asynchronous mode, avoids most of this problem by operating in a master-slave mode. The NCAP is in charge and it issues commands and receives responses. If a TBIM needs to send a message to the NCAP it must either wait until it is polled by the NCAP or it could violate the strict master-slave relationship and transmit the message when it detects that the bus is not busy. If this is allowed them collisions will happen. However, in many systems this mode of operation is quite satisfactory. In the asynchronous mode the NCAP will issue a trigger when it desires to acquire data from a sensor. The trigger can be addressed in one of four ways. First it can be addressed to a specific transducer. The second method of addressing would be to all transducers in a specific TBIM. The next method requires that the NCAP program specific transducers to be members of a trigger group and then issue the trigger to the group. The final method of issuing a trigger is to address it to all transducers on the transducer bus. This is called global triggering. Once a sensor receives a trigger it will begin collecting a data set. A data set can contain from one to many samples of data. The maximum number of samples in a data set is contained in a sixteen-bit field in the TransducerChannel TEDS. The actual number of samples in a data set can be programmed to be anything equal to or less than the number specified in the TEDS. The relationship between samples in the data set is also contained in the TransducerChannel TEDS. In most cases that relationship will be a time interval but variables other than time are allowed in the standard. Once the NCAP decides that the entire data set has been captured, either by waiting for a period of time or reading the TransducerChannel status, it will issue a read data block command and read the data. All TBIMs must be able to operate in the asynchronous mode.

Isochronous Operation

In the Isochronous mode of operation time is divided into fixed length “epochs.” Each epoch is divided into an isochronous interval and an asynchronous interval. The isochronous interval is allowed to occupy up to about 80% of the epoch. The remainder of the epoch is reserved for asynchronous operation. The isochronous interval is divided into 200 microsecond “time slots.” A given transducer is assigned a time slot in which to begin transmitting a data set. The NCAP must allot enough time slots to that transducer to transmit a complete data set. The first time slot in an isochronous interval is always assigned to the NCAP to transmit a “Beginning-of-Epoch” message. This message notifies all devices on the bus that the isochronous interval is starting and they may only transmit in their assigned time slots. It also contains acknowledge flags for data packets which were transmitted in the last half of the previous isochronous interval. The last time slot in the isochronous interval is also assigned to the NCAP and is used to transmit the “Start Asynchronous Interval” message. This message notifies all devices on the bus that they may attempt to transmit messages using the asynchronous mode of operation. This message also contains acknowledge flags for packets transmitted in the first half of the present isochronous interval. If a TBIM receives a negative acknowledge it will attempt to retransmit the packet during the asynchronous portion of the epoch. If it fails to successfully retransmit within the next asynchronous interval the data is lost and no further attempt will be made to retransmit the data.

One consequence of isochronous mode operation for transducers that are sampled at a rate higher than the epoch rate, i.e. they are sampled several times within the same epoch, is that they must be buffered. One characteristic of buffered sensors is that the data that is transmitted in a given epoch is the data that was sampled in the previous epoch.

TBIMs are not required to be able to operate in the isochronous mode so if you need this mode of operation that the unit you are buying can support isochronous operation. Additional logic is required for devices that operate in the isochronous mode. They must also support the synchronization signal. This signal is a two megahertz signal that acts as a clock. The sync signal is modulated to provide a more precise method of marking the beginning of an epoch and the beginning of each time slot in the isochronous interval. Asynchronous only TBIMs do not need to be able to receive this signal. Triggers for TBIMs operating in the isochronous mode are not messages but are based on the beginning of the isochronous interval. Since these occur at regular time intervals the data sampling is at regular intervals.

The advantage to isochronous operation is that a higher overall through put can be achieved since collisions should never occur in this mode of operation. The disadvantage is that more planning is required to determine the number of time slots required and which transducer to assign to each time slot. However, this does appear to be a simpler problem than designing a PCM frame format for an IRIG 106 chapter 4 type system.

Determining the time of occurrence of a data sample

There are several ways of determining the time of occurrence allowed in the standard. For the discussion here we will start with the simplest methods and proceed to the more complex.

Fixed delay

If the time interval between the receipt of a trigger and the acquisition of the first sample in a data set is fixed this delay can be included in the TransducerChannel TEDS in a field called “TransducerChannel Update Time.” The NCAP needs to remember the time that the trigger was issued, add this time to it and the time of the first sample is known. In most cases the time for each remaining sample in the data set is a constant so by knowing the time of the first sample it is possible to calculate the time of occurrence of any sample in the data set. There are cases where the delay between the receipt of a trigger and the occurrence of the data sample is not constant and if the interval between samples in a data set is not in units of time then this method will not work.

