Proceedings of the European Telemetry Conference

Garmisch - Partenkirchen, Germany

May 24 to 27, 2004

etc2004

European Telemetry Conference

with Exhibition

and

Aircraft Integrated Monitoring Systems

Edited by: **German Society of Telemetering**
Arbeitskreis Telemetrie e.V.

CONTENTS

CONGRESS DATA

OPENING SESSION OF ETC 2004

DATA RECORDING AND STORAGE

Test Range, Ground Stations

Telemetry Systems

Data Acquisition, Processing and Monitoring

Flight Test Instrumentation

Data Networks and Coding Techniques

Data Collection and Transmission

Aircraft Integrated Monitoring Systems - AIMS

etc2004

Congress with Exhibition for Telemetry
Test-Instrumentation, Telecontrol

and

Aircraft Integrated Monitoring Systems
(AIMS)

May 24 – 27, 2004

Garmisch-Partenkirchen, Kongresshaus / Germany

---

organized by*:* **Arbeitskreis Telemetrie e.V.**
German Society for Telemetering

in cooperation with:

- **Deutsche Gesellschaft für Luft- u. Raumfahrt**
  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**

etc2004:	*Hans-Joachim Klewe*
ETSC / ICTS:	*Gerhard V. Mayer*
Exhibition:	*Werner R. Lange* *Daniela Fessl*
Registration and Conference Secretariat:	*Brigitte Rüba* *Inge Schade*
Tour and European Dinner:	*Herta Klewe*

Ladies and Gentlemen,

I'm very glad to welcome you again, or may be first time, here in Garmisch-Partenkirchen, for our 24th. European Telemetry Conference. It is our 13th meeting here at this very place since 1978.

Many things have changed within this quarter of a century and particularly in our field of interest, namely telemetry, telecontrol and test technology, there are innovations, which were scarcely imaginable 25 years ago.

At the beginning telemetry and telecontrol was due to relatively high expenses more or less confined to applications in the military research and development area and to astronautics and aeronautics.

Nowadays the progress in the development of high sophisticated semiconductor components and computer technology enables new applications in data transmission, data handling and processing of high rates and amounts of data, so that new fields of application can be opened. The daily use of telemetry in homes for the transmission of weather or security data, the use of telecontrol in car-keys and many more applications serves only as examples for a great many possibilities to use these technologies. The increasing use of components of the shell (COTS) even in more demanding applications leads to the reduction of cost and enables in this

way a more widespread use of these modern technologies.

Coming back to our conference. The organisation of etc 2004 made the decision, not to print a proceedings volume as all the years before, but to produce instead as it is general use nowadays a CD which shows the advantage, that coloured diagrams of the presentations can be seen on the monitor screens or can be printed out. An abstract booklet serves to inform the conference participants about the presentations of the lecturers in the different sessions.

The symposium "Aircraft Integrated Monitoring Systems (AIMS) was reduced this time to a lecture series of etc 2004, due to the fact, that only a reduced number of papers were offered.

Along the conference we have meetings of the European Telemetry Standardization Committee (ETSC) as well as of the International Consortium on Telemetry Spectrum (ICTS). The ICTS tries to get a new frequency band for use in the aeronautic wideband telemetry in the range of above 3 Ghz.

The exhibition will give an extensive overall view of the latest developments in technology and on the great variety of hardware and software for instrumentation, installations and systems concerning Telemetry, Test Instrumentation and Remote Control. Many vendors and exhibitors are showing their supply at etc2004.

A European Dinner offers the opportunity for social contacts alongside the conference. A spouses program with a bus-tour to the surroundings is planned.

I hope now, that the European Telemetry Conference etc 2004 will fulfill your demands and will lead to many contacts between lecturers, Participants and exhibitors.Let me wish you now an enjoyable stay in Garmisch-Partenkirchen

Let me finally say thanks to all who contributed to make etc 2004 successful.

Hans-J.Klewe
Conference Chairman of etc 2004
German Society of Telemetering
Arbeitskreis Telemetrie e.V.

Data Storage Suited to Flight Data Recorders

Alan Fitzgerald / Chief Technology Officer
Adtron Corporation / Phoenix, AZ 85034 / USA

Abstract

Flight data recorders must operate in the most demanding environments. Data storage technologies have advanced beyond magnetic media in tape and disk drives to the logical equivalent built using flash memory. Flash based storage delivers high immunity to shock, vibration and wear out. Additionally, flash exceeds the performance and security found in disks and tapes.

The session attendee will be presented with the recent advances in interface management and flash media management as required in flight data recorders. The concept and the technology used to achieve drop-in replacement for existing tape and disk systems will be presented as well as the advantages for new installations.

Introduction

Flight data recorders must operate in the most demanding environments. Data storage technologies have advanced beyond magnetic media used in tape and disk drives to the functional storage equivalents built using flash memory. Flash based storage delivers high immunity to shock, vibration and wear out. Additionally, flash exceeds the performance and security found in disks and tapes. This broad topic covers many applications, each sharing the basic components of a processor, storage, I/O, and system interface as shown in the figure below.

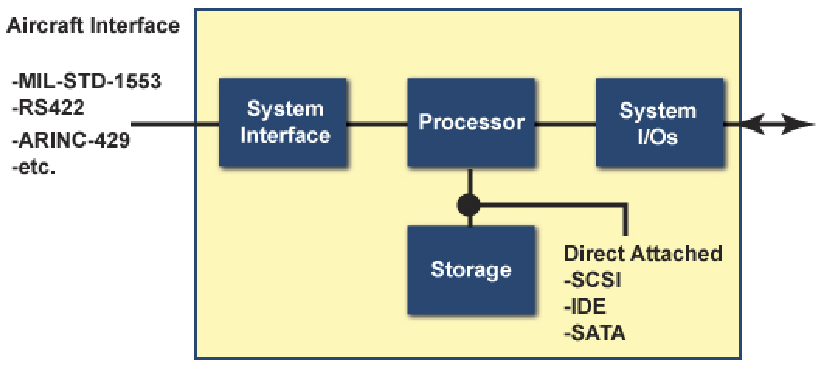


Figure 1 Basic components

This paper focuses on the storage element as required by several fundamental applications. These applications include:

- Health and Usage Monitoring Systems(HUMS)
- Airframe monitoring
- Mapping and mission data transfer
- Voice and video data recording
- Electronic countermeasures
- Surveillance recording

Each of these applications place different demands on the storage device used for recording and information retrieval. Quantitative differences include:

- Storage capacity
- Read and write performance
- Environmental durability
- Fixed or removable operation
- System interface

Fundamental to all of these applications is the need to employ a cost effective storage medium. To achieve cost effectiveness requires leveraging industry-standard component technology and a successful transition from commercial to military level COTS reliability.

Environmental hardening of commercial computer disk and tape drives has been attempted and accomplished in the past through the use of:

- Dampeners to absorb shock and vibration
- Heaters to ensure operation of the media above freezing
- Atmospheric sealing to eliminate vacuum and contamination of the media chamber

The design and cost of mechanical systems to absorb shock and vibration and to heat and cool disk and tape drives adds significantly to the cost, weight and size of the original commercial storage device as shown in the table below.

Flight Hardened Storage			
Storage Device	**Volume**	**Weight**	**Power**
3.5-inch hard disk 10 GBytes	680 cc	8 kg	41 W (w/ heater)
DAT drive – 5GBytes	2,540 cc	12 kg	25 W (w/ heater)
3.5-inch flash disk – 10GBytes	380 cc	2.5 kg	12 W (no heater req)

Table 1 Storage device comparison

Solid state alternative

A recent trend of employing solid state technology in the form of flash memory has proven to be successful in reaching high capacity densities in small volumes, with low power and decreasing costs. The solid state nature of flash memory allows full environmental durability without the extra mechanical support hardware required for tape and disk media.

When implemented as a disk or tape replacement, flash memory has proven to offer improved performance, higher reliability, significantly higher data integrity, and lower power operation than its magnetic counterpart.

Technology of system interface management

The interface technology designed for traditional media of disk and tape is now being adapted to storage systems built with flash memory. Advancements in the management of flash memory now allow the rapid implementation of practically any computer interface now used in standard tape and disk storage systems.

In the same way that the ISO seven-layer communication standard opened the architecture for reusable communications elements, the standardization of storage interfaces allows cross platform and application implementation of storage. A well behaved system stratifies to these storage system elements:

- Application
- Operating system storage management
- Storage command and status protocol
- Electrical interface
- Mechanical connection

By adhering to these layers and standards, it is possible to integrate flash media to a number of standard storage interfaces and to incorporate a wide range of emulations to match application requirements.

The layers diagram below illustrates the fundamental layers of a storage implementation that allows interface, emulation and media to be tailored to the application requirements.

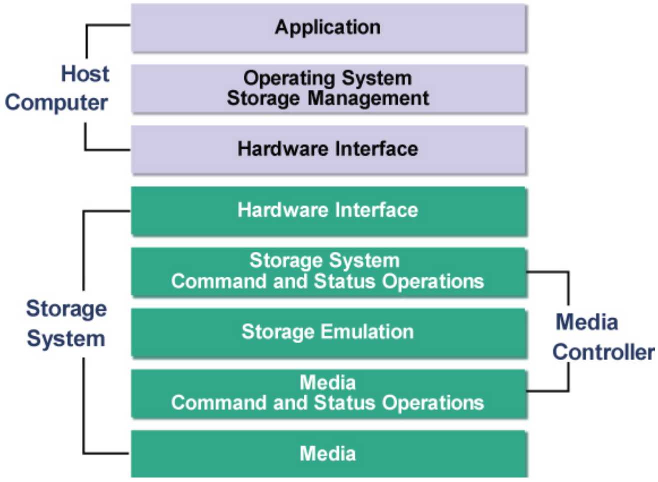


Figure 2 Storage layers

Flash based storage systems are available today with the following characteristics:

- Emulation
  - Fixed disk
  - Removable disk
  - Tape
- Direct attached interfaces
  - SCSI
  - IDE / ATAPI
  - USB
  - Firewire
- Network attached
  - Ethernet TCP/IP
    - NAS / NFS
    - SAN / iSCSI

Traditionally storage has connected as direct attached to the processor through SCSI, IDE, and serial interfaces. Many versions of these interfaces exist as illustrated by the timeline chart below.

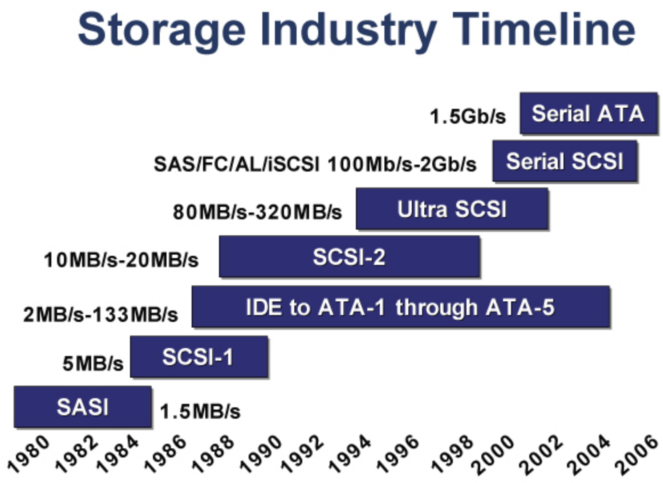


Figure 3 Timeline

Managing these interfaces for installed equipment through spares has proven to be very difficult. Commercial product life cycles are too fast to meet the long term defence and aerospace requirements.

Flash disks available today have targeted the legacy SCSI and newer IDE interfaces, and are looking forward to the next generation interfaces of high speed SATA, Ethernet and Firewire.

Following commercial standards, enhanced to airborne requirements, the next generation aircraft systems will implement data networks based on Ethernet. This allows for distributed storage and supports high availability operation to overcome failures within the network. The nature of direct attached storage does not allow sharing or failover in case of a CPU failure. High availability network management, built into the operating system or as a separate middleware layer, allows redundant storage across a network with failover capability.

As shown below, the flight data recorder can now share the storage elements in a distributed system.

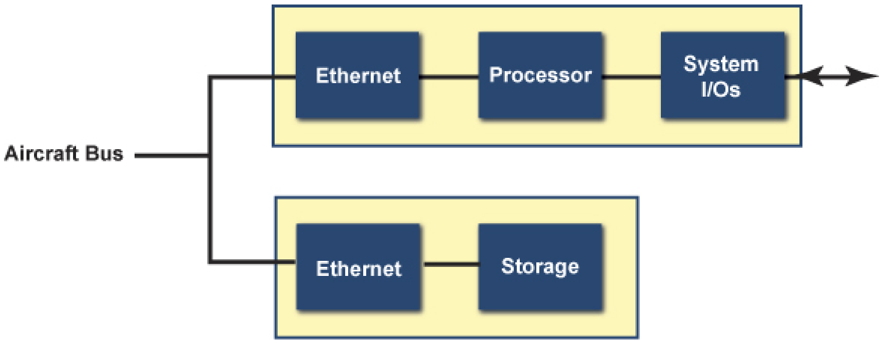


Figure 4 Storage in a distributed system

Flash performance

Flash storage systems can exceed the performance of magnetic media principally through the elimination of the time wasting mechanical motion required to find the data. The sequential or track oriented nature of tape and disk data requires seek operations to find the information. Flash is a random access technology and does not add latency overhead to data transfers.

The true performance of a storage system is not indicated by the bandwidth of the data payload bus as often sold by the disk industry. Interface modes such as Ultra-160 or UDMA-100 only indicate the transfer rate and not the end-to-end rate. The overall effective throughput depends on the random nature of data access and the data transfer block size. The following table shows an example of a random access benchmark using small file transfers, which shows how seek operations slows down a higher-rated hard disk drive when compared to a flash disk.

Random access Small file transfers	**Flash disk Ultra-20 Wide S35FB Sequential rate up to 40MB/s**	**Hard disk Ultra-80 Wide Quantum Sequential rate up to 160MB/s**
Sustained read	8.8 MB/s	1 MB/s
Sustained write	9.5 MB/s	1.5 MB/s
Burst read Avg / Peak	36 / 37 MB/s	10 / 152 MB/s
Burst write Avg / Peak	34 / 37 MB/s	65 / 91 MB/s
Track to track seek max	0.5 ms	16 ms
Track to track seek avg	0.5 ms	8 ms
Rotational latency	0 ms	4.17 ms

Table 2 Flash versus Disk

Flash tape drives offer a similar speed advantage over magnetic tape based tape drives. As files are transferred the tape must frequently relocate to find and write file markers. A rewind operation can add more than five minutes to a tape data transfer, where as a flash tape drive can rewind in about 500 micro seconds.

Higher performance flash memory will enable applications that have found transfer rate limitations in applications such as electronic countermeasures, threat tracking and recognition, surveillance and video recording.

Technology of flash management

With flash maturing to achieve storage grade operation, it is now feasible to characterize flash as a truly advanced version of tape and disk media. This new understanding means systems designers can move forward with solid state flash implementation, taking advantage of disk and tape storage technology that is appropriate for the application.

Decreasing cell geometry, change over from single to multi level cells, and more dense control architectures, make flash based storage systems more dependent on defect management. The flash disk manufacturer qualifies the flash and verifies the effectiveness of the controller-based algorithms to validate write endurance, data disturb and data retention.

With modern write endurance and defect management techniques there are very few applications that are limited by write endurance. The two most important management techniques to extend the write endurance life of flash are wear leveling and spare sectors. Spare sectors are just like spare tires, they are replacements for failed sectors. When a sector fails during a write or has a correctable read error, it is retired and the data is written to the spare sector. This technique is also used in hard disk drives to overcome similar failures.

The inherent write endurance is effectively increased through the use of wear leveling techniques that even out the write cycles across a flash array used in a solid-state disk. The controller that manages the flash keeps track of the write usage within the flash array and moves the writing around the array to prevent concentrated write areas. Even static or read-only areas are moved to accommodate the leveling of writes.

To combat data disturb errors, the defect management in the flash controller detects data errors and corrects data errors on the fly using error correction codes (ECC). Just like magnetic media, ECC is used to manage random bit errors to significantly increase the data integrity above the inherent media quality.

The archive quality of flash data, i.e. the time that data can be stored without power, is the retention time. A typical value is 10 years at 25 degC, and is significantly better than magnetic media.

Security

While all tape and disk magnetic media based drives have erase capabilities, flash based storage offers significantly faster erase and sanitize operations, as well as erase operations that do not require processor activity.

One special feature of a flash disk or tape is the auto resume operation, active during intermittent power conditions, that automatically restarts the secure erase function when power is restored to the drive. Progress indication is available during each secure erase command operation. Erase operation progress, including both the sequence step and step percent completion, is available through the drive interface. An option is available to connect a push button or other actuator to manually initiate a configured secure erase operation.

Flash Characteristics for Securing Sensitive Data		
Feature	**Technique**	**Available in Disk or Tape**
Fast erase	Bulk erase memory	No
Sanitize erase	Over write erased memory	Yes, 10x to 100x longer
Write protect	Disable writing to all or portions of the memory array	Limited
Read protect	Password protect areas for read back with varying access for writing	Limited

Table 3 Security features

Several standards exist that define the secure erase operations. There is ongoing activity to standardize these for flash memory technology.

	Specification	Device	Clear	Sanitize
DoD	**NISPOM 8-306 DoD 5220.22-M 1995 Original**	FEPROM	Perform a full chip erase as per manufacturer's data sheets.	Overwrite all addressable locations with a single character then perform a full chip erase as per manufacturer's data sheets.
DoD	**DoD 5220.22-M NISPOM Supplement 1**	FEPROM & EEPROM	Not specified	Overwrite all locations with a character, its complement, then with a random character.
NSA	**NSA 130-2**	EEPROM	Same as sanitize operation.	Overwrite all locations with a pseudo-random pattern twice and then overwrite all locations with a known pattern.
Army	**AR 380-19**	FEPROM & EEPROM	Perform a full chip erase as per manufacturer's data sheets.	Overwrite all locations with a random character, a specified character, then its complement.
Navy	**NAVSO P-5239-26**	EEPROM	Erase per manufacturer's specifications.	Erase, program all locations with a random pattern, wait 2 minutes, erase, program all locations with another random pattern, verify the random pattern.
Air Force	**AFSSI-5020**	FEPROM & EEPROM	Erase, verify then overwrite all bit locations with arbitrary unclassified data.	Erase, verify then overwrite all bit locations with arbitrary unclassified data. Declassify the media after observing the respective organizations verification and review procedures.
RCC-TG	**IRIG 106-03**	FEPROM& EEPROM	Not specified.	Erase; Write 55h; Erase; Write AAh; Erase; Write single file containing string "SecureErase" repeated to fill all available space.

Table 4 Security standards

Conclusion

Solid state flash disks are a drop-in replacement for traditional disk and tape storage devices. Flash disks function like hard disk and tape drives with many of the same features, using the same industry-standard interfaces and connectors. Unlike disk and tape, flash disks provide extreme ruggedness under the conditions that are demanded of flight data recording applications. Flash exceeds the durability requirements, improves wear-out rate and performance without the additional mechanical apparatus for dampening and environmental controls required by hard disk and tape drives.

Application examples

Helicopter HUMS

In this Health and Usage Monitoring System the storage device must provide a small amount of storage with the ability to remove the data via a transfer to a PCMCIA card. This megabit RS422 interface incorporates a robust protocol between the host and storage device using CRC to validate the data stream for both reading and writing.

During flight, up to 128Mbytes of flight information is written to flash memory. Once on the ground, a large PCMCIA card is inserted by the ground crew to extract the recorded information. One of the many flexible features of this design includes the fast expansion from 128Mbytes up to 2GBytes by changing one plug-in module.

UAV flight recorder

This is an example of a non-removable flash tape that replaces a DAT tape drive for recording airframe and systems operations in an Unmanned Airborne Vehicle (UAV). The two problems with the initial DAT system were: 1) the operating temperature range required special heaters for environments below freezing; 2) and despite mechanical dampeners and environmental harden packaging, the overall vibration and shock caused unpredictable failures.

Flash tape, operating with the command set and storage capacity of a DAT drive, provides an operating range beyond the envelope of the UAV operating environment. This allows the elimination of the heaters and their respective controls, and the reduction in weight and volume through the elimination of special packaging required for the DAT.

With the benefits of size, weight and reliability, and no system modifications required the flash tape drive functioned as a drop-in replacement for the commercial DAT drive within the UAV computer system.

Map and mission transfer

Loading the flight mission and maps into an aircraft is accomplished through a data transfer unit to a removable disk cassette. In this system a ground based station transfers mission information and maps to a flash disk cassette which is transported to the waiting aircraft. These time critical operations require high speed writing and reading.

The durability of flash provides two types of protection, first the disk must survive the handling when transporting the cassette across the flight line to the aircraft, and second the durability must exceed the mission environment for shock, vibration, altitude, and temperature.

A flash disk replaced the original design that used a hard disk. With this implementation the additional features of heaters and mechanical dampeners were eliminated.

Design of a Gigabit Distributed Data Multiplexer and Recorder System

Albert Berdugo /Teletronics Technology Corporation
Bristol, PA, USA

Abstract

Historically, instrumentation analog tape based data recorders did not have a built-in data multiplexer, due to the nature of multiple track capability. Digital tape based recorders have been available with and without built-in data multiplexers. Recent solid-state data recorders, and in particular, the high capacity and the high data rate systems, have been assumed to include the solid-state media and multiplexer electronics within a single unit.

This paper challenges the assumption of a single multiplexer/solid-state unit when a large amount of data and large number of input sources are to be recorded. This paper describes a distributed data multiplexer and recording system, acquiring data from high-speed avionics data busses (Optical Fibre Channel and 1394B), PCM, wideband analog, video, and others. In addition, each multiplexer within the distributed system operates as a data acquisition unit for data retrieval down to the parameter level from input channels for transmission of flight safety information.

Key Words

Multiplexer, Recorder, Gigabit, Data Acquisition, Solid State

Introduction

Instrumentation engineers are in a constant struggle to accommodate ever-increasing demands to acquire and record a wide range of input sources from low data rates to very high (gigabit) rates. These data sources may include PCM, video, 1553 bus data at the low to medium rate, and Ethernet, FireWire, Fibre Channel, and other packetized digital communication at the medium to very high data rates. The variety and rates of data sources dictates that the multiplexer/recorder system must utilize high power wide bandwidth processor/bus architecture solution. Such a solution provides a designer with the choice of a very-high rate multiplexer at a cost of minimal I/O slots. In addition, some newer avionics data buses such as FireWire and Fibre Channel must be acquired as close as possible to the multiplexer/recorder unit.

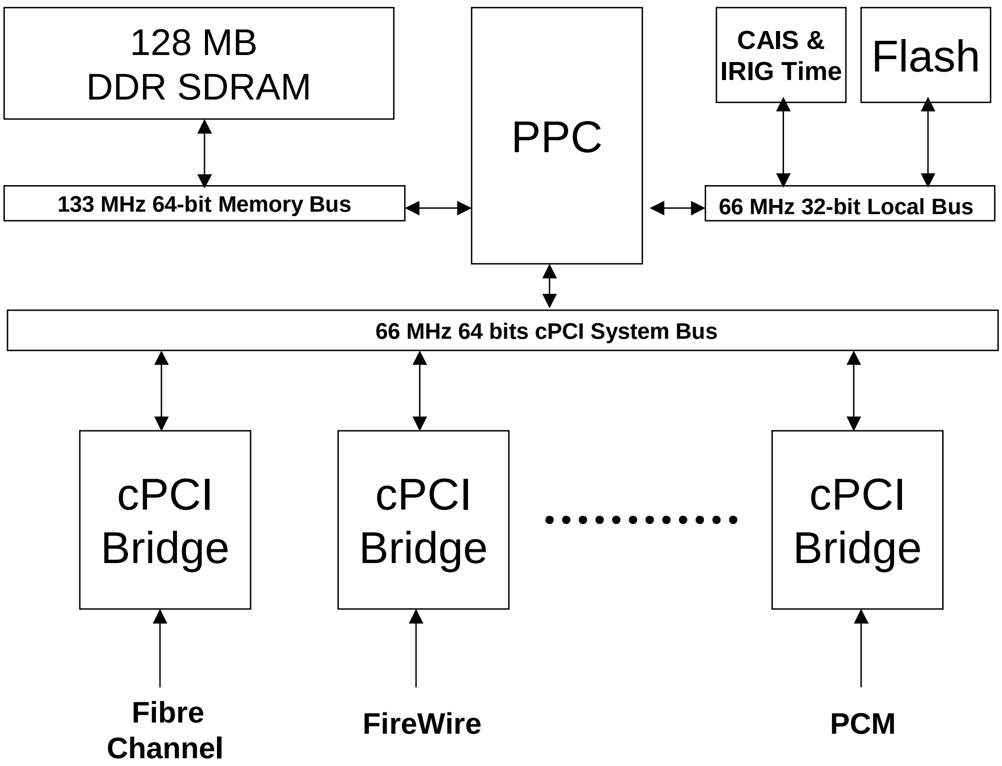
The paper will describe a multiplexer architecture that provides the user with the flexibility to multiplex large amount of data sources with low to very high data rate, and the ability to locate the unit as near as possible to the data sources, using a distributed data multiplexer solution. This layered system approach allows the flight test engineer to apply a multiplexer/recorder system in natural and incremental steps to accommodate upwards of gigabit data sources in an evolutionary manner.

Multiplexer / Recorder Architecture

An extensive and exhaustive evaluation was made in the development architecture of the multiplexer system shown in Figure 1. There are four core functions that together make up the multiplexer architecture that include:

- Backplane
- Processor
- Operating system
- Acquisition I/O cards

Figure 1 Multiplexer System Architecture



Backplane: A CompactPCI Bus-like backplane was chosen as the backbone of the unit. The backplane operates with 64-bit wide at 66 MHz operating rate using up to four I/O slots. This translates to a peak bandwidth of 528 megabytes per second (MB/s). Accounting for protocol overhead, bandwidth of over 200 MB/s is realizable within the multiplexer. Several signals were added to the backplane bus to meet IRIG-106 Chapter 10 time tag requirements, and other miscellaneous signals.

The design allows a migration path to higher bandwidth using the PCI-X protocol at the expense of fewer slots. The PCI-X provides a more efficient protocol that can result in a peak bandwidth exceeding 1 GB/s. The backplane can operate with 33 MHz rate in order to increase the number of I/O slots to six. This translates to a peak bandwidth of 264 MB/s.

Processor: The multiplexer's backplane bus is controlled and managed by an overhead card with a PowerPC core processor. The processor and its peripherals form the basic building block upon which the unit architecture is based. The PowerPC core includes a PCI-X Bus controller, DDR-SDRAM controller, a peripheral bus controller, two Fast Ethernet MACs, two UARTs, two I2C Bus controllers, and other functions. The processor core has a peak performance rating of 800 Dhrystone 2.1 MIPS. Peak performance is attained with the help of integrated Level 1 instruction and data caches. Another key element to the performance is the memory controller. A high performance Double Data Rate Synchronous Dynamic RAM (DDR-SDRAM) controller, which is capable of peak data rates of 2.1 gigabytes per second, is supported. Adding to the primary functional blocks of the processor is a PCI-X Bus controller. The controller supports both 64-bit conventional PCI and PCI-X Bus protocols. At a maximum speed of 133 MHz and in PCI-X mode, the bus has a peak data rate of just over 1 gigabyte per second. In conventional PCI Bus mode, the peak data rate is 533 megabytes per second. Another important interface to the processor is the peripheral bus. The available 32-bit demultiplexed, general-purpose bus is ideal for interfacing to non-volatile memory, SRAM and slower peripheral devices. The peripheral bus can operate up to 66 MHz for a peak rate of 266 megabytes per second.

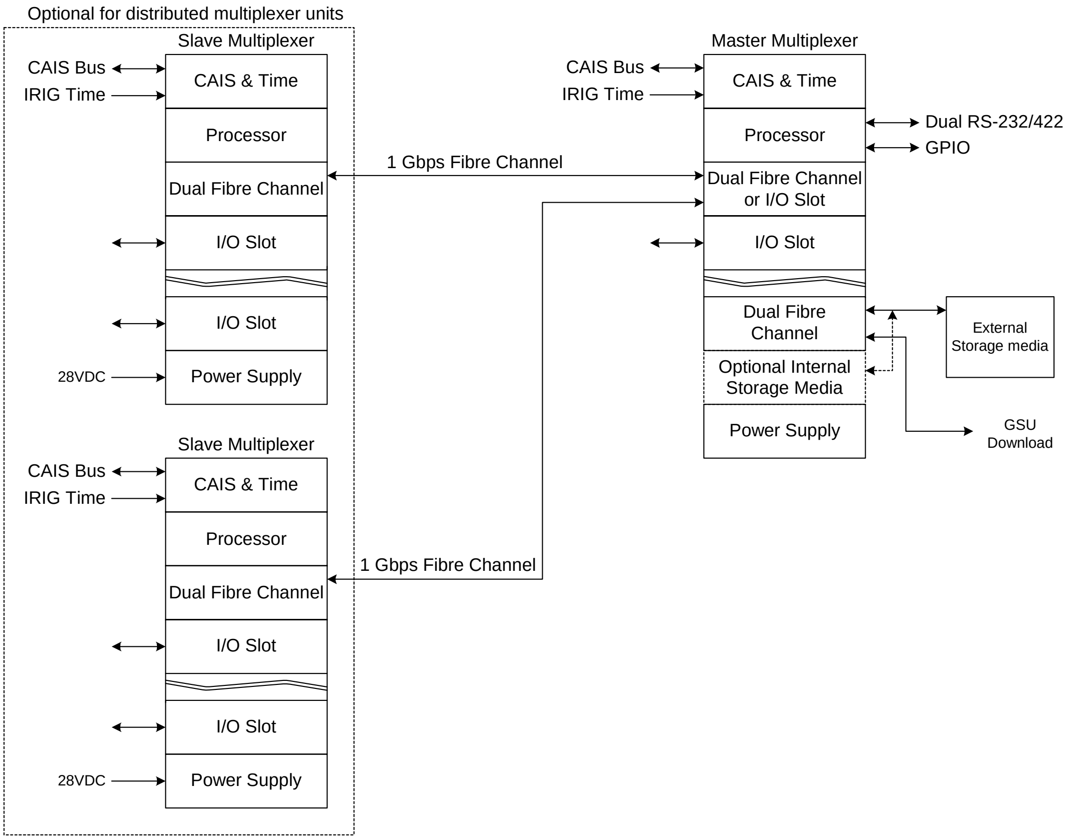
Operating System: The operating system used is a customized 2.4.18 Linux distribution that provided a preemptive kernel with real time scheduling. It provides a very good support of the processor, FireWire, and Fibre Channel. Development cost, runtime cost, source code, IDE tools, and real-time capability are all-important factors in the use of the operating system of the multiplexer.

Acquisition I/O Cards: The architecture allows the interface with peripheral I/O cards via the PCI bus. Each I/O card contains either a PCI2.2 or PCI-X 1.0 compatible bridge. The bandwidth requirement depends upon the type of peripheral card used. The type of cards range from low to medium bandwidth such as 1553 bus, PCM, video, etc., and the medium to very high bandwidth cards such as FireWire, Ethernet, Fibre Channel, etc.

Distributed Multiplexer Architecture

A multiplexer unit is limited in the number of peripheral I/O slots due to the high-speed nature of the backplane. In addition, the physical distance between the data source (i.e. FireWire) and the multiplexer must be such that no violation will result in the source's cable length. A distributed (or multiple box) multiplexer system overcomes both issues, and provides an elegant system solution. This architecture uses a multi-slot chassis populated with a common set of system and peripheral cards and interconnected into a group of 1-5 units for integration into a total onboard flight multiplexer / recorder package. An example of configuration is shown in Figure 2.

Figure 2 Integrated Multiplexer/Recorder Package



The external storage media is connected to the master multiplexer through a fibre channel interface. Slave multiplexers communicate with the master unit through a dedicated point-to-point fibre channel cable operating at 1 Gbps. Unit configuration of master vs. slave is done through a software load. Each unit in the distributed system contains a fixed number of slots and the number of slots is dependent upon the required backplane speed. It is assumed that the designated master unit will operate at an equal or higher speed than the slave units. The baseline unit supports a total of 4 peripheral slots and contains a backplane that provides a peak system throughput of 533 Mbytes/sec. An alternate unit using a peak bandwidth of 264 MB/s and allowing 6 peripheral slots is also supported.

To allow maximum flexibility, the electrical fibre channel interface between boxes was optimized for distances of 1 to 100 ft. An optional optical fibre channel interface will allow greater distances.

Time correlation is of utmost concern when distributed multiplexer architecture and/or multiple storage media are used. Each box receives IRIG time. Additionally, each box maintains a Relative Time Counter in accordance with IRIG-106 Chapter 10. So equipped, each device generates time packets conforming to Chapter 10 Time Data Packets. Time Data Packets are generated at 1-second intervals and transmitted to the master multiplexer for recording. To accommodate simultaneous recording sessions, the master broadcasts all Time Data Packets to all active recording sessions. Thus, in a multi-box system, multiple data channels exist for time; one per box, and each time channel is broadcast to all active recording sessions.

The units packetize all ingress port data in accordance with the Chapter 10 standard. Each packet contains the Packet Header. Within the Packet Header, the Relative Time Counter value represents the free-running counter maintained on the box from which the original ingress port data was captured. The units support packet types that require Intra-Packet Time Stamps as per Chapter 10. All Intra-Packet Time Stamps containing relative time (as indicated by the Packet Flags in the Packet Header) shall conform to the same requirement as Relative Time Counter values. Thus, Intra-Packet Time Stamp values represent the free-running counter maintained on the box from which the original ingress port data was captured. In accordance with Chapter 10, for a given recording session, multiplexer units (master or slave) do not store ingress port data until a representative Time Data Packet for the original ingress port's box has been recorded.

All data packetized in accordance with IRIG-106 Chapter 10 must include a 16-bit unique value to all channels called channel ID. To allow a unique channel ID in a distributed multiplexer system, Teletronics has enhanced the semantics for Packet Channel IDs. The enhanced Channel ID uniquely identifies the original location of a packet's ingress into the system. Teletronics Channel IDs maintain Chapter 10 compliance, while defining sub-fields for box, slot, port, and logical channel ID as shown bellow.

<table>
<tr><td>msb</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>lsb</td></tr>
<tr><td colspan="3">15 13</td><td colspan="3">12</td><td>9</td><td colspan="3">8 6</td><td colspan="6">5 0</td></tr>
<tr><td colspan="3">Box</td><td colspan="4">Slot</td><td colspan="3">Port</td><td colspan="6">Logical Channel ID</td></tr>
</table>

Box: This 3-bit field represents a physical box address in a multi-box solution. Box addresses range from 0 to 7, with a master multiplexer (the unit that interfaces with the recording media) typically assigned address 0.

Slot: This 4-bit field represents a physical slot within a given box unit. Slot numbers range from 0 to 15, typically with the unit's processor board occupying slot 0, and slot numbers increasing with distance from the processor.

Port: This 3-bit field represents a physical port within a board. Port numbers range from 0 to 7. The relationship between port numbers and the physical location of external connectors is board-specific.

Logical Channel ID: This 6-bit field represents a logical channel ID within a port's data stream. Logical channel IDs range from 0 to 63. The logical channel ID is "0" for all port types that do not define logical channels.

As a result of the channel ID breakdown, all channels from a system utilizing a single multiplexer box or from a master multiplexer in a multiple box system will have channel IDs ranging from 0x0001 through 0x0FFF. All channels from slave multiplexer box 1 in a multiple box system will have channel IDs from 0x1001 through 0x1FFF, and so on. Time data packets in a multiple box system will have a unique channel IDs.

Conclusion

The distributed system architecture discussed here allows for the creation of flexible multiplexer / recorder system that can accommodate from a few channels to a large amount of channels, and allows over 100 megabytes per second of data acquisition, multiplexing, health monitoring, recording and general-purpose airborne processing in a modular, yet compact package rugged enough for the avionics environment.

References

Berdugo, A., "Design of a Gigabit Data Acquisition and Multiplexer System", Proceedings of the International Telemetry Conference, 2003, pp. 975-984.

"Telemetry Standards", IRIG Standard 106, September, 2003, Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range.

OMEGA DATA ENVIRONMENT

DROWNING IN DATA, STARVING FOR KNOWLEDGE

Keith Coble /General Dynamics-Advanced Information Systems

ABSTRACT

The quantity Test and Evaluation (T&E) data has grown in step with the increase in computing power and digital storage. T&E data management and exploitation technologies have not kept pace with this exponential growth. New approaches to the challenges posed by this data explosion must provide for continued growth while offering seamless integration with the existing body of work. Object Oriented Data Management (OODM) provides the framework to handle the continued rapid growth in computer speed and the amount of data gathered and legacy integration. The OMEGA Data Environment (ODE) is one of the first commercially available examples of this emerging class of OODM applications.

INTRODUCTION

Moore's Law states that the rate of technological development in the semiconductor industry doubles every 18 months. Technology roadmaps predict that Moore's Law will continue for at least another 10 years, offering another 100-fold improvement in computer speed as shown in figure 1. A similar progression has held for hard-disk storage—in fact, the rate of progression in disk storage over the past 10 years has actually been faster than for semiconductors.

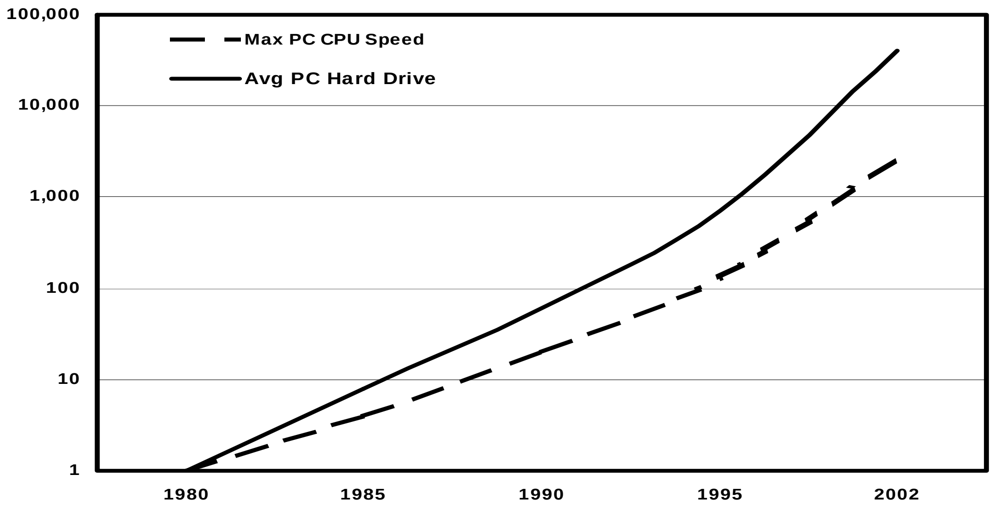


Figure 1

Some of the laws governing data include:

- Parkinson's Law—data will expand to fill the space available for storage.
- Wood's Law—if it is possible to measure, image, or capture a data point, it will be done.
- Johnson's Law—the time it takes to locate information is the inverse of how urgently it is required.

Executives, managers, and researchers are witnessing the convergence of these laws at an accelerating pace. Technology has delivered to our doorstep gigahertz notebook computers, petabytes of mass storage, gigabytes of memory on a stick, and high-resolution displays less than half an inch thick—super computer power at appliance prices.

High performance computing has become pervasive, and with the advent of the Internet, the expectation of instantaneous and accurate access to selected information has grown accordingly. In parallel, the expectation of virtually limitless storage, either locally or over networks, has become the bedrock of our information infrastructure.

OMEGA Data Environment

Implications for Test and Evaluation

This growth in computing power and deep storage has transferred directly to T&E. In the twenty years since the introduction of the PC, clock rates and the size of the average PC hard drive have grown by six orders of magnitude. In that same period, the amount of data gathered per hour of flight test has grown by seven orders of magnitude. The growing body of evidence suggests that this order of magnitude gap between the commercial sector and T&E will be sustained and will perhaps widen over the next twenty years.

The key challenges for the T&E community associated with absorbing this explosive growth in information volume fall into three categories:

- Storage and Infrastructure**—**Maintaining physical storage and related infrastructure
- Data Management**—**Managing, formatting, and processing data
- Data Exploitation**—**Locating specific data elements within the enterprise data superset

Implications for Test and Evaluation

The world produces between 1 and 2 exabytes of unique information per year, which is roughly 250 megabytes for every man, woman, and child on earth. An exabyte is a billion gigabytes, or 10^{18} bytes.[1]

Analysts forecast that disk shipments as measured by storage density will continue to grow by a compound annual growth rate of over 60% in the foreseeable future. In 2002 the global demand for storage for just enterprise software applications was over 80 Petabytes. Other markets including personal computing, digital appliances, engineering, and scientific research increase this figure by almost an order of magnitude. The result is that over 36 billion gigabytes of new digital information, which will require storage, will be created over the next two years.

The total market for T&E-related storage infrastructure accounts for a fraction of a percent of the global storage infrastructure market. The expectation that unique T&E-related R&D in this sector will deliver a better return on investment than the commercial sector is no longer valid. The technical requirements of T&E are not significantly different from the commercial sector with regards to bandwidth, data integrity, and density. Significant differences arise only regarding in situ environmental test conditions and are handily met by specialized packaging.

For this reason, physical infrastructure is the simplest area for the T&E community to address. In responding to the demands of their enterprise customers, the computer and datacom industry have

[1] www.sims.berkeley.edu/research/projects/how-much-info; senior researchers Peter Lyman and Hal R. Varian

[2] NRC-CRC Information and Telecommunication Technology Briefs; http://cisti-isist.nrc-cnrc.gc.ca/ittb/2000-01e.html

developed a robust pallet of technologies that the T&E community can leverage. For example, from 1996 to 2001, available network bandwidth in the U.S. grew by roughly two orders of magnitude.[2]

Adoption of commercial-off-the-shelf (COTS) technologies enables the entire community to ride the wave of innovation created by billions of dollars of commercial research and development.

Data Management

Traditionally the T&E community has responded to information technology (IT) management challenges with domain-specific T&E solutions, which include:

- **Standards (IRIG)—**T&E unique standards ranging from file formats to hardware specifications.
- **Nonrecurring Engineering (NRE)—**One-time, task, or program-specific solutions to solve a point problem.
- **Synthetic Enterprises (SE)—**NRE that transitions from a point solution to an internally funded entity in order to recoup sunk cost by marketing a point solution to other T&E users.

One needs to look no further than his or her own organization to find unique file formats, software applications, and data management solutions. Interestingly, the degree to which an organization attempts to market its unique solution to other organizations via a synthetic enterprise is directly proportional to the amount of money invested in the solution. Doing so results in organizational heat loss as personnel focus on recovering costs at the expense of their core T&E competency.

The result is a landscape of independent point solutions that long outlive their useful lives. Contemporary budgets and technology demand a re-engineering of this approach. They demand the application of IT solutions from general industry to solve IT problems. This preserves capital and provides more effective use of scarce and expensive T&E resources.

As enterprise-level computing continues to obey Moore’s Law, unique point solutions become less compelling. Moreover, as budgets become constrained, focus on non-core activities becomes virtually impossible. Specifically, the problems facing T&E today require pervasive IT solutions from industry, not unique one-of-a kind domain specific T&E solutions.

Data Exploitation

While numerous commercial vendors are addressing the challenges of data storage, infrastructure, and management, the challenge of data exploitation is just beginning to appear on the technology horizon. Data exploitation in the context of binary data sets, or binary large objects (BLOBs), has three components:

- Finding the Data—Locating one or more specific pieces of information out of hundreds, thousands, or even millions of binary data sets across distributed computing environments.
- Presenting the Data—Reconstituting the data with the appropriate and properly versioned processing and visualization engines and their associated support files and information.
- Sharing the Results Through Collaboration—Creating resultant data products, retaining their associations with the spawning data set, and sharing the resultant output.

Finding the Data

Industries facing this task include not only T&E but genomics, proteomics, and imagery. Specifically, how does one find, review, and share the golden needle in so many haystacks?

Once again commercial technology leads the way. Commercial internet search engines enable users to casually explore terabytes of globally distributed text documents located in heterogeneous computing environments.

The resultant subset enables users to quickly drill down to locate information of value. Returns can be culled by iterative fine-tuning of queries. Unfortunately, BLOBs do not lend themselves to the type of indexing and easy retrieval that commercial search engines employ. And because of the unique nature of BLOBs (size, format, symbology), it is unreasonable to expect that commercial vendors will build BLOB-specific indexing and search technologies.

The solution to the BLOB search challenge lies in another family of emerging technologies centered on XML. XML metadata can provide a framework enabling BLOB consumers to build programmatic bridges between raw data and text representations so that commercial search technologies can be used for search and retrieval functions.

Presenting the Data

After the data of interest is found, it must be reconstituted via processing and visualization engines. Significantly, these engines often require applications, variables, and associated files to be present in order to control data presentation, data definitions, and parameter processing. Specific subroutines, libraries, and text loaders may also be required. Hence the second challenge of data exploitation is the holistic association and delivery of all relevant digital elements associated with the core binary data set.

Object Oriented Programming (OOP) offers a suitable solution model. Encapsulation of related applications, files, and variables within a common framework or object model provides comprehensive integration and access to the data elements. Abstraction of the raw data and support elements utilizing this object model yields an elegant set of methods and properties. These methods and properties then provide standardized programmatic interfaces to the raw data, processing engines, and support elements based on their high level class definitions irrespective of the underlying structures.

Sharing the Data

The third step, which follows data presentation, is to create data products in the form of data slices, reports, and analysis. Often resultant data products are separated from the original source data, negatively impacting the extended enterprise's ability to leverage the efforts of all users in the extraction, collaboration, and exploitation of data. Anecdotes have users writing essentially the same report multiple times against a single set of data or repeating test points because of the difficulty in finding historical data of interest.

Most reports are created with COTS tools including Microsoft® Excel®, Word®, and MATLAB®. Inclusion of these documents in the object model enables users to view, review, and collaborate on the efforts of other extended enterprise participants.

Object Oriented Data Management

OODM is a new application class that combines text-based indexing and search capabilities with standardized interfaces. OODM provides a solution set that enables standard search technology to find and return data objects, coupled with an underlying object model that allows legacy and future data formats and processing engines to be accessed via standardized interfaces.

At the core of OODM is the data object. Data objects are the collection of necessary and sufficient data and support elements required for any given raw data set to be self-describing and self-instantiating. Data objects are accessed via published methods and properties allowing standardized programmatic access to the underlining data, processing engines, and resultant output elements.

Because data objects and services can be instantiated on either the client or server, they lend themselves to enterprise-wide distribution using web services technology.

OMEGA Data Environment

The OMEGA Data Environment (ODE) is one of the first applications designed from the ground up to be Object Oriented Data Management (OODM) compliant. It is designed to provide a contemporary IT solution to the challenges presented by Moore's Law in the T&E community. By leveraging proven architecture and technologies from the commercial sector, it offers a robust, scalable solution to the problems associated with managing and exploiting the exponentially growing volume of T&E data. ODE adopts contemporary storage and infrastructure technologies to store, manage and exploit data.

ODE is comprised of three entities as shown in Figure 2:

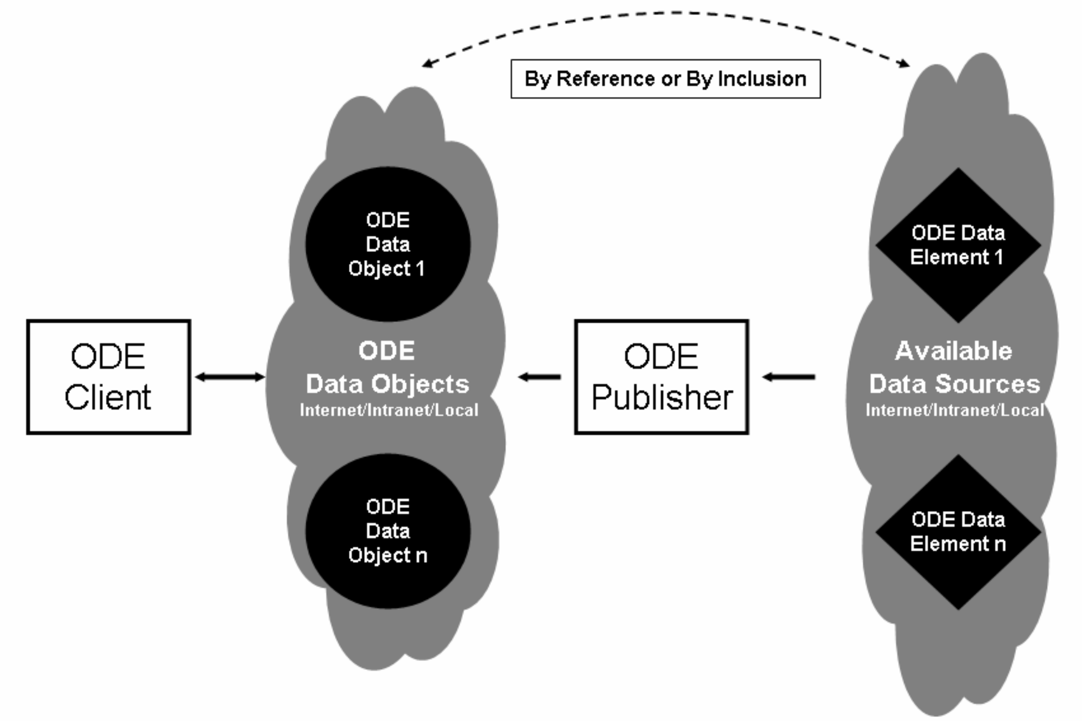


Figure 2

ODE Publisher

The ODE Publisher allows users to aggregate and interrelate the data elements used to generate ODE data objects. As a server side application, it uses the ODE Data Object Model (ODE DOM) to provide ODE data object assembly, formatting, versioning, and publishing services.

ODE Data Objects

ODE Data Objects (ODOs) are composed of three components:

- XML Metadata
- Standardized Interfaces
- Data Elements

ODE Data Object Metadata is an XML wrapper that describes in detail the ODO elements, interfaces, and sub-element specifics for the elements included and referenced by a given data object. ODO metadata provides a searchable index of data elements and subelements within ODOs.

Based on an Object Oriented Programming class model, ODO interfaces are the programmatic framework exposed by the ODE Data Object model for access to, and interaction with, the data elements contained within the data object. The interfaces consist of a series of methods and properties that control I/O and the manipulation of the encapsulated elements. (Figure 3)

ODE data object elements are the specific files, loaders, executables, documents, tools, and raw data sets that are required for an ODO to be self-describing and self-instantiating. These elements are attached to data objects by inclusion or by reference. If an element is attached by inclusion, it is held local to the data object and has a static link to current object instantiation. If an element is attached by reference, a logical path is held internal to the ODO as a pointer to the element with a dynamic link. Both methods have implications for object size and integrity.

ODO elements are divided into four groups:

- Source Elements
- Processing Elements
- Output Elements
- Variables

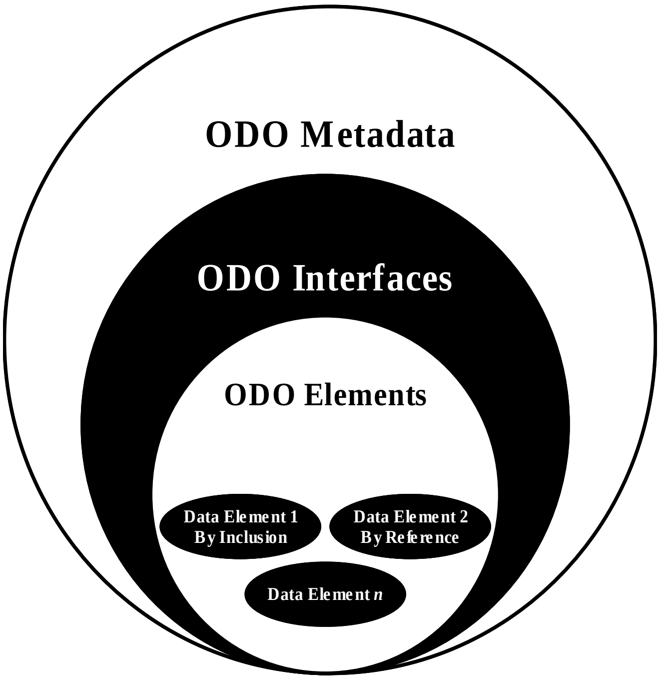


Figure 3

Source elements include raw data and baseline reference data sets for processing elements. Source elements can be local or remote. Processing elements include processing, visualization, output, and formatting engines. Processing elements can be local or remote.

Output elements are the products created by users as a consequence of interaction with source elements via processing elements that are deemed worthy of retention. Output elements can be local or remote. They typically consist of the documents and files accessed by post-processing applications such as Microsoft Word, Excel, Acrobat, Probe, or MATLAB.

Variables are the data used to vary the settings in processing elements as well as properties of ODOs. Variables are held locally and are exposed as part of the ODO DOM via the metadata XML schema.

ODE data objects are dynamic. Specifically, the ODE Publisher creates the first instance of a data object. The object is subsequently accessed by one or more users via browser or other user interfaces utilizing one or more of the included processing elements. During interaction, users may create additional output elements, source elements, or revised variables.

Examples of new output elements might be revised reports and templates relating to the source elements. New source elements could be slices of the source data in the time or frequency domain, data versus data, reprocessed data, or even decimated data.

OMEGA Viewer

The ODE Client is a web service rendered on the user’s desktop. The client enables users to peruse all available ODE data objects within their network horizon. ODOs are accessed via named paths or are located using queries and COTS search engine technology.

Queries are run against the ODO metadata contained within the ODO XML wrapper that is indexed by the search engine. A list of matching ODOs is returned to the user by parsing selected ODO XML tags through Extensible Stylesheet Language Transformations (XSLT). See figure 4 on the following page.

Using the ODE Client, ODOs of interest are located and called. Another page is rendered with a more exhaustive visualization of the ODO XML metadata representing the elements contained within the ODO. ODO elements are presented in a well-structured, logical fashion for ease of navigation and instantiation.

Elements that are called from the viewer can be run on the client, on the server, or both depending on the element type. For example, if a user wants to replay a raw data recording of a telemetry downlink archive, the raw data source element, which may be hundreds of gigabytes in size, would remain on the server and a replay processing element (not unlike Adobe Acrobat Reader) would be called from the ODO and instantiated using processing-on-demand (POD) technology. This replay element would stream raw data from the server and render data visualization locally on the client.

To create an Excel export file of selected parameters over a specified time slice, a user would use the local instance of the replay processing element to export the data to a local Excel file. This local Excel file would be reviewed using a local copy of Excel, and the user would have the option to add that file to the ODO by inclusion or by reference. The resultant file is then available for review by others who might access the same ODO in the future. Collaboration in this most basic form is sometimes referred to as an ad hocracy.

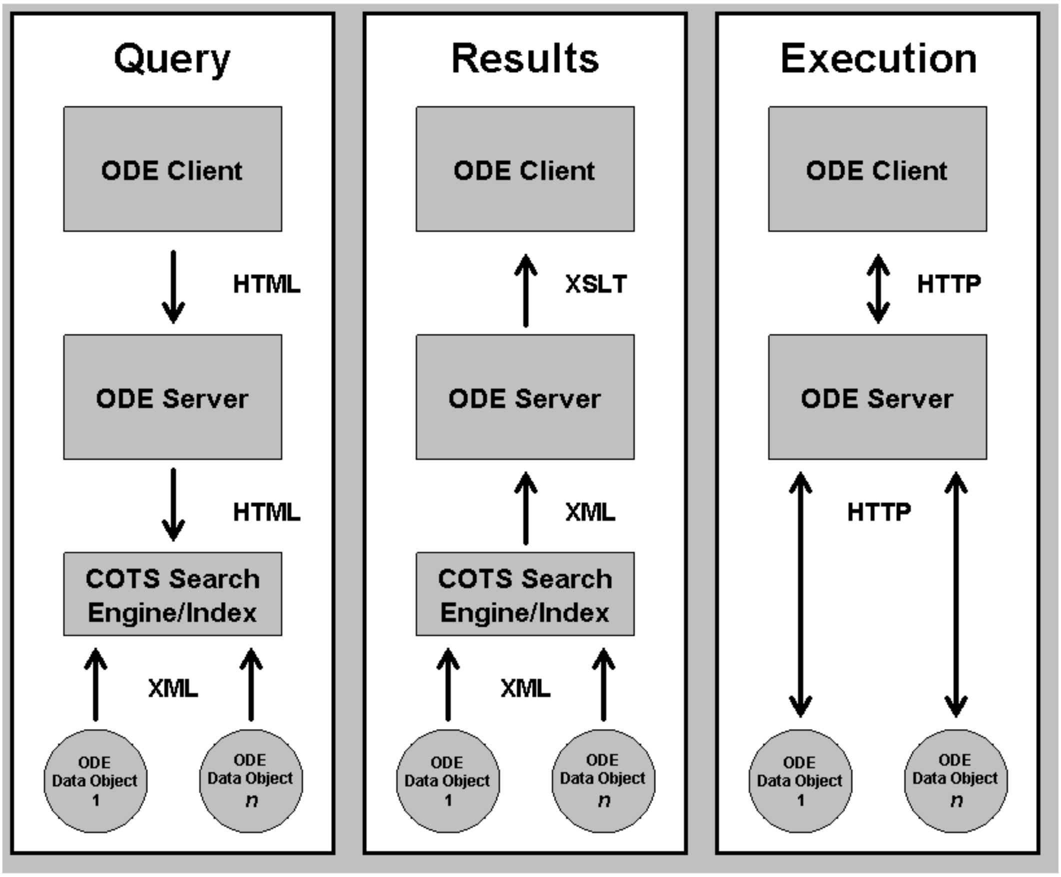


Figure 4

Collateral Benefits

Legacy Integration

ODE provides standardized open interfaces to the underlying data elements. These data elements can include legacy and future file formats, applications, and output templates. ODE mitigates the challenges associated with legacy integration by providing common programmatic interfaces for all underlying data elements regardless of the data's heritage. This abstraction of underlying data elements specific to a common object model with open interfaces allows users to continue to leverage their existing investment while building scalable systems for future growth.

Historical Perspective

As users interact with ODE data objects, they have the opportunity to add information to those objects. The information resulting from these interactions is captured in the object metadata, which is indexed and made available to other users. This organic growth of data objects through user interaction provides a powerful vehicle for enterprise-wide collaborative knowledge growth. The result is a heretofore unrealized ability to leverage the collective knowledge of the enterprise enabling users to learn from history rather than unknowingly and unintentionally repeating it.

Time to Results

As the pace of commercial product development continues to accelerate, T&E customers will demand results in less time and for less money. ODE offers a solution to this problem by offering a standardized framework for information management and exploitation using (and reusing) COTS tools. This allows testers to focus on performing quality testing instead of building one-of-a kind tools and technologies. Most importantly, ODE can deliver an order of magnitude increase in productivity when searching and managing BLOB data.

Centers of Excellence

ODE is collaborative at its core. Iterative interaction with the enterprise knowledgebase provides for the emergence of centers of excellence within the enterprise. Enterprise dynamics are Darwinian in nature. As each group of users interacts with the enterprise knowledgebase and its underlying data elements, groups will emerge as de facto centers of excellence. Some will excel at building high performance, real-time rendering engines; others as posttest, output tool creators. The actual function is immaterial. What is impactful is that ODE provides a platform for the enterprise marketplace to select the best in class through data element use and reuse.

Information Pull versus Data Push

The information universe is changing from push to pull. A few years ago banks sent monthly hard copy statements to customers regarding their bank accounts — push. Today's user logs on 24/7 via the Internet to see the real-time status of their accounts — pull. T&E customers expect the same. They expect access to their data, processing engines, and output formats from any machine, 24/7. They also expect to see meaningful interaction with the information by other team members. ODE provides the mechanism for this to happen.

CONCLUSION

The tremendous increase in data acquisition bandwidth, storage depth, and processing capability has the potential to produce increased fidelity in test results. It also presents a rapidly mounting challenge in how data is stored, distributed, managed, and exploited. The OMEGA Data Environment is one of the first of the class of emerging Object Oriented Data Management applications available for commercial consumption. By utilizing XML metadata to expose native data elements, it provides a rich framework for programmatic search and interaction with complex data. It also provides a solution set for the incorporation of legacy data while extending a flexible coupling to future data types. Because ODE can encompass all data types, from raw data to end results, collaboration is enhanced and meaningful results are generated in significantly less time, with less effort, and for significantly less money.

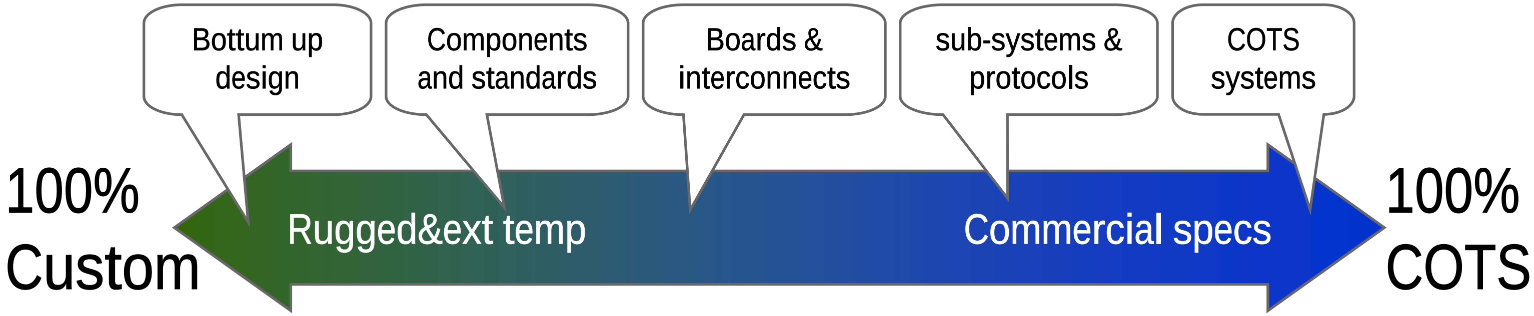
How to leapfrog development of High-speed data acqisition applications through COTS Hardware and Software

Harald Schibbye
Product Manager
www.vmetro.com

Challenges in real-time data acqisition projects

- Time to market
- Choice of standards – technology and interfaces
- Apply COTS products to get the newest technology at the lowest possible price
- Minimize the use of custom hardware/software
- Focus on the application, limit to the essential ”glue” software
- Lifetime support planning, module replacement, technology refresh
- Identify ready-built subsystems in the market place such as: Recorders and I/O Interfaces

"The COTS Meter"



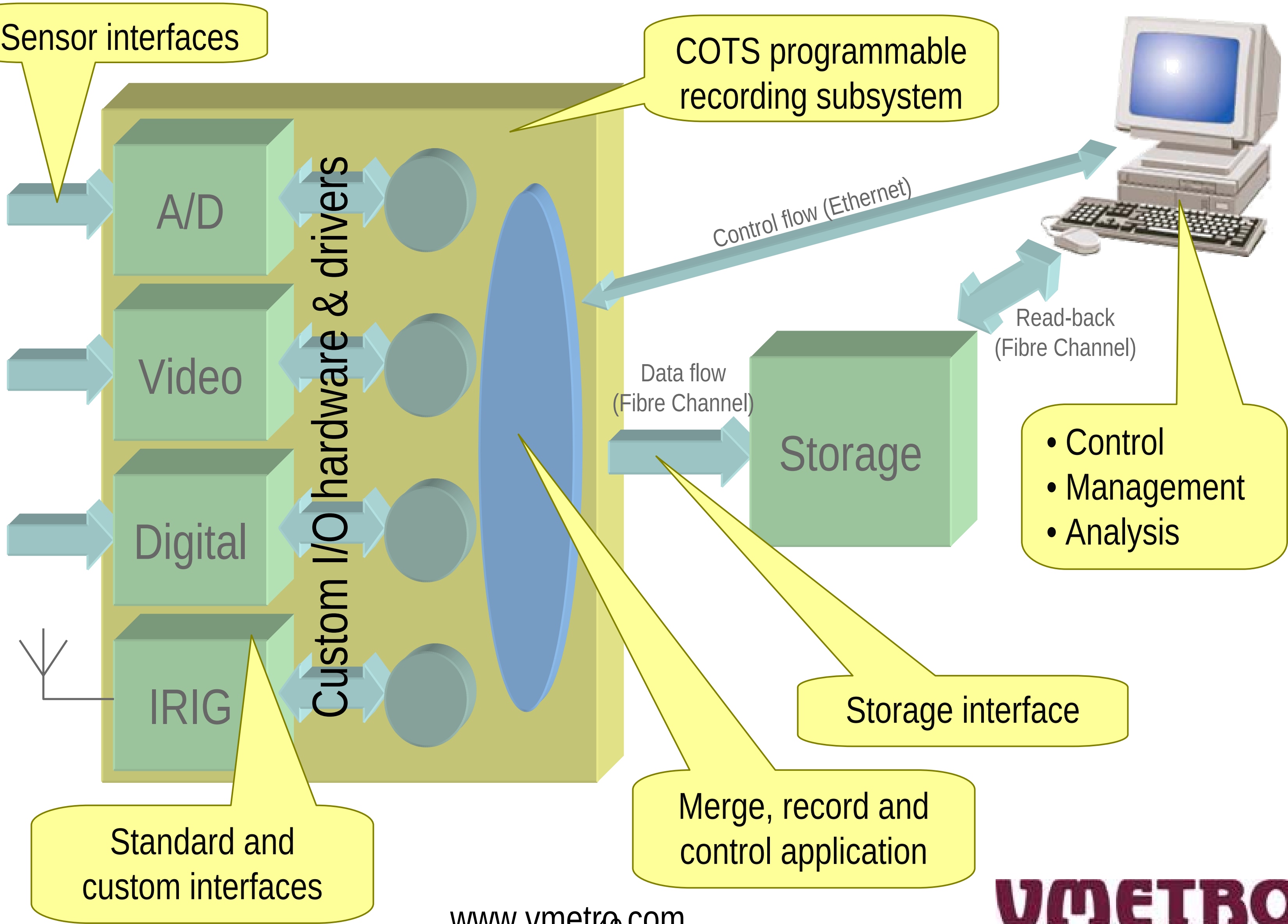
- Point design
- Proprietary architecture
- Project pays R&D
- Project initiates upgrade
- Long lead time
- Performance & Schedule drives cost

- Generic design
- Open architecture
- Industry already paid R&D
- Industry initiates upgrades
- Short lead time
- Cost & availability drive performance

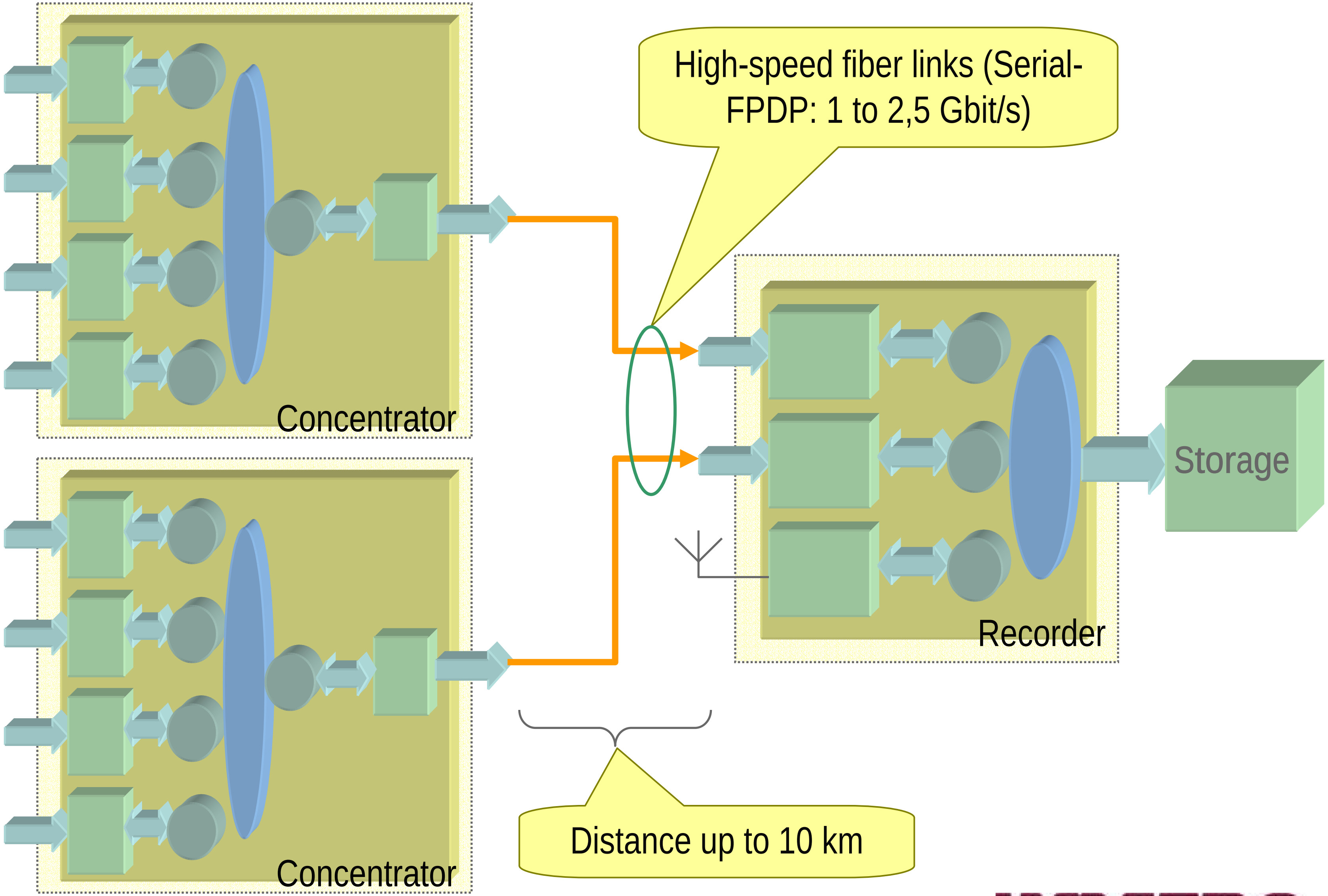
COTS = Commercial Off The Shelf:

Technology acqired "as-is" perhaps with tailoring capabilities

Custom Telemetry Recording



Multi Channel, distributed concentrators



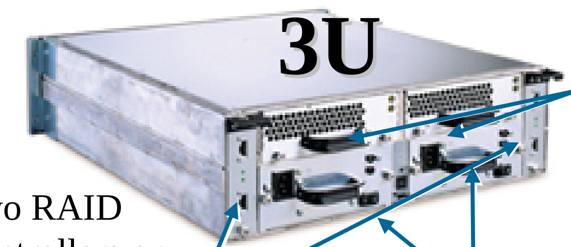
Requirements for a high-speed recorder in high-end telemetry applications:

- Storage technology: Large capacity in scaleable and flexible storage architecture, leveraging on commercial standards for cost
- Speed: Ranging from 5-300 MBytes/sec, sustained operation
- Recording interfaces: Digital parallel, serial, STD 1553, ARINC 429, PCM, analog, RF, video, multiple channels merged
- Playback in real time, read-back for analysis, dissemination and archiving
- Form factor and platform: PC/PCI for availability of products and cost, possibility to migrate to cPCI and VME for high-reliability and rugged applications
- High flexibility and programmability - ”tailoring” capabilities:
  - ⇒ Easy to integrate I/O to accomodate different types of acquisition inputs
  - ⇒ Data management, reduction, stream merging, timestamping, signal processing
  - ⇒ Customizable control and operation using programmable Graphical User Interface

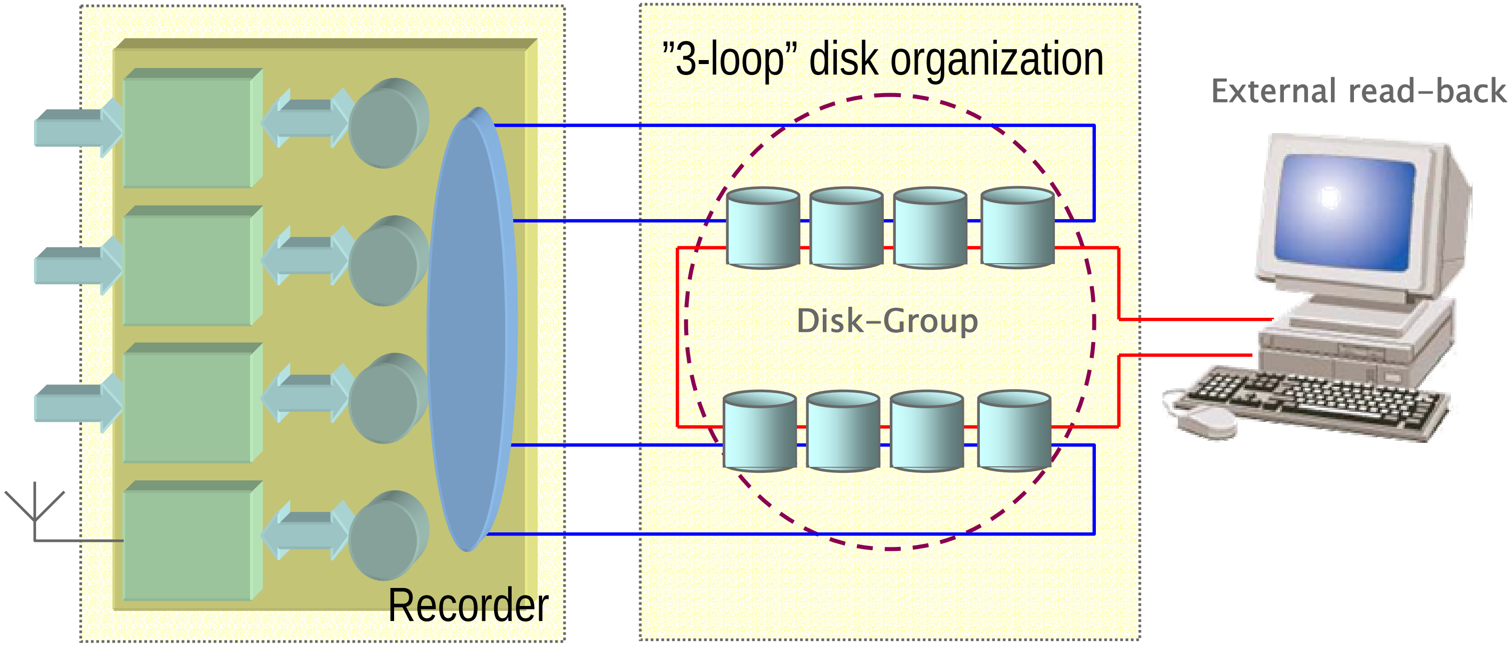
Storage technology

Fibre Channel Disk Array (JBOD)

- JBOD for lowest cost storage
- High reliability, redundant PSU and fan units
- 1 or 2Gb/s Fibre Channel Interface
- Up to two Terabyte of storage (14x146GB drives)
- Storage redundancy options (RAID)



Benefits of disk array with "split" FC Backplane



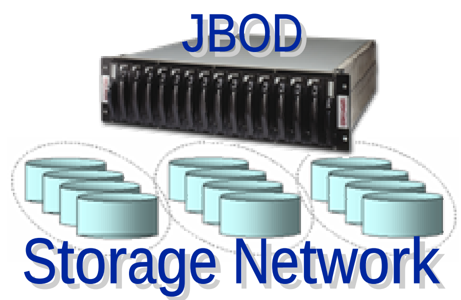
- The recorder gets double Fibre Channel bandwidth
- Read-back is not as speed critical, access to all drives on a single loop
- Transparent to application

Recording SAN – FC Storage Area Network

- Large storage capacity, up to 126 disks connected in 2Gbit/sec <u>Fibre Channel loop network</u>, up to 18 TBytes capacity
- Uses standard Fibre Channel devices and infrastructure
- <u>Fibre Channel Switch</u> for larger configurations and concurrent high-speed paths

High-speed recording technology

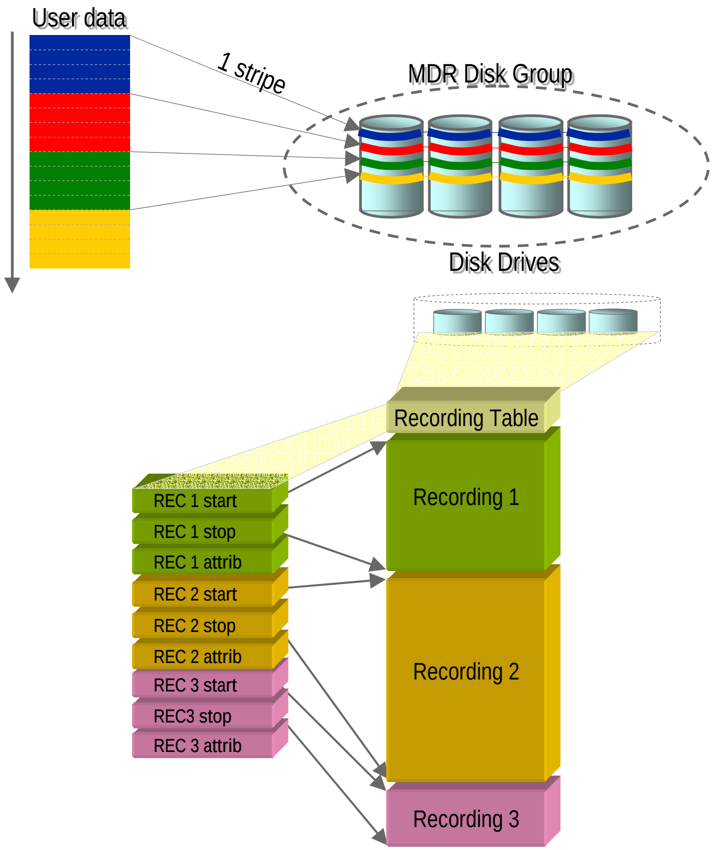
Hi-Speed Recording Technology



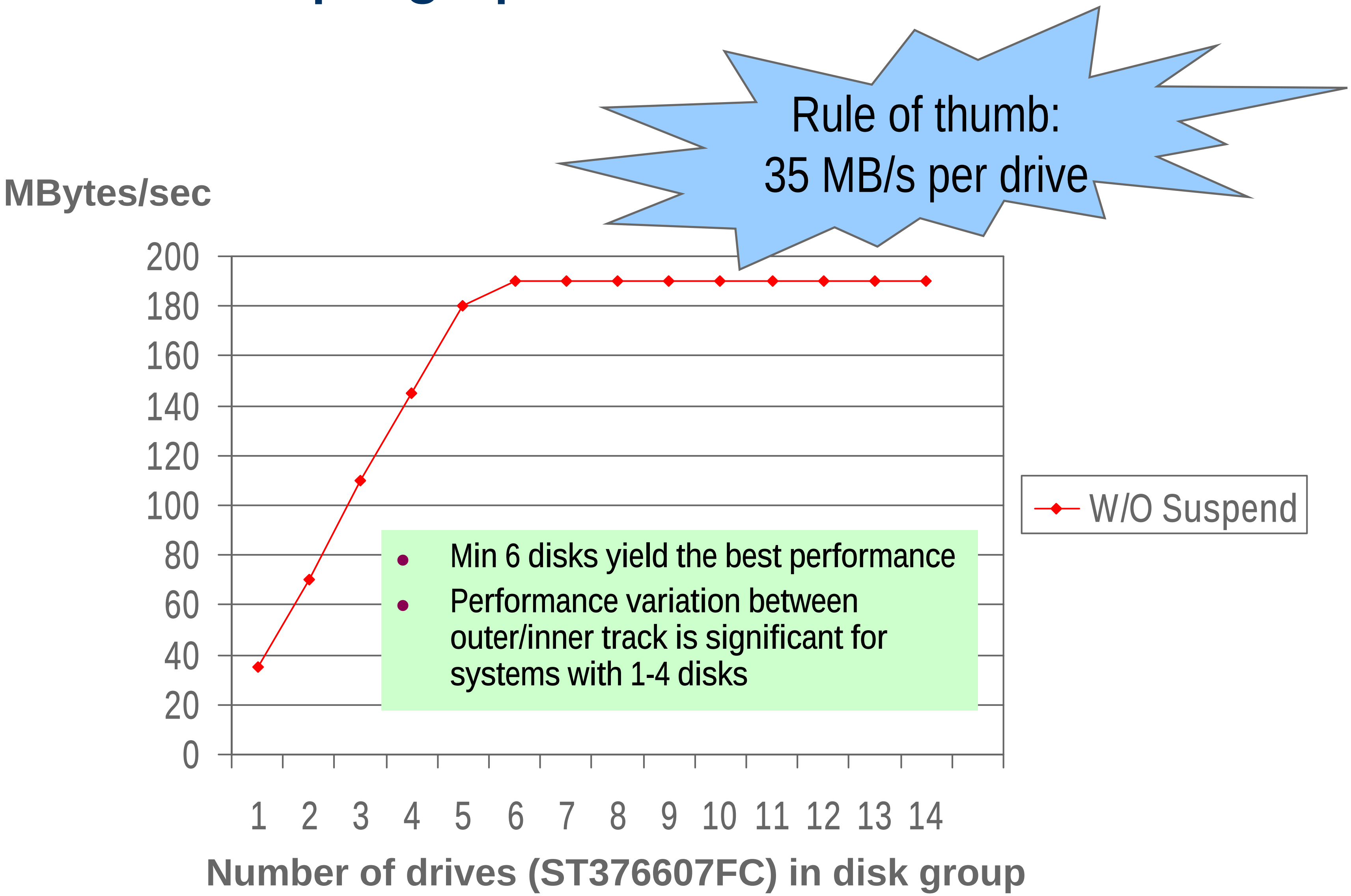
- DISK-GROUPING for organization of large amount of storage capacity divided on many disk devices

- RAID-0 ”striping” to achieve high recording and playback speed by dividing load on several disk drives. Option for RAID-1 ”mirroring” for redundant storage

- REAL-TIME FILE SYSTEM to allow for high-speed and predictable performance, with targeted features for data acquisition such as circular ”endless” recording



RAID-0 stiping speed vs. # of drives

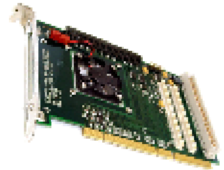
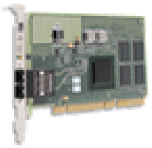
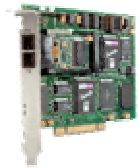
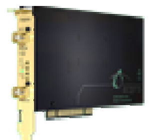
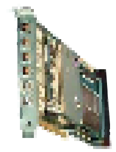


Recording interfaces

Recording Interfaces:

Want to choose from any COTS PCI board in the market

- Parallel
  - ⇒ FPDP (Front Panel Data Port)
  - ⇒ Interfaces with on-board signal processing, DSP or FPGA
- Serial
  - ⇒ FibreXtreme (S-FPDP)
- Network
  - ⇒ Ethernet, Gigabit Ethernet, Fibre Channel, FDDI
- Analog and RF
  - ⇒ Analog-to-Digital (A/D) converters
  - ⇒ Software Defined Radio (SDR) subsystems
- Video
  - ⇒ Digital camera interfaces, TV-boards, MPEG stream, DVI-D, HDMI

Only requirement is the essential driver support

Form factor and platform

PC-Based Recorder with external Disk Array

Web based Graphical User Interface operates locally or can be fully networked as a regular web-site

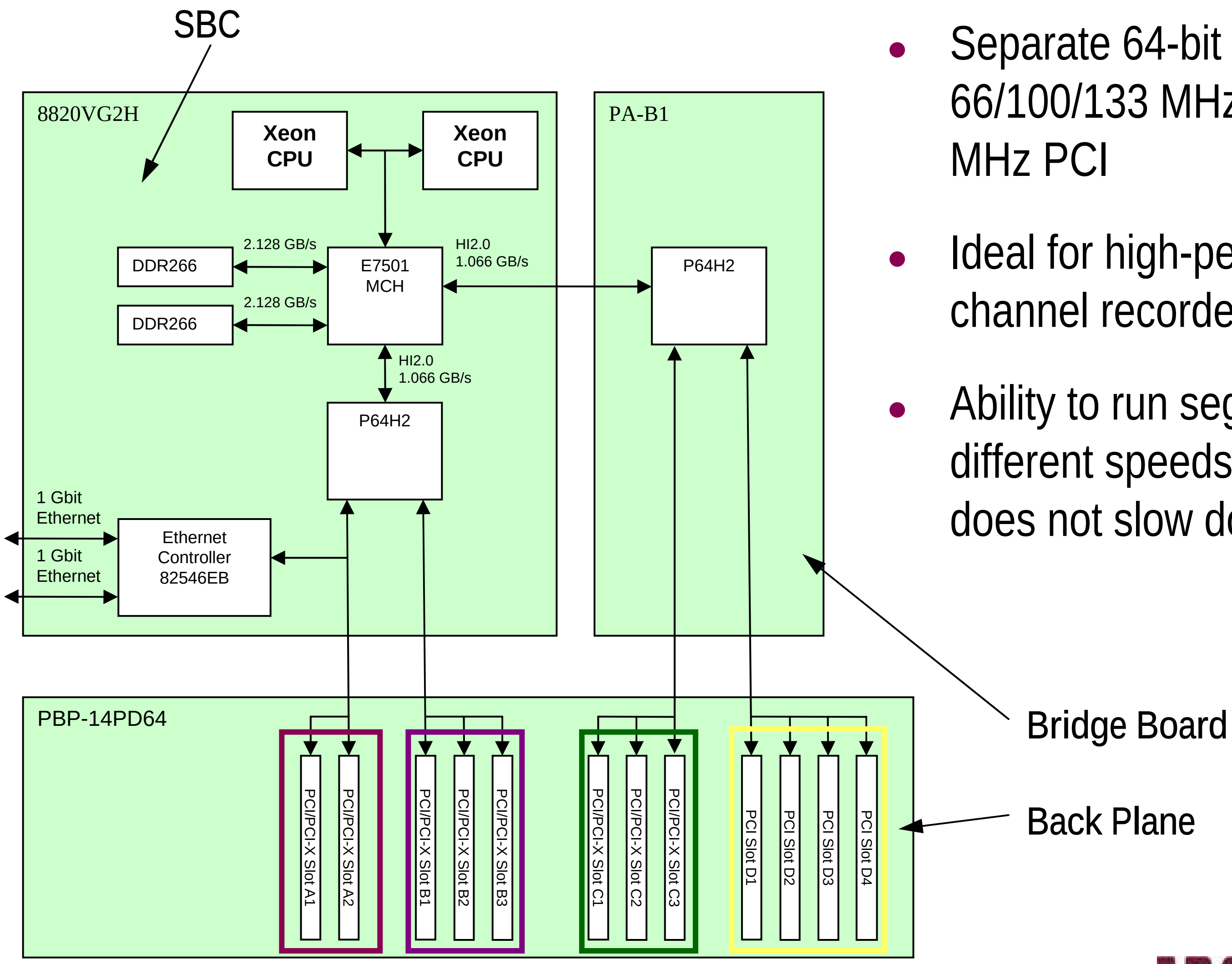
External Fibre Channel connections to external storage (SAN) and read-back network

External Disk Array. Virtually limitless storage capacity can be connected

High-end industrial PC with multiple PCI-X segments for advanced multi-channel CP-MDR applications

Internal Fibre Channel disks

High-performance PC Architecture (block diagram)

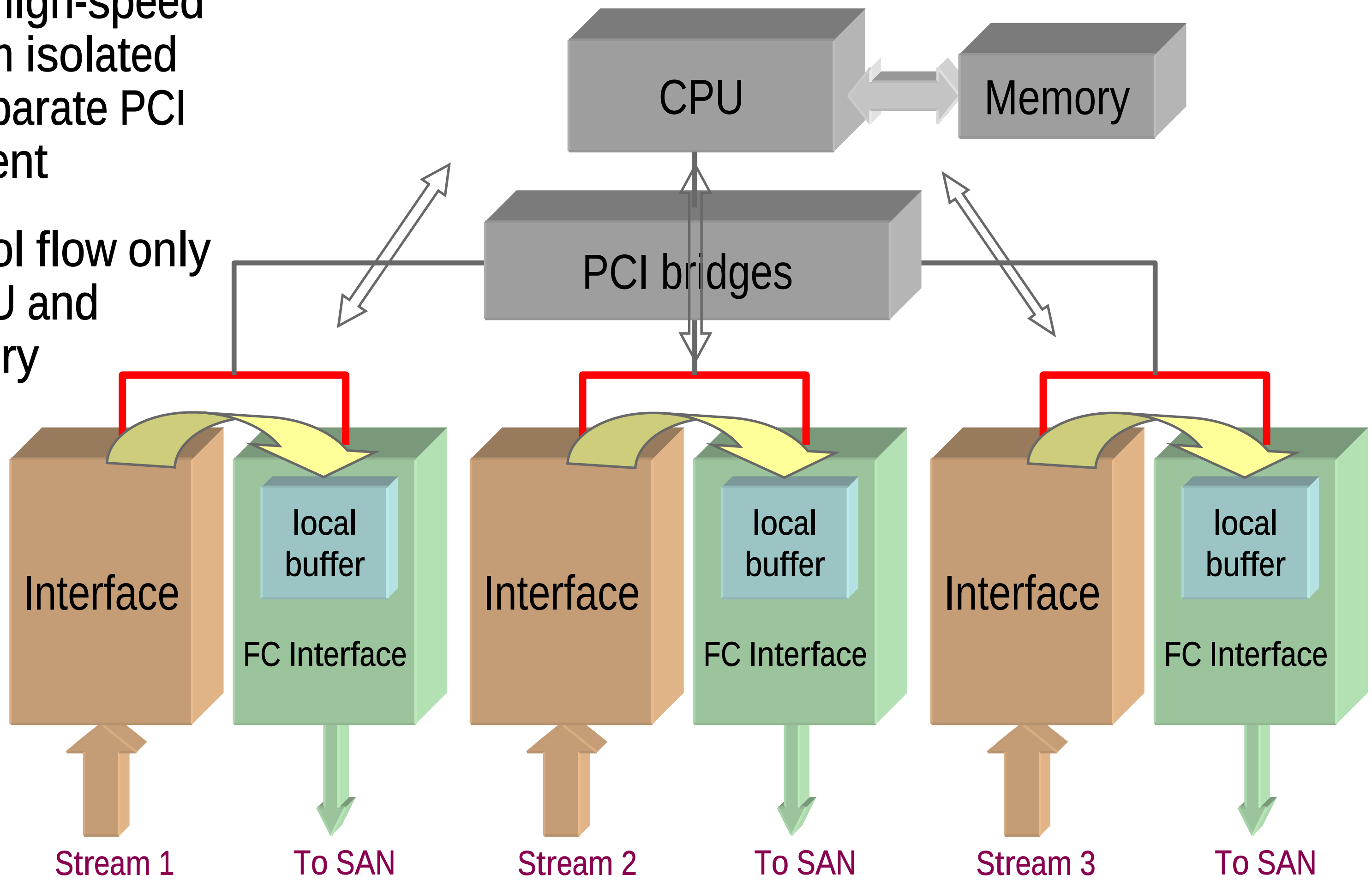


- Separate 64-bit PCI segments,, 66/100/133 MHz PCI-X and 33 MHz PCI
- Ideal for high-performance multi channel recorder applications
- Ability to run segments at different speeds - slower boards does not slow down faster boards

Multi Channel Application Example

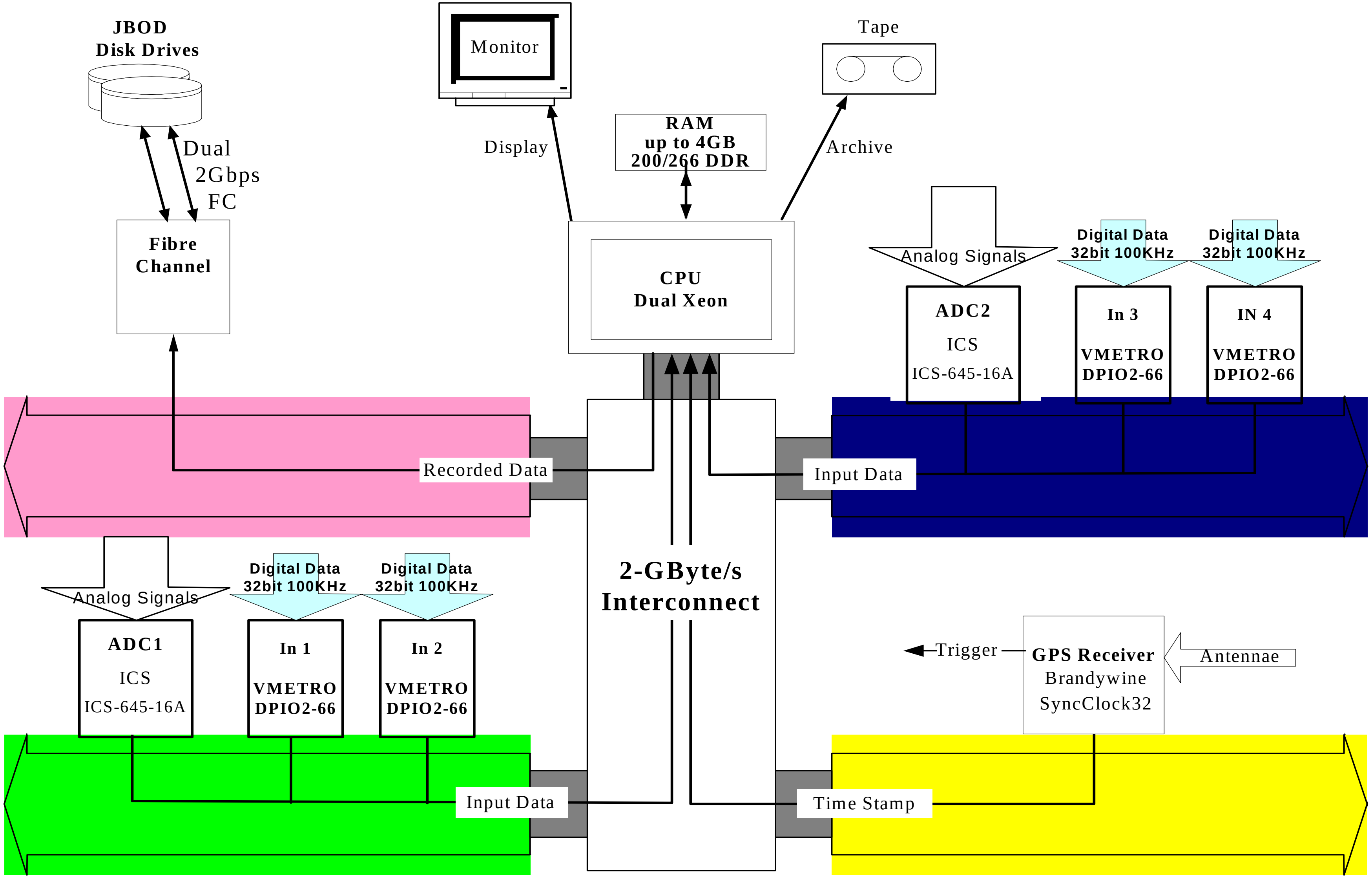
Utilizing Fibre Channel interface with local buffering

- Each high-speed stream isolated on separate PCI segment
- Control flow only to CPU and memory



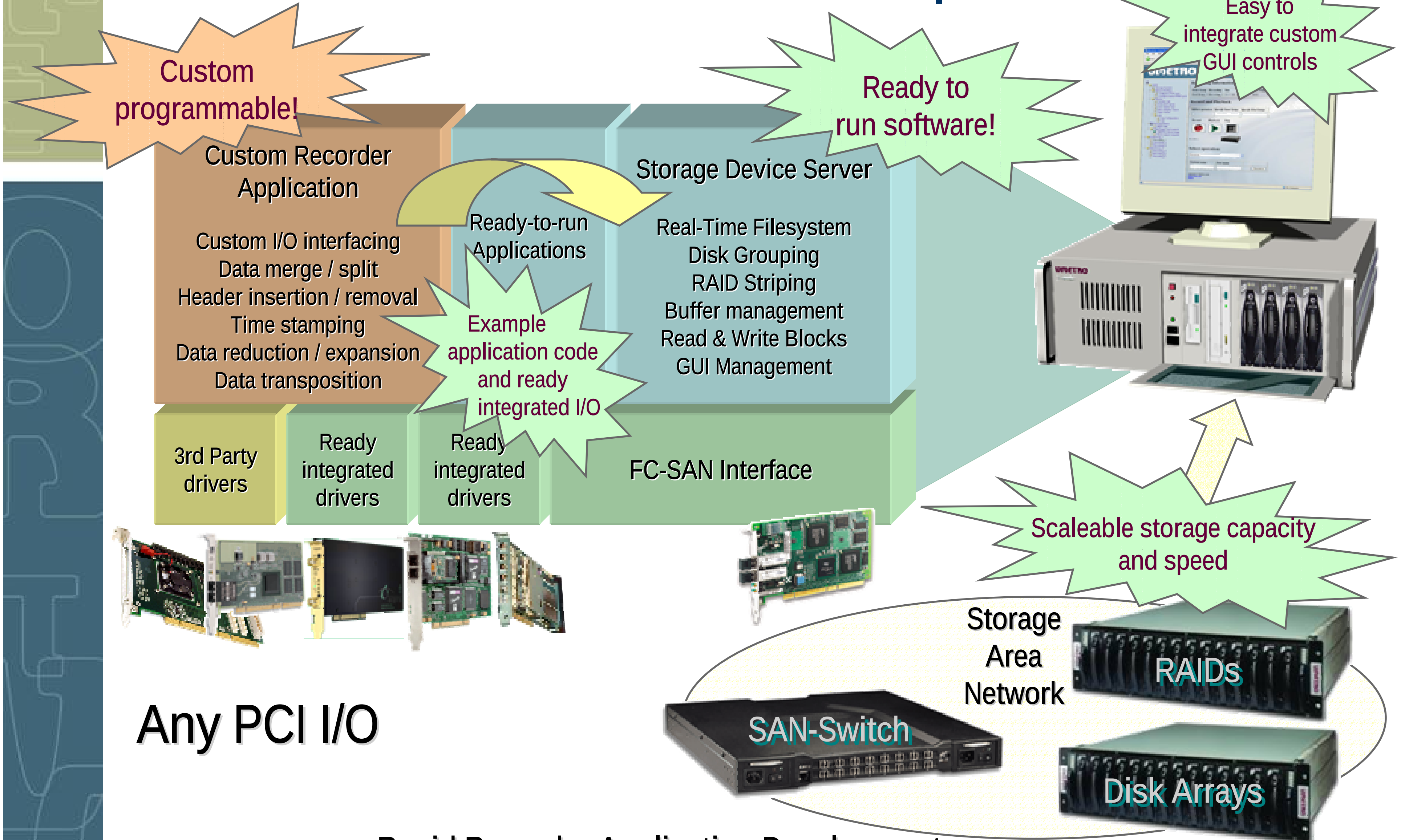
Example Application

Gathering streams at different speeds



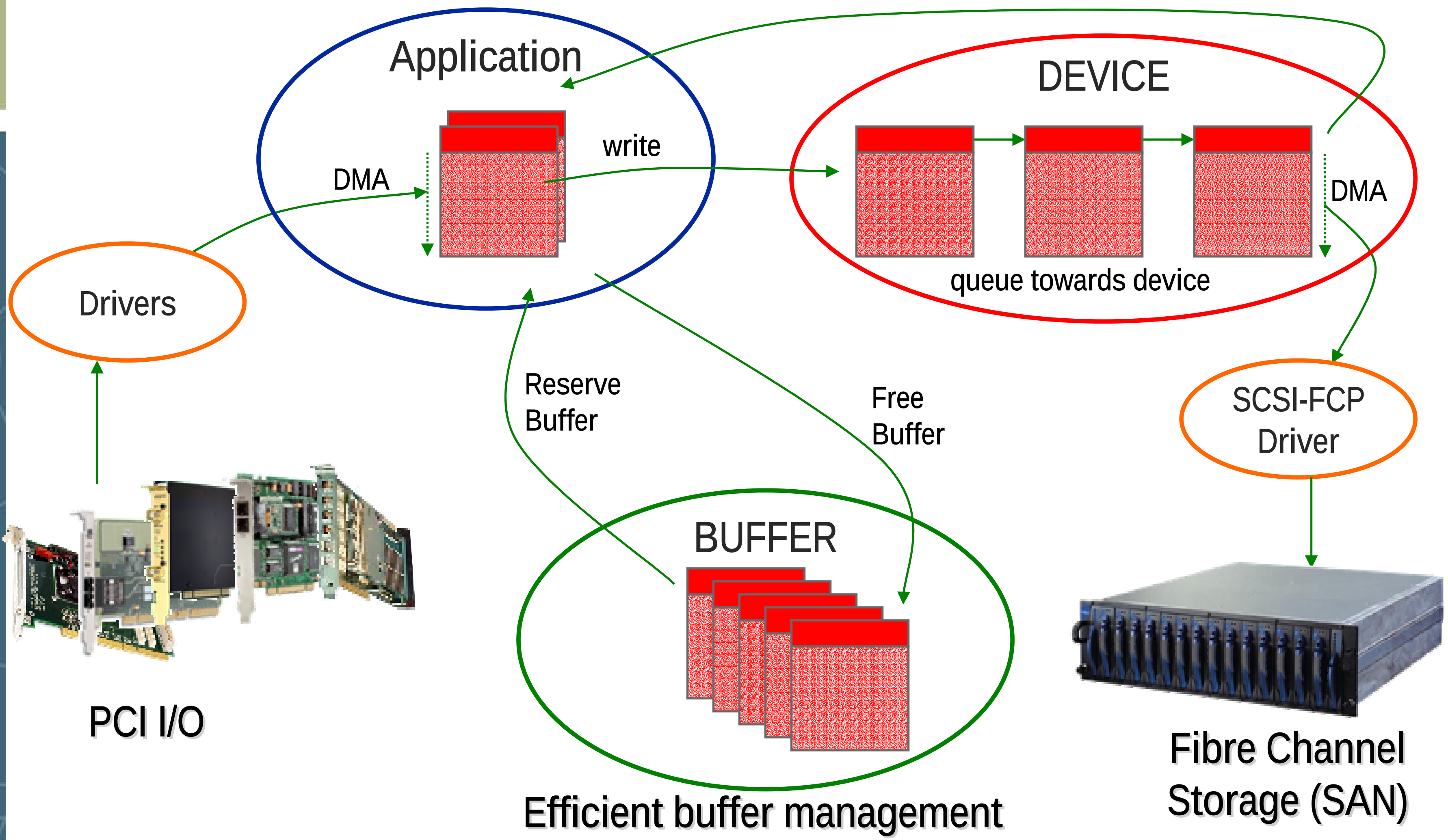
Ease of integration, customization and programmability

The Custom Recorder Concept



Rapid Recorder Application Development

Recorder Programming Model



Application Library

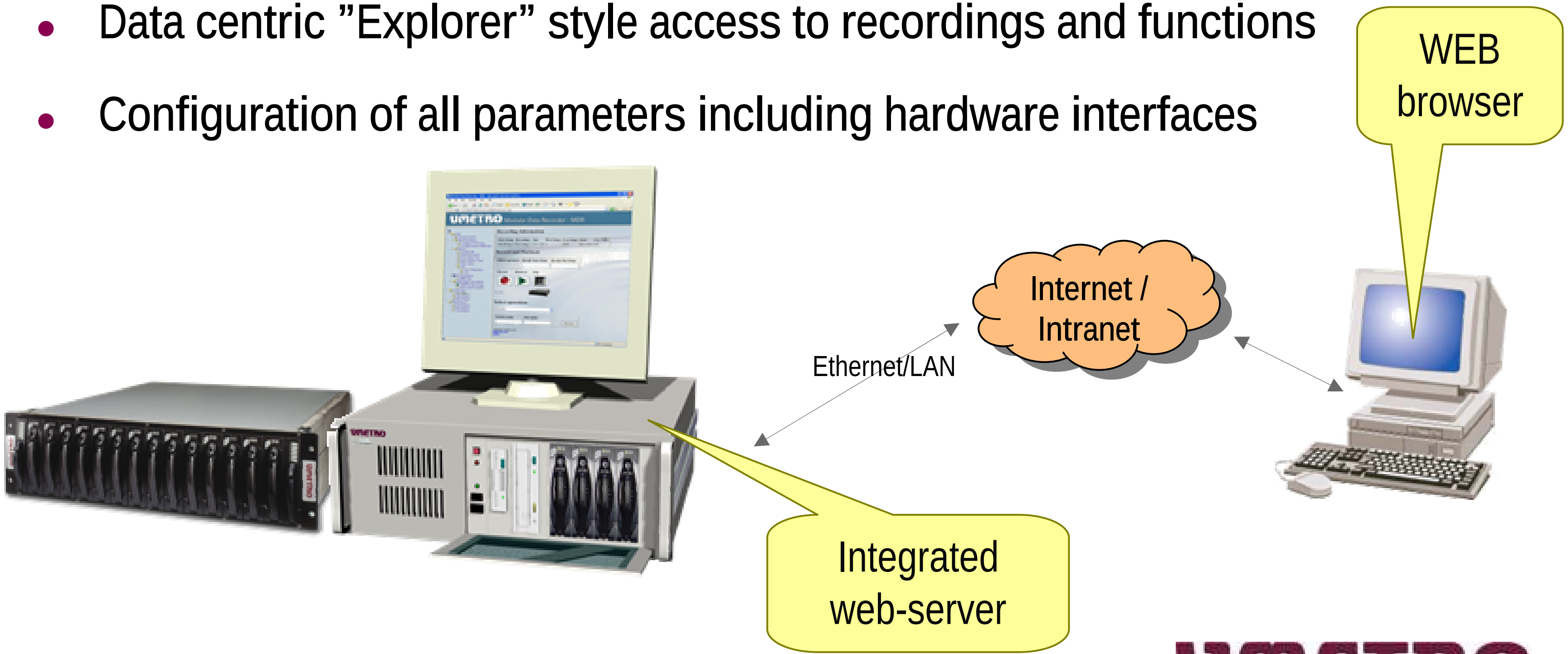
- Application-code based on "OPEN-Recorder" framework
  - ⇒ Consistent look and feel with basic GUI functionality
  - ⇒ Easy to create custom remote/networked management - Client-Server framework of Remote Procedure Calls (RPC) generated directly from function definitions
  - ⇒ Different types of functionality and IO boards offered as a variety of turnkey solutions
  - ⇒ Example application source code for tailoring to custom requirements
  - ⇒ For complex applications, vendor may support and/or perform integration

Component-based SW development
Application Library

- Application-examples managed through configuration control
- Templates (conventions) and design-rules for the application developers
- Documentation;
  - ⇒ Executive summary listing functionality, features, applicability
  - ⇒ Detailed Application Notes
  - ⇒ Well documented Source Code
- Test specification and test-suites

Graphical User Interface (GUI) ”Networked Recorders”

- WEB/html based interface
- No need for software installation on remote workstation
- WEB server on recorder accessed by normal browser
- Data centric ”Explorer” style access to recordings and functions
- Configuration of all parameters including hardware interfaces



Normal WEB browser

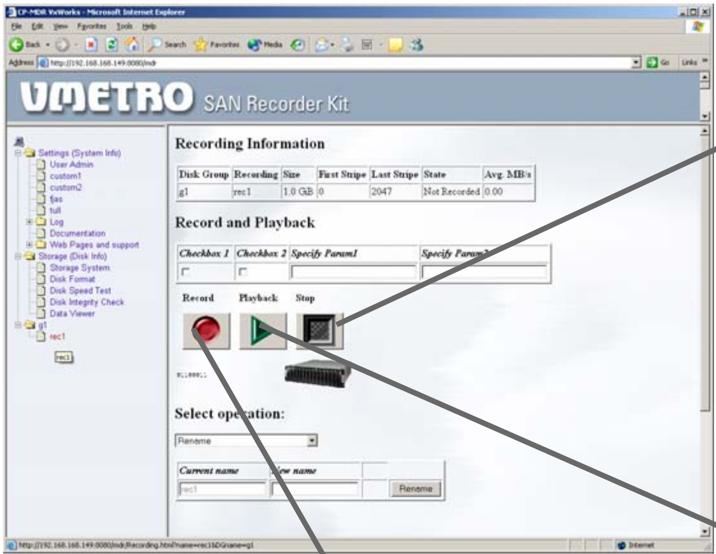
Disk Group properties and configuration

Recorder interface configuration

System utilities:
- Disk utilities
- Integrety and speed testing
- Data view
- Event log

Recording properties and operations

Custom GUI framework



On StopButtonPush {

.. custom code ..

Example-code: <Flush Buffers and stop>

}

On PlaybackButtonPush {

.. custom code ..

Example-code: <Transfer buffers from FC storage>

}

On RecordButtonPush……

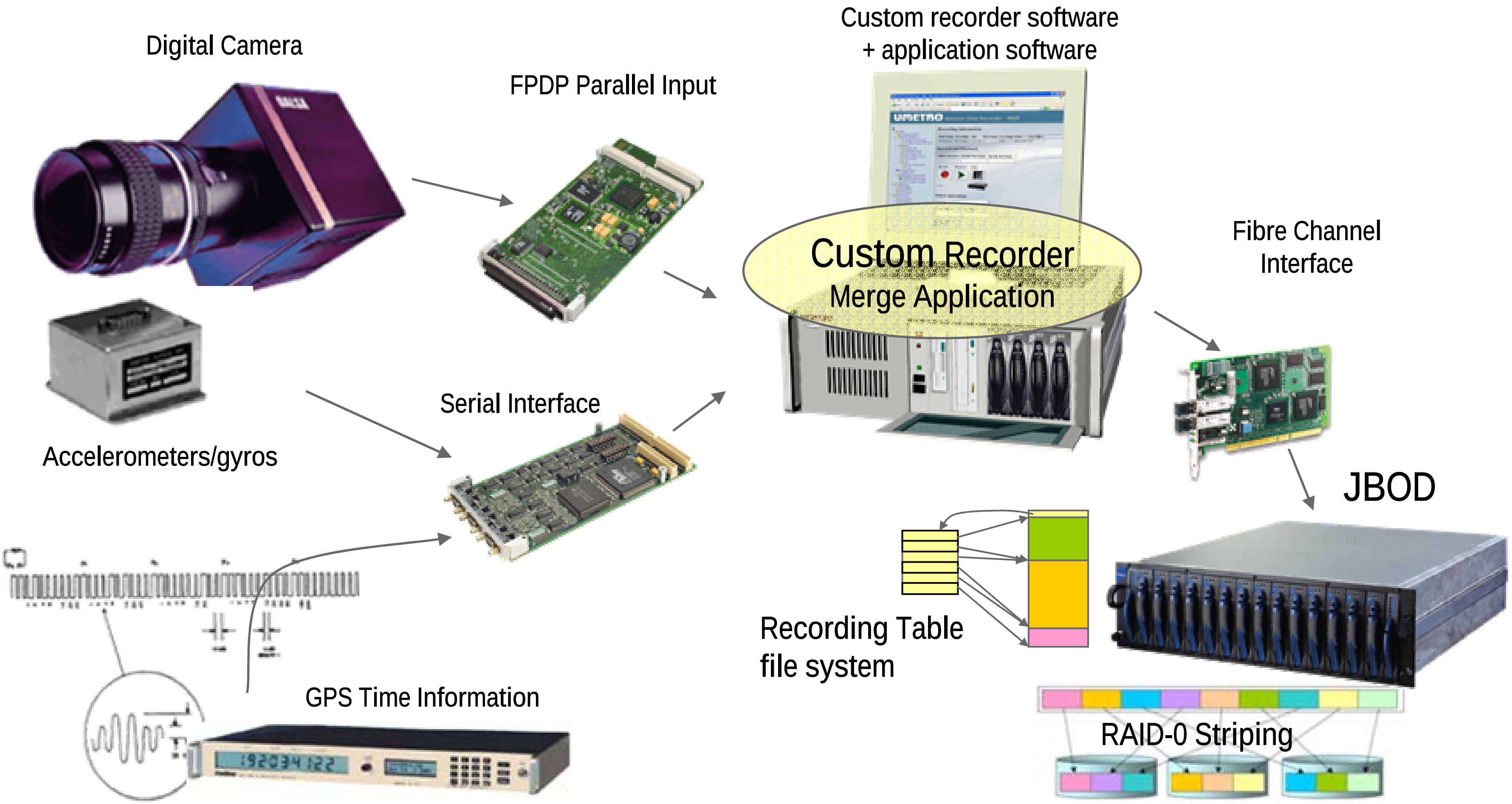
.. custom code ..