Time Interval Sensor

A time interval sensor is used to measure the time interval between the receipt of a trigger and the acquisition of a sample in a sensor or the application of a sample of data in an actuator. It is a sensor and is treated the same as any other sensor except that it is triggered by the trigger signal for a different transducer within the same TBIM. It will have a TransducerChannel TEDS and may have a calibration TEDS like any other transducer. It must be described in a ChannelGroup with a group type of 11. The grouping will list the transducer number for measurement transducer followed by the transducer number for the Time-interval sensor. The data set size for the time interval sensor may be either one or the same as for the measurement transducer that is in the same ChannelGroup. If a time interval sensor has a Calibration TEDS then the system may use this TEDS to determine how to convert the output bit pattern from bits to seconds. The resolution of the time interval sensor can be determined by reading either the TransducerChannel Data Model or the Worst-Case Uncertainty from the TransducerChannel TEDS.

Time-of-day Sensor

A time of day sensor is very similar to a time interval sensor in most respects. The difference is that a time-of-day sensor outputs a time of day instead of a time interval. The format of the Time-of-day sensor output is not specified in the standard nor is it included in the TEDS so that will need to be determined by consulting the manufacturers printed data sheet or one of the text based TEDS.

Use of the Calibration and Transfer Function TEDS

The Calibration TEDS and the Transfer Function TEDS are optional TEDS that the manufacturer may provide to allow the output of a device or the input to an actuator to be corrected. The manufacturer may or may not include them in the TBIM. However, if they are provided the most desirable location for them is in the TBIM. Making these TEDS virtual increases the possibility of the TEDS being linked to the wrong device. Since they are optional you will need to check to see if the manufacturer supplies them before purchasing the device.

Calibration TEDS

The use of networked transducers raises some questions and allows some capabilities that were rarely in question in the past. One of the most obvious is the ability for several different processors to access the data from a single sensor at the same time without any central control node being involved. This raises the question about where the correction process should take place. It can be done in each node that requests the data because they should all have the capability to access the Calibration TEDS. Besides being inefficient in terms of processing power this process always leaves the system open to the possibility of getting different answers in different processors because of some error happening someplace. For this reason it is desirable to have the engineering units conversion take place at a single point in the system for a given transducer. With the system as envisioned in the IEEE p1451.3 standard that leaves two places where this could be accomplished. On place is in the NCAP. Since all of the data for a given transducer must pass through the NCAP to get to the network this qualifies as a place where the conversion could take place. For systems with a low total bandwidth this may be a very practical place to put this conversion. For systems with higher bandwidth requirements more processing power will be required which may require the addition of a Digital Signal Processor (DSP) to the NCAP. The other possible place to put the conversion is in the TBIM itself. From the system setup point of view this may very well be the optimum place to put this conversion. If the conversion is in the TBIM then the question never arises as the size of the system increases “does the NCAP have enough processing power to handle the task.” As more TBIMs are added to the system the appropriate amount of processing power is added to handle the workload. The drawback to placing the engineering units conversion in the TBIM is additional complexity in the part of the system that should be the lowest power and lowest cost part in the system.

The engineering units conversion process that is defined in the standard is very powerful. There are very few transducers whose output cannot be converted to engineering units using this algorithm. It may not always be the most efficient algorithm to use but can allow a single process to handle most, if not all, of the conversions required by a system. The war output from one or more sensors can be applied as inputs to the process. For most conversions in the past a single input was used to produce a single output and for the near future that will probably continue to be the normal situation. However, the ability to apply multiple inputs to the conversion process allows for some interesting possibilities. Most sensors are sensitive to temperature and the manufacturer goes to great lengths to minimize this sensitivity. With this process it is possible to measure both the sensor output and the sensor temperature and use both as inputs to the conversion process thus removing the need to spend a great deal of time minimizing the temperature sensitivity of the device. The same is true of the signal conditioner. In the past the signal conditioner was designed with the components with the lowest possible temperature sensitivity. With this conversion process the temperature of the signal conditioner can also be included in the calibration process and the less costly components used in the signal conditioner. The only requirement that this process places on the devices is that they be repeatable. Of course this comes at a cost. The calibration process that the calibration lab must use to calibrate a device with multiple inputs is much more involved. To calibrate a sensor over temperature requires that multiple calibration runs be made at different temperatures to determine the response of the device to both temperature and the parameter that is being measured. To do this type of calibration cost effectively will require that the process be automated and that the transducers be processed in batches wherever possible.