Example-code: <Transfer buffers to FC storage>

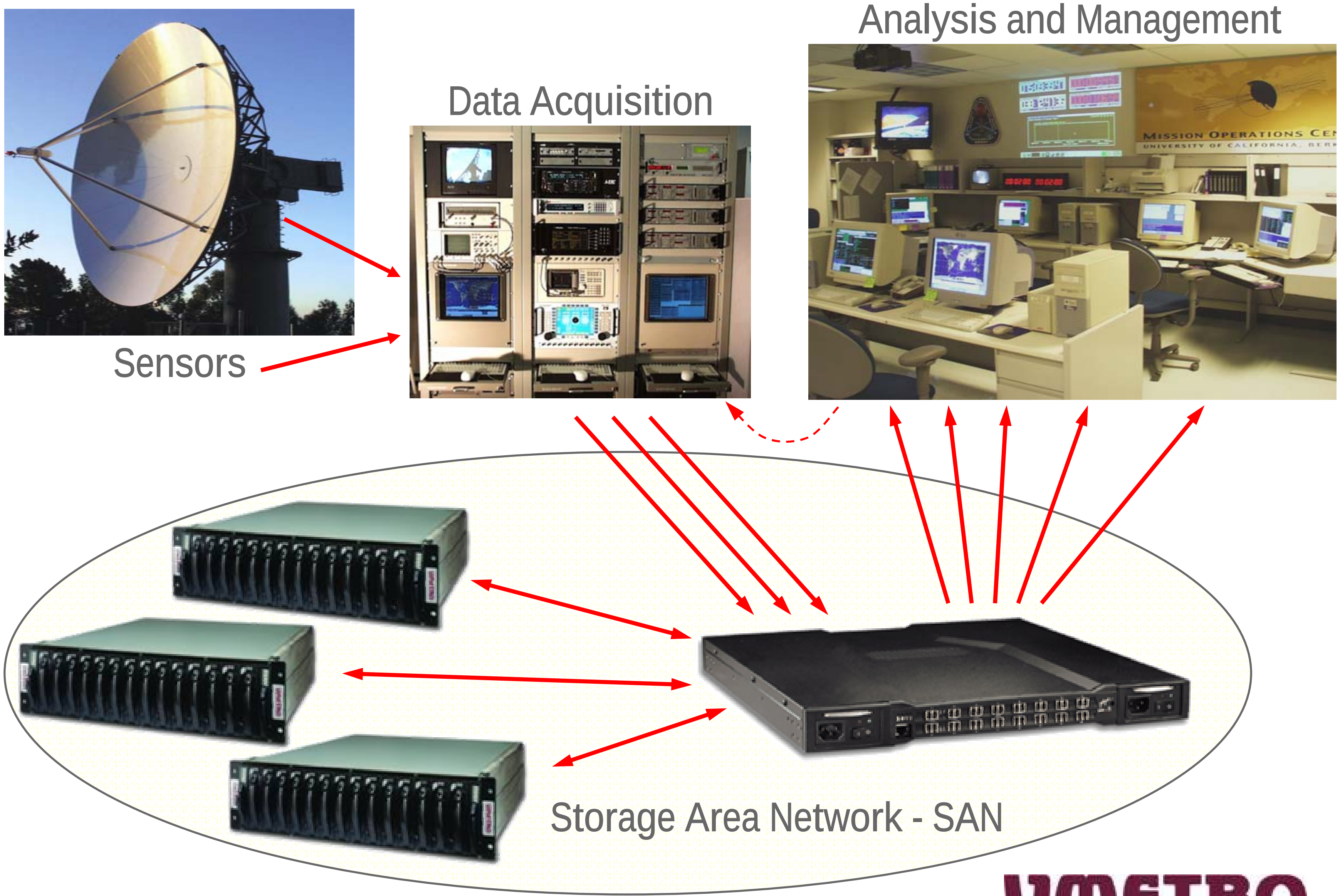
}

Recorder Application Examples

Digital Video Recorder:
Merging Navigation input and GPS Timing



Mission Operations Center



Conclusion

- Flexible COTS platform with open architecture
- Ready-made software for high-speed recording
- Ready made integration to common interfaces
- Framework for easy integrating of custom interfaces
- Ready made GUI for storage handling, GUI framework for custom control
- Leveraging on commercial standards

<u>Rapid data acquisition application development!</u>

Visit us at:

www.vmetro.com

Or at your local COTS distributor in Europe:

www.vsystems.com

RUGGED AND RELIABLE COTS STORAGE SOLUTIONS FOR DATA ACQUISITION SYSTEMS

Ofer Tsur, BSc, MBA
M-Systems
Kfar Saba, Israel

ABSTRACT

Due to the rotating mechanism in mechanical disks, they cannot provide the top-level reliability required for operation in harsh military environments. This paper describes three COTS alternatives to mechanical disks: ruggedized mechanical disks, solid-state flash disks and stacked PC Cards. It discusses their cost-effectiveness and aspects such as environmental specifications, endurance and data reliability. It highlights several methods used by flash disks to enhance endurance and reliability, as well as flash pricing and density trends. It presents data security requirements in actual emergency situations, and how flash disks can meet these requirements. It concludes with a feature-by-feature comparison of ruggedized disks, flash disks and stacked PC Cards.

KEYWORDS

Solid-state flash disk, NAND flash, SCSI, IDE, Sanitize

INTRODUCTION

Reliable data storage is a major concern for engineers designing military data acquisition systems in equipment such as data recorders, telemetrics and reconnaissance. All of these systems must operate under harsh environmental conditions. Although rotating mechanical disks provide very high storage capacity of more than 200GB and are priced at less than $500, inherent design limitations make them unsuitable to operate reliably under environmental extremes.

Their mechanical design, based on spinning platters and head-arms that read/write the information from/to the disk platters, cannot insure data integrity. In addition, mechanical disks do not operate reliably in temperatures outside the range of +5°C to +55°C. Military applications must guarantee reliable performance within the industrial temperature range of -40°C to +85°C. Another drawback of mechanical disks is their low tolerance for shock and vibration. They operate under maximum shock levels of 125G for 2.5” IDE/ATA disk (common for laptops) and up to 65G for SCSI disks (common for servers/desktops), and maximum vibration levels of up to 1G. These shock and vibration levels do not comply with MIL-STD requirements for tracked and wheeled vehicles, nor do they meet MIL standards for airborne and shipboard use. To overcome the limited reliability of mechanical disks, COTS solutions have been introduced to the marketplace.

RUGGEDIZED MECHANICAL DISKS

A rotating mechanical disk can be ruggedized by sealing it in a rigid cartridge. This cartridge encompasses the entire disk mechanism, including electronics, protecting it from high humidity and altitude fluctuations. Advanced sealed cartridges are used for embedded closed-loop servo systems, automatically compensating for temperature variations to ensure reliable head positioning over the entire operating temperature range. Ruggedized mechanical disks are available in capacities of up to 160GB, and deliver sustained read/write performance rates as high as 40MB/s. The cost of ruggedizing mechanical disks ranges from hundreds to thousands of dollars, depending on the ruggedization level required.

Although a sealed cartridge improves the ability of mechanical disks to withstand high altitude, humidity and higher level of shocks and vibrations, additional factors need to be considered. Sealing a mechanical disk doubles and sometimes even triples the size of the unit, in addition to adding excessive weight. A larger and heavier unit for airborne applications within helicopters and fighters translates into a high dollar premium, which is measured per square mm.

In order to improve the shock and vibration specification of a ruggedized mechanical disk, some designers mount it on a shock absorber. If the casing is insufficient to meet the required operating temperature range, a heating and cooling device is used. But the addition of these two components add weight and size, while consuming more power and making the total solution more costly. Based on current pricing for high capacity disks of more than 30GB, ruggedized mechanical disks are cost-effective. But for smaller capacities, the cost of ruggedization is too high per MB/GB to make them a viable option.

SOLID-STATE FLASH DISKS

Flash disks are solid-state with no moving parts, thereby eliminating seek time, latency and other electro-mechanical delays inherent in conventional disk drives. Since flash is a non-volatile memory technology (vs. volatile memory technology such as DRAM and SRAM), it retains data when power is off, as do mechanical disks.

Flash memory has become an ideal solution for replacing mechanical disks where reliability is a key requirement. For flash disks to provide true "drop-in replacements" for mechanical disks, they have identical dimensions, the same mounting holes and the same interfaces. The most common flash disk form factors are: 2.5" (laptop size disk) with IDE/ATA and Narrow SCSI interfaces and a 3.5" (desktop size disk) with Narrow SCSI and Wide SCSI interfaces.

Flash disks operate in the harshest environmental conditions, as defined in MIL-STD 810F. They are used as rugged data storage within military and aerospace systems, delivering significantly higher reliability and a maintenance-free solution as opposed to traditional mechanical disks that are susceptible to mechanical failures and performance degradation in harsh conditions. Solid-state flash disks operate within -40°C to +85°C temperature ranges, absorbing shock conditions at 1500G and random vibrations of 16G at 80,000 feet altitude.

Table 1: Mechanical Disk vs. Solid-State Flash Disk

Category		Mechanical Disk	Solid-State Flash Disk
Environmental Specifications	Operating Temperature Range	+5°C to +55°C	-40°C to +85°C
	Non-Operating Temperature Range	-40°C to +70°C	-55°C to +95°C
	Operating Shock	20G - 25G	1500G
	Operating Vibration	1G (22-500Hz)	16G (20-2000Hz)
	Humidity	5%-90%	5%-95%
	Operating Altitude	15,000 ft	80,000 ft
	Acoustics, Idle/Ready	2.9 (Bels)	0
Environmental Standards	Shock and Vibration MIL-STD 810F	Does not comply	Complies, MIL-STD 810F
Reliability	Actual/Fielded MTBF	<70,000	>700,000
Performance	Average Seek	7.0-3.0msec	0.5-0.02msec
	Average Latency	5.0-2.0msec	None
	Sustained Read Rate	15.0-50.0MB/sec	2.0-30.0MB/sec
	Sustained Write Rate	10.0-40.0MB/sec	2.0-20.0MB/sec
Power	Power Idle	5.0-0.8 Watts	1.0-0.035 Watts
	Power Read/Write	10.0-5.0 Watts	3.0-0.325 Watts
Security	Delete disk data in emergency without retrieving the data	Does not comply, requires degaussers or total destruction	Complies with: - Fast Secure Erase - Sanitize (Purge)
Capacity	3.5" Form Factor 2.5" Form Factor	40GB-300GB 20GB-80GB	128MB-160GB 128MB-90GB
Cost	Procurement	$70-$600	<$500/GByte

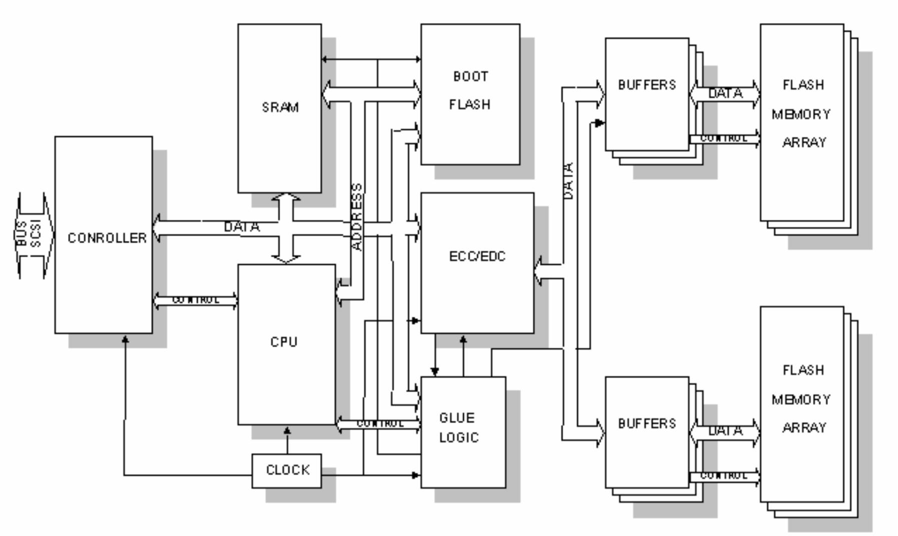


Figure 1: Solid-state flash disk based on SCSI or ATA controller, Error Detection and Correction Code and a CPU, enabling the disk read/write operations to the flash array.

Figure 2: Solid-state flash disks operate within -40°C to +85°C temperature ranges, absorb shock conditions at 1500G and random vibrations of 16G at 80,000 feet altitude.

CHOOSING THE RIGHT SOLID-STATE FLASH DISK SOLUTION

Choosing the right flash disk is much more complicated than simply choosing the right storage interface (IDE/SCSI/Wide-SCSI/FC) and the required disk capacity (in MBytes/GBytes), or evaluating the product that will deliver the best disk performance (sustained read/write rate). Since NAND flash technology has some inherent limitations that affect reliability, the right flash disk must overcome these limitations to meet the extremely high reliability requirements of mission-critical applications.

Addressing the issue of reliability requires understanding how flash works. Flash is non re-writable and must be erased before it can be written to again. Flash is erased in blocks (typical block size is 4 to 64 KBytes), which are much larger than disk sectors (512 bytes). In addition, flash has a limited number of erase cycles of 100,000 to 1,000,000 (flash has no limitation for read operations). NAND flash can accumulate up to 2% of bad blocks during the manufacturing process, as well as additional bad blocks during flash operation. The number of bad blocks also accumulates due to the write/erase operation, during which electrons are captured in an oxide layer and create internal electrical stress. The stress is created when only one block is accessed repeatedly by an erase/write operation, while the remaining blocks are untouched. This stress increases the bad block accumulation rate during flash erase/write operation.

ENHANCING SOLID-STATE FLASH DISK ENDURANCE

Some flash disk manufacturers incorporate methods to enhance endurance. One of the most common techniques is called *erase before write* or *counter wear-leveling*. This method implements a counter for every flash block to count the number of write cycles. Every new write operation is preceded by an erase operation to the block where the data will be stored, and the block counter is updated. When the specific counter reaches the flash erase cycle limit, the block is marked as a bad block. Although the data in that block can be read an unlimited number of times, it cannot be written anymore. When the application tries to execute a new write operation to such a block, the new data is stored in a different block taken from a pool of spare blocks, and a pointer points to the new location. The "erase before write" algorithm intensively wears out the flash over time, as the whole erasable block is erased every time even though only part of the block is updated. If the application executes write operations to the same location over and over again, these blocks will reach the erase cycle limit, decreasing the total flash disk capacity available for write operations.

A more advanced method to enhance flash disk endurance, while keeping the entire media size available for write operations without a decrease in capacity over time, is called TrueFFS® (True Flash File System). TrueFFS technology uses *dynamic wear-leveling*, *virtual mapping*, *garbage collection* and *bad block mapping-out* (BBM) algorithms to optimize flash usage.

The dynamic wear-leveling algorithm guarantees that all blocks in the flash disk are erased the same number of times, preventing the application from repeatedly writing to the same location until flash blocks wear out. Dynamic wear-leveling enables the entire available capacity of the flash disk to be used for write operations. TrueFFS performs virtual mapping of logical sectors to physical blocks, transparent to the user's application. The TrueFFS garbage collection process eliminates the need to erase the whole block prior to every write. This process accumulates data marked for erase as garbage, and performs a whole block erase as space reclamation in order to re-use the block for the next write operation. Once a block becomes problematic, the BBM algorithm marks the block as a "bad block" so that TrueFFS no longer uses it. Large pools of spare blocks, up to 4% of the flash disk capacity, are used to increase disk endurance.

IMPROVING DATA RELIABLITY IN SOLID-STATE FLASH DISK

Some flash disk manufacturers use a volatile DRAM/SRAM data buffer to increase disk performance. Powering down when the disk is written, or when data resides in the cache, causes an incomplete write sequence. A DRAM/SRAM cache buffer also causes disk performance to decline when the cache buffer is full (during write operation) and when data does not reside in the cache (during read operation). Using a flash disk without a volatile data cache increases disk reliability under unstable power conditions, and also provides sustained read/write performance that is undisturbed by cache status.

Even if no volatile caching is used, power cycling may cause data corruption. It is important to verify that the flash disk does not tolerate “in-between” data states caused by a power failure, during which the data is only partially written to the disk during a write operation. To prevent this, the flash disk should use the following sequence: perform the write operation, verify that all data was written, and only then update the mapping information. Mapping must always reflect the correct status of the write operation. Only after the success of this sequence should the flash disk update the mapping as “block was successfully transferred”.

Since flash disks are designed to operate in mission-critical systems for many years, removing them to perform status checks is unacceptable; hence, remote monitoring is needed. One example of remote monitoring is *SMART (Self-Monitoring, Analysis and Reporting Technology).* When SMART is activated, the disk performs internal monitoring and reports back the test results, indicating the disk status. SMART is commonly used in mechanical ATA/IDE disks to test, among other things, the reliability of the mechanical disk spinning mechanism. Since flash disks have no moving parts but accumulate bad blocks over time, SMART was converted by some flash disk manufacturers to analyze the flash disk bad block status. SMART calculates the total number of bad blocks accumulated after manufacturing relative to the total capacity. This result provides the user with an indication of flash disk reliability and expected life span.

STACKED PC CARDS (PCMCIA ATA CARDS)

Some solid-state flash manufacturers provide hybrid designs that incorporate several units of PC Cards (PCMCIA ATA Cards) to compose a single solid-state flash disk. This hybrid design is less expensive for small capacities that use one or two units of PC Cards, since it uses standard PC Cards available in the marketplace for non-military applications. A solid-state flash disk with higher capacities using three or more units of PC Cards is more expensive than standard solid-state flash disks. With each additional PC Card, there is an additional payment for the PC Card casing, the PC Card internal controller and the adapter mounted within the disk.

Some hybrid PC Cards designs can cause reliability problems under high shock and vibration conditions, due to their Lego-like structure. This issue needs to be address closely, especially in airborne applications.

PC Cards support the ATA/IDE command set. For a SCSI interfaced solid-state flash disk based on PC Cards, there is a need for “on the fly” protocol conversion. ATA/IDE must be converted to SCSI during read operations, and SCSI to ATA/IDE during write operations. The conversion time can lower the disk read/write performance. If the conversion is not smooth, abnormal disk operation may result.

Since PC Cards were originally designed for industrial applications and not specifically for the military, they do not provide Secure Erase and Sanitize. In addition, they must manage bad blocks, an inherent flash limitation, to verify that bad blocks that contain confidential information are completely erased.

Table 2: Stacked PC Card Design vs. Solid-State Flash Disks

Category	Stacked PC Cards (PCMCIA ATA Cards)	Solid-State Flash Disk (not using PC Cards)
1. Fast Secure Erase & Sanitize 2. Partial (Selective) Erase 3. Auto-resume erase during power cycling 4. Erasing confidential data from bad blocks	Does not comply, must be solved externally	Complies, supported internally by some solid-state
5. MIL-STD 810F Shock and vibration	Must to be addressed due to Lego-like design	Complies
6. SCSI commands	Requires on the fly translation from IDE to SCSI and back	Complies, has direct SCSI controller
7. Wear-leveling 8. Bad block mapping out	Does not comply, must verify support	Complies, supported internally
9. Removability	Complies	Complies with: - 80-pin SCA Ultra Wide SCSI - Mounted in removable cartridge
10. Cost	Cost effective for 1-2 units of PC Cards (small capacities)	Cost effective for > 2 PC Cards are needed (higher capacities)

SOLID-STATE FLASH DISKS TRENDS

In the past, cost was a real barrier to solid-state flash disks deployment, but the flash industry has its own version of Moore's law that overcomes this barrier. According to this law, the density of the flash component doubles within the same silicon footprint size every 12 months, enabling double the capacity every year in the same casing size while sharply reducing flash cost.

Limited capacity and very high flash costs prevented designers in the past from using flash disks. But leading flash manufacturers such as Toshiba and Samsung have improved their processes over the past four years by using less silicon, reducing costs and increasing flash capacity. In 1999, solid-state flash disks were being sold at $5 per MB (1GB for $5,000), while in 2000 the cost came down to $3 per MB (1GB for $3,000). In 2001, it dropped to $2 per MB (1GB for $2,000) and in 2002 it dropped even more to $1.2 per MB (1GB for $1,200). During 2003, the cost has declined yet again to less than $600 per GB. This trend should continue in the future.

Solid-state flash disk performance has also improved dramatically. Until 2000, Narrow SCSI sustained read/write rates were only up to 3MB/sec. In 2001, Ultra Wide SCSI solid-state flash disks were introduced, increasing sustained read/write rates to more than 20MB/sec. This performance enables the storage of video applications and high resolution images.

SECURITY IN EMERGENCY CONDITIONS

On April 1, 2001, a US Navy surveillance plane (EP-3E ARIES II 156511/PR-32) was forced to make an emergency landing in China after what officials described as a "minor" mid-air collision with a Chinese Navy Shenyang F-8-II "Finback" fighter. The incident occurred over the South China Sea when two Finbacks intercepted the EP-3E ARIES during what the U.S. Navy described as a “routine” patrol flight.

The EP-3E crew's procedures for handling classified materials would have involved erasing data and software from computer hard drives and destroying CD-ROMs, floppy disks and key pieces of equipment, including cryptographic systems that encode the electronic signals gathered by the aircraft. The crew had between 12 and 20 minutes in the air to destroy all classified material before making the emergency landing. They had approximately another 12 minutes after landing and before emerging from the aircraft to complete what they probably began while airborne, according to reports. U.S. officials said that in the final moments before the spy plane landed, the crew may have been trying to destroy the hardware with hammers and axes.

Just how much the crew was able to destroy is not clear. However, the potential damage to the collaborative intelligence effort is clear. If the Chinese were able to access the aircraft's top secret equipment, they were able to discover what the Pentagon knows and doesn't know about their communications and operations. This information would enable them to change their methods and develop countermeasures, thus depriving Americans of a powerful advantage in wartime.

Cryptographic keys, databases that maintain U.S. intelligence information on Chinese systems and classified computer codes are of far greater value to the Chinese than the hardware systems alone. However, electricity is required to degauss, or erase, crypto systems and other hard drives. Damage to the aircraft could have hampered the crew's ability to take such actions.

CLEANING, SANITIZING AND DESTROYING PROCEDURES

Security agencies in the US define several levels of “erasing” sensitive data for various storage media type, such as tapes, magnetic disks and optical disks. These levels were originally set by the DoD (Department of Defense) 5200.28 and by the NSA (National Security Agency) CSS 130-2, Media Declassification and Destruction Manual. In 1995, the DoD published the 5220.22 NISPOM (National Industrial Security Program Operating Manual). This manual was issued in accordance with the National Industrial Security Program (NISP) and was developed in close cooperation with the industry. It prescribes requirements, restrictions, and other safeguards to prevent unauthorized disclosure of classified information and to control authorized disclosure of classified information released by the US.

Each US military force has compiled its own internal version, drawn from the DoD/NSA instructions as described by the US Air Force AFSSI (Air Force System Security Instruction) 5020, the US Army 380-19 Information Systems Security (ISS) and the US Navy NAVSO P-5239-26 INFOSEC (Information Systems Security).

Since “erasing” is an ambiguous term, several others terms are used. These terms are applied to magnetic tapes, magnetic disks, optical disks and various other types of memory devices (such as DRAMs, EEPROMs and SRAMs):

- Clearing: Clearing is the process of eradicating data on the media before it is reused in an environment that provides an acceptable level of protection for the data previously stored on the media before clearing.

- Sanitizing (also called Purging): Sanitizing is the process of removing data on the media before it is reused in an environment that does *not* provide an acceptable level of protection for the data previously on the media before sanitizing. Sanitizing mechanical disks and magnetic tapes requires the use of a degausser or otherwise destroying by means of disintegrating, incinerating, pulverizing, shredding or smelting the disks and tapes.

- Destroying: Destroying is the process of physically damaging the media to make it totally unusable as a media, thereby making it impossible to retrieve data.

Declassification is a separate administrative process, whereby classified data stored on a media is deemed to no longer require protection as classified information.

Various procedures have been set forth by the DoD to meet these “erasing” and declassification processes. For the disposition of unclassified DoD mechanical hard drives, the DoD issued special instructions. Software packages can be disposed of after undergoing six passes of special overwriting procedures. These procedures meet the minimal security standard, but are not authorized for use to sanitize classified data. Damaged mechanical hard disks with sensitive data that cannot be sanitized must be degaussed or destroyed. For declassification, degaussing procedures are used to reduce the magnetic flux on the media virtually to zero by applying a reverse magnetic field.

NSA approved special degaussing equipment to declassify magnetic tapes, mechanical disks and optical disks (as within the NSA L1-MTC-4A testing procedure). This equipment is available in several levels indicative of its magnetic field strength, each with a different Oersted (Oe) rating. Each type of magnetic media is distinguished by the rate of coercivity required to return it to its zero state.

Some solid-state flash disks comply with the NSA, DoD, Air Force, Army and Navy sanitization processes for flash NAND EEPROM, which require disk erases, character fill and random data fill in a specific sequence. Therefore, such solid-state products do not require degaussing or destruction.

ENHANCED DATA SECURITY IN SOLID-STATE FLASH DISKS

Solid-state flash disks use NAND flash technology (non-volatile EEPROM) as opposed to NOR flash technology for mass data storage. NAND’s high density and capacity (256 and 512MByte memory chips) and lower price per MB make it more attractive as a mass memory solution. NAND flash memory writes zeroes in page size (512 to 2048 Bytes) and erases them to ones in block size (one block equals 32 pages).

Some flash disk vendors provide attractive features for data security in emergency conditions. None of these features requires degaussing or disk destruction to ensure that what has been erased remains permanently erased. This makes the procedures quicker, easier and more cost-effective. Some solid-state disks provide features described below.

Fast Secure Erase enables the user to erase the entire disk contents in a matter of seconds, between 10 to 60 seconds, depending on the disk capacity. The very nature of NAND flash technology, whereby data is "burned" into the silicon to perform both read/write and erase operations, ensures that erased data cannot be retrieved. In addition, there is no indication of the number of erase cycles that have been performed since a cell was programmed to zero. In contrast, magnetic technology continues to retain some of the original level of magnetic data, even after being overwritten more than 20 times. Fast Secure Erase can be activated by a software or hardware interrupt locally or remotely.

Selective Fast Secure Erase enables the user to erase only part of the disk, for example, only sensitive data but not the operating system. This ensures disk readiness for the next mission without reinstallation, saving valuable time. The user can partition the disk into up to 8 different areas, and decide which to designate for fast erasure.

Usually during emergency conditions, the power supply is unstable, preventing the completion of special security processes to erase sensitive data. In such cases, ***Auto-Resume Security Erase*** ensures that a Fast Secure Erase that was halted before completion, due to lack of power, will automatically be completed as soon as power is restored. Auto-Resume Security Erase is supported by the flash disk internal processor, which guarantees Fast Secure Erase completion, regardless of the host.

The ***Sanitize (Purge)*** process for NAND flash (in the NSA/CCS 130-2, DoD 5220.22 NISPOM, Air Force AFSSI 5020, Army 380-19 and Navy NAVSO P-5239-26) require sanitizing NAND flash with disk erase, same character fill and random data fill, using the specific sequence specified in each of the above procedures. Bad blocks must be repeatedly erased ("strong erasure") to guarantee total disk sanitization.

CONCLUSION

Mechanical disks continue to be the weak link in total system reliability under harsh environmental conditions. As such, solid-state flash disks are being designed as true "drop-in replacements" for data storage in mission-critical applications. Solid-state flash disks provide top data integrity under harsh environmental conditions of extreme shock, vibration and humidity, and meet industrial temperature requirements. Cost is no longer an insurmountable barrier in using solid-state flash disks in mission-critical applications, since flash prices have declined dramatically over the past two years, a trend that experts expect to continue.

Securing confidential data in emergency situations is essential. Sanitizing mechanical disks and magnetic tapes is an arduous process, requiring special degaussers, stable power conditions during the process, and ample time, all of which may be lacking during an emergency. Solid-state flash disks can sanitize the disk in seconds with Fast Secure Erase and Sanitize procedures. In addition, once Fast Secure Erase has been activated, Auto-Resume Secure Erase guarantees successful completion of the process.

TerraSAR-X Ground Station at DLR in Neustrelitz

J. Schwarz, H. Damerow, H. Maass, J. Richter
DLR, German Remote Sensing Data Centre
Neustrelitz, Germany

Abstract

The German Remote Sensing Data Center operates a ground segment for small scientific satellites and remote sensing missions in Neustrelitz. This system represents the basis for the TerraSAR-X ground segment in Neustrelitz for data reception in the S-Band, in the X-band and for SAR-data processing. The purpose of this document is to inform about the most important requirements in respect of X-band data reception and the technical solution to prepare the ground station for TerraSAR-X data reception.

Introduction

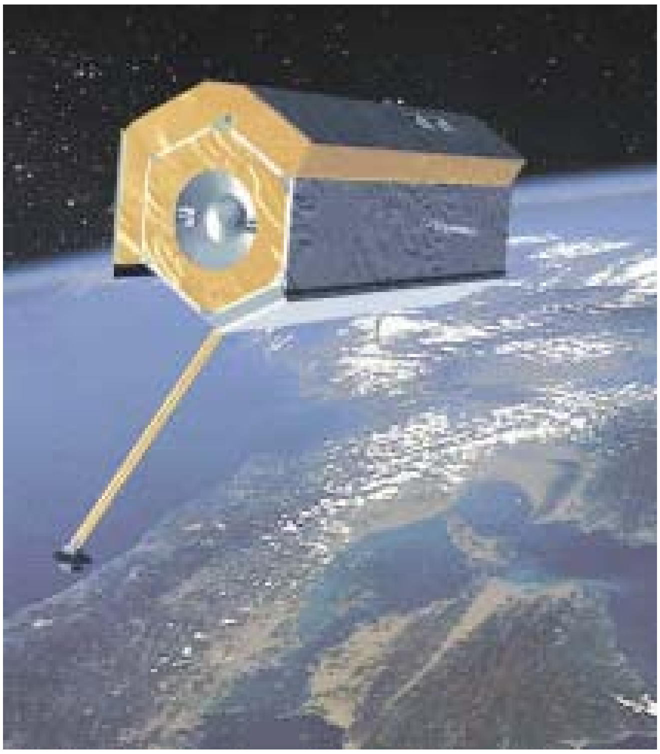


Figure 1: TerraSAR-X spacecraft

In the field of synthetic aperture radar technology the DLR and EADS Astrium GmbH prepare the construction and operation of an operational radar satellite for the scientific and commercial utilization. The project is called TerraSAR-X and will come into being in the form of a public private partnership, i.e. both partners take part in funding. The TerraSAR-X satellite is shown in Figure 1.

The main instrument on the spacecraft is an X-Band SAR, which operates at 9.65 GHz. Several modes are possible to fulfill very different user requirements. The fact that the instrument can be used at squint angles between 20-55 degrees. (15 – 60 degrees. with reduced performance) to both sides is of special interest. This enables a short repeat cycle. All data can be recorded in single or dual polarization mode. The following table gives an overview of the instrument modes:

	Spotlight Mode I	Spotlight Mode II	Experimental Spotlight	Stripmap Mode	ScanSAR Mode
Ground Resolution - Across Track - Along Track	 2m* 1m	 2m* 1m	 1m* 1m	 3m 3m	 16m 16m
Product Coverage - Along x Across	5 x 10 km	10 x 10 km	5 x 10 km	<1500 x 30 km	< 1500 X 30 km
Access Range (full Performance)	20° - 55° 2 x 463 km	20° - 55° 2 x 463 km	20° - 55° 2 x 463 km	20° - 45° 2 x 287 km	20° - 45° 2 x 287 km
Access Range (data collection)	15° - 60° 2 x 622 km	15° - 60° 2 x 622 km	15° - 60° 2 x 622 km	15° - 60° 2 x 622 km	20° - 60° 2 x 577 km

Table 1: TerraSAR-X SAR modes (* at 30 ° Incidence Angle)

The spacecraft is equipped with a solid state mass memory (SSMM) of 256 Gbit. The SAR data from all data takes are stored in this memory and dumped to the ground station in the X-Band at 300 Mbps. The main transmission parameters are summarized in the Table 2.

Transmission Frequency	8150 MHz
Polarization	RHC
Modulation	QPSK (with differential coding)
Coding	Randomising Reed-Solomon Coding
Encryption	Encryption of the SAR data
Data structure	According to CCSDS standard

Table 2: TerraSAR-X transmission parameters for the X-band-downlink

TerraSAR-X ground segment

The DLR ground segment consists of three main parts:

· **The Mission Operation Segment** (MOS) for controlling and commanding the satellite, for orbit analysis and acquisition planning. The German Space Operation Centre is responsible for this segment.

· The **Instrument Operations and Calibrations Segment** (IOCS) for generation of all SAR instrument commands, for SAR-calibration and for monitoring of the performance of the SAR-data. The Microwave and Radar Institute is responsible for this segment

· The **Payload Ground Segment** (PGS) for data reception of the X-band downlink, the generation of the basic products as well as the data archiving. It is also the interface for the scientific users. The design, development and the operational scenario will be covered by the Remote Sensing Technology Institute and the German Remote Sensing Data Centre .

The National Ground Segment of the DLR-DFD in Neustrelitz will be part of the Payload Ground Segment and responsible for the X-band-data reception and the generation of the basic products. Additionally the S-band-data (1 Mbps) will also be received and the R/T house-keeping data will be made available to the MOS in real-time.

X-Band ground station for TerraSAR-X

It is planned to receive on average five passes daily @ 8 minutes of the TerraSAR-X spacecraft. This represents a data content of 70 Gbyte/day. This must be carried out with utmost reliability and high data quality up to low elevation angles of 5 degrees.

At the ground station are three 7.3m S/X-band antenna available with nearly identical technical parameters. In Table 3 the most important technical data are summarized:

Frequency range	**2200-2400MHz**	**8025-8400 MHz**
Polarization	RHCP or LHCP	RHCP or LHCP
Axial Ration	Max. 1.5dB at beam peak	Max. 1.5dB at beam peak
Antenna Tracking	Auto track or Program track	Auto track or Program track
G/T @ 5 degree Elevation	17.0 dB/K	31.0 dB/K
Minimum Elevation, at which reception is possible / for TS-X/	10 degrees	5 degrees

Table3: Mean technical parameters of the S/X band antennas in Neustrelitz

According the link budget there is a 3 dB margin at 5 degrees elevation for a required bit error rate of 10exp-6. It will be used an antenna system which has free optical sight to the satellite for all elevation angles greater than 5 degrees. This antenna has a dicroic sub-reflector and is able to receive the X-band-signal and also the S-band-signal at the same time. A third axis is available to prevent tracking problems at high elevation angles. The high reliability will be reached by the full redundancy of all components necessary for the data reception (antenna system, demodulator, direct archive system). Figure 2 shows the TerraSAR-X ground station antenna.

This antenna will not only used for TerraSAR-X. It will be included in the whole multimission reception scenario. Approximately 8000 satellite passes of more than 10 satellite missions were received by this system in 2003. Figure 2 gives a first overview of which components will be used for the TerraSAR-X data reception in the X-Band. But practically all functionality necessary to enable the multimission was already reported in /2/ and is not considered in figure 3. The antenna tracks the satellite very accurately and receives the S-band and X-band signal. The X-band signal is converted to the 720 MHz IF-frequency and a special demodulator is used for data demodulation and differential encoding. The High Rate Multimission Demodulator (ALCATEL) is used. The output signal is the serial ECL data stream which is used in the Direct Archive System (MacDonald Dettwiler). This device enables the frame synchronization and ingests the data stream at the RAID in real-time. After the data reception is finished the first pre-processing of these data starts, which means that the derandomizing of the data and the Reed-Solomon encoding have to be carried out before data-take-files are generated for further processing. Each data take file contains all instrument source packets of this data take and some added quality information in the FRED-format . These files are already encrypted and will be decrypted in the transcription processor before (the screening and the generation of the ordered products starts in the operational SAR-processor TMSP).
For the ground station it is very important that there is also a simulation system, for testing the compatibility between the TerraSAR-X satellite and the ground segment before the launch and also for making operational tests during the operational phase. It consists of the test-modulator and the downlink-simulator. Some additional information about the downlink-simulator will be provided at a later point in this document

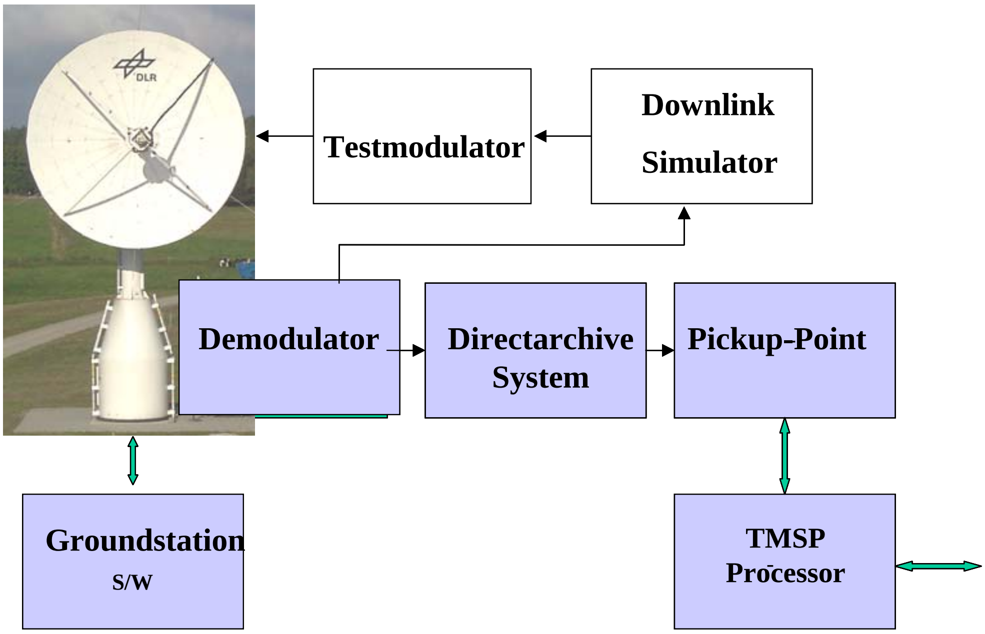


Figure 2: Overview about the TerraSAR-X components for the reception of the X-Band-downlink

Figure 3 S/X-band ground station antenna at DLR-DFD Neustrelitz

Monitor&Control System at the ground station

There is a multimission Monitor&Control System at the station, which enables a very useful tool for the operator to plan all data reception activities in advance and gives some information as to whether the satellite pass ordered can be received or not in the event that there are too many satellite passes at the same time. It is used to configure every activity automatically and to give the operator a message if something is out of specification. The third important point is that it collects a large amount of measurements and status data (field strength, tracking accuracy…) during the reception activities which characterize the behavior of the system. This data will be used to generate a reception report and these data are stored and can be analyzed later in case of technical problems.
The following Figure 4 gives an overview of all components used in the TerraSAR-X data reception .

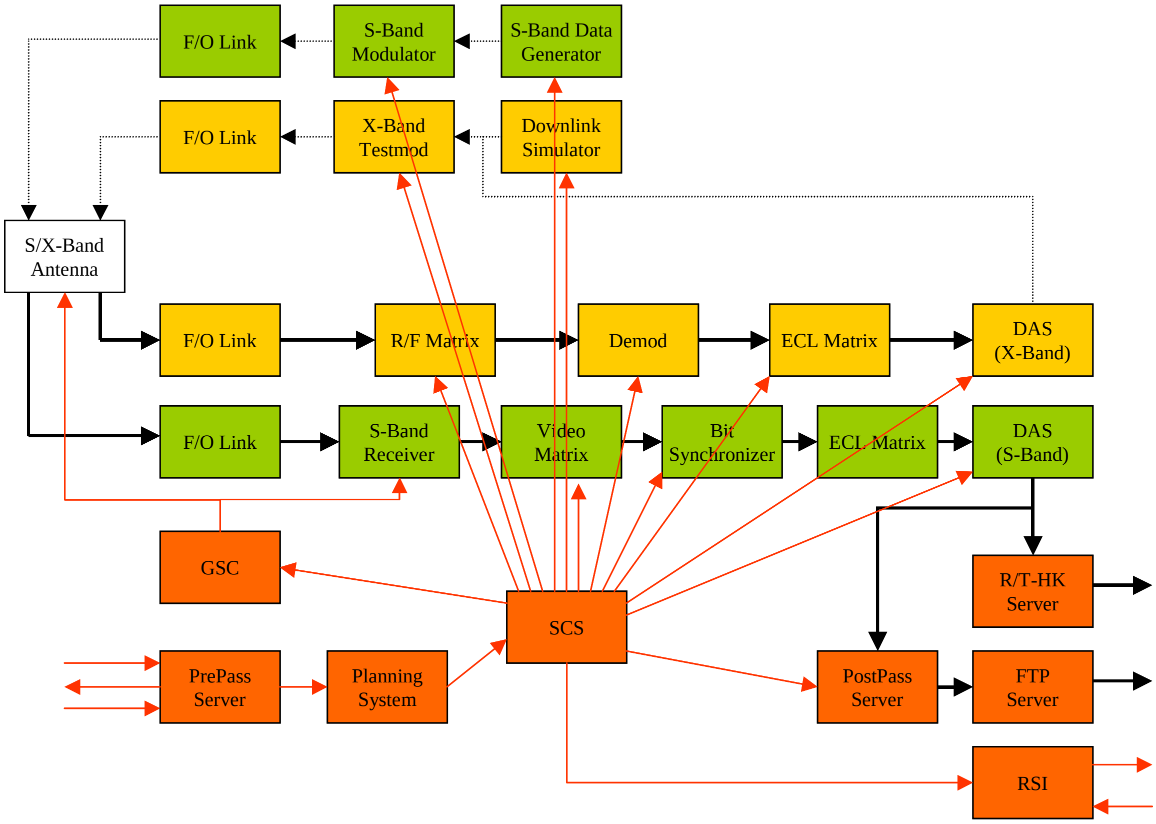


Figure Overview of all components used for TerraSAR-X data reception at the ground station Neustrelitz (F/O-link: fibre optic link; SCS: Station Control System; GSC: Ground station Controller, RSI: Receiving Station Interface ; DAS: Direct Archive System)

Some time before the satellite passes are scheduled to be received the planning of all activities at the ground station starts. The pre-pass server gets all information (orders, orbit data) which are necessary to this end and the planning system collects the orders from all different projects, analyzes it and inform the partners in the event of conflicts. A valid schedule is given to the Station Control system for every day. Some 5 – 10 minutes before the pass, the Ground Station Controller (for configuration and control of the antenna system), all other components for X-band reception (demodulator, direct archive system) and for S-band reception (bit-synchronizer, direct archive system, real-time server) as well as all matrix-components (for routing the signals through the system) start. A maximum of 4 such activities can run in the system in parallel and the operator need merely observe the running and has only to act in case of technical problems.
After the pass is successfully received, the metadata is stored at the post-pass-server for generation of the reception report and also the S-Band-data received are made available at the ftp-server for further processing at the Mission Operation Segment.

The X-band direct archive system starts the first preprocessing of the data received, which will be transmitted for encryption, screening and processing to the transcription processor and the operational SAR-processor TMSP

Compatibility between spacecraft and ground station

For testing the compatibility of the spacecraft and the ground station in respect of the X-band downlink the RF-compatibility test (X-band) is planned at the station in Neustrelitz.

ASTRIUM will take part with the relevant spacecraft components. The X-band signal will be injected into the X-band ground station and bit error measurements will give a result concerning the quality of the data regeneration at the ground station.
Also in respect of data compatibility some measurements are planned during this test. The target is also to regenerate the original data take files in the direct archive system, which are stored at the solid state mass memory (SSMM) of the spacecraft.
During the test, only simulated data will be used. Therefore the data compatibility tests have to be repeated several times, if more and more realistic data is available from the spacecraft. For this test the TerraSAR-X downlink simulator is used, which can store original TerraSAR-X data and can generate the original TerraSAR-X serial data stream with 300 Mbps.

TerraSAR-X downlink simulator

The TerraSAR-X-downlink simulator is a system, which will be used to store a serial data stream (max. 300 Mbps) at a RAID of a PC. Additionally this data can also be output as a 300 Mbps serial data stream.
This device can therefore be used to store data direct at the spacecraft and to simulate the TerraSAR X-band downlink at the ground station. It is planned to perform all necessary data compatibility measurements at the ground station by this simulator.

According to figure 5 the system consists of a pc system, equipped with a 2 channel Ultra320 SCSI RAID controller with 6 hard disks (37 GB each) and a fast I/O card NI 6534 (National Instruments). This card can input and output an 8bit, 16bit or 32 bit broad data stream. In out application the input/output data stream used is 16 bit broad. Additional hardware is necessary to convert this data format into a serial one with max 300 Mbps. There is also an additional I/O card NI 6503 (National Instruments), which only configures the additional hardware according to the mode chosen at the PC (input mode, output mode, data rate…).
Software has been developed at the ground station to enable data input and output up to 300 Mbps in a very simple manner. This device will be necessary to prove the compatibility of the ground station in the TerraSAR-X project. It can however also be used for a lot of other purposes – at example as a backup storage device.

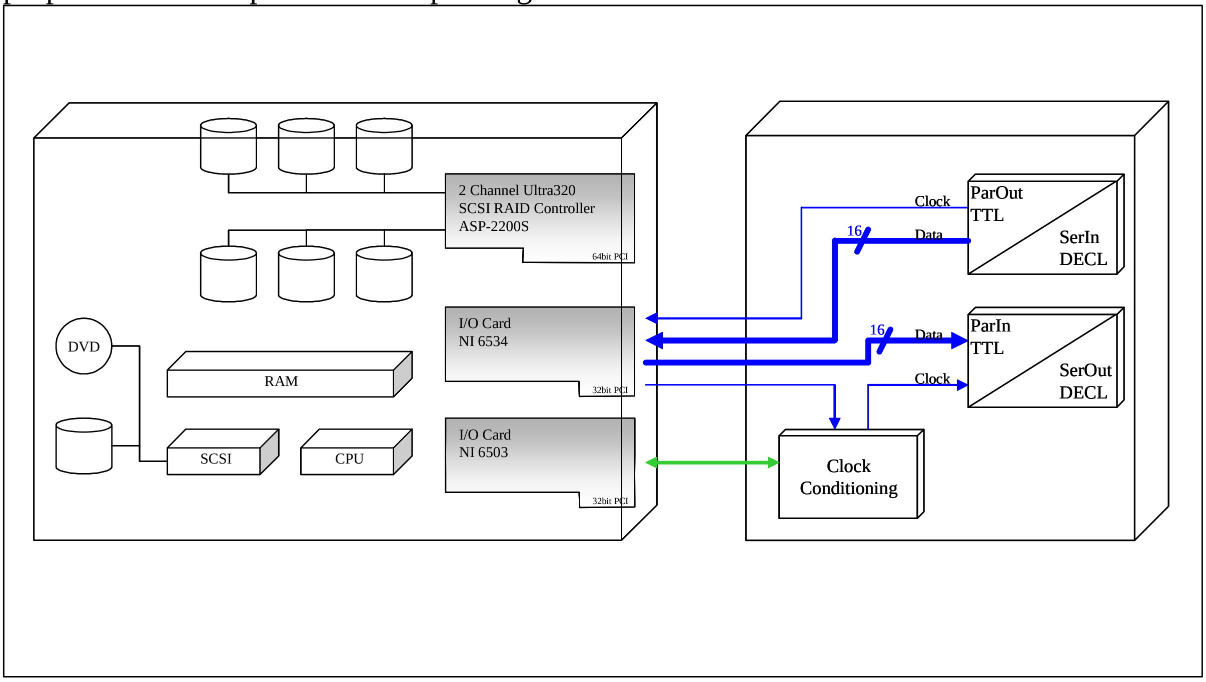


Figure 5 Overview TerraSAR-X spacecraft simulator

SAR – Downlink Interference

The X-band antennas in Neustrelitz don't have filters before the low noise amplifiers (LNA) because this gives the highest possible sensitivity of the system. In the event of interference of the X-band downlink-signal by the SAR-pulses, this will reduce the received data quality. In the past, interference problems were not of great significance. The most important problems were

- sun interference (if sun noise and satellite signal are both in the antenna beam)
- inter-satellite interference (if the signals of two satellites are inside the ground station antenna beam)

Both effects are in-band effects, which cannot be reduced by additional filters. The TerraSAR-X - SAR interference is different, because the SAR-instrument operates at 9.65 GHz and has an EIRP which is approx. 60 dB higher than the EIRP of the X-band downlink. In the event that the SAR antenna is directed to the region of the ground station the SAR pulses are transmitted directly into the ground station antenna and it will result in saturation of the LNA (low noise amplifier) for some seconds.

Depending on the mission requirements, the operation of the SAR-instrument and the X-band-downlink should be possible at the same time without any restrictions. This is not possible without any filters. To overcome this problem the ground station can be equipped with an additional band pass filter for the X-band transmission range, which will give an improvement of at least 40 dB. This will be enough to overcome any saturation effects by the SAR instrument pulses. Disadvantages of such a filter are:

- the G/T of the ground station will decrease by 0.4 dB
- an additional group delay variation must be considered

The degradation of the G/T reduces the margin of the required data quality but at an acceptable level.

The effect of an additional group delay variation has to be further investigated by special measurements during the planned ground station tests.

Summary

The planned national remote sensing mission TerraSAR-X, which is a public private partnership between ASTRIUM and DLR, will provide a great deal of possibilities in the operational remote sensing. The DLR will operate the ground segment. The X-band data reception as well as the standard processing will be planned at the DLR ground segment in Neustrelitz. This document has served to inform about technical requirements and the planned activities to achieve the ground station's compliancy with the TerraSAR-X project.

Literature

/1/ I. Zerfowski : TerraSAR-X Mission, Tagungsband 20. DFD Nutzerseminar, 6.-8. Oktober 2003

/2/ J. Schwarz: Highrate Data Acquisition for Earth Observation Satellites, Proceedings of the European Telemetry Conference etc2002, Garmisch-Partenkirchen, May 27 – 30, 2002

MULTI-PURPOSE TELEMETRY SYSTEM :

SPACELINK SOLUTION

Nicolas MAURY / SMP (SYSTEMES MIDI-PYRENEES)

Introduction

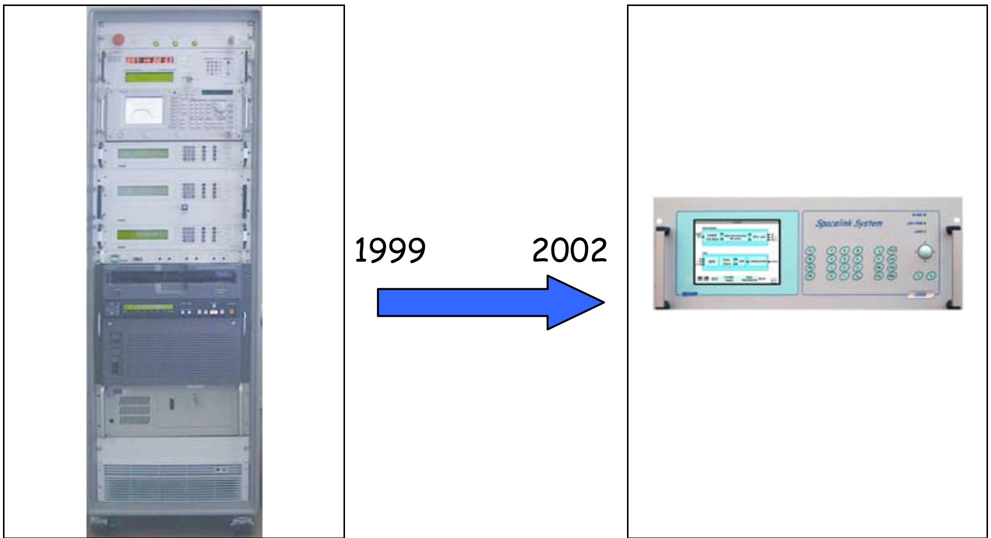
Since two years, System Midi-Pyrénées concentrates all their acknowledge to develop a new concept for ground stations:

- Low cost ground station with high sub-system integration
- Multimission Modem to be compliant with all satellites and telemetry system Remote sensing, TTC, Ranging, Flight test …

Today, this goal is reached with Spacelink System.

On one side, we have integrated a full-ground station in a 4-unit equipment.
On the other hand, this micro-station has a multi-purpose design

SPACELINK SYSTEM = from 1 kbps to 450Mbps data rate

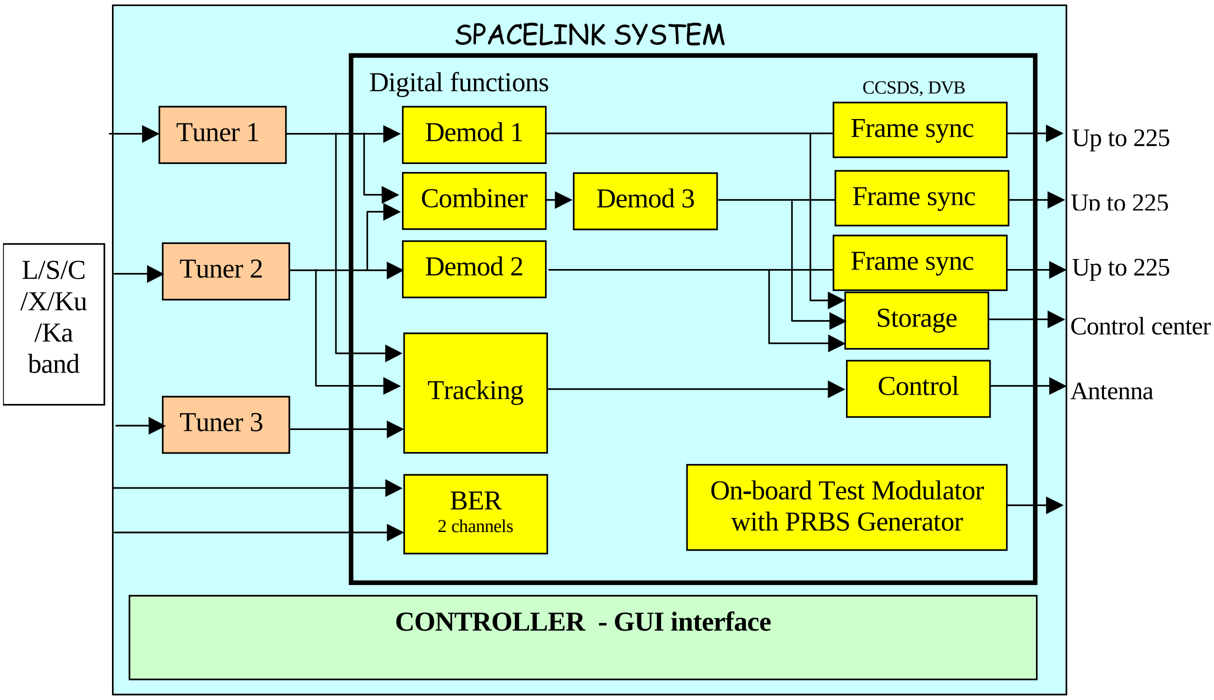


MULTIPURPOSE GROUND STATION

SPACELINK SYSTEM

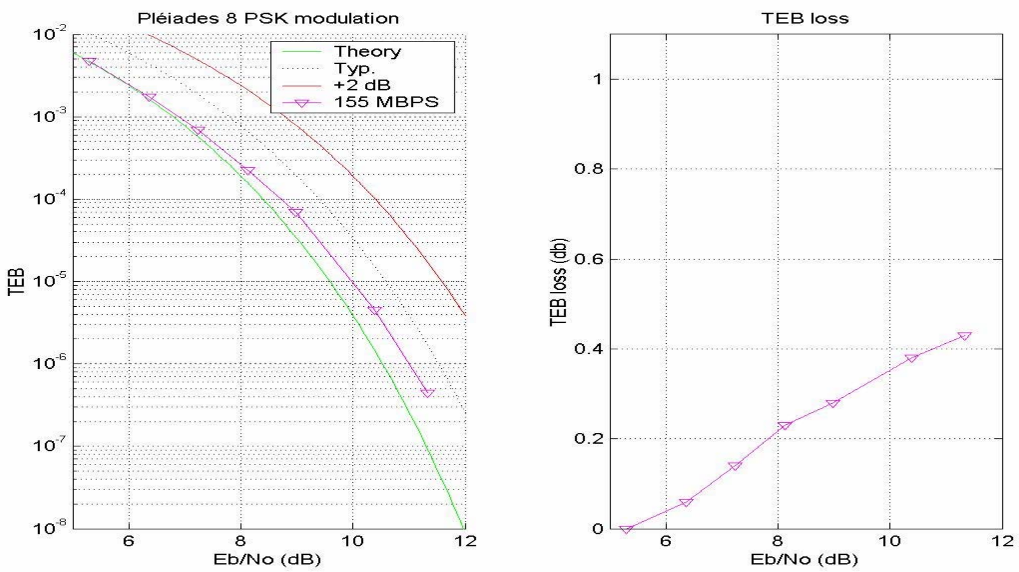
SPACELINK SYSTEM – High Data Rate Multimission Modem

Based on mastering the last digital technologies, Spacelink mixes high performance and flexibility. Indeed, PC architecture (with Windows or Linux embedded system) ensures a easy-to-use displays. But, before going further, let's make a break by analyzing the functional diagram:

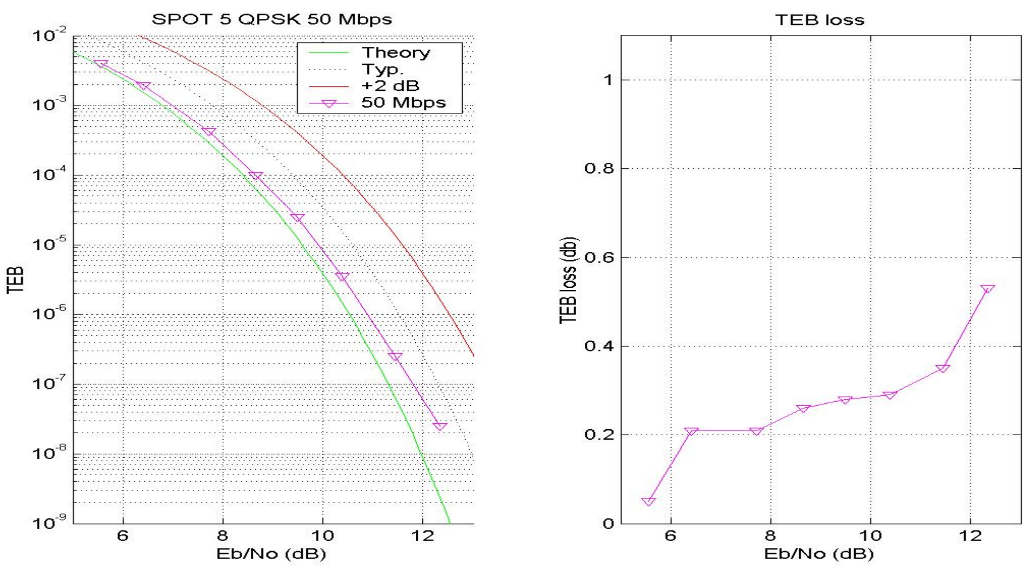


To reach the best performances, we are selecting the last component generation and the results are excellent since the degradation is ***less than 0,5 dB over the full range : 20 – 450 Mbps***.

Results



Pleiades constellation
(8-PSK modulation – 155 Mbps)

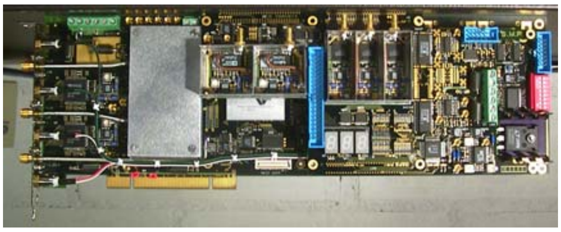


SPOT 5
(QPSK modulation – 50 Mbps)

These results can be optimized by Customers !!!. Indeed , users can programs their own filters for a better adaptation with on-board modulator.

That means SPACELINK SYSTEM can be compliant with all satellites as it accepts:

- ***synchronous*** modulations : QPSK / BPSK/ 8 PSK / SQPSK
- ***asynchronous*** modulations : AQPSK / UQPSK



Users have to focus on the fact that SPACELINK SYSTEM accepts suitable configurations. Your SPACELINK SYSTEM is fully configurable to reach your needs such as :

- **L**OW **D**ATA **R**ATE **M**ULTIMISSION MODEM : 1 kbps to 20 Mbps
  – Low bit rate telemetry receiver with acquisition capabilities

- **H**IGH **D**ATA **R**ATE **M**ULTIMISSION MODEM : 10 Mbps to 450 Mbps

- 3-CHANNELS **TRACKING S**YSTEM
  – With RF down-converter (from L to Ka band)

- **R**ECORDING **U**NIT : UP TO 150 GO

- **TTC/ RANGING** and test configurations

- **R**EMOTE **S**ENSING / **T**ELEMETRY / **T**ELECOM **COMPLETE GROUND STATION**

Test capabilities

On-board testing (PRBS data, BER measurement …) is also available. System Midi Pyrénées provides others equipment to improve the simulation of downlink telemetry with the CPE.
The CPE (Channel Propagation Emulator) synthesizes the principal phenomena of propagation occurring on RF signal links between earth and space. Developed by the R&D laboratory under CNES license, the CPE demonstrates the know-how of SMP in the field of high-speed data processing.

The CPE applies a transfer function on a ***125 MHz wideband*** channel. It can simulate the following disturbances:

- Phase continuous variable delay up to 167 ms,
- Time jitter,
- Frequency Doppler shift,
- Level attenuation over 2 outputs to simulate 2 polarization channels,
- Broadband AWGN noise generator : S/N or absolute level calibrated.

Typical applications for the ECP include :

- Earth terminal testing,
- Satellite payload testing,
- Satellite system integration test bench,
- Wideband spectrum checking.

Easy to Use, Graphical display and Monitoring Capabilities

SMP built a powerful user interface with intuitive displays that allows easy manipulation, control, setup and display of the system in real time. Upon initialization of the Spacelink System, a windows style GUI pops up that allows complete control, setup and manipulation of the demodulator receiver. Easy to use pop-up windows allow user to select default parameters and add custom parameters for specific mission. 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 guide "GUI Interface User Guide" that is available on-line at our web site **www.smpfrance.com**.

Conclusion

Today various communication sectors such as deep space, satellite and mobile are converging. This requires developing a common platform to reduce cost and increase flexibility. This configuration provides a very powerful communication processing system with high flexibility.
This platform is now available and is fully functional in stations. You can see a demonstration at our booth : SMP – Systems Midi – Pyrénées.

GPS Simulation – A Tool to Spare Test Time and Enhance Accuracy and Quality of Platforms

Werner R. Lange
Lange-Electronic GmbH
Rudolf-Diesel-Str. 29 a, D-82216 Gernlinden
www.lange-electronic.de

Simulation is a tool that is widely used in areas like flying air- and spacecrafts, commanding ships or training of drivers or pilots. But more and more complex technical projects are simulated already during the design phase. Simulated either as parts of a system or even as complete systems.

Navigation data are very often an integral part within the telemetry data chain and the use of GPS receivers for navigation or timing is a common technique.

The paper presented will show that the use of simulators of satellite signals like GPS, Galileo or Glonass is able to predict the behaviour of systems, saves design and integration time and gives faster and better results; to make it short, will produce more economic results in a shorter time at less risk.

Why Simulate ?

Well, sometimes it is simple mandatory – for example if you like to get an FAA approval for a new GPS based equipment for an aircraft. It is off course possible to fly with an aircraft to certain predefined positions – in case of an helicopter it is also possible to maintain this precise position for a couple of minutes. If this position is in the middle of the Atlantic, the thing with the helicopter may not be too easy, but it starts to become impossible if you now call the USNO and ask them to switch off a satellite or at least change the pseudo range of one or two of it for a couple of minutes.

But there are also additional risks with equipment that is used in the near future; new codes, new frequencies will influence the presently used equipment by producing different kinds of noise or unwanted signals. This influences cannot be seen in the present satellite constellation, but can be precisely simulated.

Another item is to think about the influence of satellite errors like clock errors, pseudo range errors, bit errors or power failure or changes of the received signals. They are not to test in real life, but you require predictions about the behaviour of your system during test.

I had my first experience in GPS receivers with the old Datum 9390 Timing Receiver. It was basically a large 19” rack mount unit, based on a Trimble model, modified for timing applications.

One of our customers liked to use it in Kiruna, Sweden, but could not find out when to synchronize the local clock with the receiver – at this times 4 or more satellites have been available about 2 to 3 times a day for periods between 30 min and 2 hours – if you have been lucky. Kiruna was a special place, far north, so the coverage was even worse.

The receiver had a nice feature, one could see the satellite coverage at a future day, just presetting the correct date.

This is at least one item of "simulation" – to predict the coverage of satellites at a given time at a given position.

But Simulation means a lot more.

What does simulation really mean?

1. Produces real satellite signals as they are "live" at a given time, either in the past or in future.

2. Is able to produce errors and anomalies in a given scenario.

3. Is able to replay given scenarios with or without changes over and over again with a very high accuracy.

4. Provides a scenario like in the real world.

Nowadays satellite signal simulators provide real RF signals, including

- the original data of original satellites
- doppler frequencies derived from the motion of the satellites
- doppler frequencies derived from the motion of the UuT
- original almanach
- WAAS and EGNOS satellites
- (almost) free constellation of satellites
- variable output powers of satellite signals
- free antenna pattern defined
- inducing errors in single or multiple satellites
- and "replay" the same scenarios over and over
- with or without changes
- test multipath effects

Besides this there are other ways to test your equipment for future applications including satellite signals that are not yet available like L2C, L5, M-code or M-noise.

A few examples:

Manouvering Aircraft

Let us assume you have to install your equipment into the bay of a combat aircraft, a fighter like Tornado or F18 or EFA, now called Typhoon. You have perhaps watched the movie “Top Gun” ? You recall the intensive air battles, the curves and loops and all kinds of weared manouvers? Even with several antennas the received signal will change dramatically within a short time. To test your equipment does need two alternatives: you get into your aircraft and fly your curves and test and measure your receiver. Well, that’s fine, may be a little bit expensive, but you can do it once. After you return safely back to ground your flight engineer tells you that you have to do exactly the same flight again – next to impossible. Especially because the GPS configuration has changed, there are some satellites that disappeared behind the horizon, some are new to be received. And every single satellite has changed its position. No way to repeat your scenario.

With a simulator you are able to replay your scenario completely, over and over again. You are able to change things – switch off one or even all satellites, change output power, insert bit errors or timing errors, pseudorange errors and so on.

Large Vessels

One of the most interesting examples how to use a GPS receiver was given by an engineer from a Norwegian shipbuilder. These people designed a new gear to get the big hoses to transport oil from one ship to an other. They combined two ship simulators and a dual channel GPS simulator; with this equipment they could simulate the movements of each of the two ships governed by the ships simulators. Can you imagine the cost of a test that required two of this 100.000 tons supertanker for a couple of hours or even days?

And there is no risk that one of the captains reacted wrong and damaged his own or even both ships. By the way, when these people finally equipped the first two ships with the new gear every manouver worked very well, no errors, no damage.

Let me give you some ideas what can be changed before or during such a running scenario:

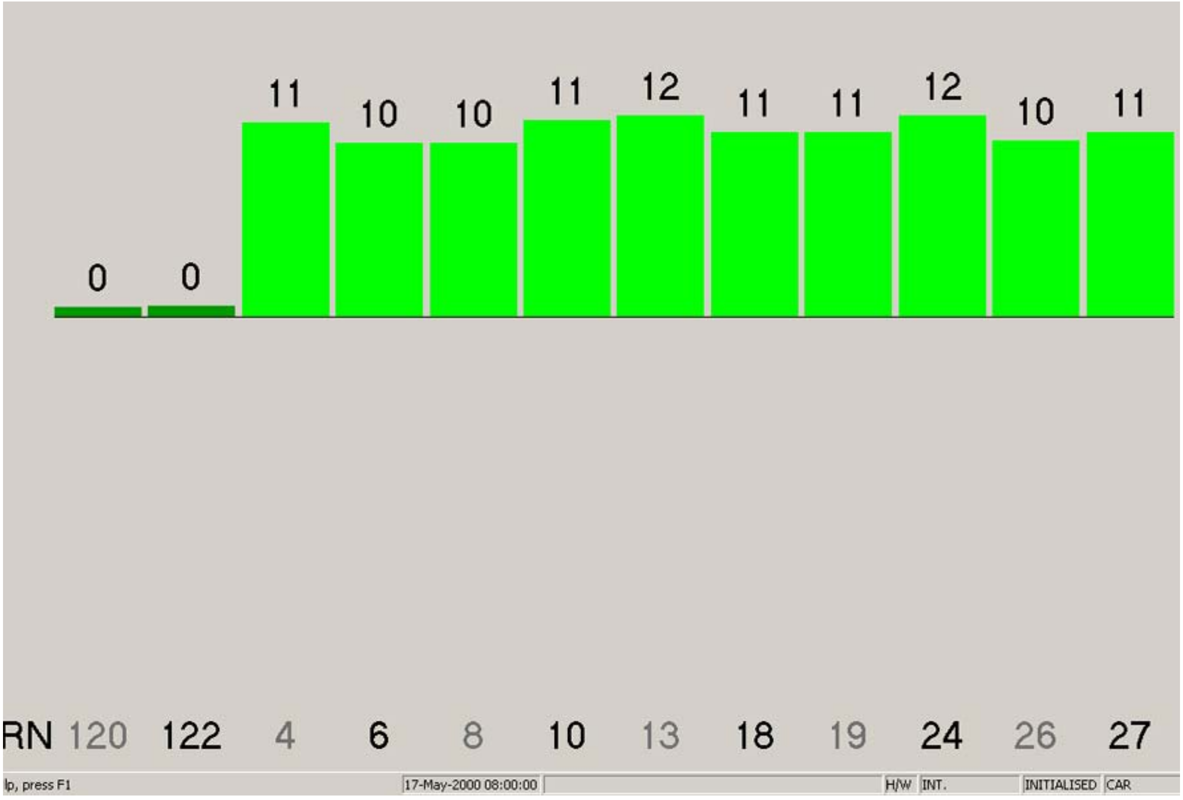


Figure 1
Output power diagramm, showing 10 GPS and 2 SBAS satellites

Figure 1 shows the output power of 10 GPS satellites, the zero line indicates the value of -130 dBm, the specified signal level at a 0 dB antenna.

Besides this there are the output power diagrams of two SBAS satellites. The specified signal level is about 10 dB less than the GPS signal level.

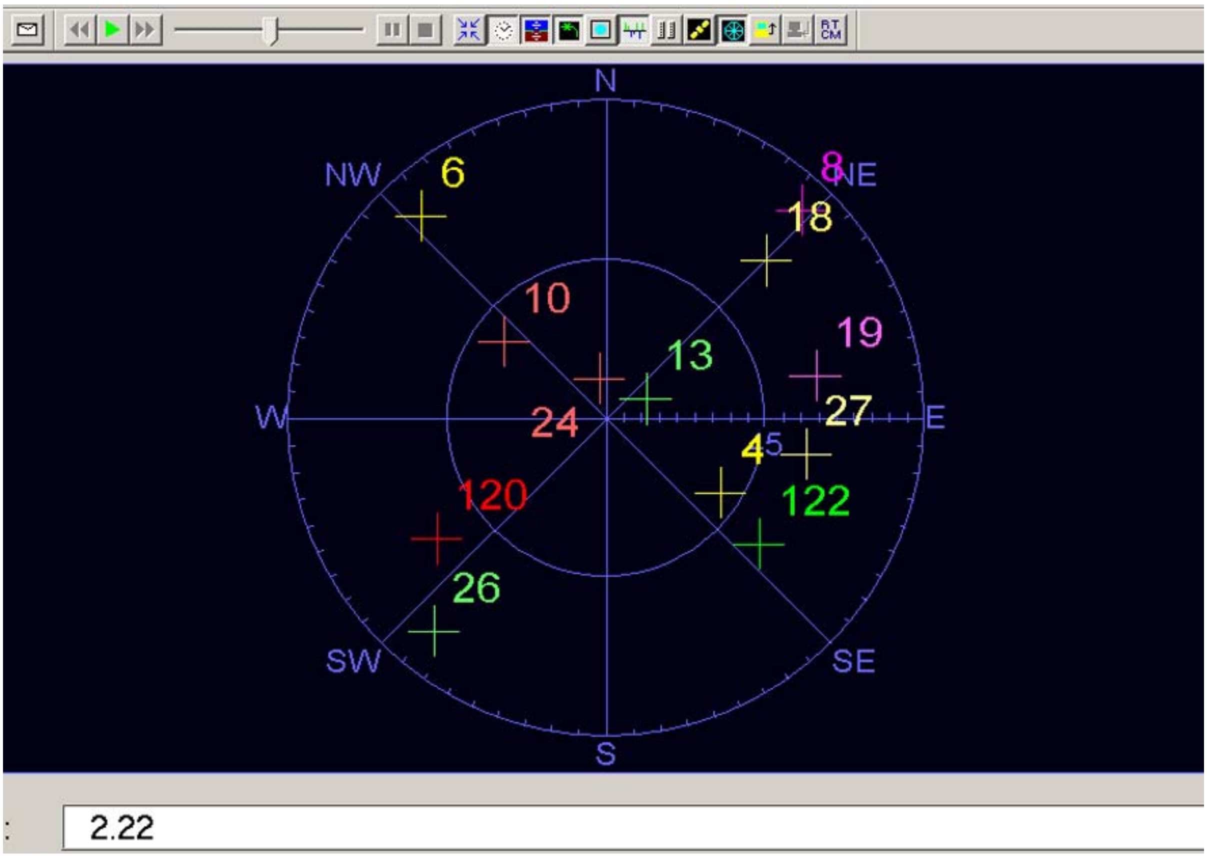


Figure 2
The satellite constellation to figure 1

It is to be seen that the GPS signal level corresponds with the elevation of the respective satellite. The lower the elevation the longer the pseudorange of the satellite the higher the attenuation of the signal.

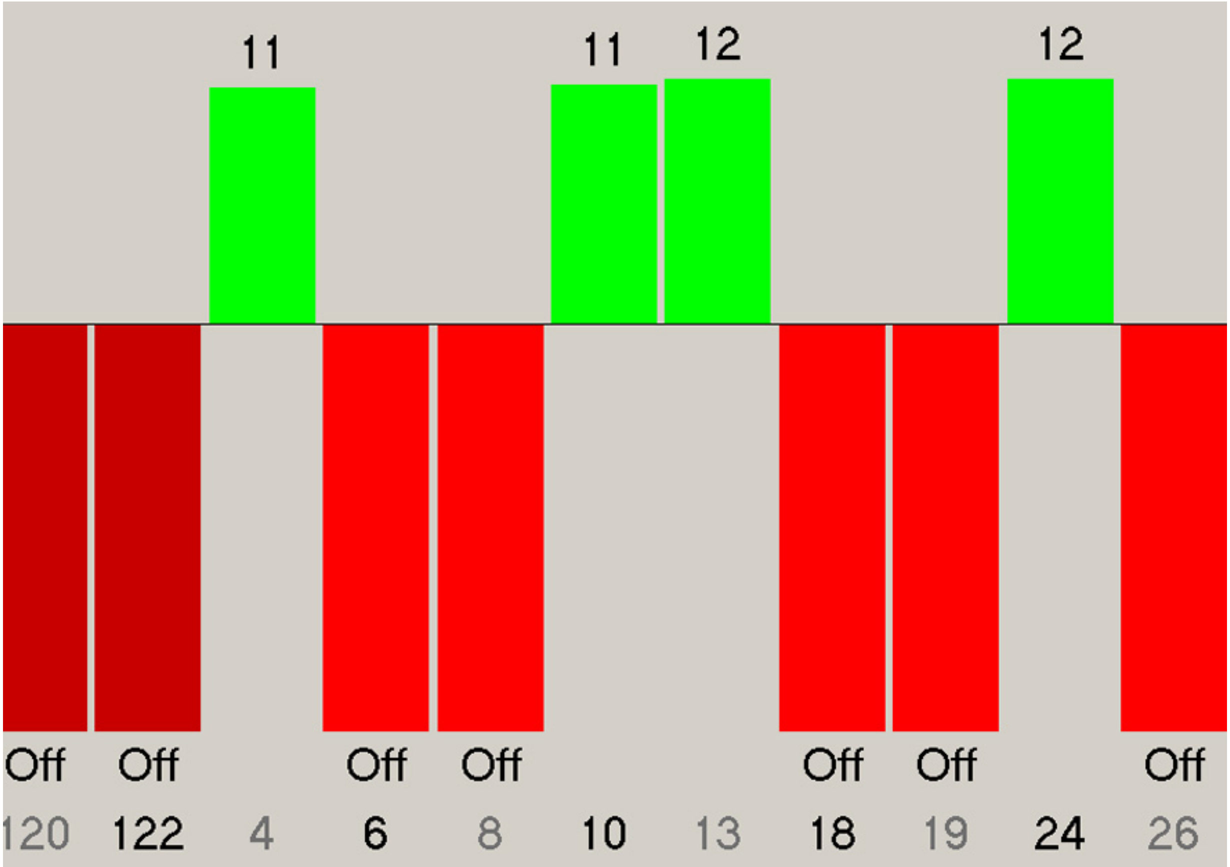


Figure 3
Signal levels in an urban canyon

The antenna can “see” the satellites with the highest elevation, all other satellites are switched off. In this scenario there are no multipath effects used.

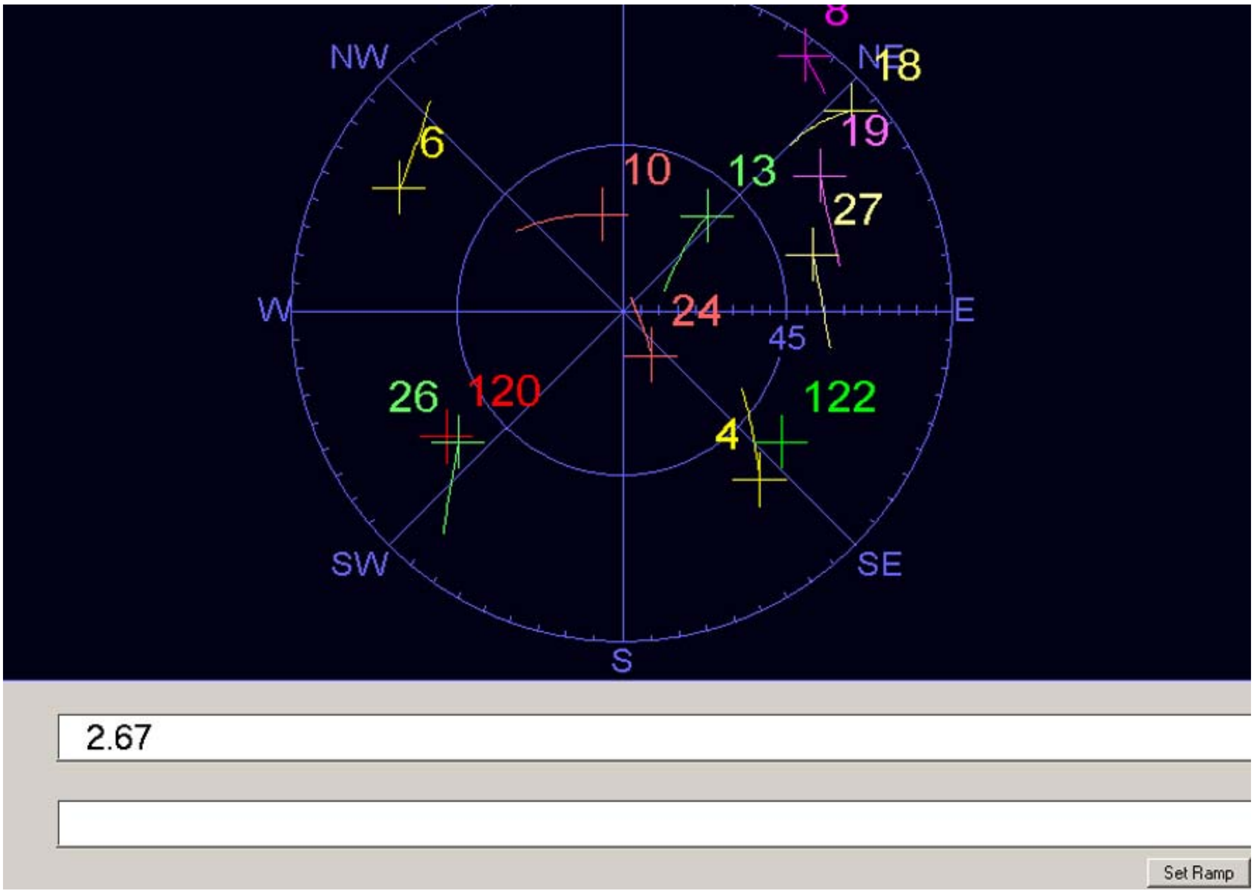


Figure 4
The tracks of the satellites during a half hour walk through Tokio

The satellite 8 already disappeared below the 5° horizon elevation and is switched off. Soon another satellite will appear. Number 120 and 122, the two SBAS satellites, are geostationary and remain on their initial positions; this is due to the small movement of a pedestrian. If the moving item would have been an aircraft, this two satellites would also show a track that differs from the GPS satellites.

					Delay (m)	Delay(m)	(m)	(m/s)	(dB)
AS	1	120	31.2	-125.5	4.9	4.4	38501215.8	-0.51	-99.90
AS	2	122	34.0	129.5	4.5	3.5	38259010.3	-0.52	0.70
S	13	13	28.8	49.5	5.2	3.6	23142308.1	539.76	-99.90
S	6	6	17.1	-90.9	8.5	6.4	23898466.9	257.57	-99.90
S	17	17	23.6	-41.9	6.3	5.0	23378194.7	-649.82	-99.90
S	10	10	62.7	57.3	2.8	2.4	20792914.9	116.62	11.80
S	9	9	5.7	-162.0	23.1	7.4	25069756.5	-752.87	-99.90
S	2	2	7.2	107.9	19.0	4.7	25317765.9	-340.19	-99.90
S	19	19	6.7	38.9	20.1	4.7	25078931.8	583.05	-99.90
S	24	24	42.8	163.8	3.7	3.2	21574376.4	527.65	11.40
S	26	26	57.6	-96.5	3.0	2.7	20616512.7	-227.27	11.90
S	27	27	23.0	46.9	6.4	4.0	23620876.7	431.72	-99.90

Figure 5
The actual data of the satellites seen above

A list of data of every satellite, showing the SVID, elevation and azimuth, ionospheric and tropospheric delay, pseudorange and pseudorange rate plus the actual antenna power levels.

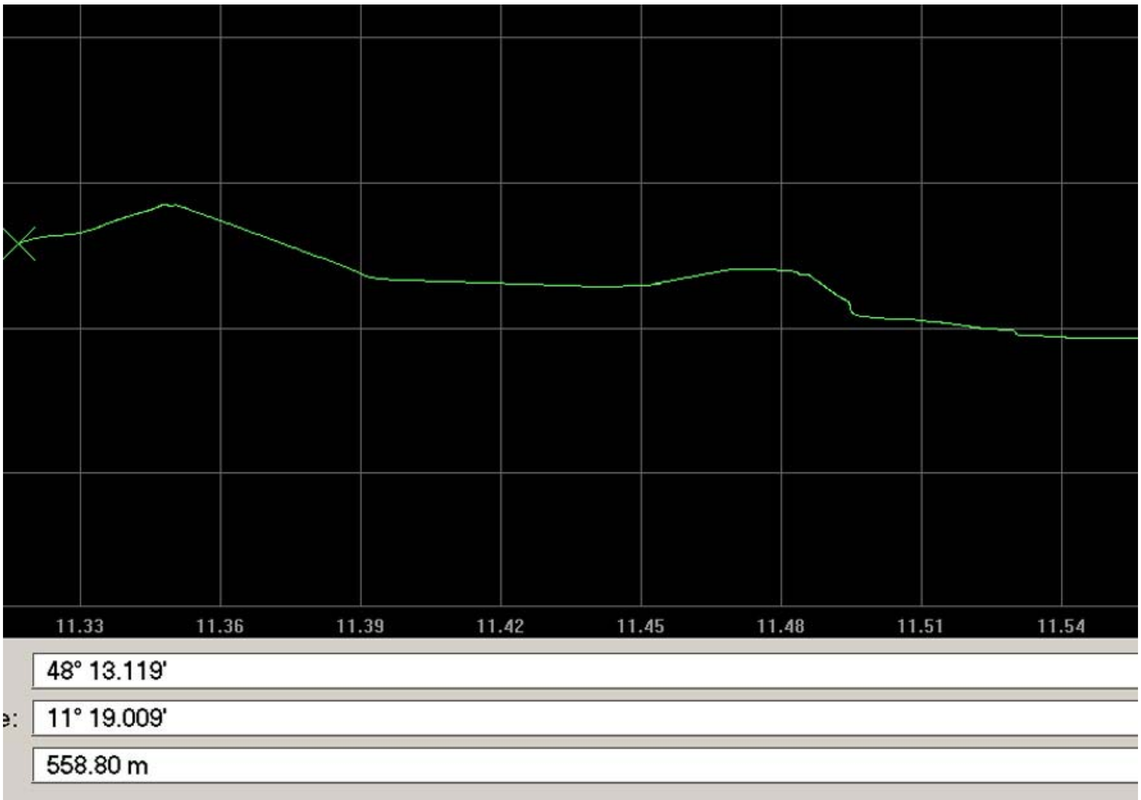


Figure 6
A ground track derived from an actual drive through Munich

The ground track through Munich – better to say a part of the way from my office to BMW – is originated from the NMEA data derived from a GPS receiver during an actual drive. It is to be seen that actual data can be used to define a scenario. The satellite constellation can be changed later – it must not be the same constellation as during the recording of the data.

Summary

Satellite signal simulation is a tool that is required during all phases of navigation system, not only during the design of chip sets, the integration of chip sets into a receiver, the integration of a receiver into a navigation system, but also during the integration of a navigation system into a telemetry, data acquisition or aircraft control system, and not to forget, in case of troubleshooting and test.

Figures taken from actual scenarios supplied by the SIMPLEX programm of Spirent Communications (SW) Ltd, Paignton, England

Application of the Enertec 3801 Baseband technology to Satellite Simulation

Franck HARROY – Jacques DAVAINE
Enertec – Space Division
185, av du G[al] de Gaulle - BP 316
92143 Clamart Cedex France
j.davaine@enertecgroup.com / f.harroy@enertecgroup.com

Abstract

This paper deals with satellite IF simulators involved in the ground segment validation during satellite development programs, either used in a stand-alone mode or as a modem between a dynamic satellite simulation software and the ground segment.
Enertec has developed such simulators based on the same hardware and software architecture as digital baseband equipments (3801). The main functions are reversed (the downlink becomes the up-link) and some specific functions are added. This paper emphasizes on PLL optimisation related to TC acquisition, on the simulation of Doppler frequency shift and synchronous range variation. The papers gives an overview of some peculiarities related to the ranging process, the management of the different standards of transmissions or the coherency mode where the carrier of the telemetry is computed from the knowledge of the carrier frequency of the telecommand link. A paragraph is dedicated to spinning satellite simulators where the timing requirements imply specific developments.
The conclusion points out the flexibility of such equipment, including satellite orbit simulation models, the new functions like the FARM as the on-board part of the Communication Operation Protocol.

Keywords

Intermediate frequency, satellite, simulator, Doppler, Range, spinning satellite

Introduction

ENERTEC Space Division is a leading supplier in Satcom, Science and Military satellite markets.

It is exclusive in base band equipment to the majority of the satellite operators, and has a long association in business with all major American, European and Asian aeronautic and space organizations and industries.

For over 15 years, ENERTEC Space Division has provided flexible, reliable and innovative ground system solutions.

The extensive use of COTS real-time software technology improves total ownership cost.

ENERTEC Space Division offers very competitive solutions to Customer needs.

The solutions cover the whole life of the satellite from satellite integration up to the in-orbit satellite operation, such as:

- Satellite Assembly, Integration and Test (AIT)
- TT&C Service:
  - Launch and Early Orbit Phase (LEOP)
  - In Orbit Control (Housekeeping)
  - In Orbit Test of the satellite
- Payload Service
  - Uplink Transmission
  - Downlink acquisition

The Enertec 3801 TT&C Digital Processor unit is modular in nature and supports a number of configurations to best meet the application-specific operational requirements.

The purpose of this presentation is the implementation of a satellite simulator at IF level. The satellite simulator performs TC reception, TM transmission, Ranging simulation and Doppler simulation. The satellite simulator also has the capability to produce the specific FM synchronisation signals used by spinning satellites.

The common architecture

The 3801-20 units are very compact, and are based on the use of industry standard processors, operating systems and busses. The 3801 TT&C Digital Processor Chassis Unit integrates TELEMETRY, COMMAND, RANGING, SIMULATION and TEST functions in a single 3 U or 7U 19-inch rack-mount chassis as indicated in Figures 1. A 7U 19-inch rack-mount also exists providing more telemetry or telecommand links.

Figure 1 : 3801-20 TT&C Digital Processor 3U Compact Chassis

The 3801 TT&C Digital Processor unit, configured as a Baseband Equipment (BBE) performs Baseband telemetry, ranging and command processing and includes the necessary hardware and software for:

- TM demodulation
- TM processing
- Coding/decoding : Viterbi and Reed-Solomon (223,255) with interleaving
- TC generation, formatting and verification
- TC modulation
- Ranging Tone modulation
- Ranging tone processing
- Telemetry simulation and PM/FM modulation
- Connection with the satellite control center

These functions are performed by the combination of :

- analog IF input module
- analog IF output module
- digital demodulator
- digital modulator

- real-time signal processing software
- network services management software

The key to converting a BBE into a satellite simulator, or reversed BBE (RBBE) is based on the modules achieving the signal processing. The demodulator normally used in TM receiving is used to receive the TC. The modulator normally used in TC transmission is used to transmit the TM. Range simulation involves the reception of the ranging tone pattern on the same input as the TC and re-transmission with a known delay on the same output as the TM. This is mainly a matter of software adaptation.

The following figure points out the different inputs and outputs and also the different blocks related to the signal processing stages.

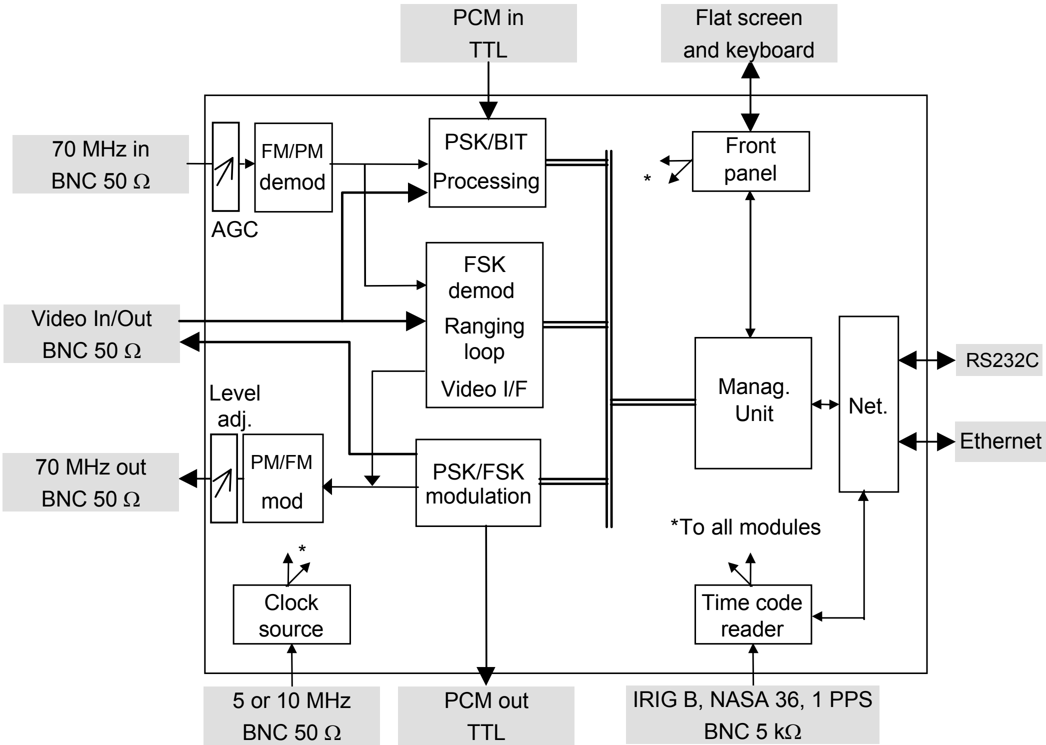


Figure 2 :architecture of the 3801 RBBE

Different applications

The ENERTEC satellite simulators provide an open test tool that can be used for a variety of testing applications.

One of our customers uses it to validate his test cabinets before connecting them to the actual satellite. In such a case, the satellite simulator requires to be connected with the RF up and down-converters in order to “transpose” its signal generated at the IF level (70 MHz).

The satellite simulator can also be used to validate the behavior of the ground stations, at the IF level or at the RF level with additional RF up and down converters.
Another way to use this tool is to connect it to the actual base band equipment (BBE) involved in the satellite program in order to test the interface between the Satellite Control Center (SCC) and the BBE at the network communication level.

In all of these applications, the simulation is best achieved if some realistic telemetry data is available for transmission. This telemetry simulation can be achieved in three ways:

- through the internal simulator, which can generate frames compliant to the different transmission standards (CCSDS, ESA)
- from data files previously stored on the disk
- by data transmitted in real time through the LAN

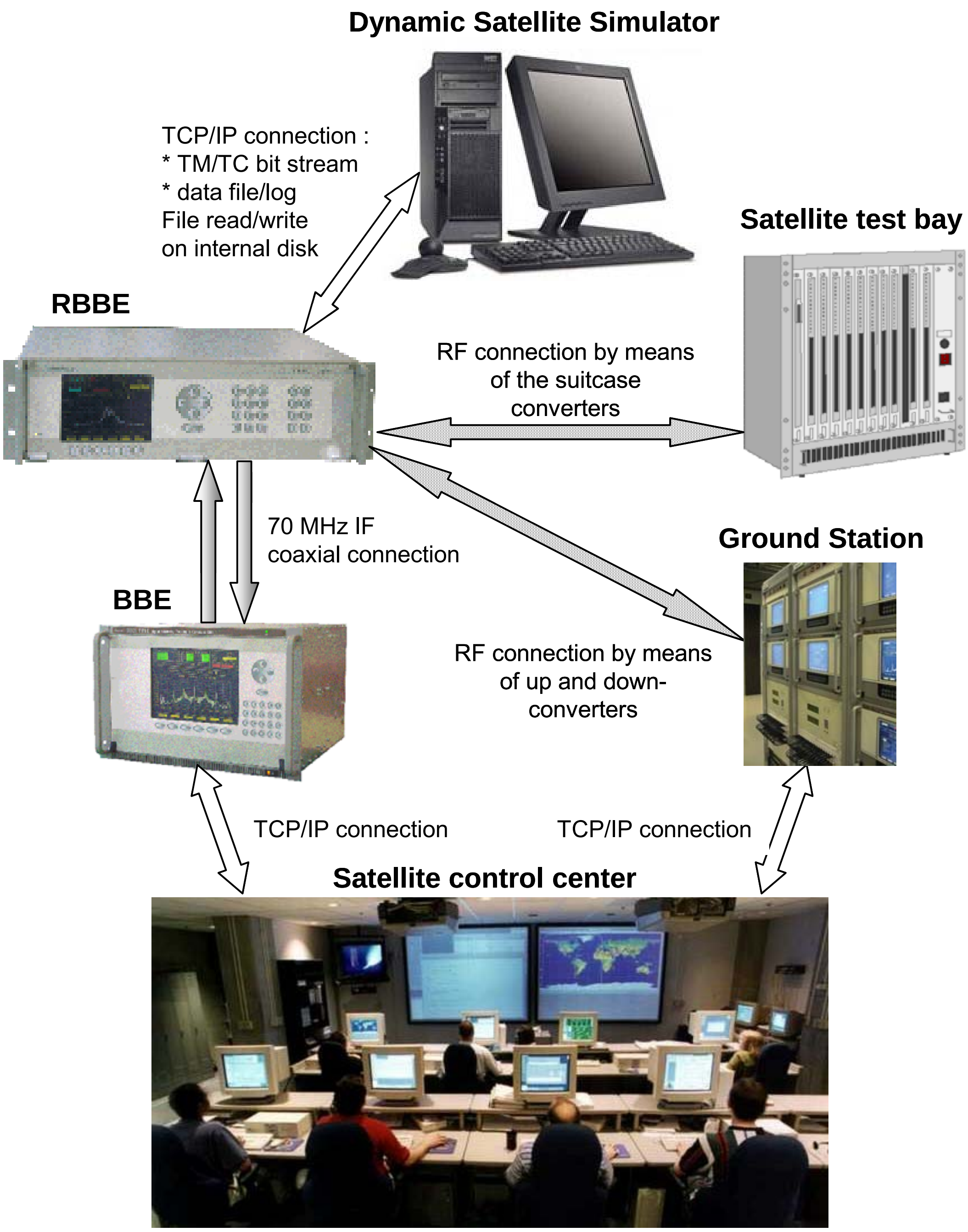


Figure 3 : multiple missions for the satellite simulator

A Dynamic Satellite Simulator (DSS) software, generated by a satellite manufacturer, can be connected through the LAN to Enertec's RBBE to perform a very realistic platform-dependent satellite simulation, while retaining the detailed satellite behaviour knowledge at the satellite manufacturer level. Enertec's RBBE transmits the received CLTU to the DSS over the LAN, sends the telemetry frames generated by the DSS from its own sensor data. Realistic timing behaviour can also be achieved with this connection of a DSS to the RBBE.

The block diagram in figure 3 above illustrates how each equipment contributes to the overall satellite simulation and testing of the ground station.

SPECIFIC FUNCTIONS OF THE RBBE

TC decoding

The following features are missing in a standard baseband equipment in order to perform TC decoding:

- capability to lock the IF receiver on a fast sweeping signal
- capability to lock the subcarrier demodulator fast enough to capture the first bits in the data transmission (only the carrier is present in order to keep the analog demodulation stage locked)
- capability to perform FSK demodulation
- capability to determine the end of the TC whose size is variable from one CLTU (Command Link Transmission Unit) to another

The IF receiver acquisition strategy was consequently modified to allow the PLL to be locked on signals sweeping as fast as 50 kHz.s^{-1}. This was achieved by a predictive algorithm taking into account the result of FFT analysis of the received IF signal.

The subcarrier demodulator algorithm was then improved in order to lock and start transmitting data within less than 5 ms from the rise of the subcarrier modulation.

FSK demodulation was added to the equipment, using digital signal processing on the acquired video signal. The implementation allows FSK tone frequencies up to 50 kHz and sufficient tone separation for all usual FSK modulation schemes.

Finally, a strategy based on timeout detection was implemented to detect the end of the TC. Below is an example of a captured CLTU.

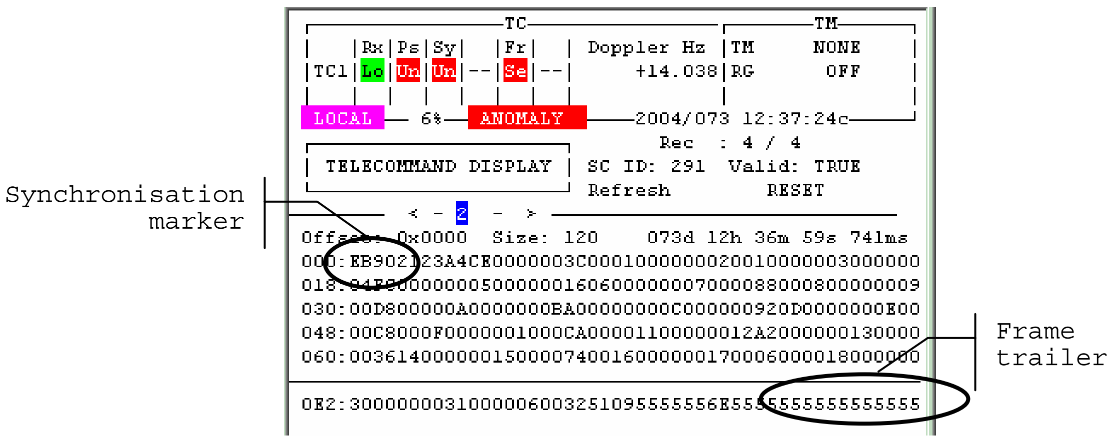


Figure 4 : the HMI page for one extracted CLTU

The range simulation process

The purpose of the ranging process is to determine the distance between the satellite and the antenna. Different methods exist for such a measurement, which is in all cases based on the determination of the travel time of the ranging signal.

Some methods are based on a set of frequency tones. Measurements are obtained from phase differences between the emitted tone and the received tone. The highest frequency in the set of tones provides the measurement accuracy. The lowest frequency in the set of tones provides the maximum distance capability. Intermediate frequencies are used to remove the distance ambiguities.

Other methods use a code that is correlated between the emitted signal and the received one.

The aim of the range simulator is to introduce a programmable loop delay between the received ranging signal and the emitted ranging signal. The RBBE is able to offer a large range of delays from a few hundreds of nanoseconds to hundreds of milliseconds. The lowest delays in this range may represent delays introduced inside the transponder. The highest delays in this range may represent a geo-stationary satellite or a scientific platform tripping far away from the earth.

One big advantage of the programmable delay line is to allow the update of the set-up of the delay every 50 ms and thus to simulate satellites at non-constant distances, such as the LEOP phase of geo-stationary satellites or LEO satellites.

Ranging modulation index adaptation

When the modulation scheme used for the downlink is based on phase modulation, the simulator is able to build a downlink signal where the modulation index of the ranging signal is set-up independently from the modulation index applied to the telemetry data. As the signal passes through the delay line, the adaptation is made by estimating the average dBm level of the input signal then the gain is computed according to the new index to apply.

The following table shows measurements performed on the RBBE with different ranging index setups. It can be observed that the ranging index follows the desired values whereas the TM index remains stable. Such measurements are made on the 70 MHz IF with a spectral analyser at the output of the analog modulation module. "J0" stands for the Bessel function of the 1st kind.

Ranging tone PM index (β) in radian	0.4	0.8	1.2
PM index estimated for RNG tone $10\log\left(J_0(\beta_2) / J_1(\beta_2) \right)$	13.3 dBm $\Downarrow$ ind ≈ 0.425	7.11 dBm $\Downarrow$ ind ≈ 0.805	2.41 dBm $\Downarrow$ ind ≈ 1.215
PM index estimated for TM tone $10\log\left(J_0(\beta_1) / J_1(\beta_1) \right)$	10.26 dBm $\Downarrow$ ind ≈ 0.595	10.27 dBm $\Downarrow$ ind ≈ 0.595	10.28 dBm $\Downarrow$ ind ≈ 0.595

Table 1 : ranging modulation index adaptation

The coherent mode

In the coherent mode, the EHF value of the downlink is linked to the uplink frequency by a proportionality factor α :

$$f_{RF\_TM} = \alpha \times f_{RF\_TC} \Rightarrow f_{IF\_TM}^{Coherency} = \alpha \times (f_{IF\_TC} + \Delta f_{D/C}) - \Delta f_{U/C} \quad \textbf{(Eq. 1)}$$

An example of the resulting frequency values is given in the table below:

$\Delta f_{U/C}$ is the transposition frequency shift of the up converter

$\Delta f_{D/C}$ is the transposition frequency shift of the down converter

α is the coherency ratio

f_{IF_TC} is the IF frequency of the received TC signal

f_{IF_TM} is the IF frequency of the transmitted TM and ranging signal

$\Delta f_{U/C}$	2160 MHz
$\Delta f_{D/C}$	1983,46 MHz
α	240/221 ≈ 1.086
f_{IF_TC}	70 MHz
f_{IF_TM}	70,0018 MHz

Table 2 : coherent mode frequencies

If one introduces the impact of the Doppler effect when the satellite is passing above the antenna, the equations become the following, providing the uplink emission and the downlink reception are affected by the same Doppler shift:

$$f_{RF\_TC}^{Satellite} = (1 - \frac{v}{c})\, f_{RF\_TC}^{Antenna}$$

$$f_{RF\_TM}^{Satellite} = \alpha \times f_{RF\_TC}^{Satellite}$$

$$= \alpha\,(1 - \frac{v}{c})\, f_{RF\_TC}^{Antenna}$$

$$f_{RF\_TM}^{Antenna} = (1 - \frac{v}{c})\, f_{RF\_TM}^{Satellite}$$

$$v << c \Rightarrow f_{IF\_TM}^{Antenna} \approx \alpha (1 - \frac{2v}{c}) \left[f_{IF\_TC}^{Antenna} + \Delta f_{D/C} \right] - \Delta f_{U/C}$$

$$f_{IF\_TM}^{Antenna} = f_{IF\_TM}^{Coherency} + \Delta f_{Doppler} \qquad \textbf{(Eq. 1)}$$

$$\Delta f_{Doppler}(v, \alpha) \approx -\frac{2\alpha v}{c} \left[f_{IF\_TC}^{Antenna} + \Delta f_{D/C} \right]$$

The Doppler shift simulation

In the Enertec 3801 units, Numerically Controlled Oscillator (NCO) drives the carrier frequency and the subcarrier frequency. It is possible to use this ability to control the emitted telemetry signal in order to simulate the effect of the frequency shift when the satellite passes above the antenna.

The generic equation of the Doppler shift is: $\Delta f_{Doppler} = \frac{v}{c} f$

Where:

- v is the radial velocity (projection of the speed vector along the axis from the antenna to the satellite)
- c is the light velocity (c = 3 x 10^8 $m.s^{-1}$)
- f is the emitted frequency

The value of the Doppler shift on the IF signal is:

$$\Delta f_{Doppler} = \frac{v}{c} f_{RF\_TM}^{Satellite}$$

or, when the coherent mode is active, is equal, as mentioned above, to:

$$\Delta f_{Doppler} \approx \frac{2\alpha v}{c} f_{RF\_TC}^{Antenna}$$

This leads with the frequency values in table 2 and a radial velocity of 10,000 $m.s^{-1}$, to the following Doppler shifts of the carrier RF frequency:

- Coherent mode inactive : $\Delta f_{\text{Doppler}}$ = 74,333 Hz
- Coherent mode active : $\Delta f_{\text{Doppler}}$ = 148,669 Hz

The same calculation applied to the RF frequency corresponding to the subcarrier, for instance 65,536 Hz which is a commonly used frequency in Satcom applications, results in an apparent subcarrier Doppler shift after carrier demodulation of 2.2 Hz in both coherent and non coherent modes.

This subcarrier Doppler shift is small enough to consider that the PLL used in the PSK demodulation stage will correctly compensate for the actual difference on the subcarrier frequency. The same remarks apply to the bit rate, which is only marginally affected by the Doppler shift.

Consequently, a realistic simulation only requires to apply the Doppler shift to the carrier.

The orbit simulation

Orbit simulation involves simulating distance variation and Doppler shift in a synchronized manner.

Below is a general description of the trajectory of a satellite flying above a ground station:

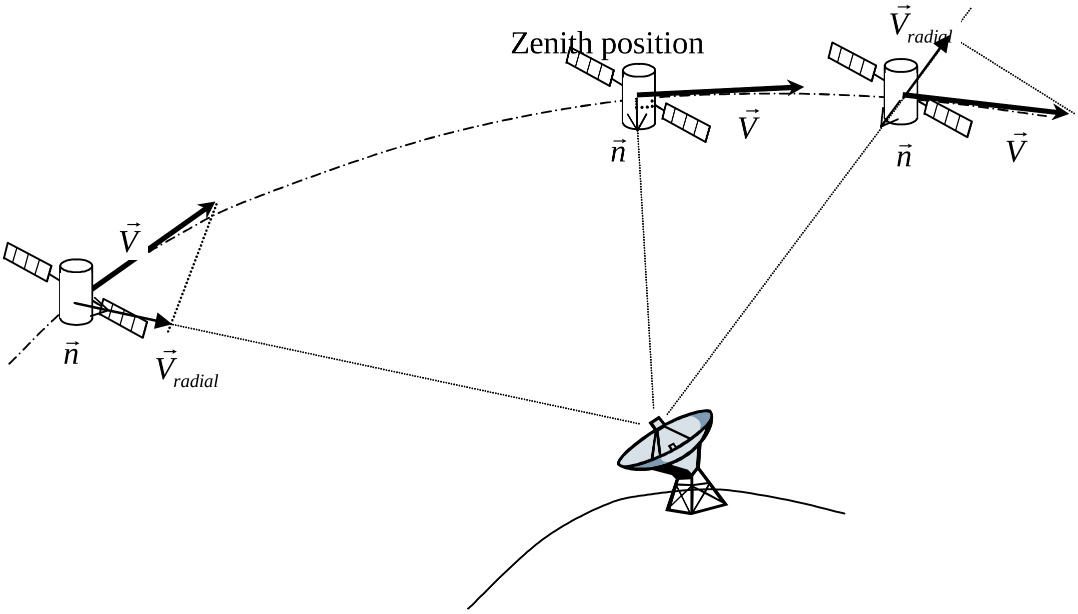


Figure 5: General orbit trajectory

One purpose of such a simulation is to test the ability of a baseband equipment to acquire and track the carrier in order to perform the extraction of the relevant bit information.

Another purpose is to provide range variation and Doppler shift data in order to validate ranging measurement methods.

The meaningful parameter in the evaluation of the capability of a baseband equipment to withstand Doppler shifts is the maximum radial speed variation rate. For a circular orbit, when a satellite emerges out of the horizon, its radial speed has the highest value due to the smallest angle between the trajectory and the direct path from the Satellite to the Antenna. But its variation rate is low.

On the other hand, as the satellite comes close to the zenithal position, the radial speed decreases while the absolute value of the variation rate increases. At the zenith, the radial speed is null and the variation rate reaches its maximum value. Afterwards, the process is reversed, the radial speed increases and the rate decreases until the satellite goes out of sight.

The model implemented in the RBBE is quite similar to such a reality for LOE satellites (altitude small compared to the earth radius). The model consists of a satellite flying at a constant altitude and a constant speed over a flat earth.