What is involved in this process? Each input can be divided into one or more segments. In the past we have had different conversion processes for linear single section and linear multi-section conversions. However, given a little thought it is obvious that the linear single section case is a special case of a linear multi-section conversion with the number of sections set to one. Using the same logic a polynomial conversion is a general case. A linear conversion is a special case of the polynomial with the maximum exponent set to one. The method defined in the standard takes this into account to produce a multi-section polynomial conversion process. This can then be used for linear single section conversions as well as multi-section polynomials. Expanding this for multiple inputs requires changes in thinking in both the segmentation and the polynomial areas. In the segmentation area, think of segmenting a conversion with two input variables. In this case instead of each segment representing a part of a line it represents an area on a surface. If three inputs are segmented it represents a volume. As more inputs are involved the segment is bounded by more terms. Each segment has its own polynomial conversion equation. As the number of inputs increases the number of variables in the polynomial also increases. The calibration laboratory has the opposite problem. How does it take all of the measurements it has collected and to use this information to determine how to segment the inputs and how to generate the polynomials for each segment? The biggest problem will probably be how to get the boundaries of the segments to join without discontinuities. Clearly some computing capability will be required. The advantage to using this process is that a single conversion process, and thus a single definition for the Calibration TEDS, can be used for most conversions.

Transfer Function TEDS

The Transfer Function TEDS is new in the IEEE p1451.3 standard. It was not present in the IEEE 1451.2 and is thus not as well developed as the Calibration TEDS. For example there is no provision for using this TEDS in the TBIM yet. However, in most ways it is similar in principal to the Calibration TEDS. Its purpose is to allow the system to compensate for the frequency response characteristics of the transducer and signal conditioner. This allows the system to produce a measurement with a more desirable frequency response than can be provided by the transducer and signal conditioner alone. It may also allow the designer to put less effort into the design and to tailoring the response of each device and to just measure it and to correct for the undesirable characteristics. It can be a question of manufacturing cost. Does it cost less to design with higher precision components and to measure the response to make sure that it is within tolerance or to build with cheaper components, measure the response and to put the correction in the TEDS? Of course the user needs to choose between higher purchase cost and the cost of providing the processing power required to compensate the device.

Attributes

The transducer attributes are used to either define or control the operating characteristics of a transducer. There are four sets of attributes defined in the standard. The information in the TransducerChannel TEDS specifies which attributes are incorporated into a particular transducer and whether or not they are programmable or fixed. If you want a particular mode of operation you will need to check before purchasing the device if it supports the attributes that you desire.

Sampling Attributes

There are two attributes in this class. They control how the transducer responds to a trigger. If the “Trigger Initiated” attribute is set then the first sample in a data set will be acquired or applied immediately following the trigger. If the “Free Running” attribute is set then a clock internal to the TBIM controls the sampling and the first sample in the data set will be taken at the beginning of the next clock cycle after the receipt of the trigger. In terms that were defined in IEEE 1451.2 devices with the Trigger Initiated set would be sensors or actuators. Devices with the Free Running attribute set would correspond to data sequence sensors. There is no equivalent for an actuator. Another difference is that in IEEE p1451.3 these attributes can be programmable allowing one device to operate in either mode.

Buffered Attribute

The buffered attribute defines for the system whether or not the transducer has multiple data buffers or not. If the attribute is set then multiple data buffers are available. The field in the TEDS tells whether or not the buffers are available and also defines whether or not they can be turned on or off by the system. This programmability was not present in IEEE 1451.2.

Streaming Attribute

Streaming operation is a new mode of operation that was introduced by IEEE p1451.3. In streaming operation a dedicated data communications channel or time slot exists for each streaming transducer. Data sampling in a sensor or application in an actuator begins with a trigger and then continues until interrupted by the NCAP. Read commands are not issued to obtain the data sets they are transmitted as soon as possible after they are acquired. For the HomePNA physical layer selected for IEEE p1451.3 streaming operation means that the transducer is given a time slot as described above under Isochronous mode of operation.

End of Data Set Operation Attributes

There are two possible attributes in this set. They apply to actuators only and they define what happens at the end of a data set. IF a data set contains only a single data sample then they are equivalent. However, it the data set contains more than one sample they allow for entirely different operations. The “Hold” attribute being set requires the actuator to apply each sample in the data set and then to hold the final data value until it receives another trigger. This would be used where you want a device to follow a particular pattern to get from one position to another and then to hold at that point. The “Recirculate” attribute being set causes the actuator to step through the data set after receiving a trigger but when it reaches the end of the data set instead of holding at the last value it returns to the beginning of the data set and steps through it again. This attribute would be used if you want to generate a repeating waveform. This attribute can be either fixed or programmable.

Conclusion

IEEE p1451.3 is an emerging member of the IEEE 1451 family of standards that expands upon the base established by IEEE 1451.2. It is aimed at a different market and includes significantly more programmability than the previous standard. The working group is developing functional prototypes of the standard at this time. Balloting on this standard is expected to begin in the late spring or summer of 2002.

Airborne Icing Characterisation Prototype

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Abstract

The aeronautical industry, for flight certification purposes, uses airborne probes to characterise icing conditions by counting and sizing cloud droplets. Existing probes have been developed for meteorologists in order to study cloud microphysics. They are used on specific aircraft, instrumented for this type of study; they are not adapted for an industrial flight test environment.
The development by Airbus France of a new probe giving a real time response for particle sizes between 10 and 500 microns, adapted to operational requirements, is in progress.
An optical principle by coherent shadowgraphy with a low coherency punctual source is used for the application. The size of the droplets is measured from their shadows on a CCD. A pulsed laser coupled to a fast camera freezes the movement.
Usually, image processing rejects out-of-focus objects. Here, particles far from the focal plane can be sized because of the large depth of field due to the point source. The technique used increases the depth of field and the sampled volume is enough to build a histogram even for low droplet concentrations.
Image processing is done in real time and results are provided to the flight test engineer. All data and images are recorded in order to allow on-ground complementary analysis if necessary.
The probe is designed to be easily installed through a dummy window. A telescopic prototype is in process. Retracted, it will allow the aircraft to fly at VMO (Maximum Operating Limit Speed)

Introduction

Icing flight tests necessitate the use of cloud characterisation probes, in order to count and size droplets. The existing probes have been designed for scientific aims by the microphysics research community. During the scientific campaigns, probes are installed on aircraft dedicated to this purpose. The bulk they represent and the difficulties of installation on the aircraft are not considered as an inconvenience as they would be in an industrial context. Furthermore, there is a growing interest in the characterisation of the large droplets ("SLD") during icing flight tests, which implies the use of a second probe as bulky as the first one. In order to have convenient equipment matching installation requirements and allowing droplets between 10 and 500 µm in diameter to be sized, Airbus France designed a probe for icing certification tests.
We will first describe the basic icing flight test installation. Secondly, we will focus on the aim of the new probe. Then, we will describe the principles used by this instrument. We will indicate project progress and perspectives.