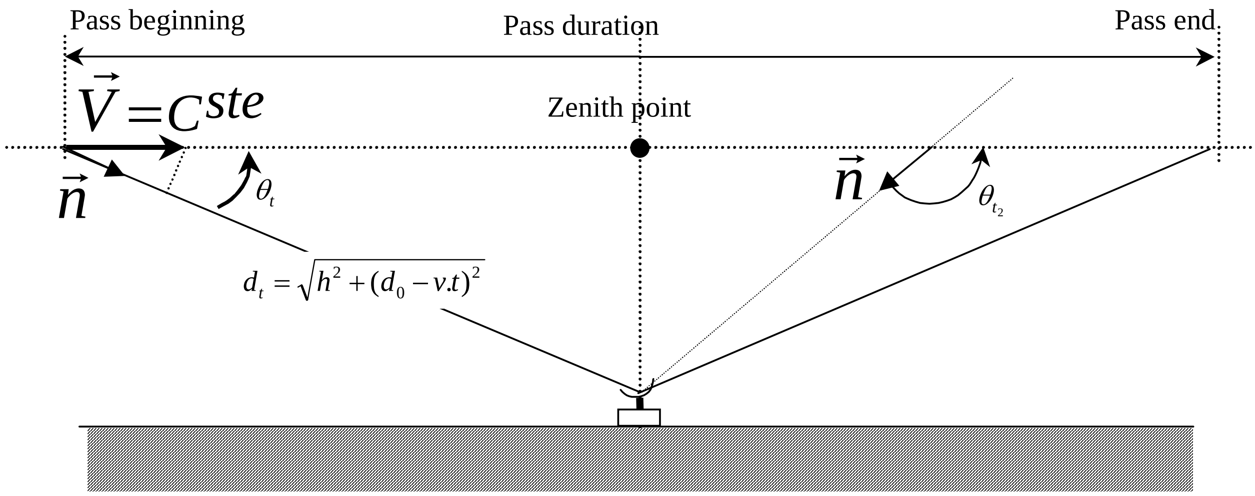


Figure 6 : orbit model with a flat ground, constant altitude and constant speed

The equations describing such a model are easily obtained and implemented.

Let us consider *V* the satellite speed, *h* the altitude and *T* the whole duration of the symmetrical satellite pass.

The radial speed is then : $V_R = V\cos(\theta_t)$

The distance from the satellite to the receiver is : $d_{Sat\,Rec} = \sqrt{h^2 + \left(V(t - T/2)\right)^2}$ **(Eq. 2)**

The Doppler shift Δf is therefore : $\Delta f = (2\alpha)\,\dfrac{V}{c}\,\dfrac{V(t - T/2)}{d_{Sat\,Rec}}\,f_{RF}$ **(Eq. 3)**

The presence of the (2α) term and the choice of the RF frequency depends whether the coherent mode is active or not.

The delay *Dly* introduced by the ranging loop is directly deduced from the round trip time : $Dly(t) = 2\,d_{Sat\,Rec}/c$ **(Eq. 4)**

Below are examples of a satellite distance and the associated Doppler shift obtained with the orbit model.

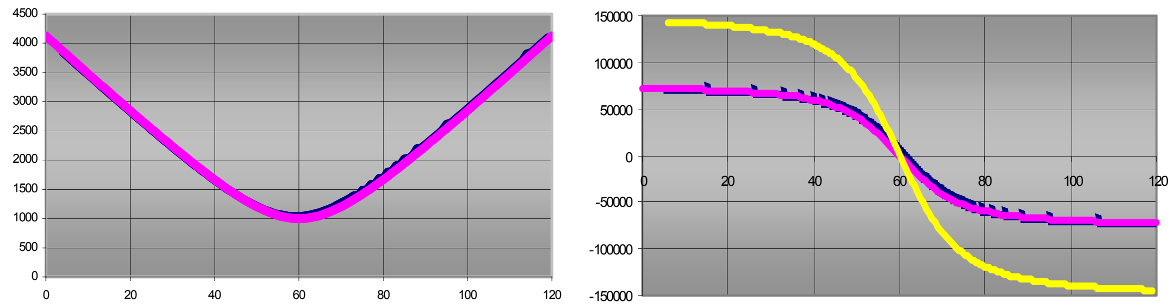


Figure 7 : Curves for the delay (left) and the Doppler shift (right) during the satellite pass

Test conditions are the following:

- altitude : 150 km
- speed : 10000 m.s^{-1}
- pass duration : 120 s

On above figures, it can be observed that the curves corresponding to the model (the gray ones) fully match those obtained from measurements performed on the outputs of the simulator (the black ones). On the curves related to the frequency shift, the measurements corresponding to the coherent mode has been added (yellow curve). In the coherent mode, at the zenith position, the BBE have to support a Doppler rate of about 10 $kHz.s^{-1}$.

The resolution of the NCO, whose frequency can be setup with a step lower than 10 mHz, explains the quality of the simulation.

It should be noted that parameters do not need to match the Keppler equations or physical constraints!

The spinning satellite simulators

Boeing has developed a specific class of satellites, which are spin-stabilized. All Boeing 376 models have two telescoping cylindrical solar panels and antennas that fold for compactness during launch. The basic bus accommodates a wide range of customized payloads, and the satellite can be launched by any of the world's major launch vehicles.

As a consequence, a specific function has been introduced in the satellite simulator (also called BTU) to dynamically simulate the satellite attitude sensors data. This simulation consists in the simultaneous transmission of two IF signals. The first one is modulated by the analogue Real Time FM telemetry signal (specific to BSS 376) according to a PM/FM modulation scheme and the other provides the standard PCM telemetry signal with the PM/PSK modulation. The first one is called real-time because the sensor data are reported without delay. Both telemetry signals are transmitted coherently and synchronously. Moreover the received commands (data and execute tones) detected by the BTU reception channel are reported inside the simulated telemetry signals with time coherence.

CONCLUSION

This paper has pointed out some specific functions developed for the satellite simulators. Starting from a common architecture shared with the basic baseband equipment, Enertec has introduced the necessary evolutions for the TC decoding, the range functions and the simulation of the Doppler effect. As a consequence, the product is available to fulfill multiple missions.

To meet some new requirements, complementary developments may be considered. Some adaptations can be applied to the protocols supported by the simulators. Mainly, as some baseband equipments manage the FOP1, which is the ground part of the Communication Operation Protocol recommendation of the CCSDS, the state machine associated to the FARM could also be implemented. This function will close the loop based on the SCC, the BBE and the simulator, offering a larger spectrum of tests.

Some additional functions could be considered. For instance, TC echo could be inserted in one telemetry stream. To enlarge the tests of the communication link with the BBE, using the flexible architecture of the product, additional telemetry channels could be added without difficulty. At last, as some satellites use two subcarrier streams on the same carrier frequency, the capability to generate the signal on the dwell telemetry channel could easily be implemented because the modulator board receives digital signal samples and the software can easily prepare such samples. The Doppler simulation can be improved by allowing the user to provide the orbit data as a set of samples (carrier frequency, ranging delay) in order to describe any trajectory.

To conclude with, starting from a popular baseband equipment in the TT&C word, satellite simulators offer versatility and are open enough to evolve and meet future customer needs.

A CASE STUDY ON THE BIT ERROR RATE PERFORMANCE OF A TYPICAL GROUND RECEIVING TELEMETRY CHAIN

Manmohan Sandhu, Gautam Sadhukhan, Mrinal Goswami
Telemetry Group, Integrated Test Range
Chandipur, Orissa, India. 756025
Tel: +91-06782-372048/372229, FAX: +91-06782-372072
E-mail: mn_sandhu@rediffmail.com

ABSTRACT:

This paper evaluates the Bit Error Rate (BER) performances of entire PCM Telemetry ground receiving chain and efforts have been made to understand the BER improvement or deterioration due to its various subsystems when added to the telemetry chain. The test includes stage wise loop back test of telemetry instrumentations like Multicoupler, Telemetry Receiver, Diversity Combiner, Bit Synchronizer and Magnetic Tape Recorder using bit error rate detector. This paper concludes that individual instruments like antenna feed, multi-coupler, receiver, diversity combiner and magnetic tape recorder of typical telemetry chain contributes significantly towards overall BER performance. This paper also identifies those critical instruments, which are important for configuring the telemetry stations and responsible for Bit error rate performance of the typical telemetry chain.
Index Term: BER, PCM, signal to noise (S/N) ratio.

1.0 INTRODUCTION:

The Telemetry ground receiving station extracts the PCM (Pulse Code Modulated) serial data stream from RF Carrier (S- Band or L- Band) and processes clean PCM serial stream of standard IRIG codes, i.e., Bi∅-L, NRZ-L, etc. using bit synchronizer and frame synchronizer. These codes before being processed by telemetry data acquisition system are supposed to be very clean and noise free resembling the actual event onboard but in real time the acquired PCM stream will be contaminated by various system noises. Apart from this noise, there are atmospheric noises, which are actually introduced through receiving telemetry chain i.e. through tracking antenna feed. The performance of telemetry receiving chain can be evaluated in terms of Bit Error Rate (BER). Defined by Eq.1.0:

$$BER = \frac{\text{No. of error bits over a time period}}{\text{No. of bits arrived over that period}} \qquad ...(1.0)$$

The purpose to evaluate BER performance of a ground telemetry chain is to know contribution of individual equipments in BER performance and to identify the critical elements contributing to BER. Here, in this paper we have mostly considered the noise over PCM stream due to sub-systems only.

2.0 SYSTEM ARCHITECTURE:

A typical ground receiving telemetry chain consists of receiving Antenna Feed, Multicoupler, Receivers, Diversity combiners, bit synchronizer, Magnetic Tape Recorders, data acquisition and processing system. The chain is shown in fig.1.0.

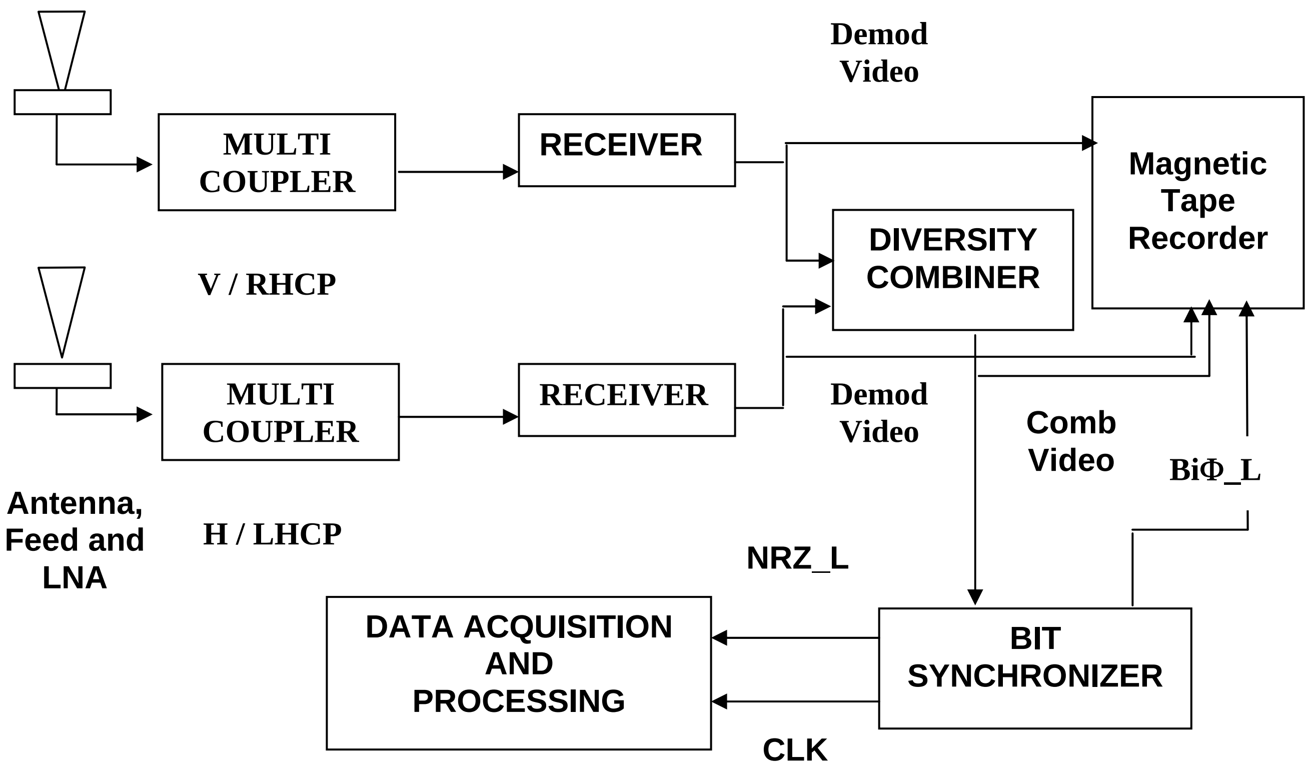


Fig.1.0 : Typical Telemetry Ground Receiving Chain

The Receivers receive RF signal with selected polarization from receiving antenna feed via Multicoupler unit. The receiver noise [1] gets added over PCM data Eq. [2.0].

$$\text{Receiver Noise} = -10.\log [\,KT_sBF] \qquad ....(2.0)$$

Where,

K = Boltzman's constant
B = IF Bandwidth of receiver.
T_s = Receiver Noise standard temperature.
F = Noise figure of Receiver (T_o/T_s).
T_o = Absolute temp. (273 ^oK)

In a standard polarization diversity telemetry system, Diversity combiner combines received signals in two orthogonal polarizations and provide a combined video signal with improved S/N ratio [2] as per Eq. [3.0] and Eq. [4.0]. Due to this improvement in S/N ratio, overall BER performance should be scaled up proportionately with respect to that from receiver alone.

If $(S/N)_{RX1} = (S/N)_{RX2}$ then

$$\text{S/N improvement} = 2.5 \text{ db} \qquad .... \qquad (3.0)$$

and for unequal S/N ratios

$$(S/N)_{DC} = 10 \log [(S/N)_{Rx1} + (S/N)_{R\,x\,2}] \qquad .... \qquad (4.0)$$

The demodulated combiner video signal is fed to the Magnetic Tape Recorder for recording and also to bit synchronizer for deriving clean NRZ_L and clock which in turn fed to PCM frame synchronizer for decommutation and extraction. The bit synchronizer also produces clean recordable bipolar BiΦ_L signal, which is ultimately recorded on the instrumentation Magnetic Tape Recorder. Later, those recorded signal are reproduced for offline analysis. The Magnetic Tape recorders direct recording modules provide record and replay equalization together with flat frequency response. The primary functions of record drive circuitry are to provide required amplification to enable the input signal to drive the record heads. Tape replay characteristics are both frequency and speed sensitive. The replay equalization provides the necessary amplification and frequency compensation to restore the replay signal to its original form. Thus the above feature of Instrumentation magnetic tape recorder reflects an improvement of overall S/N ratio and hence, BER of overall system.

3.0 EXPERIMENTAL SETUP:

To evaluate the BER performance of overall telemetry chain, the individual equipments are added to the chain to know the stepwise performance. The PCM stream is simulated by generating it from Bit Error detector, the NRZ_L and clock signal from the instrument under test are fed to bit Error detector which after sync and load measures number of bits with error over a particular period. An external noise source is used to add noise over PCM stream and varied in step of 3 dB to evaluate BER performances. The following 5 setup show the configurations details. The experimental data input to the systems are as follows

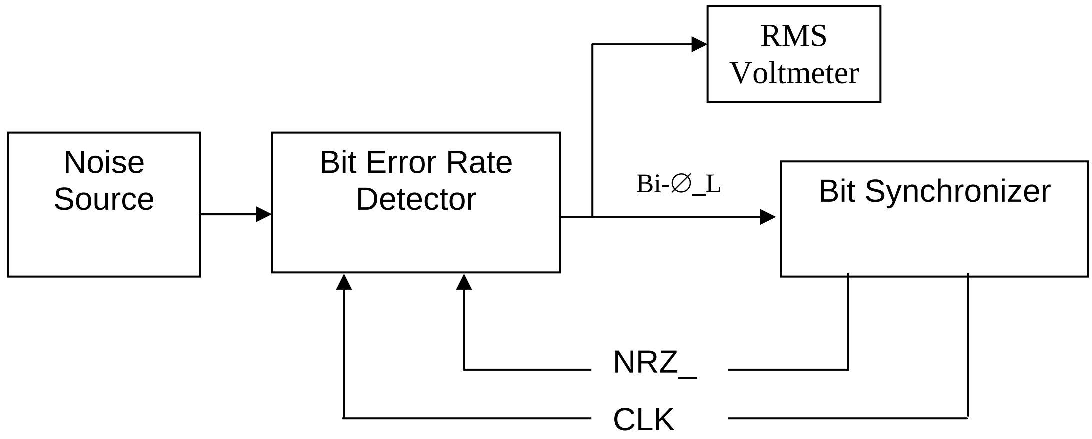
- Bit rate of PCM stream : 1 Mbps.
- Words / Frame of PCM : 512
- Output pattern : 11 bit PN sequence
- Output Code : BiΦ_L
- Period of measurement : 10^{6} Bit period
- Measurement error count : Both 1's and 0's
- Noise : External, White

3.1 INSRUMENTS USED :

- EMR 721 Bit Error detector
- EMR 720 Bit Synchronizer
- Microdyne 1100 MR Telemetry Receiver
- 3200-PC Programmable Diversity Combiner
- Scientific Atlanta S Band Feed and Multi-Coupler
- RACAL DD4 Instrumentation Magnetic Tape Recorder
- RMS Voltmeter- HP3466A

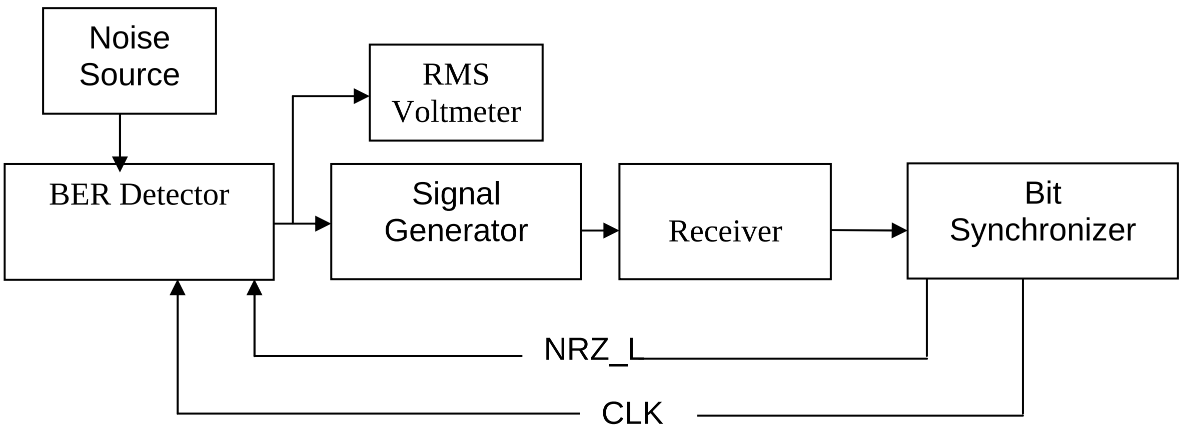
3.2 EXPERIMENTAL SETUP - 1 :

In this setup the instrument under test is bit-synchronizer alone. The generated PCM stream from bit error detector is fed to bit- synchronizer and the output NRZ_L and clock is fed back to BER detector and V-RMS meter is used to measure the S/N ratio of input PCM streams. The step-wise variation on S/N ratio is done via Bit Error Detector.



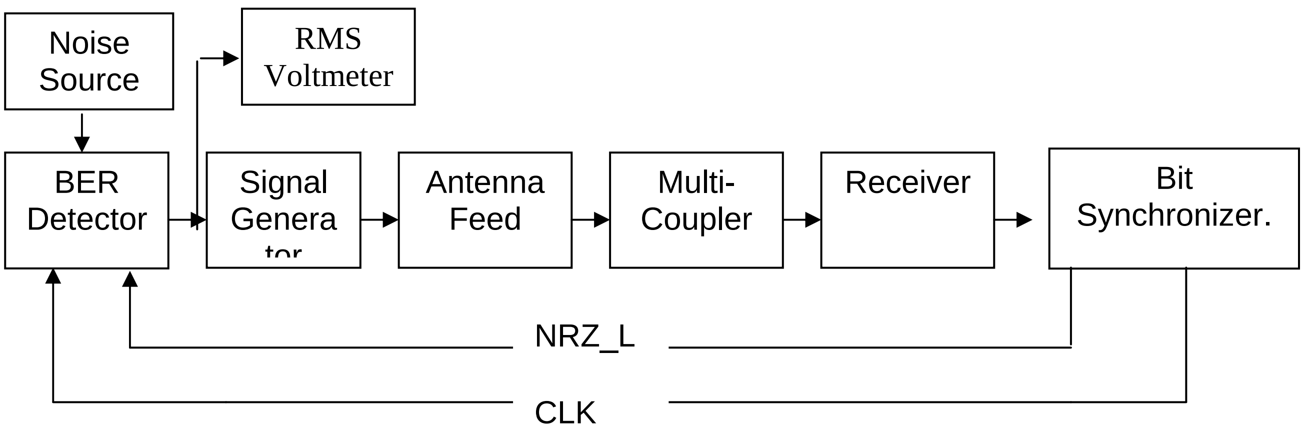
3.3 <u>EXPERIMENTAL SETUP-2</u> :

Apart from the other measurement setup, in this setup the instrument under test is bit-synchronizer and receiver.



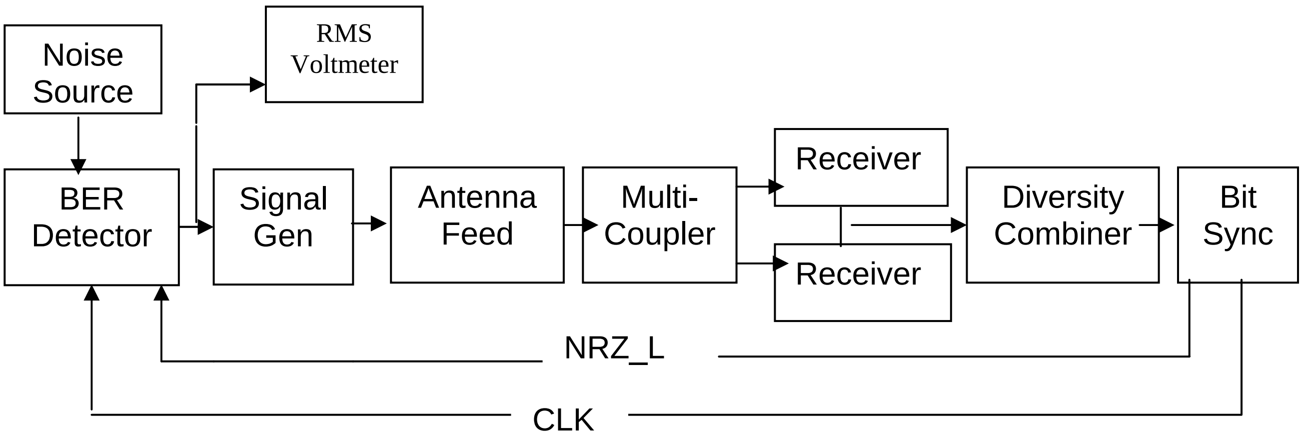
3.4 <u>EXPERIMENTAL SETUP-3</u> :

In this setup the instruments under test are antenna feed, multicoupler, receiver and bit-synchronizer. The generated PCM stream from bit error detector is fed to signal generator for FM modulation. The output is fed to antenna feed through test port, the signal is then fed to multicoupler then receiver and demodulated PCM is given to bit synchronizer.The output NRZ_L and clock is fed back to BER detector.



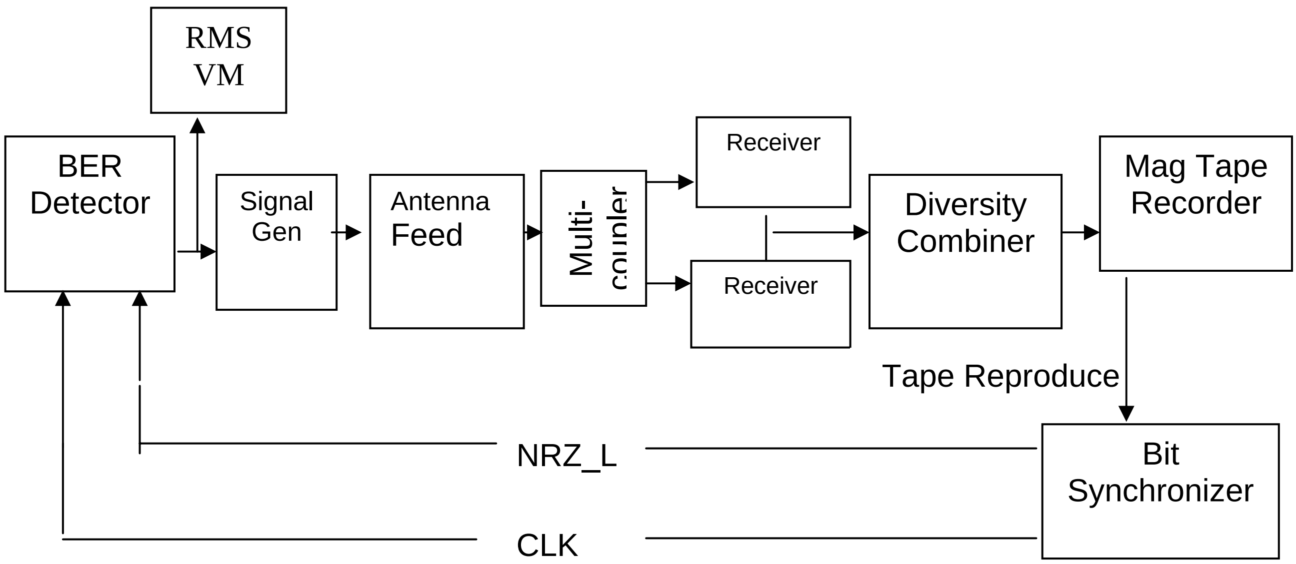
3.5 <u>EXPERIMENTAL SETUP-4</u>:

In this setup the instrument under test is antenna feed, multicoupler, receivers, diversity combiner and bit-synchronizer. The generated PCM stream from bit error detector is fed to signal generator for FM modulation. The output NRZ_L and clock is fed back to BER detector.



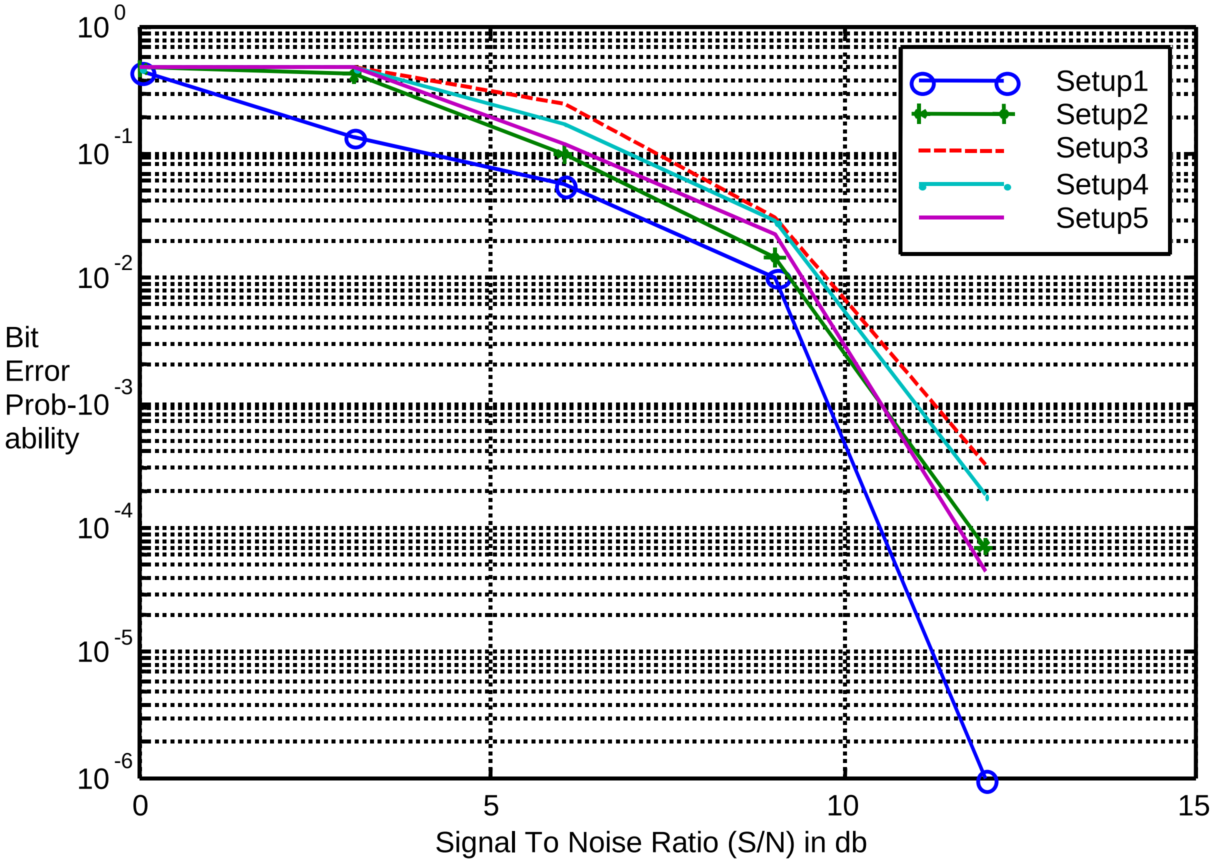
3.5 EXPERIMENTAL SETUP-5:

In this setup the instrument under test is antenna feed, multicoupler, receivers, diversity combiner, magnetic tape recorder and bit-synchronizer. The generated PCM stream from bit error detector is fed to signal generator for FM modulation. The output is fed to receiver and demodulated PCM is given to bit synchronizer. The output NRZ_L and clock is fed back to BER detector. V-RMS meter is used to measure the S/N ratio of input PCM streams.



5.0 EXPERIMENTAL RESULTS :

All the measurements have been carried out for SNR ≤ 12 dB. The experimental data corresponding to setup 1 is taken as reference to analyze the contribution towards the noise and hence BER by the instruments in the telemetry chain. A qualitative comparison has been made at 12 dB SNR, which is considered to be threshold for base-band telemetry chain. From the experimental data, it has been observed that the BER readings vary as S/N ratio is varied.



As shown in the graph for the experimental setup-1 the BER reading is observed to be less than that of the experimental setup-2 of the order of 10^2 at 12 dB SNR. This shows that the BER performance deteriorated by the addition of telemetry receiver in the chain and this is mainly due to receiver noise characterized by noise figure of the receiver. The BER performance gets further deteriorated by addition of antenna feed and multi-coupler as shown in setup 3 in the chain by the factor of 10 at SNR of 12 dB.

The BER readings get improved by the addition of Diversity combiner in the chain as per the predicted formula. The BER gets further improved when the data is taken from the magnetic tape recorder reproduce output. This is due to the fact that gain and frequency equalization of the record and reproduce head improves the S/N ratio and hence BER.

6.0 CONCLUSIONS:

The paper concludes with the fact that the critical components affecting the BER are antenna feed, multi-coupler and the receiver. From the results, it is concluded that in normal telemetry chain, polarization diversity system using diversity combiner improves SNR and hence BER performance. Further, it has been observed that reproduce output of the magnetic tape recorder improves the BER performances due to its in-built signal conditioning and gain improvement. More detailed analysis on BER performance of the system can also be carried out by using signal simulator to incorporate the effects of pre-modulation filtering, multi-path, signal fading and jitter effects.

REFERENCES :

[1] . International Telemetry Conference (ITC) Proceedings 1994 and 1996.

[2]. System manuals, 3200-PC Programmable Diversity combiner, Mycrodyne.

[3]. System manual , Bit Error Rate Detector.

[4]. Introduction to Telemetry , By O.J. Stroke.

[5]. Telemetry Computer Systems, By O.J. Stroke.

Achieve Cost Effective Over-the-Internet Telemetry by Combining Embedded Processors and Mobile Phones.

Jan van Niekerk
Microchip Technology Inc.

Abstract

This paper shows how to combine the low cost of mass-market GSM (Global Standard for Mobile Communication) phones with the flexibility of cost effective embedded processors. Most modern mobile phones contain a Java™ - based Kilobyte Virtual Machine that implements the MIDP (Mobile Information Device Profile) specification. Analog to digital conversion is performed by an external, single-chip embedded microcontroller. In stead of powering mobile phone games, Java™ applets on the phone are harnessed to forward the serialized, digital telemetry data from the embedded processor directly to the Internet using built-in TCP/IP library calls. The telemetry data can then be recorded and displayed by remote Internet nodes such as a personal computer.

The GSM Mobile Phone Standard

The GSM standard, first implemented in Europe in the 1990s, has become the most popular mobile phone standard in the world. In February 2004, there were 1024 million GSM subscribers in 205 countries [1]. In February 2004, 72% of all mobile phone users used GSM.

GSM is a full digital standard, and was designed to interface well to the ISDN digital data land-line system. In the GSM system, speech is converted into a digital bit stream by speech encoders. At the receiving end the received digital bit stream is converted back to audio by the speech decoder [2].

Since it is essentially a digital system, GSM also allows point-to-point data connections at 9600 bits per second. The GSM mobile phone is typically connected to a computer's RS232 serial port through an interface cable. The phone emulates the command set of a land-line dial-up modem and enables dial-up communication with other modems at up to 9600 bits per second.

General Packet Radio Service (GPRS)

General Packet Radio Service is a new service implemented on top of the GSM infrastructure. GPRS uses the existing GSM infrastructure, with enhancements, to enable the exchange of packets of data with the Internet. Like the Internet, the service is "connectionless", meaning that no point-to-point connection is required to send or receive Internet packets. In essence, as long as the GPRS-enabled phone is in the coverage area, connectivity to the Internet is always on and immediate. The theoretical maximum data rate of GPRS packets is 171.2 kilobits per second [3].

Mobile Edition Java

The programmability of mobile phones has developed in parallel with their Internet connectivity. Programmability has primarily been focused on the development of wireless games and office connectivity applications. The Java programming language has evolved as the programming platform of choice for mobile phones. By mid-2003, Java programs ran on over 100 million phones and 53 networks. [4]

In November 2003, Sun Microsystems, the developer of the Java platform, released the eagerly awaited version 2.0 of the Mobile Information Device Platform (MIDP 2.0) specification. This second revision of "Java for cell phones" contains many enhancements derived from the lessons learned through the use of MIDP 1.0. In particular, MIDP 2.0 contains enhanced connectivity functions such as standardized serial port access, Internet datagrams, and Internet sockets [5].

Analog to Digital Conversion

As we have seen above, Internet connectivity via GPRS as well as Java-based access to the serial port via MIDP 2.0 are both built into modern cellular phones.

One additional, external element is required to implement remote measurement of analog voltages: An analog-to-digital converter/serializer. Figure 1 is a block diagram that depicts the basic components of such a GPRS-based analog measurement system.

Fortunately, the combination of an analog to digital converter and serializer can be found in low cost embedded microcontrollers [6]. In addition, these embedded controller devices offer low cost, a small form factor and free development tools.

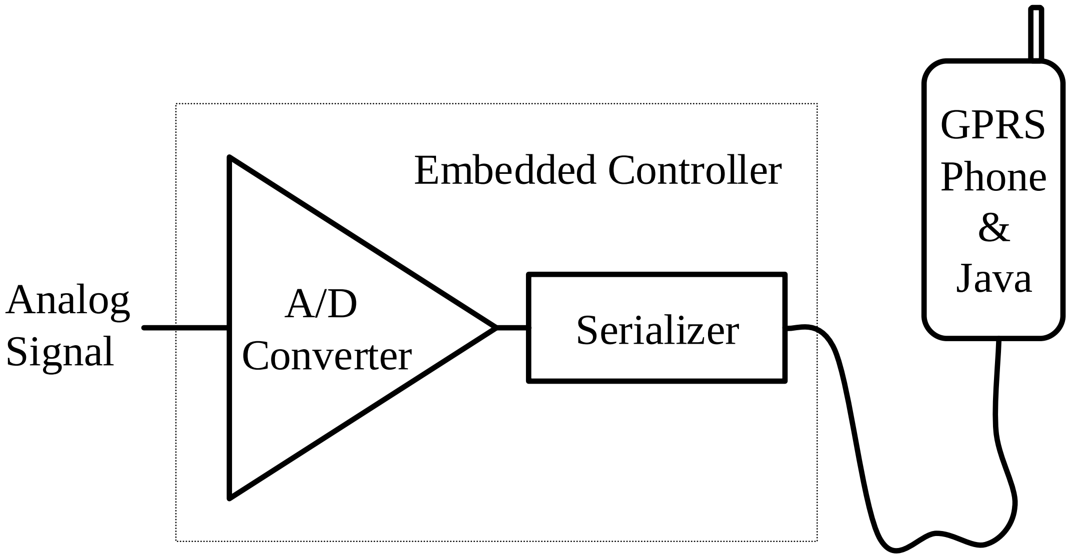


Figure 1. Basic Components of GPRS Phone-based Analog Measurement

Cost of Data Transfer

German-based T-Mobil announced in early 2003 that it will price GPRS-based data transfers between phones and the Internet around $5-$10 per megabyte. This cost is bound to come down as infrastructure, service use and competition continue to expand.

Implementation

A brief summary of the implementation of a GPRS-to-Internet based data acquisition system is as follows:

1. Find a GPRS cellular service provider that covers the planned operating area.

This may be the hardest part of the entire process, as customer service personnel are often uninformed of technical terms such as GPRS, or GPRS is actually marketed as "e-mail", "Internet", "multi-media", "always-on", etc. The best solution is to either find a knowledgeable technical individual inside the organization or search the Internet for technical announcements and information regarding a particular service provider. Also be sure to look only at GPRS coverage maps, which will be more restricted than voice services coverage maps.

2. Purchase an GPRS-enabled phone supported by your GPRS service provider.

Only fairly modern phones have GPRS capability. Moreover, a Java-enabled phone running MIDP 2.0 Java is required. MIDP 1.0 is not good - it has to be MIDP 2.0. Once again, service staff at the cellular service provider may be uninformed regarding which phone models contain the MIDP 2.0 Java platform, and an Internet search of the provider's phone models and the phone manufacturer's website are the most likely sources of valid information.

3. Purchase a true Asynchronous Serial Data Cable for your GPRS Phone

Many phone-to-computer interface cables nowadays conform to the USB standard. However, we are interested in obtaining a true asynchronous serial cable. Again, phone shop assistants generally do not understand the difference and the Internet is the best source of information for specialist cable providers. To add to the confusion, some cables are USB on the computer side, but contains a USB-to-serial converter in the cable, so that the phone side of the cable is again a true serial port. See figure 2.

4. Purchase and program an Embedded Controller.

A small embedded controller such as the Microchip PIC16F88 can be purchased in single quantities for around five US dollars. A comprehensive, free development environment for these embedded controllers can be downloaded from the Internet [7]. A small assembly language program to read the analog to digital converter, and to stream out the measured data, needs to be programmed into the device. Since the device is reprogrammable, it can be reprogrammed many times to modify parameters such as the sampling interval, serial baud rate, and averaging or filtering. An in-circuit serial programmer (ICSP) can be found from several sources on the Internet or can be purchased from the IC vendor for around $200.

5. Cut the Phone's Serial Cable and solder it to the Microcontroller

This is probably the biggest technical challenge. The serial input of the phone cable connects to the microcontroller serial port output. The serial output of the phone cable connects to the microcontroller serial port input.

In addition, the wire that carries power from the phone (as well as the ground wire) needs to be connected to the supply and ground connections of the microcontroller - in effect the cell phone is supplying power to the microcontroller.

Note: The microcontroller inputs are NOT RS232 compatible. RS232 which represents a one with -10V and a zero with +10V. However, all cellular phone serial ports tested by this author do NOT actually output RS232 voltage levels - the conversion to ±10V is implemented in voltage conversion circuitry embedded in the interface cable. Consequently, by cutting the interface cable before the voltage conversion, normal 0V/5V logic levels from the phone's serial port are available to connect to the microcontroller.

6. Write Java using MIDP 2.0

The next step is to create a small Java Program to read data from the mobile phone's serial port, as provided by the microcontroller, and pass the data to any IP address and port you desire on the Internet. The free Java mobile phone development system to create such a program can be downloaded from www.sun.com [8].

7. Write Java on destination Computer

A simple Java application running on any computer connected to the Internet is required to receive the packets of telemetry data sent by the mobile phone and microcontroller combination. In essence, the receiving Java routine opens an IP port and waits for packets of data from the GPRS cellular phone to arrive via the Internet. The application can plot a graph, draw an analog meter, or simply write the received Internet packets containing the measured data to a disk file. See figure 3.

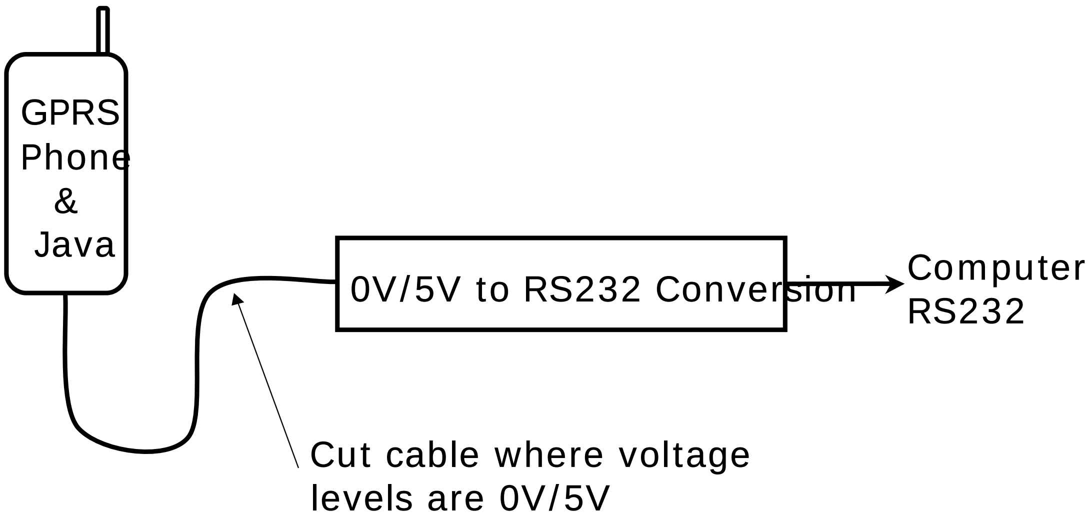


Figure 2. GPRS Phone-to-Computer Serial Interface Cable with In-Cable Voltage Conversion

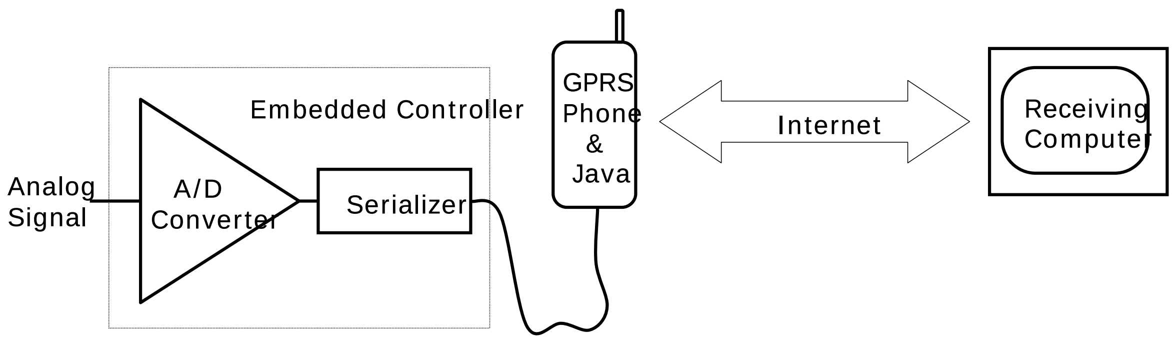


Figure 3. Conversion of Analog Signals, Transmission to GPRS Phone via Serial Cable, Transmission to Destination Computer via Internet.

Conclusion

GPRS-over-GSM provides low cost ($5-$10 per megabyte) wireless telemetry capabilities using the GPRS cellular phone network. A low-cost embedded microcontroller reads analog voltages, converts them to serialized digital format and feeds them to the serial port of a Java-enabled mobile phone. A simple Java program on the phone reads the data from the serial port and forwards it to any IP address on the Internet, where a receiving application can store or process the received data packets.

References

1 "GSM statistics" gsmworld.com
http://www.gsmworld.com/news/statistics/index.shtml

2 "Overview of the Global System for Mobile Communications" John Scourias
http://ccnga.uwaterloo.ca/~jscouria/GSM/gsmreport.html#1

3 "What is General Packet Radio Service?" gsmworld.com
http://www.gsmworld.com/technology/gprs/intro.shtml

4 "Java set to heat up applications" Wireless Week, June 15, 2003
http://www.wirelessweek.com/index.asp?layout=articlePrint&articleID=CA305214

5 "MIDP 2.0 is here" ADM + Partners, November 4, 2003
http://www.admpartners.com/archives/2003/11/000214.html

6 "PIC16F87/88 Data Sheet" Microchip Technology Inc., 2003
http://www.microchip.com/download/lit/pline/picmicro/families/16f8x/30487b.pdf

7 "MPLAB IDE Vx.x" Microchip Technology Inc.
http://www.microchip.com/1010/pline/tools/picmicro/devenv/mplabi/mplab6/index.htm

8 "Java 2 Platform, Micro Edition (J2ME)" Sun Microsystems Inc.
http://java.sun.com/j2me/index.jsp

A New Type On-board Phased-array Telemetry Antenna

Yu Zhijian Feng Bingxuan Chen Aiping Fang Hongrui

Beijing Institute of Tracking and Telecommunications Technology

ABSTRACT

Antenna array, auto-tracking mechanical antenna and phased-array antenna are normally adopted on the airplane for on-board telemetering system. However, the phased-array antenna arranging in 2-D can hardly achieve all-directions coverage. To overcome above limitation, a kind of phased-array antenna arranged in pyramid-trapezia type is put forword by authors.

KEYWORDS

Phased-array , Beam dithering, On-board , pyramid-trapezia

INTRODUCTION

Three styles of on-board telemetry antenna are adopted, including antenna array, auto-tracking mechanical antenna and phased-array antenna. Antenna array refers to several antennas arranging at different places of the airplane, such as the front, the tail or wings, to achieve its coverage with connecting of radiation pattern. The advantages are simple and low-price; while disadvantages is losing of signals because of the concave of connections. In addition, it will raise the price cased by its number of receivers of antennas. Auto-tracking mechanical antenna is designed of paraboloid antenna with four horns or elements to achieve Az/El tracking. It's good at wide-range tracking but not easy to perform the maintenance because of the hard environment with high altitude, low temperature and dust, which will also affect the system reliability. 18 inch and 24 inch antennas are taken as typical of those with Az ±60° El–60 to +10°. For the phased array antenna, with much more antenna elements and more symmetrical distribution comparing with common antenna array, it adopt electron beam sweep for tracking . In this way, the disadvantages of antenna array and auto-tracking mechanical antenna shall be polished up. However, since on-board phased array telemetry antenna elements are usually arranged in 2-D array and the antennas are mounted at two sides of plane head, the full-direction radiation pattern is difficultly to achieve.

Based on performance comparison of varieties of on-board telemetry antennas, a certain type telemetry system adopts phased-array antennas. In order to avoid its disadvantage, a new type of pyramid-trapezia phased array antennas are proposed. Computer emulation express that it can achieve full direction tracking with Az 0°~±360°, El –5°~–80°.

ANTENNA STUCTRURE AND PRINCIPLE

On-board phased array antenna outline is illustrated as figure 1.

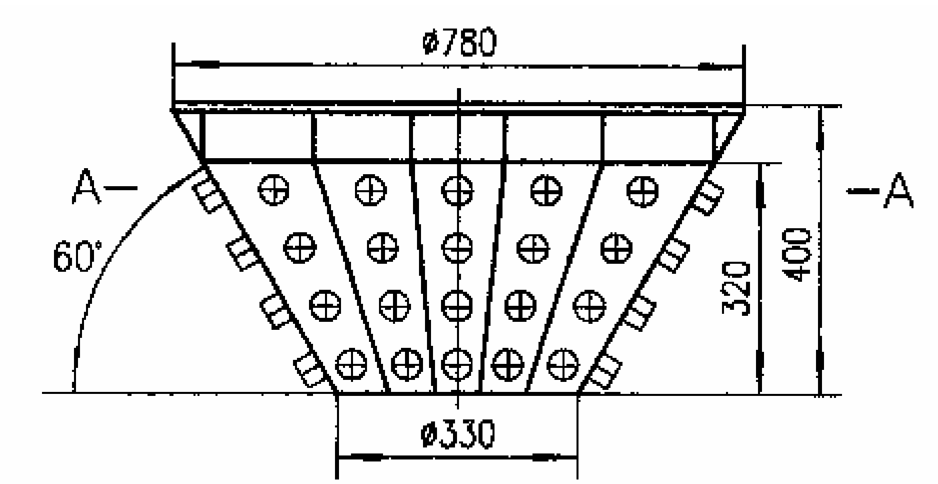


Figure 1 on-board phased array telemetering antenna structure

On-board telemetry phased-array antenna is composed of radiation unit, electric bridge, band-pass filter, LNA, splitter, switch net , phase-shift components, combine network. The total number of the antenna array is composed of 64 antenna units arranged on 16 plane of the pyramid-trapezia with 4 units each plane.

The principle of antenna beam coverage is as follow: The array can form 3 kinds of sub-array, including 4×4 array, 3/5/5/3 array and a circular array with 16 units, can be formed by using of switch matrix. And the total number of sub-array is 18. With the switch matrix the sub-arrays can be shifted between 4×4 array and 3/5/5/3 array to realize large angle sweep with 11.25° Az step, the maximum Az range is -90° to +90° and the maximum El range is –5°to –80°. The sweep during 11.25° uses the phase-shifter to realize accurate sweep with the step of ±5.625°.

On-board telemetry phased-array antenna is mounted at abdomen of the airplane, antenna cover is made of wave penetratable material in streamline.

Beam-controller capable of wave controlling and target tracking is the main component of phased-array antenna. It’s composed of TCU, BCU and angle-error modulation unit, control panel ED/P, etc.

ANTENNA MAIN FEATURES

Antenna radiation pattern

Phased-array antenna, in which phases are changeable, is developed from array antenna.
The function without considering couples is shown as follows.

$$F(\theta,\varphi)=\sum_{i=0}^{M-1}\sum_{K=0}^{N-1}\alpha_{IK}\, f(\theta,\varphi)e^{j[i(d_{r1}\sin\theta-\beta)+k(d_{r2}\beta\cos\theta\sin\varphi-\alpha)]} \tag{1}$$

Whereas, M and N stand for the units on two directions;

- f,θ,φ,stands for diagram of unit antenna;
- α_{IK} swing factor;
- β,α stand for sweeping phase;
- $dr_1=(2\pi/\lambda)d_1$
- $dr_2=(2\pi/\lambda)d_2$
- d_1, d_2 stand for distance between array;

1D line array antenna radiation pattern is shown as follows.

$$F(\theta,\varphi)=\sum_{i=0}^{M-1}\alpha_i\, f(\theta,\varphi)e^{j[i(d_{r1}\sin\theta-\beta)]} \tag{2}$$

Side-lobe of Line Array and Maximum Sweep Angle

Side-lobe is generated when more than one maximum wave-lobes are existed under certain conditions of difference array.
The maximum sweep angle is shown as follows.

$$\left|\sin\theta_{\max}\right|\geq\frac{m\lambda}{d}-1 \tag{3}$$

The side-lobe isn’t existed under the following condition.

$$d<\frac{\lambda_{\min}}{1+\left|\sin\theta\right|} \tag{4}$$

Half-power beamwidth

$$\Delta\theta_{\text{0¡£}}\approx\frac{1}{\cos\theta_{\mathrm{B}}}\frac{51\lambda}{L} \tag{5}$$

Coupling and Influence

Radiation pattern of array antenna is decided to distribution of current and phase difference between neighboring units. In fact, current distribution in one antenna unit shall be influenced by the shapes and coupling of current distribution in neighboring antenna units. Coupling affects each other units, especially those in neighboring positions. The couplings also cause the variation of current distribution and impedance output, which lead to blind angle.

Current distribution variation caused by coupling shall bring the raise of antenna side-lobe level, descend of antenna gain and main lobe expanding; impedance output variation shall increase antenna unit reflection, augment reflection loss and generate second reflection wave lobe. When antenna approaches to the maximum angle, blind angle shall generate if antenna achieves full reflection, because the coefficient value reaches "1" cased by source inflection while coupling. To avoid blind angle, the maximum antenna sweep angle shall be less than the value in (3). The structure of vehicle (such as plane) shall also be considered.

Design and Implementation of IF PCM/FM Telemetry Digital Receiver

Chen dahai Sui xiurui Zheng guiqiang
Electronic Engineering Institute of China Academy of Engineering Physics
Mianyang, Sichuan, P.R.China

Abstract

In this paper, design and implementation of an IF (intermediate frequency) PCM/FM telemetry digital receiver are presented in detail, carrier frequency of PCM/FM signal is 10.7MHz and code rate is 2Mbps. Experimental results reflect the receiver has a linear dynamic range of more than 50dB, and functions naturally when the SNR (signal noise ratio) of PCM/FM signal is higher than 7dB.

1 Introduction

For traditional analog PCM/FM receivers, phase locked loop demodulator are always applied. The basic model is shown in fig.1. Output of $e_0(t)$ can be expressed as equ.1,

$$e_0(t) \approx \phi_i^{'}(t) / K_0 \qquad (1)$$

Where $\phi_i{}'(t)$ is the instantaneous frequency of the composite vector of PCM/FM signal and normally distributed noises, K_0 is the sensitivity of frequency detection of the loop. The limiter is generally implemented with a non-linear analog limiter and a band pass filter, they would cause changes in the spectrum and would introduce noises as well. The phase locked loop consists of a phase detector, a loop filter and a VCO (voltage controlled oscillator), noises in the loop includes those outside the loop as well as noises produced inside the loop such as spikes etc. In summed up, the loop has following disadvantages: 1 being sensitive to the DC(direct current) drift and saturation of analog parts; 2 higher-order loop is difficult to be built up; 3 initial rectification and periodic adjustment are required. Therefore the phased locked demodulator is hard to design, and the reliability and performance will not be ideal. However, compared with analog techniques, digital alternatives have advantages of having stable performance, large noise tolerance and great flexibility. With the high development of DSP (digital signal processing) algorithms and VLSI (very large scale integration) circuits, especially for high-speed, high-resolution analog-to-digital converters, high speed, high performance FPGAs and DSPs, it becomes quite possible to perform digital demodulation of IF signals that have several tens or hundreds of MHz (mega hertz) bandwidth.

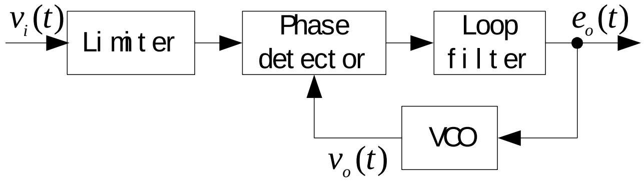


Fig.1 Model of phase locked demodulator

An IF PCM/FM digital receiver has been designed and implemented with high speed, high resolution ADC (analog-to-digital converter), wideband DDC (digital down converter) and high-performance FPGA. In this paper, we will first analyze the design principle and key techniques; then introduce methods of implementation; followed, experiment results will be presented; at last, we make conclusions for our design.

2 Design Principle and key techniques

2.1 Design principle

Fig.2 is the diagram of the digital receiver. It can seen from it the receiver is composed of four parts: ADC, DDC, frequency discriminator and DPLL (digital phase locked loop) modules. PCM/FM signal is directly sampled by a high speed ADC at a fixed frequency that meets with Nyquist sample theorem. Sampled data is fed into the DDC, where the frequency of NCO (Numerically controlled oscillator) is set to be same as the carrier's, namely, 10.7MHz. Sampled data multiplies with outputs of NCO and forms I (In-phase) and Q (Quadrature) components, they will be further filtered and decimated to reduce their data rate to a degree that succeeding DSP units can handle and a proper decimate factor should be selected according to the requirements of bandwidth. In frequency discriminator, phase of I, Q signals output from DDC are detected with CORDIC algorithm and by exerting first order differentiation on them frequency of I, Q signals can also be detected. Still, it can be understood the actual carrier frequency of received PCM/FM signal would not be exact of 10.7MHz but would vary slowly around it due to doppler shift of carrier or some other reasons. Whereas, as mentioned above, the frequency of local oscillator is set to be 10.7MHz, so there certainly exists deviation of carrier frequency between them. The deviation would cause errors, and EBR performance would degrade if decisions are made directly on the signals output from frequency discriminator, a DPLL (digital phase locked loop), however, is applied following frequency discriminator and responsible for removing these errors.

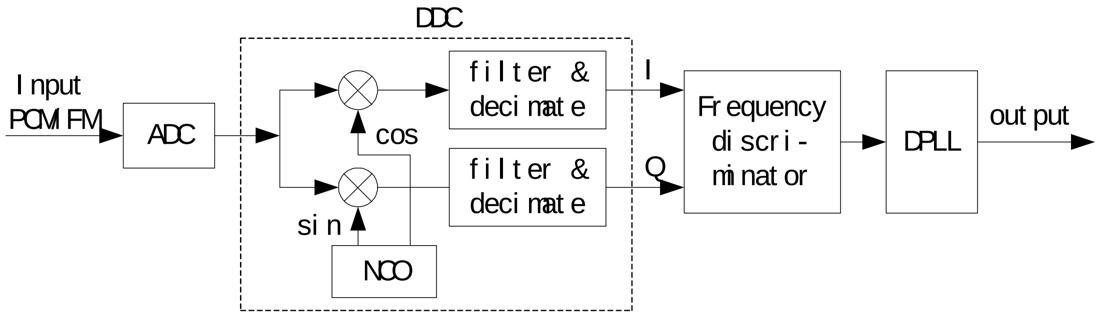


Fig.2 Block diagram of PCM/FM digital receiver

2.2 Key techniques

2.2.1 DDC

Suppose the received PCM/FM signal is $r(t)$, it is directly sampled by an ADC and becomes discrete forms of $r(nT_s)$ and feeds into DDC, where T_s is the sample period. The process of quadrature demodulation can be depicted in equ.2~3.

$$I(n) = r(n)\times\cos 2\pi f_0 nT_s \quad (2)$$

$$Q(n) = r(n) \times \sin 2\pi f_0 nT_s \quad (3)$$

where $\cos 2\pi f_0 nT_s$ and $\sin 2\pi f_0 nT_s$ are the two local oscillating signals generated by NCO, and the performance of DDC would be determined greatly by their resolutions. Filtering and decimating of I(n) and Q(n) can be performed with some efficient methods such as polyphase or multistage schemes. In our design, however, the latter method is applied that several CIC (cascaded integrator-comb) filters are placed on the front stages to do large integer decimating and on the last stage, an FIR (finite pulse response) filter is placed to compensate the unrealistic frequency responses of CIC filters, especially on pass band, besides that, FIR filter can further decimate signals if needed.

2.2.2 Frequency discriminator

I, Q signals output from DDC module cab be expressed as in equ.4~5,

$$I'(n) = \cos(k_f \sum_{k=1}^{n} f(k)T_s) \qquad (4)$$

$$Q'(n) = \sin(k_f \sum_{k=1}^{n} f(k)T_s) \qquad (5)$$

Where k_f is the index of frequency modulate, and $f(k)$ is the modulated signal. Phase of $I'(n)$ and $Q'(n)$ can be detected by arctangent operation,

$$\theta(n) = \arctan[Q'(n) / I'(n)] \qquad (6)$$

Frequency can be detected by exerting 1st-order differentiation on $\theta(n)$,

$$\omega(n) = f(n) \times T_s = \theta(n) - \theta(n-1) \quad (7)$$

Fig.4 is the structure of frequency discriminator, where phase detection is performed with CORDIC (Coordinate Rotation Digital Computer) algorithm[1], which can be depicted in equ.8~12.

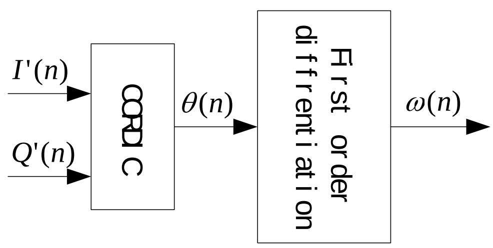


Fig.4 Structure of frequency discriminator

$$\alpha_i = tg^{-1} 2^{-(i-2)}, i > 1, Y_i = r_i \sin\theta_i, X_i = r_i \cos\theta_i \qquad (8)$$

$$Y_2 = d_1 X_1 = r_1 \sin(\theta_1 + d_1 90^0), X_2 = -d_1 Y_1 = r_1 \cos(\theta_1 + d_1 90^0) \quad (9)$$

$$Y_{i+1} = \sqrt{1 + 2^{-2(i-2)}}\, r_i \sin(\theta_i + d_i \alpha_i) = Y_i + d_i X_i 2^{-(i-2)} \qquad (10)$$

$$X_{i+1} = \sqrt{1+2^{-2(i-2)}}\, r_i \cos(\theta_i + d_i\alpha_i) = X_i - d_i Y_i 2^{-(i-2)} \quad (11)$$

$$d_i = \begin{cases} 1 & Y_i < 0 \\ -1 & Y_i \geq 0 \end{cases}, Z_{i+1} = Z_i - d_i\alpha_i \quad (12)$$

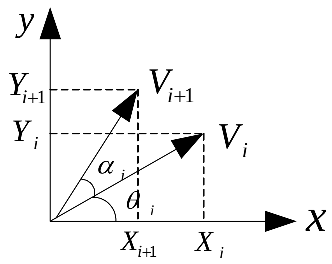


Fig.5 Example of i^th micro rotation

Example of the i^th micro rotation is shown in fig.5. Suppose Z_{i+1} is the angle after i^th micro rotation and lets $Z_1 = 0$, when $n \to \infty$, $|Y_n| \to 0$ and $Z_\infty \to \varphi = arctg(y_1 / x_1)$, thus the phase of original vector (x1, y1) is detected.

In our design, limited instead of infinite iterations are performed when detecting phases, which may cause a possible maximum errors of $\pm\alpha_i$. The CORDIC algorithm is integrated in FPGA with a structure of N stages of pipeline.

2.2.3 DPLL

A 2^nd order uniformly sampled DPLL is employed in our design[2], it is composed of three parts: the DPD (digital phase detector, DLP digital loop filter and NCO, as can be seen from basic model of fig.6.

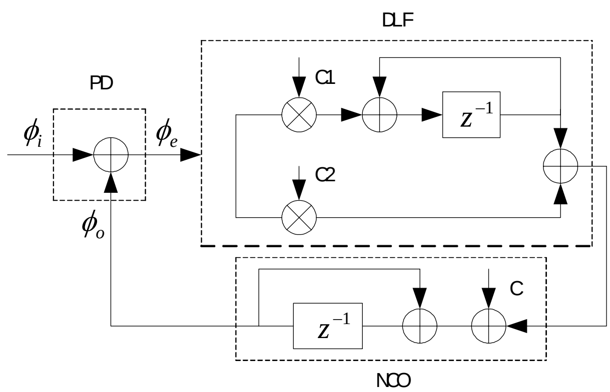


Fig.6 Basic model of 2^nd order DPLL

In the DPD, input phase of ϕ_i is subtracted by the output phase ϕ_o of NCO, the phase difference ϕ_e passes through DLP and control the instantaneous phase of NCO. C_1 and C_2 are the parameters of DLP, which determine the bandwidth of the loop and response time. C is the center frequency of DPLL. This type of DPLL has advantages of having linear phase, small capture time and large phase locked range.

Lets $Z = e^{j\omega}$, and we get the magnitude spectrum of transfer function of DPLL,

$$\left|H_e(e^{j\omega})\right| = \frac{4\sin^2(\omega T/2)}{\sqrt{[-4\sin^2(\omega T/2)+C_2]^2 + 2[-4\sin^2(\omega T/2)+C_2](C_1-C_2)\cos\omega T + (C_1-C_2)^2}} \quad (13)$$

Parameters included are set as follows:

(a) damp ratio η£½0.707 ;

(b) freely oscillated frequency of the loop $fn = 10Hz, 20Hz, 50Hz, 100Hz$ respectively;

(c) sample rate $f_s = 1KHz$, sample period $T = 1/f_s$;

(d) $C_1 = {\omega_n}^2 T^2 = C_2^2 / 4\eta^2$;

(e) $C_2 = 2\eta\omega_n T$;

Curves of magnitude spectrum of error transfer functions are plotted in fig.7, it can be seen evidently from them DPLL have a high-pass characteristic, the cutoff frequency are almost same as the freely oscillated frequency f_n, which indicates an expected high-pass filter can be realized by selecting proper values of f_n, especially when the cutoff frequency is small, because in that condition, pass band response becomes more flat accordingly.

In our design, DPLL is also integrated in FPGA, the input phase of ϕ_i corresponds to signals output from frequency discriminator and because DPLL is employed in base band, so the center frequency C of DPLL should be zero. Moreover, the freely oscillated frequency f_n is set to be 100Hz or so and can remove the slowly varied deviations of carrier frequency.

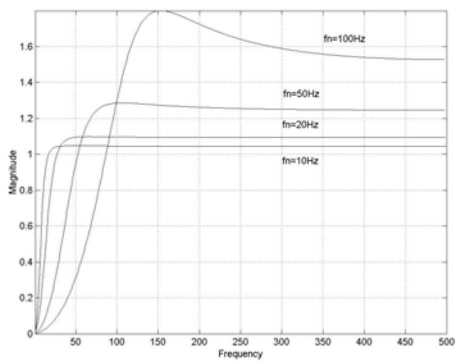


Fig.7 Magnitude spectrum of error transfer functions

3 Implementation and experimental results

3.1 implementation

(a) an AD6644 is applied to do IF sampling, it is a high speed, high performance, low power, 14 bits monolithic ADC with a maximum sample rate of 65Msps. We have designed an ADC PCB(printed circuit board) with AD6644 and high speed latches and on it AD6644 works at 64MHz sample rate. (b) a wideband DDC chip of AD6620 is used, it integrates digital quadrature demodulation and decimating and filtering. The accumulator and outputs of NCO have 32 bits and 16 bits resolution respectively. There are three input modes: single channel real mode with a maximum input data rate of 67Msps, dual channels real mode and single channel complex mode with a maximum input data rate of 33.5Msps. Filtering and decimating can be performed by the CIC2-CIC5-RCF multistage filters inside the chip, decimating factor can be programmed between 2~16384. The maximum pass band that can be processed by the chip is up to 2.5MHz, and correspondingly, the maximum IF input bandwidth should be under 5MHz. There are two output modes: parallel and serial. In parallel mode, the chip outputs 16 bits of complementary coded data. In addition, two separate ports of control and configuration are also provided. In our system, AD6620 works at single channel real input mode and parallel output mode. The overall decimating factor is 8, and shared by the CIC2-CIC5-RCF filters of 1, 4 and 2 respectively, thus data rate of I'(n) and Q'(n) is 8Msps. (c) CORDIC phase detection (8 stages of pipeline), 1st order difference frequency detection and DPLL are all included in an XILINX FPGA X2V250CS144. Block diagram of the hardware system is shown in fig.8.

In the system, the CLK module outputs 64MHz clock, an ALTERA CPLD EPM3064 is employed to generate configuration logic for AD6620 and control signals for FPGA, PROM is used to store VHDL codes of FPGA.

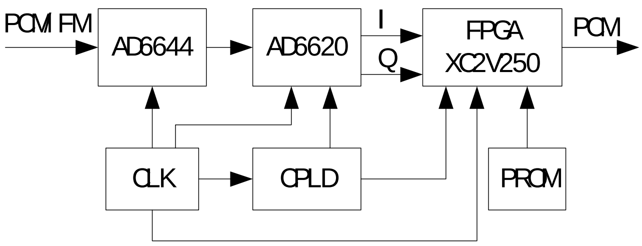


Fig.8 Block diagram of the hardware system

3.2 Experimental results

An input of 10.7MHz PCM/FM signal with 2Mbps code rate is generated by a microwave generator, and we get the following results:

(1) Correctness Test

Fig.9 is the original PCM data observed on an oscillograph, while fig.10 is the corresponding output PCM data observed on a logic analyzer, form it, we can see the input and output data are matched and proves the digital receiver functions correctly.

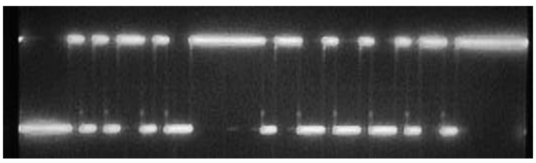


Fig.9 Original PCM data

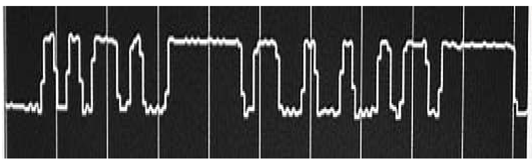
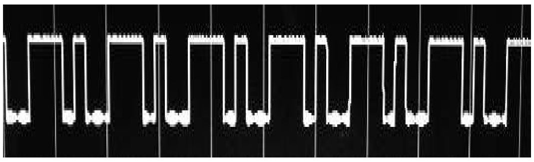


Fig.10 Output PCM data

(2) Linear dynamic range test

Adjusts the magnitude of PCM/FM signal and observe the corresponding PCM outputs, we find the system has a dynamic range of more than 50dB, as showed in fig.11~12.



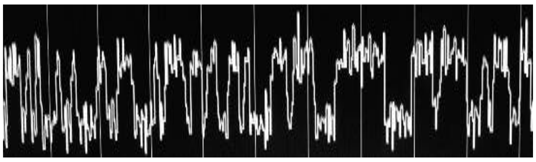


Fig.11 Output when PCM/FM level is -50dBm

Fig.12 Output when PCM/FM level is –1dBm

(3) SNR test

Normally distributed noises are generated by a noise generator and is incorporated by the PCM/FM signal with a power divider to form an input signal having certain SNR, we find the system can work normally when the input SNR is higher than 7dB.

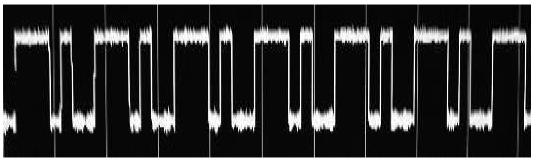


Fig.13 Output PCM data when SNR is 7dB

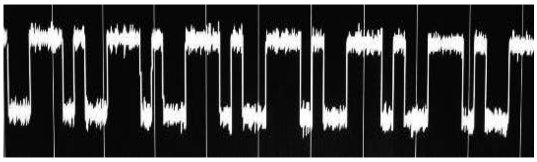


Fig.14 Output PCM data when SNR is 16dB

4 Conclusions

An IF sampled digital PCM/FM telemetry receiver is implemented with a high speed, high resolution ADC (AD6644), a wideband DDC (AD6620), and an FPGA that is applied to perform frequency discrimination and DPLL functions. Experiment results indicate: 1 the system can demodulate 10.7MHz IF PCM/FM signal with 2Msps code rate correctly; 2 the system has a linear dynamic range of more than 50dB, and is determined by the ADC's effective number of bits(ENOB) , if ENOB can be improved, then the dynamic range would increases accordingly; 3 the receiver functions naturally when SNR of PCM/FM is high than 7dB. Meanwhile, the receiver has advantages of being high reliability and flexibility.

References

[1] J. E. Volder, 'The CORDIC trigonometric computing technique', IRE Transactions on Computers, vol. C-8, pp. 330-334, Sept. 1959.

[2] Y. R. Shayan, T. Le_Ngoc, 'All digital phase-locked loop: concepts, design and applications', IEE, proceedings, vol. 136, Pt, F, No.1, February 1989.

Technical Data Management in Design and Validation

What happens after your simulation and test data is saved on hard disk?

Thorsten Mayer
European Business Development, Manager
National Instruments

Abstract

Technical product data is being generated throughout the entire development process – no matter whether by simulating a process or actually testing a real prototype. Costs such as for simulation systems, data acquisition hardware, automation systems and the associated personnel costs make this data a significant investment. Being able to easily share technical data and results between cooperating project groups or partners and quickly access them to apply standardized analysis and reporting methods is critical for the efficiency of the overall development process.

One of the greatest challenges in industrial production is to bring the three conflicting aims of short model cycles, minimized costs and better product quality together. To be able to offer the customers innovations or to be a cut above the rest of the competitors, product quality has to be improved and product cycles shortened, under growing financial pressure. In production, the factors involved in increasing efficiency are advanced; construction data can be readily exchanged between development and production or between manufacturers and suppliers. In simulation, measurement and testing technology, consistent exchange of data between various applications, test rigs, department or even companies is still in the initial stages. Although Computer Aided Testing has had a significant impact on reducing development times, there still remains a bottle neck in managing, processing and reporting of technical data

National Instruments offers tools that support the development engineer throughout various phases of the design process. National Instruments Software DIAdem is a key component to Technical Data Management applications that will help the user making the right decisions from his data in the least amount of time.

Introduction

The product development process is generally broken down in a certain number of manageable sub tasks; respectively products are broken down in components. For instance, an automobile is comprised of a body, an engine, a transmission, the chassis, and tires and so on. However, the successful accomplishment of general development goals such as “improving the fuel consumption of a vehicle” or “maximizing the MTBF (Mean Time between Failures) of a product requires optimized “interplay” of multiple or even all components of a product. Therefore designers need to have access to measured and simulated characteristics of all components which are relevant for their development task. Being able to easily access test and simulation results for verification, comparison, etc. and to derive intelligent decisions as quickly as possible is essential for the overall efficiency of the development process.

The today’s information landscape in design and validation is very inhomogeneous and perhaps can be compared to the CAD and production related data management five or ten years ago. Where many different tools are storing their data to various data formats. Different programs use these data for analysis and report generation and thus create new results which also have to be administrated. The different data formats and access methods make it even more difficult to combine the various tools. Further more, given the evolution of PC based test systems; today it is very easy to collect more data, faster then ever before.

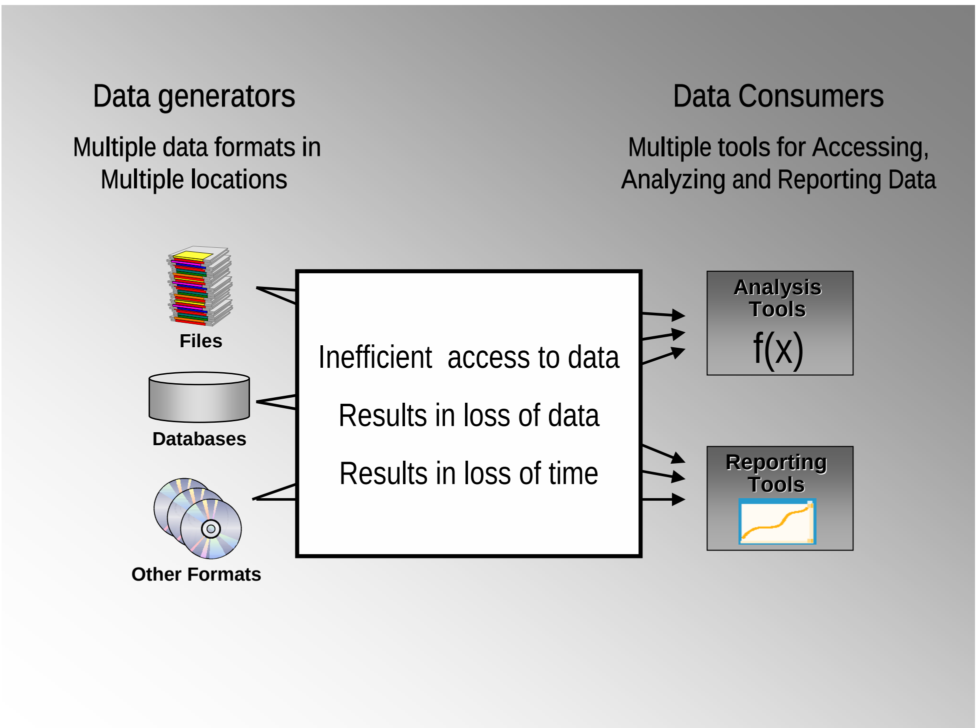


Figure 1: The “Data Problem”. Many point-to-point connections between data producers and data consumers result all too often into loss of data, inefficient access to data, inefficient processing of data, loss of time and thus money.

Viewing this in the context of today's business trends such as, faster time to market, large companies building distributed R&D Centers, outsourcing of tests, it's obviously that we face a **"data problem"** which results all to often into, *loss of data, inefficient access to data, inefficient processing of data, loss of time and thus money*.

*For example: For a new passenger aircraft to receive the official approval, it requires many (round about 2000) hours of flight test. Given that it takes many engineering hours to analysis the data generated during one single hour of flight testing, the value of our "**data investment"** becomes very obvious.*

For solving the "data problem" respectively to minimizing the loss of time and money caused by the "data problem" we will be looking at the following key areas:

- Accessing and sharing data from different data sources
- Best practices for turning data into interpretable results in a minimum of time

In the course of this paper we'll briefly talk about methods to cope with the "data problem" and then introduce you to NI DIAdem - a product which is well established as a standard tool for analysis and reporting in design and validation at international operating companies such as (Daimler Chrysler, General Motors, Airbus, Cummins, Raytheon and others).

Accessing and sharing data from different data sources

The goal of this task is to reduce the cost for developing and maintaining all point–to-point connections necessary to access the different data formats from the various tools which are used to generated and post-process technical data. The actual requirements from a data consumer point of view are

- Easily accessible data - independent from original data format
- Search functionality to search for data by using key words or properties to easily locate the data one want to work with
- Apply filters to only extract a certain amount of data such as a data which was acquired during a certain time interval or data which corresponds to a certain operational condition (e.g. a certain flight conditions, a certain state of a test rig)

General approach

On common methodology to achieve the goals described above, is to add descriptive information to your data. By adhering to the following steps you can ultimately gain significant cost savings by reducing the time to locale and share data as well as results with cooperating project partners.

- **Identify the descriptive information you want to use to re-locate your data for post-processing after it's stored**: You need to store information such as Unit Under Test Name, Serial Number, Test Date, Configuration, Min/Max values, and so on - such information the data consumers want to use to identify the data they want to work with.

- **Create a database respectively a database structure which includes columns to store your descriptive information:** Databases offer the possibility to define so-called database queries in order to search data records based upon certain conditions. This means by storing our descriptive information in a database, a data consumer can use some of that information to search for specific data records as opposed to browsing manually through directories or relaying on phone calls or emails to locate data.
- **Implement a searching and data mining tools that allow you or the data consumer to find exactly the data set he wants to work with:** As a last step, the tools that are used by the data consumers to access data need to offer a user-friendly interface that allows them to interactively search for the data in which they are interested in.

The universal database interface ODBC (Open Data Base Connectivity) and the manufacturer-independent query language SQL (Structured Query Language) provide access to a huge variety of database which are available on the market today. This standardized access mechanism allows us to read from as well as write into database by using so called "database queries" to define the data we want to work with. This database interface is widely used for any type of database applications. It provides a stable basis for measured data management, evaluation result management and methods for data acquisition and analysis.

Using Industry standards

In some industry areas working groups, made up by representatives of OEM's and suppliers, have defined standards for data storage and exchange to facilitate the data exchange between products form different vendors to reduce the development and maintenance costs. Examples are the CDF (Common Data Format) standard which is mainly being used in the Aerospace industry as well ASAM-ODS (Association for the Standardization of Automation and Measurement systems/Open Data Services) which has been developed by the automotive industry. Both standards provide methods and rules how to store and exchange data.

- An information model for the entire storage of measured data, simulation results and descriptive data. Individual application data structures can then be derived from the basic data structure. These individual structures provide the basis for data exchange between various applications.
- Standardized protocols to access data via an API (Application Programming Interface)
- Standard format file format for data exchange and storage

Both formats are widely used and have helped to significantly reduce the cost for data storage, exchange as well as system development and maintenance.

Best practices for turning data into interpretable results in a minimum of time

Being able to store and exchange test and simulation data quickly is only one half of the process. Raw data is not what helps make decisions; rather it is the information contained in the data which you are seeking since they'll help you making reasonable decisions and taking the required actions to improve your design and processes. Uncovering information and the speed by which you do this, is the ultimate measure of how well you convert on your data investment. Selecting the right tools for processing technical data is critical to the efficiency of the entire development process. The ability to easily identify the data which you are interested in as well as to apply individual as well as standardized analysis and reporting methods is essential for making decisions more quickly. This process can be broken down in a set of steps shown in the diagram.

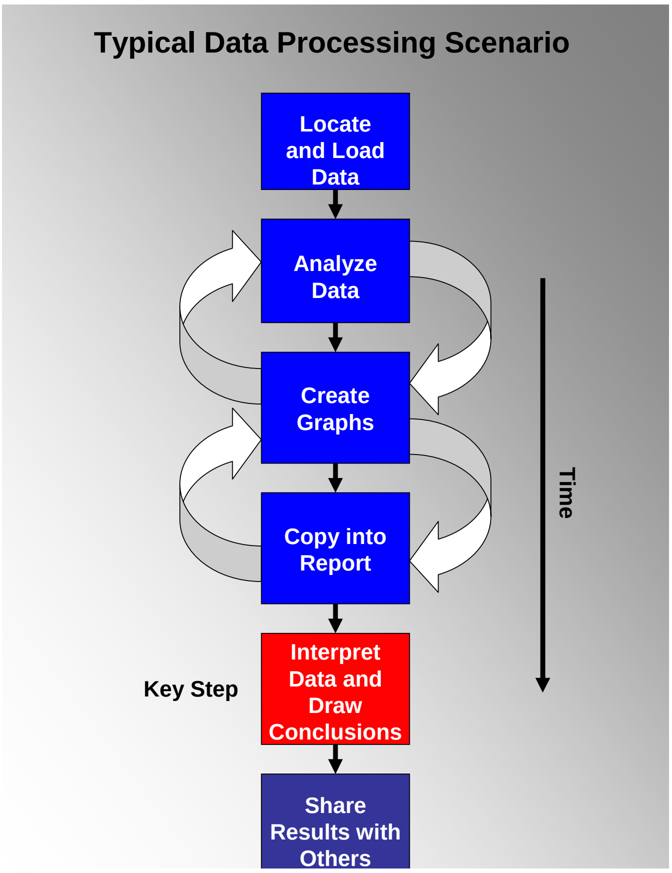


Figure 2: The wrong choice of analysis and reporting tools leads to inefficient use of resources and prolongs the time it takes to convert raw data into information

All too often, companies rely on the evolution of broken processes and inadequate tools to create the necessary results. This unnecessarily extends the time it takes to reach the key step of investigating the results. By automating repetitive analysis and reporting tasks, you can dramatically shorten the time it takes to convert the data into the results which you are seeking for. Key requirements for optimized conversion of raw data into results are:

- Unified data access to various formats -> fast and easy data access for data consumers in the enterprise
- Standard methods for data processing -> comparability of results
- Reusable report templates -> standardized documentation and visualization of test data and results

- Automated data process and reporting -> the fastest way from test data to results

National Instruments DIAdem

By combining tools for managing, inspecting, analyzing, and reporting test data, NI DIAdem provides an interactive environment for turning technical data efficiently into results.

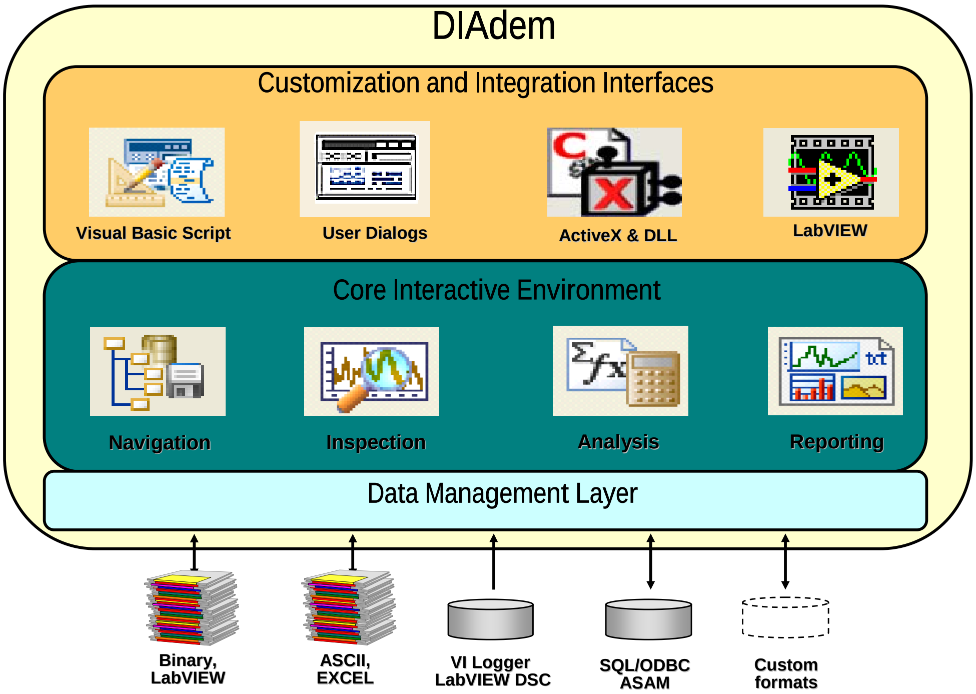


Figure 3: DIAdem combines functionality for analysis and report generation while also providing an open data interface as well as comprehensive features for automating repetitive tasks

Managing data with NI DIAdem

By offering a unique environment – the Data Navigator - for exploring and accessing various data sources and formats, DIAdem enables the user to access data from other applications while allowing you to load datasets with more than 2 billion data points.

Apart from industry standards such as ODBC/SQL and ASAM-ODS, NI VI Logger, LabVIEW Datalogging and Supervisory Control Module, and NI Lookout™ real-time databases, DIAdem natively supports the file formats commonly used in industry including, binary, ASCII, WAV and Excel. In addition, the ASCII and Excel import wizards provide a configuration based way of determining how custom text and spread-sheet files are parsed. Further more DIAdem offers an open data architecture (plug-in interface) that allows you to extend the data interface by additional formats.

Inspecting Analyzing and Reporting technical data with NI DIAdem

Being able to interactively inspect technical data gives you a valuable insight and understanding of the characteristic of your data. In DIAdem you visually inspect your data and draw conclusions by interacting with it in both tabular and graphical forms by using functions for scrolling, zooming, measuring as well as for the manipulation of your data.

To convert technical data into usable results, DIAdem provides libraries of most commonly used analysis functions. Such as basic mathematics, curve fitting, signal analysis, statistics, matrix operations and 3D analysis.

Sharing information with collaborating projects partners requires you to communicate results clearly and concisely. With a drag-and-drop environment tailored for creating engineering and scientific reports, DIAdem offers an interface to graphically create reusable report templates. A report may contain as many 2D and 3D graphs and tables as you need to report your findings. Each report also can have an unlimited number of pages and can include additional texts, pictures, and variables. A template can be easily reused with similar datasets (e.g. create a report form 10 datasets which belong to one test series). The content of your report will be populated automatically depending of the dataset(s) which are loaded into DIAdem. Reports maybe printed or exported in various formats such as HTML, JPEG, BMP, etc.

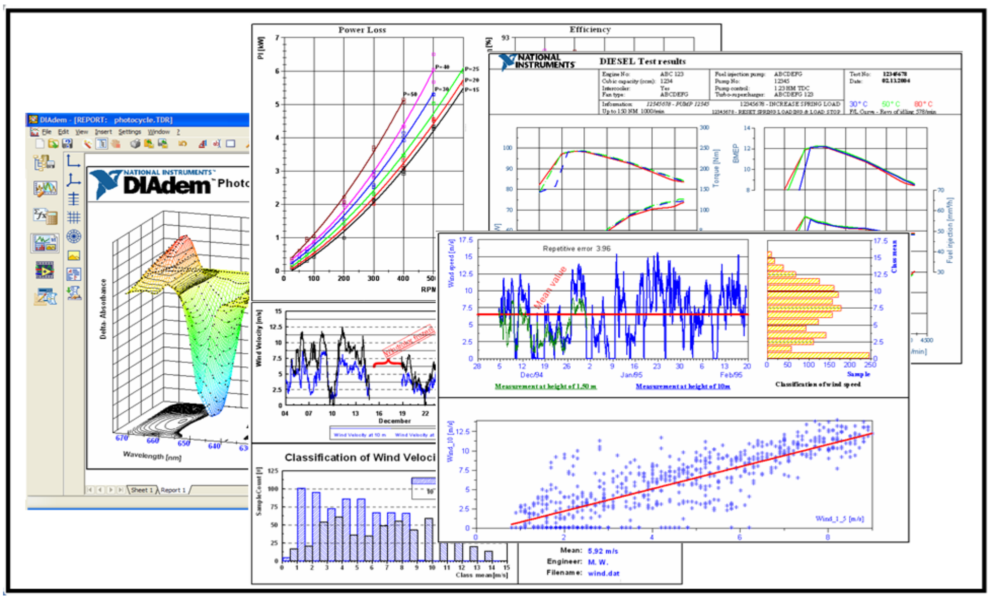


Figure 4: DIAdem allows you to create resalable report templates for engineering and scientific reports

Many companies have developed libraries of DIAdem report templates which are being shared throughout their organizations; this offers consistency and eliminates the overhead associated with interpreting report data in an infinite variety of ways.

Automating repetitive analysis and reporting tasks with NI DIAdem

By automating repetitive analysis and reporting tasks in DIAdem you can dramatically shorten the time it takes to turn your raw data into the results. DIAdem contains a built-in visual basic script development environment that allows you to create everything from a simple sequence of analysis functions to completely customized interactive analysis and reporting solutions.

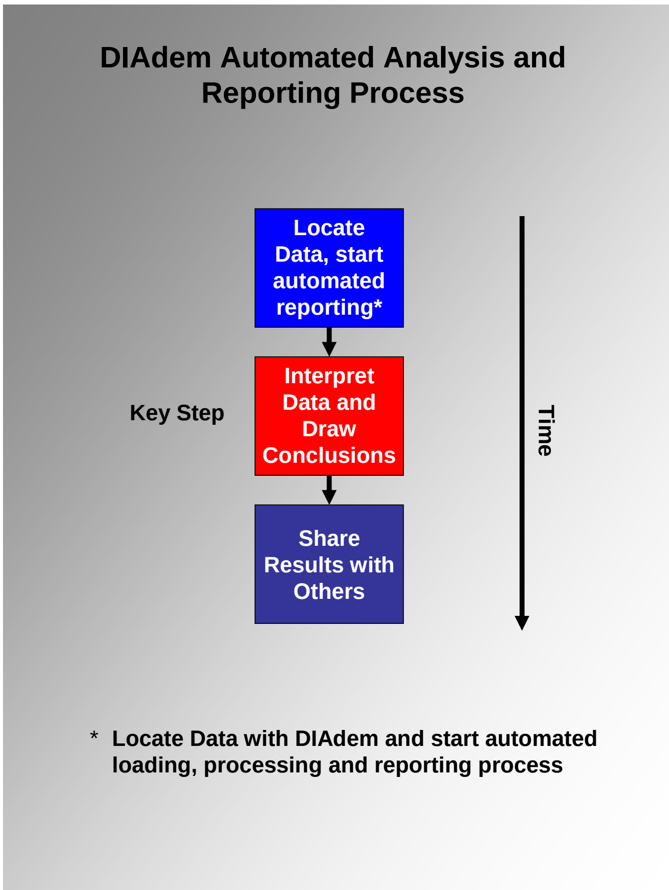


Figure 5: Leveraging the automation capabilities in DIAdem significantly reduces the time it takes to analyze and report data, leaving you with much more valuable time to investigate the results and draw conclusions

Individuals are using DIAdem to create simple scripts in order to automate their daily work. To facilitate this, DIAdem offers a built in macro recorder that permits switching between recording user operations on-line and entering code manually. For those analysis tasks that require some level of decision making as part of processing the data, Visual Basic Script offers normal programming constructs, such as loops and case statements.

Companies are deploying DIAdem on an enterprise level and are using the automation capabilities of DIAdem to deliver analysis and reporting applications based on DIAdem to their technicians and engineers. Providing their employees a customized DIAdem solution concentrates their efforts on the key step of interpreting the results and has proven to reduce test cycle times while also improving their overall understanding of the test data.

Companies such as Raytheon (www.raytheon.com), Cummins (www.cummins. com) or Daimler Chrysler do benefit from large time reductions in their post processing process of technical data by leveraging the automation capabilities of DIAdem.

"By using DIAdem, we can turn our data into usable results in minutes rather than days. We have documented an overall time reduction of <u>95 percent</u> since we integrated DIAdem into our system." Jim Knuff, Principal Systems Engineer Raytheon Missile Systems.

Conclusion

Your test and simulation data represents an investment in time and money. How fast you convert your raw data into information which helps you making intelligent decisions is a measure of your organization's efficiency. If it routinely takes hours or even days to receive the results from a recent test you might be suffering from the "data problem".

DIAdem provides a professional environment for locating and loading data from a variety of different data sources, while also providing the important combination of tools such as for graphically inspecting, analyzing and reporting technical data. An integrated developed environment based upon Visual Basic Script allows you to adapt to DIAdem to your business intelligence. These capabilities make DIAdem a standard tool for processing of technical data throughout companies, departments and applications.

A Satellites Signals Quick Acquisition Algorithm for the High DynamicGPS Receivers in Cold Start

Chang Qing , Zhang Bo-chuan, Zhang Qi-shan
(School of Electronics and Information Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100083, P.R.China)

Abstract Quick acquisition of satellites signals and positioning is a key technology in the high dynamic GPS receiver's research and development. In this paper, the method for estimating valid almanac for the GPS satellites is introduced, and for the received GPS signals how the Doppler shift components impact the satellites signals acquisition time are analyzed. On the basis of above, a new algorithm for satellites signals quick acquisition is proposed, which can efficiently shorten the cold start time for the GPS receivers.
Key words High dynamic GPS receivers, Cold start, Doppler shift

Introduction The cold star time of GPS receiver is the time that the receiver expends from boot-strap to first getting available orientation solution without available almanac.

When the receiver do not store almanac or available almanac because of not working for long time, it cause the receiver cold star. When almanac prediction error is not tolerable, the receiver will expend long time to acquire GPS signals and get ephemeris then orient exactly. Exact reckoning of the orbit parameters and the star clock parameters integrated with rational algorithm can efficiently shorten the orientation time for the GPS receivers.

Doppler shift components of the receiver

Our receiver utilize GP2010 and GP2021 of GEC inc. The frequency of the satellites signals is first down converted to the 4.308 MHZ intermediate frequency signal, then the intermediate frequency signal is undersampled by 5.715 MHZ signal and output the digital signals. The digital signals is expressed:

$$r(t)=\sum_{i=1}^{M} A_i C_i[(1-\frac{f_{io}}{f_0})kT_s-\tau_i]D_i[(1-\frac{f_{io}}{f_0})kT_s-\tau_i]\sin[2\pi(f_1-f_{io})(kT_s-\tau_i)-\phi_i]+n(t) \quad (1)$$

where A_i is the signals intensity, $D_i(t)$ is the ephemeris data of the I star , $C_i(t)$ is the spreading code of the I star, τ_i is the lag value of satellites signals transmit, $f_0=1575.42MHz$, ϕ_i is the phase of the satellites signals.

$T_s=\frac{1}{5.715M}$ f_1=1.405MHZ, M is the number of the eyeable stars.

$$f_{io} = \Delta f + f_{rec} + f_s \qquad (2)$$

f_{rec} is the frequency error that the frequency drift of the receiver clock brings, f_s is the frequency drift of the GPS star, Δf is the Doppler shift of the GPS signals that is lead by relative movement between GPS stars and the receiver,

$$\Delta f = \Delta f_{sv} + \Delta f_{rec} \qquad (3)$$

where, Δf_{sv} is the Doppler shift of the GPS signals that is lead by relative movement between GPS stars and the immobile receiver along the direction that the GPS signal transmit, Δf_{rec} is the Doppler shift of the GPS signals that is lead by relative movement of the mobile receiver along the direction that the GPS signal transmit.

reckoning of the GPS stars clock parameters and frequency drift of the GPS signals f_s

The phase of the reference crystal in the GPS star that generate clock signal can express the function of time,

$$\phi_c(t) = f_{sv}[(1+\delta)t + \frac{1}{2}\alpha t^2] \qquad (4)$$

The phase of the GPS signal $\phi(t) = f_0[(1+\delta)t + \frac{1}{2}\alpha t^2]$

f_0=k f_{sv}

where, δ is the error of the frequency drift, α is the crystal aging velocity, f_{sv} is the standard frequency, f_0 is 1575.42MHZ , k is the converted coefficient between f_{sv} to f_0.

The actual frequency of the GPS signal can be expressed

$$f_r = \frac{d\phi(t)}{dt} = f_0[(1+\delta) + \alpha t] \qquad (5)$$

The time error $\Delta t = \Delta t_{t_{oc}} + \int_0^{t-t_{oc}} \left[1 - \frac{f_0}{f_r}\right] dt \quad \Delta t_{t_{oc}} + \int_0^{t-t_{oc}} \left[1 - \frac{f_0}{f_0[(1+\delta)+\alpha t]}\right] dt$

$$= \Delta t_{t_{oc}} + \int_0^{t-t_{oc}} \frac{\delta + \alpha t}{[1+\delta+\alpha t]} dt \qquad (6)$$

When δ α are both less than 10^{-9},

$$\Delta t \approx \Delta t_{t_{oc}} + \int_0^{t-t_{oc}} (\delta + \alpha t) dt$$
$$= \Delta t_{t_{oc}} + \delta(t - t_{oc}) + \frac{1}{2}\alpha(t - t_{oc})^2 \qquad (7)$$

At the same time, refer to the GPSICD200C Interface Control Document, the time error of the GPS star clock is[4]

$$\Delta t_{sv} = af_0 + af_1(t - t_{oc}) + af_2(t - t_{oc})^2 \qquad (8)$$

Where, af_0 af_1 af_2 are the clock parameters of the navigation data of the GPS star.
Compare (7) with (8),

$$af_0 = \Delta t_{t_{oc}} \quad af_1 = \delta \quad af_2 = \frac{1}{2}\alpha \qquad (9)$$

and $af_1 = {(f_r - f_0)}/{f_0} \quad af_2 = \frac{1}{2}\frac{daf_1}{dt}$ (10)

Thus, $af_{0_{t_2}} = af_{0_{t1}} + af_{1_{t1}}(t_2 - t_1) + af_2(t_2 - t_1)^2$ (11)

$$af_{1_{t2}} = af_{1_{t1}} + af_2(t_2 - t_1) \qquad (12)$$

Where, $af_{0_{t2}}$ $af_{1_{t2}}$ are the values of t_2, $af_{0_{t1}}$ $af_{1_{t1}}$ are the acquired values at t_1.

We can get the f_s of t_2

$$f_s = af_{1_{t_2}} \times f_0 \qquad (13)$$

Reckoning of the Δf_{sv} and f_{rec}

1) Reckoning of the Δf_{sv}

According to the orbit parameters of the GPS stars in the ephemeris of t_0 ,that is, semi-major axis $a(t_0)$ eccentricity $e(t_0)$ inclination angle $i(t_0)$ preparative longitude of ascending node $\Omega_0(t_0)$ argument of perigee $\omega(t_0)$ mean anomaly $M_0(t_0)$, we can get the orbit parameters of the GPS stars of t, synchronously suppose six correction parameters to be zero, thus get the almanac of t [5].

$$a(t) = a(t_0)$$

$$e(t) = e(t_0)$$

$$i(t) = i(t_0)$$

$$\Omega(t) = \Omega(t_0) - (\frac{3}{2} a_e^2 \frac{J_2}{p^2} n \cos i)(t - t_0) \qquad (14)$$

$$\omega(t) = \omega(t_0) + \frac{3}{2} a_e^2 \frac{J_2}{p^2} n(2 - \frac{5}{2}\sin^2 i)(t - t_0)$$

$$M_0(t) = M_0(t_0) + [n + \Delta n - \frac{3}{2} a_e^2 \frac{J_2}{p^2} n(1 - \frac{3}{2}\sin^2 i)\sqrt{1-e^2}](t - t_0) \text{ [module } 2\pi \text{]}$$

Where $p = a(1-e^2)$ $n = \sqrt{\frac{\mu}{a^3}}$ $J_2 = 108263 \times 10^{-8}$ $a_e = 6378137\text{m}$

$\mu = 3986005 \times 10^8 \, m^3/s^2$

$$\Omega_0(t_0) = \Omega(t_0) - GATS_\omega \qquad (15)$$

$$\frac{d\Omega}{dt} = \frac{3}{2} a_e^2 \frac{J_2}{p^2} n \cos i$$

$$\Omega_0(t) = \Omega_0(t_0) + \frac{d\Omega}{dt}(t - t_0) + \omega_e \times 604800 \times (WN_{t_0} - WN_t) \text{ [module } 2\pi \text{]} \qquad (16)$$

Where, WN_{t_0} is the number of weeks in the ephemeris of t_0, WN_t is the corresponding number of weeks of t, $GATS_\omega$ is the Greenwich time at the beginning of the week epoch.

By the orbit parameters of the GPS stars of t,we can get the position and velocity of the GPS star at t.Synchronously considering the position of the receiver, we can get Δf_{sv} of t.

2) Reckoning of f_{rec}

Because the clock of the receiver is stable for long time, and different receiver has different f_{rec}, we reckon f_{rec} in advance and use it in program directly.

Considering $f_{io} = \Delta f_{sv} + \Delta f_{rec} + f_{rec} + f_s$ and the ephemeris of the GPS stars being unaltered for hours, we can get Δf_{sv}^j of the j star at the observation time by the ephemeris that is got minutes before and the position of the receiver at the observation time.

We can get f_s^j at the observation time by (12) and (13).

The receiver is actionless at the observation time, here Δf_{rec} =0. Synchronously we can get Δf_{sv}^{j} of the j star, f_{rec}^{j} of the j star at the observation time is got

$$f_{rec}^{j} = f_{io}^{j}, \Delta f_{sv}^{j}, f_{s}^{j} \qquad (17)$$

f_{rec} of our receiver is $7196HZ$ .After get it ,the receiver can save 56 seconds in the course of capturing the j star.

Experiment

1) Reckoning result of the star clock parameters

We had got the ephemeris of the 16# star through our own receiver for one mouth and reckoned the new parameters of 2003.8,28.12.0.0 from the parameters of star clock of 2003.7.1.11.59.44.

actual parameters of star clock at 2003.7.1.11.59.44	af_0 =0.596651807427e-04	af_1 =0.579802872380e-11
actual parameters of star clock at 2003.8,28.12.0.0	af_{00} =0.724918209016e-04	af_{10} =0.477484718431e-11
reckoned parameters of star clock at 2003.8,28.12.0.0	af_{01} = 0.7237169739 e-04	af_{11} =0.4706628 e-11

$f_s = af_{10} * f_0$ =0.477484718431e-11*1575.42e06=0.007522HZ

af_{00} *speed of light=0.724918209016e-04 e-04*2.99792458e8=217475km

The error of the pseudo range caused by reckoning of star clock parameters

(af_{00} - af_{01})*speed of light=36m.

Precise reckoning of af_0 make the receiver orient exactly after acquire four satellites signals in the course of cold star.

2) Reckoning result of the star orbit parameters

We had got the ephemeris of the 16# star through our own receiver for one mouth and reckoned the new parameters of 2003.9,1.12.0.0 from the parameters of star clock of 2003.7.31.11.59.44.

Actual star orbit parameters of t_1	Ω_{0t_1} = -2.09716567564	ω_{t_1} = -1.71643691820	$M_{0_{t_1}}$ = 3.08373107049
Actual star orbit parameters of t_2	Ω_{0t_2} =-2.72117917258	ω_{t_2} =-1.67529031669	$M_{0_{t_2}}$ =-2.08799859062
reckoned star orbit parameters of t_2	Ω'_{0t_2} =-2.720653	ω'_{t_2} =-1.666083	$M'_{0_{t2}}$ =-2.085210

Where, t_1 =2003.7.31.11.59.44., t_2 = 2003.9,1.12.0.0.

3) Experiment of the receiver

State of the receiver: stillness, import the approximate position of the receiver and time in advance, has reckoning of almanac

Number of the star : 15 26 21 29

Actual Δf :	7320	2579	4120	2381
Δf by reckoning:	7201	2566	4356	2210
Δf of the receiver setup:	7201	2566	4356	2210

Time of cold star: 21 seconds (without regard to f_{rec})

Time of cold star: 82 seconds(take into account f_{rec})

REFERENCE

[1]The Study on Mathematical Model of High Dynamic and Intelligent GPS Satellite Signal Simulator's software[D].Beijing: Dept of Electronic Engineering, Beijing university of Aeronautics and Astronautics, 2003(in Chinese)

[2]Steve Lazar, Martin Bottjer, Don Watanabe, Steve Craig. A GPS Modernization Simulator[A]. Ln:Proceedings of ION GPS[C], 98,15-18 September 1998, Nashville, Tennesee, 1887-1893

[3]Global Positioning System: Theory and Application Volume 1[M] American Institute of Aeronautics and Astronautics,Inc.

[4] GPSICD200C Interface Control Document[R]

[5] Zhang Shouxin. The foundation of the extratellurian trajectory survey and the satellite orbit survey[M]. BeiJing: National defence industry Press,1992

XML: A GLOBAL STANDARD FOR THE FLIGHT TEST COMMUNITY

Alan Cooke ,Diarmuid Corry
ACRA CONTROL

ABSTRACT

Much effort has been spent on developing physical layer standards to ease multi-vendor inter-operability. However as anyone familiar with real-life system integration knows a large gap exists in defining system configuration and set-up, not just between vendors but also between different groups on the base.

Different solutions to this problem have been attempted (for example TMATS). However, the emergence of XML (eXtensible Markup Language) as a commercial standard presents a new opportunity to define a powerful and extensible tool for data-interchange between different systems.

This paper introduces the self-documenting standard for information exchange that is XML. A generic model for flight test data acquisition is presented. Finally, an XML vocabulary (or schema) based on this model is proposed. This schema could form the basis for an industry wide XML standard to simplify the problem of data interchange between vendors, between programs, even between different databases in the same organisation.

KEY WORDS

XML, XML Schema, XIDML

INTRODUCTION

At any given flight test facility a broad range of activities contribute to the overall goal of testing aircraft and analysing the resulting data. These activities range in character from instrumenting aircraft to ground-station data analysis and typically involve personnel from a wide variety of organisations and groups.

The task of achieving the overall goal is further complicated by the fact that the equipment and software used on a project are usually derived from a multitude of different vendors. Vendors in turn have their own unique requirements that typically employ proprietary software and data formats. The process of integrating many heterogeneous systems can become a major impediment to the successful completion of a project.

What is needed is a recognised standard that caters for the requirements of a typical flight test project. A standard that captures and models the different elements of a project and that can be used when data needs to be exchanged between the different groups participating in a project.

There have been several attempts to define such a generic standard, most notably the Telemetry Attributes Transfer Standard (TMATS). However the rapid acceptance of XML as a generic data interchange standard presents the opportunity to develop a modern, flexible and extensible standard for the future. This paper proposes just such a vocabulary for the flight test community.

It is not the intention of this paper to describe what XML is, or how it is applied in a generic solution. This ground has been covered before[1]. Instead, this paper proposes a vocabulary (or in XML terms, a "schema") that allows XML to be used to exchange data between the disparate groups and functions during flight test.

WHY XML?

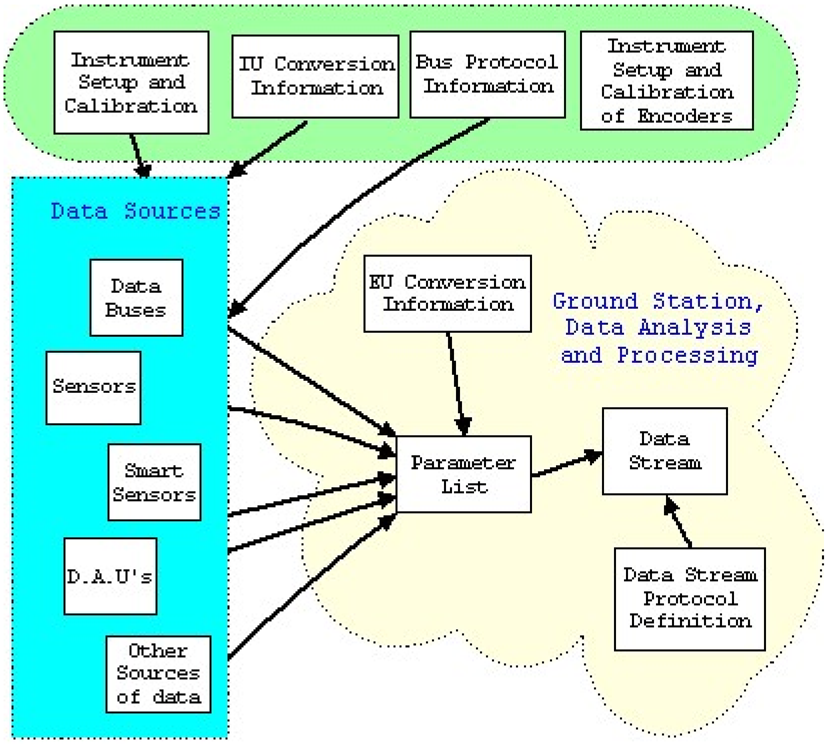
If an XML schema is designed properly then XML offers the following advantages over TMATS and other mechanisms.

- XML is the de facto commercial standard for data exchange.
- XML is an open, non-proprietary standard. There is no need to pay any royalties, license fees or for any other services in order to use it.
- A large number of tools and utilities exist for the processing and creation of XML documents. Many of these are available for free.
- A large body of XML knowledge already exists. Familiarity with FTI and related areas is not a prerequisite for using XML.
- XML allows a standard for the FTI industry to be defined that is both rigorous and flexible enough to cater for any future requirements.

[1] In particular, see the paper RDBMS AND XML FOR TELEMETRY ATTRIBUTES from ITC 2003.

A GENERIC DATA ACQUITION SYSTEM

The following figure outlines, in broad terms, the various elements, inputs and outputs of a generic data acquisition system.



Elements of a Data Acquisition System

Figure 1

In general, a typical data acquisition system consists of the following.

1. Physical hardware used to retrieve raw data. Examples include sensors, smart sensors, data buses and various types of data acquisition units.
2. Information used to interpret data from these systems. Examples include information on the protocol used by a data bus, calibration information for the data acquisition modules or sensors and the information used to transform data from instrumentation units to engineering units.
3. A data acquisition system encodes the acquired data into one or more data streams in some particular format for transmission or storage. An example would be the encoding of data into an IRIG-106 PCM data stream.

Depending on the circumstances, only a subset of this information may be of interest at any particular time. For example, a ground station vendor may only be interested in the data stream in which the acquired data is transmitted, the transmission protocol and how the transmitted data should be interpreted.

SCHEMA DESIGN GOALS

Given the generic data acquisition system outlined above. An XML schema should meet the following criteria

- The schema should be vendor neutral.
- The schema should capture as many of the recognised elements of a generic data acquisition system as possible in order to be useful to as many potential consumers or producers of flight-test data as possible
- The layout of the schema should be logical and easy to understand and therefore lend itself easily to the extraction of information.
- The schema should be extensible and future proofed.

ACRA CONTROL has created a schema, called XIDML, that we believe meets these goals.

FEATURES OF XIDML

Generic and Multi-purpose

XIDML has been designed to be generic and vendor independent and has been constructed to be as useful as possible to as many groups and organisations that work in the flight test area. Furthermore, wherever possible, use of existing established standards, MathML for example, have been included as part of the schema.

Data Reuse

One of the main features of the XIDML schema design that should be noted is the emphasis on the reuse of data and the decrease in data redundancy. For example, an IRIG PCM frame description can be reused more than once. The same can also be said of other protocols such as the MIL-STD 1553 and ARINC-429 bus protocols. Where it makes sense, this ability to reuse data has been built into other areas of the schema.

Atomic Structure

The XIDML schema has been designed to group data logically and in ways that make sense to those who work in the flight test area. By grouping, for example, all parameter definitions together and all protocols definitions together and so on, users of XIDML based data need only look at the information *they* are specifically interested in. This is a feature that has been leveraged directly from the XML standard.

Extensibility

Although it is not possible in this paper to rigorously describe the extensibility mechanisms that have been built into XIDML, the schema has been designed with the future in mind. XIDML fully utilises the features of the XML Schema[2] standard that facilitate the extension of XML schemas This means for example, new types of protocol definitions can been included trivially, TEDS, FireWire and other standards

[2] These features include Substitution Groups, Type Substitution and Type Derivation.

can also be added readily. Importantly, where the need arises, vendor specific information can also be included in the schema at will.

XIDML SCHEMA OVERVIEW

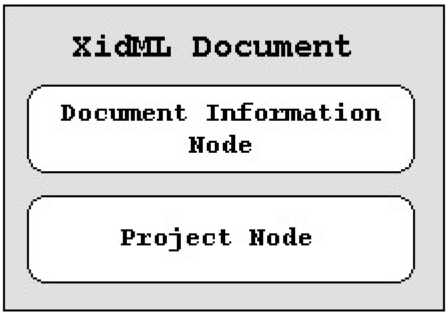


Figure 2

At the highest level of the document are the *Project* and *Document Information* nodes. Figure 2 shows the high level structure of a XIDML document. The *Document Information* section contains general information about the XML document such as when the document was created and a description of the project. An optional reference to more detailed information outside the document can also be included

PROJECTS

The *Project* section contains all information about a flight test project such as its name, a description of the project as well as optional references to more detailed information about it in another document. Most importantly however, a *Project* also contains the definitions for all **data acquisition systems** that are part of a flight test project. There can be more than one *Acquisition System* node defined in a project depending upon the nature of the flight test project being modelled.

ACQUISITION SYSTEMS

An *Acquisition System* is the most fundamental and important construct in the XIDML schema. In the context of XIDML, an Acquisition System is defined as a system that is used to retrieve and/or process telemetric data. Table 1 lists some of the main components of an Acquisition System as understood in XIDML. All of the sections in Table 1 are *optional* and only need to be included if they make sense in the context of the Acquisition System being modelled.

Figure 3 gives a high level overview of some of the main components of an Acquisition System as understood in XIDML. All of the sections shown in Figure x are *optional* and only need to be included if they make sense in the context of the Acquisition System being modelled.

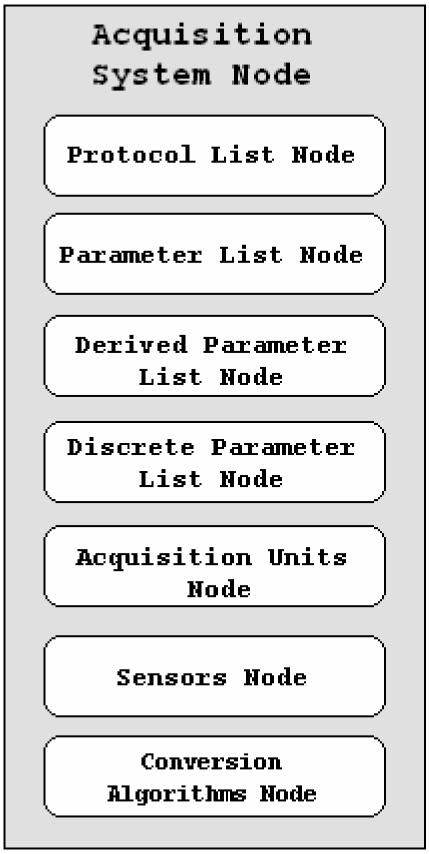


Figure 3

Table 1: Main sections in the Acquisition System node

Node	Description	Observations
Protocols List	Contains descriptions of the PCM frame, MIL-STD 1553, ARINC-429, Ethernet packets and other protocols used by an acquisition system.	A protocol definition may be reused many times and across multiple projects. Any type of protocol definition can be added to the Protocol List section[3].
Parameters List	Lists all the parameters or signals sourced in, or used by, an acquisition system. Each one is identified by a unique name.	Each definition can include information such as, units used, data format and mechanisms for the conversion from raw data to IU or to EU
Derived Parameters List	Defines how a parameter is derived from one or more other parameters.	The MathML XML vocabulary is used to describe any mathematical relationships.
Discrete Parameters List	Defines how a parameter is composed of one or more discrete subset(s) of other parameter(s)	
Acquisition Units List	Lists the uniquely named DAUs to be used to describe the set-up, configuration and so on.	A DAU can be from any vendor.
Sensors List	Lists the EU range (gain/offset), defines the conversion to IU, filter cut-off and excitation	A Sensor can be from any vendor.
Conversion Algorithms List	Describes how raw data is converted to IU and EU. Each algorithm is identified by a unique name.	Each conversion algorithm can be reused in more than parameter definition or in Sensor and DAU descriptions.
Wiring	Describes the connections between data sources and sinks	

VENDOR INFORMATION

XIDML has been designed with flexibility and extensibility in mind. To this end, one or more *Vendor* sections can be added to (or referenced from) the XIDML file if vendor specific information needs to be included. This allows, for example, information required by ACME Inc. to be in the XIDML document alongside that of ACRA Control and other third party vendors without the structure and integrity of the rest of the XIDML file being affected.

SOME EXAMPLES

The following examples illustrate how a simple IRIG PCM frame containing 3 placed parameters can be defined. Note that a complete and detailed schema is available which provides a more comprehensive description of XIDML. The examples further show how to specify and define IU to EU conversion for a parameter as well as showing how a derived parameter is specified.

[3] As long as it meets some minimal requirements (see the PCM Frame Definition section below).

PCM Frame Definition

The example below shows the definition of a simple PCM frame with one minor frame and three placed parameters. This frame definition can be included inline within the main XIDML file or be located in an external file and just referenced in the XIDML file[4]. A PCM frame definition can be used more than once which increases reuse and reduces data redundancy.

```
<ProtocolList>
   <IRIG106FrameDefinition Name="MySampleFrame" LayoutRevision="1.0">
      <PCMFrameStructure>
            <MajorframeProperties>
                 <NumberOfMinorFrames>1</NumberOfMinorFrames>
                 <NumberOfMinorFrameWords>4</NumberOfMinorFrameWords>
                      <MinorFrameStartIndex>0</MinorFrameStartIndex>
                      <SyncWordReference>0</SyncWordReference>
                      <FillPattern>AAAA</FillPattern>
                      <Justification>LEFT</Justification>
                      <Parity>NONE</Parity>
                      <BitsPerWord>16</BitsPerWord>
            </MajorframeProperties>
            <SynchronisationStrategy>
                  <SyncPattern>1110101110010000</SyncPattern>
                  <SyncMask> 1111111111111111 </SyncMask>
            </SynchronisationStrategy>
      </PCMFrameStructure>
            <FramePlacement>
                  <PlacedParameter>
                        <Name>LeftWingTemperature</Name>
                        <WordIndex>1</WordIndex>
                        <Frame>0</Frame>
                        <Samples>1</Samples>
                        <BitMask>FFFF</BitMask>
                        <MSB>First</MSB>
                  </PlacedParameter>
                  <PlacedParameter>
                        <Name>RightWingTemperature</Name>
                        <WordIndex>2</WordIndex>
                        <Frame>0</Frame>
                        <Samples>1</Samples>
                        <BitMask>FFFF</BitMask>
                        <MSB>First</MSB>
                  </PlacedParameter>
                  <PlacedParameter>
                        <Name>AverageWingTemperature</Name>
                        <WordIndex>3</WordIndex>
                        <Frame>0</Frame>
                        <Samples>1</Samples>
                        <BitMask>FFFF</BitMask>
                        <MSB>First</MSB>
                  </PlacedParameter>
            </FramePlacement>
      </IRIG106FrameDefinition>
                  .
                  .
<ProtocolList>
```

[4] Data located in external files is referenced using the XLink and XPointer standards.

It should be noted that all protocols belonging to the *ProtocolList* above must have the same basic structure. In XML schema parlance, they must be the same type and belong to same substitution group. In this case, a protocol must have a (unique) name[5] and a version number. Any protocol conforming to these rules can be included legally as a protocol in a XIDML file.

Parameter Definition

This example shows how a parameter can be defined. Each parameter definition references an EU conversion algorithm named *StandardLinearConversion*. This algorithm is used to convert IU to EU. An example of how to specify a conversion algorithm is show later.

```
<ParameterList>
                  .
                  .
   <Parameter name="LeftWingTemperature">
                  .
      <Units>Centigrade</Units>
      <EUConversionRef>StandardLinearConversion</EUConversionRef>
                  .
   </Parameter>
   <Parameter name="RightWingTemperature">
                  .
      <Units>Centigrade</Units>
      <EUConversionRef>StandardLinearConversion</EUConversionRef>
                  .
   </Parameter>
                  .
                  .
</ParameterList>
```

Derived Parameter Definition

This example shows how a derived parameter can be defined and illustrates how to get the average of two values. In this case, the derived parameter takes in two parameter values, *LeftWingTemperature* and *RightWingTemperature*, adds the two values together, and then divides the value by two and assigns the resultant value to the derived parameter called *AverageWingTemperature*. All mathematical operations are defined using MathML. MathML is the internationally recognised standard for the definition and display of mathematical expressions.

```
<DerivedParameter>
      <Name>AverageWingTemperature</Name>
      <Composition>
            <DerivedParameterMathAlgoritm>
                  <InputParameters>
                        <ParameterRef>
                              <Name>LeftWingTemperature</Name>
                        </ParameterRef>
                        <ParameterRef>
                              <Name>RightWingTemperature</Name>
                        </ParameterRef>
                  </InputParameters>
```

[5] The uniqueness constraint is again specified using the XML Schema standard.

```
                  <MathAlgorithm>
                        <mml:apply>
                            <mml:divide/>
                            <mml:apply>
                                <mml:plus/>
                                <mml:ci>LeftWingTemperature</mml:ci>
                                <mml:ci>RightWingTemperature</mml:ci>
                            </mml:apply>
                            <mml:cn>2</mml:cn>
                        </mml:apply>
                  </MathAlgorithm>
            </DerivedParameterMathAlgoritm>
      </Composition>
</DerivedParameter>
```

Conversion Algorithm Definition

The following example shows how the conversion algorithms referenced in the parameter definitions earlier is defined[6].

```
<ConversionAlgorithms>
      <ConversionAlgorithm name="StandardLinearConversion">
            <tc:PolynomialCalibrator>
                  <tc:Term coefficient="0" exponent="0"/>
                  <tc:Term coefficient="1" exponent="1"/>
            </tc:PolynomialCalibrator>
      </ConversionAlgorithm>
</ConversionAlgorithms>
```

Vendor Information

The following example shows how vendor specific information can be included in a XIDML document. It should also be noted that this information could alternatively be included in an external file. This example shows how information for a DAU provided by ACRA Control would be included.

```
<VendorSection>
            .
      <Vendor name="ACRA Control">
                  .
            <KAD_ADC_001 Name="MyADC001" SerialNumber="01234">
                  <InstrumentSetup>
                     <ANALOG SourceBits="16">
                        <SourcedParameterName>LeftWingTemperature
                        </SourcedParameterName>
                        <Gain>1</Gain>
                        <Offset>-10</Offset>
                     </ANALOG>
                     <ANALOG SourceBits="16">
                        <SourcedParameterName>RightWingTemperature
                        </SourcedParameterName>
                        <Gain>1</Gain>
                        <Offset>-10</Offset>
                     </ANALOG>
```

[6] It should be noted here that the algorithm definition uses the standard submitted to the OMG.Space Domain Task Force Telemetric and Command Data Specification Space RFP-1. Reference space/2003-03-01. Issue 1.2, 3 March 2003.

```
                  </InstrumentSetup>
            </KAD_ADC_001>
                  .
      </Vendor>
            .
      <Vendor name="ACME Inc">
            .
            .
      </Vendor>
            .
</VendorSection>
```

CONCLUSION

In this paper some of the problems involved in the successful completion of a flight test project have been outlined and a model for a generic data acquisition system was described. An XML vocabulary, or schema, called XIDML was then presented that is based on the generic model of a data acquisition system. Finally, several reasons were highlighted why it is believed XIDML may form the basis of a standard that could be adopted by the flight test community. Some of the reasons outlined are

- XIDML is designed to be generic and multi-purpose.
- The schema promotes data reuse
- The atomic nature of the schema
- The schema was designed to be flexible, scalable and future proof.

REFERENCES

[1] The XML home page can be found at http://www.w3c.org

[2] The XML Schema homepage can be found at http://www.w3.org/XML/Schema

[3] The home page for MathML can be found here http://www.w3c.org/Math

[4] An introduction to MathML can be found at
http://www.dessci.com/en/support/tutorials/mathml/default.htm

[5] Tutorials on various XML standards can be found at http://www.w3schools.com/

GLOSSARY OF TERMS

DAU	Data Acquisition Unit.
DTD	Document Type Definition. A mechanism used to validate XML documents. The predecessor to the XML Schema standard.
EU	Engineering Units
FTI	Flight Test Instrumentation
IU	Instrumentation Units
MathML	Mathematical Markup Language. An XML vocabulary used to describe the definition and display of mathematical expressions.
Substitution Group	An XML Schema construct that represents a class or type of data structure.
TMATS	Telemetry Attributes Transfer Standard
XIDML	Extensible Instrumentation and Definition Markup Language
XML	Extensible Markup Language
XLink	An XML standard used to reference other XML files
XPointer	An XML standard used to reference data contained in specific locations in other XML files
XML Schema	An XML vocabulary used to validate an XML document. It is designed to be the successor to the DTD standard

CAIS: FTI SYSTEMS FOR ADVANCED APPLICATIONS

Mansour Radmand
Teletronics Technology Corporation
Bristol, Pennsylvania USA

Doug Vu
Lockheed Martin Aeronautics
Fort Worth, Texas USA

Abstract

Today's Flight Test Instrumentation (FTI) engineers are faced with a variety of "traditional" challenges including equipment installation in composite aircraft, fitting and wiring the equipment in tight locations, developing standardized low-cost ground support processes, and increasing the utilization of low-cost, computerized tools and technology. FTI engineers are also responsible to select solutions that will satisfy "non traditional" programmatic requirements such as supportability, interoperability, expandability, flexibility, and long-term support, especially when the equipment is used on long-term, multi-year programs. Finally, in order to respond to the inevitable need for change, the FTI engineer must also plan for ways to effectively incorporate new technology such as high-speed serial data networks including Fibre channel, IEEE-1394b Fire-wire, Ethernet and others. And all of this must be done in such a way as to be compatible with the existing baseline FTI system.

This paper demonstrates that CAIS-based FTI Systems satisfy all of these requirements for today's advanced FTI system requirements. The paper will describe the features and capabilities of these systems considered most important to the modern FTI engineer. The paper also discusses those enabling CAIS features that guarantee CAIS' role as the key standardization concept for flight test programs of the future.

The paper also summarizes experience gained during the selection and application of the Joint Strike Fighter (F-35) FTI system. JSF uses a CAIS-based FTI, and is prototypical of today's modern aircraft development program, serving well to illustrate the concepts covered throughout this paper.

Key Words

Common Airborne Instrumentation System (CAIS), Flight Test Instrumentation (FTI), Data Acquisition, Fibre Channel, Firewire, Smart Sensors

Introduction

CAIS stands for "Common Airborne Instrumentation System", and has been used for many years throughout the flight test industry. Most CAIS products are available as pre-qualified, COTS solutions with extensive flight test history on major programs such as the F-22 program. CAIS can be described as a robust, open-architecture command/response communication bus protocol with system-wide synchronization capability. The system is scalable to operate at data rates of up to 1 Gigabit per second with the capability to expand to 2 Gigabits per second.

The CAIS concept was developed and first deployed over 15 years ago, which is a “long time” in this age of rapid technological development. Flight Test Instrumentation has seen significant growth and development since then, but CAIS remains the “tool of choice” for many instrumentation system designers, even as performance and throughput demands continually escalate. The longevity of the CAIS system is especially important when considering the long-term, multi-year nature of modern aircraft development programs.

CAIS is a paper standard describing a command/response communication protocol. It was developed to promote interoperability among equipment used throughout the flight test instrumentation industry. After the release of the paper standard, several companies pioneered a new breed of advanced instrumentation products and components that capitalized on the benefits of the standardized CAIS system. These products now form an arsenal of fully compatible, flight-qualified tools available for use by the entire Flight Test Instrumentation community.

Although each CAIS bus command/response communication port is limited to a 5 Mbps data throughput rate, the concept has been utilized on systems requiring data throughput several orders of magnitude greater. System topologies have been developed to handle data in the gigabit-per-second range.

Benefits of CAIS Standardization

CAIS compatible products and software are available for use on a variety of systems, ranging from low bandwidth “simple systems” up through extremely advanced and complex systems such as those used on the F-22 and more recently on the F-35 (JSF).

Since major programs can run for dozens of years and the proposition of retooling the entire FTI system is neither desirable nor economically affordable, the flexibility, growth potential and longevity of CAIS systems are extremely attractive and cost effective. CAIS has enabled F-22 and several other major flight test programs to not only achieve baseline goals, but to evolve through the years along with technology in order to meet an ever growing demand in the overall vehicle development.

The CAIS community is continually developing new products to further enhance operation and better utilize the latest technology. CAIS compatible equipment is modeled after the “Plug-and-play” capability initially pioneered for use in the Personal Computer (PC) industry that are now taken for granted by modern computer users. Instrumentation products are now expected to offer growth expansion in terms of both hardware and software compatibility; CAIS compatible products satisfy this need.

CAIS on F-22

The F-22 program was started in 1987 and is still running today. F-22 EMD (Engineering and Manufacturing Development) relies on the CAIS system for the flight test instrumentation, and software products. CAIS was able to fully support the initial development portion of the F-22 program, and is still able to fully support the current phases of this ongoing program. F-22 has seen a revolution in the available technology, and CAIS has enabled this technology to be used within the same baseline FTI system architecture. F-22 is an excellent example of long-term FTI evolution, based on the CAIS concept.

System Requirements

Vehicle complexity is one of the key drivers for the selection and application of FTI equipment. As the amount of vehicle data increases, the demands on the FTI system increase as well. The ability to efficiently handle large amounts of data results in a direct reduction in the required number of flight test hours. As the flight test program matures, the FTI system must respond to changes in the kinds of data that must be acquired, as well as the amount of data needed to support post-mission analysis and real-time safety-of-flight checks. The system must often be reconfigured to tailor the system on a flight-by-flight, aircraft-by-aircraft basis.

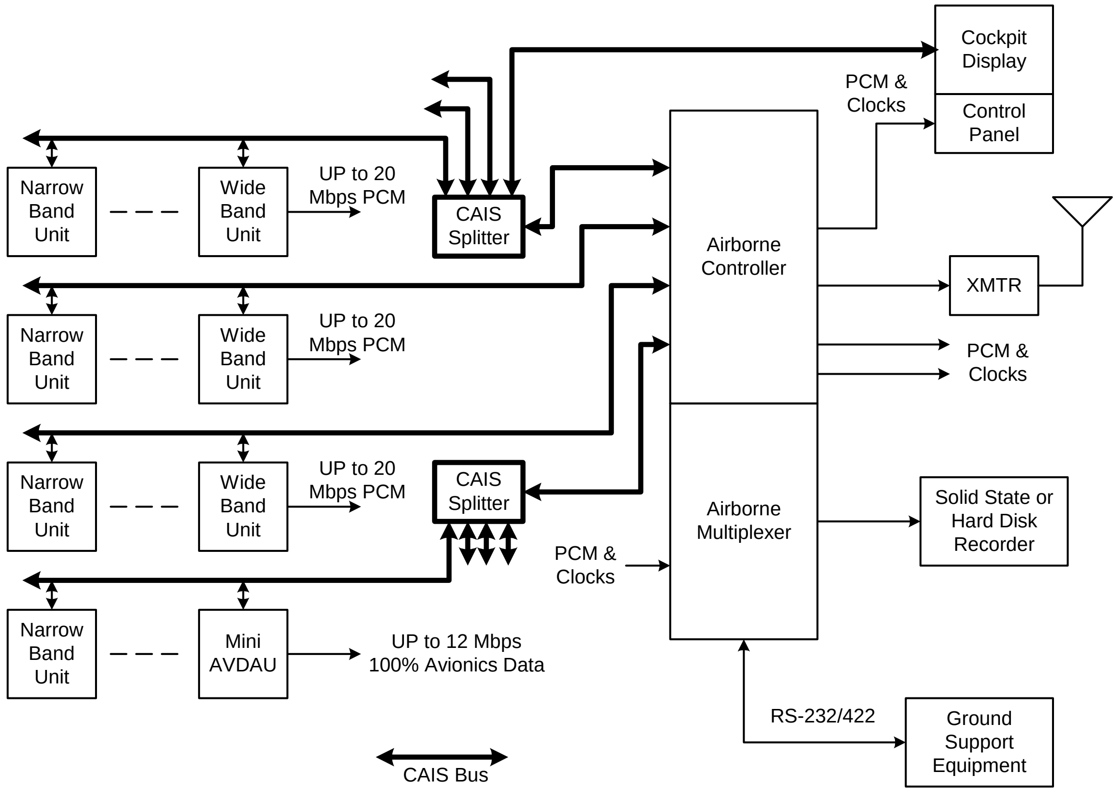
The primary goal for the FTI system is to monitor data in the areas of performance and flight safety. But it has become very favorable for the FTI to also communicate with other vehicle systems such as avionics, stores, pilot communications, telemetry, etc. The CAIS FTI has evolved to accommodate these sources and interleave these various kinds of data in such a way that it improves system performance and safety, and reduces the overall cost of vehicle development.

New high-speed technologies are delivering data to the FTI system at faster than ever rates. The introduction of Fibre Channel and Firewire technologies into aircraft instrumentation has now driven CAIS-based FTI systems to breach the 1 Gigabit data transfer threshold. CAIS-based FTI systems now provide program and communication links with cockpit displays, recorders, transmitters, and a variety of other complex equipment. It seems inevitable that the number of measurements will always be increasing, the amount of data will always grow, and the diversity of various systems and components outside CAIS will be growing and becoming more complex. A typical CAIS System example is shown in Figure 1.

Performance is not the only issue. Flight Test Engineers are always looking for ways to speed up the integration and checkout process. CAIS has pioneered the use of "single-point-access" to all system components so that installation, setup, operation and maintenance activities can be consolidated into a single set of standardized tools and software. CAIS systems utlilize their communication cables to achieve these additional links, thereby reducing system wiring complexity and cost.

PC-based products are now quite common in the support of advanced aircraft systems as the old days of complex, customized systems are diminishing. Turn-key CAIS-based software systems now provide the user with fully integrated tools to support all airborne acquisition and ground based data recovery/analysis activity. Operators no longer need to be experts in multiple, non-synchronized computer languages in order to support a single, CAIS FTI system. The result is that training requirements are reduced, preflight checkout time is minimized, support equipment and software costs have been reduced, and vehicle availability has significantly increased.

Figure 1 Typical CAIS System Example.



Technology Insertion

The CAIS “open architecture” allows adaptability to a variety of new bus interfaces. These include smart sensors, Fibre channel, IEEE-1394b Fire-wire, Ethernet, along with existing MIL-STD-1553, RS232 and others. Greater reliance on computerized software tools has resulted in solutions that can be quickly configured to accommodate new communication schemes without the need to retool the instrumentation hardware. Plug-in modularity allows new interfaces to be quickly developed and integrated into the existing FTI equipment base. This integrated development/product environment also promotes participation by new vendors, manufacturers and customers within the CAIS community.

Application on the JSF Program

The Joint Strike Fighter contract was awarded in late 2001. The program involves the production of an initial 22 aircraft in the program's $25 billion System Development and

Demonstration (SDD) phase formerly known as Engineering and Manufacturing Development (EMD). The F-35 Joint Strike Fighter is a stealthy, supersonic multirole fighter designed to replace a wide range of aging fighter and strike aircraft. Three variants derived from a common design will ensure F-35 meets the performance needs of the U.S. Air Force, Marine Corps, Navy and allied defense forces worldwide, while staying within strict affordability targets.

The flight test program centers on three different variants of the F-35 aircraft. Multiple instrumented aircraft will be operated from multiple test sites and will be supported by instrumentation personnel from multiple organizations. CAIS-based instrumentation data acquisition systems were selected to meet the system requirements, to facilitate commonality of flight test instrumentation between aircraft types, and to guarantee interoperability between DoD and contractor test facilities.

The most important feature of the CAIS bus is that it 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 data coherency based on the sample timing from the placement in the PCM format. Single Point System Programming allows operations and setup of the instrumentation system via a single RS-232/422 interface using COTS turn-key Ground Support Units. This equipment consists of affordable, lightweight, versatile, fully functional laptop tools, each configured with integrated receivers, bit synchronizers and decommutators. The reliance on industry-standard PCMCIA form-factors greatly enhances the equipment portability, supportability and expandability, and also dramatically reduces cost.

The simplicity of serial communication cables between CAIS remote DAU's allows a distributed data acquisition to be installed on test aircraft as it is being built on the production line. Typical measurements such as acceleration, current, discretes, flow, mechanical positions, pressures, RPM, strain gage, temperatures, and vibrations would be wired to remote DAU's strategically installed in various sections of aircraft to "contain" signal wiring within a bay or section of aircraft. This reduces the number of disconnects and minimizes the amount of "orange wires" that have be routed across bulkheads. System checkout will take place on production line using turn-key Ground support solutions that are small, lightweight, portable and versatile. Future measurement requirements throughout the flight test program can be accommodated via growth provisions that were carefully planned during system design, thereby reducing aircraft down times. The result is that the instrumentation system will be ready to support flight test activities when the aircraft rolls out of the production line. Ultimately, significant savings in cost and schedule will be achieved.

Conclusion

CAIS is a proven, qualified solution to meet all goals of major FTI programs. The concept satisfies all needs at both the performance and programmatic level, and has been shown to be a reliable baseline on which to plan the support for long-term flight test instrumentation programs such as the F-22, M346 and the F-35 (JSF). The CAIS concept is wide open to the flight test community at both the user and developer level, and the benefits of reliance on such a long-term, well accepted, internationally recognized standard are many.

List of References

Berdugo, A., "Design of a Gigabit Data Acquisition and Multiplexer System", Proceedings of the International Telemetry Conference, 2003, pp. 975-984.

Brown, T.R., "The Common Airborne Instrumentation System, Program Management Overview", Proceedings of the International Telemetry Conference, 1994, pp. 735-745.

Brown, T.R., "The Common Airborne Instrumentation System, Test Program", Proceedings of the International Telemetry Conference, 1995, pp. 180-189.

Grace, T., "Common Airborne Instrumentation System; A Fresh Look", Proceedings of the International Telemetry Conference, 2001, pp 311-319.

Distributed Wireless Data Acquisition

Udo Namyslo
Tentaclion GmbH
Otterfing, Germany

Abstract

This paper describes a multi-purpose wireless data acquisition system based on distributed intelligence combined with WLAN-compatible telemetry. With this concept, each of the unlimited number of acquisition stations has the ability to communicate with each other and without needing central access points or control units. All stations can also operate as gateways to receive data from the previous station and forward it to the subsequent one.
Implemented Linux-controlled embedded systems with FIFO memories realise a 100% error-free wireless high-speed transmission through a bi-directional TCP/IP connection with data validity check. A highly-precise synchronisation procedure between the stations generates a unique clock and enables the use of the time stamp principle. All data sets are marked at the moment of acquisition and can be reconstructed on the receiver side, independent of the unknown and variable transmission time.
Further highlights are the modular outdoor design as well as the support of almost all sensors and IT protocols, like HTTP, FTP, POP3 and SMTP. This also ensures simple connection to the internet and that e.g. parameter changes can be made using a standard web browser or measured data can be automatically transferred by e-mail to the office. HTTPS and SFTP protocols enable secured connections to avoid access of unauthorised users.

Introduction

The history of the above-described system began in 2001 with the target to design a very flexible data acquisition system for “Distributed Measurements”, defined as follow:

“A random number of different physical quantities are to be recorded time-synchronised from diverse stationary or mobile measuring points distributed over a wide area and transmitted error-free to a control centre”

Although the problem is phrased in a single sentence and applies to still highly specific measurement applications, no universally applicable approach has existed until now. To be suitable for a large number of different measurements, the system has to fulfil a lot of requirements:

• Modular	• High data rates
• Wireless or cable	• Intranet and Internet protocols
• Support of all sensors	• Support of all interfaces
• Unlimited channel number	• Firmware update capability
• All-weather proof	• Flexible power supply
• Wide transmission ranges	• Adaptable and re-configurable
• All network topologies	• Remote maintenance capability
• Time-synchronised	• Small and light
• 100% error-free	• Simple assembly
• Standardised	• Cost-effective

The modules

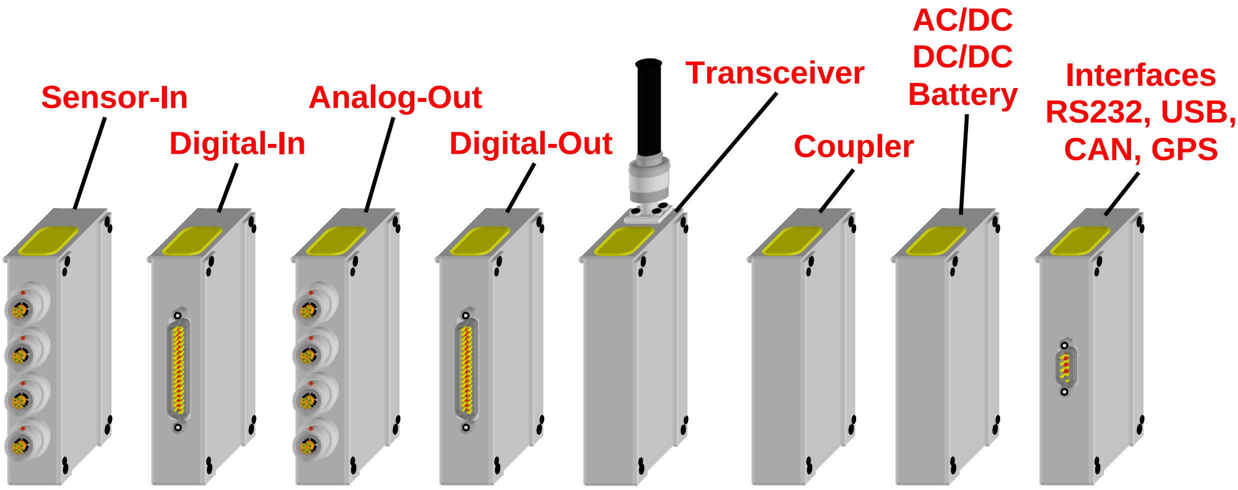


Figure 1: The modular structure of the system

The frameless architecture with the freely scalable number of channels and types guarantees the most flexible and cost-effective adaptation to all measurements. With the modular design a strictly separation of tasks is provided, which allows the uncomplicated use of the same components for different applications by recombination and reconfiguration of modules. This can be understood as a kind of modern recycling of data acquisition systems, which is not possible with systems which are especially developed for a special target application. The robust, small, light, shock and waterproof design together with the extended temperature range makes the system suitable for almost all environments. Compact systems can be combined within seconds by a screwless, dovetail-guided spring-locking mechanism and solid jumpers. Various ways of fixing enable the rapid and simple mounting of the modules on different objects. Numerous threads and holes can be used for magnetic feet, vacuum cups, tripods and cable straps.

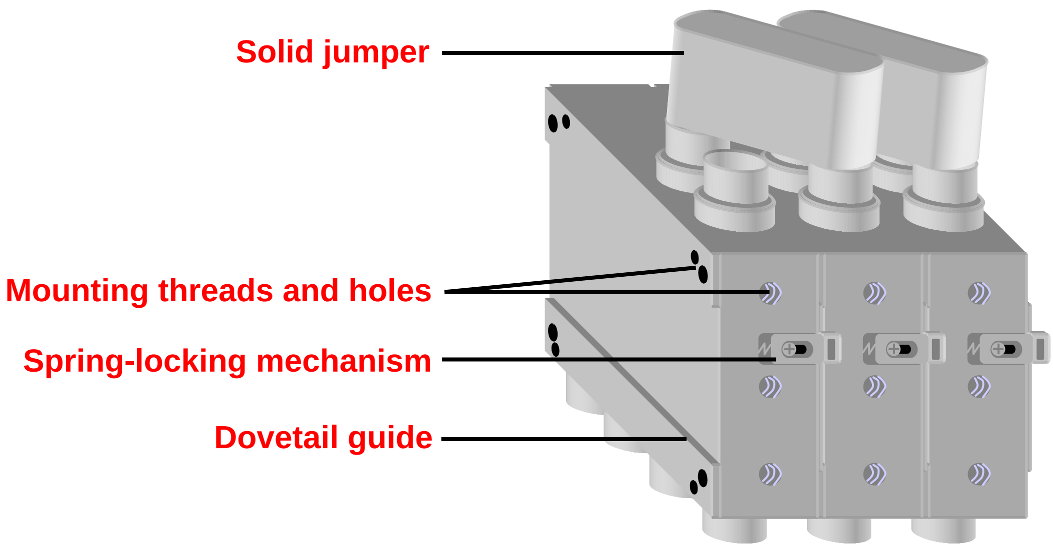


Figure 2: Mechanical features

For data transmission purposes, every module has two LAN/Ethernet ports with integrated power lines to communicate with its previous and subsequent neighbours. The decision for LAN as interface enables the compatibility to the most widespread network infrastructure and ensures future-proof investments through the ongoing upgrading of the system performance and backwards compatibility, e.g. related to speed with 10, 100 and 1000Mbps. The two independent LAN ports enable a distance of up to 100m between each of two neighbouring modules without any limitation to the total network length. Software switches connect these two ports virtually, so that all modules operate with their own IP address in the same LAN network and are able to communicate directly with each other. This concept of decentralised intelligence allows to place the modules with signal conditioning and processing near the sensor and avoids long sensitive analog lines with the corresponding injection of noise and other disturbances from the electro-magnetic environment.
The step from wired to wireless distributed measurements is simply realised by a transceiver module, which operates as a converter from LAN to Wireless LAN and vice versa. This makes the system suitable for all measurements on mobile or rotating objects and stationary applications, where cabling is not possible or to expensive. Every cable can be replaced by a pair of transceiver modules operating both as a wireless bridge or as access point and access point client. Wireless multi-point networks are also supported by WLAN. With the currently used standard 802.11b (11Mbps at 2.4GHz) net bit rates of 4Mbps and transmission ranges up to 2km are possible within a premised line-of-sight connection. A detailed overview of the international regulations are given in figure 4. The newer standards 802.11g (54Mbps at 2.4GHz) and 802.11a (54Mbps at 5.8GHz) enable net bit rates of up to 20Mbps with the restriction of lower transmission ranges and will be implemented in the next version.

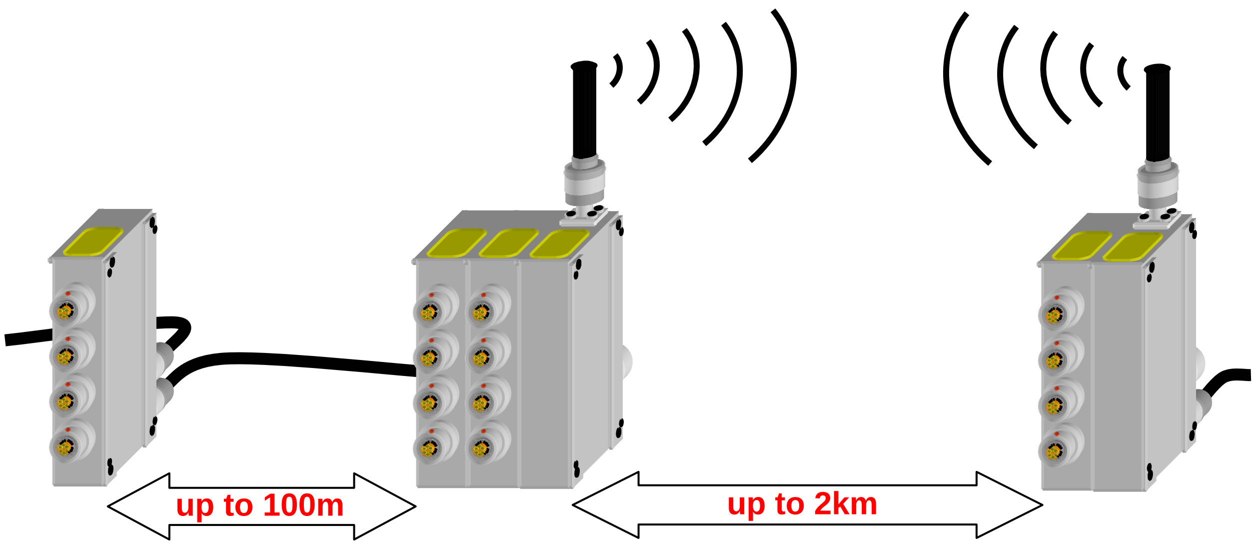


Figure 3: Transmission ranges

			Permissible Channels					
		Max. emitted Power	30dBm = 1W		20dBm = 100mW			
		Transmission Range	1000 – 2000m		300 – 500m			
		Regulatory Domain**	FCC	IC	ETSI	FRANCE	SPAIN	TELEC
Channel	Carrier Frequency	Frequency Band	US	Canada	Europe*	France	Spain	Japan
1	2.412GHz	2.401-2.423GHz	yes	yes	yes	no	no	yes
2	2.417GHz	2.406-2.428GHz	yes	yes	yes	no	no	yes
3	2.422GHz	2.411-2.433GHz	yes	yes	yes	no	no	yes
4	2.427GHz	2.416-2.438GHz	yes	yes	yes	no	no	yes
5	2.432GHz	2.421-2.443GHz	yes	yes	yes	no	no	yes
6	2.437GHz	2.426-2.448GHz	yes	yes	yes	no	no	yes
7	2.442GHz	2.431-2.453GHz	yes	yes	yes	no	no	yes
8	2.447GHz	2.436-2.458GHz	yes	yes	yes	no	no	yes
9	2.452GHz	2.441-2.463GHz	yes	yes	yes	no	no	yes
10	2.457GHz	2.446-2.468GHz	yes	yes	yes	yes	yes	yes
11	2.462GHz	2.451-2.473GHz	yes	yes	yes	yes	yes	yes
12	2.467GHz	2.456-2.478GHz	no	no	yes	yes	no	yes
13	2.472GHz	2.461-2.483GHz	no	no	yes	yes	no	yes
Channels for independent operation			1, 6, 11		1, 7, 13	-		1, 7, 13

*Austria, Denmark, Finland, Germany, Iceland, Italy, Luxembourg, Netherlands, Norway, Sweden, Switzerland, United Kingdom
** Able to be used also in Australia, Hong Kong, Korea, New Zealand, Singapore and Taiwan

Figure 4: International regulations for the WLAN 802.11b standard

The Sensor-In module has the task of enabling the connection of almost all sensors. This is realised by very flexible signal conditioning and data acquisition stages to support voltage and 4-20mA current signals, strain gages, resistors, ICP® acceleration sensors and microphones as well as RTD elements and thermocouples. For other sensors, like inductive LVDT, RMS values or frequencies, individual solutions are provided.

The unit controller in figure 5 is an embedded system with microcontroller, two independent ethernet ports, RAM and flash memory driven by an uCLinux operating system. It manages the further transfer of the measured data from and configuration data to the DSP. To provide a calibrated sensor excitation, the DSP controls digital-to-analog converters (D/A) followed by power amplifiers (P) to drive loads. This generates programmable and stable output voltages for strain gages or other voltage supplied sensors. For current driven sensors, like RTD or ICP® elements, a voltage-to-current converter (V/I) is used.

The incoming signal from the sensor is led to an offset compensation stage (O), e.g. for auto-zeroing of strain gages, followed by a gain stage (G) for signal amplification. To avoid anti-aliasing effects, an analog pre-filter (APF) cuts out very high frequencies which cannot be handled from the later following digital filter inside the DSP. The next sample and hold stage (S&H) ensures a simultaneous sampling between all channels, before an analog-to-digital converter (A/D) reads the data with over-sampling. From here the DSP receives the data and realises digital anti-aliasing filtering, offset and gain calibration as well as linearization of sensor characteristics with programmable channel-individual bandwidth and sample rate. The connected temperature sensor (T) serves for cold junction compensation of thermocouples and elimination of possible non-linearity caused by changing of temperature during the measurement.

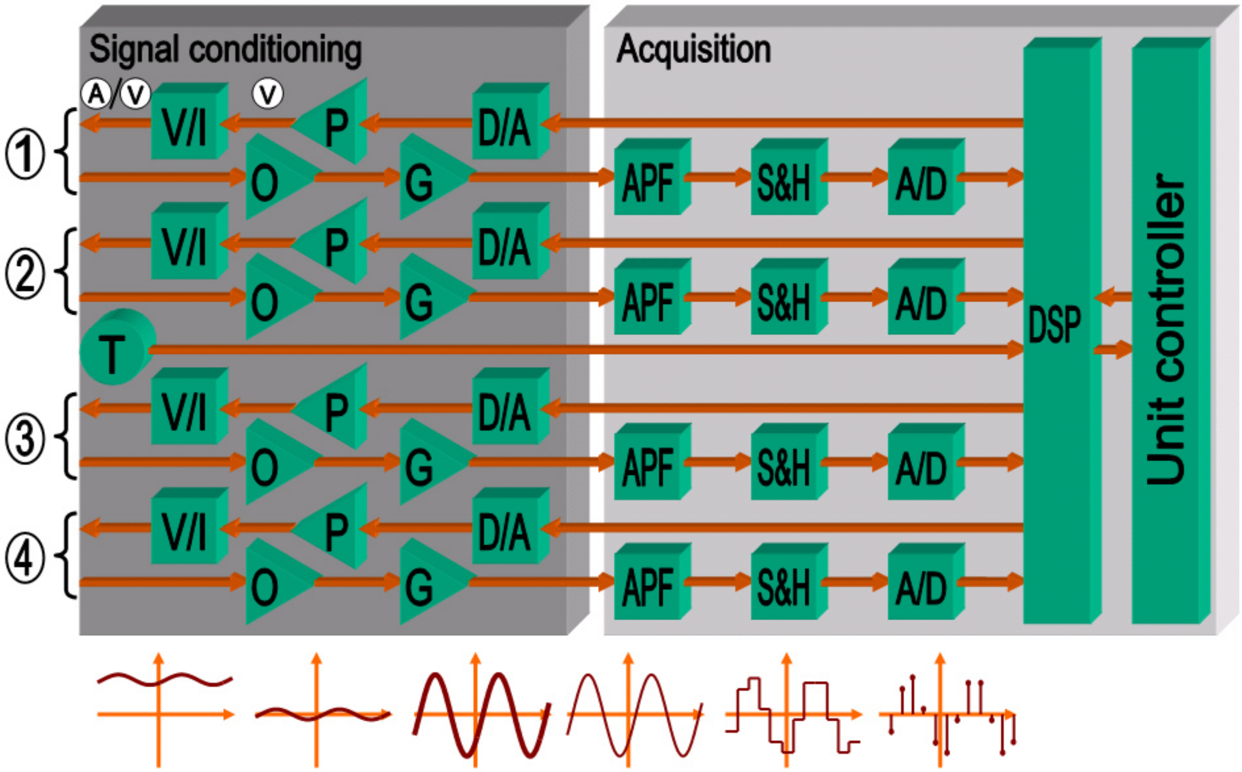


Figure 5: Sensor excitation, signal conditioning and processing inside Sensor-In module

The Analog-Out module enables the output of analog signals as voltages. Together with a Sensor-In and two transceiver modules, for example, an analog-like telemetry system can be built, which copies the sensor signals from one point to another. As described later, a constant, predefined delay time occurs due to the necessary buffers for the error-free bidirectional transmission.

The Digital-In and Digital-Out modules support serial and parallel digital signals. Applications are for example to copy PCM signals from one point to another for replacing older susceptible unidirectional PCM telemetry systems or to copy a complete 16bit parallel bus.

With the daisy-chained cable connection of the modules a linear network is created. For higher reliability the first and the last module can be connected by an additional cable with a resulting ring structure. This network is then also able to work without restrictions, when one of the cables is damaged. To support other topologies as well, a coupler module is part of the system. This operates like a hub or switch inside an ethernet network and is able to combine or branch out different data streams. This enables also centralised star-shaped and hierarchical networks as well as combinations of it, so that all topologies can be designed.

Using the wireless medium, all the same topologies are supported, but in a different way. The default connection is the star-shaped network, where the central station operates as access point and all others as access point clients. Every module has also the ability to communicate directly with each other inside the transmission range without a need of central access points. Inside a linear structure, for example, a module can receive the data from the previous module and send it together with its own data to the subsequent station. This is one of the main advantages of distributed intelligence, because new applications can be covered, like the wireless monitoring of a pipeline, with equidistant measuring points.

Also hierarchical networks are supported, where one station collects all data from a number of connected lower level stations. By combination of all 3 basic topologies any kind of network can be created, for example, for the wireless monitoring of a power plant with hundreds of free distributed measuring points.

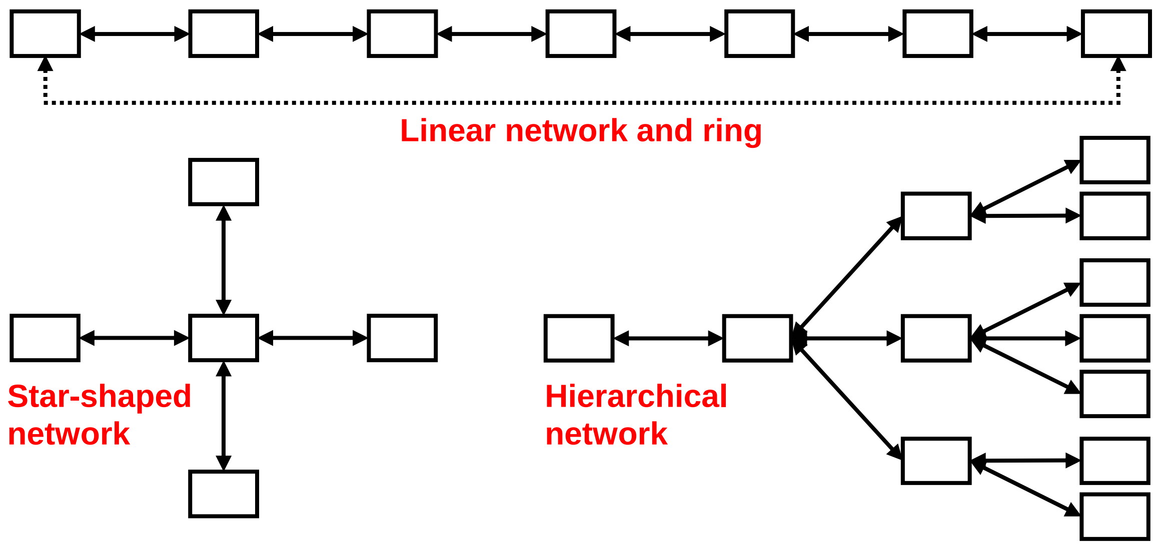


Figure 6: Cabled and wireless topologies

All modules are powered from the bus and have a wide supply voltage input range from 9-36V DC to be immune against voltage drops from long cables. For other power sources there is an AC/DC module for 100-240V AC and a DC/DC module for 36-72V DC as well as a battery module, which can be optionally combined with a solar panel for recharging. All consumer modules have an intelligent power management with electrical isolation of 1500V DC to avoid earth loops, a shut-down mode with a programmable wake-up time for temporary measurements as well as voltage, current and temperature monitoring.
Finally a set of interface modules enables the integration of all other components into the system. Examples are RS232/485, USB, CAN, GPS, Bluetooth, GSM and 3G.

Data transmission

One of the main requirements at the beginning of the project was to realise absolutely reliable wireless data transmission. The use of a synchronous unidirectional transmission was not possible, because every radio interference causes a loss of data. Therefore, asynchronous bidirectional telemetry has to be used, where implemented FIFO memories on the transmitter side and a data validity check on the receiver side guarantee a 100% error-free transmission.

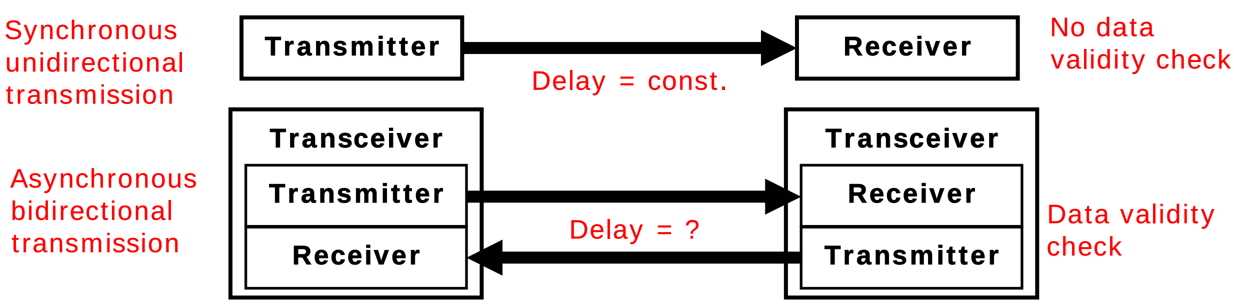


Figure 7: The two types of wireless data transmission

In practice, the continuously acquired data inside the Sensor-In and Digital-In modules are led to the input of a first small-size, high-speed FIFO with up to 128kB memory depth and up to 100MHz input clock to realise a buffered transfer to an embedded uCLinux system, which reads asynchronously larger data packets from the FIFO output. From here the data are sent to a second large-size, lower-speed FIFO memory with up to 12MB which operates as transfer buffer. Depending on the bit rate a loss of the physical connection can be over-bridged without data loss from several seconds, e.g. 24s for 4Mbps, to several hours, e.g. 2h 40min for 10kbps. Inside the Analog-Out and Digital-Out modules, both FIFO memories are placed in reverse direction as data output buffers.

The first FIFO enables also high-speed single-shot data acquisition with up to 100MHz until the memory of 128kB is filled up. The resulting data acquisition time of only 0.64ms in case of 16bit samples is enough for many ultrasonic applications, e.g. the measurement of wall thicknesses.

The data validity check is realised by using the TCP/IP protocol, where the receipt of every data packet must be confirmed. The real data transfer is implemented by high-layer protocols, like HTTP (web server and client), FTP (FTP server and client), SMTP and POP3 (e-mail server and client). For applications with further requirements on data security, SSL connections can be established using HTTPS and SFTP.

The use of standard IT protocols enables, in combination with existing standard gateways, remote maintenance by authorised users via ethernet and internet, for example download of measurement data from the homepage of the sensor, system parameterisation with a web browser, automatically FTP log file transfer to the support centre, firmware updates and data exchange via e-mail.

Time synchronisation

One of the problems resulting from the bidirectional data transfer is that in the case of a radio interference a retransmission of data is necessary and an unknown and variable time delay occurs. That means that the receiver gets all data without errors, but without knowing the delay. Therefore it is not possible to calculate, at which time the data are acquired and time-synchronous correlations of data from different sources, e.g. one mobile and one stationary measuring point are not possible. For this reason, all data have to be marked with an exact time stamp at the time of acquisition.

This requires high-precision synchronous running clocks inside of all modules, which is difficult to realise in an asynchronous operating network. However, a solution was found and the results increasingly meet the earlier specified target of stable 10µs accuracy. This is equivalent to a half sample at 50KHz sample rate and by using high-performance digital filters to a bandwidth of more than 20kHz. This covers almost all time-continuous measurements including acoustics. The argument is known that for some kinds of modal analyses more phase accuracy is required, e.g. max. 1° difference. This is given between all channels inside one module due to simultaneous sampling. For different modules we should not forget that we talk about distributed measurements with wide distances between the measuring points. With a sound velocity of 330m/s in air, an acquisition accuracy of 10µs is equivalent to a positioning accuracy of 3.3mm, which is much more difficult to realise over a distance of e.g. 500m.

For the synchronisation, one module operates as time server and all others as time clients. In networks where modules do not have direct access to the time server, e.g. in hierarchical wireless networks, the first level modules synchronise at first with the time server and after them they act as time servers themselves for the next level. The total network time accuracy decreases with increasing number of levels in the topology.

The synchronisation procedure itself works in such a manner that the client asks the server the time and adjust its own clock to it. The only remaining problem is that some time passes between sending and receiving of data. This transfer time must be added by the client to the information on time received. To calculate the transfer time, the client pings the server which reflects the signal. From the measured running time, the client can calculate the time for one way, which, in best case, is 50% of two ways. In practice some more has to be considered, like interrupt response times, fixed operation times of handling routines and variable ping times inside LAN and WLAN networks. The last was solved by statistical methods and a special algorithm, where actually not only one ping is sent, but a series of pings. This leads, in combination with the fast and efficient uCLinux operating system, to a currently reached accuracy of 2μs inside a cabled LAN and 10μs inside a WLAN network under the condition of no other data traffic. The first synchronisation is made before starting the real data acquisition, where this condition is given.

The next problem is now to keep this synchronisation constant over long periods of time. Although oscillators are very accurate compared with other electronic components, the tolerance is remarkably related to the requirements. The currently used quartz crystals have only 5ppm, but this means a time drift of 5μs per second, so that for full speed a half sample inaccuracy of 10μs is reached after only 2 seconds. For compensation two solutions are possible. The offline method is to measure the quartz tolerances before starting data acquisition. This is done by a second synchronisation starting a given time after the first from which the real time shift is calculated. The accuracy of the clock tolerance determined is the accuracy of synchronisation divided by the intervening time. With the current values of 10μs inside a wireless network 1ppm can be reached after 10s and 0.1ppm after 100s. The disadvantage of this method is that effects after the clock tolerance measurement, like temperature drifts, are not considered. Therefore the online compensation is preferred where synchronisations are carried out periodically. The accuracies are lower because of the existing network traffic during data acquisition and the resulting increased ping times. Currently 500μs stable synchronisation accuracy is reached for continuous operation of 2 stations with 160kbps data acquisition rate. Future efforts are to improve the quartz accuracy from 5ppm to 1ppm and to reduce the time of the synchronisation procedure from 1s to 100ms. This enables the option to increase the period for resynchronisations and to stop data transmission through the network for this short time. This is possible because of the implemented FIFO memories, where no data are lost during this time. With the known clock tolerances, synchronisation of the acquired data is currently done by removing one sample of the faster channel after a pre-calculated time, which has no major effect on most of the analysis methods. However, the future is to work with digitally controlled clock generators, where depending on the results of synchronisation the speed can be softly increased or decreased, so that no samples will be missed.

Applications

The flexibility and performance of the system enables a variety of applications. In the wireless monitoring section these are process plants, oil rigs, tunnels, buildings, pipelines, bridges, dams and wind power plants. Another area is the civil and military vehicle test with cars, motor bikes, aircrafts, tanks, busses, trucks, helicopters, oil tankers, heavy and agricultural machines as well as passenger and airships.

The protection of investments which are worth billions in the electricity generating and process industries, e.g. power, chemical, oil and water plants, has always been associated in the past with huge inspection costs which are incurred by the examinations of plant parts for the occurrence of rust, crack formations, depositions and material depletion. In conjunction with state-of-the-art sensor technologies, e. g. ultrasonic arrays, the introduced system is able to manage all the data communications wirelessly.

One of the numerous customised applications for this technology is currently developed for the British oil and gas industry, where, in the near future, hundreds of installed sensors in one environment are able to operate completely without power and data transfer cables. Through the concept of distributed intelligence, the data can be routed from sensor to sensor to the final control centre without the need of central access points. Especially in explosive environments this leads to the desired cost reduction.

Another increasing market are sound and vibration measurements on large constructions, like bridges or paper machines, where currently large distances between the numerous measuring points result in enormous costs for cabling.

The system is also applicable in aviation for flight test systems, where internal wireless communication cannot be realised due to prohibited electro-magnetic emissions. Here, it is no problem to connect up to 1000 sensors to the system. The admissible distance of up to 100m between 2 modules without any limitation for the total network length allows the positioning of the complete signal conditioning near the sensors and avoid long analog lines with the associated signal distortions.

Conclusions and future aspects

The system introduced is one example for the use of high performance IT communication standards for measurement tasks and the proceeding integration of data acquisition systems in existing intranet and internet infrastructures. The author is convinced that in the near future WLAN will have the same importance for wireless data acquisition as currently ethernet for wired applications. The paper describes a realistic way to combine both.

The target of the next years will be to miniaturise this technology and to reduce the power consumption further, so that one day it can be implemented as single chip solution directly in every sensor.

References

[1] IM.guide 2002/2003, Daten-Kommunikation Wireless LAN – Bluetooth – X-DSL, Ingram Micro Distribution GmbH

Hardware-in-the-Loop Simulation for the Phoenix Shuttle

Klaus Alvermann, Matthias Bodenstein, Rüdiger Gandert,

Stephan Graeber, Henrik Oertel, Egbert Rippel

German Aerospace Center, Institute of Flight Systems, Braunschweig, Germany

Abstract

Within the Phoenix project the DLR Institute of Flight Systems participates with several tasks. One of those is the hardware-in-the-loop simulation for the flight control computer of the Phoenix shuttle. The Phoenix shuttle, built by EADS Space Transportation, is a downscaled version of the Hopper (a future reusable launch vehicle), which is used to demonstrate the autonomous landing capability required for Hopper.

The hardware-in-the-loop simulation has the following features:

- Integration of the flight state simulation from EADS, which is a Matlab/Simulink simulation model.
- Simulation of Phoenix shuttle components and their interfaces: inertial navigation system, radar altimeter, laser ranger, air data system, DGPS, and the control surface actuators.
- Interactive control of the simulation: error injection, state simulation data override, flight test data replay, data storage, and quicklook.

This paper describes the system concept, implementation and operation of the simulation computer, as well as results.

1 Phoenix Shuttle

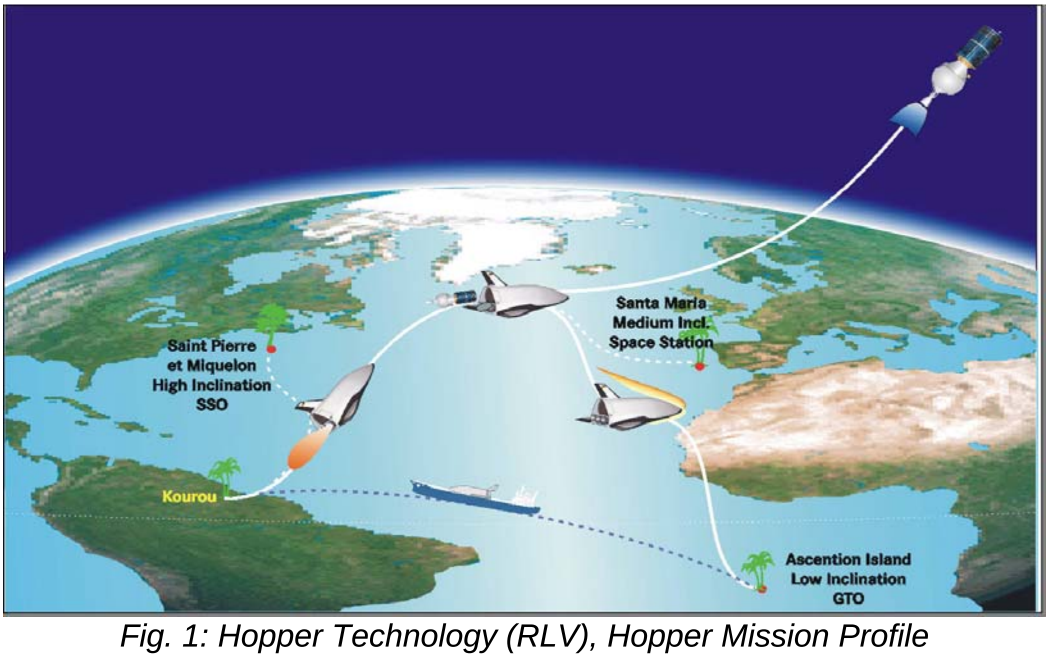


Fig. 1: Hopper Technology (RLV), Hopper Mission Profile

The German ASTRA program aims at supporting the development of future European space transportation systems. One project which is funded within ASTRA is the concept of a reusable launch vehicle (RLV), called Hopper. Hopper is supposed to be launched horizontally on a sled and to land autonomously after delivering the payload to approximately 130 kilometers altitude, Fig. 1. The development regarding the autonomous and propulsionless final approach and landing of the Hopper vehicle will be tested by means of the test vehicle Phoenix, which is a downscaled version of Hopper. This demonstrator, built and operated by EADS Space Transportation in Bremen, is just less than seven meters long with a wingspan of about four meters and a weight of up to 1200 kilograms [1]. The Phoenix shuttle is a vehicle with limited low speed flight performance and high sensitivity to disturbances. After dropping the vehicle from a helicopter at an altitude of more than 2 kilometers, it will operate autonomously during the free flight phase, gliding approach, flare and touch-down on the runway, Fig. 2. The actual flight will only take 90 seconds. The capability of horizontal landing on concrete runways will be a major design driver for future commercial acceptable and operable RLVs.

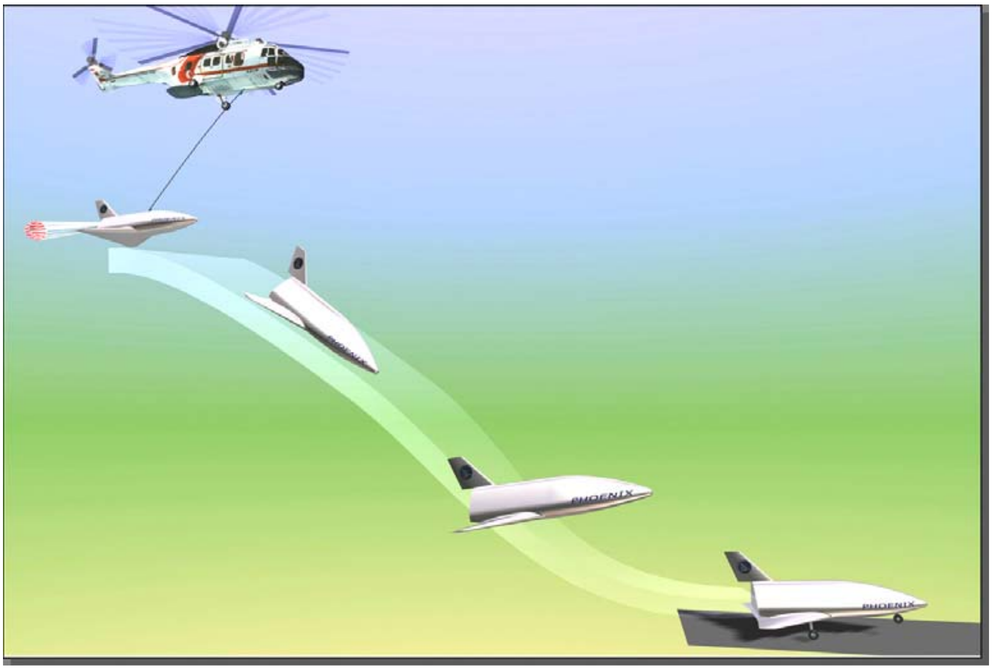


Fig. 2: Helicopter Drop Test using Phoenix

2 Hardware-in-the-loop simulation

System simulation is an important task in the development procedure of controllers and other embedded systems. A special application of a system simulation is the so called hardware-in-the-loop simulation where components are tested under realistic real-time conditions. In the frame of the Phoenix project the hardware-in-the loop simulation SAS (Sensor and Actuator Simulator) for the flight control computer (FCC) respectively for in-the-field tests with the Phoenix onboard system has been developed at DLR. During these tests all those parts of the system which cannot operate in their normal environment, were simulated in real-time, Fig. 3:

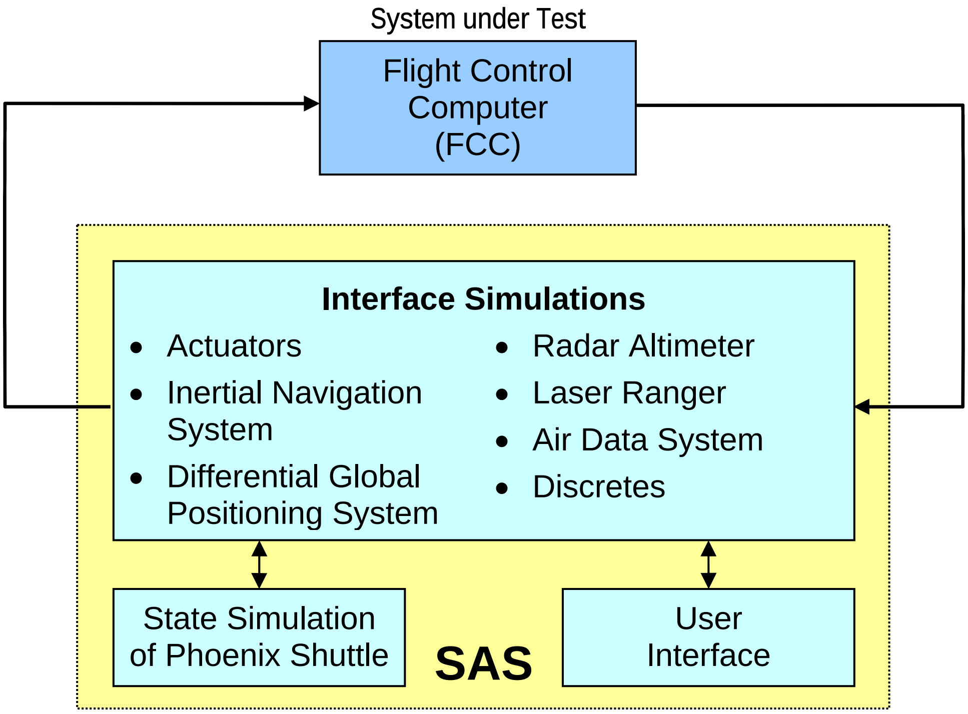


Fig. 3: Hardware-in-the-Loop Principle

- *Actuators:* The FCC is connected to nine actuators from Wittenstein. The interface is a bidirectional CAN interface. All actuators operate asynchronously. Eight actuators are used to steer the control surfaces and one is used to steer the nose landing gear.
- *Inertial Navigation System (INS):* The FCC is connected to an INS H764-G from Honeywell. The interface is a MIL-STD-1553B interface. The INS operates as a remote terminal, i.e. the FCC is the bus controller. Additionally, the 1 PPS (pulse per second) output pulse from the INS is fed to the FCC.
- *Differential Global Positioning System (DGPS):* The FCC is connected to a DGPS Sharpe XR6 GPS Receiver from Parthus. The interface is a serial RS422 interface.
- *Radar Altimeter:* The FCC is connected to a HG8500 Series Radar Altimeter from Honeywell. A dedicated conversion box provides a serial RS422 interface for the FCC.
- *Laser Ranger:* The FCC is connected to a Laser Ranger LDM 300 C from Jenoptik. The interface is a serial RS422 interface.
- *Air Data System:* The FCC is connected to the Phoenix air data system which consists of a nose boom with pressure sensing ports from Rosemount, pressure transducers from Setra, and a temperature sensor. The interface is analog.
- *Discretes:* The FCC is connected to several discretes determining whether the helicopter is connected to the shuttle, whether the landing gear measures weight on wheels and which telecommands have been sent from the ground station. In the opposite direction commands (disengage, deploy, brake) are transmitted to the landing gear.

In order to simulate these interfaces a state simulation for the Phoenix shuttle itself is required covering flight mechanics and aerodynamics of the aircraft.

3 Hardware

The hardware of SAS consists mainly of a VMEbus based system for the real-time application, and a PC with two monitors for the user interface. In the VMEbus system two PowerPC processors are used. One of them is equipped with two PMC modules. One module provides a MIL-STD-1553B interface, the other one provides a CAN interface. Since four serial interfaces are already available with each PowerPC processor, only two additional VME based interface cards are used. One is a 16 channel digital-to-analog converter, the other is a 32 channel digital I/O board. Most hardware components are from Radstone Technology. Several dedicated adapters were developed for the customer in order to enhance the flexibility of the system:

- A break out box for the serial interfaces helps to quickly change between simulated and real sensor systems for the FCC.
- A “NetIO board” enables reset commands for the SAS enclosure as well as the FCC via Ethernet.
- A 1 PPS level conversion box adapts the voltage of the PPS signal to a different level.
- An additional PC receives the flight state via another serial interface and displays a three dimensional view of the shuttle over a simulated terrain.

SAS is connected to the FCC of the Phoenix shuttle. Since software development for SAS and the FCC took place at different locations, SAS was built twice and another VMEbus based system was built to act as a simulator for the FCC interfaces. Therefore, both system development groups could work concurrently, one group using the FCC together with one SAS, the other group using the other SAS and the FCC interface simulator.

4 Software

The software is decomposed into two main parts: the real-time simulation part running on the VMEbus system and the user interface part running on the PC. The simulation itself is split into the simulation of the sensor and actuator interfaces running on one processor and the Phoenix shuttle and sensor model simulation running on a second processor.

The model simulation was developed by EADS and integrated by DLR, the interface simulation program and the user interface was developed by DLR.

4.1 Interface Simulation

The interface simulation program is an application written in C running under the Wind River real-time operating system vxWorks on one PowerPC processor. The main tasks of the application are:

- simulation of the sensor interfaces;
- simulation of the actuator motors and interfaces;
- transmission of configuration data and commands to the model;
- reception of the flight state and calculated sensor data from the model;
- signal management (data acquisition, transfer, output, storage etc.);
- communication with the user interface.

An application run consists of the initialization, operation, and finalization. During operation a main task is activated periodically with 2 ms cycle time. This task activates the sensor and actuator simulations, handles the communication with the model and the user interface and performs the periodic parts of the signal management.

4.1.1 Sensor Interface Simulation

Each sensor interface simulation is executed in its own task, which is activated periodically by the main task. The activation interval depends on the simulated sensor, mainly its data output rate. For example, the DGPS interface is activated with a frequency of 10 Hz, since the real DGPS sensor sends messages with 10 Hz.

The sensor itself is simulated in the model (according to the shuttle simulation that is also part of the model). The model runs asynchronously to the sensor interface simulations on a second processor, see 4.2.

When activated, the sensor interface simulation uses the last received model data record for the sensor, encodes this data according to the sensor message protocol, and sends the data via the interface hardware.

Some sensors also receive commands from the FCC (e.g., the laser ranger or the INS). When activated, those sensor interface simulations will first take the commands received during the last cycle. Administrative commands are then handled directly in the sensor interface simulations, other commands are forwarded to the model.

4.1.2 Actuator Motor and Interface Simulation

The actuator interface simulations work in principle like the previously described sensor interface simulations. However, the model only simulates the flaps and speed brakes connected to the actuators. The actuators themselves (motor, gear, CAN protocol) are simulated in the actuator interface simulations. The Wittenstein actuators use relative position commands and position feedbacks, while the model uses absolute positions. The interface simulations translate between these interpretations.
The motor simulation also includes the states of the Wittenstein actuator (reset, control loop open, control loop closed, fault behaviour).

4.1.3 Model Data Handling

The interface simulation program communicates periodically with the model program over the VMEbus. The following data is sent from the interface simulation to the model:

- initial model parameters used during a model reset: runway position, initial shuttle position, orientation, and speed, etc.;
- model state commands: reset model, start captive flight under helicopter, release shuttle from helicopter;
- landing gear commands: deploy, brake, etc.;
- correction values for the INS sensor;
- actual flap and speed brake deflection commands.

The first three are received from the user interface, the correction values are received from the FCC, and the deflections are calculated by the actuator motor simulation according to the commands received from the FCC.

Conversely, the following data is received from the model:

- sensor state and data (in engineering units) for the sensors (DGPS, INS, etc.);
- deflection and state of the flaps and speed brakes;
- state and position of the landing gear wheels;
- flight state simulation data (shuttle position, orientation, altitude, wind data, etc.);
- administrative state of the model.

The first two are transferred to the sensor interface simulations respectively the actuator interface simulations. All values can be transferred to the user interface for display.

4.1.4 Signal Management

The signal management is a software pattern that is used in several data acquisition and simulation systems at DLR [2, 3, 4]. The central idea is, that the data processing system (the system that receives, sends, or processes data) need not know the meaning of a signal. Depending on what to do, it needs to know only the location, the size, and/or the data type to handle the signal.

A signal in this sense is any data structure (usually a base data type or an array of base data types) that is handled by the system as a single unit. This can be the data received from a sensor, the data sent as sensor output, internal data of a controller etc. A signal can be a complete message; other signals can be message parts (as needed).

The signal management is based on the signal data base consisting of several lists:

- input device list: contains the signal sources and their properties;
- input device record list: a signal record is a combination of one or more signals with the following properties: all data is received from the same input device at the same time (e.g., within one message) and the received data is stored consecutively in memory (this allows to handle the data of a record as one unit);
- signal description list: contains the properties of the signals: a name, the record in which the signal is stored, a data type, whether it is an array, an optional unit etc.;
- bit signal list: contains the descriptions of individual bits of signals as a pointer to the source signal and a bit mask.

These lists are the static part of the signal management. For the interface simulation program the signal data base is compiled into the code (and also into the code of the user interface program). In other projects the data base is part of the system parameters which are loaded at run time.

Two more lists are used at run time:

- signal list: each entry contains a pointer to a signal description and a pointer to the received signal data;
- signal access list: this is the connection between the individual hardware drivers of the various interfaces and the generic signal handling.

Each interface driver stores the received data in input handlers (double buffers). At the begin of each main cycle all double buffers are toggled, such that the application can use the data received in the last main cycle, while the interface handlers can receive the actual data in parallel.

All application parts that use data (e.g., the data storage) are initialized with a list of signal description identifiers. The signal handling then configures itself accordingly and supplies the associated signal data automatically to the application.

4.1.5 User Interface Communication

The interface simulation program and the user interface communicate via several TCP and UDP connections over Ethernet. The main connection is between the interface simulation (as a client) and the actual user interface program (as the server). After an initial connection and identification, the initial parameters are sent to the interface simulation. During operation the user interface sends commands (model commands, data storage commands, commands to change the state of the interface simulations, etc.) and activations of signal data to the interface simulation. Conversely, the interface simulation periodically sends back the data of activated signals (until they are deactivated again).

Other connections exist to services to handle data storage, data replay, and the progress log.

4.2 Model Integration

The actual model of the Phoenix shuttle and its sensor was developed by the company EADS under Matlab/Simulink. EADS generates source code out of Matlab/Simulink, compiles it under vxWorks and delivers one object module and several header files. DLR integrates that into its system environment programmed for the model processor.

The interface consists of many data structure definitions and three routines: Init, Cycle, and Done. The Init and Done routines are called when the model is resetted (due to a command from the user interface). The Cycle routine is called periodically (with 10ms) by the system environment on the model processor. The model code runs in its own task to separate it from the system work.

The necessary model input is received via the VMEbus from the interface simulation program and transferred to the model task via a message queue (this allows the continuation of the system program when the model task blocks). Directly before the call of the Cycle routine, the accumulated data is taken from the queue and the input data structures of the model are filled accordingly. After the Cycle call returns, the output data is extracted from the data structures and sent to the interface simulations via the VMEbus.

After a few revisions of the model interface at the beginning of the project, it now typically takes only a few hours to integrate a new model version. The new version is taken from a FTP server, integrated at DLR with the system code, and the executables are placed back on the server, from where EADS installs them on the SAS system according to defined procedures.

4.3 User Interface

The user interface program is an application written in Delphi running under Windows XP on a PC.

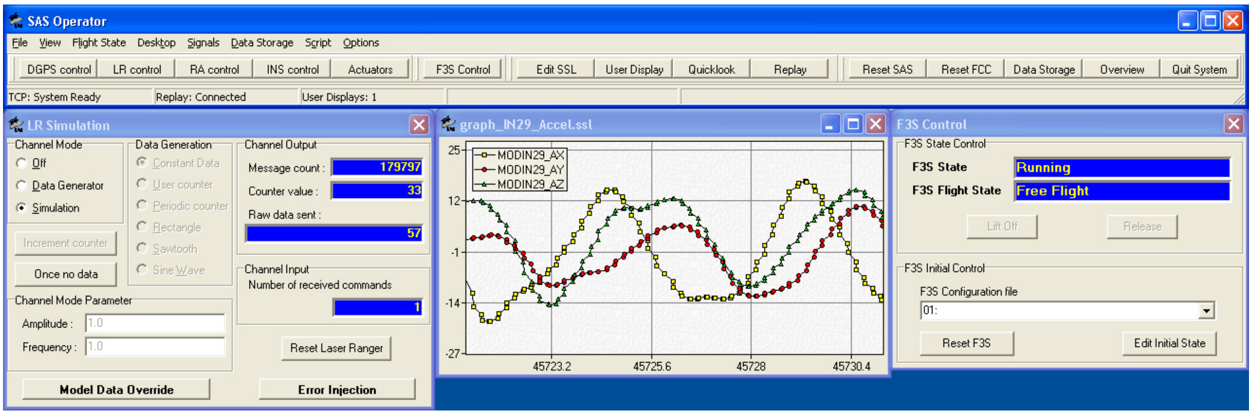


Fig. 4: Main Window with some Control Windows

The main tasks of the user interface program are:

- control of the interface simulations;
- control of the model;
- display of data from the interface simulations and the model;
- setup of parameters for the simulations and the model;
- handling of data storage data;
- sending of replay data;
- display of log messages from the interface simulations and the model;
- automatic execution of all tasks listed above in scripts.

The user interface shows a standard menu bar, a tool bar for short cuts, and a status bar to display state information. Each function (e.g., the control of the DGPS interface simulation) has its own window. The user can open and use several of these windows in parallel. Such a window layout can be stored and loaded.

The user interface and the interface simulation program are connected via Ethernet and communicate via TCP (see 4.1.5). The VMEbus system is resetted and booted from the user interface program, this can be done several times during one session. The interface simulation program will connect to the user interface server each time after booting.

The TCP connection and the user interface are handled in different threads. This prevents a blocking of the user interface if the communication with the interface simulation blocks.

As described in 4.1.4 the signal data base is compiled into the code of the user interface program. Additional information (not used by the interface simulation) is attached for user convenience: long signal names, display format strings, etc.

5 Features

5.1 Interface and Actuator Simulation

5.1.1 *Sensor and Actuator Control*

Each sensor can be controlled in its own control window; several of those windows can be opened and operated in parallel (see 4.3).

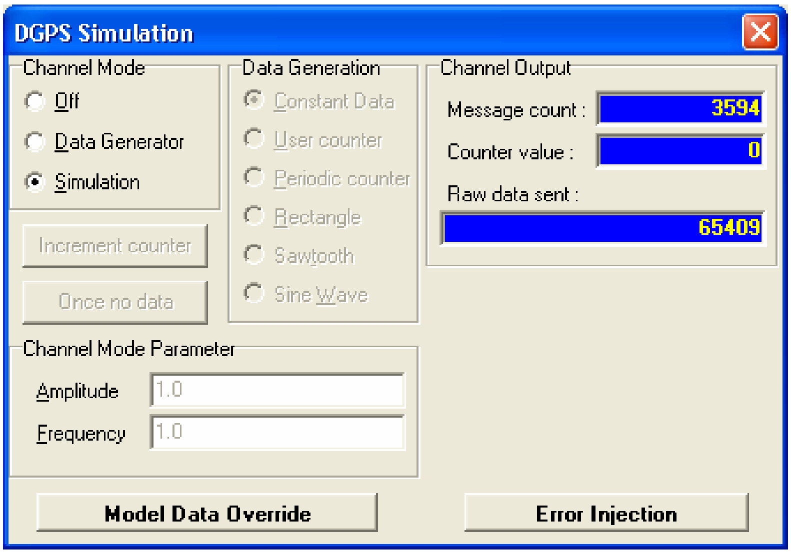


Fig. 5: DGPS Control Window

Each interface can be operated in the same basic modes: off, data generator, and simulation. In mode "off" no data is sent over the interface, this is used to test how the flight control computer (FCC) handles missing input data. In mode "data generator" the messages are filled with artificial contents (constant, counter, sine wave, etc.). This is used to test the low level interface drivers of the FCC. In mode "simulation" the messages are filled with simulated sensor data. The controls for these general settings can be found in all interface simulation control windows.

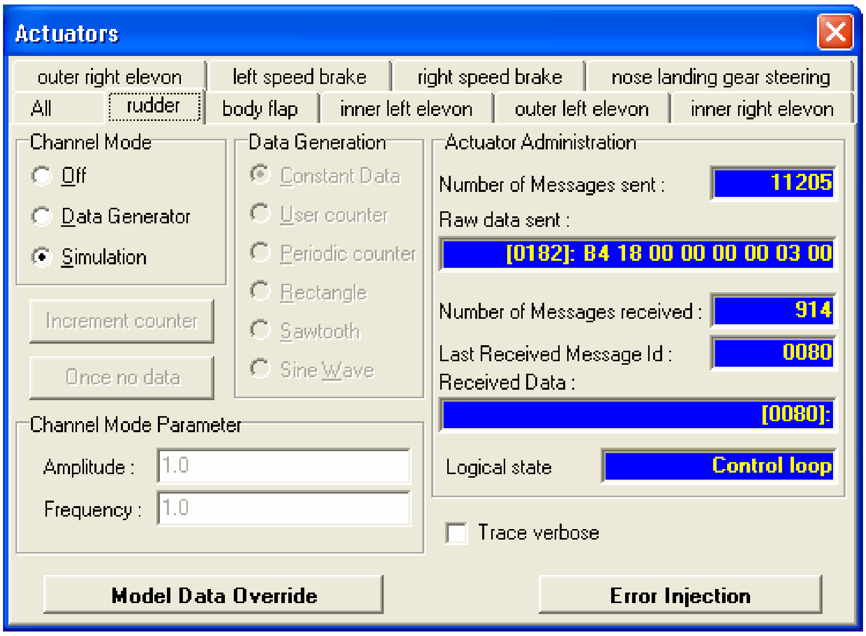


Fig. 6: Actuator Control Window

Depending on the actual sensor, additional information is displayed: usually raw data, the number of sent respectively received messages etc. If an interface consists of several channels then each channel is controlled separately in its own page of the control window.

Most interface simulations allow a modification of the final output stream by "error injection" (see 5.1.2) and "model data override" (see 5.1.3). The data stream of a typical sensor can be modified as follows:

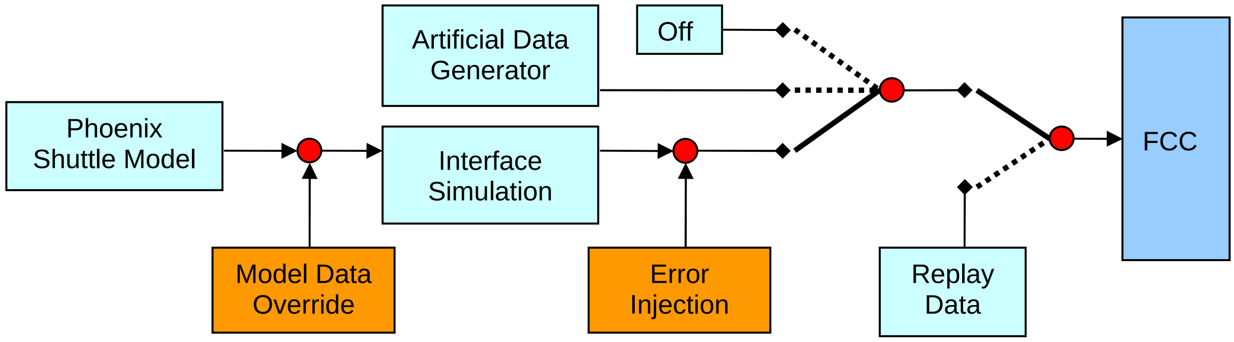


Fig. 7: Data Flow of Sensor Signals in SAS

5.1.2 <u>*Error Injection*</u>

The error injection allows the modification of the final output messages of a sensor.

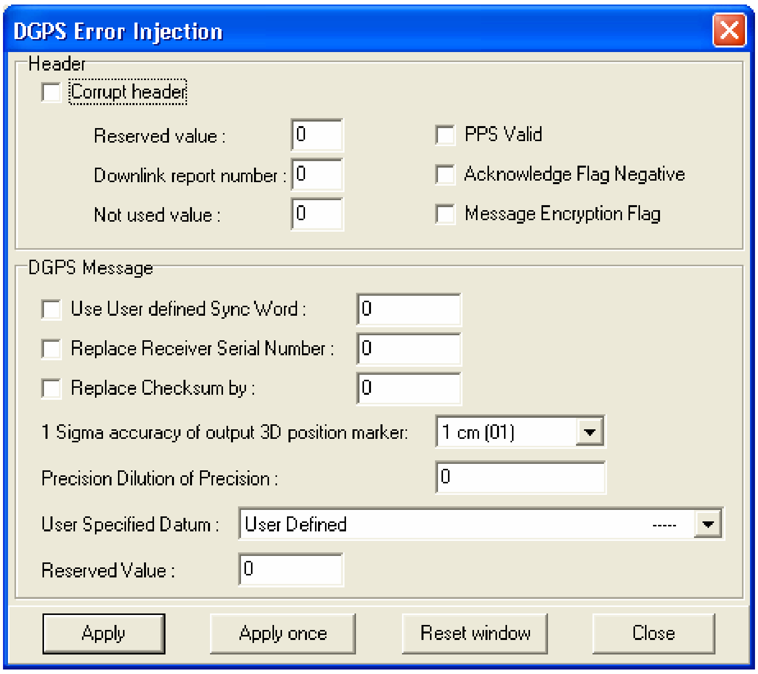


Fig. 8: DGPS Error Injection

Each error injection depends on the actual sensor. For example for the DGPS simulation the following modifications can be specified:

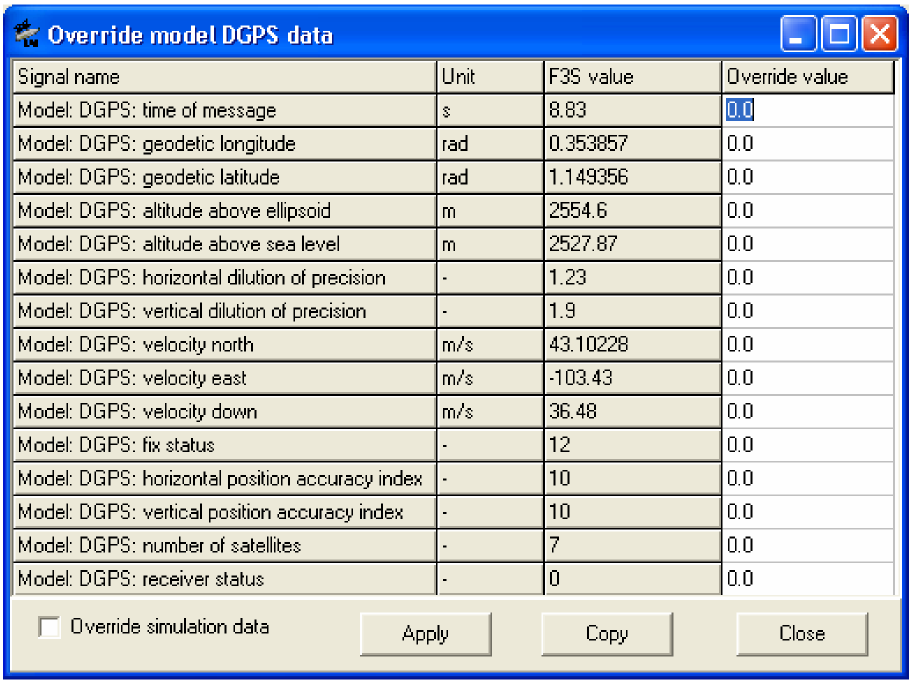
- corruption of the message header (modifying individual bits);
- corruption of the synchronization word;
- corruption of the check sum;
- specification of the precision data and other words not generated by the model sensor simulation.

All settings can be modified independently.

For all interface simulations it can be specified, whether the error injection modification happens only for the next message or for all messages until switched off. This allows testing the robustness of the FCC against single corrupted messages and against longer corruptions of the interface or sensor.

5.1.3 <u>Model Data Override</u>

The model data override allows to inspect and modify the data received from the model simulation before it enters the interface simulation (to be encoded in the message), see Fig. 7 and 9.



Signal name	Unit	F3S value	Override value
Model: DGPS: time of message	s	8.83	0.0
Model: DGPS: geodetic longitude	rad	0.353857	0.0
Model: DGPS: geodetic latitude	rad	1.149356	0.0
Model: DGPS: altitude above ellipsoid	m	2554.6	0.0
Model: DGPS: altitude above sea level	m	2527.87	0.0
Model: DGPS: horizontal dilution of precision	-	1.23	0.0
Model: DGPS: vertical dilution of precision	-	1.9	0.0
Model: DGPS: velocity north	m/s	43.10228	0.0
Model: DGPS: velocity east	m/s	-103.43	0.0
Model: DGPS: velocity down	m/s	36.48	0.0
Model: DGPS: fix status	-	12	0.0
Model: DGPS: horizontal position accuracy index	-	10	0.0
Model: DGPS: vertical position accuracy index	-	10	0.0
Model: DGPS: number of satellites	-	7	0.0
Model: DGPS: receiver status	-	0	0.0

Fig. 9: DGPS Model Data Override

Using the button "Copy" the actual model data can be copied to the override value column. There changes to individual values can be applied. The model data override can be enabled and disabled with one control for the whole sensor. This can be used to test the whole input range of a value for the FCC and to test the robustness of the FCC against, e.g., unexpected border values.

5.2 <u>Model Control</u>

The model control displays the actual states of the shuttle model and allows initiating events to change the state:

- lift off: begin of captive flight, i.e., the Phoenix shuttle is lifted by a helicopter and a specific manoeuvre is flown;
- release: release of the Phoenix shuttle from the helicopter and start of actual flight;
- reset: reset of the whole model simulation.

The model control also allows specifying the initial configuration of the model, which is loaded with the next reset.

5.3 Quicklook and Displays

All signals generated by the interface simulations (see 4.1.4) can be displayed as text or in graphs: this includes the raw data sent by the interface simulations, input and output data of the model, etc.

For both displays a selection of signals can be chosen from the list of available signals. This includes an optional display format string and a unit conversion. Such a selection can be stored in a file. The signals of a selection can then be displayed as alphanumeric text or graphs.

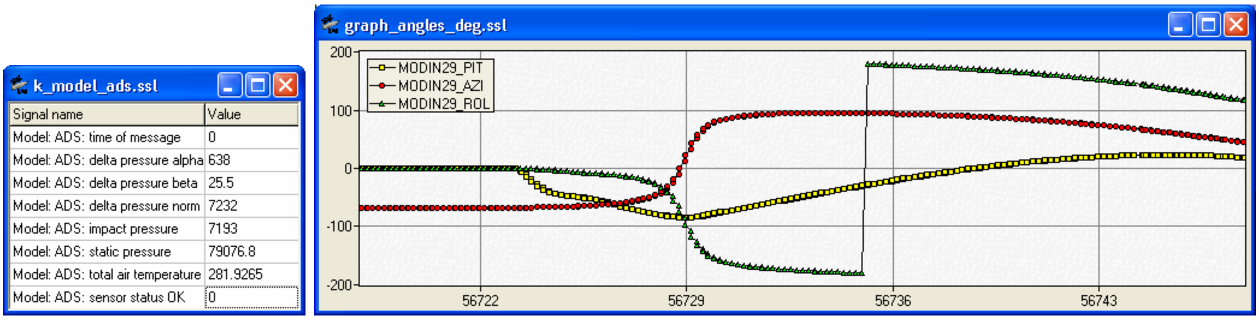


Fig. 10: Text Display and Graphical Display

Both displays are updated with about 10 Hz.

5.4 Parameters

Initial parameters of the interface simulations and the model are specified in a text file. This text file is loaded by the user interface program and sent after each reset of the interface simulation program. Parameters include, e.g., the ports and Baud rates of the serial interfaces, CAN identifiers of actuator nodes, actuator gear ratios, etc.

5.5 Data Storage

An arbitrary selection of any signals generated by the interface simulations (see 4.1.4) can be recorded and stored in a file. The selection is specified on the user interface and sent to the interface simulation program. Data storage can be started and stopped on the user interface.

The data of the selected signals is sent by the interface simulation program via Ethernet to a service running on the user interface PC. The service receives the data and stores it on disk. The service is separated from the user interface program for simplicity and to relieve the user interface of the data storage work.

The stored data can be evaluated later, e.g., with Matlab.

5.6 Replay

In 2003 helicopter test flights took place to evaluate some Phoenix shuttle sensors (INS, DGPS, laser ranger, and radar altimeter). The recorded sensor data can be fed back to the FCC to test the FCC against original sensor values.

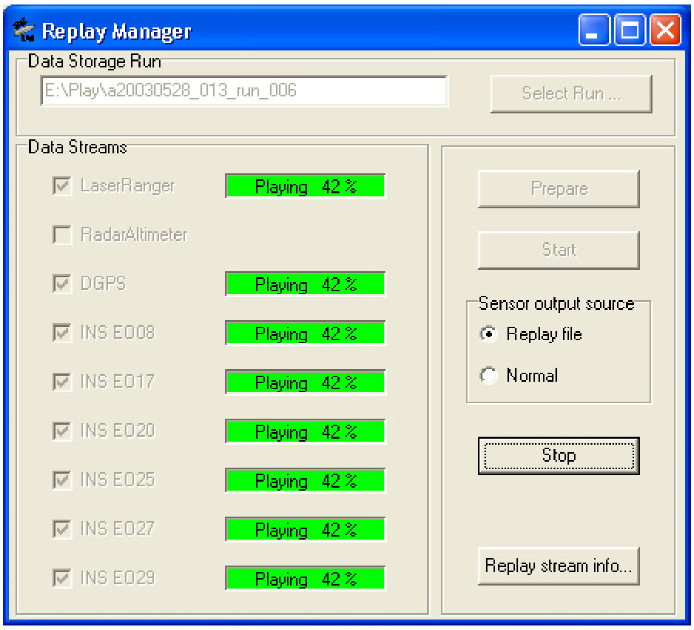


Fig. 11: Replay Manager

This is done using the SAS system in the following way: A standalone program reads all specified data streams and sends them to the interface simulation program via Ethernet. Here the data is buffered such that the output can always be fed in real-time. On the user interface a selection of sensors is switched to "replay" mode, then the interface simulation program replaces the generated messages with those from the recorded data.

5.7 Scripting

All of the features described above are usually controlled manually by an operator. However, to allow deterministic, automated, and repeated tests, most features can be controlled via script. Such a script is started on the user interface and executes commands at specified points of time.

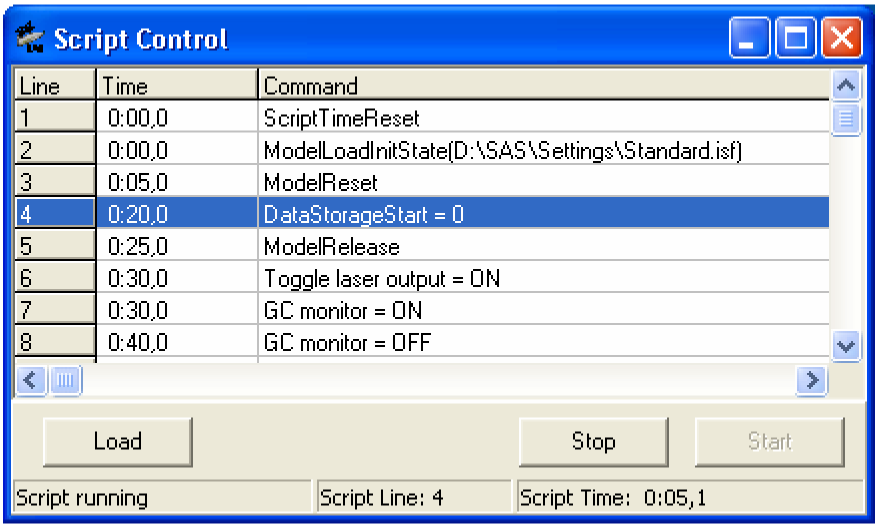


Fig. 12: Script Control

The script is written as a text file containing time stamps together with commands. Several script files can be linked in a master script and executed consecutively.

6 Results

The SAS system was developed within three main steps:

- The first system simulated some pre-selected hardware interfaces with a basic software protocol. This version was delivered during an early phase of the project and helped EADS Space Transportation to develop the software for the FCC.
- The second system simulated all hardware interfaces of the onboard system with a basic test protocol. Basic error injections for the modification of the interface protocol were allready available. With the aid of this system the customer could implement and test all communication software on the protocol level.
- The final system incorporates the flight state, sensor and actuator simulation. The system is mainly used for hardware-in-the-loop simulation of the onboard flight control computer. By simple means of configuration the system can be used for hardware-in-the-loop simulation with the complete Phoenix shuttle.

EADS tested their software for the FCC thoroughly and improved it with the aid of the hardware-in-the-loop simulation. By running the state simulation model with a frequency of 100 Hz and the interface simulations with 500 Hz, latencies inside SAS are small compared to the FCC cycle time of 20 ms (50 Hz).

Most releases were generated due to upgrades of the state simulation model. In total more than ten releases were generated during the half year when the system was used most. The software was exchanged via a FTP server. The integration, basic test, and delivery of a new version could be handled in less than a day.

A flight of the Phoenix shuttle has not been carried out until now, it is planned for May 2004. The results from the hardware-in-the-loop simulation have contributed to a lower risk and more efficient Phoenix flight test program.

Abbreviations

ASTRA	Ausgewählte Systeme und Technologien für Raumtransport-Anwendungen
CAN	Controller Area Network
DGPS	Differential Global Positioning System
DLR	*Deutsches Zentrum für Luft- und Raumfahrt,* *i.e.* German Aerospace Center
EADS	European Aeronautic Defence and Space Company
F3S	Flight State and Sensor Simulation
FCC	Flight Control Computer
FTP	File Transfer Protocol
INS	Inertial Navigation System
I/O	Input/Output
PC	Personal Computer
PCI	Peripheral Component Interconnect
PMC	PCI Mezzanine Card
PPS	Pulse per Second
RLV	Reusable Launch Vehicle
SAS	Sensor and Actuator Simulator
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

References

[1] Wilhelm Gockel: "Phoenix RLV Flight Test Demonstrator", Proceedings der DGLR-Jahrestagung 2003, Deutsche Gesellschaft für Luft- und Raumfahrt, München, November 2003.

[2] Klaus Alvermann, Rüdiger Gandert, Bernd Gelhaar, Stephan Graeber, Henrik Oertel: "ACT/FHS On Board Computer System", Proceedings of the European Telemetry Conference, Garmisch Partenkirchen, Germany, May 1998.

[3] Bernd Gelhaar, Heinz-Jürgen Pausder, "A Flight Test Experimental System for Multi Use", Proceedings of the 27th European Rotorcraft Forum, Moscow, Russia September 2001.

[4] Bernd Gelhaar, Henrik Oertel, Klaus Alvermann, Matthias Bodenstein, Rüdiger Gandert, Stephan Graeber, and Hans-Peter Schwaneck: "FHS - Experimental System for Flying Helicopter Simulator put into Operation", Proceedings of the American Helicopter Society, International 59th Annual Forum, Phoenix, Arizona, May 2003.

FLIGHT TEST DATA HANDLING
THROUGH EXTENSIVE USE OF PARAMETER GROUPS

Sergio D. Penna, Antônio Magno L. Espeschit
EMBRAER Flight Test Division
São José dos Campos, Brazil

Abstract

The number of aircraft parameters used in flight-testing has constantly increased over the years and there is no sign this situation will change in the near future. On the contrary, in modern, software-driven, digital avionic systems, all sorts of parameters circulate through digital buses and can be transferred to on-board data acquisition systems more easily than those converted from traditional analog transducers, facilitating the request for more and more parameters to be acquired, processed, visualized, stored and retrieved at any given time during a flight-testing campaign.

The constant unbalance between what parameter quantity engineers believe to be "sufficient" for developing and troubleshooting systems in a new aircraft, which tends to increase with aircraft complexity, and the associated cost of instrumenting a test prototype accordingly, which tends to grow beyond budget limits, pushes for new creative ways of handling both tendencies without compromising the ease of performing an engineering analysis directly from flight test data.

This paper presents an approach for handling a very large collection of flight test parameters through the extensive use of "Parameter Groups", particularly in two important scenarios, the very basic creation and administration of the traditional "Flight Test Parameter List" and the processing of selected data for visualization, recording on a mass-storage media, and transmission over a telemetry link.

Keywords

Flight Test Data Processing, Flight Test Parameters, Telemetry.

Introduction

In the last 30 years, the number of parameters used for flight-testing probably increased by 2 or 3 orders of magnitude, in particular due to the implementation of more complex digital systems in commercial and military aircraft design.

Digital parameters are easier and cheaper to acquire and process when compared to traditional analog parameters. Several hundred parameters flows in a single-channel digital data bus and can be monitored by connecting only a couple of wires. As aircraft systems complexity increases, more and more digital buses are added, quickly multiplying the total number of parameters available for engineers to analyze, triggering a desire for more and more information after each test flight and putting enormous pressure on instrumentation costs, telemetry bandwidth, not to mention the consequences in real-time processing and test data storage systems.

Statistics performed on parameter usage during a traditional flight-test campaign showed that:

- a small number of parameters is used by almost everyone
- a large number of parameters is used most of the time by the same people
- a significant number of parameters is used once or never used

These findings could be seen as symptoms of poor resource management, where parameter instrumentation and parameter usage are totally unbalanced. In fact, part of the cost of maintaining a test aircraft could be reduced by instrumenting parameters when they are needed. Unfortunately, this is not a trivial task:

- adding or changing parameter instrumentation in a test aircraft often requires several hours of intensive work, during which the aircraft is not flying
- the precise time a particular parameter or group of parameters is needed changes dynamically when test campaigns are moved in time or migrate from one prototype to another
- engineers tend to react negatively, always for justifiable reasons, when asked to “trim” their parameter list
- parameter instrumentation history must be tracked, even for parameters used just once in a single test.

Engineers tend to be more disciplined with respect to parameter usage when they are performing post-flight analysis. This activity requires a lot of their own time and often interactive computational resources; therefore, engineers tend to optimize how much data is really needed. Better selection of time-slices combined with a smarter selection of parameters that add significance to the analysis process in general lead to faster and more accurate results. Observing engineers at work, it is often to see parameters being grouped together following some association logic: produced or processed by the same aircraft system (engine, avionics, hydraulics, flight commands, etc), required for a particular analysis (flight qualities, take-off and landing performance, flutter, etc), or simply categorized as troubleshooting aid.

Making groups out of countable items is a common initiative when quantities involved exceed some subjective limit. The next sections will stress this technique when applied to the management of a large collection of test parameters within a flight-testing environment.

Common Problems Building and Managing Parameter Lists

A “Parameter List” is necessary to guide the installation of on-board data acquisition systems, a task assigned to flight-test instrumentation personnel. Parameters are created by engineers as certification requirements get organized in flight-test campaigns (some of them) and as aircraft systems get designed (most of them). Certification regulations are documented and there is in general little questioning about what test parameters are needed to verify them, while for aircraft systems this is not the case.

In early stages of any aircraft development, information about aircraft systems is incomplete. If a “Parameter List” is built very early, it will contain low quality information about parameters belonging to these systems and will need to be revised constantly, adding more work to the “Parameter List” management task and little quality to the list itself. In this respect, its not uncommon to have two different parameters created by two different engineering areas representing the same physical quantity and requiring the same type of instrumentation.

As the aircraft matures, parameter information acquires quality and, after a certain point, it becomes sufficient for a good on-board data acquisition system design, one that matches engineers need for test data in aircraft certification and development.

Managers desire for keeping on-board data acquisition systems within budget and engineers desire for flight-test data are opposite forces: there is always a reason for instrumenting more and more parameters! Since resources are finite, some limit line must be drawn and the number of available parameters often becomes “frozen”. Under this scenario, groups of parameters are eventually replaced in on-board data acquisition systems as the flight-test campaign progresses, so other systems can be debugged without increasing the agreed total number of available parameters, at the cost of modifying the existing instrumentation.

In summary, following concerns are evident:

- quality of parameter data must be assured as early as possible
- the balance between availability and usage must be constantly monitored

Failure to address these issues properly can assume catastrophic proportions when parameter quantities involved reach three or four digits number. One can expect to spend little effort managing parameter usage in a 500 parameter installation, but practices used in this scenario may not hold in a 10,000 or 20,000 parameter installation.

For large parameter quantities in the range of multiple thousands, new ways to deal with routine parameter acquisition and usage must be created.

An Approach to Parameter List Management

As parameters are created and added to a "Parameter List", parameter ownership can be tracked by recording a reference to the parameter user, always a member of an engineering group. Frequently, parameters created by one user are consumed by many others, adding a new dimension to parameter-user relationship. For instance, parameters listed in Table 1 are so basic that they are expected to be consumed by almost every engineer doing analysis. As aircraft development progresses, parameters are eventually no longer required (a certification regulation is already demonstrated or an aircraft system is operational) and could be removed from the current instrumentation installation, saving time in pre-flight activities, processing time and storage space in ground station systems. If "owners" and "consumers" are properly tracked, any particular parameter could be safely removed when it has no "consumers", provided that an agreement from the "owner" is obtained.

1	Airspeed
2	Barometric Altitude
3	Static Air Temperature
4	Total Air Temperature
5	Pitch Angle
6	Roll Angle
7	Yaw Angle
8	Pitch Rate
9	Roll Rate
10	Yaw Rate
11	Mach Number
12	Air-Ground Switch
13	Rudder Position
15	Aileron Position
16	Elevator Position
17	X Acceleration
18	Y Acceleration
19	Z Acceleration
20	Vertical Speed

Table 1 – Very Basic Flight-Test Parameters

If parameters could be divided in classes indicating a different usage or processing priority, managing alternatives in a limited resource scenario could be facilitated, because it would be previously known what groups of parameters could be manipulated. In general, it is possible to segregate parameters in at least three usage classes: those declared "Safety-Of-Flight", those required for certification and those dedicated to system troubleshooting.

Figure 1 depicts a data model that may help addressing the issues above.

It has five tables, USER, BRANCH, PARAMETER, GROUP and CLASS, and two auxiliary relationship tables ("r-table"), BRANCH x PARAMETER and GROUP x PARAMETER.

Entries in BRANCH table are created before entries in USER table, so each new user is added belonging to an existing branch. Each new parameter creates an entry in PARAMETER table belonging to a particular branch and creates a new entry in BRANCH x PARAMETER r-table. Parameter classes are defined creating new entries in CLASS table. Groups of parameters are created by adding new entries in GROUP table associated with an existing class. Parameters are added to groups by adding new entries in GROUP x PARAMETER r-table.

From Figure 1, users "Bob" and "Chuck" belong to branch "Avionics", branch "Flight Test" shares interest in parameter "Airspeed" with branches "Avionics" and "Propulsion", parameter group "Basic" belonging to branch "Flight Test" contains parameters "Airspeed", "Altitude" and "SAT", parameter groups "Engine 1" and "Engine 2" are classified as "Certification", "AP" and "SPS" as "Troubleshooting" and "Basic" as "SOF".

The concept of parameter "owner" and "consumer" can be easily accommodated when the "owner" is considered simply the first "consumer", that is, the first branch to add an entry in BRANCH x PARAMETER r-table is the "owner" and any other branches adding new entries for the same parameter are "consumers".

This data model allows for multiple parameter associations, that is, the same set of parameters can be part of different parameter groups, as long as the association makes sense to its creator. From Figure 1, parameter "Airspeed" belongs to groups "Basic", "AP" and "SPS".

Using this model, one can formulate a few important queries:
1. Which groups do parameters belong to?
2. Which parameters <u>do not</u> belong to any group?
3. Which branches do parameters belong to?
4. Which classes do parameters belong to?

Query 1 is a measure of general interest for a particular parameter. If the answer to query 2 is a non-empty parameter set, these are serious candidates for removal from on-board instrumentation. Query 3 helps identifying which engineering areas need to be involved for negotiating instrumentation configuration changes and query 4 what parameters could be used for balancing resource limitations.

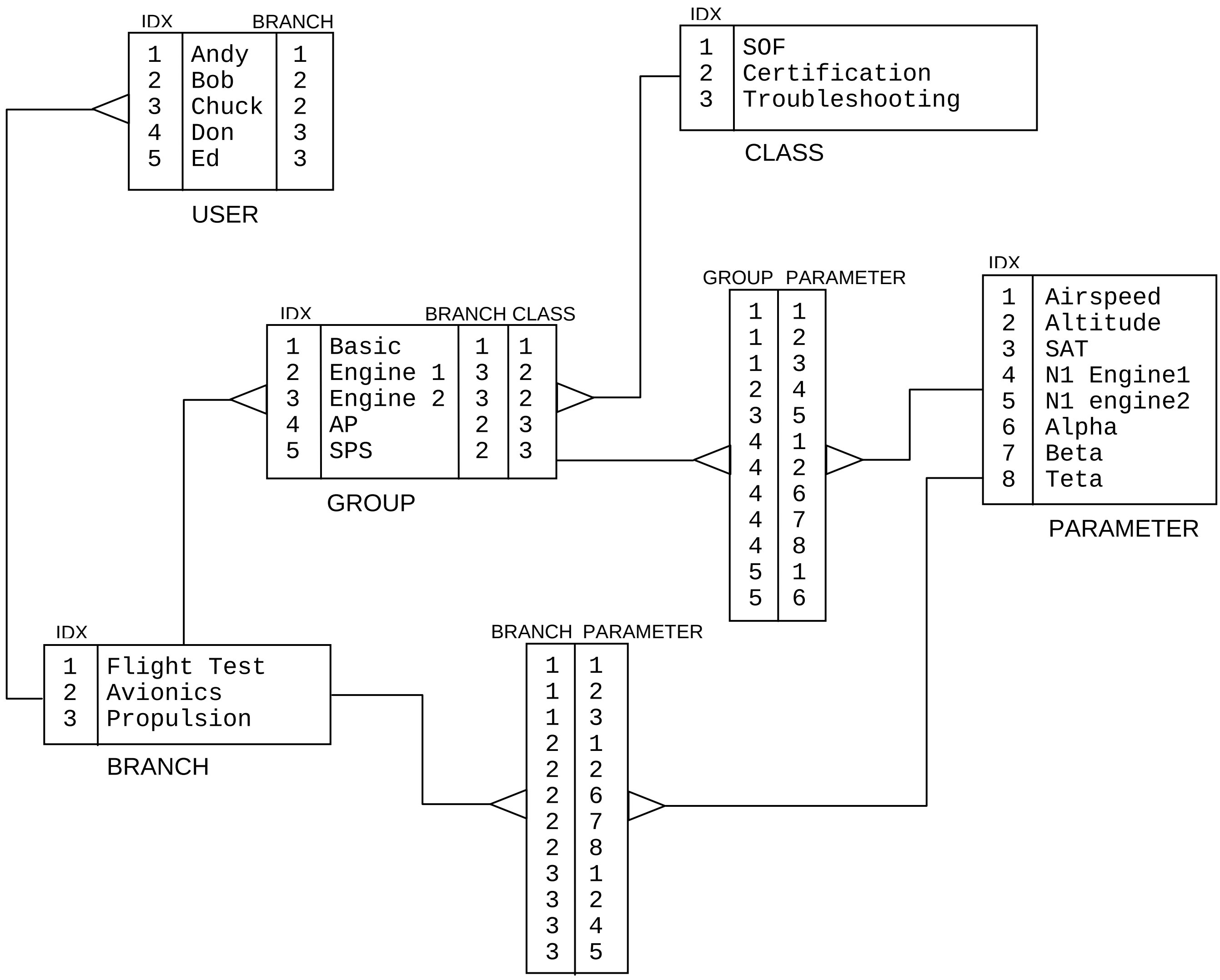


Figure 1 – Proposed Data Model for Parameter List Management

Using Parameter Groups in Data Acquisition

In Ethernet-based on-board data acquisition systems [1] [2] [3], parameter samples are collected in data structures called “datagrams”, packets of data exchanged by network nodes. In such systems, datagrams are built in real-time, time-tagged and sent to a fast switched network for processing in one or more digital computers dedicated to data visualization in a monitor screen, data recording in a mass-storage device, PCM formatting for telemetry purposes, etc.