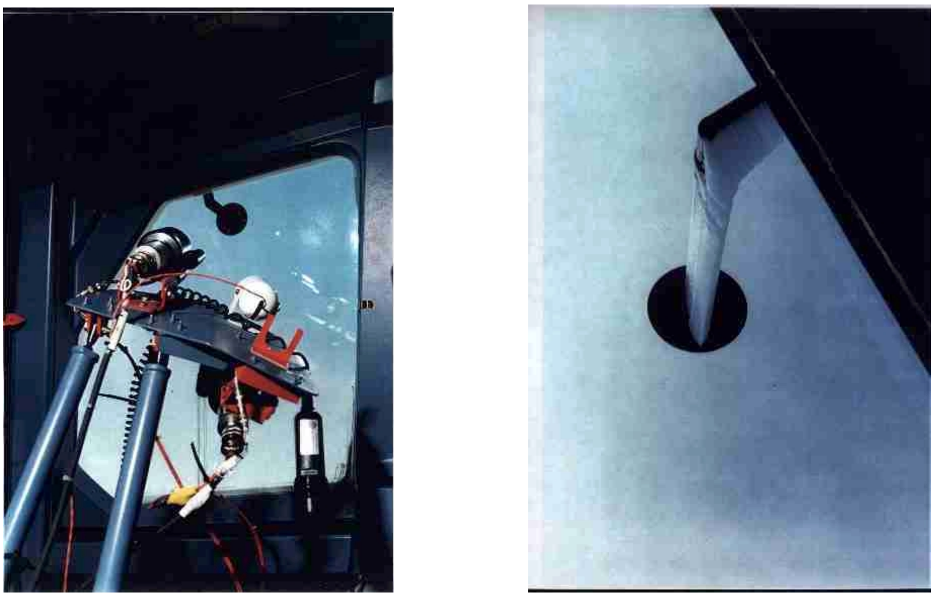

figure 1 : "CEV" icing probe

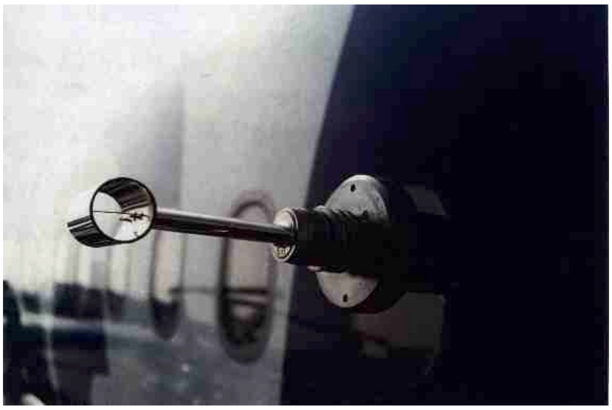

figure 2 : "Johnson Williams" Hot Wire

figure 3 : FSSP Probe installed on A340

Icing installation

In order to characterise clouds (counting and sizing of particles) during icing flight tests, AIRBUS uses specific instruments. The basic flight test installation is composed of a "CEV" icing probe (CEV stands for "Centre d'Essais en Vol" that means "flight test centre"), a hot wire device[1] and a FSSP (Forward Scattering Spectrometer Probe)[2].
The CEV icing probe is composed of a cylindrical rod with a graduated disk at its top. It is used to estimate icing accretion (shape and thickness). It is visible by the pilot and it is filmed throughout the flight, as showed on figure 1.
As hot wire devices, AIRBUS usually uses "Johnson-Williams" (figure 2) or the "King Probe"[3,4,5]. They measure the Liquid Water Content (LWC) of the cloud.
The FSSP (figure 3) provides a diameter histogram of the cloud. It counts and sizes droplets but it cannot distinguish crystals, which are classed as droplets. As FSSP also delivers the LWC from these measurements, the ambiguity is eliminated by a comparison with the hot wire measurements.

The most used FSSP allows to size particles up to 50 µm, with a resolution of 3µm. An extended version exists, for which the maximum diameter measured is 100 µm, but the resolution is decreased (6 µm).
The main problem with this kind of probe is its large overall dimensions. As seen on the picture, the FSSP is a bulky (1 m long) and heavy probe. It is generally mounted on two dummy windows. Installation duration is quite long and once ready, the icing instrumentation does not allow the plane to perform any other kind of flight tests than icing ones.
Sizing larger droplets involves the use of another probe, the Optical Array Probe (OAP)[6]. It is based on imagery so it can differentiate droplets from non-spherical crystals. The mechanical design is quite similar to that of the FSSP and has the same drawbacks.

A new probe

Taking into consideration the problem of installation, the wish to size larger droplets and detect crystals, Airbus France is designing a new probe.
The main measurement objectives to be met are:
- sizing and counting droplets of diameters between 10 and 500 µm
- differentiating droplets from crystals
- evaluating crystal number and size
- providing LWC, MVD (Median Volume Diameter) and histogram of diameters in real time
- recording raw data to allow post processing on ground with a better accuracy.

Another general aim is to improve competitiveness and one way to achieve this goal is to reduce test cycles. This equipment will allow other kinds of test to be performed:
- when the meteorological conditions are not adapted: the probe will be easily and quickly installed or removed. The aircraft will not be grounded because of the icing test installation, waiting for icing clouds.
- during flight to an icing area: the instrument is designed to allow flight at maximum speed and to perform other types of trial.

The design of this probe has started with a study of airborne icing characterisation probe state of the art[7], which shows that no existing instrument combines all the requirements.
The next step has shown the feasibility of the design principles through a thesis[8] and experiments. Then a prototype to be tested is being developed. Finally, the definitive probe will be manufactured[9].
At present, the project is in its prototyping phase.

General measurement principles

The principle used by this instrument is "shadowgraphy". This means that the shadow of particles is cast on a CCD. Images are processed in real time to provide results (LWC, histogram of diameter, MVD) to the flight test engineer who can manage the flight in consequence.
The general form of the probe is a cylinder installed through a dummy window (figure 4). The design takes lightning problems into consideration. Icing flight tests can involve cumulonimbus clouds where lightning occurs frequently. The instrument is composed of a "measuring" part, all in non-conductive materials, which corresponds to the cylinder and a "processing" part including electrical devices installed inside the cabin.
An inlet in the cylinder lets the air flow pass through it. Aerodynamic calculations have been performed to optimise the shape of the probe and of the inlet in order to keep the flow representative of the cloud composition.

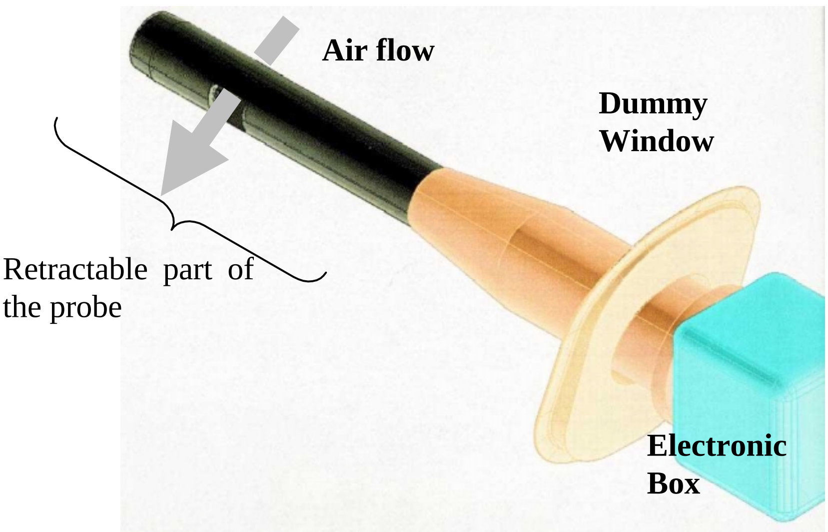

figure 4: Preliminary CAD view of the probe

Because of the very wide range of diameters to be sized (10 to 500 µm), we use two channels in parallel; one is adapted to the smallest droplets with a pixel resolution of 3 µm and the second one to bigger particles, with a pixel resolution of 15 µm. Each channel is imaged on the same CCD alternately and is illuminated by its own laser (figure 5).
In order to increase sampled volume, especially on channel 2 (biggest particles are rarer), we can produce several flashes on the same image. Between the flashes, the

aircraft will have moved sufficiently (about 0.1 m at 100 m/s) not to snap the same particles twice.