Since datagrams in this context are also an organized collection of test parameters, does the data model presented in the previous section help their generation and processing?

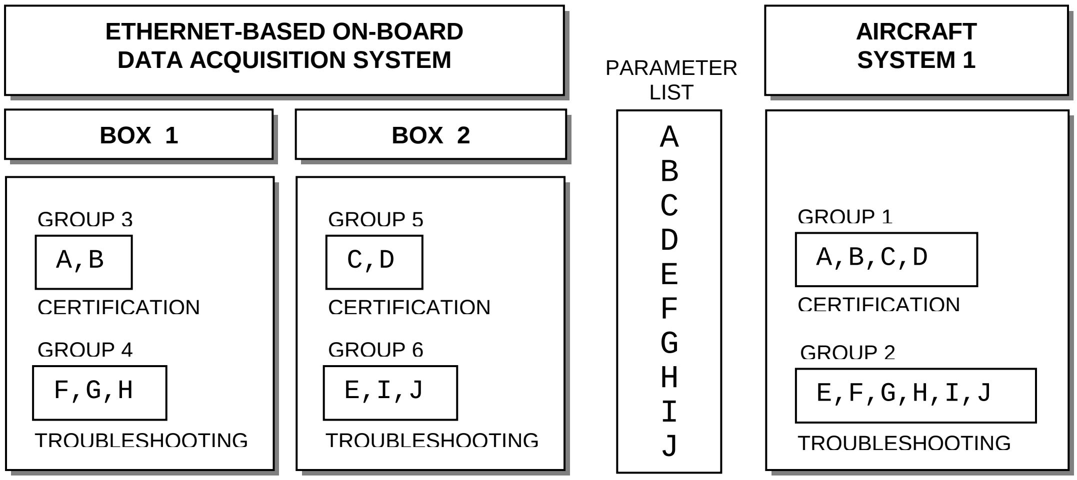


Figure 2 – Parameter Groups in Data Acquisition

Figure 2 suggests a basic parameter set “A-J” that, under the perspective of “Aircraft System 1”, associates parameters “A-D” in “Group 1” of class “Certification”, and parameters “E-J” in “Group 2” of class “Troubleshooting”. The same basic parameter set, under the perspective of “On-Board Data Acquisition System” associates parameters “A-B” in “Group 3” and “F-H” in “Group 4” for “Box 1”, “C-D” in “Group 5” and “E;I-J” in “Group 6” for “Box 2”. Note that classes remain consistent across groups, so parameters belonging to a group of class “Certification” belong only to groups associated with the same class.

“Datagrams” could be created in direct association with “Parameter Groups” under the perspective of an Ethernet-based on-board data acquisition system, preserving certain granularity resulting from the fact that parameters are acquired in small, box-shaped, pieces of hardware.

Parameter groups of different classes could form datagrams that could be routed to different processing nodes in the network. Figure 3 suggests that all datagrams transmitted by the on-board data acquisition system are routed to a test data recording node, but only datagrams formed after groups of class “SOF” and “Certification” are routed to a telemetry formatting node. In the same scenario, if there is enough control in network routing algorithms, some datagrams formed after groups of class “Troubleshooting” could be eventually re-routed to the telemetry-formatting node in an emergency case.

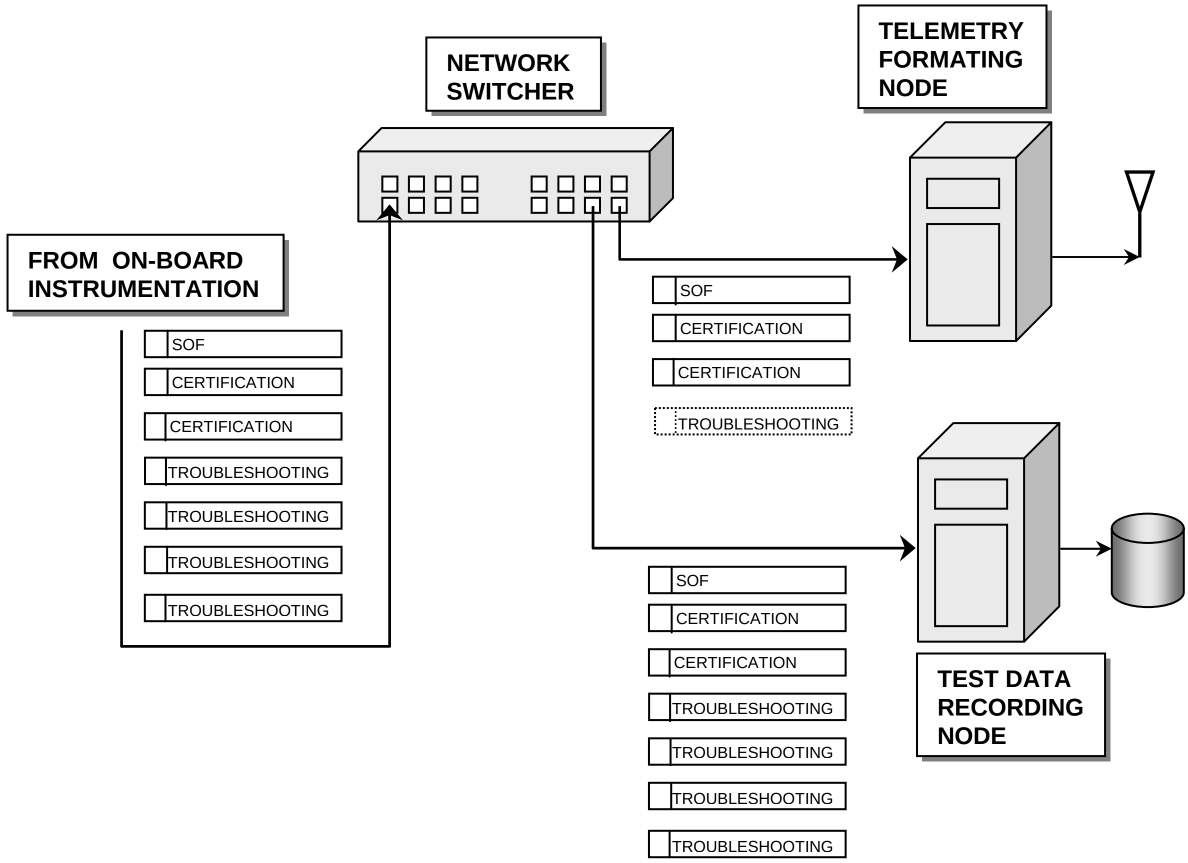


Figure 3 – Datagram Processing by Group Class

Using Parameter Groups in Data Processing

Datagrams transmitted by Ethernet-based on-board data acquisition systems and received by computers attached to the same network require very fast processing to minimize delays in data manipulation. One approach for efficient processing of datagrams is to use a datagram identification field to index run-time libraries of processing routines coded to manipulate parameter samples extracted from datagram payload.

These processing routines could take advantage of the same data model structure ("Parameter Group") used to create datagrams, as suggested in the previous section, to guide the assembly of these run-time libraries, so a particular set of processing routines could be uniquely assigned to process a specific parameter group contained in a specific datagram, independent of how datagram data is made available, either by receiving a network transmission, or by reading from a hard-disk file.

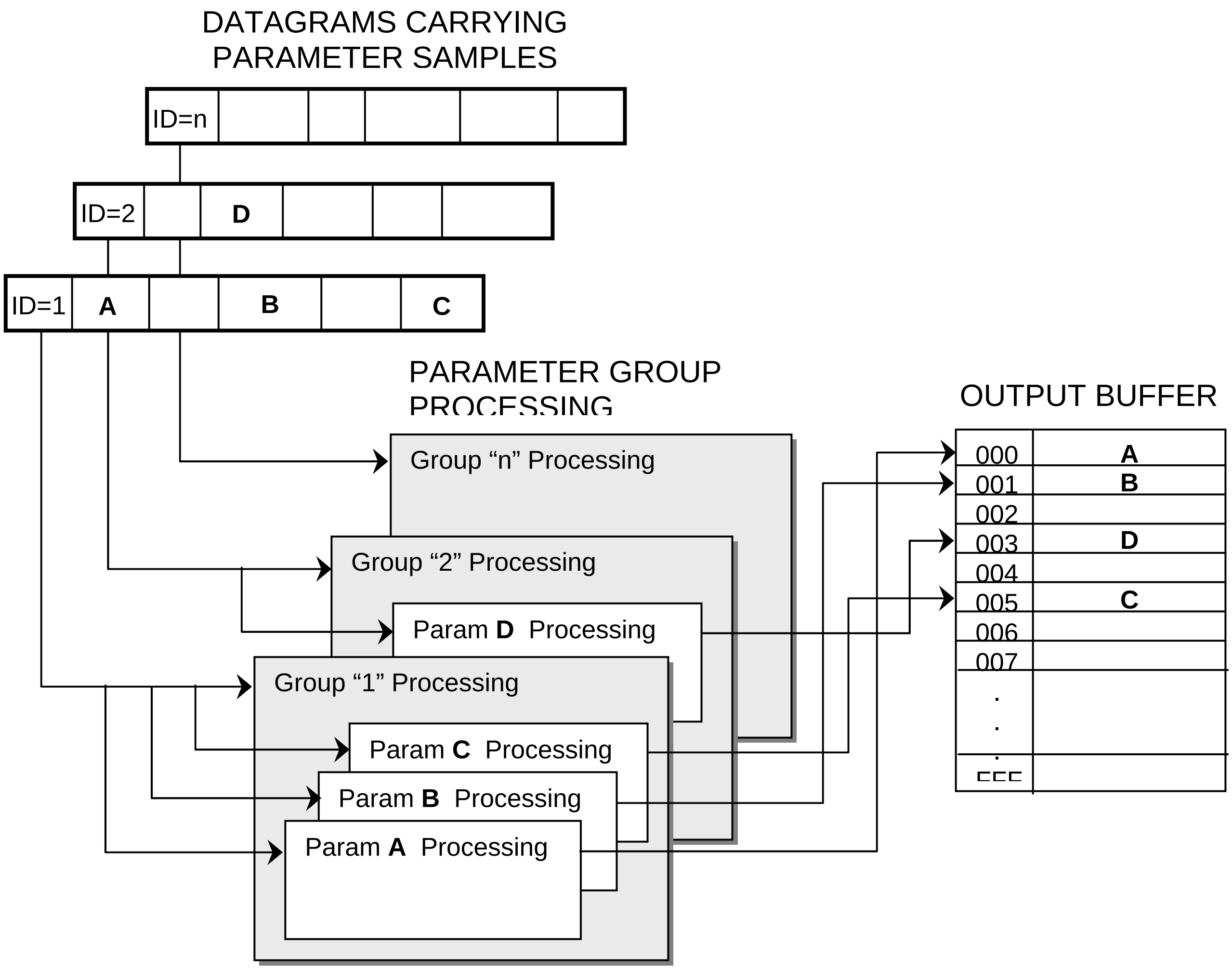


Figure 4 – Datagram Processing by Datagram Identification

Figure 4 suggests a sequence carried out in a computer capable of processing datagrams transmitted by an Ethernet-based on-board data acquisition system. Each datagram received by this network node is vectored through a set of run-time library routines that extract parameter samples from datagram payload, process and copy the results in an output buffer. This output buffer could be either a reflective-memory buffer used for data display in other network nodes, or could be a buffer built for recording in a hard-disk file.

Conclusion

The previous sections tried to demonstrate how logic associations of test parameters in entities of a higher hierarchical level such as “Parameter Groups” could facilitate a few aspects of parameter data handling in a flight-testing environment.

Benefits of this construction in managing a very large parameter installation were addressed and the direct association of parameter groups with datagram construction in Ethernet-based on-board data acquisition systems and datagram processing was established.

Although a complete discussion on the subject exceeds the context of the present paper, one extension to the presented data model is worth mentioning.

“Parameter Group” is a single level of hierarchy above “Parameter”. In a multiple thousand parameter installation, this may be insufficient for indexing the whole collection of test parameters. As in other indexed file structures, more than one index level may exist, so “Groups of Parameter Groups” could also be formed. In such scenario, parameters could be addressed by text structures similar to file paths, for instance: “Engine1\FADEC1\N1” and “Engine1\FADEC2\N1”, or “Engine2\FADEC3\N1” and “Engine2\FADEC4\N1”. This naming convention has more information content than the usual short mnemonic text, but may be limiting in some contexts, in particular when designing man-machine interfaces (they naturally become more complex).

Dealing with ever larger parameter installations is a constant challenge to flight-test people, and it will remain so until the next technology wave comes in.

References

[1] D. Corry – *Building Bridges: Linking CAIS to Ethernet and other protocols*, ETTC Proceedings, 2003

[2] N. Revaux, F. Abadie – *A380 Flight-test architecture: Switched IENA*, ETTC Proceedings, 2003

[3] J. Dai, E. Grozalis, T. DeSelms – *An Ethernet Based Airborne Data Acquisition System,* ITC Proceedings, 2003

FROM 0.5% TO 0.05%: ACHIEVING NEW LEVELS OF SENSOR ACCURACY IN AN AIRBORNE ENVIRONMENT

Paul Sweeney Ph.D.
ACRA CONTROL

Abstract:
With recent improvements in data acquisition technology, it is now possible to use an FTI data acquisition system to measure analog signals with a total error from all sources of less than 0.05% - over an extended temperature range - and at high sample rates. This accuracy a factor of 10 times better than legacy systems and is better than one count of an old 10-bit system. This includes non-linearities, initial errors (in gain, offset and excitation) and drift errors, simplifying the task of interpreting data acquisition system performance specifications.

This paper looks at some practical steps taken to achieve this accuracy, from a hardware design and signal processing perspective. This leads to a discussion of implications for the FTI system designer, including: sensor and wiring specifications, sample rate, filtering specifications, and a discussion of implications for the data processing engineers.

Keywords:
Analog accuracy, data acquisition, FTI

Abbreviations:

A/D	Analog to digital converter
D/A	Digital to analog converter
FTI	Flight test instrumentation
SINAD	Signal in noise and distortion
THD	Total Harmonic Distortion

1 INTRODUCTION:

At last years conference ACRA CONTROL gave a paper on specifying the next generation airborne data acquisition systems. This paper suggested a minimum set of specification for analog FTI modules. One of these was specifications was "Total DC error" which should include all gain, offset and non-linearity errors over the full temperature range and including the excitation.

This paper looks at some of the techniques developed at ACRA CONTROL for our next generation calibrated series of analog modules that achieve total errors of better than 0.05% FSR over (and above) the industrial temperature range.

2 BACKGROUND

To give some idea of the task facing a designer aiming for a total error of better than 0.05% from all sources over temperature it is interesting to note that a single device with a 10ppm/°C drift with temperature can drift by ±0.08% ((100° - 25°C) x 10ppm).

In older systems with multiplexers a specification of 60dB crosstalk can hide a 0.10% dc error depending on the dc value in other channels.

Another example is a "good" instrumentation amplifier might have an initial gain error of ±0.05% at 25°C and a gain drift error of ±0.1% (worst case). If this is connected to a bridge whose excitation has similar errors than the total error can be as high as ±0.3%.

This (0.3%) is six time greater than the target (0.05%) and we have yet to include in the error budget analysis

Gain and offset errors in A/D
Gain and offset errors in gain and offset adjust block
Offsets in the instrumentation amplifier
Non-linearities in all the above
Loading compliance issues on all the above

From the above it might appear that Total Dc Error from all sources over temperature of even 0.5% is ambitious enough without aiming for 0.05% over an extended temperature range of -55 to +105°C.

The next section outlines five steps taken to achieve just that.

2 FIVE STEPS TO 0.05% TOTAL ERROR FROM -55 TO +105°C

STEP 1 Use the minimum amount of analog components

All analog components drift with temperature and time and loading. To achieve 0.05% it is essential that as much processing as possible be done digitally. This includes filtering, offset and gain adjust.

An anti-aliasing **filter** will always be required but if the digital processing over-samples and decimates then a simple, low order, fixed filter can be used with the cut-off frequency set so high that drifts do not effect the bandwidth of interest.

If the A/D range is chosen correctly there is no advantage to analog **offset adjust**. Digital offset adjust not only saves on components but allows for larger adjustments at larger gains.

Digital **gain** adjust allows for infinitely more choices of range and saves on components but is limited to a range of circa 1 decade (a factor of 10 or 20dB) because non-linearites and offset drifts are amplified linearly.

STEP 2 Use a good architecture

The KAM-500 allows for distributed processing on each module. In particular there is an A/D per channel with the A/D close to the filter and this together with the processing is all on one PCB.

There are no analog multplexers. This removes the 60dB crosstalk (0.1%) and associated switching currents.

No analog signals on the back-plane allows a single star point between the analog and digital planes, allows analog tracks to be kept short and orthogonal to and digital tracks. In particular on KAM-500 modules analog components and digital components are on opposite sides of the PCB with ground planes in between.

Another advantage of distributed (FPGA) processing is that, if required for exceptional low-noise applications, data processing with respect to the A/D's operation can be strictly controlled to minimise noise.

Not only is the processing distributed but so is the calibration information, having an EEPROM on each module allows calibration information (see below) to be stored on each module for each channel and excitation.

One final trick is to have on each module a temperature sensor so that temperature drifts can be compensated digitally (see steps 4 and 5 below).

STEP 3 Use good analog components
After steps 1 and 2 we are left with excitation, instrumentation amplifier, a simple filter and an A/D. These components must be chosen carefully.

The A/D must be at least 16-bits, especially if processing includes gain. To keep the filter simple and fixed the A/D must be able to sample at many times the highest sample rate and have excellent linearity (and THD) figures across the full bandwidth. For linearity Sigma Delta A/D are an obvious choice but they have a very low output sample rate and tend to have poor drift and repeatability figures. With the calibration discussed below the most important specifications for the A/D are low the gain and offset drift with age and temperature.

Instrumentation amplifiers need significant testing as often their are trade-offs such as THD (for good ac accuracy) v.s. low bias currents (for good ac accuracy).

Capacitors are not so important for dc accuracy but tend to cause big problems with ac accuracy unless they have very low THD (e.g. NPO types). Today resistors and references are available with 0.01% accuracy and drifts of less than 10ppm. However with calibration against temperature (see below) the ageing drift specification is again very important.

After the components are selected it is vital that extensive non-linearity and repeatability (power on/off, temperature hysteresis and accelerated ageing) tests be carried out. This is important, as calibration will not improve these errors.

STEP 4 Calibrate the signal conditioning against temperature
Once the board is designed and the components tested for INL, temperature and power hysteresis and repeatability the next step is to allow for calibration of gain and offset vs. temperature.

Each module is cycled twice over temperature and the gain and offset of each channel is calibrated at each gain setting with multiple of reading at the input. These values are then used to tweak the gain and offset as a function of temperature.

The calibration values are stored in EEPROM on each board and the gain and offset is then tuned in real-time as a function of the board's temperature.

Care must be taken so that enough temperature points are chosen so that the reading does not appear to "jump". For example if the gain changes by 0.10% over the temperature range than at least 5 temperature points are required to keep gain jumps within 0.02%. The KAM-500 calibrated series modules use 125 temperature points.

STEP 5 Calibrate the excitation against temperature

Excitation errors are often neglected when doing an error budget. An excitation error of 0.10% in the excitation for a bridge will cause an error of 0.10% in gain.

The strategy used on the KAM-500 calibrated series of A/D modules is to use a low drift high-resolution D/A to set the excitation voltage or current. The D/A setting gives the lowest error at 25°C then any remaining error or errors with temperature are adjusted as part of the gain compensation with temperature.

3 IMPLICATIONS OF THIS TYPE OF ACCURACY

This section outlines some of the lessons learned during acceptance testing with customers of some of the calibrated series of A/D modules.

3.1 Lessons learned during acceptance testing

3.1.1 Have Patience

One customer, using a highly reputable programmable PT100 simulator that was fine for older FTI equipment, found that when testing for this type of low error tolerances discussed had to wait 30 minutes for the simulator to warm-up before taking measurements.

3.1.2 Use sense lines

Another test that was fine for older FTI systems had to be modified so that sense lines could be used with the test voltmeters and ohmmeters.

3.1.3 Just because it changes does not mean it is drifting

One customer expressed surprise that error specifications were being met even though the excitation when measured using a voltmeter seemed to be outside the stated accuracy specification at 105°C.

It was then explained that the excitation was not adjusted with temperature but its effects were. In other words the gain was adjusted not the excitation.

3.1.4 Do not calibrate for excitation unless it is being used

One user found that a module worked fine with a bridge but was less accurate when a simple differential ended analog signal was applied.

The problem here was that the gain was being adjusted to compensate for the excitation that was no longer being use. One the module was reprogrammed for voltage input it was fine.

3.1.5 Understand SINAD, THD, SNR and the noise from the test equipment

Another problem with high accuracy systems is that noisy test equipment is more obvious. The PT100 simulator mentioned above was fine when the module under test had its filter cut-off frequency set near dc. When it was set for a bandwidth of 100s of Hz the noise was considerable. The simulator manufactured knew this and correctly argued that temperature changes slowly.

3.2 Implications for use in the field

3.2.1 Think carefully about calibration in the field

Older FTI systems boasted about short insertion or voltage insertion (ZCAL, VCAL etc) which enabled calibration in the field. Both these methods are for calibrating the test equipment (not the sensor!) and are no longer required with instrumentation like the calibrated series. As a matter of fact introducing the circuitry to do this will cause greater errors then it will correct!

However the next generation analog module should still support **sensor** calibration (as opposed to **instrument** calibration) via pseudo-shunt or similar techniques.

3.2.2 Consider using 16-bits and forget about tweaking the range

For many applications 0.05% is far more than what is required. For example it can be argued that a strain gage sensor alone has errors 10 times greater than that even before it is connected to instrumentation.

However one powerful feature of highly accurate 16-bit FTI systems is that, rather than balancing 1000s of sensors in the hope of getting the optimum range and gain for 12-bit systems, a single range can be chosen for all.

For example rather than use a gain of 64 and 10-bits, transmit 16-bits and a gain of 1. Not only does this mean that over-shoot and under-shoot data can be observed but it cuts down considerably on the processing information for each channel that must accompany the archived data. In other words rather than store the actual gain and offset used for each channel - simply have the rule that the gain was always one and the offset zero.

At first glance it appears that the error for such a scenario would be 64 x 0.05% (3.2%) but typically it would be much less as the excitation and gain errors do not change with gain, only offsets and non-linearities.

4 CONCLUSION

The next generation analog flight test instrumentation modules, such as the KAM-500 calibrated series will have total dc errors from all sources over all temperatures of better than 0.05%.

To achieve this the minimum amount of analog components must be used along with a distributed architecture that allows for processing and calibration on the module - not centrally.

Also some care has to be taken when acceptance-testing modules with this level of accuracy.

However there are many advantages to having 21st century accuracy not only because it allows greater freedom in terms of range settings but also the extra Dc and **Ac** allow the aircraft computer models to be refined.

INTERACTIVE ANALYSIS AND DISPLAY SYSTEM (IADS)

Eileen Suszek and John Bretz
SYMVIONICS, Inc.
Arcadia CA

ABSTRACT

The Interactive Analysis and Display System (IADS) provides the test engineer with enhanced test-data processing, management and display capabilities necessary to perform critical data monitoring in near real-time during a test mission. The IADS provides enhanced situational awareness through a display capability designed to increase the confidence of the engineer in making clearance decisions within a Mission Control Room (MCR) environment. The engineer achieves this confidence level through IADS' real-time display capability (every data point) and simultaneous near real-time processing capability consisting of both time and frequency domain analyses. The system displays real-time data while performing interactive and automated near real-time analyses; alerting the engineer when displayed data exceed predefined threshold limits.
The IADS provides a post-test capability at the engineer's project area desktop, with a user interface common with the real-time system. The IADS promotes teamwork by allowing engineers to share data and test results during a mission and in the post-test environment. The IADS was originally developed for the government's premier flight test programs. IADS has set the standard for MCR advancements in data acquisition and monitoring and is currently being integrated into all the existing MCR disciplines.

INTRODUCTION

The Interactive Analysis and Display System (IADS) is being developed by SYMVIONICS, Inc. software engineers to increase the efficiency of the mission testing process. The mission test engineers in the Mission Control Room (MCR) primarily monitor data for safety-of-test considerations and for data quality; the data is later evaluated to determine test vehicle specification compliance. The IADS provides the engineer with advanced data organization, processing and display capabilities, both in the MCR and at the office desktop.

Previous real-time analysis systems were very time consuming and limited, so most of the testing analysis was conducted in a post-test environment. At critical test conditions, real-time clearance decisions came very slowly by using analysis techniques designed for a post-test environment. Stripcharts were the main tool for displaying time domain data. An analysis system running on one independent workstation provided spectral analyzer tools such as real-time power spectral density (PSD) and Nyquist plots. For loads testing, Stripcharts were used as the primary data display source. In many cases, loads analysis decisions required the engineer to hand plot peak loads from the Stripchart time histories onto paper cross-plots containing design load limit envelopes.

The primary source of post-test data for the engineer was analog tapes processed after the completion of the test mission. This process introduced delays into the test-point clearance process, ranging from several hours to days. The engineers are now being faced with program objectives, which require much higher mission test efficiency rates than in the past, and these rates cannot be supported with the previous analysis systems. The engineers need to make quicker clearance decisions based on more detailed MCR analysis, and analysis results obtained during the test mission must be made available to the engineer at the desktop within a short period of time after the mission.

In response to these needs, the test community developed a set of operational requirements for the next generation of test analysis systems. The IADS has been developed to meet these requirements. The purpose of the real-time IADS is to provide the engineer sufficient resources within the MCR to allow enhanced safety-of-test monitoring and advanced near real-time analysis capabilities to support test-point clearance decisions in a timely and efficient manner. What was once considered standard post-test data processing is now being accomplished during real-time. Results computed during a real-time test can also be transferred to the engineer’s desktop and used with IADS in a post-test environment. In post-test, data for the entire mission can be reviewed an analyzed and compared to results gathered in real-time. This paradigm provides an integration of real-time and post-test which reduces overall mission time. In addition, post-test is not limited to a review of the data, but can simulate an actual playback, allowing the engineer a flexible data environment and providing a realistic MCR training tool for new personnel.

The IADS allows the engineers to transport selected Engineering Unit test data from the MCR back to their desktop for use in post-test analysis. The requirement to obtain data from the aircraft tape before next-mission clearance is no longer necessary. Rather, the engineer will use data collected in real-time to make timely analysis decision and then transport the data to the post-test IADS for a final check, for next mission clearance decisions (quick-look) and/or as a means of data archiving. Aircraft tape data will be used only to supplement the data collected in real-time, and the amount of data requested from the aircraft tape will be significantly reduced, thus saving time and money.

SYSTEM OVERVIEW

Efficient data organization within the IADS is essential to support the analysis and display capabilities described previously and to provide the engineer with the flexibility in what is brought into and carried away from the MCR. The IADS **stores every data point** and provides integrated **full scroll back capability**. The workgroup may use this storage to transport test data of interest, user configurations, and other necessary data from the MCR back to their desktop for further analysis. The post-test IADS provides the engineer with additional data organization and archival, allowing the engineer access to all of the data accumulated during the entire test program.

As previously discussed, the IADS is comprised of two primary configurations: real-time and post-test. For each configuration, the IADS has an architecture which combines both data-driven and client/server elements. Each of these configurations provides consistent capabilities through common software and hardware.

Real-Time

The primary real-time data path through the IADS, from acquisition through display, is data driven. Data is sent from the Telemetry Preprocessor to the Caching Data Server, where it is stored, and buffered. The data is simultaneously available to the Display Workstation for presentation to the engineer. The engineer may also initiate near real-time analysis requests from the Display Workstation utilizing the stored data. Analysis requests are computed at the Display Workstation. Data latency is less than ¼ second from the test vehicle to the Display Workstation.

The IADS uses raw telemetered data that has been converted to engineering units. The IADS can hook to several commercial off the shelf (COTS) data telemetry products.

- Current COTS Data Source Interoperability.
  –L3 Comm. 550 telemetry processor (Telemetry).
  –L3 Comm. O/S90 telemetry processor (Telemetry).
  –Veridian Omega 3000 telemetry processor (Telemetry).
  –NASA Dryden Mission Simulators (F-18 AAW and C-17).
  –AFFTC TEMS Mission Simulators (F-16, X-32).

As shown in Figure 1., IADS real-time configuration consists of three major components: Caching Data Server, COTS Network, and Display Workstation.

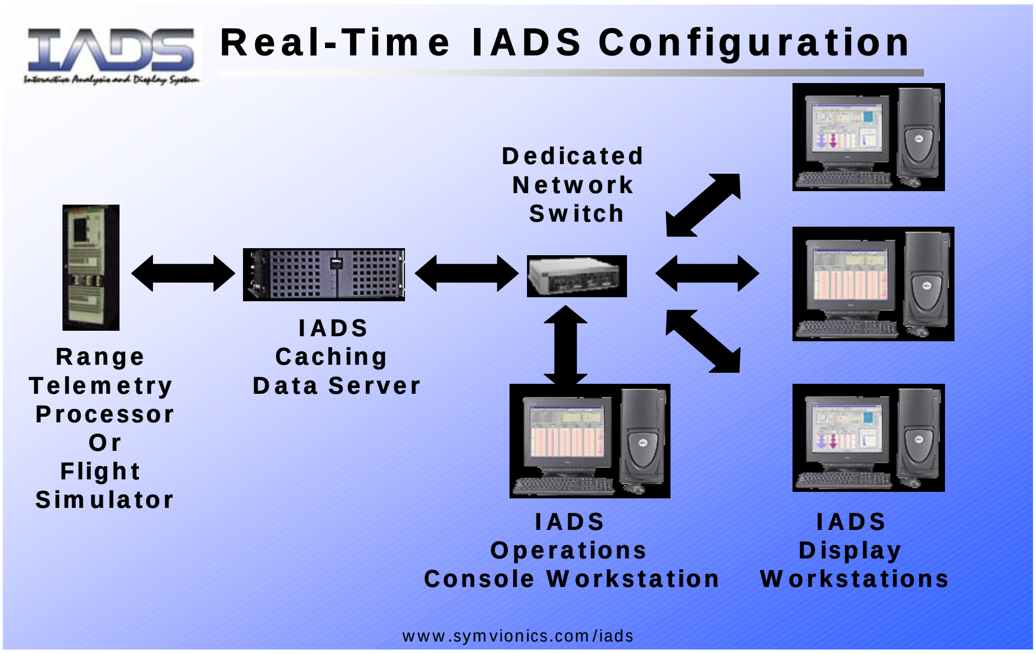


Figure 1. The Real Time IADS System Architecture

The Caching Data Server (CDS) provides the data management capability of IADS. The CDS is a multi-processor high-performance Windows-based computer, which supports both the real-time data processing needs and post-test data storage needs of the IADS. Only the data being used is archived, thus saving system space. The IADS records (saves) every data sample it receives. The CDS retains the information requested by the engineers for future analysis. This data, along with setup information, is transferred to the post-test configuration via removable media or storage area network (SAN). This data is then available to the IADS workstation for use in a post-test environment

A COTS Network provides the distribution of real-time date to the Display Workstations from the Caching Data Server. The IADS data distribution software is designed such that it may be modified to use any packed-based technology.

Display Workstations provide the graphics and user interface to perform real-time processing. Windows NT/2000/XP workstations are used for the both the real-time processing and the post-test configuration.

Post Test

The post-test IADS processes the stored data files in a client-server fashion. Each IADS Display Workstation can function as both a client and a server simultaneously (Figure 2). This allows the engineer to access all data of interest, even if another engineer is viewing that data. The data can be stored on CD Rom/Jaz Drives or removable SCSI drives, SAN, depending on the storage requirement of the data. The IADS post-test data server de-compresses the data and places it on your local Display Workstation's hard drive. The data is accessed through the same IADS software interface that is used in real-time.

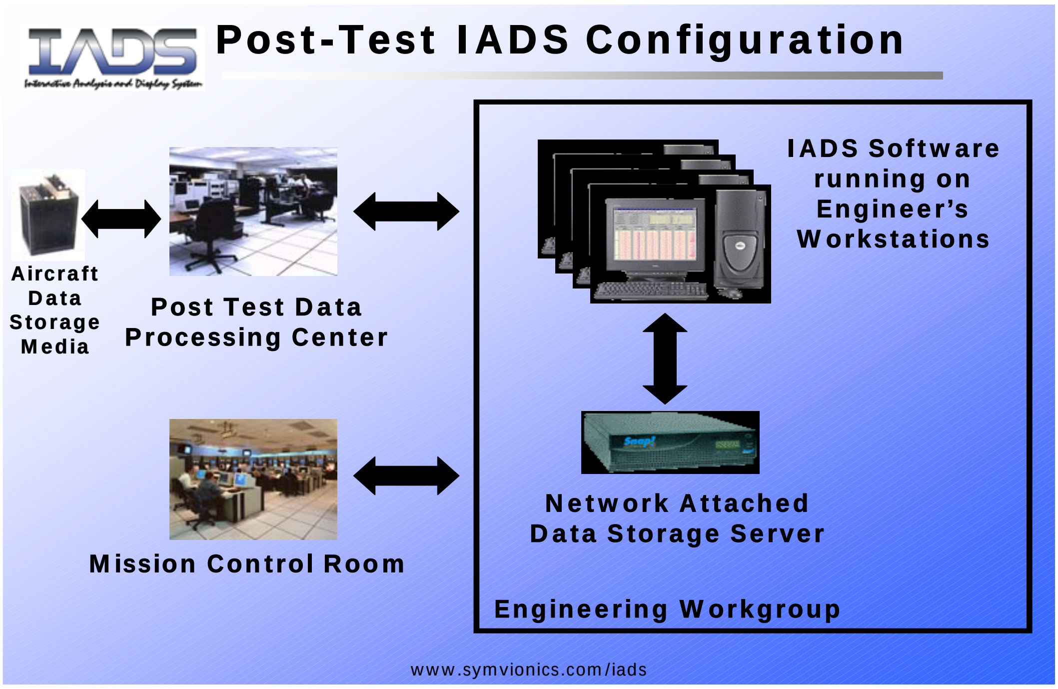


Figure 2. The Post Test IADS System Architecture

CAPABILITIES

The IADS is designed to support an engineering workgroup concept. In this concept, a group of engineers from the same engineering discipline share the configuration during a mission. The IADS provides both group and individual support to the workgroup. For example, digital filtering defaults are set at the group level, but may be modified by each individual engineer. The IADS organizes the test data so that each engineer may monitor a specific set of data, but the data is removed from the MCR at the workgroup level. Each engineer may perform their own data analysis, but all engineers within the workgroup have access to the entire groups results.

Currently, the IADS is sized to support 50 engineers simultaneously, providing the following capabilities:

- Avionics
  - -1553 Bus Monitoring
    - -Fault Reporting Codes
    - - Integrated cautions, advisories and warning (ICAW), the ICAW function bit (ICFB)
- Loads
  - -Cross Plots
    - -Data History Tail
  - -Capturing Data Load Limits
  - -Slider Displays
- Flutter
  - -Time Domain
    - -Noise Reduction Methods
    - -Frequency and Damping Results
    - -Time History Curve Fit
  - -Frequency Domain
    - -Half Power Damping
    - -Root Means Square Selective Area Sum/Peak
  - -Transfer Functions
    - -Frequency Response Plots
    - -Nyquist Plots
- Data Editing
  - -Wild Point Editing
  - - Spike Detection/Correction
  - - Digital Filtering
- Logs
  - -Thresholds
  - -Event Markers
  - - Data Point Selections
  - - Analysis Results
- Dynamic Drawing Package
- System Displays
  - -Stripcharts
  - -Numeric Displays

-Streaming Video/Audio

- Active X Controls
  -Custom Displays
    AIM-9 Display
    Aircraft Models
- COTS
  -Export to Matlab
  -Export to Excel
  -Data Views

As described in more detail in the following sections, the IADS provides the engineer with capabilities in the areas of analysis, display, data organization, and data export.

Analysis and Display Capabilities
The IADS provides capabilities to the engineer at the workgroup and individual level and with a display tool set optimized to aid in the task of data analysis and data monitoring. The IADS displays the test data in a format, which allows the engineer to efficiently, and confidently make test point clearance decisions. This display tool set includes high fidelity time history displays eliminating the need for strip chart recorders. The engineer can fully interact with the time history display to freeze and scroll back in time, zoom, annotate/mark events and select data points on which to perform requested analysis or export data. These interactive capabilities are available through drag and drop, toolbars, mouse selections, and menus. The IADS analysis capabilities include algorithms for both time and frequency domain processing, in real-time and near real-time. The engineers may choose to use the workgroup level settings for the system or may chose to override these with their own settings, including digital filtering, sample rate decimation, derived equations, data export, parameter threshold limits, and parameter scaling. The engineer may also change display types, change the size of an individual display, or drag and drop new parameters into existing displays, all of which can be performed dynamically in real time. The engineer may perform analysis on real-time data from the current test-point or on data from previous test points within the current or previous missions (post-test). The engineers may combine their analysis results with results from others within the workgroup. The engineers may monitor real-time parameters or they may chose to freeze a set a parameters and perform more detailed analysis.

Avionics – 1553 Bus Monitoring – The *IADS Fault Reporting Codes (FRC)* display is used to monitor failure reporting code data and (to a limited degree) determines vehicle system performance. The FRC also has a filter file that allows the engineer to setup multiple tabbed displays, filtering only the data on interest for that FRC. The engineer has the option in real-time to create a log of the reporting code data that can be transported back to the desktop environment.

Integrated Cautions, Advisories and Warning (ICAW), the ICAW function bit (ICFB) display is used to monitor the health and status of a test vehicle during a mission. It will show the ICAW messages associated with a parameter and bit number, and the time elapsed since the event was triggered. When a warning, caution or advisory event occurs, the message associated with that parameter will become highlighted with the appropriate color as defined in the ICFB input file. Any parameter that shows an ICAW message is forwarded to the top of the table for easy recognition. A log file is created that records the event and the time that it occurred. This log file is available for post-test analysis within local applications.

Loads – Cross Plots –The IADS provides a method of adding and displaying multiple envelopes. Load limit calculations dynamically track the user defined design load limit for the data. Data points (including a data history tail) can be logged within the IADS or exported to other COTS products

Slider Display, a bar-type display that presents a one dimensional load limit. A change in the data is represented by the movement (sliding) of a caret along the bar. Percent and peak Load Limit are constantly tracked on the display and can be "logged" for later recall and use.

Flutter – Time Domain – The IADS offers several powerful methods to average out noise (leaving only the transient response) from data and extract frequency and damping results. To extract frequency and damping information, averaging techniques can be employed to average out the noise, leaving only the responses modes of interest that have sufficient energy present in the time history. The IADS offers Randomdec, Pseudo Randomdec and Auto Correlation as a means of averaging out noise. The IADS automatically logs frequency and damping results for quick recall of desired data.

The IADS uses the following time-domain algorithms to extract frequency and damping for impulse responses that are dominated by a single mode: The *Log Decrement* algorithm is used to from a decaying sinusoidal where one mode is present, The *Log Decrement Averaging* algorithm is used from a decaying sinusoidal where one mode is dominant, and the *Log Amplitude Picking* is used from a decaying sinusoidal that does not display a clean exponential damping envelope.

The frequency response parameters from multiple modes of data can be obtained by curve fitting *Time History Curve Fit* is a method used to calculate frequency and damping from a decaying time history where more than one mode is present in the signal.

F*requency Domain* data are derived from time history data where near real-time calculations convert the data from the time domain to the frequency domain. These displays are driven by calculations of real-time time history data, or by calculations made from frozen time history data. Additional editing functions like adding spectral lines, frequency averaging, and windowing are also available.

The *Half Power Damping* algorithm is used to extract frequency and damping from frequency domain data. Sweep response data and random excitation response data can be evaluated with this algorithm.

The *Selective Area RMS* algorithm computes the RMS of a parameter over a specified frequency range. It can be used to exclude static loads from RMS computations (without using filters) and can help determine the true magnitude of a "leaky" frequency component.

Frequency Response Plot is a dual plot of various properties of the Frequency Response function. The engineer can create Phase & Imaginary, Phase & Real, Phase & Magnitude, Phase & Gain, Coquad, and Bode plots. Phase and gain margin are used to evaluate the stability of a system given its frequency response function. The *Nyquist Plot* is a rectangular/polar plot of the Frequency Response function of a system. The real and imaginary parts (rectangular) of the Frequency Response function are shown directly.

Data Editing – Wild Point Correction – A Wild Point is a data dropout or spike that might adversely affect the analysis and comparisons of the data to test limits. Wild-Point checking is accomplished for data loss, data spikes, and loss of synchronization. The lost or bad data is replaced with a default value that the engineers specify.

Spike Detection/Correction is typically used to automatically correct single spurious data points to prevent discontinuities in downstream processing such as data filtering. The IADS offers two detection methods, absolute change spike detection and slope change spike detection.

A *Digital Filter* is a computational process or algorithm that transforms a discrete sequence of numbers (input) into another discrete sequence (output) having a modified frequency spectrum. The IADS offers discrete IIR filters (Butterworth and elliptic) with Low Pass, Band Pass, and High Pass responses.

Logs – The IADS offers a variety of logs store events and analysis results. The engineer can select and log single and multiple points of interest within the data and recall these points at a later time. Each time an analysis is performed the results (along with statistical information regarding the data) are written to the IADS logs. The logs are flexible enough to allow for manual entries/deletions and imports/exports.

Thresholds allow the engineer to log statistical data information when a numerical value in the data is met. Once the statistical information is logged, the engineer can retrieve the data of interest in one step. This logging of events is an effective means of looking at specific data of interest based on an exceeded threshold.

Marking an Event of interest is a single button click in the IADS; a visual marker is placed on all the Stripcharts and Cross Plots viewed by the user or by the group (optional). Statistical information is logged for each event and can be quickly retrieved in both real-time and post test. The engineer can move from event to event with a button click. This tool is highly effective for looking at specific areas of interest within the data.

Individual *data point selections* can be logged and recalled with a single button click. This gives the engineer that ability to log a single data point of interest vs. a time of interest. Point selection and any statistical information regarding the data, i.e., filtering, etc., are logged per display.

Analysis results are automatically logged for each parameter where analysis results are obtained. These results can then be quickly accessed for further review.

The *Dynamic Drawing Package* provides capabilities similar to DataViews™, and SL-GMS™. This drawing package provides many familiar drawing primitives such as text, lines, circles, squares, triangles, meshes, and pictures. The drawing package has many powerful properties to enhance a display’s appearance such as rotation, translation, scale, extrusion, outlining, bitmap fill, gradients, color keying, and transparency blending. The drawing package offers the flexibility of graphically modeling systems or grouping the drawing primitives to form new displays. The engineer has the ability to dynamically change any property using the data. As with all IADS displays, scroll back works with these drawing primitives as well.

System Displays – Stripcharts – The IADS provides Stripcharts that emulate paper Stripcharts in form and function. The data is represented as a parameter trace. You can create vertically and horizontally oriented Stripcharts with a simple drag and drop function. The IADS Stripchart has the capability of presenting the engineer with a variety of options and does not limit the number of Stripcharts that can be created. Some of the many features include, multiple pens can be added to a single chart, thresholds can be set, data can be wrapped or the scales adjusted automatically. The engineer can change the grids, chart speed, paper length and even the paper color.

The IADS also offers several different types of *Numeric displays*. Annunciators track data numerically and show color changes when a threshold limit is met. Alphanumeric displays can represent the data as letters or numbers. The Alphanumeric Table represents data in a table format. Each of these displays can track data in a variety of ways; minimum/maximum values, latitude/longitude, etc. The displays can track range of data changes, Boolean equations, table lookup or interpretation or numerical equations.

Streaming Audio and Video displays allow the user to input video as a file and audio as a parameter. The audio player currently plays either raw Pulse Code Modulator (PCM) or Continuously Variable Slope Delta (CVSD) data input. The engineer can listen to the audio and watch the video of a test in both a real-time and post-test environment.

Active X controls are custom displays that the engineer can create or download from the Internet and use within the IADS application. IADS offers a variety of stock Active X controls; altimeter, eight ball, heading indicator, horizontal situation indicator, stick force, ADI, various aircraft models (F-16, F/A-22, T-50, C-5, C-30, etc.). Active X controls can be dynamically added, so the engineer has the flexibility to determine which Active X controls will be available. Figure 3 represents various Active X control aircraft models.

COTS – Matlab/Excel – Both the real-time and post-test IADS provide the flexibility to export data into various COTS products. The IADS allows the engineer to configure parameters that can be exported based on any time range the engineer chooses or by setting up a group of parameter to export. The engineer can also place special editing functions on the data, such as decimation. The IADS current supports data export to ASCII files, comma delimited data files, Matlab and Excel.

Extensibility – IADS has several techniques to allow end users to extend the IADS functionality without the need of source code or interaction with the IADS development team. These methods include; a full-featured derived parameter builder an automation interface similar to many Microsoft Office products, and ActiveX displays that can be dynamically added to the IADS Display workstation for use in both real-time and post-test. ActiveX controls can be built in many languages including C++, Visual Basic, Macromedia Flash, and JAVA.

Data Views screens can be viewed directly in the IADS application. The IADS provides the real-time data back-end so that no modifications to the Data View's views are necessary in order to be used in the MCR.

Figure 4 represents a depiction of the Avionics displays

Figure 5 represents a depiction of an analysis window with time history displays, alphanumeric displays, transfer function (phase vs. magnitude) and power spectral density plots.

CONCLUSION

The IADS is a combination of current state-of-the-art commercial technology (Telemetry Preprocessor, Caching Data Server, Display Workstations, and networks) and custom software running on COTS hardware. This system has been developed to provide the engineer with advanced data organization and processing both in the MCR and at the engineers desktop, increasing the efficiency of the engineer for point-to-point mission clearance decisions and during post-test analysis.

BIOGRAPHY

Eileen Suszek is a Software Test Engineer with SYMVIONICS, Inc and has been on the IADS development team for 7 years.

John Bretz is a Senior Systems Engineer with SYMVIONICS, Inc and has been on the IADS development team for 4 years.

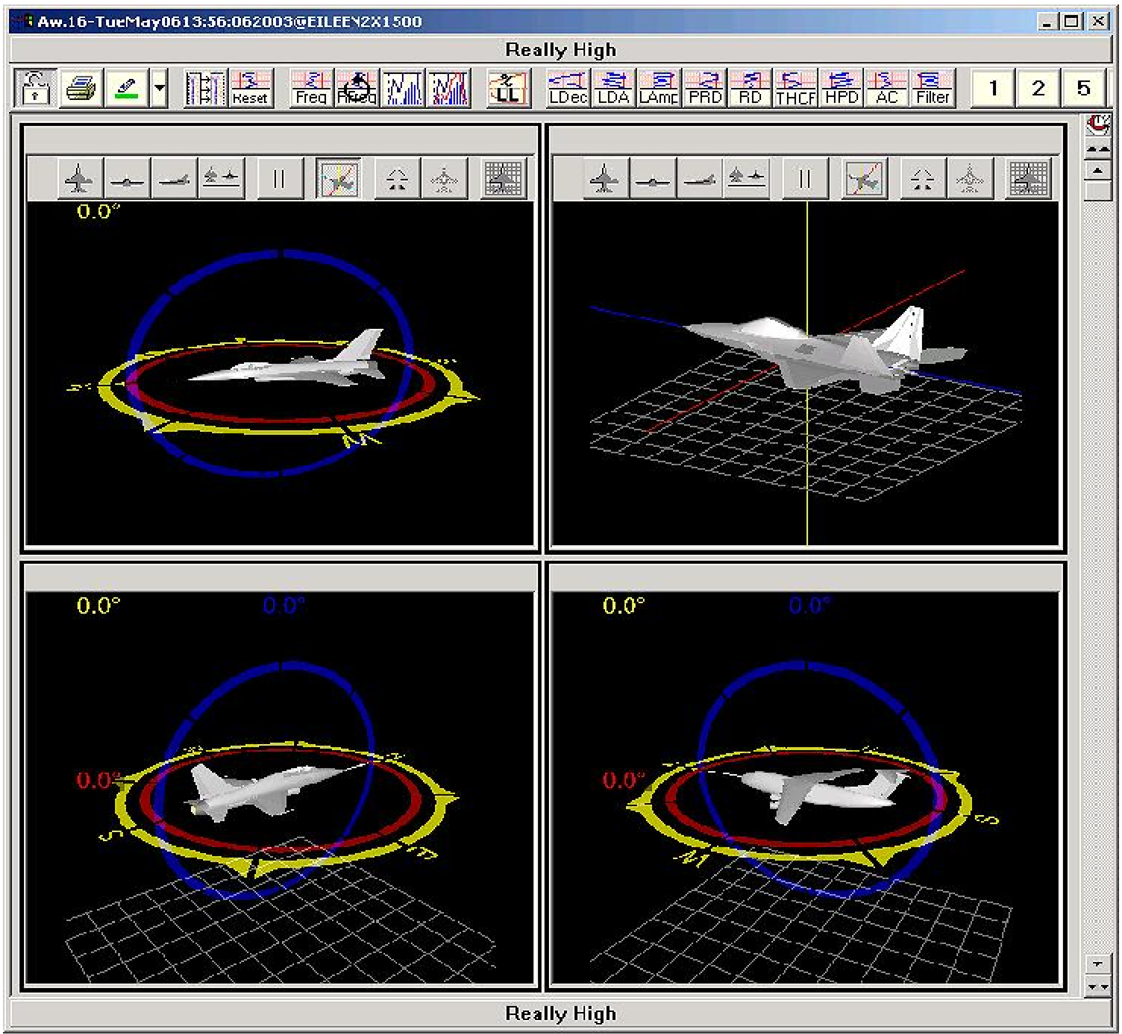


Figure 3. Example of the IADS Active X Aircraft Model Displays

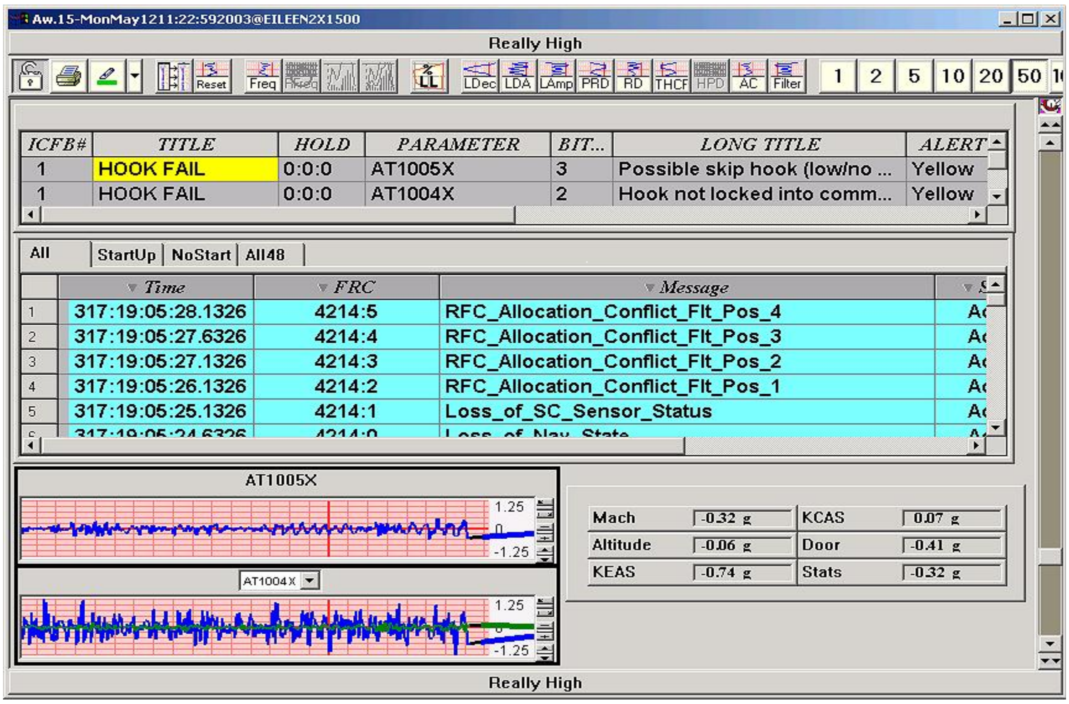


Figure 4. Example of an IADS Avionics Display

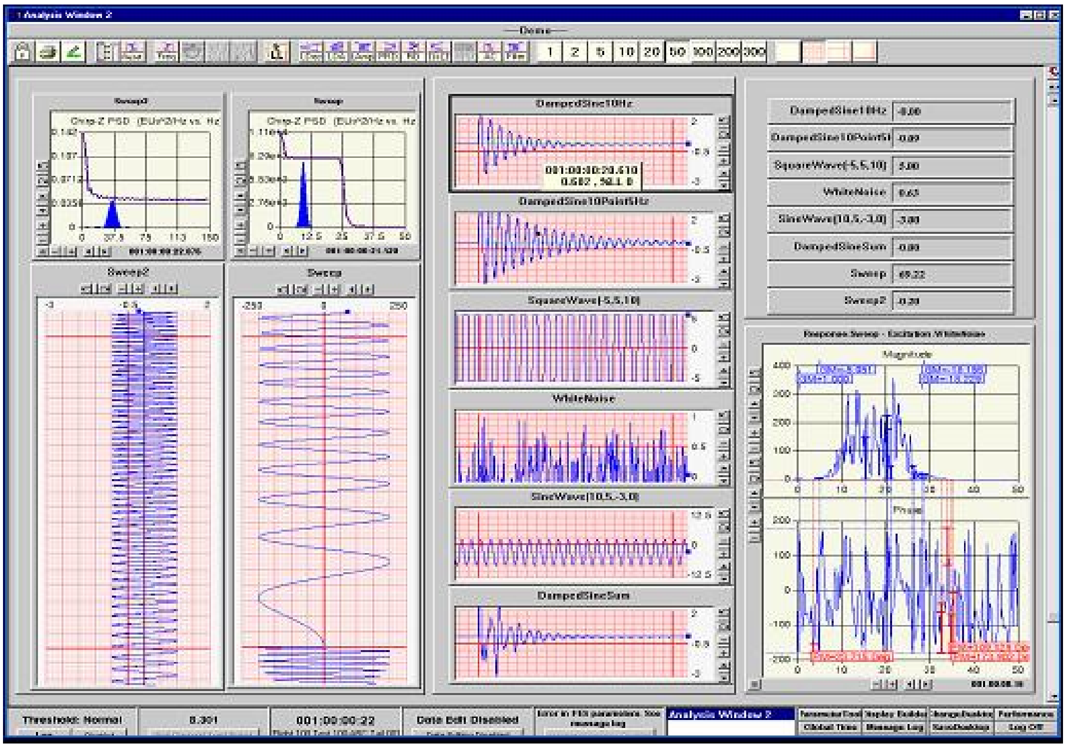


Figure 5. Example of an IADS Display

DIAPASON : SOuNd Automatic Acquisition DevIce

Hervé MAGNIN
Airbus France
Integration Test Center
herve.magnin@airbus.com

Abstract

Due to airport acoustic pollution quota, aircraft noise level becomes more and more important in airline companies aircraft selection. Aircraft manufacturers must equip their flight test and certification departments with efficient and reliable noise measurement system.
This is the aim of DIAPASON System : SOuNd Automatic Acquisition DevIce.

DIAPASON is an all in one system which allows the user to conduct his test from a movable Measurement Control Station located in a van. Automatic refreshed meteorological report, aircraft trajectory and ten fully autonomous and wireless recording station data are presented in a compact windowed environment.

DIAPASON will strongly improve ergonomics, productivity, data reliability and quality. It will be used for all Airbus acoustic certifications.

Introduction

Airbus supports ICAO in defining the international legal framework for air transport and is totally committed in ensuring that air transportation becomes less and less noise polluting.
To achieve certification any Airbus aircraft must demonstrate that its noise level does not exceed the limits defined by ICAO Annex 16.
This is why Airbus has chosen to equip its test and certification departments with one efficient, easy-to-use and reliable noise measurement system : DIAPASON (SOuNd Automatic Acquisition DevIce).

This article describes this new test facility, its architecture, its user interface and the way it will be operated.

1. BACKGROUND :

To achieve certification of an aircraft, it must be demonstrated that the noise levels measured at three certification points do not exceed the limits defined by ICAO Annex 16.

These three points are, shown in the figure 1 :

- Flyover : at 6.5km from brake release point, under the takeoff flight path ;
- Highest measurement recorded at the sideline, 450m from the runway axis, during take off ;
- Approach, at 2 km from the runway threshold, under the approach flight path.

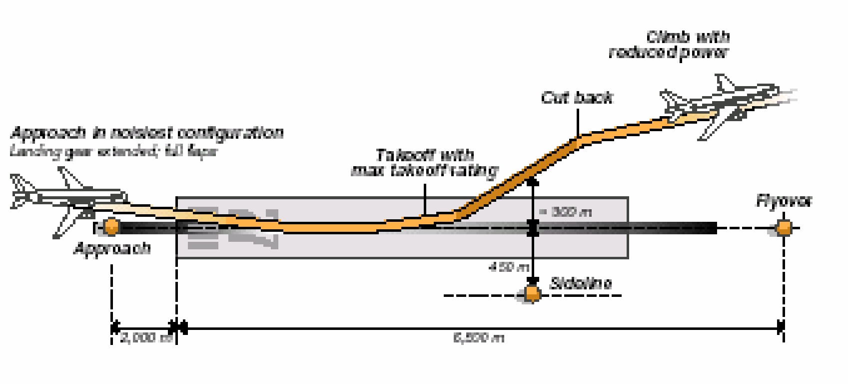


Figure 1

Cumulative levels are defined as the arithmetic sum of the three certification levels.

To measure these values, aircraft flies over, in several configurations (flaps / slats : in / out), above the microphone equipped area. These data are collected and analysed in the frequency domain. Each fly over is called a run. One day of certification contains 40 runs, one certification can last 3 or 4 days.

The unit used to measure noise levels is EPNdB, that stands for “Effective Perceived Noise” and is expressed in decibels.
This noise level in EPNdB depends on intensity of sound, noise duration and tone components in order to take into account human ear specificity.

The currently applicable international regulation is known as chapter 3. Any aircraft type certified from 1977 must be compliant with this chapter 3.
A new chapter 4 will be applicable to all aircraft type certified after January 2006, it will reduce the authorised cumulative noise level by 10 EPNdB with regard to chapter 3.

As an example the figures 2 and 3 show the flyover noise according to generations of aircraft :

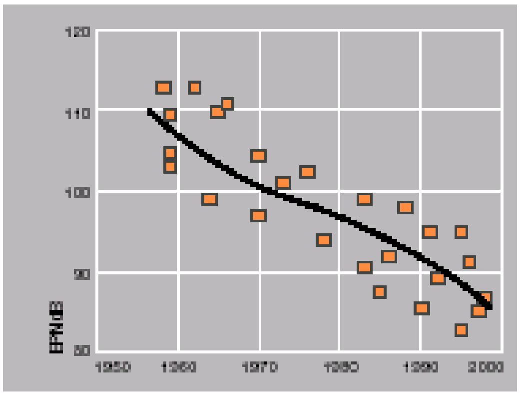


Figure 2
Orange square stands for aircraft type.
The more recent is the aircraft the quieter it is

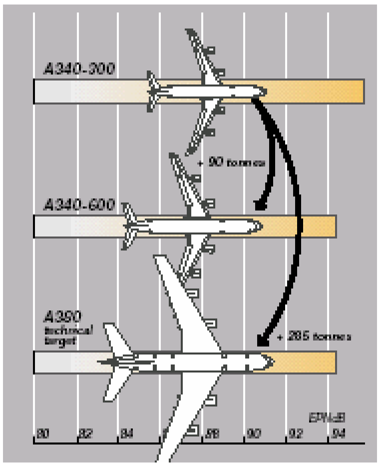


Figure 3
Noise reduction
according to design date

2. TEST FACILITY PROBLEMATIC

2.1. Weather and aircraft position

Acoustic certification procedure needs the knowledge of three kind of parameters :

- Aircraft noise
- Weather conditions
- Aircraft flight path and flight conditions

Some weather conditions are used to correct the sound level according to air noise attenuation, others forbid acoustic certification when they reach specified predefined levels.

Weather conditions are used to calculate noise attenuation ; air temperature, atmospheric pressure, hygrometry must be known between ground level and aircraft path. They are performed by atmospheric soundings.

Figure 4
Meteo sounding facility

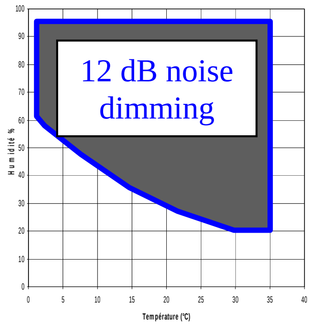


Figure 5
Acceptable noise dimming envelope

Other parameters are used for test validation : air speed and temperature must be known directly at several measurement points.

In the same way, aircraft flight path must be known to correct noise level received by microphone and to check that aircraft path is inside a predefined template as shown in figure 6.

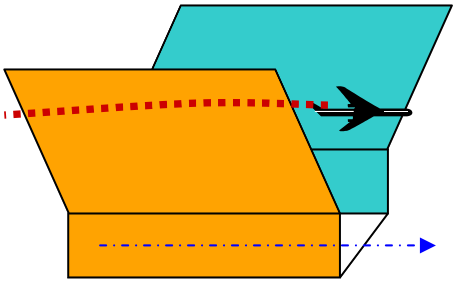


Figure 6

Moreover flight conditions like flaps, flats, landing gear position, engine rating have to be mentioned in the test rapport and check during the test

All these information must be synchronised according to the OACI recommendation that is 5 ms.

2.2. System deployment

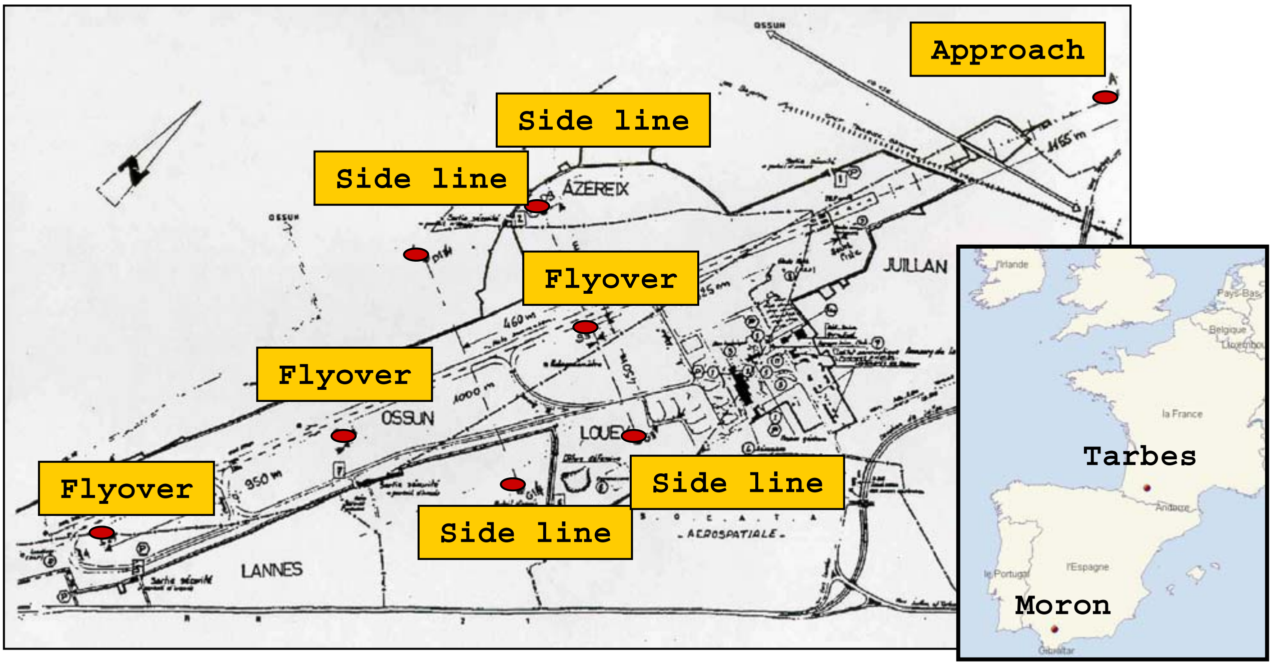


Figure 7

In order to get optimal weather conditions, the system will be installed in several test sites such as Tarbes (France) and Moron (Spain) airports. To be compatible with these test sites the system must be fully operational between –10°C and 55°C, and resists to humidity.

The figure 7 shows the test site system deployment : at least 8 measurement point must be precisely positioned they can be up to 5000m apart.

2.3. Global system constrains

The major aim of the test facility is to measure aircraft noise with the correct metrology. In addition we must strongly take into account economical point of view such as time saving by creating an easy to use and easy to install system.

Beyond required metrology the measurement system must respect aircraft development and certification time, this leads to avoid test aircraft monopolisation and reduce acoustic aircraft time test.

Last but not least, user must be able to conduct the test in the best conditions. The user must be able to evaluate and to validate the aircraft run before the next one. In order to avoid useless or missing runs.

This leads to develop a system which fulfils the following points (not exhaustive):

- OACI compliance :
    - required metrology,
    - no data loss
- real-time data display
- reduced deployment time,
- fault tolerant system,
- fully autonomous system,
- easy to use interface.

3. DIAPASON ARCHITECTURE

To fulfil the test system problematic Airbus designed the architecture described in figure 8.

The system is composed of ten noise Measurement Systems , a Measurement Control Station in a van where the user controls the test and a Meteorological Station.
Each noise Measurement System can record meteorological data from a temperature and wind speed sensor.

Each global system item (NMS, MCS, MS) and the aircraft under test are synchronised by GPS. The GPS provides a time stamping accuracy much better than the required one (+/- 2.5ms).

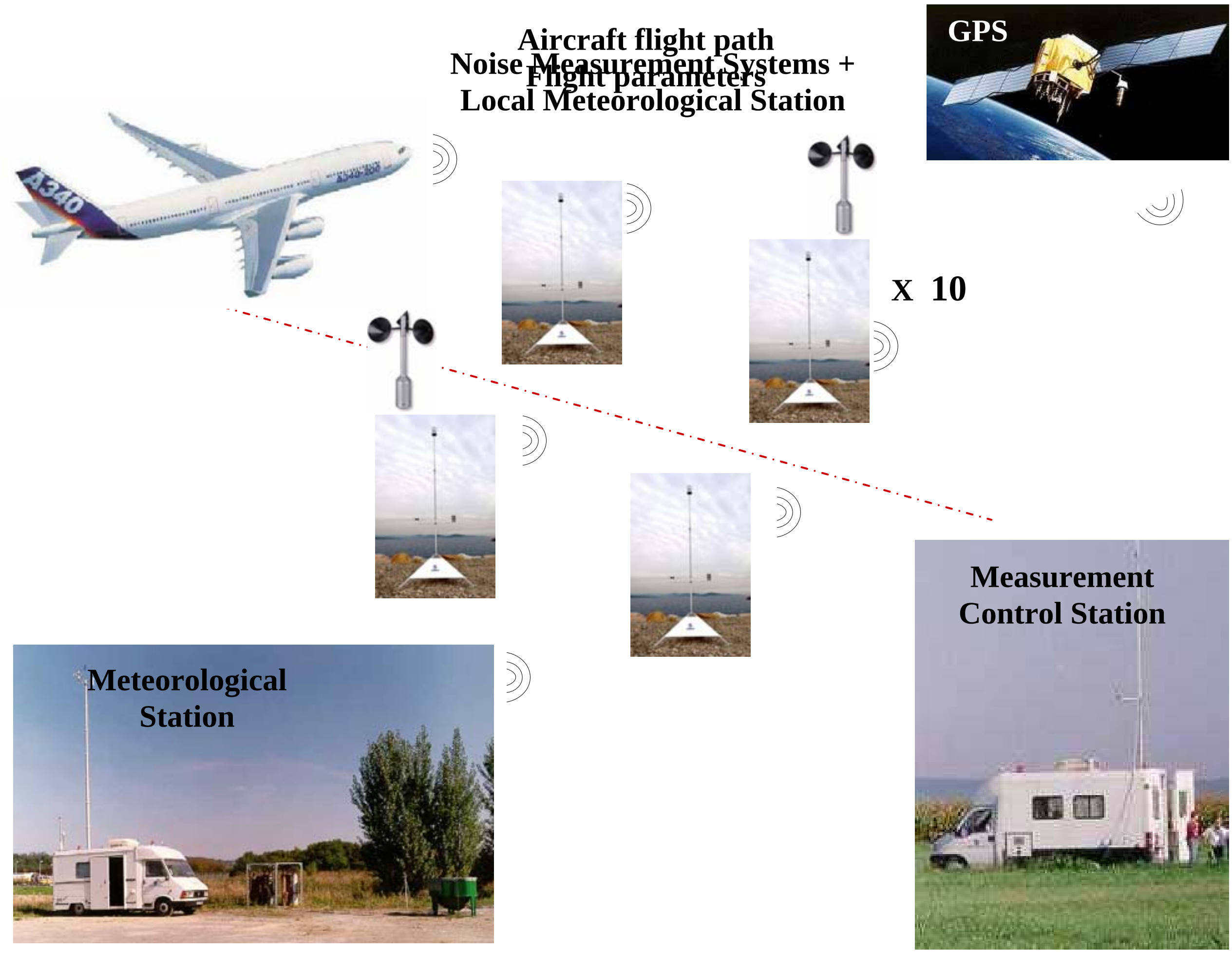


Figure 8

4. DIAPASON TRANSMISSIONS

All transmissions are wireless. Data from the aircraft under test (Flight path and flight parameters) use Airbus telemetry (on 2.7 GHz). They are received directly at the Measurement Control Station by a dedicated PC equipped with a demodulating board.

Data transmissions between noise Measurement Systems, Meteorological Station and Main Measurement Control Station use two 802.11b standard wireless loops.

The use of 802.11b protocol avoids transmission error treatment by DIAPASON. In fact transmission errors are corrected by the bridges themselves and the damaged data are sent again by the modems themselves. By this way transmission errors are seen as a reduction of the data rate.

The 802.11b modem and its integration are shown in figures 9, 10 and 11.

Figure 9
802.11b modem PCB

Figure 10
Modem packaging

Figure 11
Sun shield

Figure 12 shows the needed data flow and the exchanged data nature :

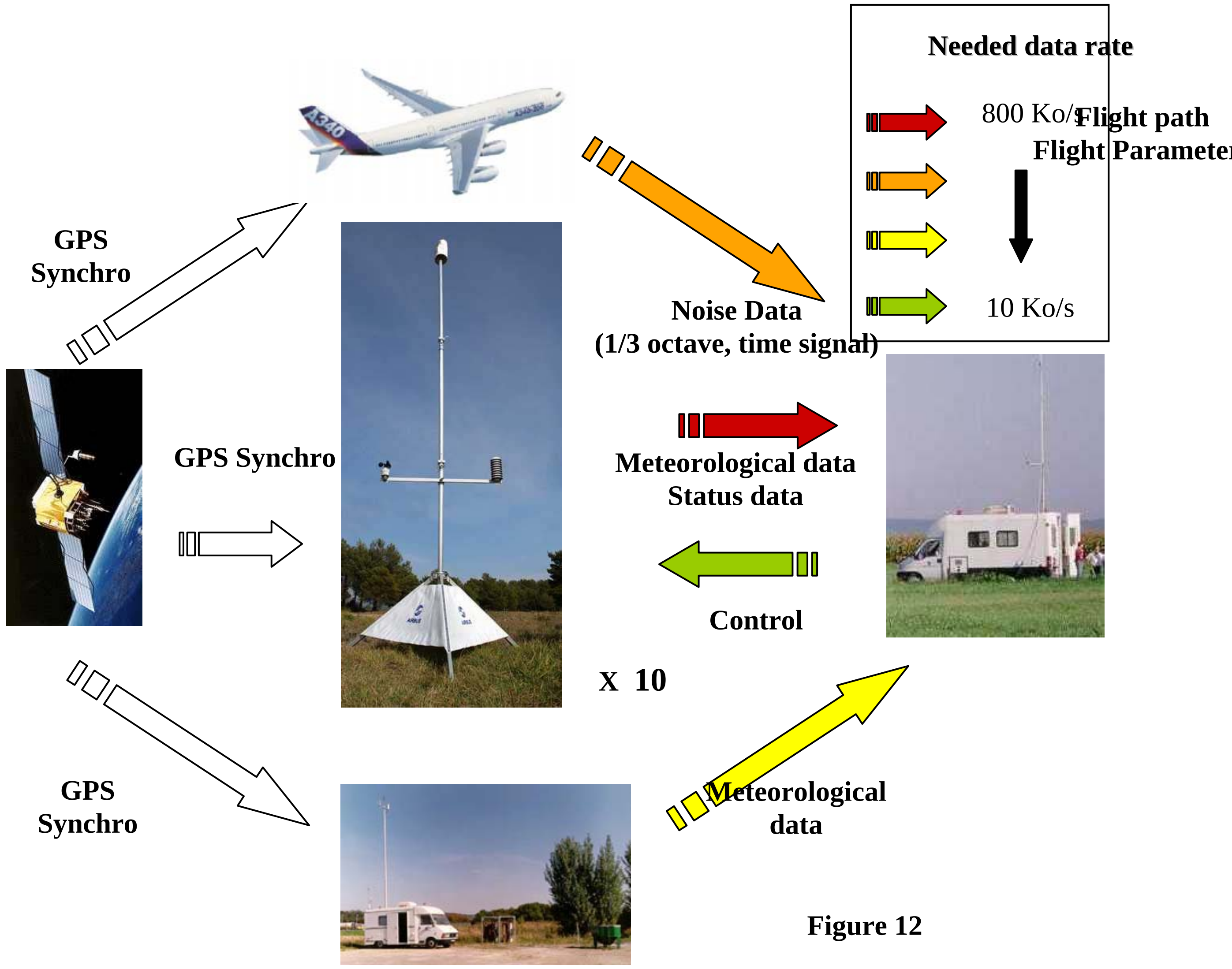


Figure 12

Two data types are transmitted from the noise Measurement Systems to the Measurement Control Station : time signal which is the digitised noise recorded by the Noise Measurement Systems and the ”1/3 octave data”.

The “1/3 octave data” are a spectral transformation of the time signal. This transformation is calculated by the Measurement Systems themselves and has a smaller volume than the time signal.

Moreover these computed values are the only essential noise measurement needed to conduct the test.

The choice of the data transfer priority derives from this last consideration : priority is given to 1/3 octave data, and only when all essential 1/3 octave data have been transferred, time signal is sent.

By this way DIAPASON guarantees 1/3 octave data transfer “in real-time”, that is before the following aircraft run. Moreover 1/3 octave uses only 1% of available bandwidth, this guarantees a quasi real time transfer even when transmissions are jammed.

Time signal is sent when transmissions are idle : between two 1/3 octave transmissions and when aircraft is preparing its next run.

5. MEASUREMENT SYSTEM

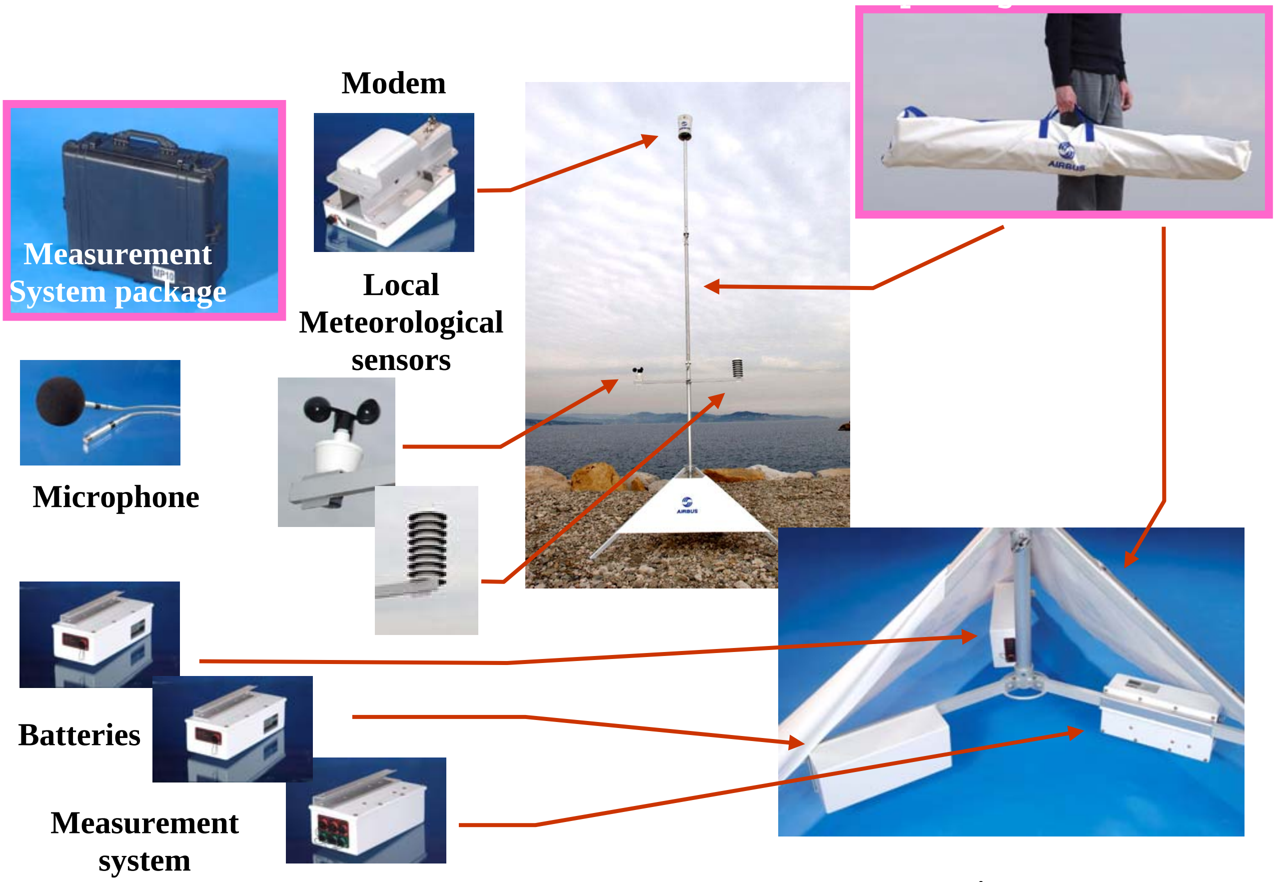


Figure 13

As shown in figure 13 : a Measurement system is included in a suit case for the electronics parts :

- Microphones, windshields,
- Modem and its antenna,
- Batteries,
- GPS antenna,
- Local Meteorological Station,
- Measurement System itself,

and a canvas bag for the mechanical parts :

- Antenna & Modem masts,
- Batteries and Measurement System tripod,
- Sun shield canvas.

The Measurement System itself is composed of 2 sigma-delta ADCs with a sampling rate of 65 kHz , and a CPU in charge of 1/3 octave computation. It can accept three input microphones and the local meteorological sensors. All time domain signals and 1/3 octave spectra are stored in an hard drive, even when they have been transferred to the Measurement Control Station. The hard drive capacity allows up to 500 runs storage.
The Measurement System is synchronised via the 1 PPS signal from the GPS module. The GPS is also useful to check the measurement point location.

The figures 14 and 15 show the Measurement System inner architecture, its realisation and integration in the 13 cm x 9 cm x 27 cm box.

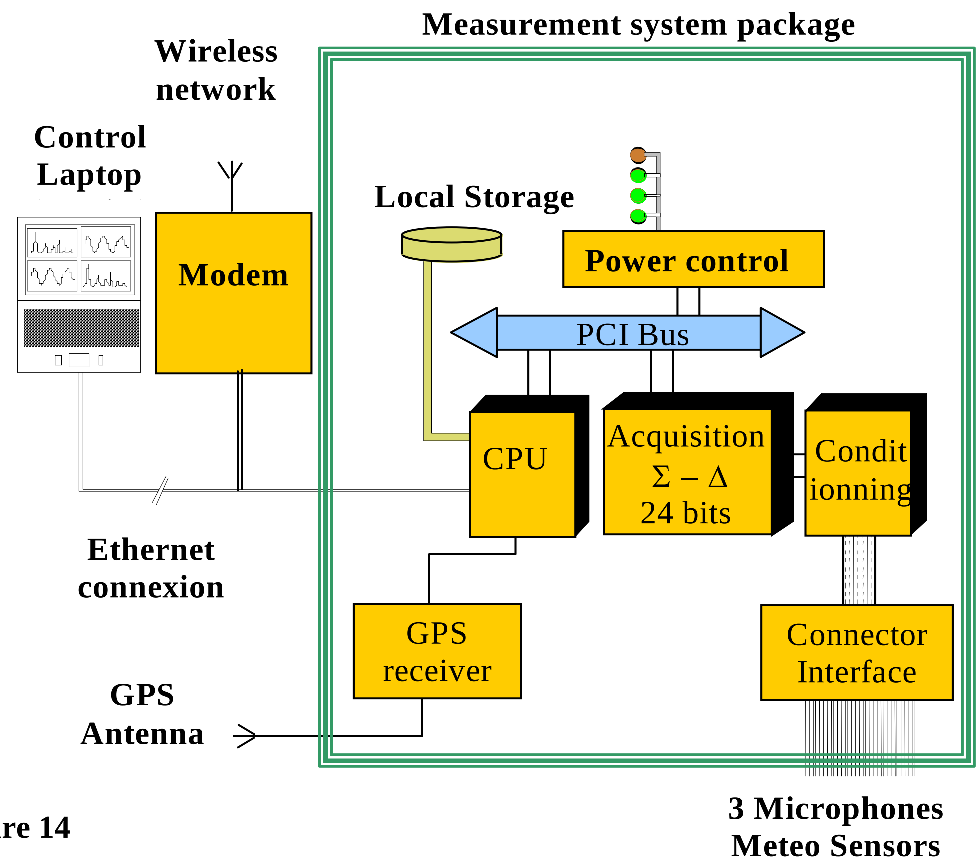


Figure 14

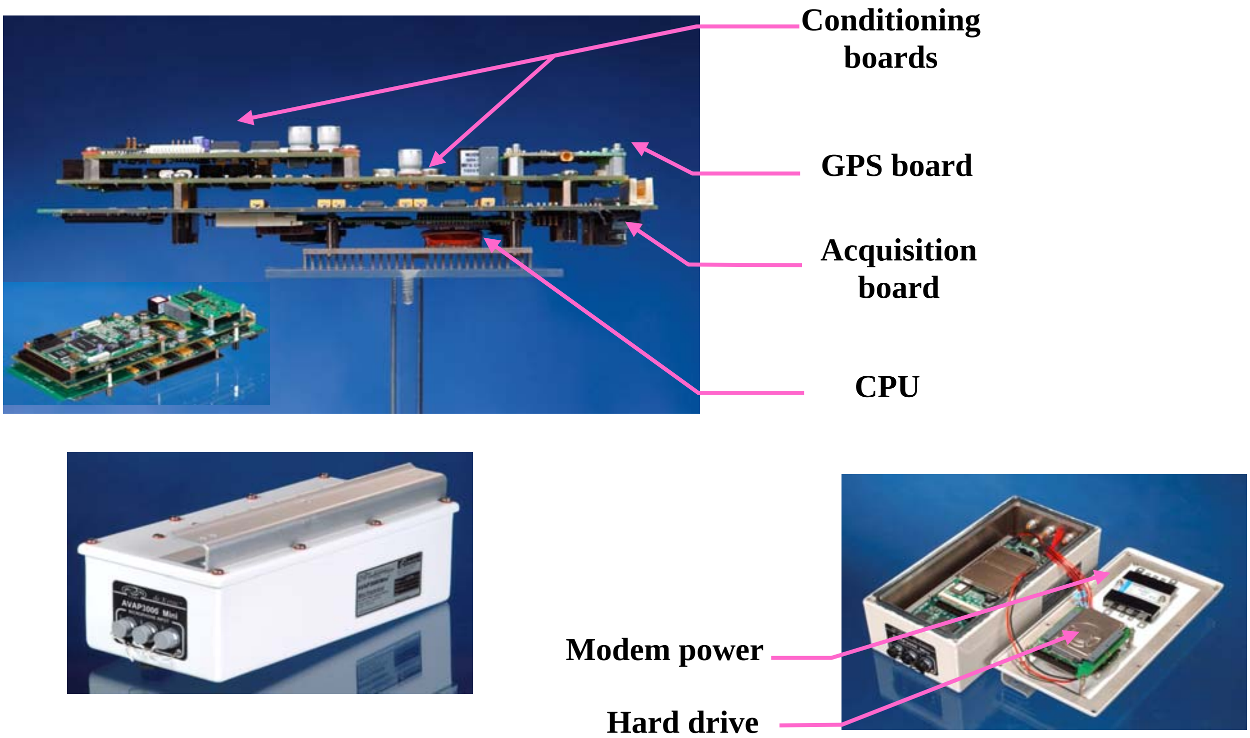


Figure 15

The Measurement System is powered by two NiMh batteries packs of 28 V. The batteries provide eight hours continuous operation. At the same time only one pack is needed, the system manages an automatic battery pack switching.

In order to reduce installation time a laptop can be connected to the Measurement System to make an optional stand alone calibration before the data are automatically collected by the wireless network. This direct control mode can also be used for maintenance or data transfer.

6. M EASUREMENT CONTROL STATION

The main user conducts the test from a converted van equipped with the DIAPASON system. The network environment is installed as shown in the figure 16.

Two swappable computers run the DIAPASON application, control the noise Measurement Systems and display the data.

This redundancy of CPU allows the user to make fine analysis, such as FFT, during the test. It gives large freedom in terms of fault tolerance and on user comfort.

Each computer is equipped with a 19’’ LCD display. One is used to display flight path, and meteorological data, the other displays noise data.

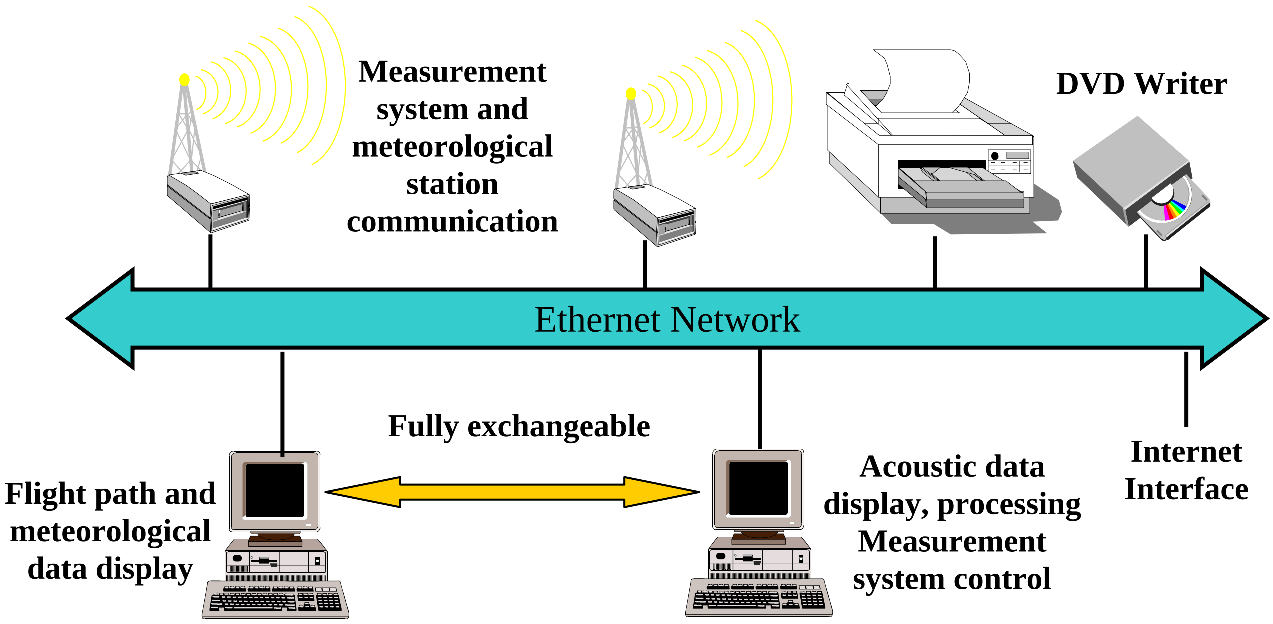
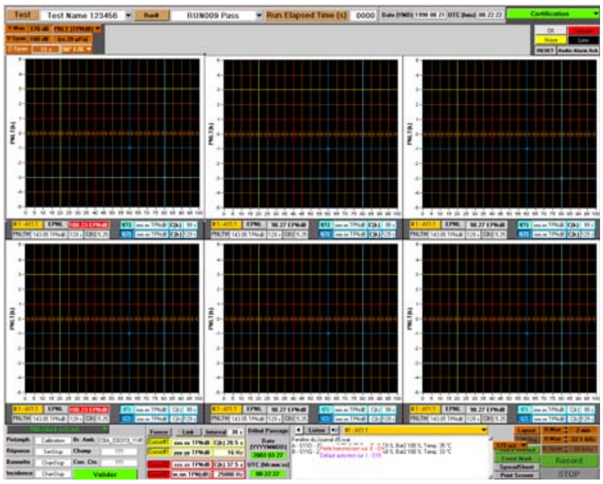


Figure 16

The numerous system warnings are displayed on the appropriate screen, they are :

- meteorological data out of correct range,
- aircraft position out of correct range,
- transmission status,
- saturation,
- Measurement System battery status,
- Measurement System hard drive status …

The following figures 17 and 18 show a sample of both displays.



Flight path and meteorological data

Figure 17

Certification noise data

Figure 18

From the two screens the user can start noise recording by clicking on a virtual button or set-up the system to record automatically from a defined aircraft position.

The 1/3 octave spectra are displayed in real time, the system computes the PNLT and PNLTM automatically after each aircraft run.

Moreover some extra features have been added, such as audio listening of noise signal from each Measurement System, GPS verification of Measurement System position, results printing and storage on DVD writer.

CONCLUSION :

DIAPASON is fully suitable for noise certification test process. This test system is fully compliant with OACI specially concerning data reliability, data transfer, time stamping and metrology.

This test system is autonomous, moveable and resists to meteorological conditions that are encountered on the different test sites.

Its ergonomic design is studied to be easy, fast to install and to be operated by a reduced number of operators. Moreover its modular conception promotes a flexible test system that accepts a lot of fault-tolerant modes.

The user interface is intuitive, fault tolerant windowed environment. Its two screens can be easily supervised by a single user.

DIAPASON will strongly improve ergonomics, productivity, data reliability and quality. It will be used for all Airbus acoustic certifications from September 2004.

Neural Networks and Telemetry

Miao Liucheng
Beijng Institute of Tracking and Telecommunication Technology

ABSTRACT

More and more theory achievements about neural network (abb. NN) could be seen in many professional mediums. With the development of micro-electronics, software and telecommunication technology, telemetry technology has been largely consummate. In this paper, we will discuss the combination of NN and telemetry. With the application of NN technology in system design and data processing, a new train of thoughts to study telemetry technology will be given in this paper. All of these may help the engineer in telemetry domain to extend their design.

1. Summarize

As an advanced technology in the international scientific research, NN has a unique function of memory and information processing; it’s a necessary technology in a biological computer for its memory design. The character of the system, based on NN theory, could be sum up as followings: (1) Random organization□(2) Distribution memory spread all over the entire system; (3) The simultaneous participation of any element in many memory traces;(4) No catastrophic failure;(5) Implicit or response reinforcement memory;(6) Automatic response (no search and comparison would be needed).

The main contents about the theory and method and application with NN could be described as: MP model of nerve cell, Hebb learning rule, stability and detectability about power system, etc. the normal form of the networks include: forward direction net, backward net, self organization net and stochastic net. With the characteristic of NN mentioned above, we have the following conclusion: the system based on NN has special characteristic: high reliability, intelligentized and adjustability.

The development period of telemetry technology could be briefly reduce to the development of several key technology, one of the tech could set the telemetry technology to a new stage, in other words, a new generation of telemetry would come to with a new technology adopted. The technology, which is key, is composed by: sensor, encoder, modulation, transmission, acceptance and demodulation. For instance, from traditional analog sensor with mechanic encorder to digital sensor with digital encorder; analog receiver to digital receiver, fixed circuit to virtual circuit, etc. The development of these technologies will make the telemetry technology a largely changed, the

embodiment of that is that the system would give us high and high precision telemetry data, reduce the transfer frequency bandwidth, system miniaturization and system reconstruction.
To use NN technic into telemetry system, we must select the junction point between NN and telemetry. That could give a new impetus to the telemetry system. The application of NN in telemetry fields will be discussed briefly in this paper, it includes sensor technology, encoder, decorder, system control. As a ripe technology, classical telemetry technology and theory will not be discussed.

2. Basic Principle of Neural Networks

The NN discussed in this paper is artificial NN. Its basic principle is come from biological NN. Neuron is the key unit in the system; the NN is composed by multi-neuron. NN is a high non-linearization dynamics system. With the study of modern mathematic tool, control theory, in the different formalization to describe the nerve cell and NN, form different kinds of description model for NN. Although the structure of neuron is simple, function is singleness, but the NN consisted by neuron is complicated. With t the theory of NN, many kinds of nature phenomena could be described, such as control, apperception, physics and chymist. In communication field, some theory and method could be described with NN theory, such as, adaptive filtering and blind equalization.

2.1 Neuron

Neuron is the basic unit of NN. In order to research NN, we must research neuron firstly. The model of NN is based on the model of neuron. The model of neuron about NN can be regarded as never cell in biology. It is an abstract concept about biological neuron. The character of neuron in NN is similarly as biological never cell. The formulation base of research is formed by neuron anatomical structure, the manner of information processed or transferred and function.

2.1.1 Anatomical structure of Neuron

In human body, the structure of one neuron is different from the other, but the basic element is simplified. The biological anatomical structure could be described as Fig1.
As shown in Fig1,Neuron is composed by soma, karyon, dendrites, axon and axon end.

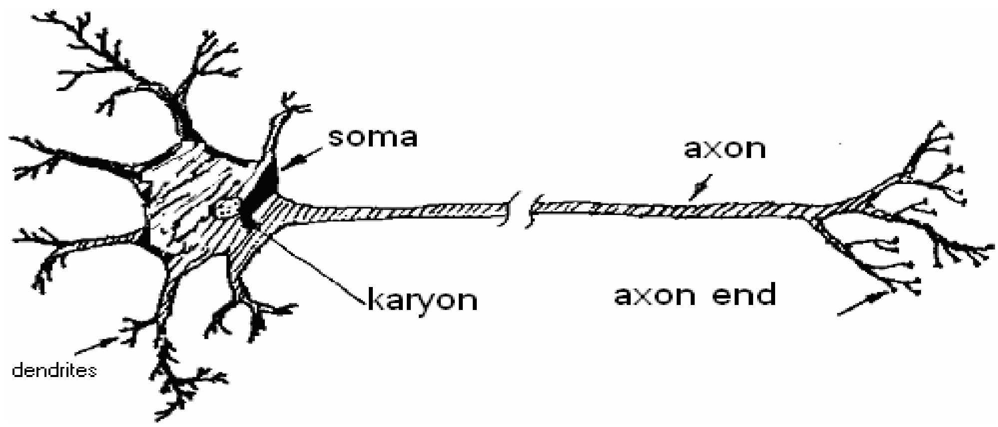


Fig1 The structure of neuron

Basically, a biological neuron receives inputs from other sources, and combines them by some way; perform a generally nonlinear operation on the result, and then output the final result. The figure above shows a simplified biological neuron and the relationship of its four components.

There are some important functions and characteristics with neuron; they can be described as following.

(1) Space-time conforming. The inputs from the same axon in different time could be conformed by synthesize. The inputs on the same time from different axon could be conformed. Both of the two functions are processed in the same time, these are called space-time conforming.

(2) Excitement and restrain. There are two states for a working neuron, excitement and restrain. When the result, induced by input impulse, processed through space-time conforming, make the electric potential of cell membrane high over a threshold, the cell will be in an excited state, and a impulse will be output; When the result make the electric potential of cell membrane low under a threshold, the cell will be in a restrain state. All of these could be expressed with on-off function or on-off circuit.

(3) A/D and D/A convert function of synapse. The information transferred on axon is a discrete impulse electronic signal, which is constant amplitude and constant width and encoded. But, the membrane potential in dendrite is continuous, it’s clear that synapse have D/A function. When the membrane potential of neuron dendrite is high over the threshold, an electronic impulse will be output by axon, it shows that synapse have A/D convert function. By all appearances, when a piece of information is passed though a neuron, converting process of D/A and A/D has occurred.

(4) Transfer delay. That means there is a time interval between two adjacent impulses, equivalent to the bandwidth of circuit. At the same time, there are zoom in and zoom out saturation in transferring an impulse, equivalent to studying and oblivion in biological theory.

(5)Multi-form of information transfer. There are chemical and physical transfer methods for information. That is Equivalent to the different transfer media in communication system.

2.1.2 Mathematical model of neuron

Neuron is an information process unit, which has one output and multi-input, and the information processing is non-linear. According to the characteristic and function of neuron, the neuron could be abstracted with a simple mathematical model. That's shown in fig2.

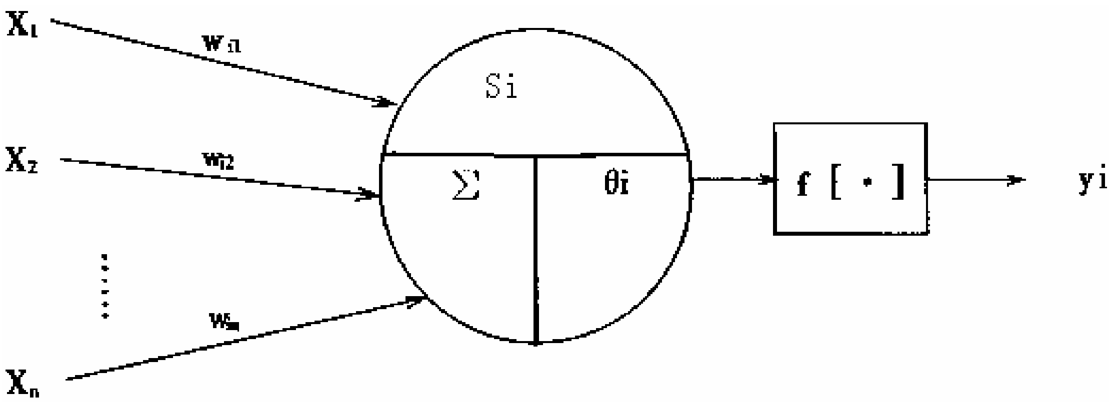


Fig2. Mathematical model of neuron

In Fig2, X1,X2,……,Xn are inputs to neuron, they come from the information of preceding stage n neuron, Equivalent to sensors in telemetry. θI is the threshold of No. i neuron, equivalent to the sensibility; Wi1,Wi2……,Win are coefficients of weight for X1,X2,……,Xn of No. i neuron. In other words, they are the transfer efficiency of the synapse. The function of the model equivalent to signal regulator; Si is the original state of neuron; Yi is the output of neuron i; f[·] is an exciting function, it would decide the output form of neuron i, when the inputs X1,X2,……,Xn has been high over the threshold.

The mathematical model of neuron could be described as following:

$$u_i = \sum_{j=1}^{n} W_{ij} X_j + S_i - \theta_i \tag{1}$$

$$y_i = f(u_i) \tag{2}$$

f() is a step function, viz.

$$f(u_i) = \begin{cases} 0 & u_i \le 0 \\ 1 & u_i > 0 \end{cases} \tag{3}$$

2.2 Neural Network (NN)

NN is composed by neurons which are connected from each other. The function of a NN is powerful than a single neuron.

2.2.1 Basic property of NN

(1) Non-linear: One of the properties of NN is non-linear, as the think process of a man.

(2) Non-local: NN simulate the non-local property of a human brain connected neurons, Distributed storage is a represent form of the non-local property.

(3) Non-stationarity: NN is a kind of dynamics system which is designed to simulate the think program of brain. It could modify its function according to the stimulating from external environment. So, it is a non-stationarity system.

(4) Non-convexity: The non-convexity of a NN could be called multiple maximum. In another words, the system have multiple stable, balanced state. These properties make the system evolved in multiple forms.

2.2.2 Model of the network

A good many of NN are familiar to us. Such as Hopfield net, BP net, Kohonen net and ART net. Semasiology methods and other mathematical methods could be used to model them.

Hopfield net is a typical feedback model. Hopfield is a self-associated monolayer net composed by the same neuron, have no ability to study. BP net is one kind of Back Propagation net. It can study through LMSE (Least Mean-Square Error) method. Kohonen and ART belong to the catalogs of self-organization net. All of the net models have two stages, execution and study.

The execution is a processing from inputs to give output.

$$u_i(t+1)=\sum_{j=1}^{n}W_{ij}(t+1)X_j(t)-\theta_i(t+1) \tag{4}$$

$$X_i(t+1)=f_i(u_i(t+1)) \tag{5}$$

Here:

Xi: the output of preceding stage.

Wij: the weight coefficient that No. i neuron synapse to No. j neuron synapse.

θi: the threshold of neuron i.

fi: non-linear activation function of neuron i;

Xi(t+1): the output of neuron i.

Learn stage is a processing that NN self-perfected, the network modify the coefficient Wij according to a special rule. The entire courses make the measure function E be the smallest.

$$E=(Ti,Xi) \tag{6}$$

Here,

Ti: the teacher signal;

Xi: the output of neuron.

The learning formula could be expressed.

$$W_{ij}^{(n)}=\varphi(W_{ij}^{(n-1)}(t),\eta_{ij}^{(t)},\frac{\partial E(t)}{\partial W_{ij}(t)}) \tag{7}$$

Here,
Ψ: a non-linear function;
Hij: the rate of change for weight coefficient;
n□the iterations of learning.

3. Neural networks and telemetry technology

The application of NN in telemetry system could be described with three aspects:
Design of system;
Design of circuit and software in subsystem;
Design of Net in system organization.
With restrict of contents and length in the paper, part of the contents will be dealt with, telemetry signal collection, channel processing and data processing.

3.1 Signal collection of front end

Both of the signal collection and signal adjustment are the important units in telemetry system. With the ability of signal recover and character taking out in NN, all kinds of signal especially for non-linear and other information could be accessed, filtered, detected. In which, feedforward NN could be used to simulate the mapping relation between input and output, when non-linear signal is being formed. Self-organizing NN could be used for autoregressive signal sorting and picture processing. Auto-adapted non-linear equalizer based on multi-layer sensor NN has a good performance than conventional linear decision directed feedback equalizer, when it be used in nonlinear channel.

The front end of telemetry sensor, based on NN theory, is shown as Fig3.

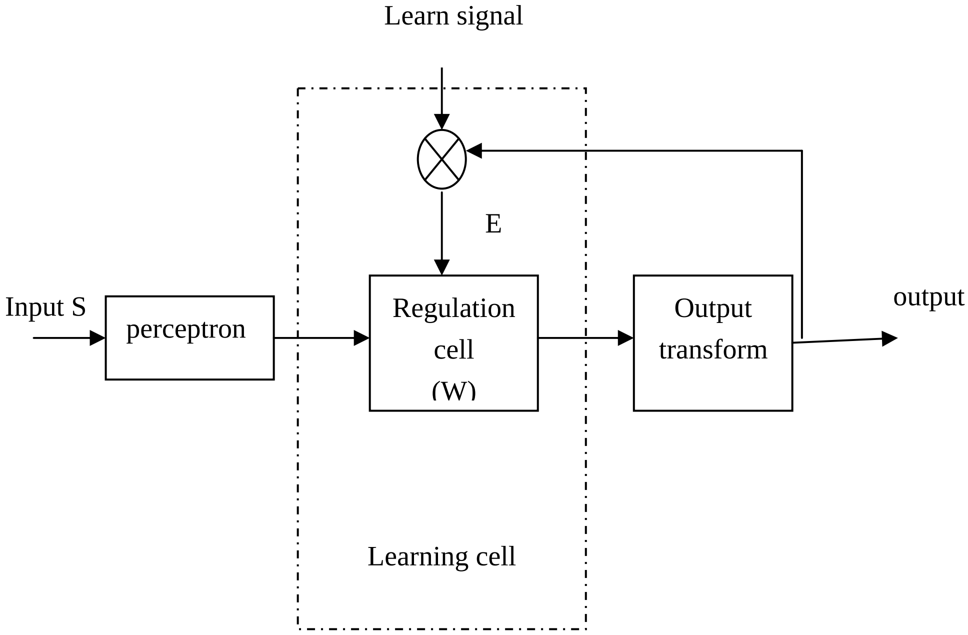


Fig3 self adapting apperception system

There are many mathematical methods to make the system realized based on above system, BP model, Hopfield model and ART model, etc. one or more could be adopted in system design.

3.2 Telemetry transfer channel

When NN theory is used in non-linear memoryless channel for modeling (such as satellite communication channel), analysis and simulating, it indicates that the performance is preferable than tradition modeling methods.

3.2.1 Self adapting blind equalizer

There are two methods for blind equalization design in NN.

One of that is using over-sampling technology and independent component analysis in NN, it is a blind message source separated method based on cumulation component. The other method is based on regression wavelet.

Because of the inherent characteristic of NN, the equalization method with NN technology has the following performance, rapid convergence, low error bit rate.

3.2.2 Self adapting blind message source separation

In recent years, blind message source separation has been the researching hotpoint in blind signal processing. The methods in this field include: like nerve arithmetic, NN separation arithmetic based on information theory, density estimate arithmetic based on multi-variable, cumulant expanding arithmetic.

In addition, NN technology could be used for self-adapting multi-path delay estimation, noise and disturb cancellation, etc.

3.3 Data processing

The human brain is a high intelligent complicated system, no heavy and complicated calculation and logic operation; it could process all sorts of complicated, imprecise and misty information. Only from the structure, the single neural cell work in a low speed (ms level), but the high performance it has proved is supernatural. When non-linear NN is used in orbit tracking system of flying object, in picture rebuilding, pattern recognition and fuzzy control system, it could help person to solve many problems that could not be solved with traditional information processing methods. All of the NN methods could be called “intelligent calculation”.

(1) Cognitive science and neural network

They have osculating relationship between cognitive science and NN. The basic researching method for NN could be divided into two sects, sign ism and connection ism. Sign ism studies the NN system through the surface phenomenon, not concerning the interior structure and mechanism of system. Connection ism studies the NN system through microcosmic structure.

Both sign ism and connection ism have their own feature. Generally, the NN based on sign ism is a precision process; the NN based connection ism is not. Each of them faces to rational and perceptual differently. Act as the left side of brain and right. So, a perfect system must be a combinative system by both of them. The key problem is how to combinate about this two system. The main

methods could be induced as fowllowing.
A. Loose coupling model: Both of them are connected through an intermediate media (such as data files, function, etc.).
B. Tight coupling model: Against with the loose coupling model, the communication process is not connected by external data, but through internal data interface. This system could be called push-in type system.
C.Conversion model: Up to now, there is no accurate method to complete this process.
D.Integration Model: In integration model, the sign mechanism and connection mechanism are combined to one system. At the same time, logic function and self-adapting function are combined in the new system.
(2) Chaos theory and information processing
In biology NN system, from microcosmic neurilemma electric potential to macroscopical brain electric wave, chaos phenomena exist. The NN system with chaos theory could describe the phenomena about dynamic association and remembrance. This modeling could be used in pattern recognition fields. Such as in non-linear forecast and decision-making, for the faintness signal submerged in noise to design a filter, self adapting storage searches system designing (characteristic picked-up, learning and search).
(3) Fuzzy theory
Both fuzzy set theory and NN belong to the domain of flexible information processing, but the methods that they adapt are different. Microcosmic network structure is emphasized in NN system; Macroscopical function is emphasized in fuzzy set. There are two methods to combine this two technology, the first is based on fuzzy set theory, NN modeling is integrated; the second is based on NN system, fuzzy set methods are integrated. The new system combined with this two technology could be a self-organization and flexible information processing system.
(4) Genetic Algorithm
Genetic Algorithm is a method to simulate anagenesis in biological technology. This method could modify each unit to fit the environment. The algorithm could be used in picture processing, character pick out, net design, etc. In NN system, the algorism could reduce the processing time in NN system. Optimize the structure of NN system.

4. Conclusion

The new generation telemetry technology will not be similar as last. With the coming of information age, more and more intelligentized technology will be used in telemetry system. The new generation telemetry system will be connected with intelligentized technology broadly. Neural network technology will be one of these intelligentized technologies that maybe used in telemetry firstly, in intelligentized source process, channel process and data process. So, the study of NN system and its application in telemetry is very important to recognize the new generation of telemetry.

5. References

[1] The Study on Neural Network with Petri Net, Miao Liucheng, 1996
[2] Communication system in range test, 2000

EFFICIENT IMPLEMENTATION OF AN LDPC CODE

Henry Chandran, IEEE member and Dr.Xavier Giraud, IEEE member
Navtel Systems, 28700 Houville, France

ABSTRACT

this paper addresses some implementation aspects of an LDPC code from finite geometry. Though very short, the selected code displays attractive performance and thanks to its algebraic structure, it can be efficiently implemented.

INTRODUCTION

Low Density Parity Check (LDPC) codes have become a promising solution for near capacity error correction as demonstrated by the selection of one such code by the DVBS2 group. Besides, it has been shown that the LDPC codes achieve a large gain with respect to convolutional codes for large packet length on a block fading channel [2]. Even short LDPC codes dramatically improve the BER of OFDM in a multi-path environment. Navtel Systems is developing coding schemes based on LDPC as a possibility for its forthcoming reconfigurable COFDM burst modem. The LDPC code selected in this paper exemplifies this work. Though very short, this LDPC code offers a 1.5 dB gain over 64 states rate 1⁄2 convolutional code at BER of 10^{-6} and it is well suited to hardware implementation.

1. An overview of LDPC codes

An LDPC code is described by its (sparse) parity check matrix **H**. Such a matrix can be efficiently represented by a bipartite graph. A bipartite graph $G = (V, C, E)$ consists of a set of variable nodes V, a set of check nodes C and a set of edges E. Each edge $e \in V$ connects a variable node $v_e \in V$ to a check node $c_e \in C$ as illustrated on figure 1. The variable nodes correspond to the set of codeword. We say that a LDPC code is (λ, ρ) regular when each variable has degree λ and each check node has degree ρ. Regular LDPC codes have an advantage in hardware implementation because the regular structure can be exploited to simplify the decoder. Further, for short block length, irregular codes may have a smaller minimum distance and regular code may be preferable to avoid the error curve flattening effect. The standard iterative decoding algorithm, known as belief propagation algorithm (BPA), passes messages along the edges of this graph. Each variable node is initialised with channel information. Decoding messages (check-to-variable and variable-to-check), referred as extrinsic information, are iteratively updated on each node and exchanged through the edges between neighbouring nodes. Many classes of LDPC have been forwarded, each offering advances in one area or another. On the hardware side, desirable features can be summarized into three “rules”:

R1. The exact structure of the parity check matrix needs to be stored at the receiver. Therefore, it is very desirable to be able to generate the graph structure algebraically.

R2. Usually, the parity check matrix is not constructed in systematic form and Gaussian elimination should be applied to determine a generator matrix for encoding. This may induce a significant increase in storage and memory access at the emitter. Therefore, cyclic or quasi-cyclic codes are desirable.

R3. The amount of computation needed at each check node (resp. bit node) is proportional to δ (resp. λ). Hence it is very desirable to keep ρ and λ as small as possible. Richarson and Urbanke [4] have shown that the performance of regular LDPC codes under BPA is best when $\lambda = 3$.

Together, these design constraints are not easily fulfilled. Navtel Systems has developed an evaluation tools for LDPC codes. Two different codes families have been selected for further investigation and hardware implementation:

F1. Codes from finite geometry [5]

F2. Codes based on congruencies [1] such as the code selected by the DVBS2 group.

In the following, we focus on some features of a (511, 256) quasi-cyclic code from finite Euclidean geometry that can be equally looked at as a code based on congruencial sequences.

2. A (511, 256) LDPC code from Finite Euclidean geometry

Kou, Lin and Frosserier [5] [3] have investigated finite geometry based LDPC. Due to their geometric structure, a class of cyclic or quasi-cyclic codes can be constructed without any cycle of length less than 6, with large minimum distance and no error floor greater than 10^{-10} BER. Although what follows can be stated in a general framework, we focus on $\mathbf{F} = GF(2^9) = \left\{0, \alpha^i, 0 \le i \le 510\right\}$ where α is a primitive element of $\mathbf{F}$. The field $\mathbf{F}$ can be looked at as a three dimensional vector space over $\mathbf{K} = \left\{0, \alpha^{73i}, 0 \le i \le 6\right\} \sim GF(8)$ and $(1, \alpha, \alpha^2)$ is a basis of $\mathbf{F}$ over $\mathbf{K}$. The usual three dimensional geometrical representation can be used as shown on figure 2. A line passing through $a \in \mathbf{F}$, directed by $b \in \mathbf{F}^*$ can be written

$$D_{a,b} = \left\{a + tb, t \in K\right\}$$

and the incidence vector of a line $D \subset \mathbf{F}^*$ is the row vector $\mathbf{h} = (h_i)_{0 \le i \le 510}$ of length 511 such that $h_i = 1$ *if* $\alpha^i \in D$ and $h_i = 0$ *if* $\alpha^i \notin D$. Let $D_{0,1}$ the line passing through 0 and directed by 1. Since the plane P generated by α and α^2 comprises 64 points, there are

63 lines parallel to $D_{0,1}$ and different from $D_{0,1}$. These 63 lines are said to form the parallel bundle B_1 of the lines of F directed by 1 that do not pass through the origin. Let $\mathbf{h}_0,...,\mathbf{h}_8$ the incidence vector of the 9 lines

$$D_{\alpha,1}, D_{t\alpha+\alpha^2}, t \in \mathbf{K}$$

It can be shown that the incidence vectors of the 63 lines of B_1 can be obtained by circularly right shifting $\mathbf{h}_0,...,\mathbf{h}_8$ by $73k$, $0 \le k \le 6$. If $S_r(\mathbf{h})$ is the vector obtained when a 73-circular right shift modulo 511 is applied to $\mathbf{h}$, the incidence matrix of the parallel bundle B_1 is

$$H_1 = \begin{pmatrix} \mathbf{h}_0 \\ S_r(\mathbf{h}_0) \\ \vdots \\ S_r(\mathbf{h}_0) \\ \vdots \\ \mathbf{h}_8 \\ S_r(\mathbf{h}_8) \\ \vdots \\ S_r(\mathbf{h}_8) \end{pmatrix}$$

Each row of $\mathbf{H}_1$ has weight 8 and since two different and parallel lines have no points in common, the columns of $\mathbf{H}_1$ have weight 1 or zero. Finally, the parallel bundle B_{α^i} of the lines directed by α^i and different from D_{0,α^i} is $\alpha^i B_1$ and its incidence matrix is obtained by applying an $i-$circular right shift to the rows of $\mathbf{H}_1$ modulo 511. The parity check matrix $\mathbf{H}$ of the code under study in this paper is obtained as the incidence of the parallel bundles B_{α^i}, $0 \le i \le 5$:

$$\mathbf{H} = \begin{pmatrix} \mathbf{H}_1 \\ s_r(\mathbf{H}_1) \\ \vdots \\ s_r^5(\mathbf{H}_1) \end{pmatrix}$$

where s_r is the unit circular shift modulo 511. The matrix $\mathbf{H}$ gives rise to a (511, 256) code and $\mathbf{H}$ is fully described with $I_0,\ldots,I_8$, the sets of the indices of the non zero coefficients in $\mathbf{h}_0,...,\mathbf{h}_8$. Each set I_k contains 6 integers smaller than 511, i.e. 54 words of 9 bits each are enough to fully describe the trellis. By removing or adding parallel bundles, the code rate can be tuned while the code length and the decoder architecture remains unchanged.

3. The encoder

Let $\mathbf{a} = (a_i)_{0 \le i \le 510}$ a 511-tuple in $GF(2)$. The row vector $\mathbf{a}$ is written serially into a (7*;* 73) array row wise. By considering the columns of this array as elements of the ring

$$R = \frac{GF(2)[X]}{(X^7 + 1)}$$

we have built a row vector $\hat{\mathbf{a}}$ of length 73 with its coefficients in R. We denote $\tilde{\mathbf{x}}$ the vector $\mathbf{x}$ when read from its last position to its first position. The (9*;* 73) matrix

$$\hat{\mathbf{H}}_1 = \begin{pmatrix} \tilde{\hat{\mathbf{h}}}_0 \\ \vdots \\ \tilde{\hat{\mathbf{h}}}_8 \end{pmatrix}$$

corresponds to $\mathbf{H}_1$ and the (54*;* 73) matrix

$$\hat{\mathbf{H}} = \begin{pmatrix} \hat{\mathbf{H}}_1 \\ s_r\left(\hat{\mathbf{H}}_1\right) \\ \vdots \\ s_r^5\left(\hat{\mathbf{H}}_1\right) \end{pmatrix}$$

corresponds to $\mathbf{H}$ with $\hat{s}_r$ (resp. $\hat{s}_l$) the unit right (resp. left) circular shift modulo 73. Observe that there are exactly 8 nonzero positions in each row and the nonzero positions contain monomials.

Proposition 1. *A 511 row vector* $=(c_i)_{0 \le i \le 510}$ *in* $GF(2)$ *is a codeword if, and only if,* $\hat{\mathbf{H}}^t \hat{\mathbf{a}} = 0$ *mod* $(X^7 + 1)$ *or equivalently,* $\hat{\mathbf{H}}_1{}^t\left(\hat{s}_l^i(\hat{\mathbf{a}})\right) = 0$ *mod* $(X^7 + 1), (0 \le i \le 5)$*.*

A rather simple systematic encoder can be obtained by applying standard gauss elimination in the ring *R* to the (54*;* 73) matrix $\hat{\mathbf{H}}$.

4. The trellis and the decoder architecture

We assume that the variable nodes are written serially into a (73*;* 7) table ***T*** column wise. The check node c_{7k} corresponding to $\mathbf{h}_k$, i.e. the 7*k*-th row of $\mathbf{H}_1$, is connected to 8 variable nodes in eight different rows of ***T*** as depicted on figure 3. Two different check nodes in $\{c_{7k}, 0 \le k \le 8\}$ are connected to variable nodes in different rows. Hence, there is one single row with no connection towards the $c_{7k}, 0 \le k \le 8$. The remaining edges do not need to be stored as explained by the next proposition:

Proposition 2. *Let* $0 \le i \le 6, 0 \le j \le 5$ *and* $0 \le k \le 8$*; in order to build the connections to the checks* $c_{63j+7k+i}$ *of the j-th bundle, one simply needs to apply a left circular* i*-shift modulo 7 to the rows of* ***T*** *and a upward left helicoidal j-shift modulo 73 to the column of* ***T*** *(see figure 4).*

In essence, proposition 2 means that appropriate horizontal and vertical shifts give rise to the whole trellis, with only $9 \times 8 = 72$ fixed connections. Besides, adding or removing parallel bundles, i.e. tuning the code rate, simply converts into increasing or decreasing the set of the permitted vertical shifts. As a consequence, the BP algorithm can be very efficiently applied avoiding expensive address computation or storage. Figure 5 shows the performance of this code on AWGN channel with 6 bits quantification and a maximal iteration number of 20. It performs as well as the turbo code selected for UMTS with comparable parameters.

Conclusion

In this paper we have demonstrated that codes from finite geometry can be very efficiently described making them suitable for hardware implementation. The example investigated in this paper can easily be extended to the other codes studied in [5].

References

1. K. Narayanan A. Prabhakar, *Pseudo-random construction of ldpc codes using linear congruential sequences*, available at http:/citeseer.nj.nec.com/cs (2002), 1–20.

2. T. Ohtsuki H. Futaki, *Ldpc coded ofdm systems*, IEEE VTC 2001 **1** (2001), 82–86.

3. S. Lin K. Abdel-Ghaffar H. Tang, Y. Ku, *On algebraic construction of gallager ldpc codes*, Proceedings ISIT 2002, 482, Lausanne, Suisse.

4. R. Urbanke T. Richardson, *The capacity of ldpc codes under message-passing decoding*, IEEE Trans. On Info. Theory **47** (2001), 599–618.

5. M. Frosserier Y. Kou, S. Lin, *Ldpc codes based on finite geometries : a rediscovery and new results*, IEEE Trans. on Info. Theory **47** (2001), 2711–2736.

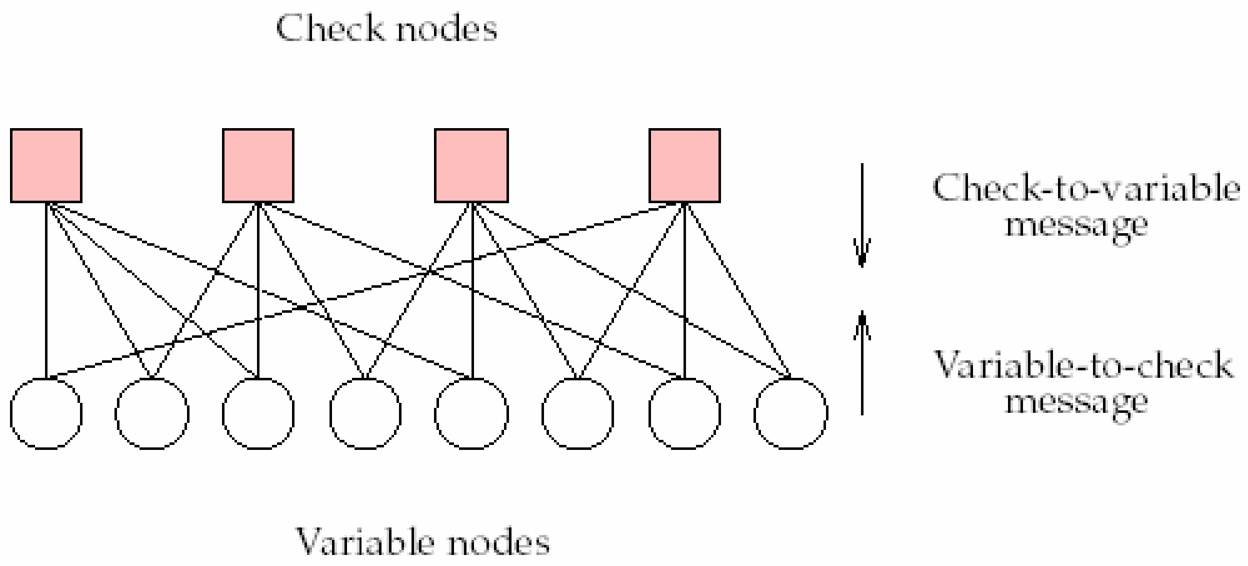


FIGURE 1. Trellis representation of an LDPC code

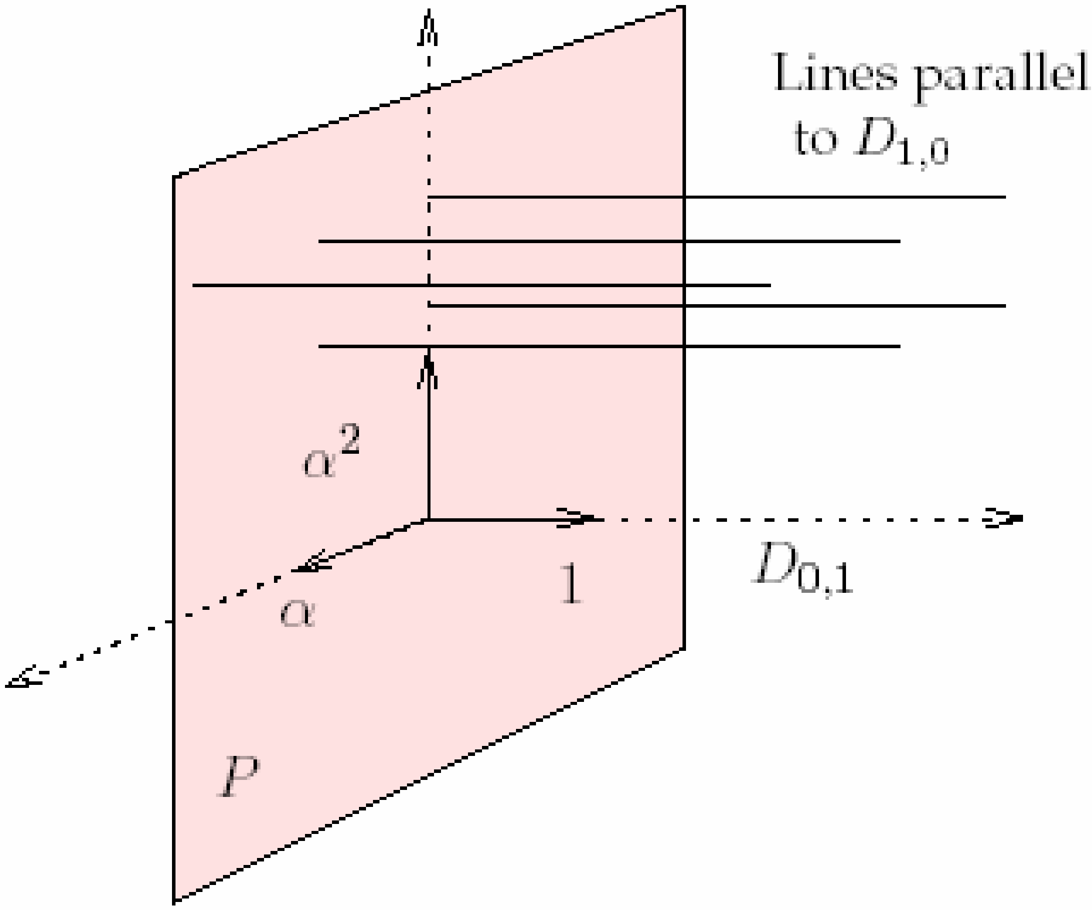


FIGURE 2. Geometrical representation of $\mathbb{F}$

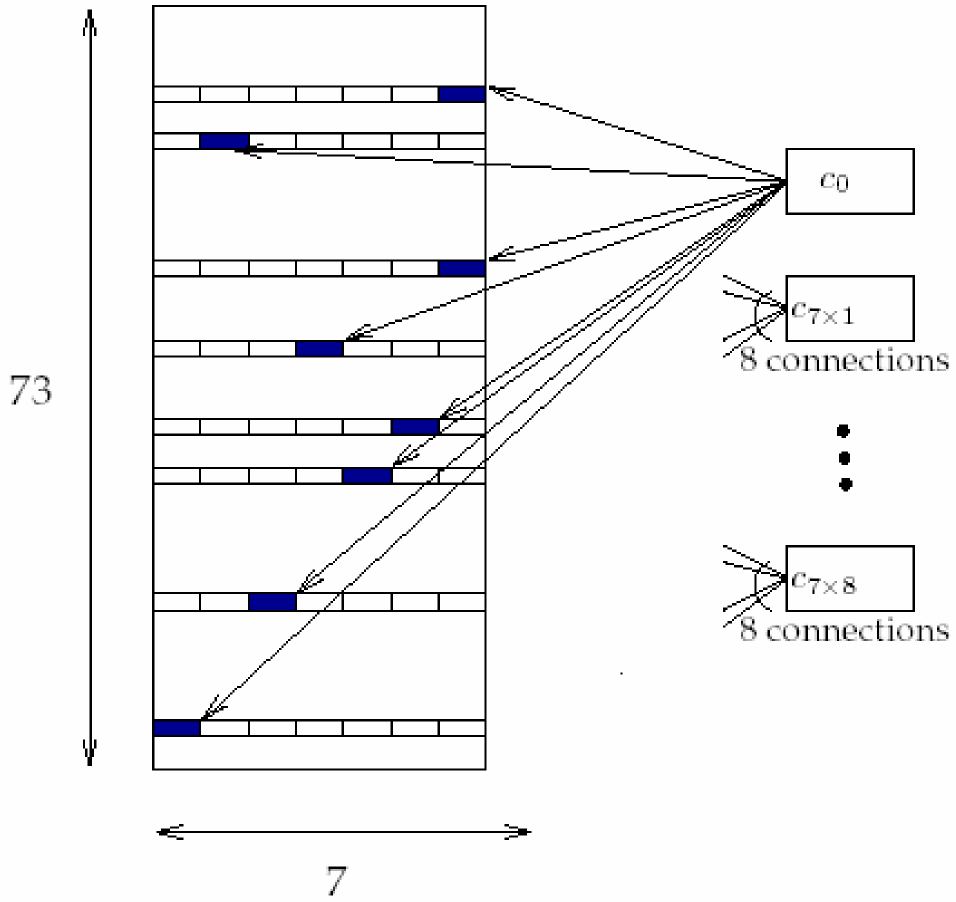


FIGURE 3. Useful connections between checks and variable nodes

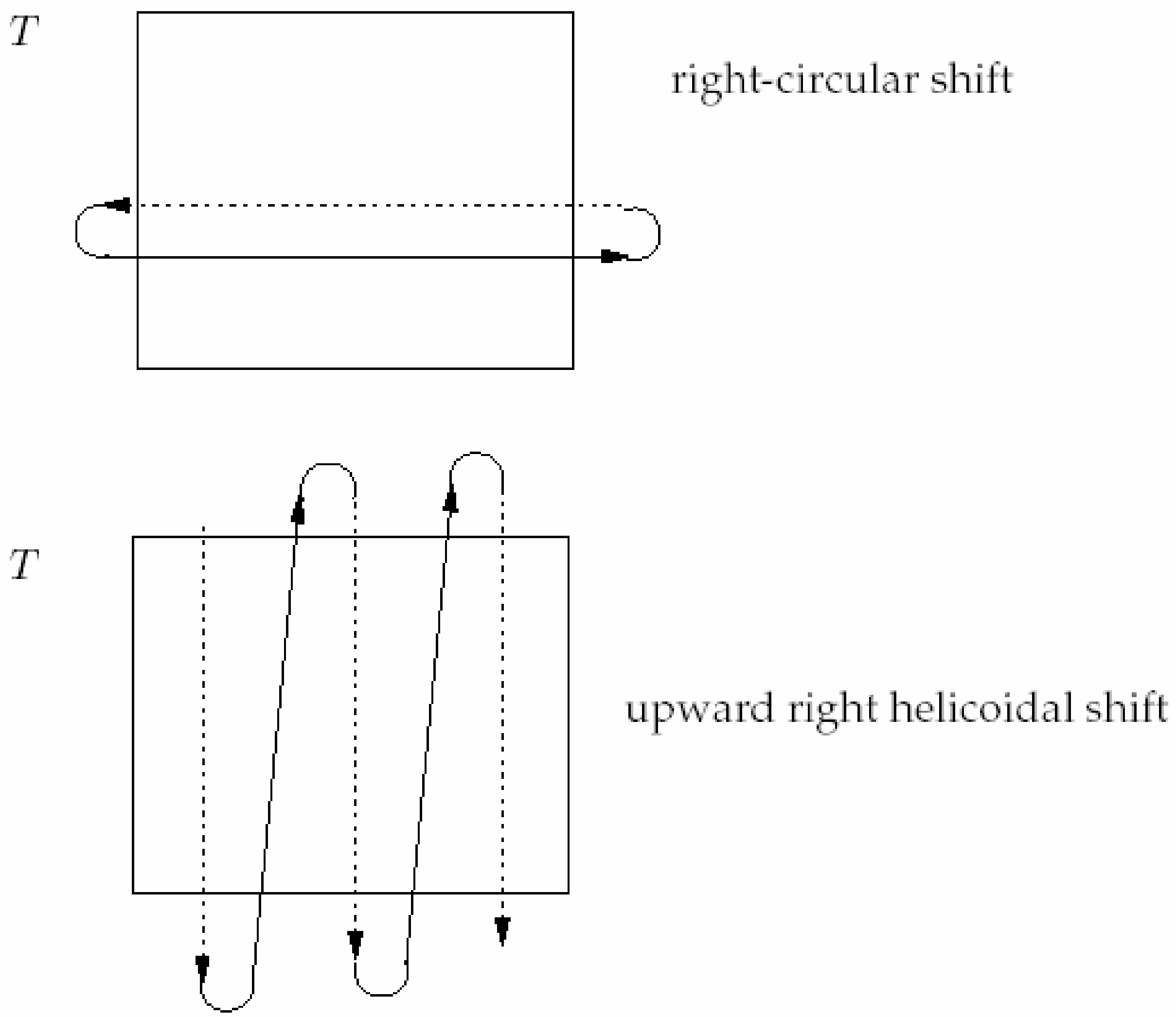


FIGURE 4. Shift definitions

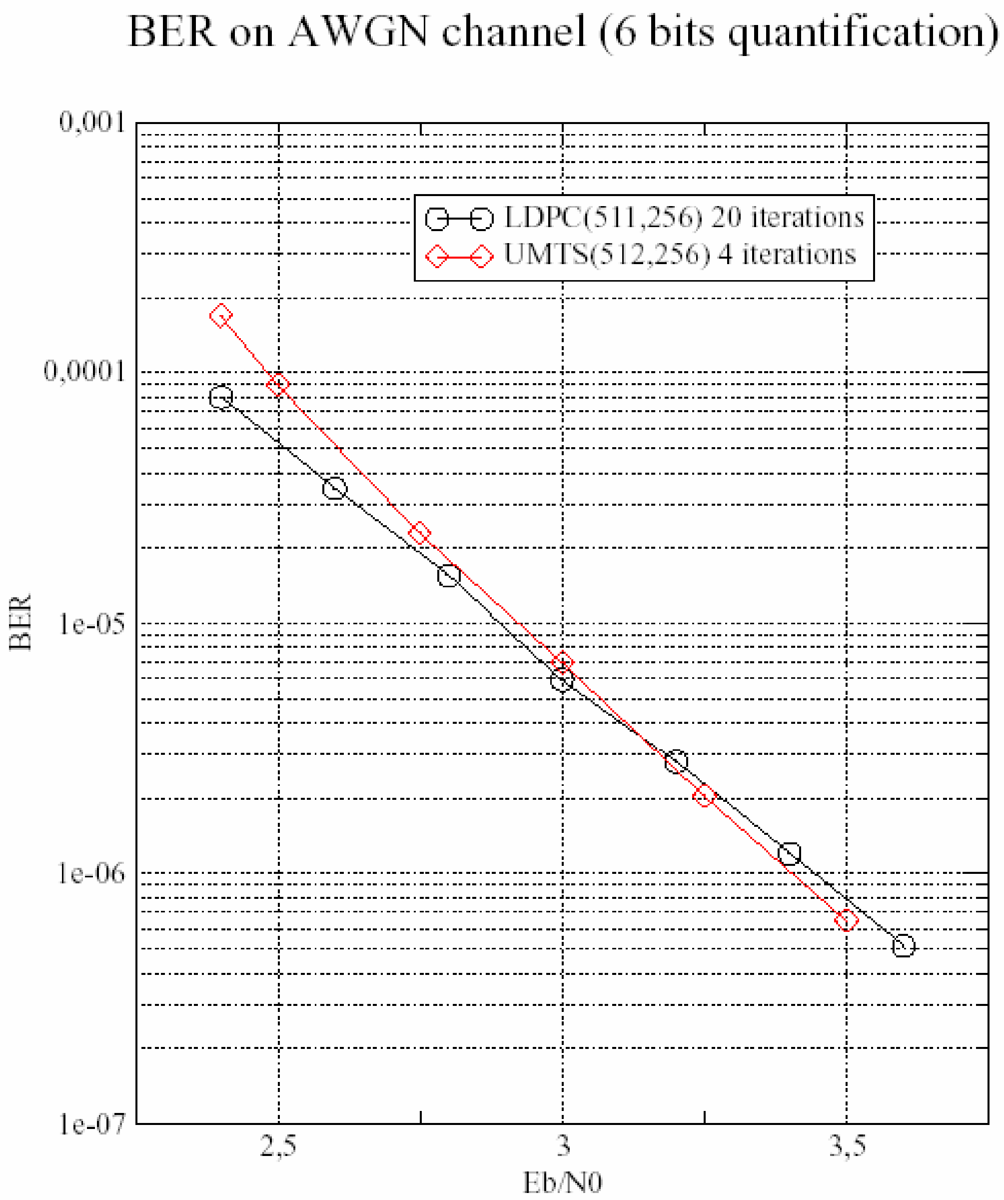


FIGURE 5. Error curve of the code under study vs UMTS turbo code

Adaptive MMSE Equalization of SOQPSK and FQPSK

Michael Rice
Telemetry Laboratory
Department of Electrical & Computer Engineering, Brigham Young University
Provo, Utah 84602, USA

Abstract

An adaptive version of a decision feedback MMSE equalizer suitable for use with offset QPSK is developed. Simulation results demonstrated the effectiveness of the adaptive equalizer for providing reliable communication with ARTM Tier-1 waveforms when operating over a multipath channel typical of that encountered at test ranges in the Western USA. The performance improvements were the most pronounced when the relative magnitude of the multipath interference exceed 50% of the line-of-sight magnitude. In this case, the bit error rate of unequalized SOQPSK-TG reached a bit error rate floor at approximately 10^{-1} while the bit error rate of equalized SOQPSK-TG showed continued decreases as the signal-to-noise ratio increased.

Introduction

The data rates required in aeronautical telemetry have increased from 100 kbits/sec in the early 1970s to 10 – 20 Mbits/sec today. The increase in data rates has caused severe crowding in the spectrum allocated to aeronautical telemetry in the USA (L-band 1435 – 1535 MHz, lower S-band 2200 – 2290 MHz, and upper S-band 2210 – 2390 MHz). The situation was made even worse in 1997 when the lower portion of upper S-band from 2310 to 2360 was reallocated to digital audio radio and wireless communications services in two separate auctions.

The spectral efficiency of PCM/FM, the dominant modulation used during this time, has proven inadequate. As a consequence, the Advanced Range Telemetry (ARTM) [1] program was launched by the Central Test and Evaluation Investment Program (CTEIP) in 1997 to identify more bandwidth efficient modulations. ARTM progressed in two phases. The goal of the first phase was to identify modulation formats with twice the spectral efficiency of PCM/FM when used with a fully saturated non-linear power amplifier while simultaneously maintaining the same detection efficiency. Feher-patented QPSK (FQPSK) [2] and a compatible variant of the MIL-STD 188-181 shaped offset QPSK (SOQPSK) [3] were selected. These two modulations, known collectively as “ARTM Tier-1 Waveforms,” have twice the spectral efficiency of PCM/FM [4].

As the data rates used for aeronautical telemetry have increased, the multipath interference has become increasingly frequency selective and has proven to be the dominant channel impairment. A model for the frequency selective multipath interference common in aeronautical telemetry is described in [8]. Since the multipath parameters change as the airborne transmitter progresses along a flight trajectory, any compensation technique (such as equalization) must be adaptive. This describes an adaptive MMSE equalizer suitable for use with the ARTM Tier-1 waveforms to compensate for the multipath distortion.

FQPSK and SOQPSK: The ARTM Teir-1 Waveforms

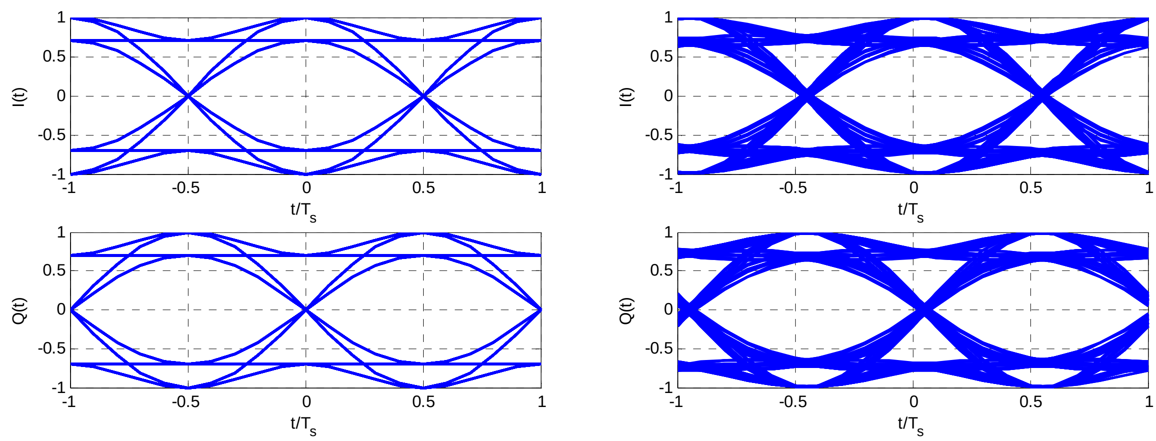
Feher-patented QPSK (FQPSK) is an offset modulation of the form

$$s_{\text{FQPSK}}(t) = I(t)\cos(\omega_0 t) - Q(t)\sin(\omega_0 t) \quad (1)$$

where

$$\begin{aligned} I(t) &= \sum_k S_{i(k)}(t - kT_s) \\ Q(t) &= \sum_k S_{q(k)}(t - T_s/2 - kT_s) \end{aligned} \quad (2)$$

and T_s is the symbol time (twice the bit time). The waveforms $S_{i(k)}(t - kT_s)$ and $S_{q(k)}(t - T_s/2 - kT_s)$ are selected from a set of 16 possible waveforms determined by the data transitions as described in [5]. The indexes $i(k)$ and $q(k)$ are thus in the set {0,1,…,15}. An eye-type plot of $I(t)$ and $Q(t)$ for FQPSK is shown in Figure 1(a).



(a) (b)

Figure 1: Eye diagrams for the inphase and quadrature components of FQPSK (a) and SOQPSK-TG (b).

The optimum FQPSK detector is a sequence detector using a trellis that accounts for the possible combinations of waveforms determined by the memory of the waveform mapper as described in [5]. In practice, a symbol-by-symbol detector like the one illustrated in Figure 2 is used since this type of detector is compatible with generic offset QPSK and SOQPSK. Simon [5] showed that the use of a detection filter whose impulse response matched to the average of the 16 possible waveforms performs 1/2 dB better in the AWGN environment than when integrate-and-dump detection is used. (The optimal sequence detector is about 1 dB better than the averaged matched filter.)

Shaped Offset QPSK (SOQPSK) is ternary CPM with modulation index h = 1/2. The modulated signal is of the form

$$s_{\mathrm{SOQPSK}}(t) = \cos(\omega_0 t + \phi(t)) \tag{3}$$

where

$$\phi(t) = \pi \sum_k \alpha(k) g(t - kT_b) \tag{4}$$

for

$$\begin{aligned} &\alpha(k) \in \{-1,0,+1\} \\ &g(t) = \int_{-\infty}^{t} p(x)dx \end{aligned} \tag{5}$$

where $p(t)$ is the frequency pulse with area 1/2 and T_b is the bit time. In MIL-STD 188-181, the frequency pulse is a rectangle with width T_b and height $T_b/2$. The ARTM Tier-1 waveform is a variant of the MIL-STD 188-181 waveform that uses a windowed raised cosine for the frequency pulse shape as described in [3]. The windowed raised cosine waveform is completely specified by 4 parameters ρ, B, T_1, and T_2. The original publication [3] presented two versions: SOQPK-A defined by ρ =1, B=1.35, T_1=1.4, T_2=0.6 and SOQOSK-B define by ρ=0.5, B=1.45, T_1=2.8, T_2=1.2. SOQPSK-A has a slightly narrower bandwidth (measured at the -60 dB level) and slightly worse detection efficiency than SOQPSK-B. The Telemetry Group of the Range Commanders Council adopted a compromise waveform designated SOQPSK-TG in 2003. SOQPSK-TG is defined by ρ=0.7, B=1.5, T_1=1.5, T_2=0.5.

The name “shaped offset QPSK” follows from the observation that each ternary symbol causes the carrier phase to either advance by $\pm\pi/2$ radians or remain at its current value. When viewed on an I-Q plot, the carrier phase appears to migrate from quadrant to quadrant along the unit circle, giving the appearance of an offset QPSK whose phase transitions have been “shaped.” A plot of $I(t) = \cos(\phi(t))$ and $Q(t) = \sin(\phi(t))$ is illustrated in Figure 1(b).

The optimum SOQPSK detector is a trellis detector that tracks the possible phase trajectories. As before, the symbol-by-symbol detector like the one illustrated in Figure 2 is used for compatibility. Detection filters for SOQPSK have been studied by Geoghegan, et. al. using experimental techniques [7].

In the numerical results that follow, “integrate-and-dump” detection is used. Integrate-and-dump detection is performed when the impulse response of the detection filter is

$$g(t) = \begin{cases} 1 & 0 \le t \le T_s \\ 0 & \text{otherwise} \end{cases}. \tag{6}$$

The I/Q detection points $x(kT_s)$ and $y((k+1/2)T_s)$ for FQPSK and SOQPSK-TG using the detection filter (6) are plotted in Figure 3 for the case of no noise. The points are scattered even though there is no noise due to the intersymbol interference (ISI) imposed by the inphase and quadrature pulse shapes. Since the pulse shapes were chosen to produce narrow bandwidth and a constant (or nearly constant) envelope, ISI is present.

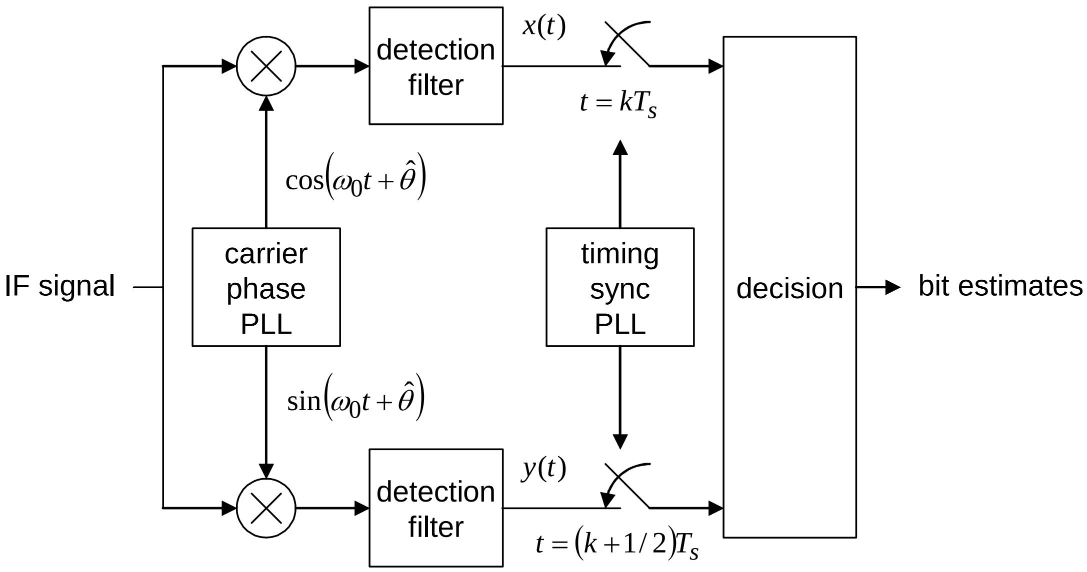


Figure 2: Generic detector for offset QPSK. This detector can also be used for symbol-by-symbol detection of FQPSK and SOQPSK.

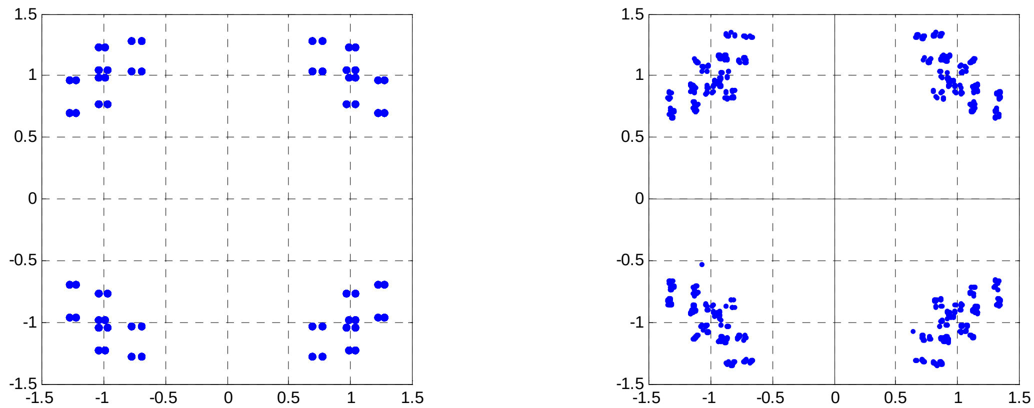


Figure 3: I/Q decision points for FQPSK (left) and SOQPSK-TG (right) using an integrate and dump detection filter in a noiseless environment.

Multipath in Aeronautical Telemetry

The propagation environments typical of test ranges in the Western USA support line-of-sight propagation when the elevation angle of the ground-based receiving antenna is high and additional propagation paths when the elevation angle is low. The additional propagation paths are characterized by a strong specular reflection with complex amplitude Γ_1 and delay τ_1 and a weaker diffuse reflection with complex amplitude Γ_2 and delay τ_2 [8]. The effect of frequency selective multipath interference is illustrated in Figure 4 for the case of a channel impulse response given by

$$h(t) = \delta(t) + 0.8e^{j6\pi/5}\delta\left(t - 45\times10^{-9}\right) + 0.01e^{j\pi}\delta\left(t - 155\times10^{-9}\right) \tag{7}$$

These are typical of the values measured at Edwards AFB, California. Figure 4(a) is a plot of the channel transfer function. Note the spectral null with 3-dB bandwidth

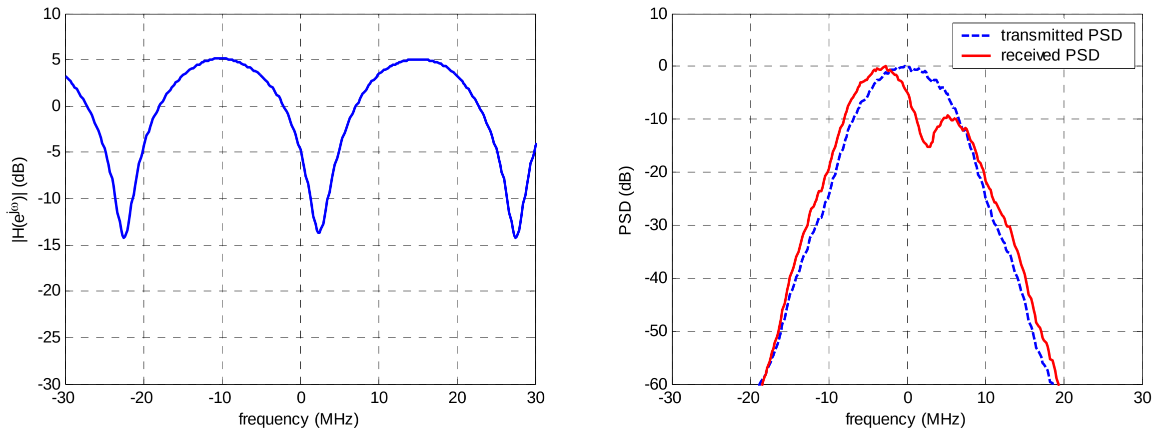
$$W_{3\mathrm{dB}} = \frac{1 - \frac{1}{\pi}\cos^{-1}\left(\frac{1 - 2\left(1 + |\Gamma_1|^2\right)}{4|\Gamma_1|}\right)}{\tau_1} = 5.5\,\mathrm{MHz} \tag{8}$$

and depth

$$D = -20\log_{10}\left(1 - |\Gamma_1|\right) = 14\,\mathrm{dB} \tag{9}$$

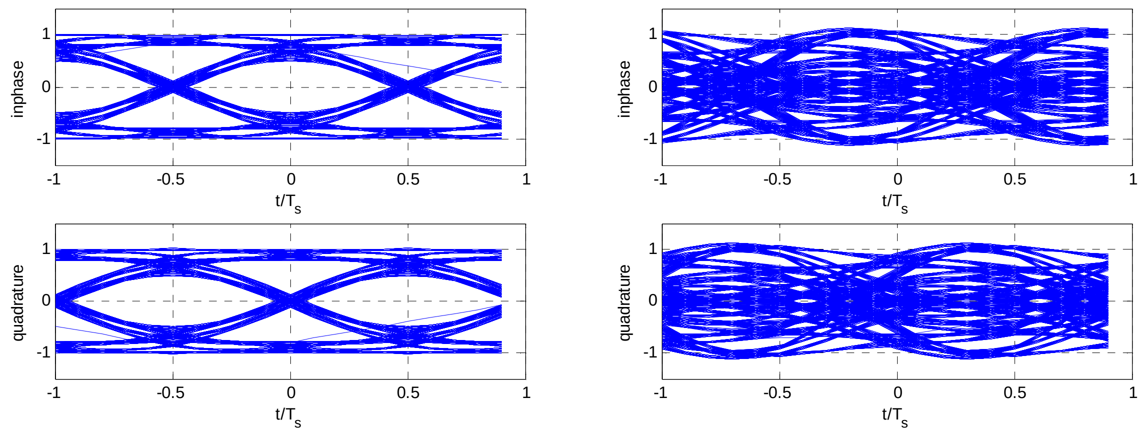
The frequency at which the spectral null occurs is determined by the phase of Γ_1 and the product of the delay τ_1 and the carrier frequency as described in [8]. The effect of this channel on 20 Mbit/sec SOQPSK-TG is shown in Figure 4(b). Note spectral null in the received spectrum just above the carrier.

The frequency selective multipath has a profound impact on the bit error rate performance of the signal. This is illustrated by the eye diagrams for 20 Mbit/esc SOQPSK-TG shown in Figure 5. For reference, the eye diagram for the case of no multipath interference is shown in Figure 5(a). The effect of the multipath channel (7) on the eye diagram in shown in Figure 5(b). Observe that the multipath distortion essentially closes the eye rendering reliable detection almost impossible.



(a) (b)

Figure 4: Frequency selective multipath commonly found in aeronautical telemetry. (a) Channel transfer function of corresponding to the impulse channel impulse response (7). (b) The effect of this channel on the spectrum of 20 Mbit/sec SOQPSK-TG.



(a) (b)

Figure 5: Eye diagrams for SOQPSK-TG using a simple integrator for the detection filter. (a) The eye diagram for the case of no multipath. (b) The eye diagram for the case of multipath interference given by the channel impulse response (7).

Adaptive MMSE Equalization for FQPSK and SOQPSK

I/Q equalizers are filters that operate on matched filter outputs in an effort to compensate for distortion induced by the channel. The equalizer filter taps may be designed based on a number of criteria as described in [9]. When the equalizer filter taps are chosen to minimize the square of the residual error between the target symbol values and the filter outputs the equalizer is a **minimum mean squared error** (**MMSE**) equalizer. When the equalizer filter is an adaptive filter, the MMSE equalizer is an **adaptive MMSE equalizer**.

The decision feedback MMSE equalizer for offset QPSK was developed by Tu [10]. In this paper, an adaptive version of the decision feedback MMSE for offset QPSK is presented. A block diagram for the adaptive version of the decision feedback MMSE equalizer for OQPSK is illustrated in Figure 6. The matched filter outputs due to the inphase and quadrature components of the received signal are sampled at twice the symbol rate (that is, at the *bit rate*) to produce a sequence pair $x(n)+jy(n)$ as shown. This sequence is filtered by the length-L_{FF} feed-forward filter with coefficients at time step n $w_{FF}^{(n)}(l)$ to produce the output

$$z_{FF}(n)=\sum_{l=-\frac{L_{FF}-1}{2}}^{\frac{L_{FF}-1}{2}} w_{FF}^{(n)}(l)\left[x(n-l)+jy(n-l)\right]. \tag{10}$$

This output is combined with the output of the length-L_{FB} feed back filter $z_{FB}(n)$ to form the signal $z(n)=z_{FF}(n)+z_{FB}(n)$. If the coefficients of the feedback filter at time step n are $w_{FB}^{(n)}(l)$, then the output of the feedback filter may be expressed as

$$z_{FB}(n)=\sum_{l=0}^{L_{FB}-1} w_{FB}^{(n)}(l)D(n-l). \tag{11}$$

where $D(n)$ is based on the decisions. $D(n)$ may be expressed as

$$D(n)=\begin{cases}\mathrm{Re}\{\hat{d}(k)\},\mathrm{Im}\{\hat{d}(k-1)\},\mathrm{Re}\{\hat{d}(k-1)\},\ldots & n\text{ even} \quad k=\dfrac{n}{2}\\ \mathrm{Im}\{\hat{d}(k)\},\mathrm{Re}\{\hat{d}(k)\},\mathrm{Im}\{\hat{d}(k-1)\},\ldots & n\text{ odd} \quad k=\dfrac{n-1}{2}\end{cases} \tag{12}$$

where the decisions are

$$\hat{d}(k)=\begin{cases}\mathrm{sgn}\left(\mathrm{Re}\left\{z\left(\dfrac{n}{2}\right)\right\}\right) & n\text{ even}\\ j\,\mathrm{sgn}\left(\mathrm{Im}\left\{z\left(\dfrac{n-1}{2}\right)\right\}\right) & n\text{ odd}\end{cases} \tag{13}$$

The error is based on the difference between the equalized output $z(n)$ and the data decisions and is given by

$$e(n)=\begin{cases}\mathrm{Re}\{z(n)\}-\hat{d}(k) & n\text{ even}, k=\dfrac{n}{2}\\ \mathrm{Im}\{z(n)\}-\hat{d}(k) & n\text{ odd}, k=\dfrac{n-1}{2}\end{cases} \tag{14}$$

The decisions and error terms alternate between real and imaginary components due to the offset nature of the modulation. The even-indexed samples carry the real part of the data while the odd-indexed samples carry the imaginary part of the data. This is the key difference between the MMSE equalizer for offset modulations and non-offset modulations.

The filter coefficient updates can be realized using any of the standard adaptive filter techniques such as LMS (and its variants) or RLS [11]. The numerical results summarized in the next section use the LMS algorithm, where the filter coefficient update follows the recursion

$$\begin{bmatrix} w_{FF}^{(n+1)}\left(-\dfrac{L_{FF}-1}{2}\right)\\ w_{FF}^{(n+1)}\left(-\dfrac{L_{FF}-1}{2}+1\right)\\ \vdots\\ w_{FF}^{(n+1)}\left(\dfrac{L_{FF}-1}{2}\right)\end{bmatrix}=\begin{bmatrix} w_{FF}^{(n)}\left(-\dfrac{L_{FF}-1}{2}\right)\\ w_{FF}^{(n)}\left(-\dfrac{L_{FF}-1}{2}+1\right)\\ \vdots\\ w_{FF}^{(n)}\left(\dfrac{L_{FF}-1}{2}\right)\end{bmatrix}+\mu e(n)\begin{bmatrix} x\left(n+\dfrac{L_{FF}-1}{2}\right)-jy\left(n+\dfrac{L_{FF}-1}{2}\right)\\ x\left(n+\dfrac{L_{FF}-1}{2}-1\right)-jy\left(n+\dfrac{L_{FF}-1}{2}-1\right)\\ \vdots\\ x\left(n-\dfrac{L_{FF}-1}{2}\right)-jy\left(n-\dfrac{L_{FF}-1}{2}\right)\end{bmatrix}$$

$$\begin{bmatrix} w_{FB}^{(n+1)}(0)\\ w_{FB}^{(n+1)}(1)\\ \vdots\\ w_{FB}^{(n+1)}(L_{FB}-1)\end{bmatrix}=\begin{bmatrix} w_{FB}^{(n)}(0)\\ w_{FB}^{(n)}(1)\\ \vdots\\ w_{FB}^{(n)}(L_{FB}-1)\end{bmatrix}+\mu e(n)\begin{bmatrix} D^{*}(n)\\ D^{*}(n-1)\\ \vdots\\ D^{*}(n-L_{FB}+1)\end{bmatrix}$$

where μ is an adjustable step size that controls the rate of convergence and coefficient error variance.

Numerical Results

The effectiveness of the adaptive equalizer is illustrated by the I/Q decision points illustrated in Figure 7. The I/Q decision points for 20 Mbit/sec SOQPSK-TG operating over a multipath channel with impulse response (7) are shown. The I/Q decision points without equalization are shown on the left while the I/Q decision points with equalization are shown on the right. 21 feed forward coefficients and 18 feedback coefficients were used in the simulation. The step size was 0.001 and 2500 training bits were used to initialize the equalizer. The improved look of the I/Q decision points also has a corresponding improvement in the bit error rate performance as illustrated by the simulation results Figure 8. The bit error rate performance with and without the equalizer are shown. It is clear that the equalizer provides significant performance gains in this type of multipath.

The performance of this same equalizer in a two-ray multipath channel with impulse response

$$h(t) = \delta(t) + |\Gamma_1| e^{j6\pi/5} \delta\left(t - 45 \times 10^{-9}\right) \tag{15}$$

are summarized in Figure 9. These plots summarizes the bit error rate performance of 20 Mbit/sec SOQPSK-TG as a function of E_b/N_0 for different values of $|\Gamma_1|$. The left plot demonstrates the bit error rate performance using an equalizer with 21 feed forward taps, 18 feedback taps and a step size of 0.001. 2500 training bits were used to initialize the equalizer filters before each simulation run. The right plot demonstrates the performance in the unequalized case. Substantial performance gains are obtained for $|\Gamma_1| \geq 0.5$. In this case, unequalized SOQPSK-TG reaches a bit error rate floor at about 10^{-1}. In contrast, equalized SOQPSK-TG shows continued bit error rate improvement as E_b/N_0 increases.

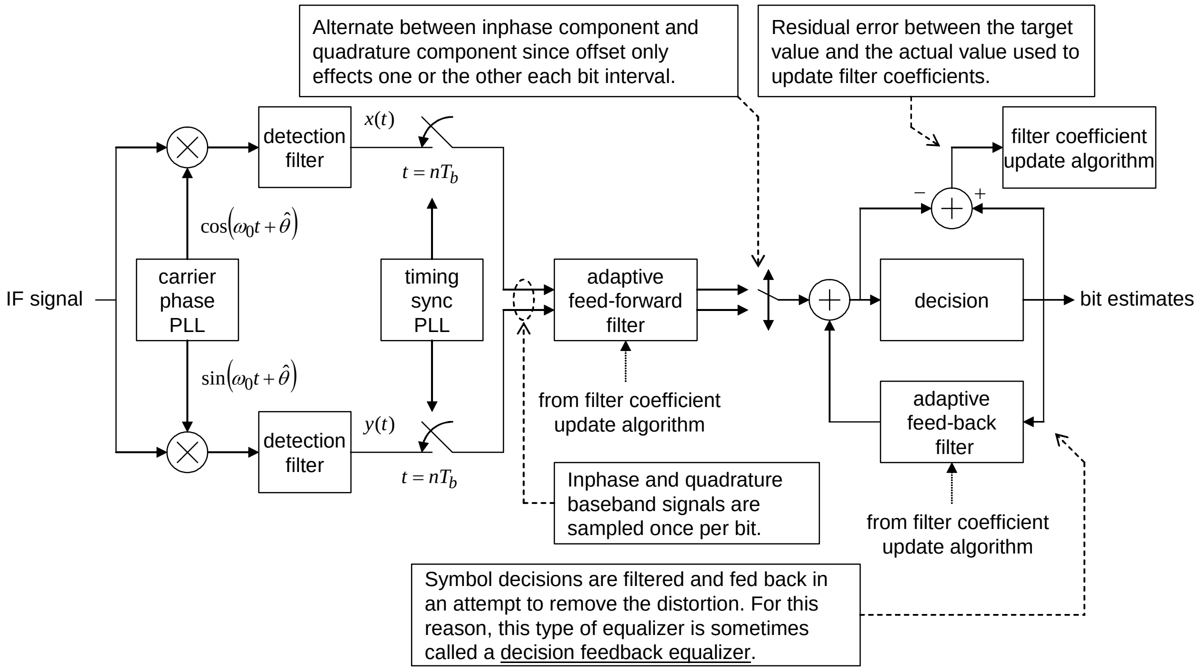


Figure 6: Block diagram of the adaptive decision feedback MMSE equalizer for SOQPSK.

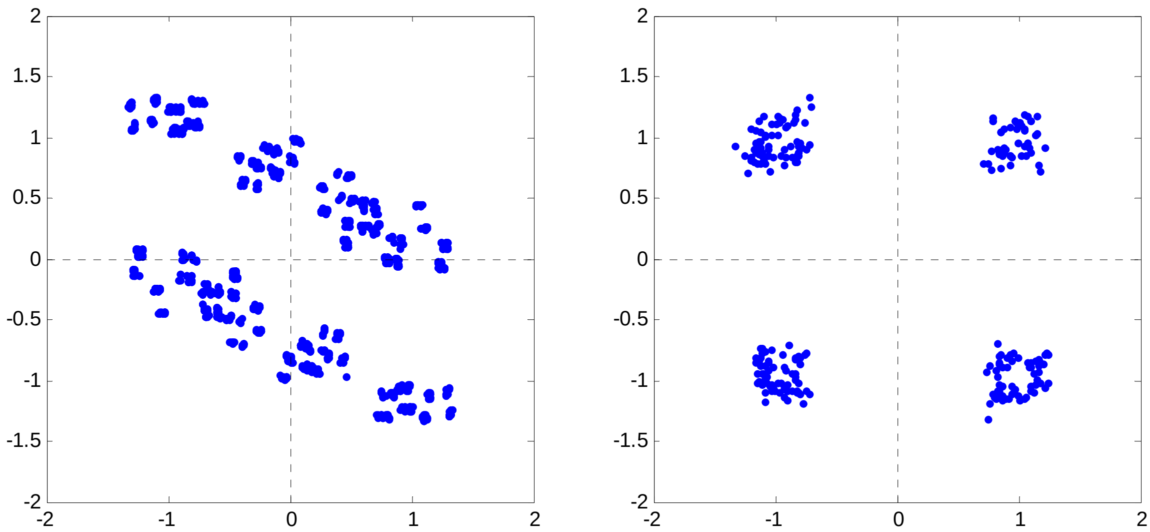


Figure 7: Performance improvement realized by the adaptive decision feedback MMSE equalizer applied to SOQPSK-TG transmitted over the channel with impulse response given by (7). The I/Q decision points without equalization are shown on the left. The decision points with equalization are shown on the right. The equalizer consisted of 21 feed forward coefficients, 18 feedback coefficients and used a step size of 0.001.

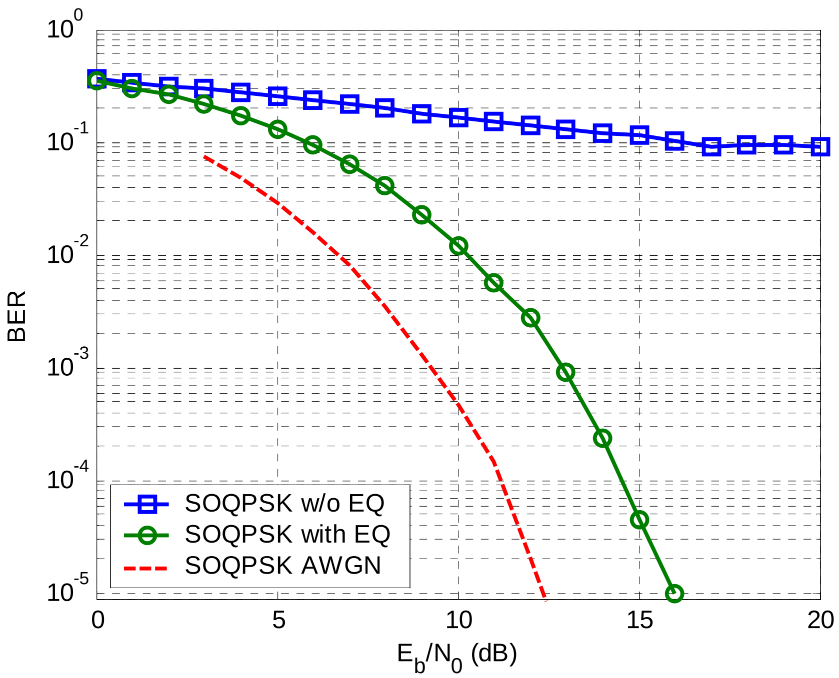


Figure 8: Bit error rate performance of 20 Mbit/sec SOQPSK-TG operating in a multipath channel with impulse response (7). The bit error rates with and without equalization are shown. The bit error rate performance of SOQPSK in the AWGN channel is included for reference.

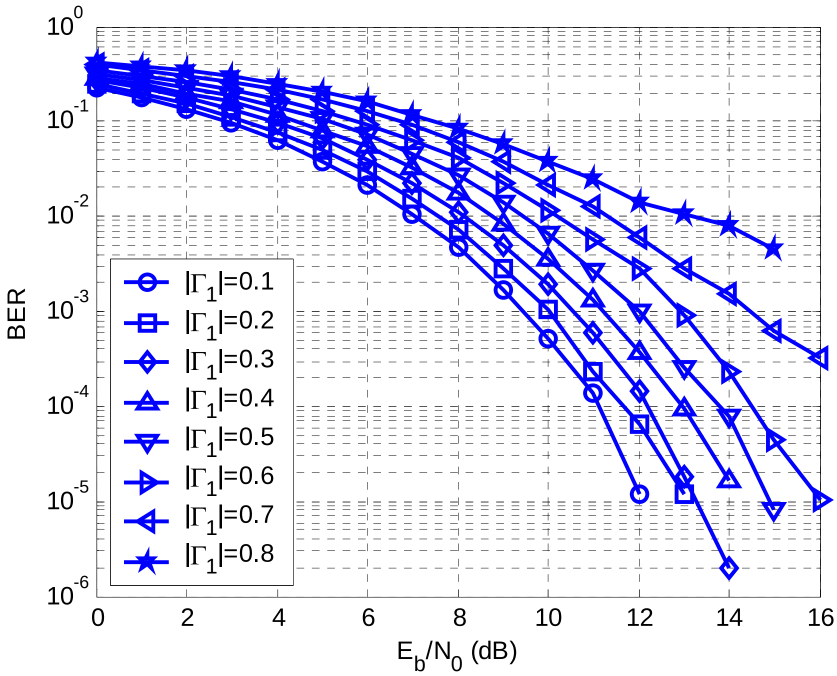


Figure 9: Bit error rate performance of 20 Mbit/sec SOQPSK-TG in the multipath channel with impulse response (15) with equalization. The equalizer consisted of 21 feed forward coefficients, 18 feedback coefficients and used a step size of 0.001. Compare with Figure 10.

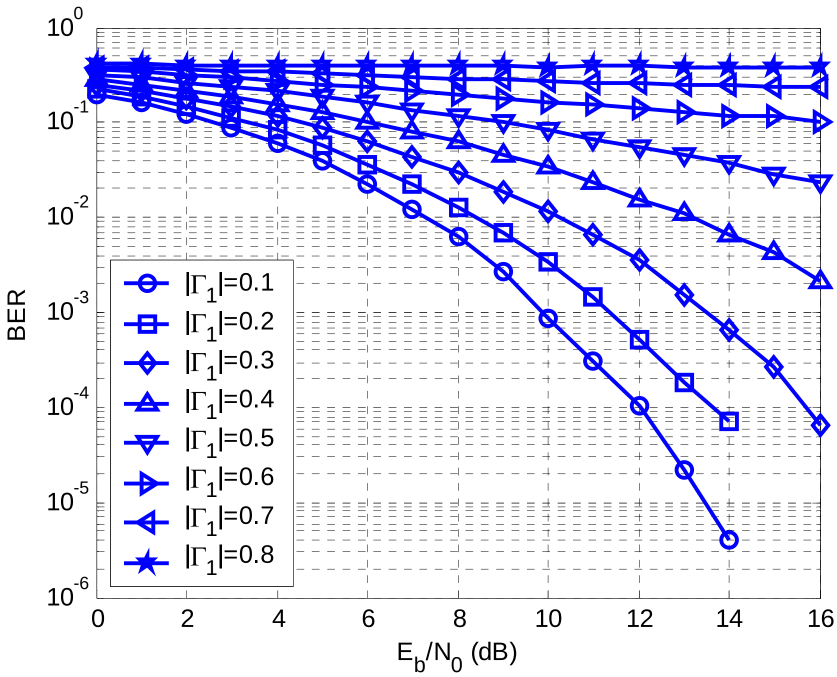


Figure 10: Bit error rate performance of unequalized 20 Mbit/sec SOQPSK-TG in the multipath channel with impulse response (15). Compare with Figure 9.

Conclusions

An adaptive version of a decision feedback MMSE equalizer suitable for use with OQPSK was presented. Simulation results demonstrated the effectiveness of adaptive equalizer for providing reliable communication with ARTM Tier-1 waveforms when operating over a multipath channel typical of that encountered at test ranges in the Western USA. The performance improvements were the most pronounced when the relative magnitude of the multipath interference exceed 50% of the line-of-sight magnitude. The adaptive form is necessary to track changes in the channel impulse response due to changes in the position of the air-borne transmitter. All simulation results used SOQPSK-TG. Similar results are obtained with FQPSK, but are not shown due to space limitations.

References

[1] C. Irving, "Range Telemetry Improvement and Modernization," in *Proceedings of the International Telemetering Conference*, Las Vegas, NV, October 1997, pp. 294—303.

[2] W. Gao and K. Feher, "FQPSK: A Bandwidth and RF Power Efficient Technology for Telemetry Applications," in *Proceedings of the International Telemetering Conference*, Las Vegas, NV, October 1997, pp. 480—488.

[3] T. Hill, "An Enhanced, Constant Envelope, Interoperable Shaped Offset QPSK (SOQPSK) Waveform for Improved Spectral Efficiency," in *Proceedings of the International Telemetering Conference*, San Diego, CA, October 2000, pp. 127—136.

[4] E. Law and K. Feher, "FQPSK versus PCM/GM for Aeronautical Telemetry Applications; Spectral Occupancy and Bit Error Probability Comparisons," in *Proceedings of the International Telemetering Conference*, Las Vegas, NV, October 1997, pp. 489—496.

[5] M. Simon, *Bandwidth-Efficient Digital Modulation with Application to Deep Space Communications*. Wiley-Interscience, 2003.

[6] *IRIG Standard 106-00: Telemetry Standards*. Range Commanders Council Telemetry Group, Range Commanders Council, White Sands Missile Range, New Mexico, 2000. (Available on-line at http://jcs.mil/RCC/manuals/106-00).

[7] M. Geoghegan, "Optimal Linear Detection of SOQPSK," in *Proceedings of the International Telemetering Conference*, San Diego, CA, October 2002.

[8] M. Rice, A. Davis, and C. Bettwieser, “A Wideband Channel Model for Aeronautical Telemetry,” *IEEE Transactions on Aerospace and Electronic Systems*, vol. 37, no. 1, pp. 1—13, January 2004.

[9] J. Proakis, *Digital Communications*, McGraw-Hill, 2001.

[10] J. Tu, “Optimum MMSE Equalization for Staggered Modulation,” in *Proceedings of the IEEE Asilomar Conference on Signals, Systems, and Computers*, Asilomar, CA, Nov 1993, pp. 1401—1406.

[11] S. Haykin, *Adaptive Filter Theory*, Prentice-Hall, 2001.

CircLink – a new concept for sharing data in distributed systems

Clemens Kästner
SMSC
Holzkirchen, Germany

Abstract

Sharing data within a Network is usually based on telegrams between certain nodes. Upper Layer Protocols care about fragmentation and data integrity. CircLink is a new concept based on a global memory within the distributed system. The CircLink protocol embedded in the CircLink controller cares about the automatic update of this global memory for all nodes implemented within the network. Various data security methods are already implemented on the hardware layer to eliminate the need for upper layer protocols.

Introduction

Networking for industrial and automotive systems started with using custom systems targeted for specific application needs and migrated to industrial standards based on technologies like CAN or other systems driven by some of the market leaders in various segments. Most of these implementations do however not really meet the actual requirements today and carry an extensive overhead of upper layer protocols. The current trend of implementing Ethernet on all levels of networking even more introduced overhead in terms of protocol layers and networking topology (switched environment) to meet real time requirement for industrial systems.

CircLink does address this issue by using a bus arbritation that guarantees deterministic behavior by its nature plus it introduces new elements like Network Standard Time (NTS) and enhanced error detection and correction methods on Layer 2 to eliminate the needs for an upper layer protocol.

Communication within a network typically is based on data telegrams between two nodes. Upper layer protocols care about fragmentation and error detection / correction. Global messages are transferred using Broadcast not implementing error detection / correction.
There are different Nodes defined. Master Nodes can initiate communication, Slave Nodes will only communicate upon requests initiated by a Master. The Arbritation controls access to the Bus.

Common methods are:

- CSMA (Carrier Sense Multiple Access) with CD (Collision Detection) or CA (Collision Arbitration). CSMA does not guarantee deterministic behavior unless it is a Single Master setup. Determinism can only be guaranteed if there is a prioritization scheme defined or a dedicated communication channel between the nodes (Switch) is implemented.
- Token Passing allows Nodes to access the Network based on a Token. Only the Node that actually holds the Token can communicate and pass the Token. The Token Round Time defines the determinism within the network.

Enhanced Token Passing Protocol
CircLink utilizes an enhanced version of the token passing protocol defined by ANSI878.1 (Arcnet). Unlike the original specification CircLink is based on a predefined token passing scheme. Each Node can transmit one data packet as soon as it gets the token and will then pass the token to it‘s own NodeID+1. If the Token passing fails the node can either retry to pass the token to ID+1 once or immediately pass the token to ID+2. This avoids the token to get lost if single nodes fail within the system. Nodes will automatically rejoin the network as soon as the problem is fixed. The token round time can be calculated based on the number of nodes to be implemented and the data packet size utilized by each individual node (between 1Byte and 256 Byte)

Number of Nodes: 8
TX packet size: 16 Byte
Data Rate: 5 Mbps

Token round time = ((141.0 + 4.4 x 16) x 8 x 2.5/5)us = 845.6us

Figure 1 Token Round Time Calculation

Upon Power Up Reset CircLink will assign the Token to Node 1, thus there is no configuration cycle needed as defined by the original ANSI standard. CircLink assumes a sequential node-numbering scheme to avoid overhead in the token passing process. Leaving certain Node ID‘s blank still allows for adding nodes.

Communication Elements
CircLink implements a basic but yet powerful handshake mechanism to guarantee data integrity. In free format communication mode the transmitting node will first send a free buffer enquiry (FBE) to the recipient, get an acknowledgment back (ACK) an will then pass the data followed by a CRC (PAC). The receiver will do a CRC calculation based on the received data packet, compare the CRC with the one attached and send an ACK to confirm. This is already implemented on Chip level without any upper layer protocol necessary.
In Remote Buffer Mode only Broadcast packets with CRC attached will be used. Packets will only be copied into the internal Buffer if the CRC calculation matches. This is a very unique method to guarantee data integrity using broadcast messages.

ITT: (Token)	ALERT | EOT | NID | NID
FBE:	ALERT | ENQ | NID | NID
PAC:	ALERT | SOH | SID | DID | DID | CP | DATA … | CRC | CRC
ACK:	ALERT | ACK
NAK:	ALERT | NAK

Figure 2 CircLink Protocol Elements

Physical Interface
A CircLink controller is purely a protocol chip used with any physical interface to meet the application specific requirement. A Coded Mark Inversion (CMI) code is utilized to allow single bit error correction and simple isolation using a transformer.

Network Standard Time (NST)
NST has been introduced to provide a powerful method to synchronize all nodes within the network. Every CircLink node implements a free running configurable 16 Bit timer. A Clock Master (CM) Node attaches its NST to all datapackets sent. Clock Slaves (CS) automatically adjust their own NST to the CM and generate an unlock flag if running out of sync. This does provide synchronization within the network down to a 0.8us resolution plus it provides a very powerful watchdog mechanism for the whole system.

Communication Modes

- Free Buffer Communications allows an individual node to pass a datapacket of variable length between 1-256 Bytes to any other nodes within the network. Broadcast messages are used if all nodes within the network should be addressed. Handshakes are implemented on protocol level. This communication mode is quite common for all network protocols used today and was already defined in ANSI878.1.

- Remote Buffer Mode is a new communication mode introduced for CircLink. While communication was typically based on dedicated messaging between certain nodes, CircLink uses a page-oriented buffer within each buffer. The fragmentation of the buffer depends on the maximum number of nodes implemented within the network and will provide page sizes between 32 Byte and 256 Byte. As soon as a node gets the token it will send its own page to the network, every other node will copy this page after a successful CRC check into its own buffer. Within one token round time all nodes will get a full update of their internal buffer. Communication in Remote Buffer Mode is not based on dedicated messaging between individual nodes any more. Every node has basically real time access to the data of any other node within the network. The internal buffer acts as a global memory for the system. This does fully eliminate the need for any upper layer protocol. System variables to be shared among the system simply have to be stored within the CircLink buffer.

Conclusion
CircLink is a perfect communication system for real embedded applications eliminating the need for upper layer protocols. Connectivity to any other open standards can be implemented using gateways. This will combine a real deterministic solution within the system and e.c.TCP/IP connectivity to the outside world.

Literature

1. Satoh, Shumei: The Development of Communication Protocol for Real Time Control, SAE2002
2. http://www.arcnet.de
3. ANSI/ATA 878.1-1999: Local Area Network: Token Bus

Advanced Network Engineering and Applications from Space Missions

Eduardo W. Bergamini
Application Services in Space Missions - SAME
Instituto Nacional de Pesquisas Espaciais - INPE
São José dos Campos, SP, Brazil

Wilson V. Ruggiero
Laboratory of Computer Architecture and Networks - LARC
Escola Politécnica da Universidade de São Paulo - EPUSP
São Paulo, SP, Brazil

Gerhard K. L. Mayer
German Remote Sensing Data Center - DFD
German Aerospace Center - DLR
Oberpfaffenhofen, Wessling - Germany

Areas / Keywords

Information Network, Near Real-Time Processes, High Volume Data Communication, Distributed Archiving, Quality-of-Service, Data Compression, Earth Sea & Land Observation & Monitoring Data, Space Data Systems Standards.

Extended Summary

This presentation reflects aspects of advanced network engineering being considered in conjunction to applications derived from space missions. It derives from the initiative being taken in a multilateral cooperation work involving Brazilian and foreign institutions. These institutions are: 1) INPE - Instituto Nacional de Pesquisas Espaciais; 2) DLR - German Space Agency; 3) EPUSP - Escola Politécnica da Universidade de São Paulo and; 4) UFRPe - Universidade Federal Rural de Pernambuco. Other foreign institutions, not mentioned in this context, are also involved in this initiative.

The basic Project that motivated this initiative is the existing, on going, International Cooperation Project between INPE (Brazil, BR) and DLR (Germany, DE), entitled 'SLIM-Space Linked Multimedia Information Network Applied to Science, Research and Education'. This Project has different topics being explored in the context of this international, multilateral cooperation. One of these topics is committed to the development and consequent pilot operation of Application Services dedicated to near real time data transport, buffering and temporary storage, derived from satellite tracking and data acquisition operations, in the form of image and other embedded and related data contents. This text summarizes that specific topic, related to the SLIM Project.

The development of the mentioned topic and operation of the resulting pilot Application Services require the use of advanced techniques related to high speed data network engineering and servicing. Those techniques include, but are not limited to, topics related to: The Management of Information Networks; The trade-offs in Quality-of-Service, which result from Measurements derived from constraints that influence the identification and choice of compromising parameters that dictate the Performance, related but not restrict to: Alternative Routing and Temporary Data Buffering and Storage; Confrontation of Medium/High Speed versus High Volume versus (Near) Real-Time Data Transport requirements; Distributed Data Archiving and Availability to Authorized Users; Content Oriented Lossless and Lossy Data Compression Tools; Exploration of Multimedia, mainly, image and other data contents for Value Addition , in support to User Oriented Data Products; Plus other topics, not mentioned in this context of this cooperation project.

It is, therefore, of fundamental importance the efficient use of the highest possible channel bandwidth and of buffering and temporary storage capacity for each information network, in support to a Pilot Application Service identified and characterized in the realm of this Project activity. For instance, the capability of servicing the topology of an information network where the use of remote visualization, static and, possibly, animated (dynamic), is required, is desirable, in respect to data products which are expected to be accessed by authorized users.

The main nodes or backbone of the network topology which is being considered for characterizing the many information networks to be considered in the pilot realization of the Pilot Application Services being considered under this initiative, are: 1) LARC/ EPUSP, in São Paulo, SP, BR; 2) DFD/DLR, the German Remote Sensing Data Center, in Oberpfaffenhofen/Wessling, in Germany; 3) INPE/MCT, in São José dos Campos, SP, BR; 4) GEOSERE (Lab. of Geographic Remote Sensing/UFRPe, Recife, PE, Brazil. Each different combination for the utilization of those network backbone nodes and of their pertinent links result in a specific topology of information network, depending on the data products which are considered in remote processes which execute the download or upload of pertinent data products. For instance, on a regular servicing time basis, TIROSN/NOAA/AVHRR image and appended data, being tracked and acquired at UFRPe will be regularly downloaded to EPUSP for temporary storage and access by INPE authorized scientific research group users, while a concurrent process for immediate (near-real-time) upload of, possibly the same, data product to DLR Remote Sensing Data Center (DFD) will be also under execution.

Another Pilot Application Service is being considered under this topic of International cooperation, related to the satellite mission BIRD (Bi-spectral InfraRed Detection), a German, Earth infrared mapping mission, of interest to INPE for the monitoring of land use and vegetation (forests, etc.), among other possibilities.

In view of the cited pilot applications and of the already cited topics, advanced network engineering with its related application tools and methodologies will be playing a fundamental role in constantly seeking an efficient use of bandwidth, buffering and temporary storage capabilities of the existing medium to high speed networks, at National and International level, where the pertinent information networks are being immersed. Additionally, as part of the strategy for obtaining the best possible performance of data transport under real circumstances, the exploration of diversity of end-to-end data link paths, in view of the existing backbones at National and International level, is also under consideration.

<u>Topology of the Information Networks</u>

The aggregated configuration obtained from the parcial information networks involved in the many applications adds us to a backbone topology which is represented in Figure 1.

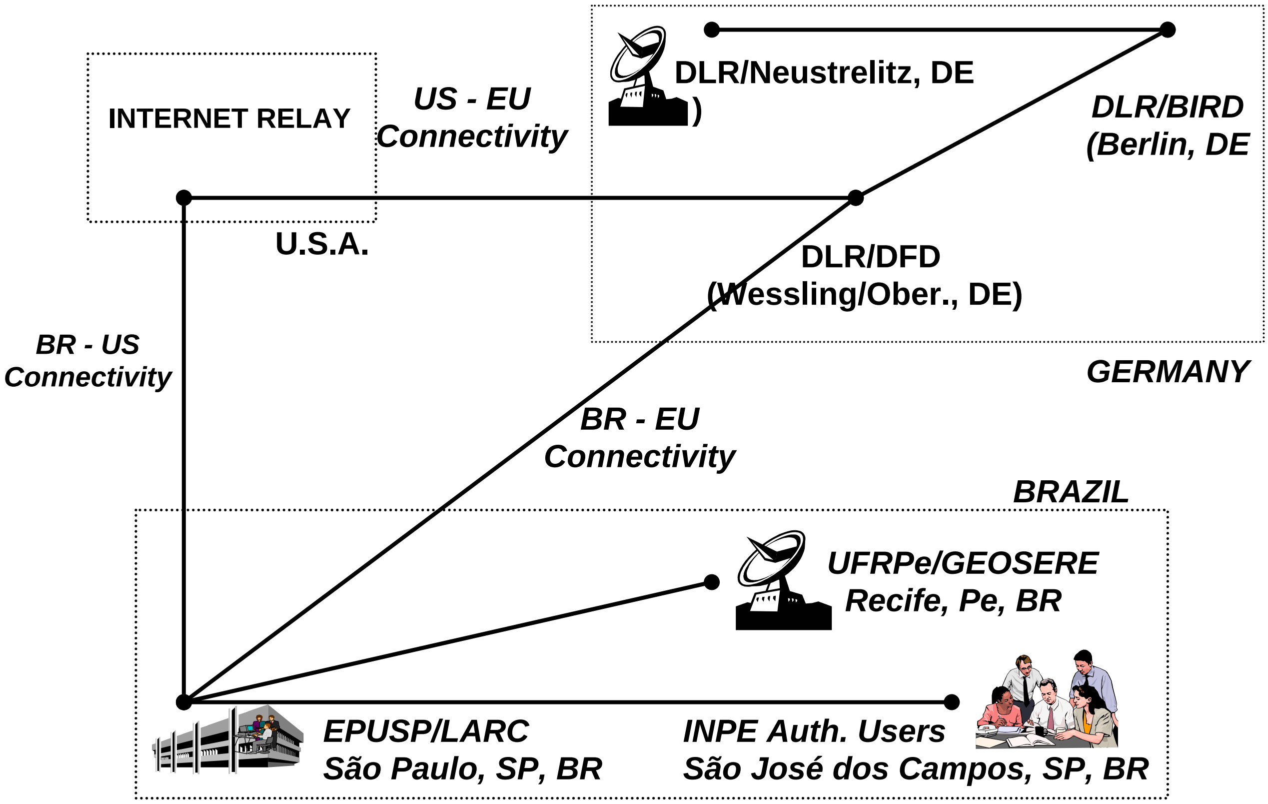


Figure 1 - Backbone Topology of the Information Networks

Breaking down in details, Figure 2 illustrates details of two nodes of the presented topology. Namely, they are: 1) The UFRPe/GEOSERE network node, in Recife, Pernambuco, Brazil, for imagery raw data and products source and; 2) The LARC/EPUSP network node, in São Paulo, SP, Brazil, acting as data collection and distribution center.

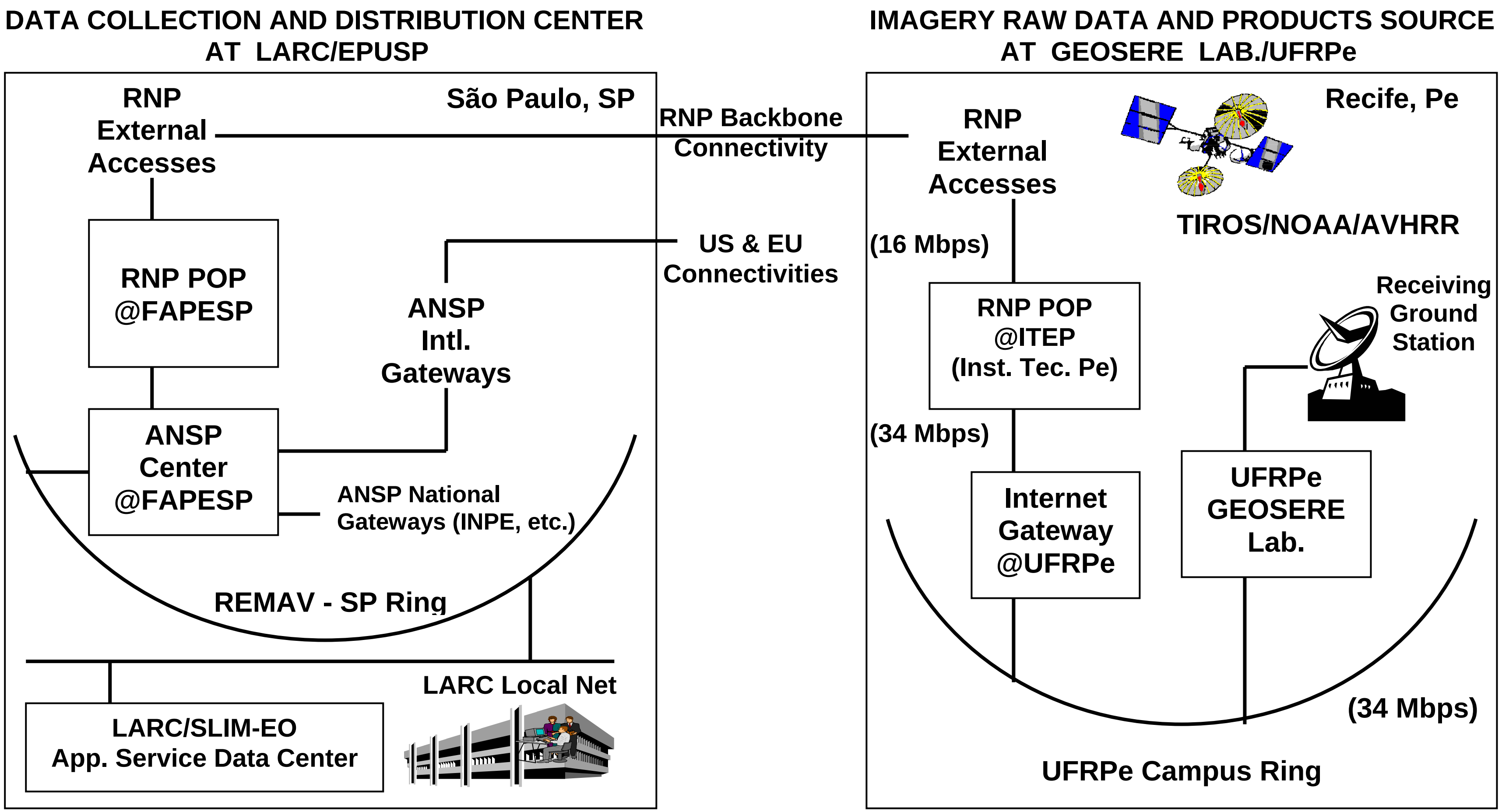


Figure 2 - Relevant Details of Local Topologies

Raw and Value Added Data Products Volumes for Transfer

The nature and volumes of data in raw and in value added product formats which are under consideration for transport through the pertinent information networks, observe the following relation:

- **RAW DATA**
  - AVHRR/NOAA/TIROS HRPT multi-spectral satellite images NOAA 17 descending orbit ; NOAA 12 and ascending orbit NOAA 16 satellites, as back-ups : 4 passes (2/day + 2/night) @ ~ 80 MB/pass, uncompressed;

  - BIRD (Bi-spectral Infra Red Detection) satellite images : Eventual collection @ ~ 40 MB/pass, uncompressed;

- **VALUE ADDED DATA PRODUCTS**
  Derived from AVHRR images :

  - NDVI (Normalized Differential Vegetation Index) Images: 2 passes/day @ ~ 10 MB/pass, uncompressed;
  - SST (Sea Surface Temperature) Images: 4 passes (2/day + 2/night) @ ~ 10 MB/pass, uncompressed;
  - LST (Land Surface Temperature) Images: 4 passes (2/day + 2/night) @ ~ 10 MB/pass, uncompressed.

Legend: HRPT - High Resolution Picture Transmission
AVHRR - Advanced Very High Resolution Radiometer

Service Information Networks (INs)

The four Information Networks (INs) which are represented in Figure 3 are the main segments of the overall network topology represented in Figure 1, now, expliciting their specific, main functions which are assigned to each one of the pertinent segments.

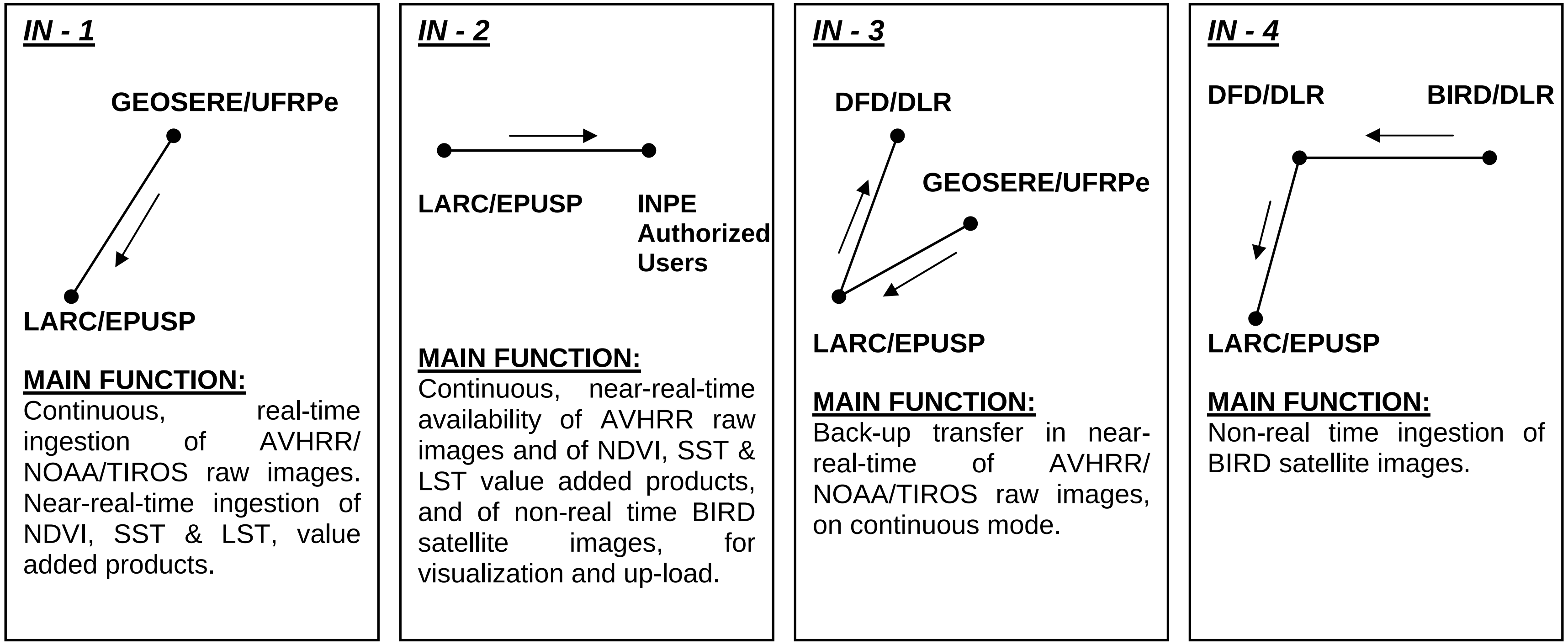


Figure 3 - Main Service Information Networks (Ins)

Pilot Applications of the Service

Two, main application services are under consideration, each one of them, covering a main topic, namely: 1) Oceanography and; 2) Land Use. Each of the two main topics are of interest for actual applications, respectively related to the following subjects:

- **Oceanography**
  - Sea Temperature of Atlantic Ocean
  - Sea Buoy Network Data (Intl. Coop. Project), from TIP (Tiros Information Processor), embbeded in AVHRR imagery
  - Sea Currents
  - Other applications

- **Land Use**
  - Land Surface Temperature
  - Vegetation Index and Thematic Survey
  - Agriculture Thematic Survey
  - Other applications

Components of the Application Service

The structure of each of the application services are being considered to be composed by the following, main components:

- Plan -of- operation (operational maintenance)
- Automatic data transfer processes
- Data transfer processes on demand
- Temporary archiving
  - Transport buffers
  - User access buffers
- Medium and long term archiving
- WWW - URL (metadata, low resolution products, etc.)
- Authorized user extranets

Important Topics under Consideration

The following topics are under fundamental consideration as part of the network features in support to the application services:

- Constant evaluation of the bandwidth of each segment of the topology: spectral capacity in function of time;
- Monitoring of alternative routing paths for National and International connections;

- Best possible performance for real and near-real-time data availability;
- Structuring of Directories for temporary, medium and long term archiving;
- Criteria for on-line and off-line archiving;
- Structuring of Web site for metadata and other complementary informations;
- Use of Extranets / Authorization for data access, delivery or dissemination;
- Exploration of data compression schemes.

Other Related Research Topics

As part of the objectives in further developments of the mentioned application services, the following, additional topics are also under consideration as part of a research for supporting the development of better features, for them:

- Exploration of Multimedia techniques for: imagery animation, composition and aggregation of other related data;
- Performance measurements for real and near-real time data servicing with hybrid, medium to high speed network topologies;
- Static and dynamic routing diversity for optimization of data speed segmentation and for availability of connectivity;
- Exploration of Tele-Education schemes with the scientific applications;
- Lossy and lossless compression schemes optimized for context oriented data structures.

Conclusion

A fairly detailed overview of a long term project destined to support application services in space missions, based on the use of medium to high speed data transport networks, is presented. Details of the: network topology, nature of applicative information associated to the data transport, besides of the basic technical features which are being considered in the implementation of the mentioned services, have been considered in this presentation. This contribution was made possible as a result of an existing international cooperation effort between Brazil and Germany, motivated from existing space mission directly derived data sources.

References

There are no specific bibliographic sources which are worth mentioning in this context. Naturally, being derived from an international cooperation project, reports do exist at internal level of the envolved organizations, related to the context. However, they do not add information which is worth referencing, in this case. As a general reference to the involved organizations, the following web site references are recommended:

1) <http://atsme.sites.uol.com.br/> and <http://www.inpe.br>

2) <http://www.dlr.de/caf>

3) <http://www.larc.usp.br>

Acquisition and Transmission of Seismic Data over Packet Radio

Martin Hinterseer
Christoph Wegscheider
University of Salzburg, Institute for Computer Science
Salzburg, Austria

1. Abstract

SEISDAC is a students project of the Univerity of Salzburg. The purpose is to develop a system of autonomous field stations and a central station which gathers, evaluates and distributes seismic data. The data will be sent to a central station via a ground to ground packet radio link, which is relatively easy to implement in regions with lack of infrastructure. In future a satellite packet radio link is also taken into consideration.

2. Introduction

Earthquake and vulcano research is an important field in tectonic instable regions because of various reasons.
On the one hand this field of interest is near the „own home“ of our indonesian partners, on the other hand many practical benefits can be discovered. The results of the research contributes essentially to save human lifes and keep physical damage on a low level.
To enlarge the possibilities of civil defence and science a continuous acquisition of seismic data over an wide area would be of great advantage.

For this reason a system of autonomous field stations is needed, which collect seismic and possibly other data. Also the data should be preprocessed to save bandwidth in such a way that no information is lost. The following points must be taken into consideration:

- autonomous operation and energy supply
- low power design
- data acquisition in real time
- data preprocessing an preevaluation for a realtime relevance check
- Data transmission to a central station as quick as possible (bandwidth problem)

A first prototype will be implemented in Indonesia because it is a country which meets the main goals of the whole project (difficult field conditions, great distances, seismic activities). The project is also supported by the University of Yogyakarta (Indonesia), which has research activities on volcanos and earthquakes.
The data would be transmitted over the local packet radio network, run by LAPAN the National Aeronautics and Space Institute.

3. System Overview

The system consists of a number of field stations located around volcanos, which gather and filter seismic data. These field stations will send the data to the central station. The data transmission will be done over a packet radio network called Jasipakta which is maintained by LAPAN. Due to the radio based data transmission a field station is not bound to a location with communication infrastructure, the only limiting factor is the power supply. To overcome this restriction the field stations will be solar powered and can therefore operate from any location within a certain radius of a digipeater (packet radio router).

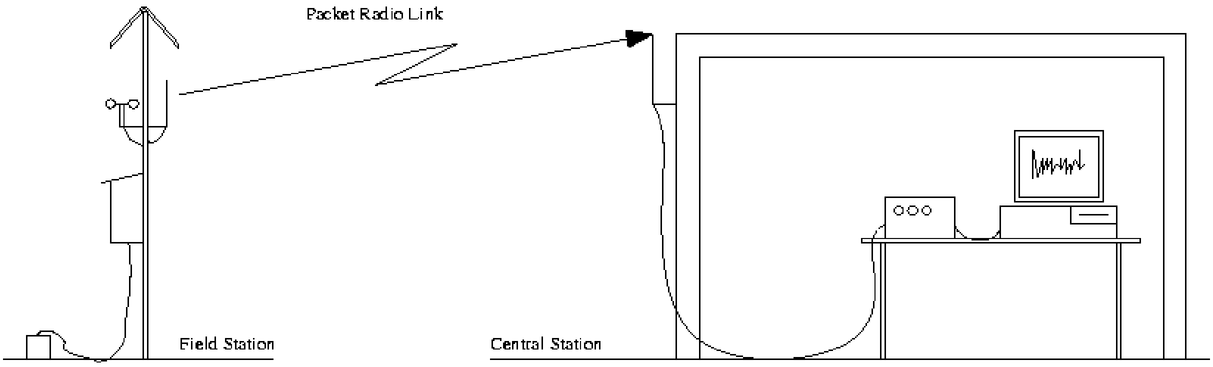


Fig. 1: Field and Central Station

3.1 Concept

The idea of the system is to continuously acquire the seismic data, split them up in discrete intervals and analyse them one after another. The goal of the analysis is to decide whether there was some seismic activity in this interval or not. If there was no activity the data of this interval are discarded, else the data are stored on a non-volatile memory (probably an USB-Stick), for backup reasons, and will be sent to the central station.
On arrival the data will be stored in a database. This database can be queried by the scientists in order to get data for their research. The field stations will periodically send status information to the central station for the operator to discover possible problems. The operator can also explicitly request such status information for a specific station. It will also be possible to switch a field station from the event driven mode (filtering the data) to a continuous mode where all gathered seismic data are transmitted.

3.2 Software

The main software of a field station consists of three parts, which implement the above described behaviour (Fig. 2). The first one is the Data Acquisition part which is getting continuous data from the seismometer, split them up into intervals, analyse them and decides whether there is seismic activity or not. It forwards the remaining data to the Network Client part (NC) which stores them on the USB-Stick and ensures that the data get transmitted to the central station.

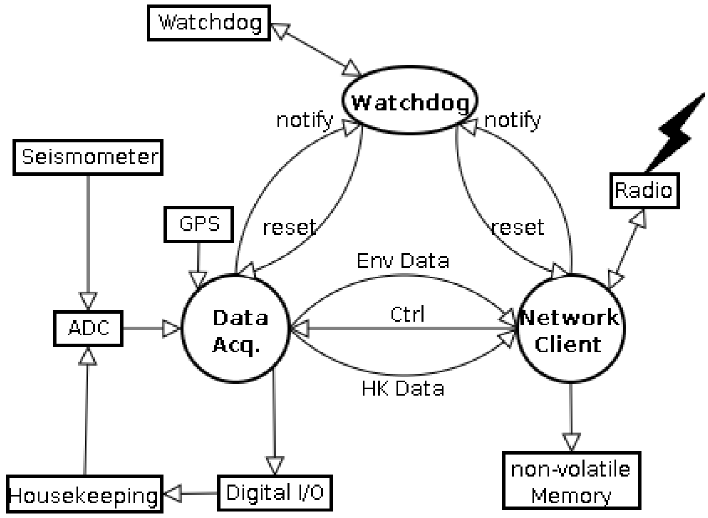


Fig. 2: Field Station: Software Overview

There the Network Server part (NS) is receiving the data and stores them in a database (Fig. 3). An application part (maybe web based) will provide an user interface to the database for the scientists. An operator can send a status query to a specific station in order to see its status. This query will be sent by the NS part to the field station where the NC answers it. The NS will receive the answer and stores it in the database along with the seismic data. This means every seismic data and status information as well as general information of the specific field stations (exact location, operating times, ...) are stored permanently in the database. The command to switch between event driven and continuous mode will be forwarded to the data acquisition module, when received at a field station by the NC.

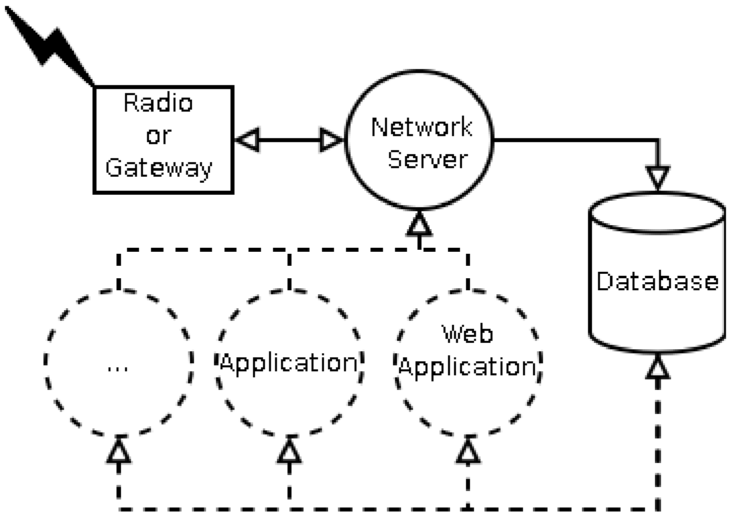


Fig. 3: Central Station: Software Overview

The NC and the data acquisition parts are periodically sending notifies to the third part, the software watchdog. If the watchdog notices that there are no more notifies from one of the two parts, it assumes that this part has crashed and restarts it. If the watchdog part or the whole system crashes the hardware based watchdog will reboot the field station. In order to detect a system crash the software watchdog periodically sends notifies to the hardware watchdog. In case of a system crash all data, not transmitted before, will be lost. This sounds dramatically but it is not, because there is still the backup on the USB-Stick.

3.3 Operating System

The operating software will be Linux. There are many reasons for choosing it:

- it is stable
- the hardware is supported including some specific driver
- it is free
- it is fast
- it can be size optimized
- it has a native packet radio protocol implementation

Especially the free argument is important, it means not only you have to pay nothing for it, but you get the whole source code along with the right to change it in any way you like. Suppose Jasipakta will some time be replaced by another network, you could simple adopt the operating system to meet the new requirements.

3.4 Hardware

As mentioned above the field station will be solar powered and therefore a low-power design is mandatory. The core of the field station is a x86 based board connected over PC/104 to a 16bit A/D Converter. This ADC converts the analog output of the seismometer as well as the output of other sensors (voltage, ...). A small GPS Module is responsible for supplying the exact time. A radio will connect the station with the nearest Jasipakta digipeater.
The central station will be a standard server system connected directly to Jasipakta over a radio or indirectly over some kind of gateway. In order to use a possible web based application a network connection is mandatory.

4. Data Acquisition

4.1 Hardware

The Data Acquisition Unit consists of two hardware parts, the geophone and the Analog Digital Converter (ADC).
The design principle of a geophone is simple: A magnetic mass is held by springs whithin a coil. If an eruption occurs, the mass will move through the coil and induce a voltage. The harder the erruption, the faster moves the mass and the higher is the meassured voltage. The used geophone is one of the 3D-class, a x-, y- and z-component is available. Geophones for sientific purposes typically recognize frequencies from 0,01Hz to 50Hz.

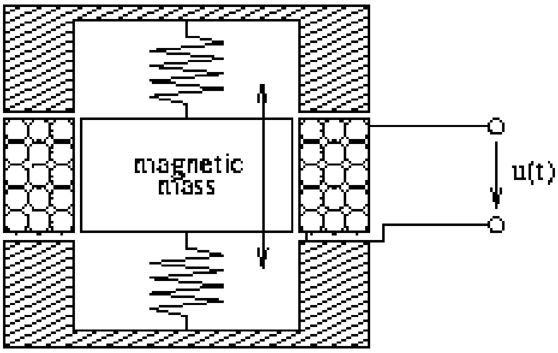


Fig. 4 Design Principle of a Geophone

For digitizing the analog signals of the geophone an Analog Digital Converter is needed. In this project a 16-bit ADC is used. Because of the failures which are generated during a conversion (temperature, linearity, ...) only 13 bit can be used.

For recording and signal processing the famous theorem of C. E. Shannon has to be taken into consideration. Due to this theorem a sampling-rate of a minimum of 100Hz is needed. The maximum bit-rate of such a raw data stream can be estimated as follows:

Bitrate_{max} = channels * sampling-rate * resolution = 3 * 100Hz * 16bit = 4800 bit/s

4.2 Software

Because of the small bandwidth of the data transmission system (packet radio) not all data from all field stations can be transmitted. The data volume can be reduced in two ways:

- **Only significant data will be transmitted**

  The field station will be equiped with a signal processing software, which is able to determine if the data are relevant and get transmitted, or not. This can be achieved by a fast fourier analysis (FFT). So the interesting frequency patterns can be recognized and the data transmission starts. In serveral cases it can be useful to transmit all data. For this case the data acquisition software can be switched from event driven mode to continuous mode by the operator at the remote central station.

- **Data Compression**

  A second way to minimize the volume of data is the use of compression algorithms. Over the years the scientific comunity developed a number of dataloss free compression algorithms. An often used compression scheme for seismic data is the STEIM compression, which will be covered in the next section.

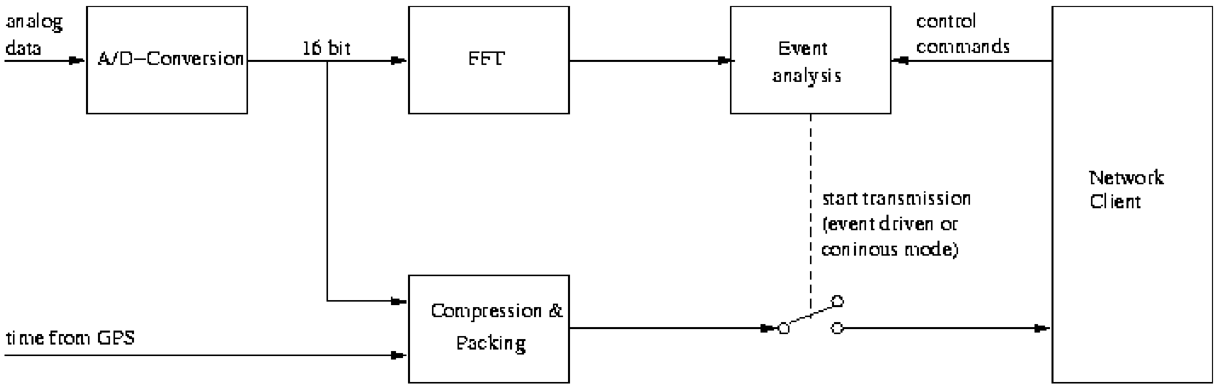


Fig. 5: Overview of the Data Acquisition Software

4.3 Data Compression

The mini-SEED format [IRIS93]

In 1991 the concept of Dataless SEED volumes was introduced and accepted at the FDSN meeting in Vienna. The idea is to split a complete SEED (Standard for the Exchange of Earthquake Data) volume into several subvolumes

- Dataless SEED volume
- Data Only SEED volume (also known as mini-SEED format)

The SEED format consists of Volume Control Headers, Abbreviation Control Headers, Station control Headers, Time Span Control Headers and finally Data Records.
The SEED format is too expensive if only the data should be stored or transmitted. Therefore many data loggers and seismic databases use the much easier mini-SEED format, which uses small and easy to understand headers and the data records themselves.

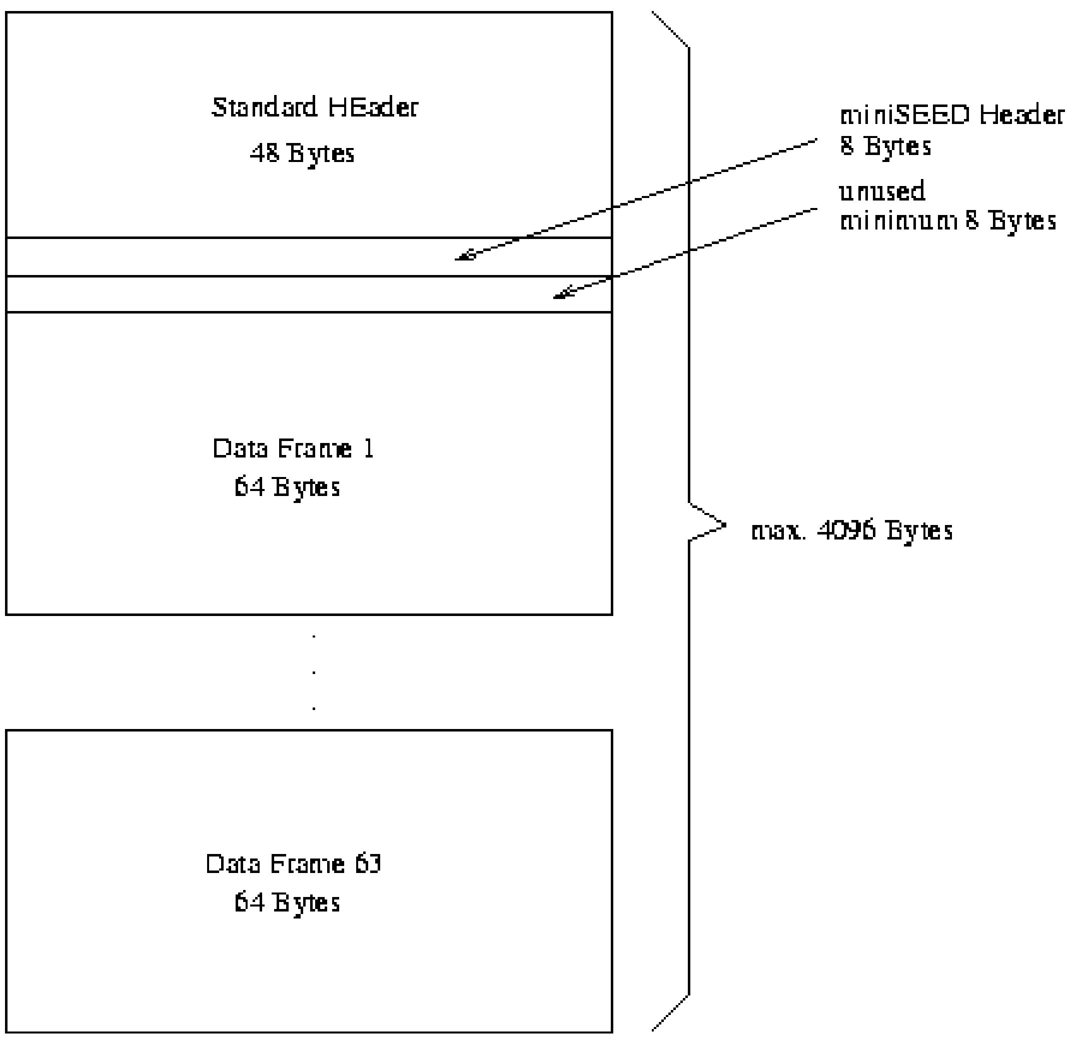


Fig. 6: miniSEED format

Field name	*Type*	*Size [Byte]*
Sequence Number	ASCII	6
Data header/quality indicator (“D”|“R”|“Q”)	ASCII	1
Reserved byte (“.”)	ASCII	1
Station identifier code	ASCII	5
Location identifier	ASCII	2
Channel identifier	ASCII	3
Network Code	ASCII	2
Record start time	BINARY	10
Number of samples	BINARY	2
Sample rate factor	BINARY	2
Sample rate multiplier	BINARY	2
Activity flags	BINARY	1
I/O and clock flags	BINARY	1
Data quality flags	BINARY	1
Number of blockettes that follow	BINARY	1
Time correction	BINARY	4
Beginning of data	BINARY	2
First blockette	BINARY	2

Table 1: Fixed Section of Data Header

The Fixed Section of Data Header holds important information as the station code, the location of the recording, time information, sample rate and various flags for quality and error handling. The size of the Data Header is 48 bytes.

Field name	*Type*	*Size [Byte]*
Blockette Type (=1000)	BINARY	2
Next blockettes byte number	BINARY	2
Encoding Format	BINARY	1
Word Order	BINARY	1
Data Record Length	BINARY	1
Reserved	BINARY	1

Table 2: mini-SEED Header

A miniSEED-Block should not be larger than 4096 bytes. A block consists of two parts the header and the data. In our example STEIM2-compression is used, so the header has the size of 64 bytes (only 8 are used) and 62*64 bytes compressed data (3968 bytes).

Every SEED header has an unique identifier, the bockette type. In the case of mini-SEED, the blockette type is 1000dec. The field „Next blockettes byte number“ points to the byte where the next blockette starts.
The Encoding Format identifies the used format of the data record, such as ASCII, 16 bit integer, STEIM2,...
The byte order has also to be specified since big endian and little endian processor types are in use.

A very important encoding format is the STEIM compression scheme, named after Dr. Joseph Steim who helds the copyright. STEIM compressed data are provided by seismic databases like the european ORPHEUS [ORFE04]

The STEIM Compression (after Dr. Joseph Steim)

The STEIM compression bases on the differences between neighbouring values and the strong correlation of such array elements.
Let the original time series be the samples x_{-1}, x_0, x_1,.., where x_i is a 32-bit signed integer. Let d_0, d_1, ..., be the first difference time series, where

$$d_0 = x_0 - x_{-1}$$
$$d_1 = x_1 - x_0$$
$$\vdots$$

Because of the small differences between neighbouring values, in most cases 32 bit integers will not be needed. Due to this effect, 32, 16 and 8 bit words can be used to represent the values without data loss. This idea is described in the STEIM-1 compression algorithm.