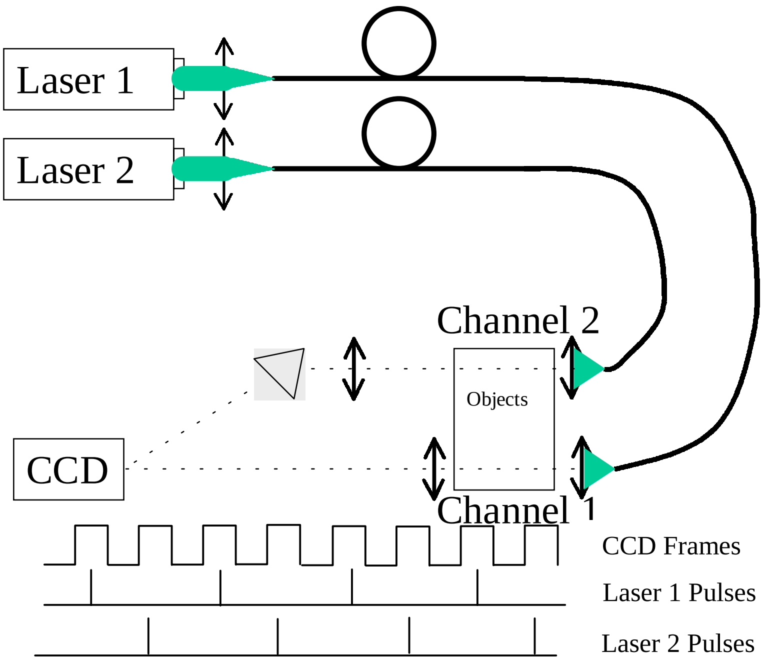

figure 5 : Architecture of the probe. Each channel linked to a laser is imaged alternately on the CCD.

In contrast, if the cloud is very concentrated, particles will be numerous on images and it is difficult to process all images in real time. Only one flash illuminates the images and the system can skip some images without degrading counting statistics.

To avoid electrical devices in the cylinder, optical fibres transport light to the end of the probe. Lasers emit light at a wavelength of 532 nm. They have been pigtailed in monomode fibres especially for our application.
The CCD has 512x512 pixels and it provides 262 images par second which are processed in real time.

Images

Instead of a traditional illumination we use a point source (figure 6) which provides a broadened depth of field. The heart of the fibre, about 4 µm in diameter is considered as a point source. Instead of a fuzzy image of the particle, the shadow is the figure of diffraction (Fresnel) of the particle due to the coherence of the laser source as seen in figure 7. We talk about "coherent shadowgraphy"[10].

The coherency of the source has generated different problems : how to reduce background noise, how to size particles.
As a very coherent source increases the risk of background noise. We have choose a low-coherent source.