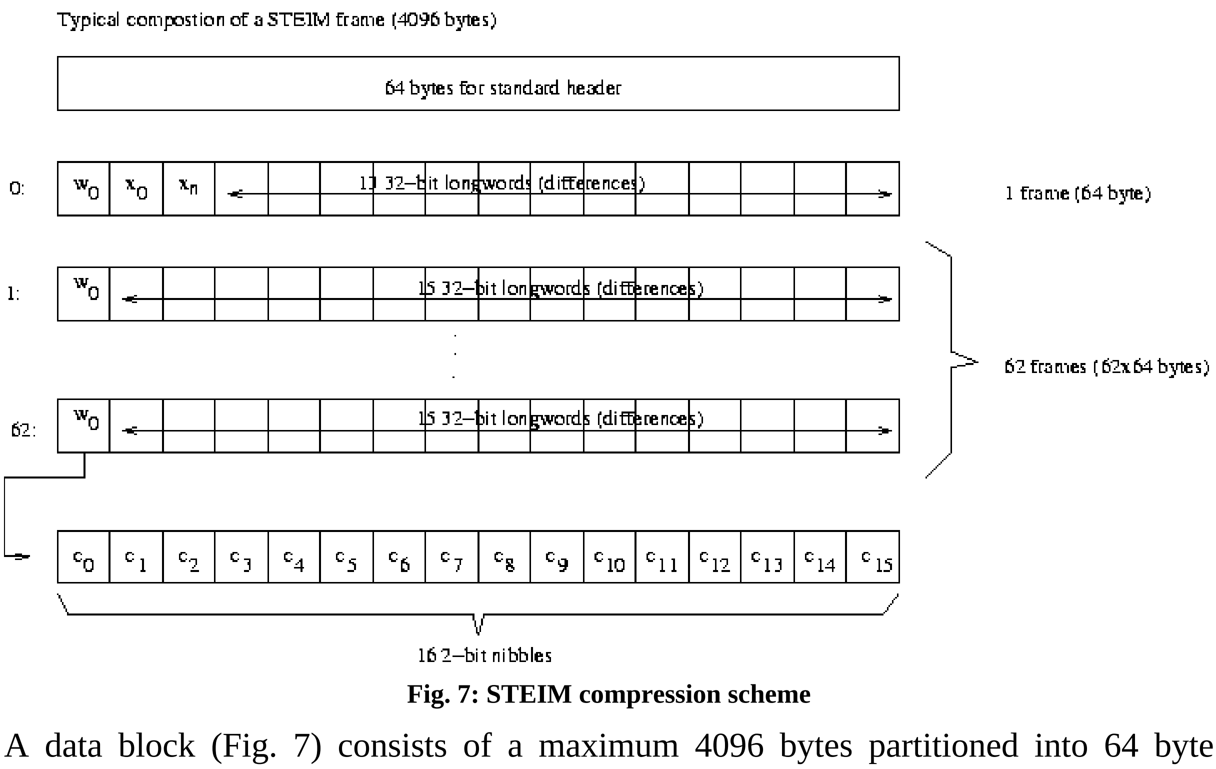


Fig. 7: STEIM compression scheme

A data block (Fig. 7) consists of a maximum 4096 bytes partitioned into 64 byte frames. The first frame is used for header information. The next 63 frames contain the data. One frame is divided into two parts, a control part w_0 (4 bytes = 32 bits) and a data part (60 bytes). The control part w_0 itself consists of 16 2-bit nibbles where each nibble corresponds with 4 byte words w_i (where i=1..15) beginning with the control part w_0. The first 64 byte data frame has a special function, too. It holds the first and the last value (x_0, x_n) of a STEIM frame. This provides a quick and easy data integrity check on the whole frame. After this frame, 62 standard STEIM frames follow.

c_i *(bin)*	*use*
00	special: wk contains non-data information, such as headers or w0
01	four 1-byte-differences (8 bit)
10	two 2-byte-differences (16 bit)
11	one 4-byte difference (32 bit)

The so called STEIM-1algorithm provides a maximum compression rate of 3,75. In this case all values d_i are represented as 8 bit words.

A much better compression rate will be achieved if STEIM-2 is used. In many practical cases the compression rate can be improved up to 6,74.

The idea behind the second version is to refine STEIM-1. The maximum length of a data word is now 30 bit (32 bit in STEIM-1). w_0 contains the c_i like in STEIM-1. Due to the maximum length of 30 bit there are 2 bits left. This 2 bit nibble is called dnib and expands c_i as it can be seen below.

c_i *(bin)*	*dnib (bin)*	*use*	*range of values*
00		special wk contains non-data information, such as headers or w0	
01		four 1-byte-differences (8 bit)	-128..-32, +31..+127
10		look at *dnib*	
	01	one 30-bit difference	$-2^{29}..-2^{14}, +2^{14}-1..2^{29}-1$
	10	two 15-bit differences	-16384..-512, 511..16383
	11	three 10-bit differences	-512..-128, +127..+511
11		look at *dnib*	
	00	five 6-bit differences	-32..-16, +15..+31
	01	six 5-bit differences	-16..-8, +7..+15
	11	seven 4-bit differences	-8..+7

Because of the strong signal correlation also a 8-bit value is too big to represent the differences. Due to this fact 4, 5, 6, 10, 15 and 30-bit words are introduced. The only disadvantage of this scheme is the need of a greater amount of computing time because more decisions have to be made and standard data types are not available in all cases.

5. Data Transmission

The goal of the data transmission is to send the data to the central station and control commands to the field stations. The transmission has to be reliable, which means dataloss or data corruption can not be tolerated. This also means the data must not be duplicated. Another goal is to provide a way of sending commands from the central station to the field station. This commands can be reboot, reset, switch to event driven/continuous mode, ... Last but not least the field station should be able to send status information to the central station for maintenance reasons.

5.1 Base Conditions

The system is primarily developed for the use in Indonesia, therefore it has to achieve at least the requirements for this operational area. Nevertheless it should be universal enough to be installed everywhere, possibly with small modifications. The only part of the system which is affected by the operational environment is the data transmission, as it relies on an existent network.

Unfortunately we do not have much knowledge of the Jasipakta network. What we know is that the uplink bandwidth is at least 9,6 kb/s and the backbone bandwidth is at least 56 kb/s. Further we know that AX.25 is in use, but we don't know whether it is plain AX.25 or a modified or enhanced version.

Another important factor is the amount of data to be transmitted. In the worst case we have to send all seismic data coming from the seismometer. As we have a sample rate of 100Hz and a resolution of 16bit on each of the three channels there are 600Byte of data every second. As we transmit them in the form of Mini-SEED data which is compressed with an average rate of 1:6,74 (STEIM-2) the remaining data per seconds are approx. 100Byte. In theory we could connect 12 field stations to one digipeater, but in reality this is not achievable. There is an protocol overhead, the network is radio based which means an high error rate depending on the environmental conditions (weather, solar eruptions, topology, ...) and of course there can be collisions especially when channel load is heavy. As there will be probably more than one station per volcano all using the same digipeater, bandwidth is the limiting factor. The traffic will appear only in bursts, because if there is an seismic event all field station around a volcano will recognise it simultaneously and want to send the data immediately.

5.2 Protocol

According to the ISO OSI reference model [TAN94] it would best fit into layer 4 the transport layer, but may also combine some features of higher layers. The reason why this functionality is not split up into distinct protocols, is the additional overhead this approach would implicate.

Design Goals

The design goals according to their importance are:

- reliability
- low bandwidth usage
- efficiency
- easy extensibility

Reliability is the most important goal, the seismic data have to arrive completely and undamaged. As described above, low bandwidth usage is also very important. Efficiency is also highly desirable, as the data should arrive as soon as possible at the central station in order to get analysed by scientists. Easy extensibility might be very important for the future of the system. This system is designed for long time monitoring, but there might appear additional requirements during usage. It should be easy to adopt the protocol to cover them.

Prerequisites

There are some requirements that the underlying protocol layers have to fulfill. First of all they must be packet oriented in some way. The packets have to be sent immediately after generation and they have to be forwarded immediately after delivery, as the protocol implements some timers that rely on this behaviour.

The whole routing process have to be done by the underlying layers. The network of all clients and the server is star shaped with the server in the middle surrounded by many clients. A client only communicates with the server, therefore the routing of packets from the clients to the server should be no problem. The routing from the server to the clients might be more complicated but is not part of this protocol.

Another important prerequisite is a bidirectional communication with a reasonable round trip time, the client rely on answers of the server within some time. The protocol parameters can be tuned to tolerate a long round trip time, but there are limits.

Vocabulary and Format

Every packet generated by the protocol is called message. There are two main types of messages, the first one are called command messages which are used by the central station to control the field stations. The second type is called data messages as they are related to transmit data from the field stations to the central station.

- **command messages**

STATUSCMD	provoke the client to send a STATUS message
RESETCMD	provoke the client to reset the system
REBOOTCMD	provoke the client to reboot the system
STARTCMD	provoke the client to start sending (seismic) data, only necessary after STOPCMD
STOPCMD	provoke the client to stop sending (seismic) data
STARTCONTCMD	provoke the client to switch to continuous mode
STOPCONTCMD	provoke the client to switch to event driven mode (default behaviour)

- **data messages**

STATUS	contain information of the system status (voltage, free memory, ...)
DATA	contains the data
ACK	acknowledge a bunch of consecutive DATA messages
NACK	might acknowledge some consecutive DATA messages but request the retransmission of others

They consist of a header common to all messages as well as additional fields where required. The header is 7 byte long and contains the sender, receiver, message type and a checksum. The checksum is calculated over the whole message including header and payload (if existent). All command messages are made up only of the header with the appropriate set message type.

Procedure Rules

All command messages as well as the STATUS message take precedence over the rest of the messages. If the checksum test of a message fails, it will be discarded.On arrival of a command message its purpose has to be realized immediately.

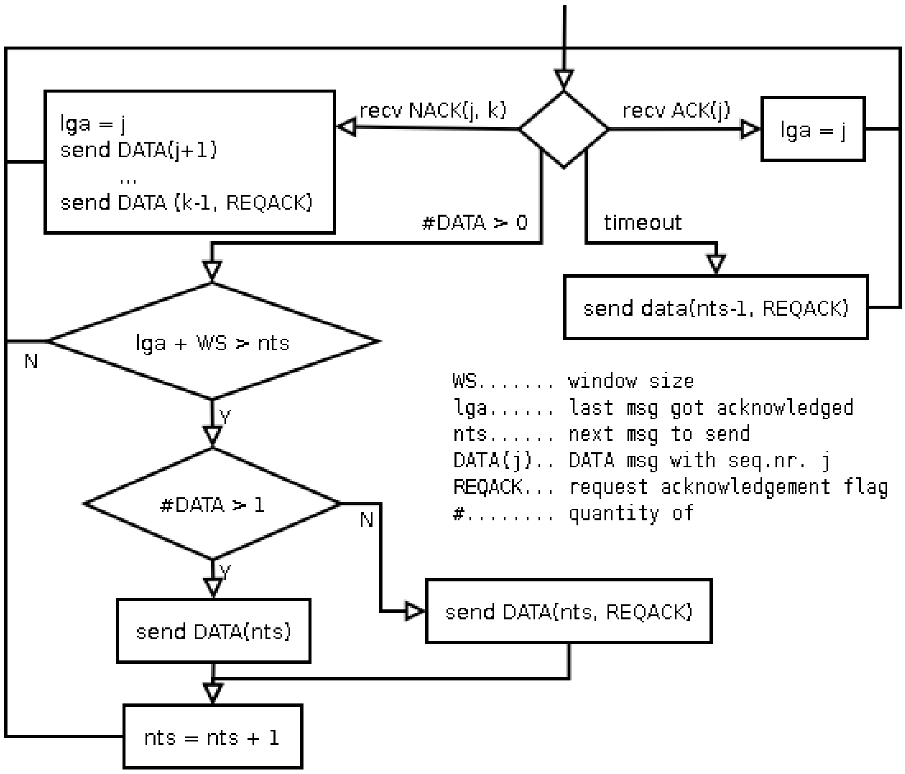


Fig. 8: Field Station: Protocol

The more complicate part of the protocol is the one dealing with seismic data transmission. In Figure 8 a simplified version of that part on the client side is shown. The client sends as many DATA messages as it can, and waits for an ACK message. The number of DATA messages allowed to send without receiving an ACK is called the window size (WS). Every DATA message has a sequence number (j). If there is at least one DATA message to send and the window is still open it will be sent. If there are no more DATA messages the request acknowledgement (REQACK) flag is set to receive an immediately ACK. This is repeated until either the window is closed or an ACK/NACK is received. In case of an ACK with sequence number j all DATA messages with sequence number <= j get acknowledged and the window is opened again. Receiving a NACK with the two sequence numbers j and k requires the retransmission of all DATA messages with j < sequence number < k, again all DATA messages with a sequence number <= j are acknowledged. If messages get lost and the client has not received ACK/NACK messages for a while, it will resend the last DATA message with the REQACK flag set.

Figure 9 shows the simplified version on the server side. As long as there are incoming DATA messages, the Server receives them. Otherwise nothing is done unless a DATA message with a set REQACK flag is received, or an already received DATA message with a sequence number greater than the one of the last acknowledged message plus block size (BS) is received. If one of these scenarios occur, the server will send an ACK/NACK message to the client, but the generation of this message is delayed until there are no more incoming DATA messages. Then the server searches for the first gap in the received unacknowledged messages. If there is no gap, an ACK for these DATA messages is sent, otherwise a NACK message with the sequence numbers of the last message received before the gap and the first message received after the gap is sent. The BS is necessary to avoid stagnation. Without the BS the client would send DATA messages until the window closes, but the ACK would only be sent when the last DATA message would have arrived at the server. With the BS (<< WS) we can avoid this.

The above described procedure rules are just a simplified version. They assume an infinite sequence number and a correctly initialized system. In reality the sequence number is finite and the client and Server are only initialized correctly if both are reseted. The sequence number problem can be solved if

$$WS = \frac{SEQUENCENR_{\max}}{2},$$

all operations are within the residue class of the maximum sequence number and some additional modifications. To solve the initialization Problem two special messages are needed:

- DATA message with no data
- NACK message with two identical sequence numbers

and some protocol enhancements, which will not be discussed here.

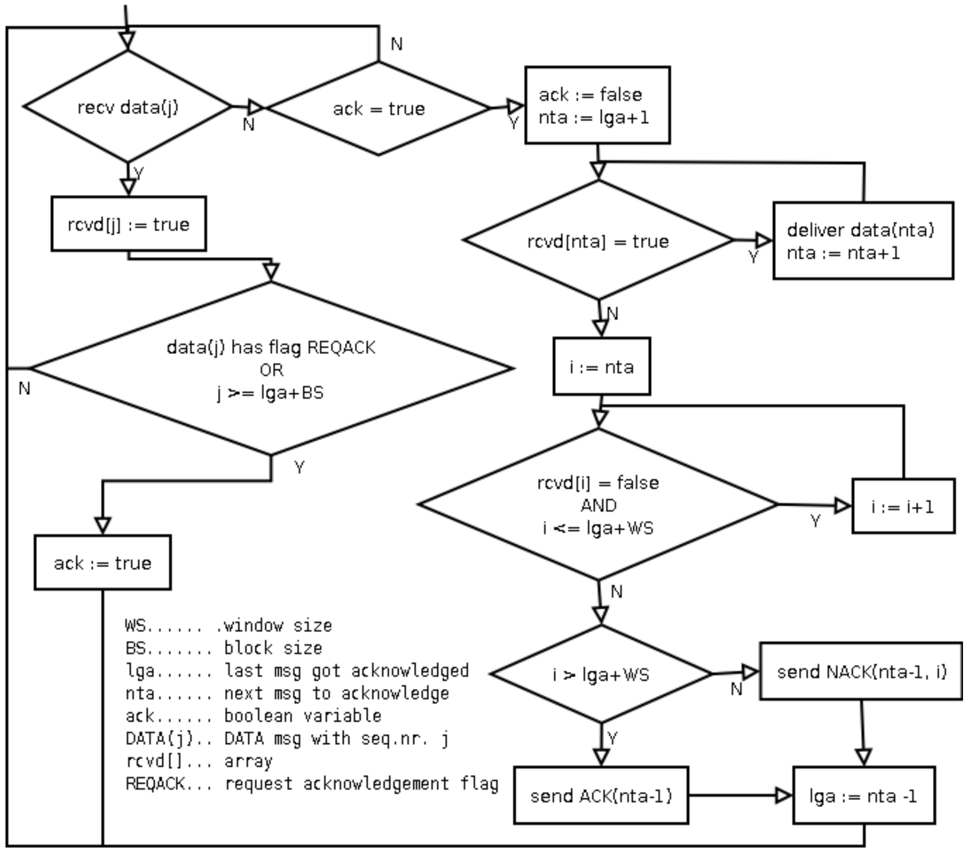


Fig. 9: Central Station: Protocol

6. Conclusion

This system provides a very flexible and inexpensive possibility to collect seismic data at locations where an infrastructure is not available. The use is not limited to seismic purposes, also weather information and other environmental data can be gathered and transmitted.

7. Abbreviation

ADC	Analog Digital Converter
bin	dual counting system
BS	Block Size
dec	decimal counting system, e.g. 1000dec
hex	hexadecimal counting system
LAPAN	National Aeronautics and Space Institute in Indonesia
NC	Network Client
NS	Network Server
ORFEUS	Observatories and Research Facilities for European Seismology
SEED	Standard for the Exchange of Earthquake Data
WS	Window Size

8. Bibliography

[IRIS93] IRIS, SEED Standard for the Exchange of Earthquake Data
Reference Manual, Version 2.3
February, 1993
www.iris.edu

[ORFE04] ORFEUS, Observatories and Research Facilities for EUropean Seismology
orfeus.knmi.nl

[TAN94] TANENBAUM Andrew S., Computer Networks, Prentice Hall 1994

Wide Band Data Transmission Equipment in the 5 GHz Bands
- Requirements & Standards -

Uwe Kartmann
CETECOM ICT Services GmbH
Saarbrücken, Germany
uwe.kartmann@ict.cetecom.de

Abstract

Across the world a communications revolution is quietly under way. Radio LANs are becoming a more and more important form of wireless communications where high bit-rates are needed over a relatively short distance. They are being deployed globally both for public and private use.
With wireless LAN technology expecting rapid growth, coexistence issues between different classes of wireless devices have become a significant topic of analysis and discussion.

Introduction

There are two main frequency bands used for Wireless LAN applications. Each of the mayor wireless standards, 802.11b/g, Bluetooth and Zigbee, operates in the 2.4 GHz ISM band which is available virtually worldwide on an unlicensed basis. For 802.11a equipment the situation is completely different. There are mayor regional differences on the 5 GHz bands envisaged for this type of W-LAN. On the other hand the 2.4 GHz band is shared with a number of other applications in a manner where interference-free operation cannot be ensured, while the 5 GHz bands offer an environment where interference is much better known and manageable.

Standard	Zigbee IEEE 802.15.4	Bluetooth	IEEE 802.11b	IEEE 802-11g	IEEE 802.11a	HIPERLAN 2
f (MHz)	868,3 (EU) 902-928 (US) 2402-2480	2402-2480	2400-2483,5	2400-2483,5	5150-5250 5250-5350 5725-5825	5150-5350 5470-5725
Pmax (mW eirp)	100	100	100	100	50 (US) 250 (US) 1000 US)	200 1000
Modulation	BPSK (CH 0) BPSK (CH 1-10) OQPSK (-CH 26)	GFSK	CCK	OFDM CCK PBCC	OFDM	OFDM
DFS/TPC	---	---	no	yes	no (11h: yes)	yes
Data rate (Mbit/s)	0,02 /0,04/0,25	1	11	54	54	54
Cannel (MHz)	1(EU)/10(US)/16	1	22	22	20	20
Distance (m)	10	100	100	100	500	200

Table 1: Wireless LAN Technologies

It is of major importance that high performance W-LANs can be widely deployed in the 5 GHz frequency bands. This step by step process started with the opening of (different) frequencies for this wireless service. After the successful launch of 802.11a equipment in the US this technique had been made available in Europe by solutions specified in the ECC Guidance Document on 5 GHz Wireless LANs. Finally on the World Radiocommunications Conference (WRC) 2003 in Geneva a final agreement on the use of the new W-LAN spectrum in the 5 GHz was taken. Under the agreement, 100 MHz of spectrum in the 5150-5250 MHz band have been allocated for indoor W-LAN use, while an additional 355 MHz, in the 5250-5350 MHz and 5470-5725 MHz bands, have been allocated for mixed indoor and outdoor use.

ACTUAL SITUATION IN THE 5 GHz FREQUENCY BANDS

802.11a represents a generation of enterprise-class Wireless LAN technology, with many advantages over current options. At speeds of 54 Mbps and greater, it is extremely fast. 802.11a and 802.11b both have a similar range, but 802.11a provides higher speed throughout the entire coverage area. The 5 GHz band in which it operates is not highly populated, so there is less congestion to cause interference or signal contention.
Different regions of the world have allocated different amounts of spectrum, so geographic location will determine how much of the 5 GHz band is available. In the United States, the FCC has allocated all 3 bands for unlicensed transmissions. In the European Economic Area (EEA), however, only the HIPERLAN 2 bands are dedicated to wireless LAN use. Being regulated by each Member State the requirements are different from state to state. In Japan, only the low band may be used. This will result in more contention for signal, but will still allow for very high performance.

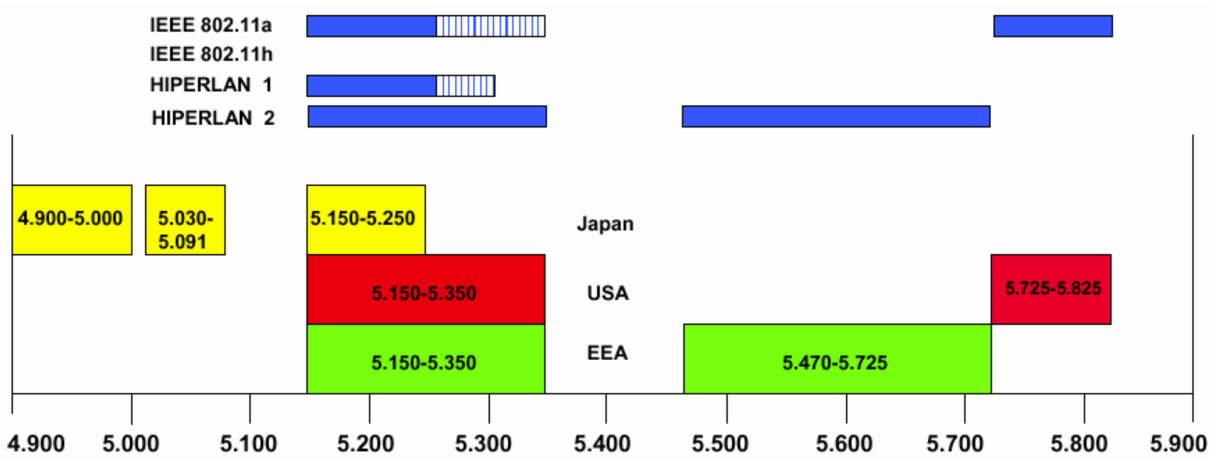


Figure 1: WLAN in the 5 GHz-Bands

DYNAMIC FREQUENCY SELECTION AND TRANSMIT POWER CONTROL

The Electronic Communications Committee (ECC) recommends its members to make frequencies available in the 5 GHz band for radio LANs, recognising that part of the frequencies are used by other users (military and satellite feeder links) and require protection. It recommends further that its members require that equipment should introduce certain technical features such as Dynamic Frequency Selection (DFS) and Transmit Power Con-trol (TPC) in order to protect the other services. Though 802.11a is not able to cover these requirements (the planned 802.11h will do this) it isn't certifiable in Europe. Efforts are currently underway by ECC to rectify this. ECC recommends interim solutions to national European administrations, in order to allow Wireless LAN products, which do not fulfil all ERC/ECC requirements, to operate in the band 5150-5350 MHz for indoor use only. Such an interim solution is applicable to countries where radars are not used in the 5250-5350 MHz band. For most countries where radars are deployed in the 5250-5350 MHz band, Wireless LAN products without DFS can only operate in the band 5150-5250 MHz in this interim period. Furthermore for equipment not fully compliant with all European requirements, ECC recommends to administrations to define additional mitigation parameters or power limits to achieve equivalent protection for other services, comparable to that which can be achieved with DFS and TPC in line with ERC/DEC(99)23.

The suggested interim solution is planned to be of a temporary nature. It will be withdrawn when the work on the DFS is finished and the Harmonised Standard for 5 GHz high performance RLAN is published in the Official Journal of the European Communities (OJEC). Administrations are asked for consideration of a transition period of some months to give sufficient time for industry to implement the DFS requirement into their product.

REGULATORY REQUIREMENTS

Harmonised Standards give a "presumption of conformity" to the essential requirements of the European Directive 99/5/EC (R&TTE-Directive). A list of Harmonised Standards is periodically published in the OJEC. Wireless LAN equipment safety requirements are covered by EN 60 950. For radio spectrum requirements ETSI developed two standards, one for applications working in the 2.4 GHz band, the other not yet being in a final status, for 5 GHz technologies. Old basic standards, as far as they are existing, are normatively referenced within a Harmonised Standard, for purpose of establishing a test method for a specification in that Harmonised Standard. For EMC requirements the old system was replaced by a new multi-part standard, consisting of a common part (part 1) applicable to all radio equipment and over 20 additional product-specific parts, one being relevant for Wireless LAN prod-ucts. The technical requirements are mostly the same as in the old product related EMC standards. The actual situation featuring the applicable radio spectrum standards and the applicable subpart of the EMC multi-part standard EN 301 489 is as follows in Table 2.

In Europe 5 GHz radio standard is not harmonised yet, it's still existing as draft document. Thus manufacturers must contact a R&TTE-Notified Body before placing their product on the market.

Essential Requirement	Europe	USA	Canada	Japan
Electrical Safety	EN 60 950	UL 60 950	EN 60 950	
Health	EN 50 370*	Safety Code 6	CSA 22.2	ORRE
EMC	EN 301 489-1, -17	FCC Part 15	RSS 210	
Radio Spectrum	EN 301 893	FCC Part 15	RSS 210	ORRE

Table 2: Applicable Standards

Caused by the fact that both frequency bands are not harmonised in the sense of the European R&TTE Directive, frequency notifications in each member state are required.

CONCLUSIONS

The above-mentioned central ideas illustrate that the effort of placing Wireless LAN equipment on the market is depending at first on the used frequency band and then on additional technical parameters. On one hand for 2.4 GHz applications the situation is clear. On the other hand manufacturers of 5 GHz equipment are confronted with different requirements in each country. In most cases this complicate situation can only be managed with the help of third parties such as consultants, test houses or certification institutes. Ongoing frequency harmonisation and the implementation of the WRC 2003 decision in a mid term will give industry the benefits of a shorter time-to-market.

References

[1] ECC Guidance Document on 5 GHz Wireless LANs; ECC 2003-06-2

[2] ETSI EN 301 893 V1.2.3 (2003-08)

[3] 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.

[4] World Radiocommunication Conference 2003 (WRC-2003): Initial Post-Conference Report, 10 July, 2003

FIREWIRE: THE NEW 1553?

Michaela Blott
ACRA CONTROL

Abstract:
MIL-STD-1553 has served the flight community well. However, in recent years several new high-speed bus standards have emerged that outperform 1553 in various respects, including data throughput and increased address space. During this time, mission requirements - including video and audio - have become more data intensive.

Although some of these buses were not initially designed for the avionics industry (such as Ethernet, FireWire, and FibreChannel), they are potentially of interest as high-speed commercial off-the-shelf (COTS) solutions for both set-up and data acquisition.

These buses offer not only improved overall system performance, in terms of aggregate sampling rates, but also simplify existing data acquisition system architectures. They require fewer high-bandwidth links which can serve for both set-up and data. This paper examines some of these issues, focusing in particular on IEEE1394, better known as FireWire.

Keywords:
IEEE-1394, MIL-STD-1553, COTS, DAU, FibreChannel, Ethernet

1. Introduction:

Over the past 20 years, MIL-STD-1553 has become the most widely deployed data bus in the avionics industry. With its reliability and deterministic behaviour, it is well suited to carry mission critical information between sensors, weapons, computing modules, data acquisition systems, recorders and transmitters. However, with more sensor data going digital, sampling rates increasing and demand for digital video transfers growing, new mission requirements have become more data intensive and exceed its maximum throughput by far. Meanwhile, various new high-speed bus standards have evolved in the communications and desktop industry, among them Fast and Gigabit Ethernet, Fibre Channel, FDDI, ATM, and FireWire. Due to their wide adoption, these busses offer low cost solutions with increased lifetime and interoperability with third party modules. Furthermore, they outperform MIL-STD-1553 in terms of data throughput, address space, and scalability.

Although there are many potential candidates, and the success of one over another depends on its technical edge, industry support and popularity, this paper will focus in particular on the IEEE1394 standard with its amendments and examine its suitability as a replacement for 1553 as a backbone avionics bus from a technical point of view. Section 2 gives an introduction to 1394b including driving applications and main characteristics. The third section evaluates FireWire in respect to a number of properties that we consider relevant to the Flight Test Community. The last part of this section provides a high level comparison between 1553, Common Airborne Instrumentation System (CAIS), FireWire, FibreChannel and Ethernet. Then the ongoing work in ACRA CONTROL with respect to FireWire is described, including the initial development of a bus monitor and eventual introduction of FireWire for synchronization, programming and inter-DAU communication.

2. The IEEE1394 Standard:

The IEEE1394 standard, better known as FireWire, was originally introduced in the mid 80s by Apple Computer and was accepted as a standard in 1995. Its purpose was to provide the means for high speed serial communication in a desktop environment, offering data rates from 100Mbit/sec up to 3.2Gbit/sec. Driven by applications such as video conferencing, high speed printers and mass storage, the primary objectives were the following:

- High data throughput
- Support for isochronous applications
- Ease of use - plug and play
- Increased address space
- Low cost

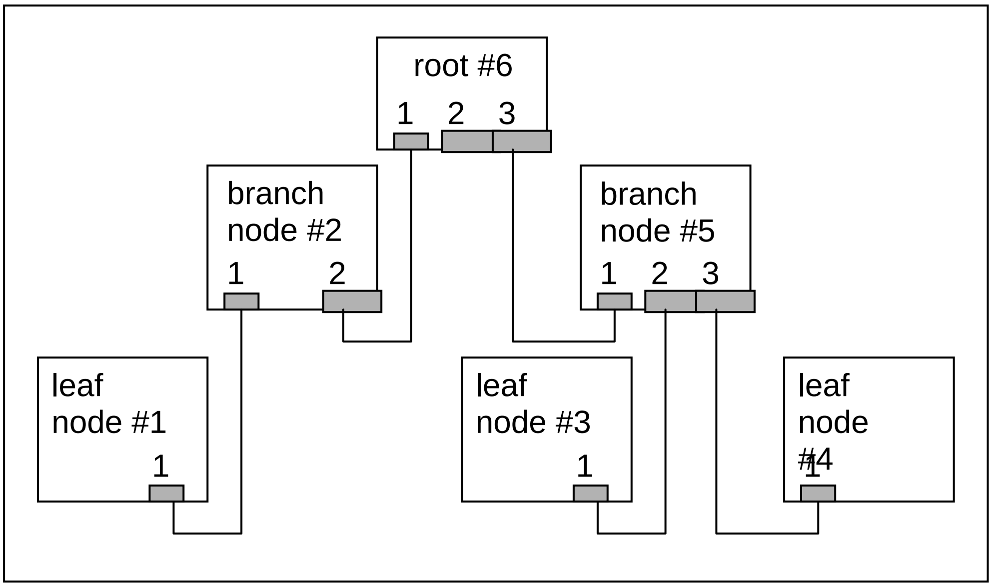


Figure 1: Example of a FireWire Topology

To achieve high data throughput, FireWire uses a bus topology built on point-to-point connections between individual nodes. Nodes that provide more than one port are referred to as branch nodes and repeat incoming traffic to all other ports. Branch nodes with more than two ports allow for tree-type topologies. Nodes with one port only, so called leaves, discontinue the bus. After an initial bus configuration, one designated node is assigned as root, which has the highest priority on the bus and is responsible for arbitration and the dynamic self-identification process. FireWire supports up to 1024 busses connected through bridges which only forward traffic that is addressed to a node on a remote bus. Figure 1 depicts a simple FireWire network, consisting of one root node, 2 branch nodes, and three leaves. Since branch nodes repeat incoming signals to all other ports, any sort of data transfers between node #1 and #2 are also visible to leaf node #3.

Support for multiple synchronous videos, as required for video conferencing, makes quality of service imperative for the bus. FireWire supports these via its isochronous transactions. FireWire guarantees pre-allocated bandwidth, fixed latency and small predictable jitter for isochronous traffic, which makes this mode of data transport not only ideal for synchronous video applications but also for data acquisition as will be discussed later on.

With the objective “plug and play” in mind, FireWire supports automatic configuration, which means that the bus enumerates itself without the intervention from a CPU and eliminates the need for address switches. Configuration is performed dynamically as the bus recognizes the removal or attachment of a node on a physical layer. Furthermore, the nodes are hot-pluggable which implies that they can be removed or inserted while the bus stays powered on. Properties such as hot-pluggable, and automatic configuration make FireWire user-friendly but might pose additional challenges in other circumstances such as flight test instrumentation (see section 3.5)

FireWire supports a 64bit address space to accommodate address intensive applications such as mass storage. 16bits are used to identify bus and node whereas the remaining 48bits represent a byte address within a node. However, read and write transactions are always based on quadlets, which is IEEE convention for 32bits. With that, the overall addressable memory amounts to 16petabytes per bus and 16exabytes overall.

Communication is based on a shared memory model and data can be transferred not only in an isochronous manner but also asynchronously. Asynchronous transactions, such as read, write and lock, are reliable in that they are acknowledged whereas isochronous transactions remain unconfirmed.

The initially standardized FireWire is a serial bus consisting of two differential signal pairs, and an optional pair for supplying power to and from peripherals [1,2]. Shielded twisted pair (STP) is used as media interface with a maximum of 4.5m cable length between individual nodes. This proved to be insufficient to many applications such as home networking and significantly restricted the scope of the bus. Since then it has evolved substantially: The 2nd amendment (IEEE1394b) introduced additional physical interfaces with a new encoding scheme (beta mode signalling) that improves signal integrity and allows for faster transmission rates on the legacy STP interface. New media interfaces include two optical ones, as well as a category 5 unshielded twisted pair (UTP) that offers with its transformer coupled interfaces electrical isolation between separate units and benefit from being compatible with existing Ethernet infrastructure. Table 1 shows a summary of the overall supported media interfaces with a small description, reach and supported transmission speeds.

Media Interface	Description	Reach (node to node)	Speed (Mbit/s)
DS (1394a)	Shielded twisted pair legacy data strobe signalling	4.5m	100, 200, 400
UTP (1394b)	Unshielded twisted pair Category 5	100m	100
STP (1394b)	Shielded twisted pair beta mode signalling	4.5m	400, 800, 1600, 3200[1]
POF (1394b)	Plastic Optical Fibre	50m	100, 200
GOF (1394b)	Glass Optical Fibre	100m	400, 800, 1600, 3200[1]

Table 1: IEE1394 Media Interfaces

[1] planned

3. FireWire in the Flight Test Community

In the last section, we gave an introduction to FireWire and described the main characteristics that make it user friendly, fast, and interesting for many desktop applications. But is FireWire suitable for the avionics industry? In the following discussion we will examine FireWire in respect to the following list of criteria, which are important characteristics for instrumentation networks and conclude with a brief comparison with other emerging high-speed bus standards.

- Reliability
- Real time behaviour/ Quality of service
- Isochronicity and Synchronicity
- Data throughput and reach
- Address space
- System topology
- Scalability and room for growth

3.1 Reliability

Reliability has to be addressed on several levels:

- Electrical interface needs to be rugged and electrical isolation between devices is desirable.
- Individual data transfers should support some level of error checking such as parity, CRC or checksum.
- Information exchange for control and set-up transactions must be confirmed.
- Redundancy is attractive to protect the system from failure when part of the communication link fails.

Although the initial 1394a-1995 standard may not be satisfactory in respect to the electrical interface, the 1394b amendment specifies a transformer-coupled interface over unshielded twisted pair (UTP) as well as two optical interfaces, which provide the desired electrical isolation between nodes. Optical media implementations alleviate emission and interference problems. All beta mode implementations, including the UTP interface, benefit from scrambling and an 8/10 bit encoding scheme which enforces DC balance and achieves a high level of signal integrity. The bit error ratio is aimed to be less than 10^{-12}.

Similarly, the in 1394a proposed 6pin and 4pin sockets proposed in 1394a are clearly aimed at a desktop environment and are unsuitable for flight equipment, whereas the RJ45 connectors used for the UTP implementation are available in robust versions. Alternatively, custom connectors could be considered to work around vibration, emission and temperature requirements.

On a packet level, FireWire supports 32bit header and data CRCs, as well as a checksum for acknowledgement, initialization and bus management packets. Set-up and control transactions can be implemented as asynchronous transactions on FireWire which are confirmed in that each transaction, such as a read or a write, is individually acknowledged on a subaction and a transaction level.

Redundancy is not built into the FireWire standard, but could be achieved by deploying a backup network and handling error detection and duplication at different system levels. Similar approaches have been taken within the industry for other bus standards such as Ethernet within the AFDX specification.

In comparison to 1553, FireWire supports in beta mode over UTP the same amount of electrical reliability, outperforms 1553 in terms of error checking, but lacks built-in support for dual-redundancy.

3.2 Real Time Characteristics / Quality of Service

To achieve quality of service, the bus needs to guarantee access to link bandwidth as well as provide for fixed and short latencies with small predictable jitter. The response time and jitter requirements differ between applications. Whereas for some control operations short and predictable latencies with low jitter are imperative, data transfer to mass storage devices are less critical. Quality of service can be accomplished in a number of ways. In the 1553 world, where real time behaviour is often associated with predictability and determinism, there is a single control over the bus through the bus controller, which assigns bus ownership to the nodes or remote terminals that need to transfer or receive data. Remote terminals only communicate when prompted. With that bandwidth guarantees can be given. The remote terminals respond within 4 to 12 microseconds which ensures fixed and short latencies. The effective jitter depends entirely on the remote terminal's physical implementation rather than current bus utilization. [4]

FireWire utilizes a very different approach. The bus access is time sliced into equal intervals of 125 microseconds indicated by a cycle start packet. Up to 80% of these intervals (100 microseconds) can be allocated as channels for isochronous transactions. These are then maintained through a so-called isochronous resource manager. The isochronous traffic has guaranteed bandwidth and fixed latency properties. The bandwidth can be allocated in multiples of 20.345 nanoseconds which is the time required to transfer 4bytes at 1600Mbit/s. Latency depends on the number of hops between source and sink node and negotiated transmission speeds. [3]

The remaining 20% are utilized for asynchronous transactions for which the individual nodes compete while fairness between the participants is ensured. It is important to note that asynchronous transactions that are issued at the end of a cycle time can delay the cycle start packet and introduce a skew of up to 50 microseconds. However, this doesn't affect overall system synchronization, since the cycle start packet contains the current time stamp including the delay that then can be utilized by each node to determine the encountered skew. However, additional data buffering might become necessary. Alternatively, in a private and controlled environment such as an avionics bus, nodes can be trusted and asynchronous transactions can be prohibited for the last critical part of a cycle time, or packets transmitted in the last part of the cycle can be restricted in size such that the cycle start packet can be transmitted on time.

Response times for actual asynchronous applications depend on a number of factors:

- Distance to sink (number of hops)
- Transmission speed (100Mbit/s or 1.6Gbit/s)
- Legacy signalling or full-duplex beta mode signalling

- Type of transaction (concatenated, split or unified)
- Arbitration service (legacy, fly-by, priority, immediate arbitration)
- Payload size

The concrete latency for a given application is a function of the specific system set-up and can be improved by changing the topology, using different arbitration services or varying the packet size. Alternatively, one could use two isochronous channels to implement confirmed operations as part of a higher level protocol. One channel carries the request and the other the response similar to CAIS. This preserves the quality of service properties associated with isochronous transactions while providing confirmed data transfers.

Although FireWire uses a very different implementation approach than 1553, it offers excellent real-time characteristics on the basis of its isochronous transactions.

3.3 Isochronicity and Synchronicity

In a distributed data acquisition system, it is important to sample at the same time. When sensors are located on physically separate units, it is advantageous if the interconnect provides built-in support for a common time and a common clock to avoid additional wiring. On a FireWire bus, a common system time that resides within the cycle master is broadcast at the beginning of each cycle interval and synchronizes all nodes every 125 microseconds. A 24.576MHZ clock controls the system timer. Furthermore, the PHY devices contain a PLL that adjusts the node clock during incoming traffic to data and strobe signals. The maximum encountered drift between two individual nodes on the bus is derived from the precision of the utilized crystals. However, the standard requires +/- 100ppm for the 49.152MHz crystal for 1394a and b. Therefore the maximum drift cannot exceed more than 25 nanoseconds during a 125 microsecond interval (200ppm x 125microseconds) at the end of which all nodes are being resynchronized.

Alternatively to the “start of cycle” packet mentioned above, standard broadcast commands are supported that could be utilized for a start of acquisition cycle indicator. In any case, the acquisition cycle is limited to multiples of 125 microseconds. With the acquisition cycle length being the lowest common denominator of 125 microseconds and all required sample frequencies, isochronous and synchronous sampling throughout a distributed data acquisition system on basis of a pure FireWire infrastructure can be achieved.

In comparison to this, MIL-STD-1553 achieves common time via the synchronize mode code command. When used with data word (mode code 17), the current cycle time is included within the mode code data word. The jitter depends on the chosen format, as well as the precision of the involved crystals. However, 1553 signalling is unsuitable to clock peripherals and requires additional infrastructure to achieve synchronicity throughout a distributed system.

3.4 Data Throughput and Reach

The current IEEE1394 standard specifies signalling rates of up to 3200Mbit/s. The actual data throughput is subject to the type of arbitration services used, transaction types, (unified, concatenated or split), as well as the percentage of isochronous over asynchronous traffic which introduces significantly more overhead. Considering a sample application such as a digital video, which requires a bandwidth of 55Mbps (in case of a 320 x 240, 24bit true colour, 30frames/sec) shows that FireWire can easily accommodate a multiple of this, especially when used in conjunction with standard compression schemes such as MPEG2.

Table 1 in section 2 indicates the maximum cable length between individual nodes as a function of the chosen media interface. Whereas the 4.5m data strobe legacy signalling and the beta signalling over shielded twisted pair enforce the introduction of many repeater nodes within a larger scale airplane, the remaining media types support sufficient cable length. In comparison, MIL-STD-1553 limits the maximum cable length to 300 feet, which equals the reach of FireWire’s UTP interface.

3.5 Address Space

Future data acquisition systems face the challenge of increasing demand for address space. For example, a single video application with 640 x 480 pixels true colour occupies 921.6Kbytes of address space alone on the data bus. Furthermore, set-up or programming bus address requirements increase as overall systems become more and more complex. For example, a linearization table for a PT100 consists of a 16bit x16bit lookup resulting in 128Kbytes of required EEPROM space. This already exceeds the overall available address space on 1553 without support for expanded sub addresses.

FireWire offers 16exabyte addressable memory which is divided into 1024 busses of up to 63 nodes each. Each node has 256Tbytes of memory address space allocated to it, and although some if it is reserved for bus management (CSR architecture), it still can comfortably accommodate set-up and data requirements.

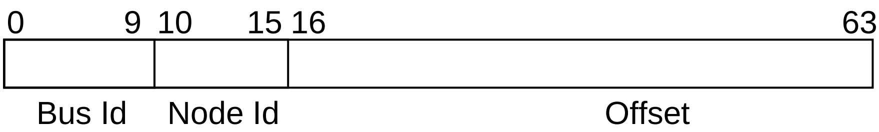


Figure 2:FireWire 64bit Address

In the 1553 world, there have been numerous attempts to increase the address space. Initially, with mode code 17 expanded sub addresses, the addressable memory increased from 59.5Kbyte (31 x 30 x 32 x 16 bit) to 7.6Mbytes (31 x 128 x 30 x 32 x 16 bit). Later introduced protocols such as the mass data transfer as defined in the MIL-STD-1760C, achieve a significant improvement with support for approximately 962Mbytes (255 files x 255 record x 255 blocks x 29 words x 16 bit). [4,5]

One of the initial FireWire design goals was hot-pluggable nodes on a self-configuring bus. The bus always undergoes a tree-identification process after a node is removed or added to the bus with the effect that the physical IDs are assigned dynamically. Although this is beneficial for consumer markets, it poses additional challenges for the avionics industry in that the nodes can change their addresses when another node on the bus fails. To illustrate this, we can look at the following example in Figure 3 of a FireWire network with its root node, branch nodes #2 and #4, and two leaf nodes #1 and #3. Leaf node #1 fails which is noticed by branch node #2. Node #2 will then initiate an overall bus reset. After the reset, the FireWire bus will first undergo a so-called tree-identification process, where all nodes determine which node is their parent/child, and the root node itself is assigned. A topology/speed map is created residing in the root node, which reflects the child/parent relationships between all nodes together with their speed capabilities. Then the self-identification process begins. Although it is a deterministic algorithm that will always establish the same address assignment for the same topology, in the unfortunate event of failure on node #1 in the topology below, it has the effect that all nodes change their physical ID.

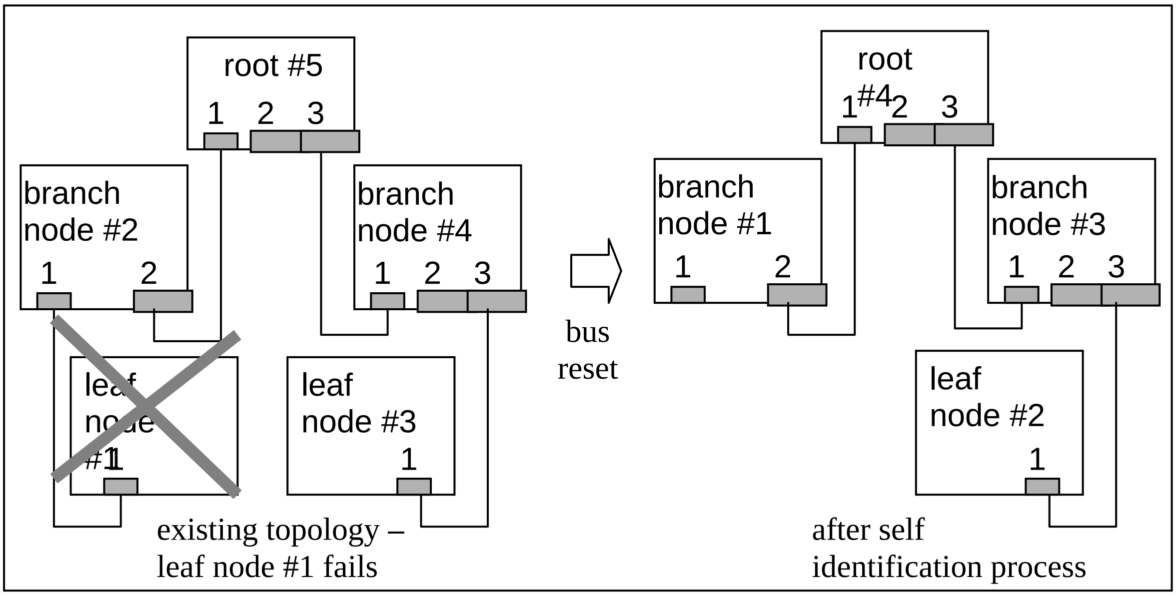


Figure 3: Dynamic Assignment of Physical IDs on the FireWire Bus

One way to resolve this issue would be to introduce a protocol, similar to the address resolution protocol (ARP) in the IP world, and hard configure each node with a higher level address. The protocol then maintains an address table that maps the hard configured node ID to the under FireWire dynamically assigned physical ID. The same problem is encountered in Fibre Channel's Arbitrated Loop where dynamic addressing is performed. A unique 64bit address (WorldWideName) is assigned by the IEEE standards organization that allows identification via a higher level protocol.

3.6 System Topology

As discussed in the previous paragraphs, FireWire is suitable not only for data but also set-up, control and timing. With that a unified avionics interconnect can be established, that handles all aspects of data acquisition. This simplified infrastructure is attractive in that it reduces not only the amount of wiring, but also complexity and cost. Although the same is true for 1553, apart from the clock synchronization between remote terminals, due to the limited number of supported nodes per bus, low data rate, and small address space, the system designer is forced to introduce numerous busses interconnected through gates, whereas with FireWire the number of bus bridges could be drastically reduced.

3.7 Scalability and Room for Growth

Scalability is a desirable characteristic for a new bus standard. However all serial busses which have no built-in concept of switch fabrics basically fail in this respect. There is a limit of maximum data throughput and maximum number of nodes that share the overall available bandwidth. With increasing numbers of nodes and increasing bandwidth utilization, the bus will encounter arbitration conflicts (or collisions to use the Ethernet BaseT analogy). However, room for growth can still be provisioned for in that data throughput, maximum number of nodes and address space exceed current requirements substantially. Whereas MIL-STD-1553 cannot accommodate today's requirements, FireWire meets those easily and with its 64bit address space, up to 63 nodes per bus and up to 3.2Gigabit/sec data rate, it is capable of sustaining those of years to come.

3.8 Comparison

Table 2 compares FireWire to other bus standards competing as a 1553 replacement for the avionics community. Although there are many other candidates, we've limited the scope of this comparison to FibreChannel, CAIS, and Ethernet. Address space refers only to addressing on a physical layer. For Ethernet for example, addressing on an IP level is not considered. Reach depends on the media interface, and in the case of Ethernet only some of the supported media interfaces are listed. The same applies to bit error ratio (BER) which is a function of the physical layer. The terms isochronicity and synchronicity mean common time and common clock respectively. [6,7]

	MIL-STD-1553	**CAIS**	**FireWire**	**FibreChannel**	**Ethernet (10/100/1000)**
Origins/ Target Applications	Avionics bus control, set-up and data acquisition	FTI set-up and data acquisition	Desktop industry video, audio, mass storage, entertainment	Storage Area Networks	Local Area Networks
Features	deterministic, predictable	deterministic, predictable faster and more address space	isochronous, big address space,	high speed SCSI, real-time, long reach	popular, cheap,
Physical Layer					
Coupling	transformer	transformer	transformer	transformer	transformer
Media	copper	copper	copper of fibre	copper or fibre	copper or fibre
Reach (point to point)	~100m	~100m	4.5m (STP) 50m (POF) 100m (GOF)	30m (copper) 500m (MM fibre) 10km (SM fibre)	100m (UTP) 500m (MM fibre) 10km (SM fibre)
Topology	daisy chain or star	daisy chain	daisy chain or tree	ring or switched network	daisy chain or switched network
Address Space					
Busses	not inherent	not inherent	10bit	16bit (switched)	not inherent
Nodes	5bit	6bit	6bit	8bit (FC-AL:126 only)	48bit (32bit IP)
Address per Node	17bit (with MC17)	22bit set-up 17bit data	48bit		
Overall	7.6Mbyte	512Mbyte	16ExaByte	64MByte minimum	256TByte minimum
Communication model	shared memory	shared memory	shared memory	message passing	message passing
Speed	1Mbit/sec	10Mbit/sec	3.2 Gbit/sec	2Gbit/sec	1Gbit/sec
Scalability	no	no	no	yes (switched)	yes (switched)
Reliability					
Redundancy	inherent	not inherent	not inherent	not inherent	not inherent
Error checking	parity	parity	header + data CRC+checksum	packet CRC	header + data checksum
BER	10^{-12}	10^{-9}	10^{-12}	10^{-12}	10^{-12} (1000BaseX)
Confirmed Transfer	supported	supported	supported	supported	supported (TCP/IP)
Live at Power-up	yes	yes	no	no	no
Timing					
Isochronicity	yes	not inherent	yes	not inherent but built into FC-AE [8]	not inherent
Synchronicity	no	yes	yes	yes	yes
Quality of Service	yes	yes	yes	yes	not inherent

Table 2: High Level Comparison of 1553, CAIS, FireWire, FibreChannel, Ethernet

4. FireWire in ACRA CONTROL – Status and Future Developments

ACRA CONTROL currently have a FireWire bus monitor (FBM) under development. It is implemented on the basis of a high-density field programmable gate array (FPGA) in conjunction with a standard commercial off-the-shelf PHY device. The FBM provides support for a transformer-coupled 1394b over UTP interface, as well as a bilingual port, which is capable of communicating via beta mode and legacy 1394a data strobe signalling. The bus monitor operates as a leaf only in the FireWire topology. This design decision has been made for a number of reasons. First, bus monitors should be passive devices that cannot interfere with ongoing traffic and must not be placed within critical parts of the network. As a branch, for example, the node would have to comply with much stronger fail-safe restrictions. Furthermore, a branch implementation enforces the implementation of a full link and transaction layer (packet transmission and reception), whereas the implementation of packet transmission is not meaningful to a plain bus monitor. The absence of these layers is communicated to other nodes during the self-identification process. Eliminating the considerable implementation overhead associated with a full transaction and link layer, valuable gates on the FPGA are freed up. We use these to parse traffic on a more intelligent level. The bus monitor filters traffic according to a user specified set-up. Traffic can be selected on a flow basis, for example all read transactions from node 1 to node 2 at address offset 1024 in the destination node. The bus monitor then parses the traffic on a transaction level, which implies that the bus monitor keeps state of individual transactions, for example whether a write request has been acknowledged, or whether a read response has been missed.

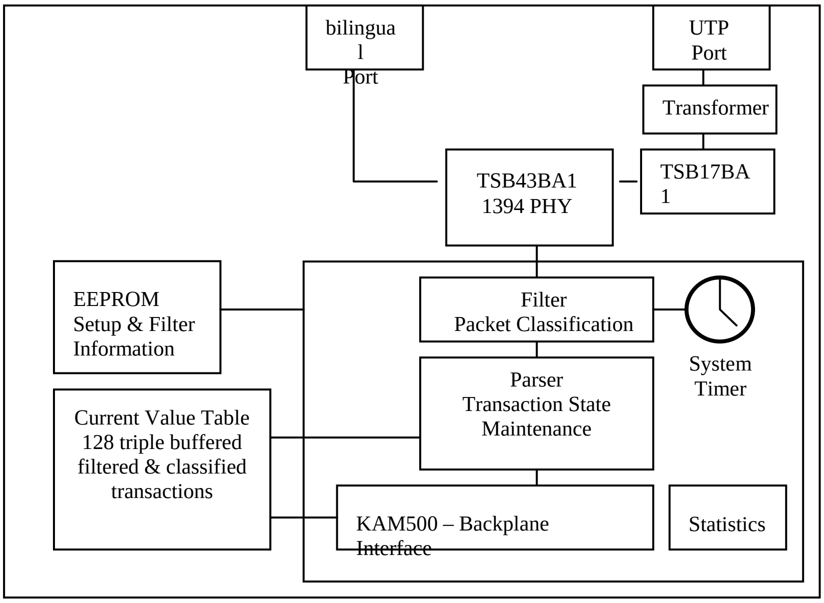


Figure 4: ACRA CONTROL FireWire Bus Monitor

Figure 4 depicts the simplified architecture of the bus monitor. The top part shows the two supported ports which feed into a standard FireWire PHY device. The traffic is then pushed from the PHY to a filter & classifier that resides within the FPGA. There, bus management traffic is discarded and cycle start packets can optionally be used to seed a system timer. Traffic that is considered relevant for monitoring is passed on to the parser. The parser maintains the state of up to 128 selected transactions which are triple buffered in a current value table (CVT) implemented in SRAM. Together with traffic statistics, the CVT can be read out over the KAM-500 backplane and from there be redistributed throughout the entire data acquisition system.

Future plans within ACRA CONTROL include the development of a number of new FireWire modules that eventually offer optional programming, data acquisition and synchronization over a pure FireWire infrastructure.

4. Conclusion

There are numerous competing bus technologies that could potentially replace 1553. The success of one individual technology does not only depend on its technical superiority, but on the level of acceptance within the industry, which in return drives the maturity of a standard, the cost effectiveness of the components and its life time. This paper focussed on FireWire in particular and examined its suitability from a purely technical point of view. We found that the electrical interfaces specified in the 2nd amendment (UTP, POF, GOF) in terms of reliability, data rate and reach should meet the industry requirements, whereas the initially proposed DS signalling and the later introduced beta mode signalling over shielded twisted pair might not be sufficient for all applications due to limited reach, lack of electrical isolation between nodes, emission and interference issues.

FireWire excels in its support for quality of service, error checking, isochronicity, and provides room for growth with its 16exabytes of address space and support for data rates of up to 3.2Gbit/s for future applications. It is especially suitable for digital video applications, but also supplies acknowledged traffic in the form of asynchronous transactions that could carry control and set-up operations. Furthermore, all peripherals on the FireWire bus can derive a clock from the bus signals. This is beneficial in that it avoids additional wiring while providing full synchronization within a distributed acquisition system.

However, additional work is required to handle the issue of dynamic node identification and redundancy. To ensure interoperability with other FireWire devices, it would be advantageous if the industry could come together to agree on a higher level protocol that handles the mapping of the dynamically assigned ID to a fixed address, as well as duplication and error checking when deploying a backup network to achieve dual redundancy.

Despite these few shortcomings that can be dealt with on other system levels, FireWire has the technical potential to play an important role as avionics bus or flight instrumentation network in future data acquisition systems.

References:

[1] *IEEE Standard for a High Performance Serial Bus,* 1996,
IEEE Std 1394-1995, Institute of Electrical Engineers, New York

[2] *IEEE Standard for a High Performance Serial Bus 2nd Amendment,* 2002,
IEEE Std 1394b, Institute of Electrical Engineers, New York

[3] *FireWire System Architecture*
MindShare Inc, Don Anderson, Addison-Wesley, 2nd Edition

[4] *MIL-STD 1553, Designer's Guide Handbook*

ILC Data Device Corporation, 5th Edition
[5] *MIL-STD-1760C*
Department of Defense Interface Standard for Aircraft/Store Electrical Interconnection System
[6] *IEEE Std 802.3 - 2000*
Institute of Electrical Engineers, New York
[7] www.fibrechannel.org
[8] *Technical Report for Information Technology – Fibre Channel-Avionics Environment (FC-AE)*
American National Standards Committee, INCITS, Information Technology, TR-31-2002

Presenting Author: ***Michaela Blott***

Company Address:
ACRA CONTROL,
Landscape House,
Landscape Road,
Dublin 14, Ireland.

Telephone: +353-1-2951264
Fax: +353-1-2951265
Email: blott@acracontrol.com

REMOTE REAL-TIME SIGNAL COLLECTION USING OC-12 NETWORK DATA FORWARDING

Bill Bullers
Advanced Systems Development
Sypris Data Systems

ABSTRACT

The resource costs and reaction time for critical signal collection and analysis is significantly reduced by real-time store and forward systems made possible using 622MHz OC-12 and 2,488 MHz OC-48 networks. Networks are becoming more available to system architects. Data from many signal collection channels are collected and temporarily stored on a digital media system designed around the OC-12/48 network. The I/O, storage, and network components can be configured, set, and initialized remotely with an in-band Java Browser interface. Recordings are started and stopped on command and can be made round-the-clock. Files of stored, time stamped data are delivered at the rate of OC-12/48 to a remote rapid reaction distribution analysis center.

KEYWORDS

Telemetry, SIGINT, ELINT, Data Networks, Signal Recording, Signal Collection, Data Storage with Long Haul Networks, FC over SONET, FCIP, FCIP over SONET, and FC over ATM

INTRODUCTION

For many years, intelligence signals and data produced in a wide variety of types, modulations, and formats has been collected and stored using magnetic tape recording equipment. Recorders are designed to continuously capture the analog and digitally modulated signals generated by various sensors, transmitters, and receivers without incurring interruptions, delays and dropouts where data is lost. Tape is a very convenient and affordable media to store and distribute data to analysis centers. Tapes are easily duplicated and can be exchanged between agencies involved in the analysis process.

Tape recording by nature requires operators to load tape, check equipment for proper operation, start and stop the recordings. Remote control interfaces common on the recording equipment, allows fewer operators to operate several recorders but the activity is typically a manually executed operation to insure that the opportunities of a collection event are not lost due to equipment malfunctions and errors for which tape recorders are notorious. Tapes are typically transported from the data collection location to an analysis center where the signals are evaluated for content and value. Long delays can be encountered between the collection of data and the evaluation and in some applications the time sensitive nature of the collected data is severely diminished in value by the delay.

Recently recording equipment that uses computer hard drives is being used more and more to record Telemetry and Intelligence signals. The recording equipment has become very 'computer centric' with network capabilities and resources. The data rate that can be continuously recorded without interruption has increased as computers, busses, memories and disks have gotten faster and faster. Computer based recording equipment is considerably more reliable than tape equipment and unlike tape recorders requires almost no operator intervention and maintenance.

Computers are designed to attach in networks that can be used to communicate and transfer data over long distances. The need to make tapes for exchange and distribution is diminishing and is being replaced with the desire to transfer data electronically on-demand using high-speed network technology. The need for intense manual activities at the collection site is also diminishing as systems become more networking capable.

TELEMETRY DATA COLLECTION
A CHANGING PARADIGM

Telemetry data collection applications have a wide variety of requirements. Signals may need to be recorded from a few sensors or from many sensors, transmitted in a single data stream or spread across several transmission streams. The signal characteristics vary but AM and FM analog signals, PCM, PSK, and PAM digital data streams are the most common in use today. Sensor equipment is also becoming more 'computerized'. Soon data produced by some sensors and transmitters will be encapsulated into packets and frames before reaching the recording equipment. The paradigm of telemetry data recording is rapidly changing as compute power and networks are integrated with telemetry applications.

Telemetry recorders that are being used today record several signal channels simultaneously and handle multiple signal types and frequencies. Analog signals are sampled and converted to digital data and multiplexed with digital data from other channels in the recording equipment. In tape recording equipment the data is multiplexed from each channel into a single data stream to be written on the tape. In disk based recording equipment some channels may be recorded on one set of disks while other channels are simultaneously recorded on other sets of disks. The composite data rates recorded by a single set of equipment typically range from a few megabits per second to several hundred megabits per second. Computer disk based telemetry recording equipment with varying capabilities is now available from a number of manufacturers.

Fibre Channel (FC) has become the protocol standard for high performance data storage systems. FC is structured to ensure a very predictable and dependable quality of service (QoS) level. QoS requirements of data storage include predictable low delays, zero data loss, and high throughput.

The Sypris Data Systems Silver Phoenix recording system is designed to simultaneously accept many continuous, streaming telemetry signals of different types and frequencies and record the signals along with a standard IRIG timecode signal – A, B, or G – to computer disks configured in RAID sets. The RAID units are 2 gigabit Fibre Channel (FC-2) devices. One or more RAID units can be structured into a system and can be interconnected using a FC network switch The number of signals to be recorded, frequencies of the signals, and storage capacity can be openly expanded by adding more circuit cards and more RAID units. Systems of many hundred megabits per second and multiple terabytes of storage are made possible by the system architecture.

A typical telemetry data recording system using RAID devices for storage includes one or more tape devices that can be used to make tapes by offloading stored data. Tapes are usually made during periods when collection is idle but can be made interactively while recording in systems configured with sufficient bandwidth. Tapes support archive, exchange and distribution of data in a manner consistent with the familiar paradigm. Systems designed to operate within this paradigm require high-speed RAID storage at the collection location, tape devices integrated with the system and operators on-site to record, change and forward the tapes – see Figure 1. Almost identical systems are required at the analysis center to accept and upload the data from tapes so that it can be separated into the several signals that were recorded and played back at data rates slower, faster, or matching the record rate.

REAL-TIME DATA DISTRIBUTION

A more cost affective implementation is one where the equipment used to record the sensor signals has data storage capacity on-site sufficient for reliable collection but only to the extent needed to make transfers over a network immediately as it is collected. Instead of relying on magnetic tapes for data distribution and archive, the data is collected and electronically delivered to a remote location for immediate evaluation and storage. The collection equipment implementation can be operated from hundreds to thousands of miles away and be only sparsely manned or completely unmanned. The data is stored in online storage or in an archive only at the remote analysis center. Only the data having true value is archived. The hardware requirement is reduced, the maintenance is reduced, and the system labor is reduced.

Recording technology and equipment available from Sypris Data Systems and other suppliers is designed to operate connected in a real-time network that can make data available at a distant location far from the collection site. Archive, analysis and distribution can operate with ‘fresh’ data at geographically dispersed centers away from the site where telemetry gathering takes place.

The Silver Phoenix Technology is designed to operate in a configuration where the FC data is transferred to a distant location at near real-time data rates. In this configuration the ‘local’ FC storage capacity at the collection location is limited to an amount essential to accomplish a reliable transfer without lost data or unwanted interruptions to the incoming signals. The local storage capacity must be sized sufficiently to accommodate whatever disruptions might be encountered with the network. This configuration is ideal for collection applications that are difficult to support with operators and available resources.

In-band-signaling control of the system equipment and software adds to the reliability and efficiency of a true network-connected system. This means that the Operation, Administration, and Maintenance (OA&M) functions important to the equipment and its operation share in the same FC network used for data exchanges. The OA&M processes share bandwidth with the data processes and extend over the same networks used to exchange data. Long distance system control and monitoring can take place from the archive center or from any connected location using an Ethernet connection supported through a Java and HTML or XML browser. Long distance operation, administration and software maintenance is a non-issue with today's technology.

DATA NETWORKS

Fibre Channel is structured to provide for the loss-less transfer of data where data frames arrive at the destination in the identical order they left the sender. This performance seems like it should be expected of any network but is not necessarily the case. Fibre Channel uses a credit buffering mechanism to control congestion on the network and manage data flow control. The receiving switch controls the data flow by issuing credits back to the sending switch. The sender speeds up or slows down the flow of data based on the rate it receives buffer credits from the receiver. The data flow-rate is managed by the receiving switch to maintain a steady, high rate data flow. If the receiver starts to become congested it stops issuing buffer credits which the sender needs to continue to send data.

Loss-less data transfer is not necessarily error free data transfer. System networking architects who plan to us FC to route data must be aware of very specific details of clock rate tolerance and bit-error-rate (BER) in order to deliver systems with the expected performance. The FC Physical Layer standard requires that a FC network have an error rate less than 10^{-12}. This corresponds to one error every 8.3 minutes in a FC-2 connection transferring data at 2,125 Mbits/s. Some applications including data storage devices are setting a more stringent standard such as 10^{-15}. The data rate of Fibre Channel can be improved by adding forward error correction information into the data stream before it is transferred to the network. The correction information is used at the receiving end of the network to correct the bits that were corrupted by the network.

Switched FC fabrics at data collection sites establish a natural configuration for easy connection within a 'long haul' communications link to provide rapid, secure, data transfer. Equipment is available today to make the necessary connections and enable the implementation.
The three predominantly used metropolitan area network (MAN)/WAN service structures are:

- IP/Ethernet
- Dense Wave Division Multiplexing (DWDM)
- SONET (Synchronous Optical NETwork)

SONET is the only service structure of the three that provides long distance networking with a reasonable QoS level. SONET is implemented as a private network operated in a direct point-to-point connection. Several private SONET channels can be multiplexed into a single connection. Four OC-3 private networks can multiplex on one OC-12 SONET connection. Sixteen OC-3 connections can occur simultaneously on one OC-48 connection. OC-3 operates at approximately 155Mbits/s OC-12 runs at 622Mbits/s, and OC-48 is 2.488Gbits/s. (OC stands for Optical Carrier. 3 means that three DS-3 transmissions can be multiplexed to a single OC-3 connection. 84 DS-1, T-1 connections can be handled by an OC-3).

IP/Ethernet has far-reaching coverage but applies transmission control protocol (TCP) to retransmit packets that are regularly dropped during data transfers. IP packets are independently transmitted from one IP router to another. Separate packets in the same data transfer may travel through several different paths before arriving at the intended destination. Packets frequently arrive out of order and some packets never make it to the destination. This is corrected by mechanisms that are included in TCP to reorder packets and request that dropped packets are resent. The performance of the IP layer severely degrades the achieved QoS level making IP not well suited for sustained uninterrupted real-time data transfers necessary in data storage systems. Even so, IP is quite acceptable for use in transactional business processes where data exchanges can be stopped if faulty, reloaded, and retransmitted in acceptable human-time operations.

DWDM on the other hand achieves a high service quality level but at the expense of restricted transmission range – about 70 km – which is the result of a required complete acknowledgment between the sender and recipient that every transfer was successful before the next transfer can occur. A phenomenon termed 'Fiber Channel Droop' occurs as the result of the buffer credit mechanism applied by FC to insure zero data loss in the FC network. The buffer credit system enforces a strict transfer process where messaging between the sender and recipient confirms successful data frame transfers. Buffer credits are allocated between sender and receiver in 2 Kbyte FC frame increments. The sending and receiving equipment is designed with built-in FC buffers to implement the buffer credit system. The message passing propagation delay that occurs in networks longer than about 70km causes FC frames to be exchanged at a reduced rate and slump below the specified FC operating tolerance.

SONET/SDH is the best choice available for a long distance data storage network. Synchronous Optical Network (SONET) is the North American Standard used by optical fiber networks. Synchronous Digital Hierarchy (SDH) is the European and World wide standard equivalent to SONET. For all intents and purposes SONET and SDH are identical.

SONET/SDH OC-3, OC-12, and OC-48 distributed across millions of kilometers of optical fibre cable connect every major metropolitan area and are used to enable all types of data transfer and communications between locations around the world. SONET is a reliable and efficient data transport service that can be used with higher-level data framing formats and packet protocols. SONET can be used as the carrier for FC as in FC over IP (FCIP) and for ATM, Frame Relay, and a variety of other stacked protocols. FC frames can also be directly encapsulated into SONET data frames.

Optical fibre bit-error-rates are tens-of-thousands of times lower than copper networks. T-1 and x.25 copper networks are engineered to have an error rate of 10^{-6} or better. Optical fiber has a BER better than 10^{-10} and trunk line networks operate at better than 10^{-11}. Bit errors in copper implemented networks tend to occur in clusters or bursts. Optical fiber exhibits single random bit errors making it well suited for economical error correction techniques. The SONET/SDH standards require that error data be collected for each individual data frame that is transmitted and be made available from the SONET transmitters and receivers to be used by higher level error correctors.

SONET OC-12 operates at 622 Megabits per second and has sufficient bandwidth to accomplish the transfer rate required in most telemetry data collection applications. The integration of OC-12 with the FC-2 RAID network of Silver Phoenix or any FC network is straightforward when all the required details are understood. There are choices that must be made that affect the selection of the network hardware. Several companies make gateways or routers or switches to connect FC to SONET. There are three favored approaches:

- FCIP or FC encapsulated on IP encapsulated on SONET – packet over SONET (PoS)
- FC over ATM over SONET
- FC on SONET

FCIP was developed by the IP Storage Working Group of the Internet Engineering Task Force (IETF), as a method to encapsulate FC frames into IP packets that can then be formatted through TCP/IP and PoS. The implementation of FCIP significantly improves the performance and QoS level of IP/Ethernet by managing the TCP/IP layer to achieve reliable data delivery and recovery. The added complexity results in five protocol layers between FC and SONET. Each layer is managed independently resulting in processing delays and operational overhead – see Figure 2. As a result of the complexity the hardware is expensive and requires a significant amount of software for the tight integration of FC to SONET. Never-the-less, FCIP is rapidly becoming a widely used standard for high speed SAN remote storage.

FC frames can also be broken into ATM packets and carried by SONET. Figure 2 shows this as a four-layer stack of protocols. Approximately 15% of the bandwidth of the network is devoted to the encapsulation overhead. Equipment for this implementation is also expensive.

FC on SONET is a 'thin protocol' as shown in Figure 2 and is less costly to implement but is a more custom implementation and not yet a standard. It does have lower added overhead than the other implementations but requires an additional out of band control path between the sender and the recipient.

TEST RESULTS

Sypris Data Systems has not determined which of these choices will be selected in the Silver Phoenix system architecture. To help make the choice a test bed has been setup to evaluate the cost, reliability and limitations of each implementation. The end-to-end test bed configuration is shown in Figure 3 and takes advantage of the Silver Phoenix capability to simultaneously record and play at data rates over 225Mbytes/s. The test bed uses a powerful high-speed bit error test capability and simulates data transfer distances to over 10,000 kilometers. The test bed was operational in December of 2003. Work with equipment providers is currently in process to implement and test each of the described FC over SONET methodologies.

Initial testing was performed with FC on SONET and FC in ATM cells on SONET. Equipment for the FC on SONET test connected quickly and easily in the Silver Phoenix FC-2 network and data was successfully transferred to distances of 10,000 KM. To accomplish the test some software issues had to be worked around and will require attention before the configuration is finalized. There is no error correction built into the configuration so error rates of about 10^{-11} can be expected with the present configuration. A BER of 10^{-11} may be acceptable for many telemetry data transfer applications. Consideration is presently being given to how such error correction can be added in the Silver Phoenix architecture.

FC on ATM over SONET has also been configured. The present FC-2 switch equipment being used by Silver Phoenix would not successfully negotiate connection with the ATM-SONET Gateway equipment and had to be replaced with equipment from a different manufacturer. The integration is still in process as of this writing. The perceived advantage of the ATM on SONET equipment is its error handling capability. When a transmission error is encountered in an ATM cell the equipment can request a retransfer of the corrupted cell. The extent to which the sustained real-time data transfer rate is impacted by such retransmissions has not been determined at this time.

One of the three methods discussed in this paper will prevail and be selected by Sypris Data Systems as the most desirable for long-haul exchange of high-speed, real-time data. It is not a matter of if or even how the implementation can be accomplished. All the methods that have been described are presently available and given integration effort can be made to operate successfully at some level of performance. Different methods may be more suitable to different applications. Some questions that remain to be answered are:

- Which approach can be used to confidently implement real-time connection between a high-speed data collection center and an analysis center separated by a long distance?
- What data storage capacity is required at the collection center to handle network anomalies and exceptions with zero data losses during 7 X 24 operations?
- Which approach produces the most cost affective solution including the cost of the leased secure network resources?
- What network limitations must be accounted for by the Silver Phoenix data collecting hardware and software, and what are the appropriate methods to resolve these limitations? Examples of the limitations are the bit-error-rate of the FC-2 network and of the SONET network.
- Which method is best for Sypris Data Systems and our data collection customers?

ON-SITE DATA STORAGE

Some amount of data storage is required at the site where telemetry is collected even in a configuration where collected data is rapidly forwarded from the collection equipment to the remote data center. The storage time may amount to a few seconds or to many minutes. An unmanned data collection operation should include primarily electronic and software components with zero or very few active mechanical mechanisms. RAID disk configurations are designed to allow uninterrupted operation without degraded performance even if one of the disks becomes sluggish or fails. Nevertheless, high data storage capacity requirements translate to many disk drives elevating the risk of an outage and increasing the possibility that data can’t be recorded or recovered without some manual intervention. Mechanical failure risk will be avoided if the need for on-site storage is a minimum and the data is forwarded over the network as its being recorded. Options for on-site storage may be economically and sufficiently satisfied by high capacity DRAM memory with RAID backup only used in the event of a network outage or slow down.

The required recording time, the maximum aggregate data rate from all channels and the need for longer term backup must all be taken into account when designing a telemetry collection system that will operate totally unmanned.

CONCLUSION

Multiple options have become available and have proven successful to connect FC data storage networks to long-distance OC-12 carriers. Each option has positive and negative features but there is no question that the capability to collect and forward high-speed real-time data from one geographic location to another exists and can be implemented. There is no argument that the cost of data collection will be reduced as the switch is made from magnetic tape equipment to digital disk equipment. Reduced or zero man hours expended at a collection site is one preferred way to control costs and make more dollars available for new equipment and for upgrades needed in other parts of system operation.

The prevailing telemetry data collection paradigm will undergo considerable change as system designers and users are exposed to methods that make unmanned collection operations feasible. They will need to develop high confidence that there is very little risk in the unmanned collection scenario. The test bed being developed at Sypris Data Systems will answer many operational questions and provide data and information that can be used by telemetry collection system designers as they explore ways to reduce the need for manned telemetry collection sites.

FIGURES 1, 2 & 3

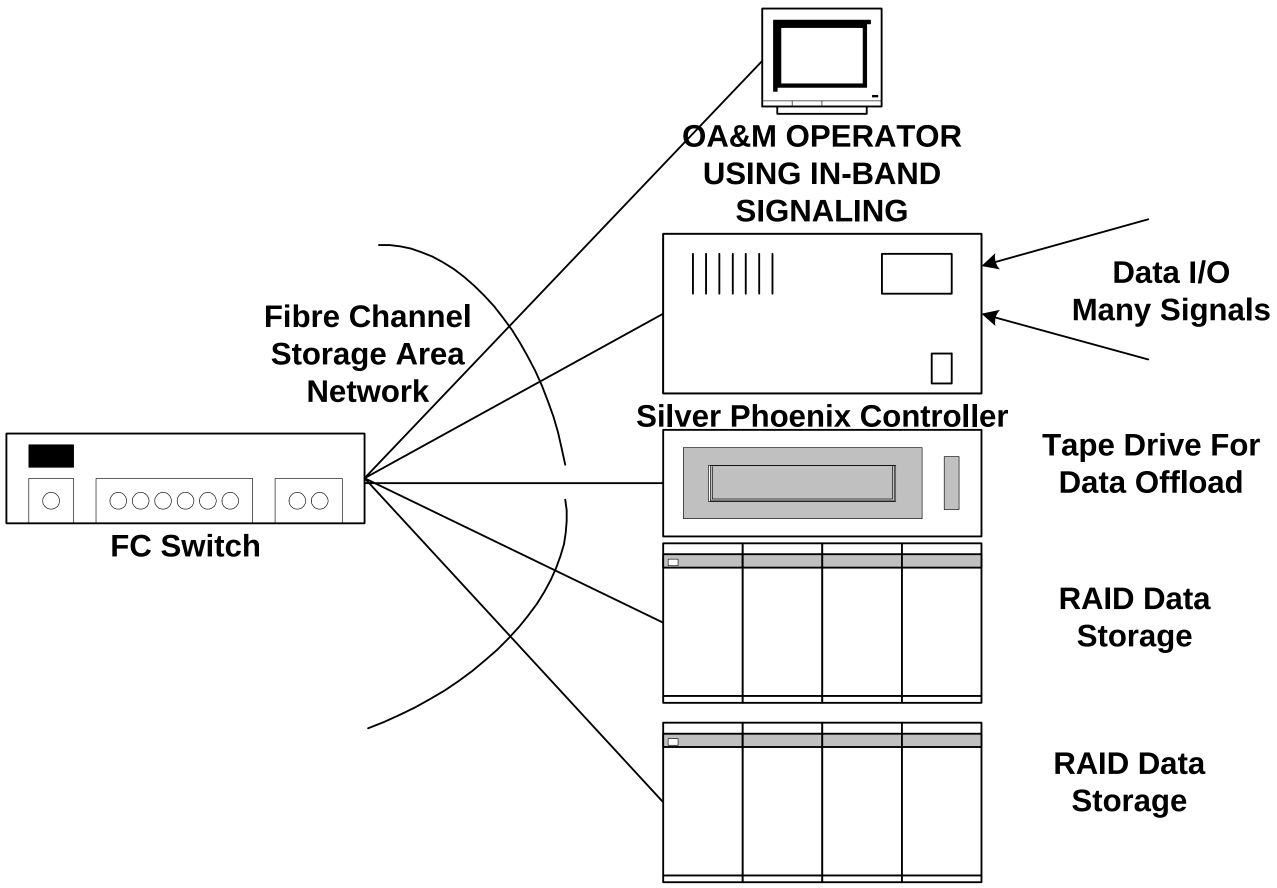


Figure 1
Telemetry Data Collection Using
RAID Storage
Manned Collection Site

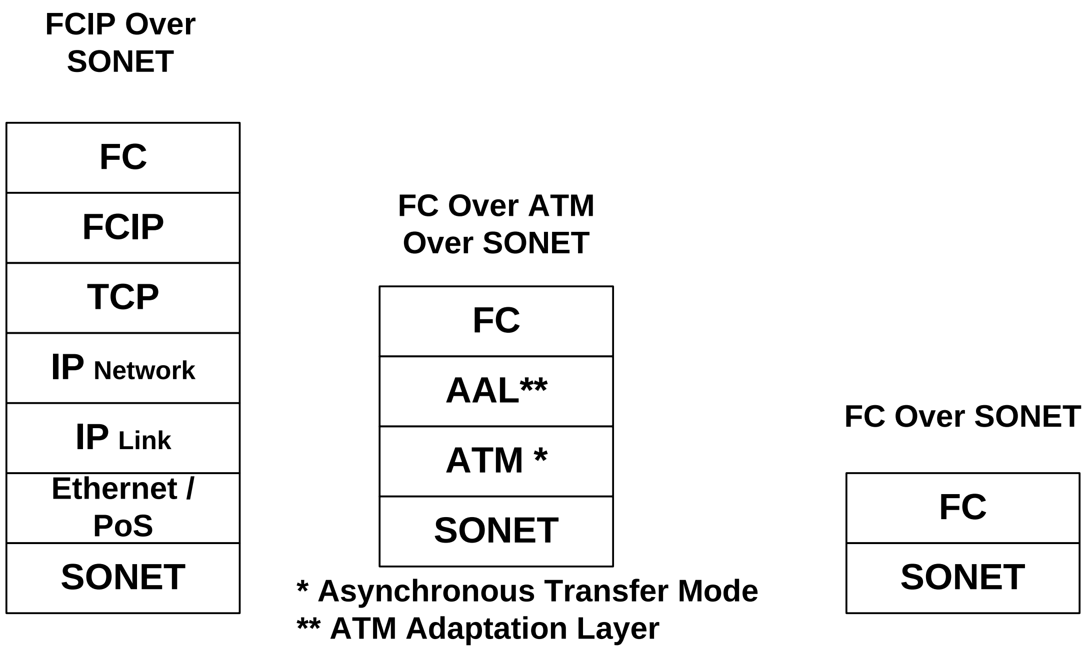


Figure 2
Network Protocol Structure of
Three SONET Adaptations

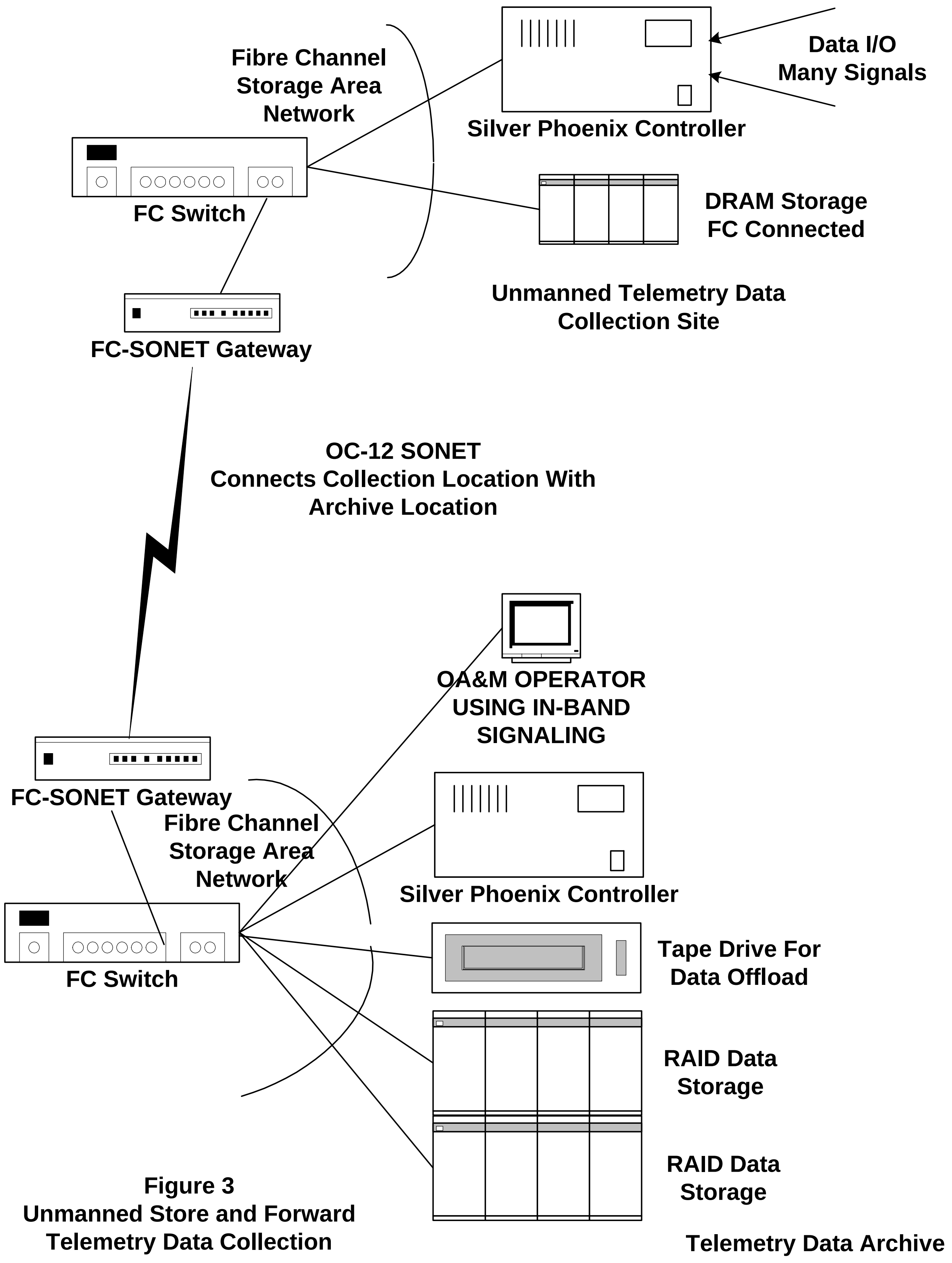


Figure 3
Unmanned Store and Forward
Telemetry Data Collection

REFERENCES

1). “Reliable, Least-Cost SAN Extension Over The MAN/WAN”, Paul Schoenau, Akara Corporation, presented at Storage Networking World, Orlando FL, Oct. 27 – 30 2002.

2). “Extending Storage Networking Over Optical IP Networks”, Robert S. Preece, Lucent Technologies, presented at Metro Optical, April 1, 2001.

3). “The Economics of Large Scale Data Transfer” Andy Helland, LightSand Communications, 2002.

4). “TCP/IP Architecture, Protocols, And Implementation”, Sidnie Feit, McGraw-Hill Series on Computer Communications, 1993.

5). “SONET/SDH”, Third Edition, Walter Goralski, McGraw-Hill/Osborne, 2002.

On-board Data Management for UAV's

Chris Duckling

L-3 Communications (Communication Systems-East)

Abstract

With the increasing payloads and range of current and proposed Unmanned Air Vehicles (UAV's), the management of on-board sensor data, be it mission or test data, demands fresh thinking. Autonomous flight and autonomous data capture coupled with wider bandwidths from multiple sensor systems offer potentially advantageous scenarios to be developed. In future systems the direct data downlink approach will not always be useable or may be non-optimal, particularly for over-the-horizon or exceptionally long duration activities. Management of collected data thus becomes critical if it is not to be immediately downloaded. Incorporating a data recorder / buffering system as part of the payload will open up new operational scenarios and permit higher effective download bandwidths to be achieved. Compression in the time domain versus the frequency domain also becomes viable. Storage Systems such as non-volatile solid-state recorders and magnetic hard-disc peripherals are evolving to meet the ever changing and challenging mission requirements. Available data storage capacity is doubling every 12 to 18 months, providing smaller implementations and / or higher storage capacity with a reducing cost-per-bit. Integral interfaces provide telemetry and mission data, audio and video streams to be multiplexed and rate-shifted to optimize bandwidth for transmission. Both embedded memory and total system solutions are available from suppliers as COTS equipment, providing flexibility for payload subsystem implementers.

This paper looks at the historical position, the current state of the technology, some system implementation ideas and the new operational scenarios that become possible.

Introduction

The operational role of most unmanned air vehicles is to over-fly some hostile or inaccessible terrain or environment, collect data and return that data for analysis. In the majority of cases it is desirable also to retrieve the air vehicle but this is not always the case. We may therefore conclude that the whole purpose of the mission is to collect and return the required data and thus the Concept of Operation (CONOPs) for the mission is, or should be, constructed to satisfy that need.

In military applications, air vehicle stealth is an increasingly important requirement for lack of detection. This should not be seen solely in the domain of audible or visual stealth; more and more we find sophisticated ground sensors able to detect transmissions from approaching air vehicles.

The quest thus becomes how to maximize the collection and retrieval of the data in a stealthy environment to maximize the mission success.

Additionally, sensors are becoming more sophisticated and multiple high data rate sensors are commonplace. Previous architectures created ‘stove-pipe’ data storage systems – each sensor having its own storage system, with the associated increase in space, power, weight and synchronization complexity. With high reliability multi-input storage devices now available to take these high data rates, alternative architectures are possible.

This paper postulates that insufficient attention is paid to the management of the collected data on-board UAV’s and that more effective techniques open up new CONOPs which will give strategic advantage and simplify the airborne system.

Data Collection

Unmanned platforms are gaining in sophistication all the time. With payload capacity and endurance increasing year on year the sensors being carried are similarly becoming cleverer. While by percentage quantity the majority of UAV’s are using ‘video cameras’ with direct low-bandwidth analogue data links for data return, there are newer systems carrying sophisticated multi-spectral sensors, synthetic aperture radars, chemical and biological sensors and relaying their data via satellite, relay platform (manned or un-manned) using wide bandwidth data links. Such systems are not merely extensions of previous UAV’s they are moving into missions previously undertaken only by manned platforms.

These highly competent sensors generate digital data at a rate many orders of magnitude greater than ‘TV cameras’. They have the ability to image vast amounts of ground area and provide detail of the target areas previously only dreamed of; but the data they provide has to be managed. In many cases this is by way of a wideband data link; but there are drawbacks to such an approach as discussed in the next section.

Of course the new sensor types do not obviate the use of the traditional ones and in many cases we see a mix of low rate data, analogue video, digital video and high data rate sensor outputs with their CONOPs priorities changing as the mission unfolds.

A new phenomenon is appearing which affects the situation and that is the ability of UAV’s to operate in autonomous flight, i.e. un-tethered. In this mode the ground controller may have little or no contact with the air vehicle while data continues to be collected, and thus no method of retrieving the collected data in real time.

Data Linking

With low data rate sensors, such as environment ‘sniffers’ the data is often low rate (in the 1 – 10 Kbits per second range) and as such neither data storage nor data transmission present much of a problem. As the sensor sophistication increases, in general, the data rate does also. For example a video camera with a reasonable resolution may generate digitized data at a few MBytes per second, while a high-resolution multi-spectral stand-off camera may generate more than 100MBytes of data per second. SAR sensors produce output data at rates depending upon their resolution and the level of onboard processing they have. So we have a range of data rates from a few Kbytes per second to greater than 100MBytes per second.

The aim for most missions, as stated in the introduction, is to collect data from the area of interest and faithfully return that data to the ground and perhaps a third-party airborne asset. The most common way to do this is via a live data link. Data links were originally analogue systems but more and more they are now full digital links with auto tracking and error detection and correction. Their use, particularly wideband links, is a major factor affecting the CONOPs.

Managing the Bandwidth and Storing the Data

Although data links are available in bandwidths in excess of 30Mbytes per second, it is not always desirable to carry such capability on board. The reasons are size, weight, power and cost. It is thus more practical to manage the data to reduce the link bandwidth needed and thus the requirements on the data linking system. Assuming defined average and peak data rates from the on-board sensors there are three primary methods to reduce data link bandwidth requirements:

1) Compress the data in the frequency domain
2) Compress the data in the time domain
3) Buffer the data to remove the peak requirement

Item 1) above is the usual technique adopted by ‘data compressors’. JPEG and MPEG compression techniques work by removing ‘unnecessary’ data from the data stream using sophisticated algorithms. However, these are not without their pitfalls as all data compressors work to ‘rules’ and some of these are associated with change rates in scene entropy. Some loss of integrity will be traded as the compression rate increases.

The second approach, that of compressing in the time domain, is less used - partly because the equipment to enable effective airborne application is fairly new. The principle is that if data is collected for a time period ‘x’ during a total mission time made up of a transit to target time of ‘y’ and loiter and return time from target of ‘z’, then if x < z it is reasonable to assume that the data can be collected and stored at full data rate and transmitted at a lower data rate over a longer time period while the air vehicle loiters and returns.

The compression ratio required is given by:

$$\text{Compression}_{req} = \text{collected data rate/data link bandwidth}$$

And the maximum time compression ratio is limited to:

$$\text{Compression}_{max} \leq z/x$$

Two points are relevant with this scenario. The first is that the return time can be extended by loitering and second that if the collection time is a large percentage of the mission time then compression ratios are small. There is no reason why a combination of frequency and time domain compression cannot be used and indeed such an approach could reduce compression requirements in the frequency (lossy) domain.

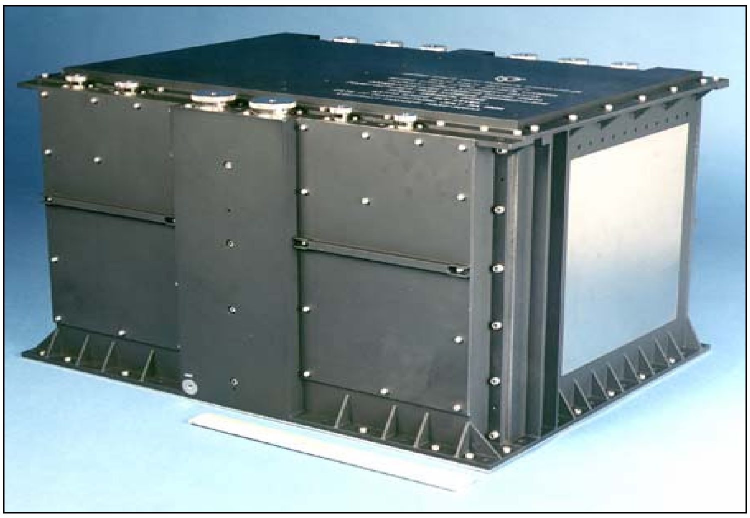
The third approach is appropriate where a sensor produces high rate bursts of data, such as a framing camera. In this scenario it would not make economic sense to provide for a data link to transmit at the peak data rate when a simple digital buffer would be able to store the data and re-transmit it in full integrity at the average rate of the data.

Finally there are other benefits to data buffering on-board. These are:

- Ability to cope with a temporary loss of data link
- Ability to cope with a permanent loss of data link
- Ability to manage for stealthier transmissions

If the mission criticality depends on getting the data back safely and the live data link is lost, there is the ability to 'recall' the buffered data from the on-board storage system. This system has been used for many years in satellite data collection systems to reduce transmissions and the number of earth receiving stations. An example of a system in orbit today is shown in Figure 1. Applying such an approach to UAV's allows greater terrain to be covered and permits un-tethered operations.

Figure 1. L-3 Landsat 7 Space Solid-State Recorder



A permanent loss of a link is less likely, but if the mission data has been stored on-board and the air vehicle is recovered the mission could be salvaged.

Finally, the stealth impact in today's crowded RF environment cannot be ignored. Telemetry links to control UAV's occupy narrow bandwidth and have good data integrity; add to this flight autonomy, and the control link is well catered for. Not so the mission data link. In some crowded environments it may not be possible to have all UAV's transmitting at once and in hostile territories the RF emissions from a wide bandwidth mission data link could alert ground sensors to the presence of an unwanted airborne asset.

For these reasons the ability to control the timing of the mission data link transmissions is essential. To permit continuous data collection but sporadic, controlled linking, a data buffer of appropriate size is necessary.

Types of Data Storage

Historically, data storage was limited to wire recorders and magnetic tape systems. Both of which are not suited to buffering, where replay could be called upon at any time. In the case of a time compression technique there might be the need to record and replay data concurrently, and wire and magnetic tape cannot easily do this.

Magnetic disk of the type used in desktop and laptop computers provide many of the required features and can be made to simulate concurrent record and playback. As will be shown later, some manufacturers have addressed the problems of survivability within harsh environments and offer system designers an effective data storage device.

As magnetic disk systems are based on commercial off the shelf (COTS) technology, adherence to industry standards is routinely achieved. With careful architectural design it is possible to package disks to provide many gigabytes of storage in a small package at an attractive price.

The alternate technology is that of solid-state digital storage. The growth in mobile telephones and digital cameras, both of which require 'FLASH' non-volatile memory, has fuelled a race to increase the density and reduce the power consumption of solid-state memory cells.

The technology has matured such that devices are extremely reliable and the cost is continuing to drop as the silicon wafer integration levels increase. With careful attention to architecture and the use of techniques such as Reed-Solomon error detection and correction (EDAC) large scale storage may be assembled. Typically storage capacities from a few GBytes to hundreds of GBytes are achievable in small, light, robust packages.

Disk and solid-state are both non-volatile memory technologies and as such their stored data is retained when power is removed.

Inherently, the solid-state technology allows variable collection and replay rates, something which tape and disc cannot do without a buffer store. So for example, data could be collected at 100**M**bytes per second and replayed at 100**K**bytes per second! (and *vice versa* for fast ground replay)

A final advantage of solid-state technology is that a large data store can be rapidly erased – something other technologies cannot achieve. Thus if the system could potentially fall in the hands of the enemy due to a loss of control or the vehicle being shot down, the stored data could be erased to an unrecoverable level in a few tens of seconds. No other storage technology comes close to this.

Multiple Input Devices

The need to reduce ‘box count’ has lead to a number of manufacturers creating systems with greater levels of integration.

For example, the system shown in Figure 2 is capable of taking the following inputs depending on configuration:

- Up to 4 Analogue Video
- Up to 2 Digital Video
- Up to 8 Analogue Audio
- Up to 4 1553B data bus
- Up to 2 Ethernet
- Up to 8 Discretes

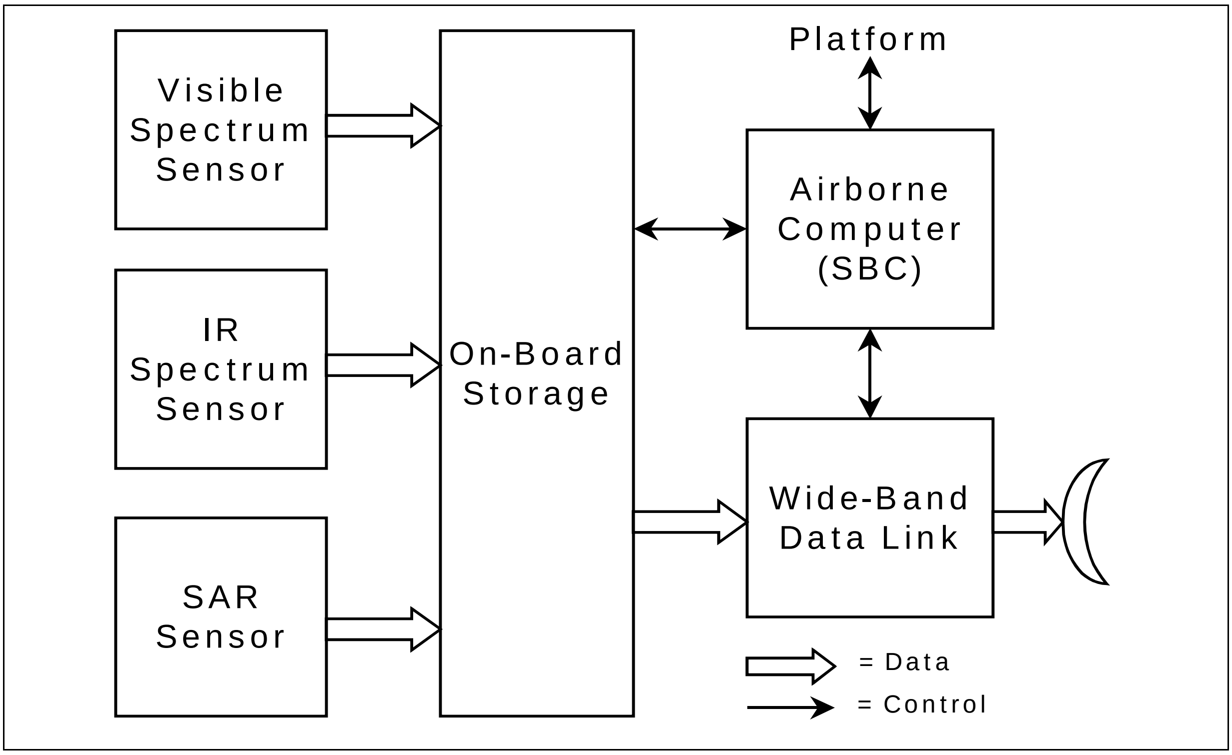
Figure 2. L-3 Communications multi-input digital recorder

And all of this in a small package with a removable harsh-environment disk memory system. By using this approach of an integrated system, time and signal synchronization is maintained for playback. This in turn simplifies ground systems for multiple sensor analysis and removes the stove-pipe approach of existing architectures.

Typical Applications

So what would a typical installation look like? Figure 3 shows the primary elements of the airborne system, and Figure 4 shows how this might be physically represented.

Figure 3. Typical UAV Installation



In Figure 3 the data streams from the multiple sensors are fed directly into a buffer/storage system at full rate, with peaks that could be four or five times the average rate of data collection.

The control of the data flow, but not the data itself is a low rate activity and thus may be accomplished by an off-the-shelf single board computer (SBC). The data link may take full-rate streaming data if the bandwidth and RF allocation are available or buffered data at a reduced rate if the CONOPs dictates. The platform processing commands from its telemetry link may also re-command the data to be re-sent in the event of a link failure.

Summary

This paper has investigated the problems associated with collecting large amounts of data in an airborne scenario where the bandwidth or availability of the mission data link is insufficient or non-continuous. It concludes that the incorporation of some form of data storage and/or buffering will greatly enhance the availability and utility of the asset and permit greater flexibility within the concept of operations.

Figure 4. Physical Elements of Figure 3

The choice of harsh environment magnetic disk or severe environment solid-state technology will be dictated by the platform environment. Multiple input devices are now available which reduce box count and permit time and mission synchronization for multi-sensor platforms.

Contact information

e-mail: chris:manyoaks.co.uk

web: www.L-3Com.com/STAR

Implementing COFDM to Provide Robust Microwave Transmission of Video Signals for Tactical UAV's and UGV's

Christopher M. Durso, President
Pacific Microwave Research, Inc.
Vista, CA

ABSTRACT

Tactical unmanned aerial vehicles (UAV's) and unmanned ground vehicles (UGV's) can deliver real-time battlefield video directly from air or ground systems to command staff providing unprecedented situational awareness and tactical advantage. The tactical video communications system must be secure, compact, lightweight, and fieldable in quick reaction scenarios. Pacific Microwave Research, Inc. has developed a system capable of providing reliable and secure video communications to handheld terminals throughout the theater from UAV and UGV assets. PMR's Coded Orthogonal Frequency Division Multiplex (COFDM) video transmission system is designed for tactical video transmission in battlefield or Military Operations in Urban Terrain (MOUT) environments. Using digital video and modulation coding, the system provides a robust link in the non-line-of-sight (NLOS) tactical environment.

KEYWORDS

Digital Microwave Transmission, COFDM, Non-Line-of-Sight Wireless Video, Tactical UAV, Tactical UGV

INTRODUCTION

Military users of analog FM/FM microwave video links have long contended with the destructive effects of multipath on link performance. In the tactical environment, multipath occurs when a radio frequency signal is reflected off a surface (or multiple surfaces) and arrives at the receiver antenna at some later time. These time-delayed signals result in a non-linear response across the channel of interest. As a result, frequencies within the desired band of operation are reduced in level while others are increased. Often, the effect occurs at critical points with the transmission baseband (video synchronizing pulses, for example) causing the video signal to roll and tear across the screen making the mission critical image data unusable. Multipath is an environmental problem that is particularly difficult to avoid.

Coded Orthogonal Frequency Division Multiplex (COFDM) is a multi-carrier digital transmission scheme consisting of approximately 2000 radio frequency carriers within 8 MHz of occupied bandwidth. Each carrier is modulated using QPSK, or16-QAM, (depending on data throughput requirements and channel response) to form an aggregate data transmission rate between 5 Mb/s to 20 Mb/s. Using forward error correction (FEC) and interleaving techniques, the data is coded onto the multi-carrier system and transmitted at the required microwave frequency. When an adverse channel response occurs as the result of multipath reflections, the FEC scheme recovers the data from the lost carriers. COFDM is provides a high immunity to multipath making possible tactical mobile high-bandwidth communications with simple antennas. The technology makes possible a wide range of first responder and tactical UAV applications.

COFDM for TACTICAL UAV's and UGV's

Small tactical UAV's and UGV's can provide realtime battlefield imagery from on-board visual and thermal sensors direct to operatives. In the tactical environment, ground troops cannot be burdened with complicated tracking antennas and elaborate ground station equipment in order to receive aerial reconnaissance imagery. A fieldable system must employ lightweight portable antennas (either stationary or mobile) to fit the CONOPs profile of a fast moving tactical response unit. The solution to reliable and secure wireless video communications in the tactical UAV environment is COFDM digital transmission.

The unavoidable problem of multipath in analog systems makes tactical video collection difficult, or impossible. Digital COFDM transmission differs significantly from analog and incorporates both digital video compression and transmission techniques. Chief among the benefits of digital technology is the ability to deliver reliable video imagery in an environment that is rife with multipath. The robustness of COFDM in the tactical environment facilitates rapid deployment systems, mobile and airborne surveillance, and high-quality tactical video collection in tactical and urban environments. To insure mission security, encryption techniques can be implemented to provide link security that exceeds the level of security (immunity to intercept) possible with analog systems by orders of magnitude.

Digital video transmission technology holds the promise of offering tactical video from a UAV or UGV platform that is secure, reliable, and robust. Airborne digital video may be delivered to portable and mobile ground stations to provide realtime situational awareness in the tactical environment. Since COFDM digital transmission can provide true non-line-of-sight functionality, both battlefield and military operations in urban terrain requiring airborne video intelligence may be effectively supported from a tactical UAV with a visual or thermal sensor.

MULTIPATH

Typically, line-of-sight video links use large tracking dish antennas. This deployment scenario is not practical for tactical operations. Tactical video applications require a portable ground station that is simple to set-up and operate. As a result, large directional antennas and tracking systems are not well suited to the application. A desirable antenna configuration for tactical operations is a low to medium gain omni-directional antenna. This allows the ground station or individual soldier to move freely within the environment without the concern of maintaining a track on the tactical UAV or UGV supplying mission video. While omni-directional antennas provide maximum flexibility, they cannot discriminate against multipath reflections and are a bad choice in conjunction with analog technology. Digital COFDM transmission makes the use of omni-directional antennas in the tactical environment possible.

Multipath is problematic in tactical video collection. Signals reflect off the ground, trees, vehicles, buildings, and thousands of other surfaces in the environment. When this happens, the desired (or direct) signal is only one of many arriving at the receiver. The reflected signals arrive at the receiver at some point later in time. When the signal travels a greater distance to arrive at the same destination, it must arrive later in time. These delayed signals will degrade analog video signal systems. Short time-delay reflections will cause the transmitted analog picture to break-up, tear, and roll. To illustrate the multipath problem, the direct wave is shown as D_1 in Figure 1, while a reflected wave is shown in its component parts as D_2 and D_3. It is important to note that only a single case of multipath reflection is shown. In real-world applications, thousands of reflected signals conspire to diminish the quality and reliability of the analog link.

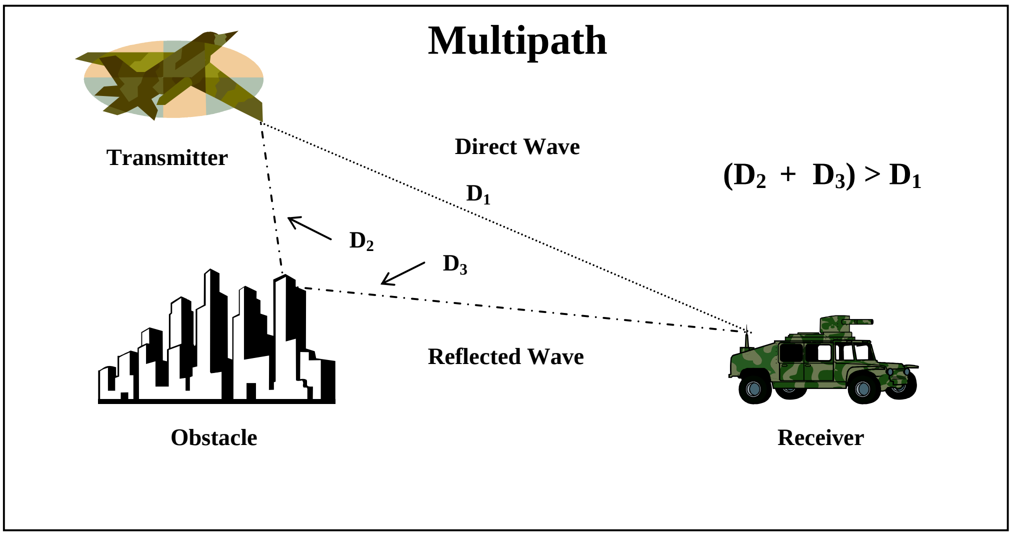


Fig. 1. Graphic Representation of Multipath

To understand how multipath fading impacts the transmission channel, refer to Figure 2. This graph represents the signal characteristic of an ideal transmission channel, where signal amplitude (or level) is constant across the bandwidth (frequency of operation) of the transmission channel. This response is typical of a direct coax connection or parabolic dish antennas in a clear line-of-sight environment.

When a radio frequency signal reflects off surfaces in the multipath environment, the energy arriving at the receiver is no longer equal across the desired bandwidth as a result of phase cancellations. The phenomena results in reduction of signal at certain frequencies within the channel bandwidth. A multipath channel response might resemble that shown in Figure 3. The deep nulls in the channel response represent a significant loss of signal at these frequencies.

Channel response will dynamically change as it is influenced by the unique multipath conditions found in the tactical environment. This is why slight changes in antenna position at the transmitter or receiver locations can have a profound impact on the quality of an analog link. Since it is difficult, or impossible, to control the reflective surfaces in the tactical environment, multipath is a problem with a temporary solution. Movement of objects within range of the transmission system (personnel, vehicles, equipment, etc.) will influence the multipath. This is why it difficult to maintain the quality of an analog tactical surveillance link over time.

Multipath in an analog system results in modulation phase distortion and loss of signal. Therefore, the artifacts of multipath limit the practical applications of analog video transmission technology for tactical deployment. Digital COFDM modulation overcomes the multipath problem making possible non-line-of-sight (NLOS) tactical video applications.

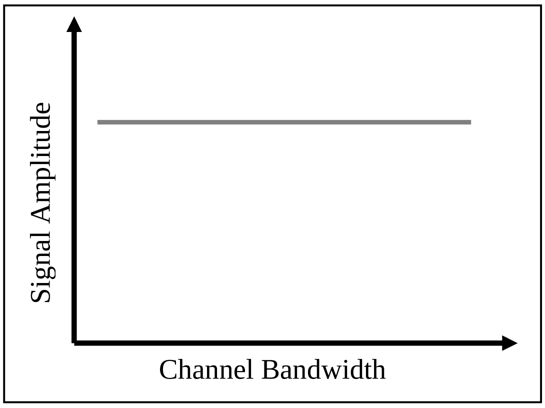


Fig. 2. Response of an Ideal Transmission Channel

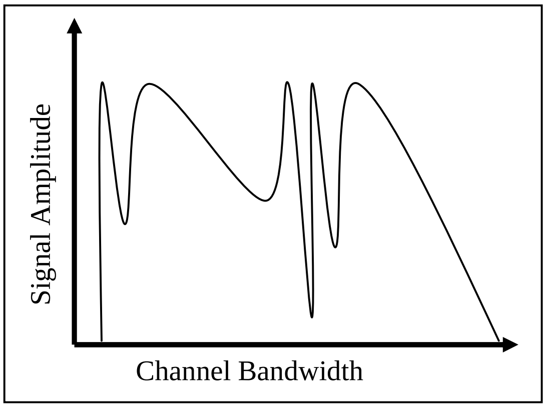


Fig. 3. Response of Multipath Channel

DIGITAL VIDEO TRANSMISSION TECHNOLOGY

Digital video transmission technology provides a significant improvement over analog technology due largely to the advantage of the modulation technique. It is the modulation scheme that results in a reliable and robust link which is virtually immune to the effects of multipath. Digital modulation makes it possible to realize NLOS video transmission.

Digital video transmission incorporates two important technologies to deliver high-quality video, audio, and data signals in the microwave frequency bands. These technologies are MPEG-2 and COFDM. MPEG-2 is a video compression technique and COFDM (Coded Orthogonal Frequency Division Multiplex) is a modulation coding technique. Collectively, with forward error correction scheme, they comprise digital video transmission.