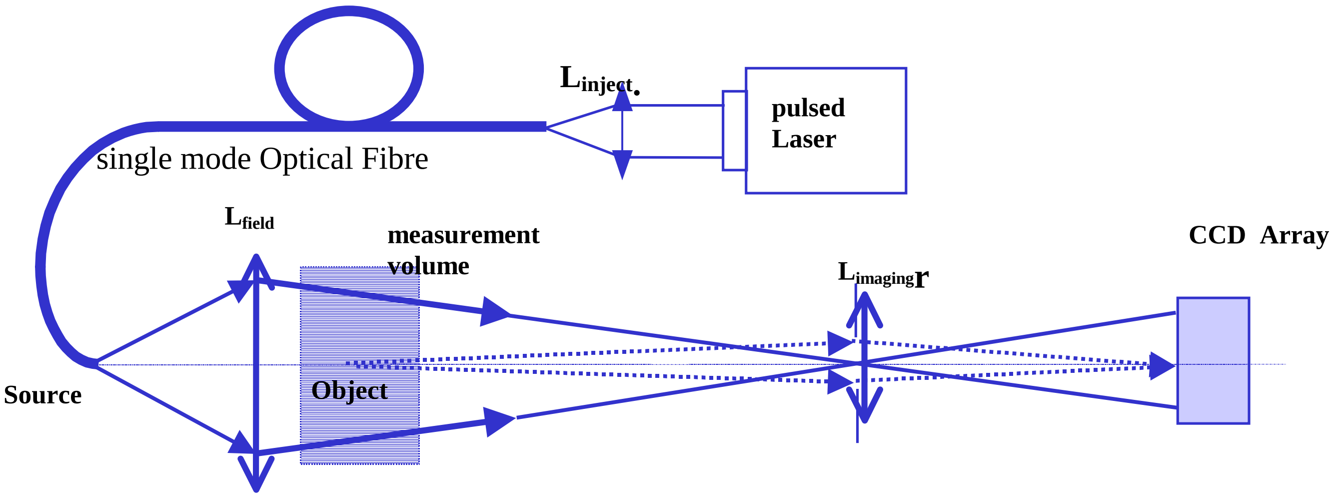

figure 6 : Schema of the illumination principle

As far as particle diameter is concerned, we can see on figure 7 that it changes significantly with out-of-focus range. The recovery procedure is described through the image processing paragraph below.

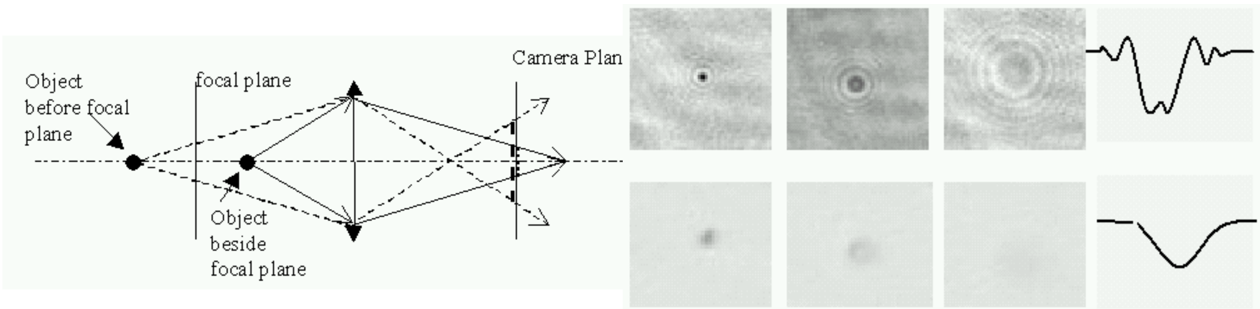

figure 7 : Comparison of images of the 10 µm particle illuminated with a point (up) and a diffuse (down) light source for identical experimental configurations: the particle is successively in focus, 1mm and 2 mm out of focus. The contrast is superior with the point source.

Image processing

For each image, spherical particles assimilated to droplets are detected, counted and sized.
Once a particle is detected, the mean profile is calculated (figure 8).

From the profile, the "energy" is deduced. This parameter is illustrated by figure 9. At first the profile is normalised. Then its absolute value is extracted. Finally, all the values of the profile are added. The energy is constant for a given diameter whatever the out-of-focus of the corresponding particle.

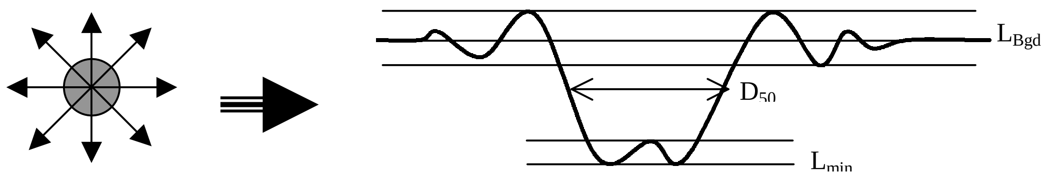

figure 8 : the mean profile is calculated from 8 profiles of the particle. L_{Bgd} is the background grey level, L_{min} the minimum level and D_{50} the "apparent" diameter calculated at half height. The contrast is the difference between L_{Bgd} and L_{min}.

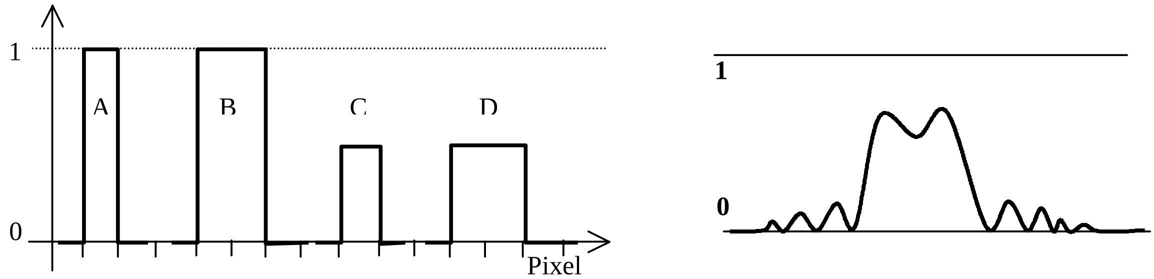

figure 9 : Calculation illustration of energy for simplified cases (right part) and diagram of a typical profile used for the calculation of a particle energy (left). Profile A is 1 pixel wide and has a maximum normalised contrast. Profile D is 2 pixels wide and has a half maximum normalised contrast. Energies for profiles A, B, C, D are respectively equal to 1, 2, ½ and 1.

Another way to find out the true diameter of the particle is to use an empirical curve of the apparent diameter versus contrast.
The two methods are being tested at the present time to determine the best one for each channel.

The camera delivers 524 Mbits/s (Dalsa CAD6: 512x512 pixels, 8 bits, 262 fps). Images are processed in real time and recorded for post-processing.
The post processing could include a more sophisticated processing for crystals, but our aim is only to differentiate crystals from droplets and estimate their number and surface; no shape recognition software implementation is planned.

Operational principles

Let us see the operational aspects.
The probe is installed outside of the fuselage through a dummy window (one of the first windows). During the take-off, landing and transit phases, the probe is retracted to prevent it being stained. This position allows the aircraft to fly at its maximum speed.
Once in the icing area, the probe is deployed. The de-icing system is automatically turned on. As no electrical material must be used to preserve from lightning, the de-icing system is composed of a warm air circulation inside the leading edge and reinforced around the intake.
In the same way, an air curtain surrounding the intake protects the optical windows from stains, or droplet deposition.

Progress

As the probe is in a phase of development, many of the parts described above are at the prototyping or validation stage.
The first prototype of the probe is all metallic and non-retractable. It includes all the measurement functions: lasers, optics, camera, image processing.
The non-conductive materials are tested with a specific retractable prototype that does not include any optical measurement capability. It allows testing of mechanical resistance, functionality and the anti-icing system.
After laboratory fine-tuning, the probe will be tested in wind tunnel and in flight in comparison with current well known probes such as FSSP and OAP.

Perspectives and conclusion

The development of this specific instrument for icing condition characterisation is taking place over several years. It started with theoretical and experimental studies of the imaging principles and its associated image processing. Next, prototypes to be tested in wind tunnel and in flight are being developed. From all the experiments, experimental and theoretical results, a definitive probe will be designed, combining the features of both prototypes. This instrument, integrating image acquisition and processing, will be non-conductive in order to avoid lightning problems, will be de-iced and retractable. It could be installed on any aircraft.

Bibliography

1. C.B. Neel, "**Measurement of Cloud Liquid-Water Content with a Heated Wire**", Aerospace Instrumentation Symposium A732131 Las Vegas, Nev. 21-23 May 73
2. R. G. Knollenberg, **"Three new instruments for cloud physics measurement: the 2-D spectrometer, the forward scattering spectrometer probe and the active scattering aerosol spectrometer"**, Amer. Meteor. Soc., Preprints Int. conf. on Cloud Physics, Boulder, 1976, pp 554-561,
3. King W.D., Parkin D.A., Handsworth R.J., "**A Hot-Wire Liquid Water Device having fully Calculable Response Characteristics**", J. Appl. Meteor., Vol 17, Dec. 1978.
4. King W.D., Maher C.T., Hepburn G.A., "**Further Performance on the CSIRO Liquid Water Probe**", J. Appl. Meteor., Vol 20, Feb. 1981.
5. PMS, "**CSIRO-KING Liquid Water Content Probe PMS Model KLWC-5 Operating and Servicing Manual**".
6. R. G. Knollenberg. "**The Optical Array : An Alternative to Scattering or Extinction for Airborne Particle Size Determination."**, J. Appl. Meteo., Vol. 9, pp. 86-103, Feb.1970.
7. Roques Sandrine **"Etat De l'Art des Sondes Granulométriques Aéroportées",** 2nd Séminaire Annuel de l'Ecole Doctorale d'Electronique de Toulouse, 12-14 Jan. 1999, pp 93-96

8. Roques Sandrine, **"Etude d'un Moyen Aéroporté de Mesure Granulométrique de Gouttelettes d'eau Applicable à l'Evaluation des Conditions de Givrage de Avions",** 2000, ENSAE Thesis.
9. Patent n°00 04432, AerospatioaleMatra Airbus: "Dispositif pour déterminer les valeurs d'au moins un paramètre de particules, notamment de gouttelettes d'eau. 7 avril 2000.
10. Roques Sandrine, Churoux Pascal, Aubry Yvan, Lopez Christian, **"Modelisation, performance evaluation and experimental validation of a new drops granulometry optical measurement method",** Europto : diagnostic Imaging Technologies and Industrial Applications, 14-15 June 1999, vol. 3827, pp66-72.