MPEG-2 VIDEO COMPRESSION

Most video cameras produce a compliant analog video signal. In North America, cameras conform to the National Television Systems Committee (NTSC) standard. In Europe, and many other parts of the world, the International Radio Consultative Committee (CCIR) standard is recognized. The CCIR standard is commonly known as PAL. Before an analog video signal can be transmitted over a digital wireless link it must first be digitized. Digitizing an PAL video signal results in a data stream at 216 Mb/s. This data rate is far too large for digital transmission in a reasonable bandwidth. To reduce the bandwidth (data rate) the data must be compressed. This is accomplished using a motion prediction coding technique known as MPEG-2. MPEG-2 compression can reduce an PAL data stream from 216 Mb/s to 4 – 6 Mb/s. The result is a high-definition digital video signal at a data rate that is suitable for transmission using COFDM.

Pacific Microwave Research has implemented a low-latency coding derivative of the MPEG-2 standard to reduce the processing delay experienced between the source coder at the transmitter and decoder at the receiver. This is accomplished eliminating the bi-directional frame (B-frame) and distributing inter-frame (I-frame) image data across a series of predictive frames (P-frame) instead of transmitting the I-frame data all at the same time. Latency is important when controlling UAV or UGV systems since it is easier to pilot a remote controlled vehicle using an on-board camera as a reference when the image latency is reduced to less than 50 ms.

WAVEFORM PARAMETERS

COFDM is a complex multi-carrier radio frequency modulation technique designed to transmit digital data and provide substantial immunity to multipath artifacts. The technique was developed to serve as a missile telemetry transmission system as a result of the problems encountered when receiving data from a moving object in a multipath environment. At the time the technique was developed, technology was not mature enough for a practical system to be built. Today's technology, including large Field Programmable Gate Arrays, high-speed microprocessors, and Direct Digital Synthesis makes COFDM a practical modulation scheme.

Unlike conventional analog transmission that utilizes a single radio frequency carrier to transmit video information, COFDM uses multiple carriers (>2000) to transmit digital information. Because data is spread over 2000 narrowband carriers instead of one wideband carrier, signal cancellation due to multipath reflections has significantly less impact on the quality of the signal. Additionally, the use of forward error correction means the signal can be reconstructed, and the data extracted, even under the most adverse transmission conditions.

The 2000 data carriers are spread across an occupied spectrum of only 8 MHz. Reduction of the system noise bandwidth as compared to a PAL analog video transmitter requiring 18 MHz of occupied bandwidth provides system gain. The data carriers may be modulated using quadrature phase shift keying (QPSK) up to 64-QAM. Fixed links can take advantage of high-order modulation constellations in order to pass up to 32 Mb/s. However, tactical links operate best using a QPSK (4-QAM) modulation constellation since it is the most robust format with respect to multipath performance. For practical purposes, it is reasonable to limit high-order modulation to 16-QAM for tactical deployment.

If multipath should corrupt a handful of carriers, forward error correction (FEC) will predict what the data should have been and reconstruct the data. Forward error correction provides significant system gain. The aggregate data payload is modified by the amount of FEC applied to the signal. In the most robust mode, a code rate of ½ results in dividing the payload to include 50% signal data and 50% correction data.

In general, the modulation technology results in at least a 10 dB improvement when compared to analog transmission technology. While this improvement can be quantified at 10 dB on the bench, the actual improvement experienced can be significantly greater in tactical applications when various levels of multipath conspire to degrade the channel response. A difference in 10 dB is equivalent to comparing the performance of a 0.1W digital transmitter to a 1.0W analog transmitter. Of course, the resultant performance differential is manifest as more than simply a difference in power levels. The ability to resist multipath means consistently good video images until no further energy is available for the link to operate properly. In comparison, as an analog signal degrades the picture will become noisy and may tear or roll.

A simple path calculation for a 1 W system at 2300 MHz indicates that an analog system will yield a reliable signal over a line-of-sight path at up to 2 miles. A digital system will provide reliable signals with a 1 W transmitter at 2300 MHz at up to 6.5 miles! The advantage of COFDM is that the picture will be good using the digital system almost anywhere within the maximum calculated range while the analog signal is unpredictable within its maximum calculated range due to the effects of multipath.

For most tactical UAV and UGV applications, the actual range the system will operate over is not as important as how well the system performs over a short to medium ranges in a difficult environment. While an analog system may have the potential to operate over a predicted line-of-sight range of over one mile, it may be completely useless when the transmitter and receiver are separated by only 50 ft. because of the effects of multipath. In most cases, a digital link will provide exceptionally good results until the receiver has inadequate signal input. Independence from the environment is what makes COFDM digital technology the best choice for reliable tactical applications.

A digital COFDM signal occupies one half of the amount of spectrum compared to that an analog video signal. This means that more signals can be used within any given bandwidth with COFDM digital transmission. This is important since spectrum is quickly becoming a scarce resource. In most economy’s, pressure from commercial interests is forcing the transfer of microwave spectrum from government(military) use to commercial use to satisfy the demands of new public telecommunications technologies. Spectrum efficient digital transmission enables entities to do more with less.

The required carrier level of a COFDM digital system is less than that of the analog level due to the performance advantage discussed above. As a general rule, it can be assumed that approximately 10 times less power may be transmitted using digital technology as compared to analog technology for any given range requirement. This results in a lower radio frequency signature making detection by an adversary more difficult.

Each of the nearly 2000 carriers in the transmission system are precisely positioned in both frequency and phase to diminish the negative effects of multipath. Unwanted reflections (or echoes) are time delayed and fall between the desired carriers in what is essentially unused inter-carrier spectrum (guard interval). The demodulator performs a Fast Fourier Transform (FFT) and the time delayed energy present as a result of the reflections is processed out leaving only the data on the desired carriers. The amount of carrier spacing in a COFDM system impacts the range performance of the system in a multipath environment. Greater carrier spacing accommodates longer echo delays at the expense of requiring more spectrum for a given number of carriers. A greater number of carriers results in greater payload capacity and more effective interleaving at the expensive of increased bandwidth.

The carriers in a COFDM system are orthogonally related such that the energy contained in the sin(x)/(x) response of each carrier is aligned with the adjacent carrier as shown in Figure 4. When integrated, the energy from each carrier yields a zero-sum resulting in the inter-carrier guardband. This orthogonal phase relationship ensures that the carriers do not interfere with each other. While the modulation envelope appears to be 2000 distinct RF carriers, it is not generated by 2048 individual phase-locked voltage controlled oscillators. The COFDM carrier is mathematically derived in the transmitter by performing an Inverse Fast Fourier Transform (IFFT) on the waveform in the time domain to arrive at a waveform in the frequency domain. The resulting in-phase (I) and quadrature (Q) signals are then applied to the modulator and the RF waveform is amplified for transmission on the desired frequency band.

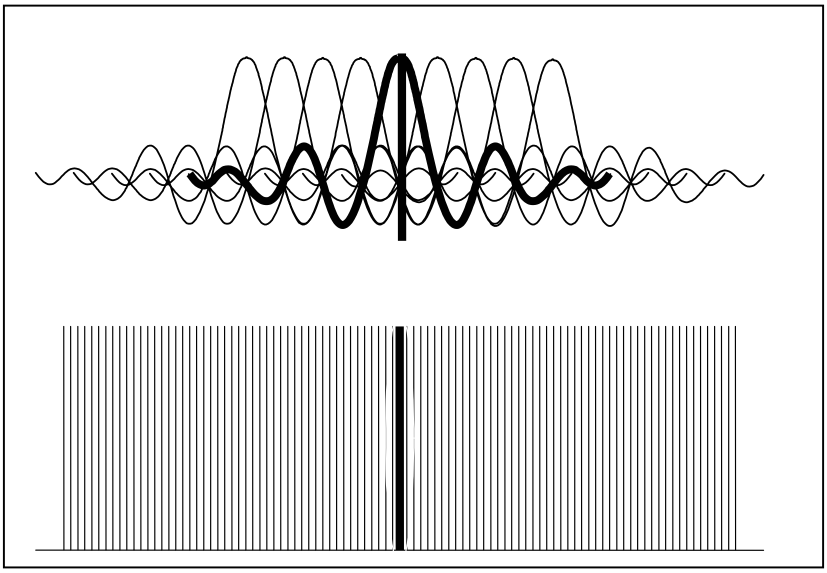


Fig. 4. The Relationship of RF Carriers in COFDM

Carrier guard interval is expressed as a fraction of the symbol rate of an individual carrier. In a 2000 carrier COFDM system, carriers are spaced by 4.464 kHz. This spacing is equal to the inverse of the maximum symbol time of 224 µs. Assuming a guard interval of ¼ (56 µs), the system will tolerate a 0 dB echo reflection over a distance of 8.4 km (round trip of 16.8 km) without any degradation in performance. While it is very unlikely that a reflection of 0 dB would occur over any distance, this performance criterion speaks to the robustness of the transmission architecture. Clearly, COFDM provides a high degree of rejection of unwanted reflections. Analog video transmission systems are not tolerant of high energy reflections in the multipath environment.

Each individual carrier in the COFDM system is modulated using QPSK or 16-QAM at a low bit-rate. The aggregate bit-rate of the transmission is the sum of the number of carriers multiplied by the bit-rate of each individual carrier. For example, when transmitting a signal at 8 Mb/s the payload for each carrier is approximately 4 kb/s. In practice, a 2000 carrier system (2K) consists of 1705 payload carriers as some carriers are designated for system overhead (synchronization and channel characterization, etc.). Additionally, the aggregate data throughput is dependent upon the channel coding (Viterbi and Reed-Solomon forward error correction) and guard interval selected. High code rates and short guard intervals (very high bandwidth applications) are more susceptible to interference issues than are low bandwidth applications (such as video at 5 Mp/s).

Code rates are expressed as fractions that define how much data bandwidth is available for user data transmission. Bandwidth not available for user data transmission is encumbered by forward error correction overhead. For example, a code rate of ¾ indicates that 75% of the total bandwidth is available for user data. Transmission data rates are affected by code rates and guard intervals for an 8 MHz COFDM system. By distributing (interleaving) the coded data across the available carriers, channel disturbances (selective fading) have less impact on transmission system throughput.

Figure 5 details the relationship between the modulation constellation (QPSK or 16-QAM) and different code rates and guard intervals with respect to available transmission payload. For example, the most robust mode of operation (QPSK, ½, ¼) provides a total payload capacity of 4.98 Mb/s. It may be seen from the table that nearly 20 Mb/s of payload data may be transmitted over the system with the proper selection of parameters. However, it is important to remember that decreasing the guard interval or code rate will decrease system performance in the tactical environment. As a result, transmission parameters should be selected for the minimum payload capacity required for the application.

COFDM 2K		**Guard Interval**			
Modulation	**Code Rate**	**1/32**	**1/16**	**1/8**	**1/4**
		Payload Data Rate (Mbits/s)			
QPSK	**1/2**	**6.03**	**5.85**	**5.53**	**4.98**
	2/3	**8.04**	**7.81**	**7.37**	**6.64**
	3/4	**9.05**	**8.78**	**8.29**	**7.46**
	5/6	**10.05**	**9.76**	**9.22**	**8.29**
	7/8	**10.56**	**10.25**	**9.68**	**8.71**
16-QAM	**1/2**	**12.06**	**11.71**	**11.06**	**9.95**
	2/3	**16.09**	**15.61**	**14.75**	**13.27**
	3/4	**18.10**	**17.56**	**16.59**	**14.93**
	5/6	**20.11**	**19.52**	**18.43**	**16.59**
	7/8	**21.11**	**20.49**	**19.35**	**17.42**

Fig. 5, Constellation Parameters and Payload

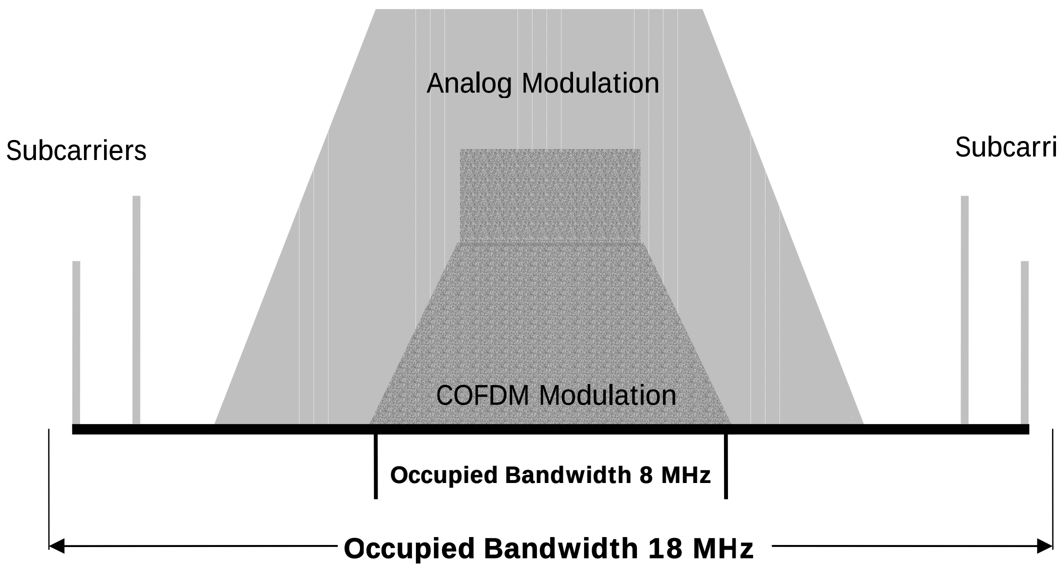


Fig. 6, Occupied Bandwidth of Analog and COFDM Digital

Since the COFDM transmission system requires only 8 MHz of occupied spectrum, system gain is achieved by improving the carrier-to-noise ratio over that of an analog system occupying 16 MHz of spectrum. Additionally, more COFDM channels can be fit into any given amount of spectrum as compared to a conventional wideband analog video transmission system. Pacific Microwave Research has conducted testing that reveals a high tolerance for co-channel and adjacent channel interference with COFDM. In one instance, two systems were operated in close proximity on the same RF channel using different code rates and guard intervals with excellent results. For tactical operations, COFDM provides a high immunity to jamming. Figure 6 compares the occupied spectrum of a conventional FM/FM analog video transmission system and a 2000 carrier COFDM system.

DOPPLER SHIFT AND TACTICAL VEHICLES

Not all multipath related issues are a direct result of reflections in the environment. It is possible to encounter phase-delayed signals as a result of Doppler shift. Laboratory tests conducted in 1997 by Deutsche Telekom Berkom examined the effects of Doppler shift on a 2000 carrier COFDM system operating in both QPSK and 16-QAM modes. The study used a channel simulator to quantify the increase in system carrier-to-noise (C/N) required to maintain image quality over a range of velocities. According to the results of the study, an increase of only 1.5 dB in C/N performance is required for both QPSK and 16-QAM operating at 1/2 code rate at a velocity of 50 km/h to maintain system performance. Increasing the velocity from 50 km/h through 200 km/h in both cases did not require any additional C/N improvement. The study indicated that in an urban environment (as would be found in tactical and MOUT operations), the predicted maximum vehicle speed for QPSK is 330 km/h and for 16-QAM is 240 km/h. In these modes, the payload capacity for QPSK is approximately 5 Mb/s and for 16-QAM it is approximately 10 Mb/s (see Figure 5). These data rates are more than adequate for high-quality imagery. In fact, multiple high-quality images could be transported at the 16-QAM data rate. Clearly, the performance degradation for COFDM systems as a function of Doppler shift at reasonable velocities is not a factor for effective tactical UAV and UGV operations.

RF POWER REQUIREMENTS AND FADE MARGIN

A common criticism of COFDM systems is the apparent power inefficiency when compared to analog FM transmitters. While on the surface this appears to be the case, a complete analysis of the system architecture helps put the power output issue in perspective.

Pacific Microwave Research's COFDM transmitter is a self-contained system consisting of the video compression and RF transmission elements. In the past, video compression units have been external components requiring integration with a third-party transmitter to form the complete RF transmission system. As such, the power consumption of the video compressor has typically not considered when examining the power consumption of the RF transmitter. PMR's approach is a completely integrated package (video compression and digital RF transmission) requiring only DC power, video, and antenna.

Typically, COFDM transmitters produce less RF power output for a given primary power consumption because the amplitude modulated carriers require a high degree of linearity optimum system performance. A typical linear amplifier for COFDM is operated 10 dB below the point an amplifier used for FM operation would be operated. For example, an amplifier that would deliver

5W of power in an analog FM application would be configured to provide 500 mW of power in a COFDM application. This 10 dB “back-off” is required to insure that a conventional saturated amplifier is operated in its linear range. The disadvantage to this approach for UAV and UGV applications is that a saturated amplifier operating with reduced drive still consumes the same amount of power as if it were driven to full output. Of course, at full output the resulting non-linear distortion would render a COFDM system useless.

In order to overcome this problem, PMR has developed a linearized microwave power amplifier. The linearized amplifier restores the modulation envelope (AM component) and provides very efficient linear power amplification. For example, a linearized amplifier capable of providing +15 dB of gain with a nominal output power of +30 dBm (1 W) will consume only 1.3 Amperes. Using the conventional approach of reduced drive to a saturated amplifier, the same amount of RF power output (+ 30 dBm) requires approximately 4 Amperes. The linearized amplifier is clearly provides a significant advantage to UAV and UGV systems with respect to power management.

A conventional digital video transmission system might consist of a video compression unit (1 A), a 0.25 W analog transmitter (0.6 A) and a 10 W RF power amplifier (5.5 A) for a total power consumption of 7.1 A. A COFDM system providing 1 W of RF power will consume 3.0 A of power. The conventional digital video transmission is a single carrier data transmission system that cannot provide the multipath immunity afforded by multi-carrier COFDM and the analog system consumes over twice the power for the same range performance. COFDM not only provides better range performance for a given power budget, but also provides unparalleled link performance in the tactical environment that conventional systems cannot.

Bench characterization of COFDM systems by PMR has revealed that, under static conditions, the COFDM system will perform 10 dB better with respect to receiver threshold than an FM system. Where an FM system fails at a level of -80 dBm, the COFDM system delivers excellent video down to -90 dBm. Additionally, the quality of the digital video image is consistent down to the minimum threshold while the analog video image becomes noisier as signal level is reduced. This is primarily due to the reduction in noise bandwidth of the receiver as the COFDM system occupies only 8 MHz of spectrum compared to a 16 MHz wide analog FM carrier.

However, while the playing field is leveled somewhat by virtue of the bandwidth improvement inherent in the COFDM system, performance in the field is substantially better with COFDM. This is a result of the frequency diversity afforded by the multi-carrier modulation system and the forward error correction applied to the data as described above. As a result, COFDM systems operating with an RF power level output 10 dB less than an analog FM video link will work substantially better in the real-world environment.

Pacific Microwave Research has conducted tests of its COFDM system in a variety of scenarios in both urban and rural environments using both directional and omni-directional antenna systems. When compared to analog FM systems, a COFDM transmission system behaves more as a “set it and forget it” appliance. As long as sufficient signal level is available, the system will deliver reliable video to the user. System performance is especially spectacular in an urban environment that is rife with short period multipath reflections. Such an environment would be consistent with MOUT operations where realtime aerial video imagery would provide valuable mission intelligence.

Another significant advantage for tactical operations using COFDM systems lies in the ability to scramble the bit-stream using an encryption key based algorithm to prevent unauthorized interception. Analog systems use cut and rotate scrambling technology that only provides a basic level of interception protection. With COFDM, it is possible to implement the 128-bit Advanced Encryption Scheme (AES) algorithm in the MPEG Transport Stream (MTS) to provide a high-degree of security. This digital encryption technology provides the type of security required when conducting surveillance on terrorism or national security targets. Use of the security feature in COFDM does not degrade system performance.

Not all "digital" link systems are the same. The conventional approach to digital video transmission requires a video compression unit and an analog transmitter. The digital output from the compressor/encoder is fed into the analog transmitter and the carrier is frequency modulated. More sophisticated approaches utilized QPSK modulation. However, each case incorporates only a single RF carrier to transmit the data. The multiple carriers of COFDM allows for the distribution of correction data over a number of low data rate carriers across the band of operation (channel) to enhance the performance in the tactical environment. The system gain provided by forward error correction and multi-carrier carrier interleaving makes COFDM the unique choice for tactical UAV and UGV applications.

APPLICATIONS

PMR has developed a compact COFDM transmitter for tactical UAV and UGV applications following two years of development. Using a compact COFDM receiver, the system can deliver tactical UAV or UGV imagery to a mobile command post or even directly to dismounted troops to support realtime tactical deployment decisions and situational awareness. A variety of tactical video missions are possible when COFDM is used as the transmission mode. COFDM provides a non-line-of-sight video transmission system that can truly be used for mobile applications.

Assuming a tactical UAV configured with a visual or thermal sensor and a 2200 MHz COFDM transmission system outputting 1W into a 6 dB gain omni directional antenna (6 dB omni antenna at receive location also) and operating at an altitude of 1000 m, the expected operational range is approximately 25 km. This range is calculated with low-gain omni-directional antennas on each end of the link! This configuration is typical for tactical UAV support of MOUT operations. A compact directional antenna located at a temporary-fixed command post would provide even greater system range. It is important to recognize that within the 25 km mobile operational range, video link quality will be excellent as a result of the multipath rejection capabilities of COFDM.

In addition to tactical UAV and UGV applications, PMR envisages a compact and rugged digital video and audio transmitter worn by military team members with a helmet mounted or handheld video camera and noise canceling microphone. The helmet mounted camera (visual or thermal) captures images as the solider moves through the tactical area of interest. The soldier also provides voice narration of the scene over the digital audio channel. Command post and unit personnel receive and evaluate the images and sounds and then direct the soldier over a secure 2-way radio link to obtain additional imagery of special interest. Because of the benefits of a COFDM digital microwave link, the soldier can roam freely (without the requirement of maintaining line-of-sight) while providing reliable and secure imagery to the command post.

COFDM technology provides substantial utility in MOUT operations because it is not necessary to maintain the line-of-sight conditions demanded of conventional analog FM video systems. Personnel can move around corners and enter buildings while still providing command staff with high-quality video. All that is necessary for reliable non-line-of-sight operation with COFDM technology is that sufficient energy is reflected back through the environment to the command post receiver. Tactical observation systems using COFDM transmission technology can be quickly attached to buildings or other structures, or even air-dropped, to provide command structure and troops with real-time video surveillance of key objectives. This video intelligence will provide a significant operational advantage and ultimately save lives in military and first responder missions.

SUMMARY

Digital video transmission using Coded Orthogonal Frequency Division Multiplex is a transmission technique that will transform the quality and reliability of video collection activities for military operations. The technology's ability to perform exceptionally well in a multipath environment with simple omni-directional antennas makes it ideal for tactical operations in both the battlefield and urban environments. Tactical UAV's and UGV's using COFDM can provide reliable and secure close-in visual intelligence direct to field command units and dismounted troops. Advanced scrambling of the COFDM signal in the digital domain reduces the risk of unintentional interception. COFDM is well suited for tactical UAV, UGV, and MOUT missions where simple and lightweight portable equipment is required for mobile operations. COFDM provides reliable and secure non-line-of-sight digital video transmission to a variety of military missions.

Loss-less Compression of AIMS Data for Transmission or Storage [1]

Armen Nahapetian
Teledyne Controls
Los Angeles, CA USA

Abstract

One of the main sources of information for an AIMS system is the parametric data recorded during flight. This data is often moved off of the aircraft for analysis on the ground. Even in cases where the analysis is done onboard during flight, the data is stored on the ground, for further analysis or expert inspection.

This paper presents recording and loss-less compression methods, which in conjunction with compression methods already in use or commercially available, significantly reduce the volume of data.

With the increase in storage capacities now becoming available, it may appear at first that there is little to be gained by such compression. However, it is just this increase in storage that is creating the need to move even more AIMS data between the aircraft and the ground. Any reduction in the volume of data has a direct affect on the transmission costs of the data, which can build up significantly even for a fleet of moderate size. Additionally, there are situations where the time allowed for transmission is limited, regardless of the cost. Such is the case for communications devices certified only for operation on the ground or at the gate. Efficient compression allows for these devices to move larger volumes of data during short turnarounds.

Though applicable to most types of AIMS data, in this paper, the benefits of the compression methods are demonstrated in the context of the Teledyne Wireless GroundLink®

Introduction

With the introduction of digital busses on modern aircraft, there has been significant increase in the volume of data available for aircraft condition monitoring and flight operations analysis. With the design of each new aircraft, the volume of this data further increases. Such data is, generally, acquired and analyzed by Data Management units on board the aircraft. A copy of the data is also stored and moved off of the aircraft for further analysis or inspection on the ground.

[1] Teledyne Controls has obtained U.S. patent 6,654,386 for the pre-processing algorithm described in this paper.

Even in cases where there is no Data Management unit onboard, a copy of the Flight Recorder (crash survivable) data is often downloaded from the aircraft for ground analysis.

The format of the flight data in the majority of such recordings is based on a “Frame-Subframe” format. This format was imposed by the hardware-only data multiplexers of decades ago, but has not changed even in the most modern aircraft being designed or built today.

The Frame-Subframe format is based on a four second cycle, where most parameters are acquired at least once every four seconds and are stored in fixed positions in the four second data structure, called the Frame. One method of acquiring and storing parameters less frequently than four seconds, is called Superframe, but as this is not relevant to the subject of this paper, it is not addressed here.

A Frame is further broken down to four Subframes, where each Subframe is used as a structure for storing the data from one of the four seconds. Parameters that are sampled more than once per second occupy multiple positions, called Words, in a Subframe. Figure 1, below, illustrates the structure of Frames, Subframes and Words, with some sample parameter recordings.

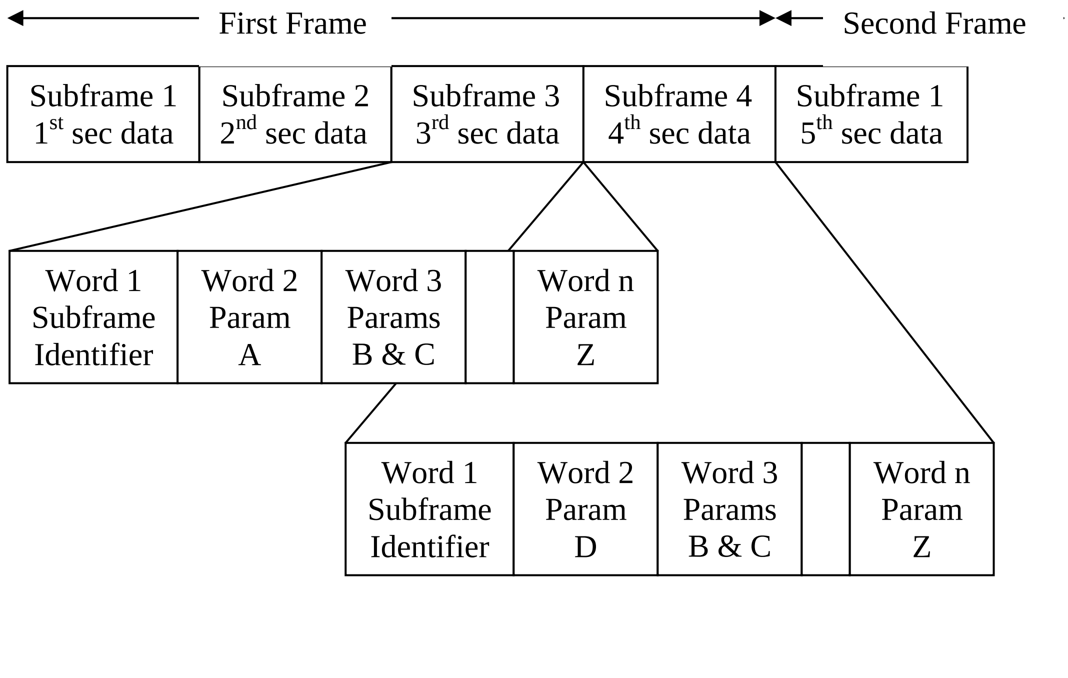


Figure 1 Frame-Subframe Structure

Note that parameters A and D are sampled once every four seconds and appear once in each frame, whereas parameters B, C and Z are sampled once per second and appear in all subframe. Furthermore parameters B and C require less bits to store, thus share the same words.

Compression

With the increased storage capacities available in the airborne systems available today, storing such data is not really a problem, even when the data represents days or even weeks of flight. However in many cases the data needs to be moved from the aircraft to a ground processing system. Here again if the media is to be removed and transported manually, the volume of data might not be of concern. However the recent trend in the industry is to deploy systems that can download the data automatically from the aircraft. As the current HF, VHF and Satcom bandwidths are limited or cost prohibitive, these systems normally start operating after the aircraft has touched down or is parked at the gate.

Here also because of bandwidth limitations or the limitation on the time available at the gate, it becomes important to limit the amount of information to be downloaded.

One method of deceasing the amount of data to be downloaded is to apply commercial compression algorithms such as ZIP or GZIP. As these compressions are general purpose and are unaware of the nature of the data to be recorded, improvements can be made by taking into consideration the structure and the dynamics of the data to be recorded.

Teledyne Controls has developed and patented a pre-processing algorithm that when applied to frame-subframe flight data prior to applying the commercial compression algorithms, significantly increases the compression ratio. Figure 2 below represents the flow of data through acquisition, pre-processing, compression and retrieval. An optional encryption step after the compression step is shown.

The pre-processing algorithm relies on the repetative nature of the Frame-Subframe format, as well as the fact that the values of most sampes change in an incremental manner or not at all in the more stable phases of flight.

The algorithm consists of selecting as many frames as the available memory allows, rearranging the words of the frame in such a way that all word 1 of all subframe 1's are positioned next to one-another, all word 2 of all subframe 1's are positioned next to one-another and so on.

On retreival of the data, the reverse of this algorithm is applied on the decompressed data.

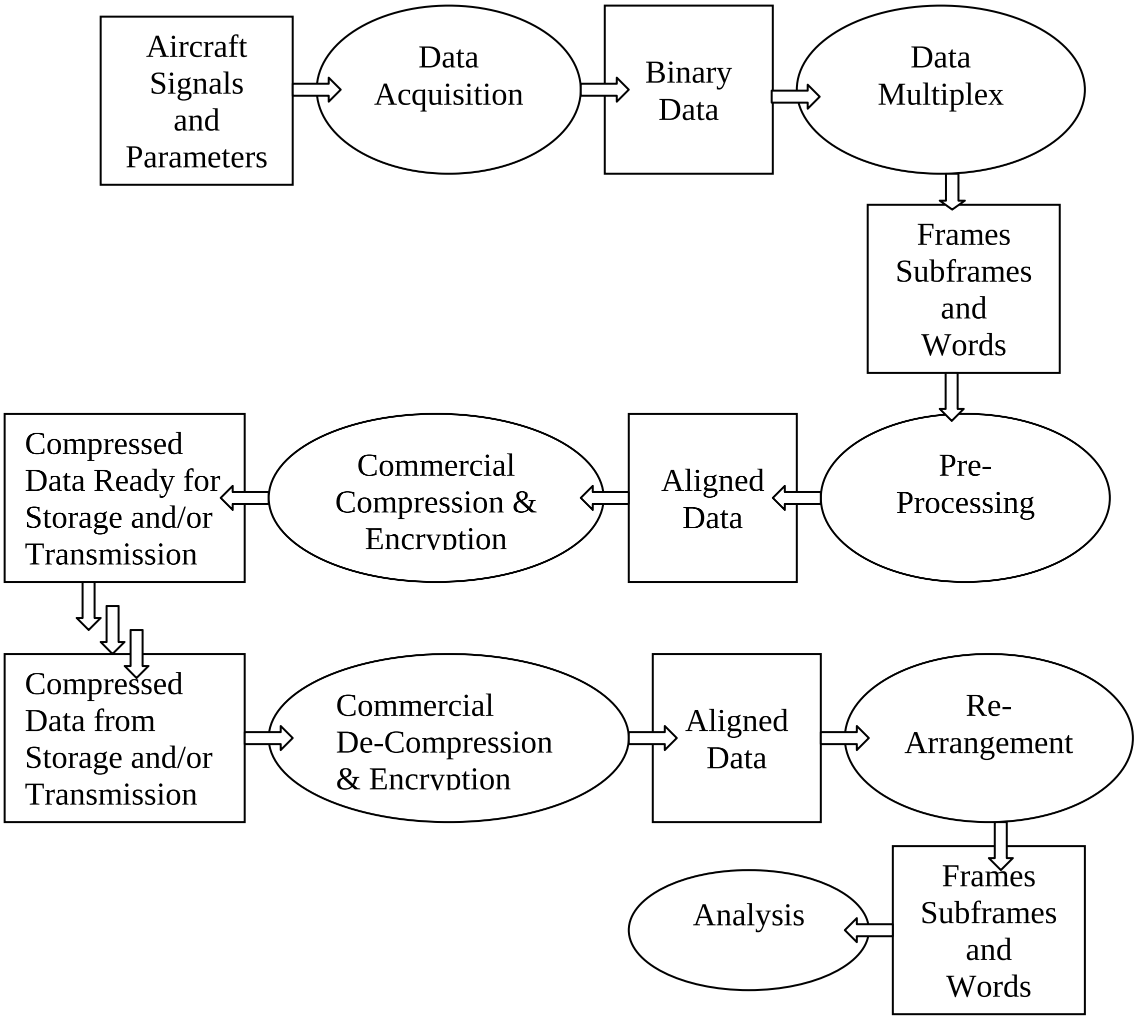


Figure 2 - Data Flow

In further refinements of the algorithm, instead of positioning positioning similar words of the frame next to one-another, similar bytes (8 bits) or similar nibbles (4 bits) are grouped together, thus increasing the possibility of generating long sequences of repeating patterns. It is also possible to take the algorithm to the extreme and position similar bits together, however as the later experimental results will show, this will not result in significant improvement.

It must be noted that the commercial compression algorithms refered to in this paper are loss-less, that is, the data in its entirety can be reproduced after the decompression. The pre-processing algorithm introduced here, is also loss-less, since it only re-arranges the data, without any reduction. Therefore the resulting compression-decompression can be considered loss-less.

Wireless GroundLink®

One of the successful applications of the pre-compression algorithm at Teledyne Controls has been in the Wireless GroundLink or the WGL. The WGL is a device built for recording and transmission of aircraft data. The primary function of the unit is to record data during flight and transmit the data to a base station when transmission is appropriate. As the unit uses mobile telephone technology for transmission, the transmission normally starts when the aircraft touches ground or when the doors of aircraft are opened.

The WGL eliminates the need for ground personnel to visit the aircraft after landing to remove the recording media holding the AIMS information. It also reduces the typical 5% to 10% data loss attributed to manual handling, and it allows for a more timely analysis of the data. Furthermore, the use of the WGL unit does not require investment in a ground infrastructure, as it uses existing mobile telephone networks available at almost all airports.

In operation, the WGL typically records different types of data from engine start to engine shutdown. Usually, the most voluminous of the recorded data is the raw flight data recorded in frame-subframe format as described above.

Either at the end of the flight or during fixed intervals during flight, the raw flight data, along with other reports generated during the flight, are compressed using commercially available compression algorithms and encrypted using Teledyne proprietary methods, in preparation for transmission to the mobile telephone system. The data is recorded on ATA PC-Card that can be physically removed, if transmission is not desired or is not possible.

The pre-compression algorithm described above is applied to the raw flight data, before the commercial compression or the encryption algorithms are applied. Use of the pre-processing, the compression and the encryption provide significant data security.

The compressed, encrypted data is transferred utilizing up to eight concurrent mobile phone connections, each establishing a separate PPP connection to service providers that support packet or circuit switched connections. The first phone to establish a connection exchanges session information with the Groundlink Base Station (GBS). This is followed by the transfer of the data as a series of fixed length blocks, sent over any available phone connection. Each block received by the GBS is acknowledged to prevent retransmission. Duplicate blocks are discarded by the GBS. Integrity checks on the packets, the blocks and the file are performed. With this scheme, it is not necessary for all eight phones to establish communication for the data to be downloaded, nor is it necessary for the phones to maintain a link during the download period. Any lost packet due to a lost connection will be transmitted by a phone that has maintained a connection. Even in cases where some packets remain un-transmitted after one flight leg, say due to power off on the aircraft, will be transmitted after the next flight leg and will be merged in the correct position by the GBS.

Comparison of Results

To evaluate the effectiveness of the pre-processing actual flight data was first compressed using an industry standard compression algorithm (GZIP), then the same data was pre-processed before the application of GZIP. The following are the results.

Test 1 - Flight data of 20 MBytes compresses to 5.3 MBytes (3.8 : 1 compression) without pre-processing, while it compresses to 3.8 MBytes (5.2 : 1) with pre-processing based on 8 bit alignment.

Test 2 - Flight data of 70 MBytes compresses to 19.7 MBytes (3.6 : 1) without pre-processing, while it compresses to 14.9 MBytes (4.7 : 1) with pre-processing based on 8 bit alignment.

Test 3 - Comparison of 12 bit Word, 8 bit Byte and 4 bit Nibble alignment produced the following results on flight data of 53 MBytes:

Pre-processing Method	File size	Compression Ratio
No pre-processing	13.2 MBytes	4.0 : 1
Word aligned pre-processing	8.7 MBytes	6.1 : 1
Byte aligned pre-processing	7.6 MBytes	7.0 : 1
Nibble aligned pre-processing	7.3 MBytes	7.3 : 1

Conclusion

The application of the pre-processing algorithm, presented in this paper, to data that is organized in frames and subframes results in significant improvement to the subsequent compression ratios obtained by using commercial data compression tools, e.g. ZIP or GZIP. Compression ratios of 4:1 without the pre-processing approach to 7:1 when the pre-processing is utilized.

In using the pre-processing algorithm, going from word alignment to byte alignment results in further improvement, however in going from byte alignment to nibble alignment the improvement is less pronounced.

Re-configurable Aircraft flight data processing, analysis and incident/accident investigation system – An impact of efficient software tool for AIMS gateway

Ananda CM, Murthy NN, Mahesh R and Shivamurti
National Aerospace Laboratories,
Bangalore, INDIA

Abstract

FAA POLICY on FOQA indicates that FOQA is a voluntary safety initiative encouraging airline participation in FOQA in the public interest with a necessary requirement that Airlines must document procedures for taking corrective action, when necessary in the interest of safety and airlines must provide FAA with access to aggregate trend data. FAA issues final FOQA rule, in what it called a major step towards reaching its “Safer Skies” goal of cutting the commercial aviation accidents rate by 80 percent by 2007. FOQA programs currently are conducted by airlines, certification authorities and engineering groups of airlines. Flight Operations Quality Assurance (FOQA) is primarily a data collection, processing and analysis system used to improve the various disciplines of flight operations. The data recorded onboard the Digital Flight Data Recorder provides a wealth of information for rest of the analysis. This information can lead to improvements in aircrew training, maintenance and conduct of flight operations. The system can analyse and report the various events, exceedences and reports including statistics for the Airlines operators.

Flight Operations Quality Assurance (FOQA) which is primarily a data collection, processing and analysis system used to automate the various disciplines of flight operations and incident/accident investigation. The onboard DFDR/SSCVFDR recorded data forms the wealth of information for rest of the analysis. The information databank is used to monitor the system behavior and operational status at various levels of flight based on the recorded parameters leading to improvements in aircrew operations, maintenance and conduct of flight operations. The system can analyze and report the various events, exceedences and reports including statistics for the various conditions and flight envelop with graphical representations

The papers presents the methodology of data processing for various fleet of aircraft with statistics and the challenges in doing so. Paper describes the methodology of data processing for various fleet of aircraft in the aviation industry with statistics and the challenges in doing so using re-configurable software tool. The Integrated Aircraft Monitoring system is realized by using voluminous data that the software tool archives every day. Presentation is more focused on the impact of a software tool NALFOQA which enhances the efficiency of operations, aircraft level data processing/analysis as part of the Aircraft Integrated Monitoring System(AIMS). Typical analysis examples and results are also presented in the paper

***Keywords**: FOQA, Digital Flight Data recorder, Event analysis, Trend analysis, SYNC words, sub frames, frames and super frames, Animation, Incident/Accident Analysis.*

Introduction

Digital Flight Data Recorders (DFDR's) / Solid State Flight Data Recorders (SSFDR's) are being successfully used on civil aircraft for decades. Their proven survival strategy, of deploying away from the aircraft and hence the crash site, allows for quick location and economical recovery of recorder information, particularly in marine incidents, where the floating recorders can readily be retrieved from the surface of the ocean. Changes in the needs of accident investigators, and in aircraft use, application, performance monitoring, routing, and avionics have resulted in the current initiatives underway to revise aviation recorder standards, their quality and data analysis. Vast majority of information gained by FOQA cannot be found in any other way as it provides objective and "actionable" data for all equipped flights.
FOQA serves as a catalyst for voluntary information exchanges in a way that the periodic line checks conducted by check airmen cannot provide the same level of insight into daily operations as the continuous monitoring of FOQA data. A program for obtaining and analyzing data recorded in flight [operations] to improve flight-crew performance, air carrier training programs and operating procedures, ATC procedures, airport maintenance and design, and aircraft operations and design. In practice, a FOQA program is a subset of a total in- flight data system that includes engine, maintenance and aircraft-systems monitoring. FOQA is, however, separately managed, has separate data requirements, specific hardware and software requirements (some measurement-system hardware and recording-system hardware may be shared), and is subject to a separate, more secure management process.

A program Provides meaningful, manageable information that can be used to facilitate sound decision- making for both day-to-day operations and long-term planning Flight Operations, Maintenance and Engineering, Pilot training and Safety. provides information on the national aviation system to allow the assessment of the safety which in turn helps in increase of efficiency of the operational use of the airspace also generates statistical data that can be used to evaluate performance of airlines with new programs.

<u>Role of FOQA in Airlines operation/ Civil Aviation</u>

The reason why the aircraft accident rate has stayed fairly flat since the mid-70' has caused many to speculate as to why. First of all, - is it at an acceptable level? or is "Zero Accidents" an attainable goal to strive for. If we look back the history of civil aviation operations, there has been a remarkable developments in terms of technology change from 1970's to current day and at the same time the airspace operations also has increased tremendously with various kinds of airplanes and systems. Present day concepts of Integrated Aircraft Monitoring Systems plays a very important role in monitoring and processing of various levels of aircraft data online and offline.

Embedded Perspective of FOQA – Integrated Monitoring Systems

Close monitoring of aircraft flight operations and systems has made continuous refinement of reliable designs and increased performance. Enabling this operational monitoring has been the continual development of even more sophisticated data recording analysis with growing capabilities to handle huge amount of raw data. Feedback into engineering and maintenance processes and into crew training has raised safety levels. Coupled with accident investigation information, operational data extracted from the flight data recorder have made it possible to refine the air transport operation to a very high standerds of efficiency, while at the same time, reducing accident risk exposure. The FOQA (Flight Operational Quality Assurance) developed from flight safety foundation(FSF) studies, is being adopted by many airlines throughout the world as an internal system of operations monitoring.

FOQA data can reveal

- If an airline's trends are out of the norm
- If anomaly is an isolated occurrence or one that has been previously detected by another carrier who may have already developed a solution.
- If occurrence is a significant event that requires prompt decision- making and actions when combined with historical data
- Allow the confirmation of problem areas identified by flight crews through voluntary safety reporting programs
- Flight training
- Airline safety improvement
- Human factors study
- Operational procedures review.
- And many more safety, quality and trend features of each aircraft, airlines as whole

Growing steps of re-configurable NALFOQA towards AIMS concept

NALFOQA is being used at airlines for variety of aircrafts from Boeing and Airbus industry covering 64 words per second format and 128 words per second format. It has proved to be one of the best tool for aircraft integrated data monitoring and analysis system. The software is designed to be an universal tool which can be easily configured for any aircraft with the characteristics of aircraft is known in terms of the Digital Flight Data Recorder (DFDR) / Solid State Flight Data Recorder (SSFDR) parameter specifications. The tool can be used as

- Aircraft integrated data monitoring and analysis system
- Incident / Accident analysis and report generation tool
- Aircraft performance monitoring system
- Pilots operations and quality monitoring and evaluation system
- Airlines statistics management system
- Post flight analysis and counseling tool
- Airlines efficiency management system
- Operations and quality control and management system

Incident :
NALFOQA software can be used for incident analysis in an efficient way. Annex 13 to the ICAO Chicago Convention defines an incident as an event linked to the operation of an aircraft, which is different from an accident, and jeopardised or could jeopardise the safety of the operation. It defines a serious incident as an incident whose circumstances indicate that an accident almost happened, and clarifies that the difference between an accident and a serious incident lies merely in the final outcome. Indeed Annex 13 defines an accident as an event linked to the operation of an aircraft and during which a damage (to people or to the aircraft) worse than a given threshold has been experienced.

Incident analysis is a major step which will un-earth many issues of maintenance, operations and crew performance. Many practical examples reveal that if the incident analysis is carried out in systematic un-biased methodology, the operations efficiency and quality assurance objectives will definitely be fulfilled. This process enhances the systems efficiency in terms of maintainability, maintenance, preventive actions and reliability of the system.

Accident :
Accident analysis is more legal oriented where lot of activity need to be produced for verification and validation including the process itself in some cases. The data is looked at in a very critical manner to the bit level in case of corrupted/damaged data. NALFOQA can be used for this purpose in a sector analysis mode with bit wise data extraction capability as an optional analysis.

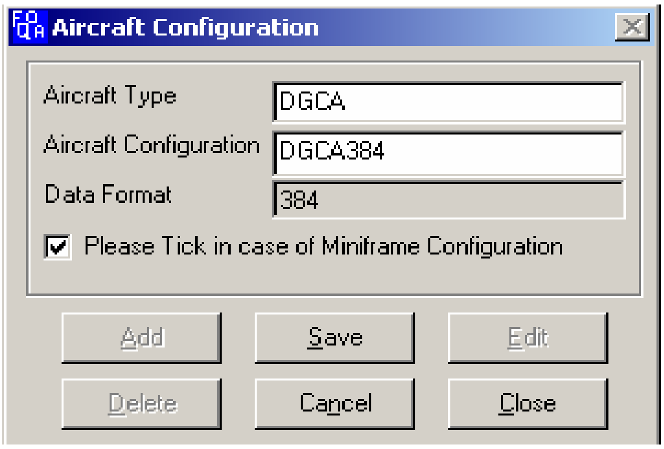
NAL's Flight Operations Quality Assurance software – NALFOQA

NALFOQA is a window-based software with database support. Database forms the base for all the trend analysis system with lot of information processed and archived. The software needs to be equipped/configured for the aircraft behavior in terms of the parameter details, phase limits and event limits. The Sequence of operations to be carried out are

- Aircraft/Configuration creation
- Parameter Configuration
- Phase Configuration
- Event Configuration
- Airlines fleet cycle configuration

Aircraft / Configuration Creation

Any new aircraft or a different configuration of the old aircraft needs to be configured into the NALFOQA for further use and reference. Aircraft and its configuration forms the basis for all the subsequent operations of incident/accident/operations analysis as part of the AIMS. NALFOQA has the provision to have database facilities for the configuration. The configuration menu of NALFOQA is as shown in Figure 1. NALFOQA can be used to configure any aircraft in the world and start using it for analysis and has no limitations for decoding and analysis. The configuration depends on number of frames, sub-frames, mini-frames and format of recording like 64 words/sec, 128 words/sec, 384 words/sec etc,. which will be derived from the Aircraft Maintenance Manuals (AMM) of respective aircraft.



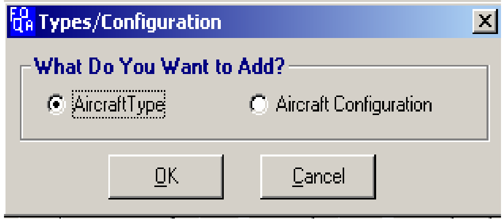


Figure 1 Aircraft Configuration in NALFOQA

Parameter Configuration

Digital Flight Data Recorder records number of parameters from various sub-systems of the aircraft. The parameters so recorded falls into different types of signals, varied operating range, different resolution, varying recording bit occupancy for each parameter and the same signature need to be fed to the NALFOQA to understand the aircraft parameters for further analysis. The configuration of parameters in NALFOQA is exercised with special security password to protect the integrity of the database. The configuration user interface of NALFOQA is shown in Figure 2. Synchronization words (SYNC) are the main known pattern words in each sub-frame to identify the state of the subframe.

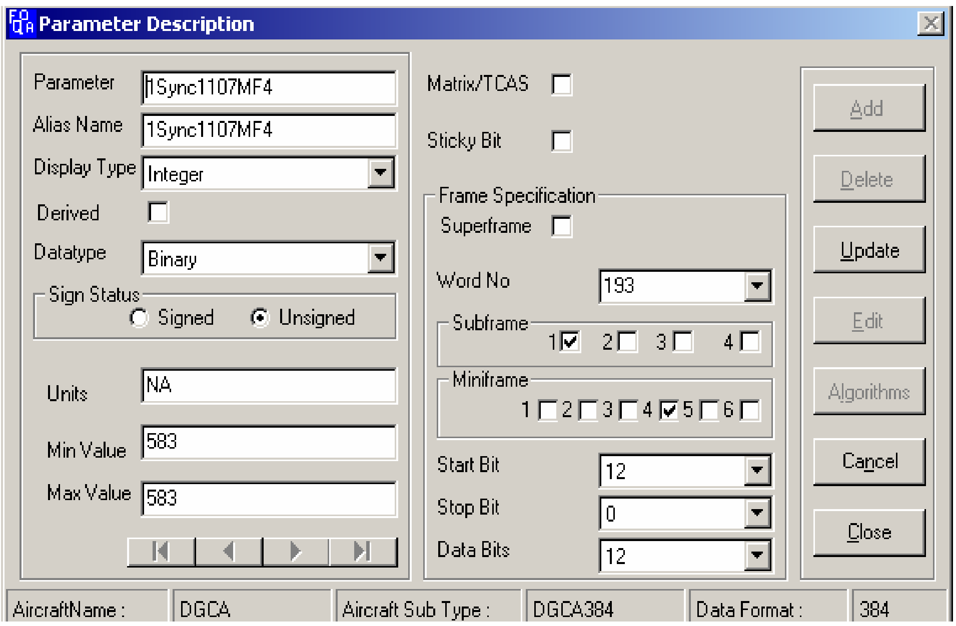


Figure 2 Parameter Configuration in NALFOQA

The Digital Flight Data Recorder / Solid State Digital Flight Data Recorder parameter decoding is done after the parameter information is configured into NALFOQA. The decoding system with the digital display of continuous flight data will be displayed for incident/accident/operations analysis to the second level resolution.

Phase Configuration

To investigate the incident for specific time of flight in terms of flight phases, the NALFOQA need to be configured for the cutting limits of various phases of the specific aircraft family. The investigation will be carried out with reference to the configured phases only.

Event Configuration

An event is an exceedence of a parameter or a set of parameters constituting the functionality of the aircraft scenario in a specified conditions deviating the norms. Each event has a set of limits to be checked during the event detection process. The Event configuration parameters are defined based on the dynamics of the aircraft and its behavior. The event configuration window is as shown in Figure 3

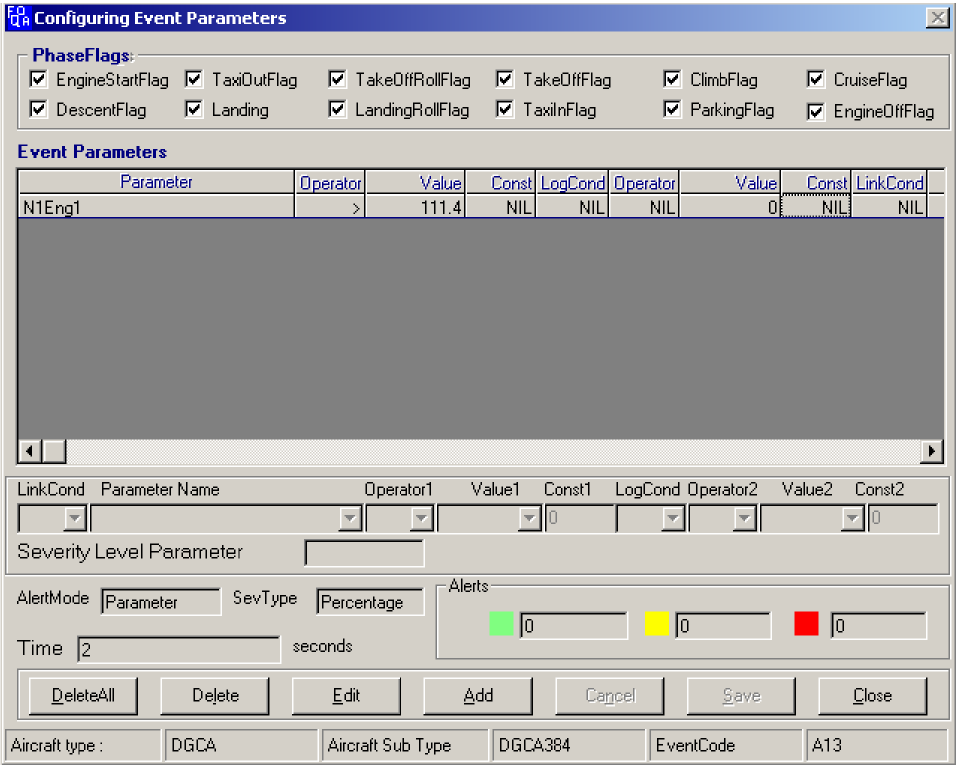


Figure 3 Event Configuration system of NALFOQA

Parameter, event and phase configuration of NALFOQA completes the configuration activity and is ready for incident/accident analysis activity. The various analysis reports and methods are listed below

- Trend Analysis
- Event Rate Analysis
- Operation Report
- Counseling Report

Each of the analysis and the resulting report are being exhaustively used at various airlines for operations and incident/accident analysis point of view. NALFOQA analyses nearly 200 hours of flight data in less than 2 minutes for its complete report.

Data Processing

The aircraft downloaded data directly from the DFDR is fed to NALFOQA for data processing and analysis. The data processing facility and its output as consolidated result.of NALFOQA is as shown in Figure 4

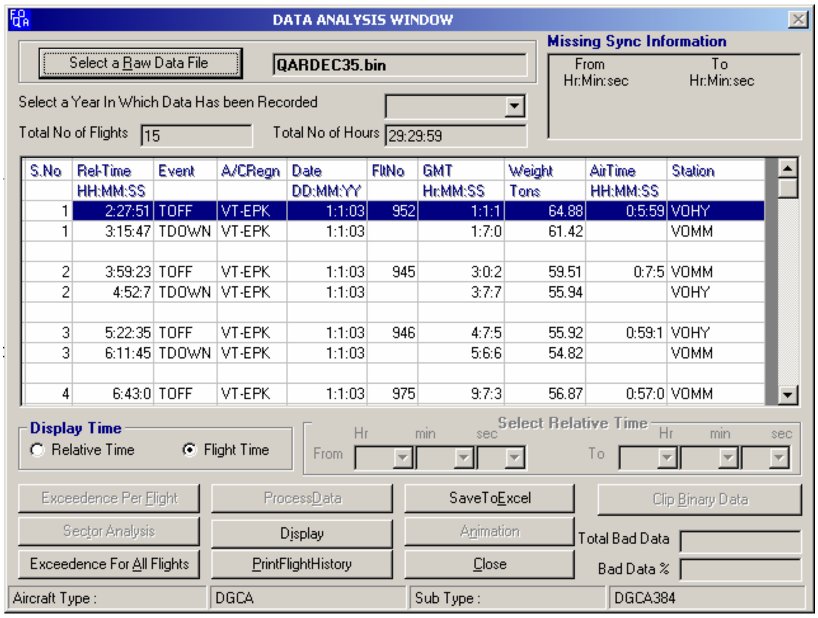


Figure 4 NALFOQA Aircraft Integrated Data Processing System

The first level of analysis reports the basic information, which will aid for further analysis. Event detection and monitoring is the most important activity of the analysis system with the event monitoring report for the full length of flight data or for each sector separately. A typical event report is as shown in Figure 5.

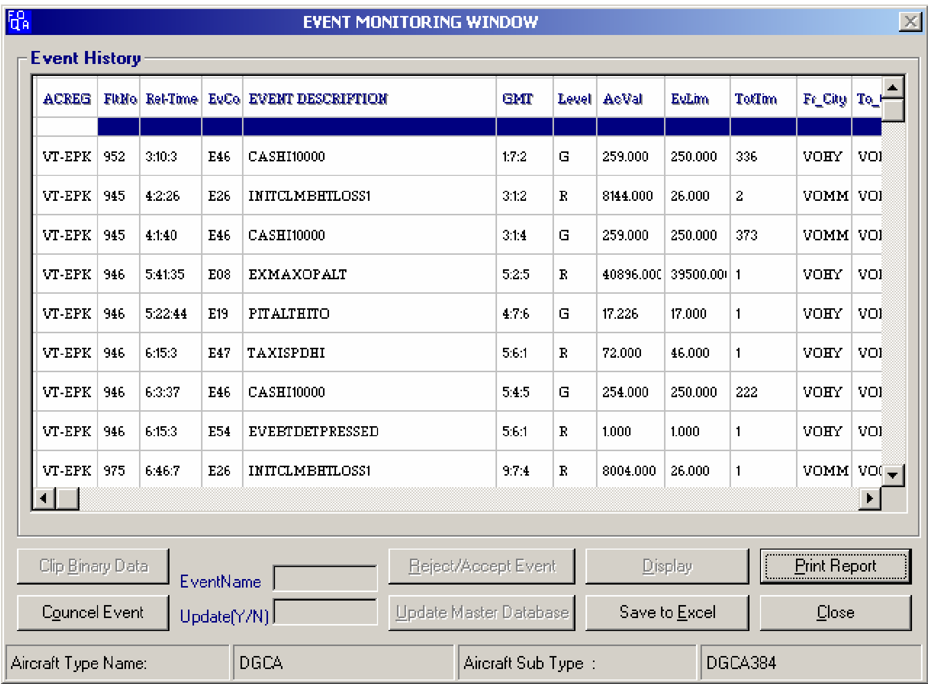


Figure 5 Typical Event Report used for incident analysis

Each event in the event monitoring report in Figure 5 is reviewed and checked for its reality and the severity-persistence in terms of the time and limit value. The entire processed data is stored into the master database for all statistical report generation.

Trend Analysis

The trend of the event is also verified from the previous flights of the aircraft from the master database of NALFOQA. The statistics of each event of a particular aircraft/aircraft configuration can be reviewed at any time using the flexible report generation system of NALFOQA. A typical Trend rate report is shown in Figure 6.

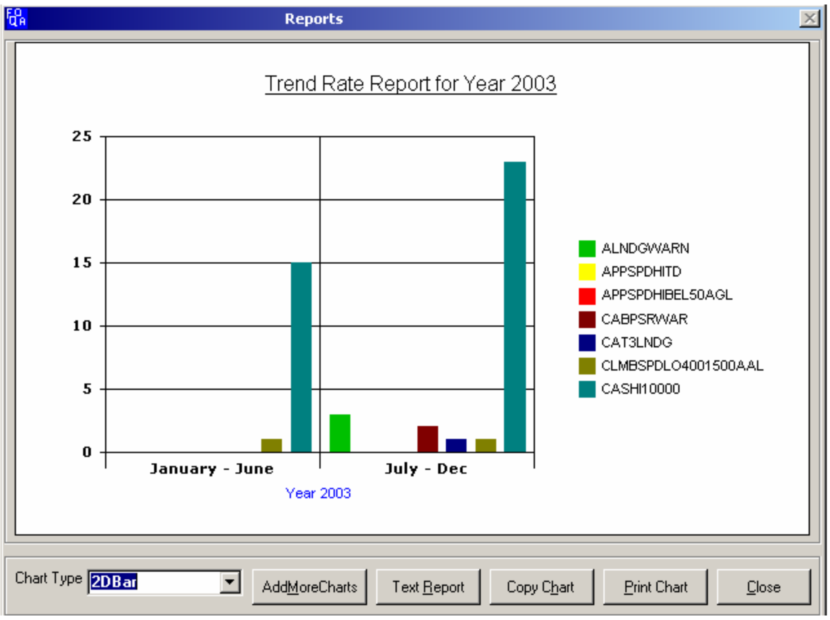


Figure 6 Trend rate report in NALFOQA

Typical trend report should show a reducing pattern of the events from time to time for an event/aircraft as shown in Figure 7.

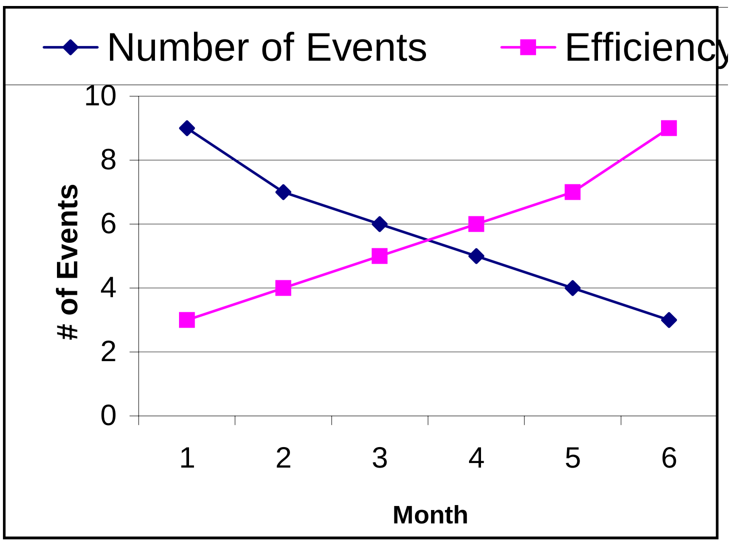


Figure 7 Typical Trend rate after using NALFOQA

Airlines have achieved this after using NALFOQA software for their operations and it proved to be one of the best software tool to airlines to improve their operations efficiency and reduced insurance premium. By the use of NALFOQA the trend of events reduces with continuous monitoring and counseling, in effect the increased quality and safety of operations. Result of the all the above artifacts, the insurance premiums have been reduced to a large extent every year and also the safety of flight on the other side of it.

The statistical analysis of events includes the **Event Rate Report**, **Trend rate Report** and **Percentage of Data analyzed Report**. Trend rate Report is further classified into **Yearly**, **Monthly**, **Half Yearly** And **Quarterly Reports**. Each Type of report has got its own significance. Reports are generated in a graphical as well as textual format. Graphical Format includes **Line Graph**, **Pie Charts** And **Bar charts**. A typical event rate report is shown in Figure 8

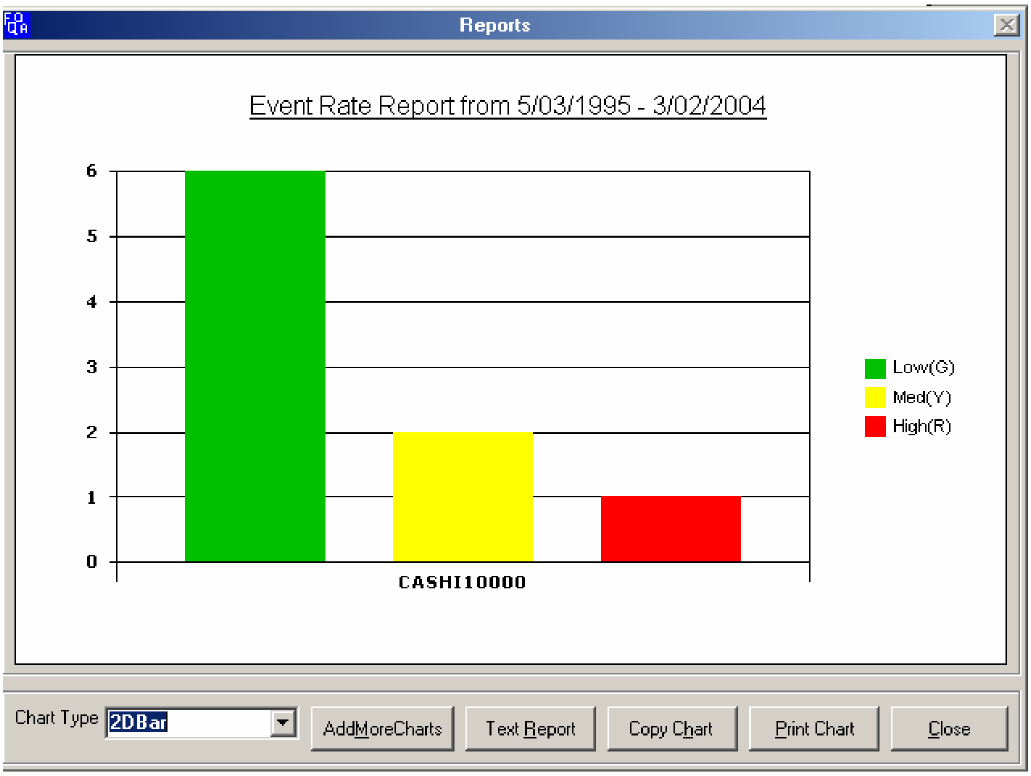


Figure 8 Typical Event Rate Report of NALFOQA

Pilot Counseling

NALFOQA has a special utility for the pilot counseling during integrated aircraft monitoring scheme. Pilot counseling is one of the critical activity resulting in increased awareness, increased operations accuracy, reduced event occurrence and finally increased safety of flying.

NALFOQA event monitoring system has the entry to counseling report with documenting the event severity and description of the event counseling details by a senior flight safety pilot-In charge. The strip of raw data is also stored for later reference along with the necessary details. The pilot counseling helps in a large way to keep the airlines operation with controlled quality system. The pilot counseling will be done with the NALFOQA tool utilities as shown in Figure 9.

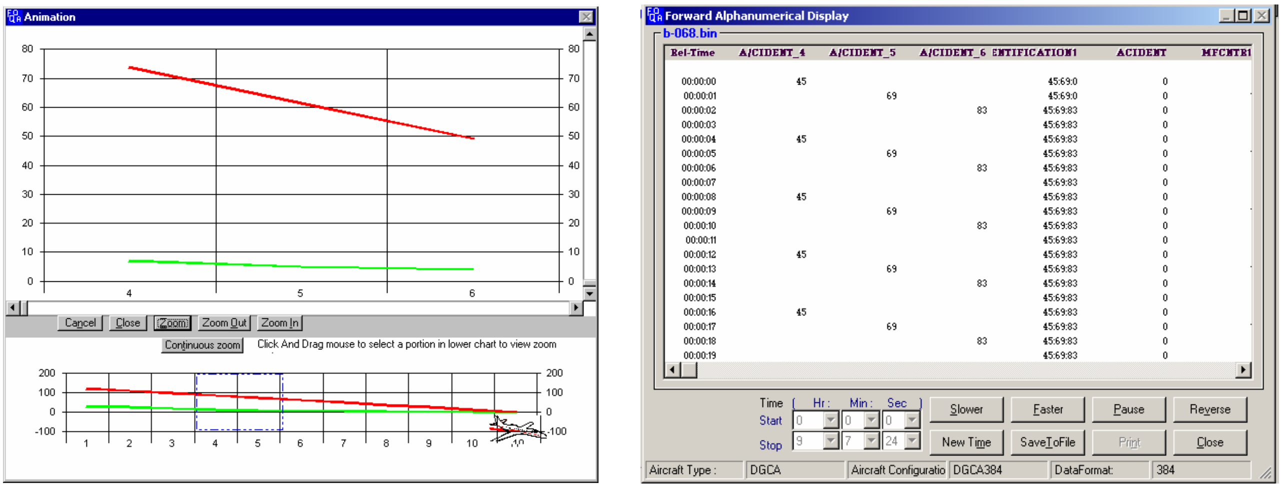


Figure 9 Pilot Counseling support utilities of NALFOQA- Animation and engineering replay

Concluding Remarks

NALFOQA - Flight Operations Quality Assurance which is primarily a data collection, processing and analysis system used to automate the various disciplines of flight operations and incident/accident investigation forms part of the Aircraft Integrated Monitoring System. NALFOQA has proved to be one of the best software aircraft data processing and monitoring tool for the aircraft data processing and the airlines operation. This will definitely has good scope with the Integrated Monitoring system on aircraft level and forms as a gateway to AIMS.

Acknowledgement

Authors wish to acknowledge the FOQA team of Aerospace Electronics & Systems Division, other technical and management support divisions of National Aerospace Laboratories for their unstinted support. We fail in our duties if we don't express our gratitude to Dr. BR Pai, Director NAL for his excellent support for FOQA activity.

References

- FOQA Team, ***NALFOQA 4.0 System Operation manual***. Release 2004
- FOQA Team, NAL, **Software Requirements Specifications**, NALFOQA Ver 4.0, Release 2004
- Software Kinetics Ltd., **'Flight Animator'** copyright 1996-1999
- Siouris, G., **Aerospace Avionics Systems, A Modern Synthesi**s, Academic Press Inc., San California, USA, 1993
- Software Kinetics Ltd., **Flight Data Monitoring System Design Documen**t, Document No 9500-05-054, Version 01, June 1997

OPERATIONAL LOADS MEASUREMENT: WHAT'S BEEN DONE AND WHERE IT'S GOING

Michael Bradley

ACRA CONTROL

Abstract:

An operational loads measurement is central to understanding the stress an aircraft is experiencing while in use. By acquiring data that represents the normal use of the aircraft and determining the fatigue index of the structure, it is possible to evaluate the potential for prolonging the life of the aircraft.

This paper examines OLM systems and their specific requirements in terms of reliability during operation and ability to produce trustworthy and reliable data for later analysis. Some examples of OLM programmes are presented along with details of how these systems have been used, and how they have performed.

Finally, some of the technology and other improvements that have allowed newer OLM systems to provide a better fatigue profile of the aircraft are described. Such improvements facilitate the acquisition of greater numbers of channels of data, with greater accuracy, and the recording of significantly higher volumes of data.

Keywords:

OLM, Loads Measurement, Fatigue Spectrum, Strain, Solid State Memory

Introduction

This paper looks at how improvements in technology have enabled Operational Loads Measurement (OLM) systems to be better able to comprehensively measure the stress experienced by an aircraft while in use. The data produced by these improved systems allows a more complete and better modelling of the forces experienced by the airframe.

OLM Programmes

The purpose of an OLM programme is to provide data on the forces exerted upon, and stresses seen by, an airframe. This data can be used to verify whether design phase calculations of the forces are correct, and using fatigue modelling it can help to prolong the active service life of an aircraft.

Basic Requirements

A basic OLM system, as shown in Figure 1, provides the necessary data and in its simplest form consists of a variety of sensors connected to a Data Acquisition Unit (DAU), which then passes the data on to a Data Recorder Unit (DRU).

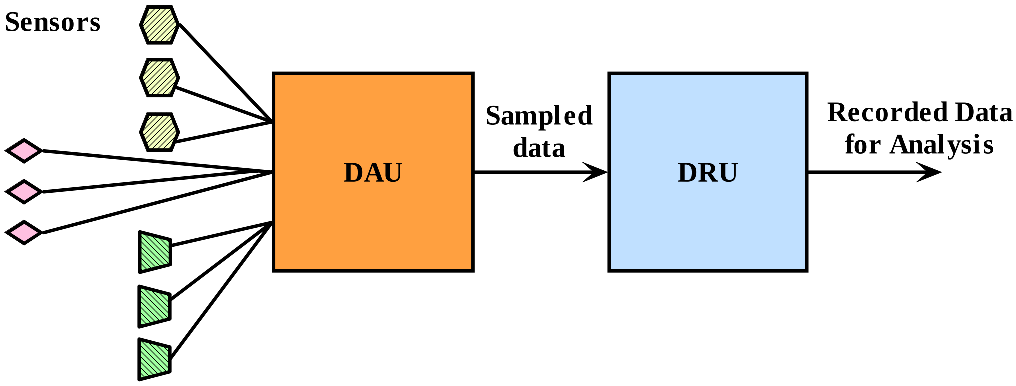


Figure 1 - Overview of a basic OLM system

The DAU provides signal conditioning and perhaps excitation, as required for the sensors to operate and digitises the input signals. It also provides for an output of some form, e.g. ARINC, or PCM to the DRU that stores the data for later retrieval and analysis.

For an OLM system to be useful it must meet three essential requirements:

- The DAU and the DRU must operate in a reliable manner. If insufficient quantities of data are recorded, then there can be little confidence in any results obtained.
- The nature, number and type of sensors used must be sufficient to give a representative fatigue spectrum.
- The quality of the data recorded from the sensors must be reliable.

OLM Technology

Some of the key OLM requirements that dictate the specifications of the OLM system DAU and DRU are the following:

- Sensor Types
- Number of Sensors
- Signal Conditioning Performance
- Storage Capacity

There is an obvious need to use as many sensors as possible in order to give sufficient data for a representative fatigue spectrum. The downside to this, of course, is that more sensors need more signal conditioning and a larger storage capacity, adding to overall cost and complexity. As with all things a balance is required.

New technologies such as higher density micro-electronic chip fabrication have allowed the size of electronic parts to shrink, while at the same time enabling vastly increased functionality, examples being computer processors, solid-state memory devices, and Field-Programmable Gate Array logic devices.

These new more integrated chips have allowed the size of DAUs to shrink from a system that occupied half a rack of equipment to a DAU that occupies a fraction of the space, while at the same time improving performance, reliability and functionality.

Sensor Types

The most common sensors types typically used are listed below. Depending on the OLM sensor requirement a DAU needs to support most, if not all of the sensor types listed.

- Strain – Full/Half/Quarter strain gauge bridges
- Acceleration/Vibration – Piezoelectric/Constant current excitation
- Discrete/Digital data – TTL, 28V/0V
- Bus Traffic monitoring- ARINC/MIL-STD-1553/Serial data

New ‘smart sensors’ are becoming available that perform the sensing and measurement of the signal at the sensor location, typically providing a serial output that can be joined to a sensor bus. This allows large number of sensors to be digitally read with only a few wires, which can vastly reduce wiring requirements.

Number of Sensors

The size and nature of the airframe strongly influence the number of sensors that are required in an OLM system to yield sufficient data to produce the required fatigue spectrum.

A large airframe also brings with it the problem of long cable runs, and the degradation of signal integrity over long lengths if a centralized DAU is used. For large aircraft a distributed approach with DAUs located near the signals they are measuring is far more appropriate, but this means that questions of time correlating and synchronizing data between separate DAUs must also be solved.

The multiple DAU approach, illustrated in Figure 2, also allows the number of sensors to be easily increased by adding DAUs as required by the OLM system.

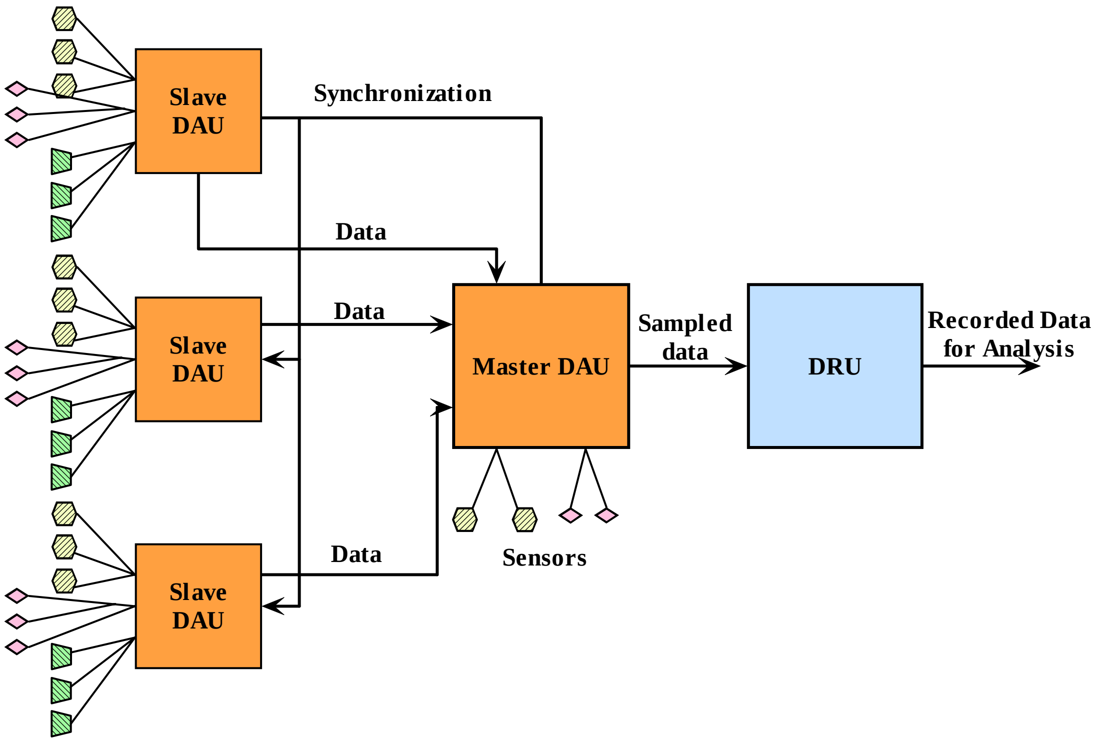


Figure 2 - A distributed OLM system

Signal Conditioning Performance

The quality of the data from the best analog sensors is dependant on the signal conditioning used to measure them, and there are several different quality measures that can be used. The DC accuracy of an analog channel being the most common gauge of quality used, though there are other, perhaps more useful indicators, such as SINAD (Signal-to-Noise And Distortion) and ENOB (Effective Number of Bits) that are less commonly stated.

Many common systems in use today quote typical analog accuracies of 0.5% to 0.25%. Next generation signal conditioning and acquisition hardware is becoming available that offer greatly improved accuracies of 0.1% over the entire industrial temperature range (-40°C to +85°C).

For digital and bus signals it is the accuracy of time, either absolute or relative, in an OLM system that is important. This is because time stamp information assigned to those signals is used to correlate digital/bus events to events that occur in the analog domain.

Equipment based on the Global Positioning System (GPS) has become available in the last few years that facilitates the synchronization of data to an extremely precise time source, and a GPS receiver on board an aircraft can act as a time source for the DAU for time stamping and recording.

Timing - in particular the synchronized timing - across multiple DAUs, is essential to obtaining data that can be easily compared and correlated across an entire OLM system installed on the airframe of a large aircraft.

Data Storage – Capacity & Media Options

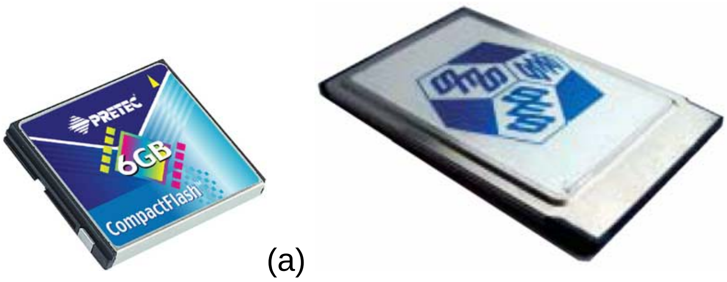
One of the limiting factors in any OLM system is the data storage capacity. Data is recorded to a medium, which is then downloaded from the aircraft and stored for later analysis.

The capacity of the storage medium limits the recording time for a given number of sensor parameters, at a particular sample rate. Increasing the capacity means that more parameters, at higher sample rates, can be stored for longer periods of time reducing the need to download the data frequently to a ground support/replay station.

Rugged tape recorders, some with add-in modules that allow them to record sensor signals directly, have been the mainstay of recording devices for many years. They offer relatively large capacities, a few gigabytes and good performance.

Looking to the future, solid-state recording devices offer a number of advantages, and the development of these has progressed extremely rapidly over that past number of years, driven to a large degree by the consumer market for electronic goods (cameras, PCs). This has allowed the cost of the recordable media to drop while the capacity increases.

Initial storage capacities of 8MB were sufficient to store 32 parameters samples at 32Hz each for a period of about 2 hours. New devices have quickly superseded these older devices and there are now storage formats that offer capacities ranging from 128MB to 6GB in the industry standard Compact Flash (CF), shown in Figure 3(a), or the PC flash card format, shown in Figure 3(b), with larger capacities coming along continually,

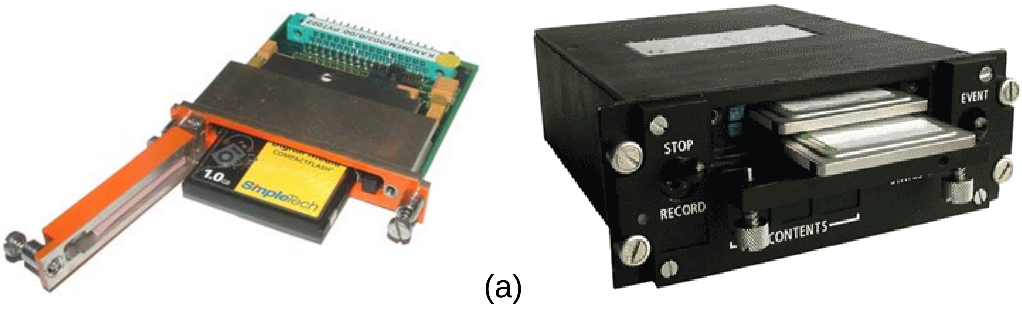


(a) (b)

Figure 3 - (a) Compact Flash Card (b) PC Flash Card

For example, a currently available 6GB CF card would allow 300 parameters at 64Hz for approximately 2 full days of recording time before the data would have to be downloaded from the recorder.

Solid-state recorders have a number of advantages over tape that makes them well suited to a flight environment. There are no moving or mechanical parts, making them far less susceptible to vibration and/or failure. The media, particularly in the case of the CF cards, is very small (almost too small!), allowing the recorder to be small as well, reducing weight and space requirement. For example, a currently available solid state recorder using the CF cards, see Figure 4(a) is able to support a 6GB recording capacity in a form factor that is not much larger than a packet of cigarettes (70mm x 80 mm x 14mm). As new capacities become available, the storage capacity is easily upgradeable by swapping in the larger CF card.



(a) (b)

Figure 4 - (a) CF based DAU recorder (b) PC card Cockpit recorder

The DRU shown in Figure 4(a) is a module within a DAU, while Figure 4(b) shows a PC card based recorder that records PCM data from a DAU, and is intended for cockpit/cabin mounting, useful if the DAUs are located in difficult to access areas.

Conclusions

The purpose of an Operational Loads Measurement programme is to provide useful data about the loads and strains experienced by an aircraft in flight.

As miniaturization of electronics hardware continues, the benefits for OLM applications are clear. There can be increased functionality in decreasing package sizes. Along with increased storage capacity comes the ability to record more sensors, more accurately than before.

With improved OLM systems yielding more data, of a better quality than previously, there can be more confidence in the results obtained when comparing computer models/fatigue tests with the real world experiences of the aircraft.

Presenting Author: ***Michael Bradley***

Company Address:

ACRA CONTROL,
Landscape House,
Landscape Road,
Dublin 14,
Ireland.

Telephone: +353-1-2951264

Fax: +353-1-2951265

Email: bradley@acracontrol.com

A MULTI PURPOSE FLIGHT DATA ACQUISITION AND RECORDING SYSTEM

Paul Sweeney Ph.D, ACRA CONTROL
and
Stephen Leaper, Penny and Giles Aerospace

Keywords: KAM-500, MPFDAU, MICRO-KAM, FDR, CVFDR, MPFR, ADR

Abstract:
ACRA CONTROL is a leading supplier of airborne data acquisition, recording and telemetry systems. The KAM-500 is an established, mature, data acquisition system with applications on civil, military, rotary-wing and fixed-wing aircraft.

Penny and Giles Aerospace is a leading supplier of Flight Recorder products, including Flight Data Recorders (FDR), Combined Voice and Flight Data Recorders (CVFDR), Multi-Purpose Flight Recorders (MPFR) and Accident Data Recorders (ADR). Their product applications range across the civil and military sectors, and across fixed and rotary wing aircraft types.

Flight Data Recorders are flight-certified products and are permanently fitted in aircraft, recording safety-critical information. Typically, Flight Data Acquisition Units (FDAUs) are used in conjunction with FDRs to acquire the flight parameters, condition them, and encode them, before being recorded by the FDR. Such FDAUs have fixed functionality and are restricted in terms of capability such as channel count and sample rate / bit rate.

The KAM-500, as a state-of-the-art airborne Multi Purpose Flight Data Acquisition Unit (MPFDAU), is highly flexible in terms of:

- types of parameters it can measure (including analog, digital, avionics buses, GPS, etc.)
- number of channels it provides (a system can be populated with modules offering various channel counts)
- sampling rates and filtering of each channel (fully configurable per channel)
- output data format (Ethernet, ARINC-429, ARINC-573, ARINC-717, MIL-STD-1553, IRIG-106, etc.) and bitrates (fully configurable per output interface module)
- system setup (fully configurable)

The KAM-500 is based on a modular design, enabling the customer to combine analog, digital, avionics and other acquisition modules into one or more chassis, and thereby achieve a wide spectrum of aerospace data acquisition requirements.

Furthermore, the KAM-500 is based on a high reliability design, using hard-wired, state-machine logic instead of microprocessors to control system operation. This gives the KAM-500 “works once, works always” reliability, without any boot-up or initialisation sequences to monitor, or any software to qualify.

Miniaturised airborne DAUs, such as the Micro-KAM are of further advantage in applications involving fighter aircraft, rotary wing aircraft and UAVs, where size, weight and power are of prime importance.

Developments in the FDAU market – such as the Penny and Giles Multi Purpose Flight Recorder (MPFR) – demonstrate the market need for FDRs with a range of inputs exceeding the existing state-of-the-art. Such developments reinforce the advantages offered by integration of the KAM-500 with FDRs, the KAM-500 as a Multi Purpose FDAU (MPFDAU).

This paper examines the application of the KAM-500 and Micro-KAM to FDAU applications, focusing in particular on integration with the Penny and Giles Aerospace FDR products.

1 INTRODUCTION

FDRs are designed to store a well-defined number of parameters (including voice) at reasonable rates to be played back later, typically in the event of an incident or accident. Because the logged data is so important, flight data recorders undergo lengthy flight certification, an important process that does however mitigate against flexibility and capability.

Current FDRs do not store as much information as they should from available sources in order to allow the engineer to arrive at more detailed conclusions from analysis of the recorded data. It is not commercially feasible for certified FDRs to be made available to the market in all of the configurations which are necessary to meet these requirements. Commercial FDRs only record what is supplied by the FDAU. Thus, with increased memory densities it is possible to record as much information as a QAR within a FDR.

In contrast, flight data acquisition units are designed to gather thousands of parameters at very high rates and pass them on right away. In addition the KAM-500's all-digital backplane allows a wide range of functions - including on-board recording, on-board processing, multi-protocol support and future-proofing for applications that might emerge within an aircraft’s service life.

By combining a flexible, flight-approved FDAU with a certified FDR, the best of both worlds can be achieved. More parameters can be recorded (even from difficult locations) without compromising the certification of the FDR or increasing cost excessively.

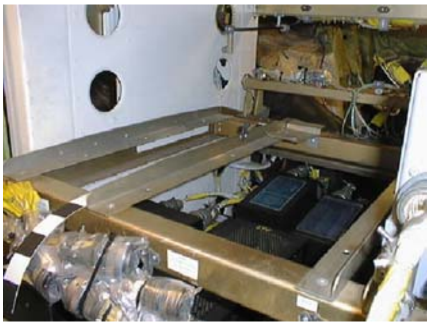
This paper discusses these two products in detail and then examines how they can be used together to get the best of both worlds - flexibility where it is useful and flight certification where it is essential.

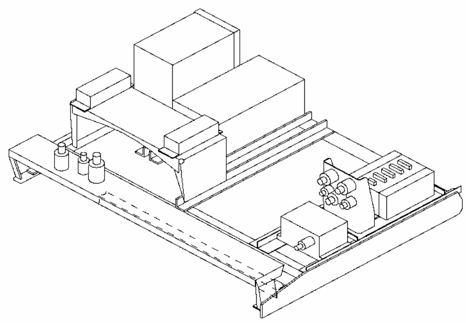
2 THE KAM-500 AS A FLEXIBLE DFDAU

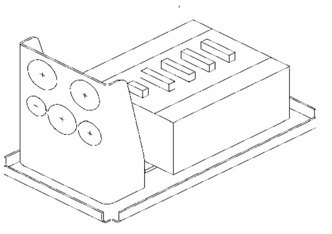
The KAM-500 is a robust, compact, modular data acquisition system with a fully digital backplane that can accept up to 14 user-modules of various types. For example, this backplane allows a broadband analog module (sampling at over 200KSPS) to be replaced with a video/audio compression module, a MIL-STD-1553 interface, an auxiliary data output to other systems, an on-board processing module or even a high-capacity flash memory module capable of archiving up to 6GB per card.

Figure 2.1 Some of the KAM-500 FDAU form-factors

Another advantage of a digital backplane, operating at modest speed with compact modules is that the modules can be arranged in different housing configurations to fit the space available. For example, in a recent E-3D Sentry L/ESS recorder application, 85% of weight and volume was saved by using a KAM-500 based FDAU solution compared to the previous solution.







- *Items totaling approximately 33.5 lbs removed from the E1-7 rack*
- *The KAM-500 totaling < 5 lbs installed in the same E1-7 rack location*

Figure 2.2 E-3D Sentry L/ESS application

A very significant aspect of the KAM-500 architecture with respect to long-duration applications is the total absence of microprocessors (unless as a plug-in user-module for specific data processing). This architecture is based around 'works-once-works-always' state-machines that are each reset at the start of every acquisition cycle.

3 DATA RECODERS

Data recorders fall into two categories, the mandatory Flight Data Recorder (FDR) and the Quick Access Recorder (QAR).

Figure 3.1 A Multipurpose Flight Recorder (MPFR), a Combined Voice and Flight Data Recorder (CVFDR) and a Quick Access Recorder (QAR).

Recognising the requirements for smaller, lighter equipment coupled with the increase in crash survivability and product functionality requirements Penny and Giles developed its Multi Purpose Flight Recorder (MPFR) program in 1999 for both rotary or fixed wing aircraft. Five years previously, the SSCVFDR had led the commercial flight data recording industry through combining the voice and data requirements into a solid state single LRU. The requirement for the MPFR system was to achieve a 65% size and weight reduction while increasing the recording capacity by four fold and providing increased crash survivability to meet the new EUROCAE survivability standards.

Penny & Giles supplies Quick Access Recorders (QAR) to most of the world's airlines and recognised that the data recorded within the flight recorder could be used to aid and enhance the operational aspects of the aircraft if access to the data were improved. To achieve this, an industry standard high-speed Ethernet connection was implemented within the recorder allowing rapid access direct to the PC ground-station environment using standard network TCP/IP. Data is available directly to the ground crew for review and analysis within a matter of minutes, thereby improving equipment and aircraft maintenance time. With the addition of data analysis functions to the replay system, the flight recorder system now operates as an active component within Flight Operations Quality Assurance (FOQA) programs rather than simply being an investigation tool in the event of a mishap.

The MPFR system meets the requirements of EUROCAE ED-55/56A, amendment 1 and (J)TSO-C123a/124a. Qualification is to RTCA DO-160D and MIL-STD-810F conditions, applicable to both rotary- and fixed-wing aircraft. Software is approved to the requirements of RTCA DO-178B for level D applications.
In August 2001, the Multi Purpose Flight Recorder became only the second product to be approved to the new JTSO standard, with FAA approval following 4 weeks later.

4 DAUs AND FDRs - APPLES AND PEARS

The contrast between FDAUs and FDRs is best understood by looking at their respective roots. Salient characteristics of FDRs can be traced back to the original accident recorders of the 1950s, i.e. crash survivability and certification. Today's multi-purpose FDAUs have their roots in flight test and data acquisition where quantity and variety of signals, small volumes and harsh operating conditions defined the product.

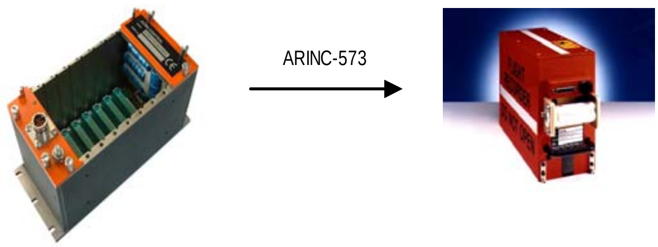
	DAU	**FDR**
Origions/roots	**Flight test instrumentation**	**Accident recording**
Topology		
Criticality	Flight approved	Flight certified
Configuration	Flexible	Rigorously defined
Location	Remote	Accessible, Tail section
Environment	Harsh	Harsh
Dimensions	Miniature (micro miniature)	½ ATR typically
Analog inputs Channel count Accuracy Audio	 1000s x 10s of types 0.05% FSR many	 10s 0.5% 4
Digital inputs Buses Time Discrete Counters	 x 10s GPS, IRIG x 1000s PWM, Freq., Period	 ARINC 717/429 or MIL-STD-1553 IRIG A few Tachometer
Output Commercial Avionics Discrete/Analog	 Ethernet, Fibre channel, Fire-wire, RS-422 ARINC-429/717, 1553, IRIG-106, 3910, CAIS Alarms etc.	 Ethernet One per FDR
Miscellaneous data processing data storage	 For CDU, HUMS etc. 6 Gbyte solid – state	 N/A 30/120 min Audio and/or+ 10/25 hr data

Table 4.1 A Comparison between FDAUs and FDRs

4.1 A CLOSER LOOK AT FORM AND FIT

Commercial FDRs typically accept data via a dedicated interface supplied directly from the FDAU, typically at one of two data rates: 768bps and 1,536bps. The availability of more information on later generation aircraft led to the FDR needing to support higher data rates and larger data frames, hence: 3,072 and 6,144bps systems are now becoming more prevalent. For example, the Penny and Giles MPFR has the capability to support these data rates but also accommodates potential bit rates up to 49,152bps, lending itself not only to series production applications but also to flight test where higher data rates are preferred.

DAUs are typically placed in equipment bays on commercial aircraft but can be placed anywhere on the aircraft, including the vibration and temperature extremes associated with engines and wing tips.

FDRs are located in the region of the aircraft least likely to suffer damage and hence survive crashes so are usually placed at the tail of the aircraft, sometimes outside of the environmentally-controlled cabin.

A micro-miniature DAU can be as small as 50mm x 50mm x 160mm. An FDR is typically ½ ATR long (123.9mm x 193mm) or ½ ATR short (123.9mm x 193m). CVRs are also ½ ATR short. With the increasing desire to reduce aircraft equipment weight, small CVFDRs are available such as the MPFR that provides the combined voice and data recorder into a compact form factor of 119mm x 89mm x 253mm weighing less than 3.2kg (<7lb.).

4.2 A CLOSER LOOK AT FUNCTION

Modern DAUs gather data from thousands of sensors about the aircraft at rates from tens of Hz to hundreds of kHz. They must also support a wide range of sensor types including bridges (half, quarter and full) for acceleration and strain, charge, ICP, power, thermocouples, single/differential ended, audio, video and isolated signals. Some of these may even require signal conditioning very close to the sensor.

These DAUs must monitor data from a range of avionics buses (ARINC-429, MIL-STD-1553, STANAG-3910,IRIG-106, etc.). They must also monitor and interface to commercial buses such as Ethernet, FibreChannel and FireWire. They must accept time from GPS or IRIG time sources. Also they must monitor hundreds of discrete inputs and counters (period, frequency etc.).

Modern DAUs can output data to a variety of commercial and avionics buses in parallel. Increasingly on-board data processing is required.

FDRs typically support up to 4 audio input channels, a rotor tachometer input and a single serial data input supplied by the FDAU. Some recorders integrate data acquisition from high speed data buses, ARINC-429, MIL-STD-1553 and Ethernet for specific (military) applications.

5 APPLICATION EXAMPLES OF FDAU/FDR COMBINATIONS

5.1 AGUSTA HELICOPTER

In this example KAM-500 is used as flight test equipment for flight trials on board the helicopter. Flight test data is both transmitted via telemetry and recorded on board to mass storage, and in addition a subset is sent via an auxilliary ARINC-717 data-stream to the on-board Penny & Giles MPFR so that extensive data would be available in the event of an accident.

Figure 5.1 Bell/Agusta AB139 Helicopter

The system is flexible enough to allow the required data to be transmitted to the MPFR asynchronously to the telemetry and mass storage data, while maintaining complete data coherency, i.e. for parameters spread across more than one transmission word, each word is guaranteed to be from the same sample of the parameter.

This concept is now being considered for a range of aircraft in other flight test fleets, including other helicopter manufacturers and national flight test centres.

5.2 TRISTAR OLM

In this application, a data acquisition system consisting of a KAM-500 FDAU with three remote DAUs, is being used to monitor operational loads on two UK RAF in-service tanker/transport aircraft. The object is to build up an accurate and detailed fatigue model of the actual mission profiles of these two aircraft. The FDAU outputs an ARINC-429 stream to the on-board Penny & Giles QAR.

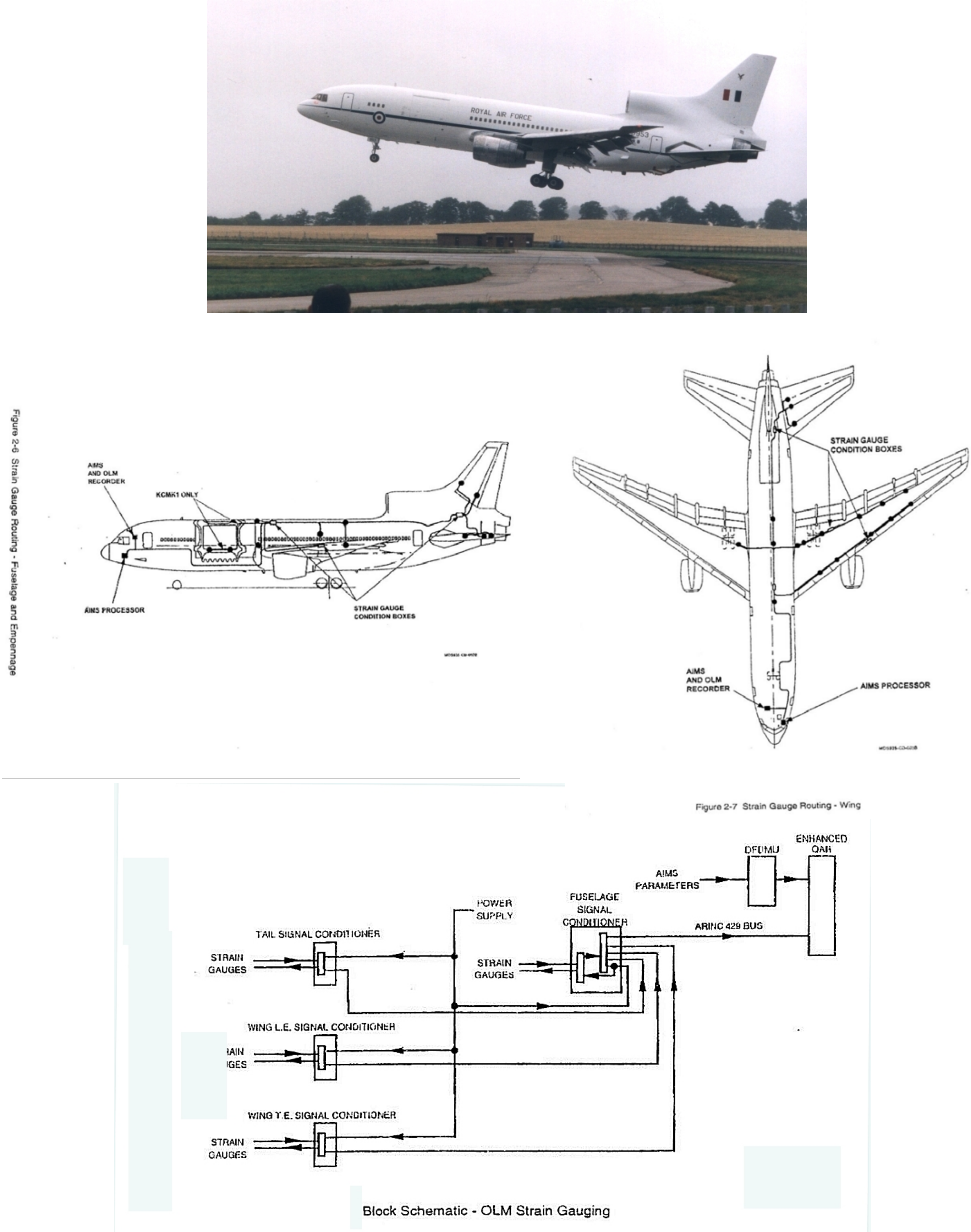


Figure 5.2 TRISTAR OLM.

6 OTHER APPLICATION EXAMPLES

For certain applications, especially where space is limited (such as aboard UAVs), it may not be possible to fit a standard FDR. Also in certain non-flight-critical applications, such as maintenance data recording, it may not be necessary to fit a fully flight-certified FDR.

Figure 6.1 Flash Memory Card Storage

In both cases, the KAM-500 with integrated flash memory card storage can serve as a combined FDAU/FDR. This provides data acquisition, transmission and storage capability in an extremely rugged and miniature unit.

6.1 UAVs

Figure 6.2 UAVs with KAM-500 on-board

Both of the above examples are fitted with KAM-500 systems for on-board data acquisition, for telemetry output, for on-board recording and also for output to the flight control computer.

6.2 E-3D Sentry L/ESS recorder

In this application, a KAM-500 system was used as a combined FDAU/FDR to replace an obsolete Loads and Environmental Spectra Survey (L/ESS) recorder.

Figure 6.3 E-3D Sentry

7 CONCLUSION

This paper discussed and contrasted Flight Data Recorders and Flight Data Acquisition systems, and showed how they can be combined to form powerful multipurpose flight data acquisition and recording systems.

In particular, the flexibility of fit and function of today's DAUs was discussed, along with the constraints of today's FDRs.

This paper also showed how an FDAU with integrated flash memory cards can be used as a combined FDAU/FDR for certain applications where space is at a premium and requirements allow**.**

Presenting Author: Paul Sweeney, ACRA CONTROL, Landscape House,
Landscape Road, Dublin 14, Ireland.
Tel: +353-1-2951264, Fax: +353-1-2951265
Email: sweeney@acracontrol.com

MONITORING NONLINEAR DYNAMICS OF TIRES DURING START AND LANDING

F.Böhm TU-BERLIN

ABSTRACT

3 D-Dynamics of Tires in the range for high velocities, high loads and also high frequencies are computed. The aim is to get data sets to interpret measured data of tire sensors. For the simulation one needs a big amount of numerical mathematics. Simulating rolling of a single tire and a complete airplane, shows the expected deformations in time by lifting the model or drop it down. Lateral wind gusts are introduced. Using a monitoring system device with three thin cables measuring deformations was built for big tires. It was very successful compared with the computer simulations. One must know that implantation of sensors in the tire rubber-cord composite itself is a hard risk. With aid of an infrared camera the growth of hysteretic heating in the laminate, in tread surface by friction and of heating the tire shoulders by bending was documented.

GENERAL CONSIDERATION OF STABILIZED MOTION

Lightweight structures are very efficient for reducing costs of transportation in global traffic. Nevertheless the transported loads and high velocities produce high frequency and nonlinear deformation of structures. The airplane is such a structure and rigid body dynamics are not appropriate to answer the questions that arise. Therefore two papers in AIMS 98 and 2000 are given Lit [I], [2] to analyse the existing problems.

The main problem is that mathematics of linear dynamics does not give exact solutions of eigenvalues of equations of more than order four. The equations of an rigid airplane have six degrees of freedom with zero roots. That means equations of flexible bodies with more than six DOF's not coupled by forces to an inertial frame or equivalent boundary conditions as vehicles, airplanes or molecules or even stellar bodies do not hold a given path.

An optimal vehicle is one which needs only a minimum of dissipated energy to stay on a desired path. The pilot, or auto-pilot, is only obliged to give steering impulses in distinct time intervals to stabilise a desired path for one time interval. In ease of dynamic contact of the tire structure in fast rolling condition the dissipative forces are crucial.

This is in contradiction to a minimum of energy loss. The tire deflection by contact forces is not small and a dynamic snap through may occure. In order to avoid this, the inner pressure must be high and the tire material in compression should not be stiff! Therefore the tire is a membrane with small bending stiffness. In order to get a smooth contact one should generate a very dense system of dynamical moving reference points for computing non-stationary rolling and this gives rise to very high-frequent subsystems.

In order to get acceptable computing time a limit is fixed for the highest frequency in the total system. For instance, if the measured eigenfrequencies of the tire (belonging to its dissipation) are not higher than 2kHz, the time step for numerical integration should correspond to a frequency of 20 kHz. Then one has to accept that the contact forces are rough according to this frequency. So the property of tire material components is for persons, who are not informed, a mystery and characteristic parameters are not easy to get. A very well but extensive survey is the book of S.K Clark [3].

TIRE MODEL TESTS

Simulating rolling of a single tire is presented to compare with measurement. Two types of tires are use: conventional tires and radial tires. They differ strongly in deformation kinematics.

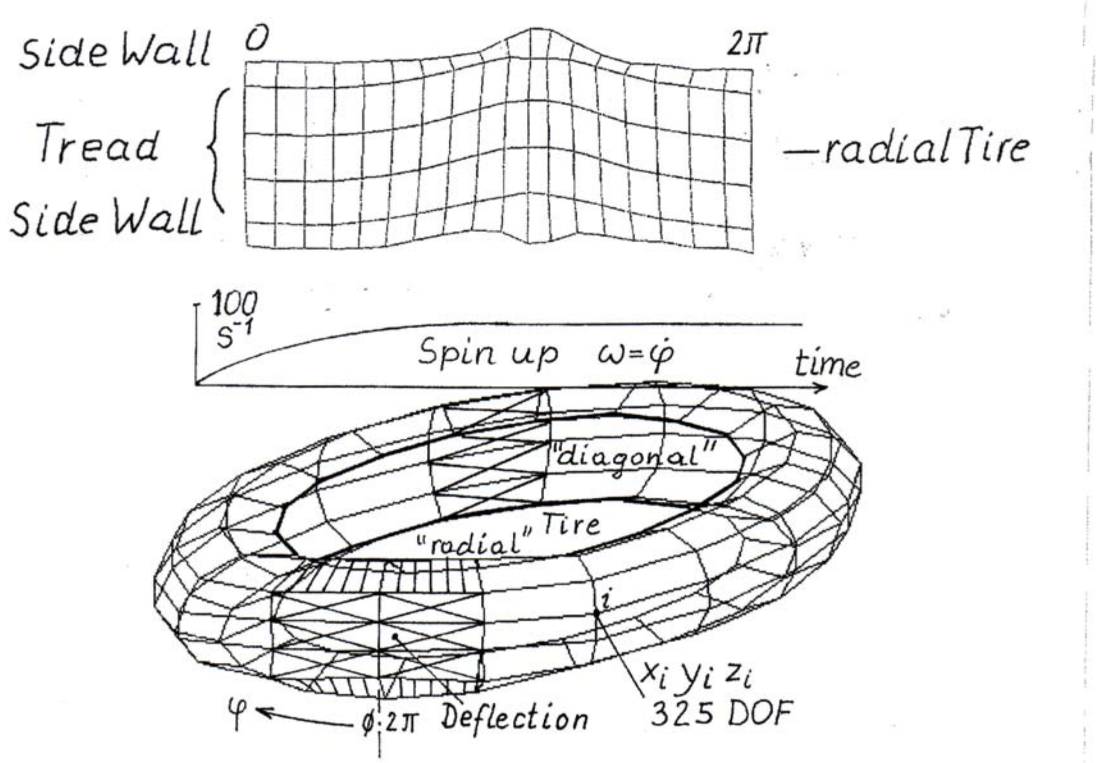
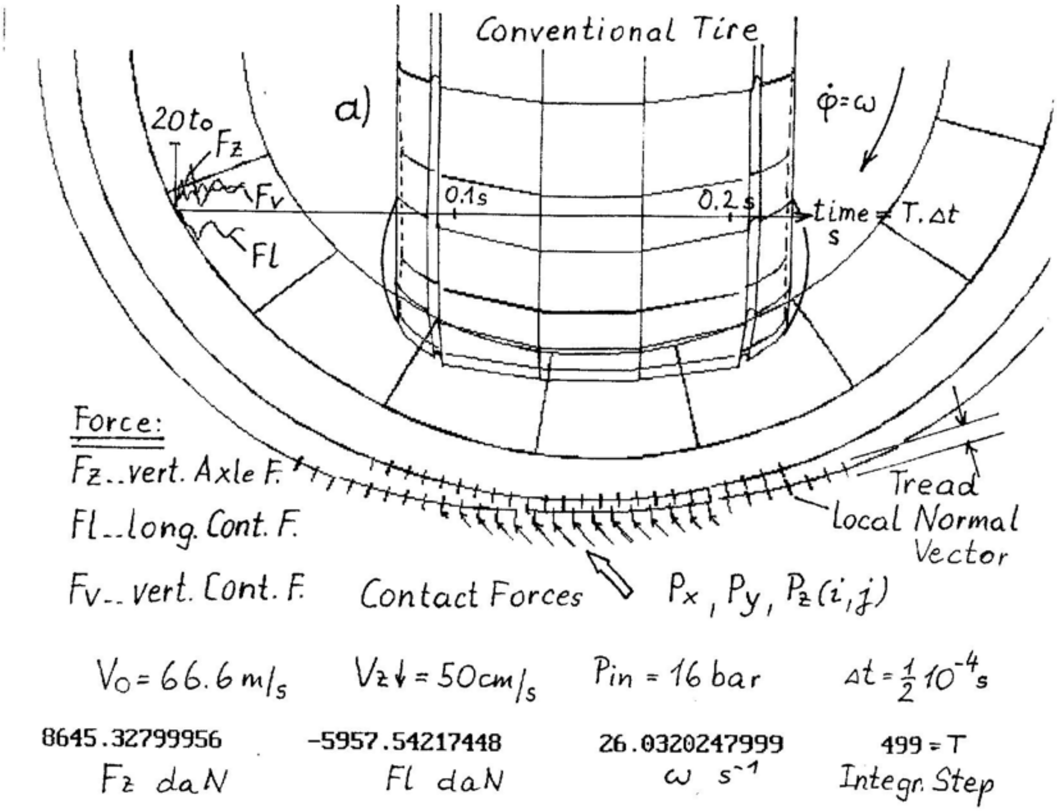


Fig. 1 For conventional (diagonal) tire sidewall and tread are enforced by cables which are crossing in several layers with the same angle, for radial tires the cables in sidewall are not crossing but in tread they are laying in three crossing layers. The computer model is only a rough numerical net for fast computation but the used parameters correspond to the continuum theory of infinite fine nets [6]. On top lateral deformation is drawn.

Rubber and flexible cables made of steel or rayon are used to produce a tire which is strongly nonlinear in its 3D-dynamics during start and landing of an airplane that is elastic and damped, too. Only the wheel rim and axle is computed as a rigid body. In order to get acceptable computing time this external rolling tire mechanics with rigid boundary conditions at rim and at the runway is simplified to a toroidal net, fig.1. With a separate computer program the internal tire mechanics stresses, strains and heating are computed when contact forces and deformations are given.

In order to analyse the dynamic contact forces of a conventional tire a landing velocity of 240 km/h and a touch down velocity of 50 cm/s are used. The load is 20 **to** according to the maximum part of weight of the airplane belonging to one tire. The airplane weight is hold by sky-hook method, fig. 2. For definitions see fig. 2a, development of forces and deformations see fig. 2b. The wheel which does not rotate spins up to $\omega = 20\ s^{-1}$ at t = 0.025 s contact time, and computation ends with $\omega == 101 s^{-1}$ at t = 0.025 s. From the beginning of the contact to 0.1 s exists only rolling resistance and then breaking forces are acting on the wheel. The same computation was done for a radial tire and the footprint length is seen to be longer but the width of this tire is smaller.



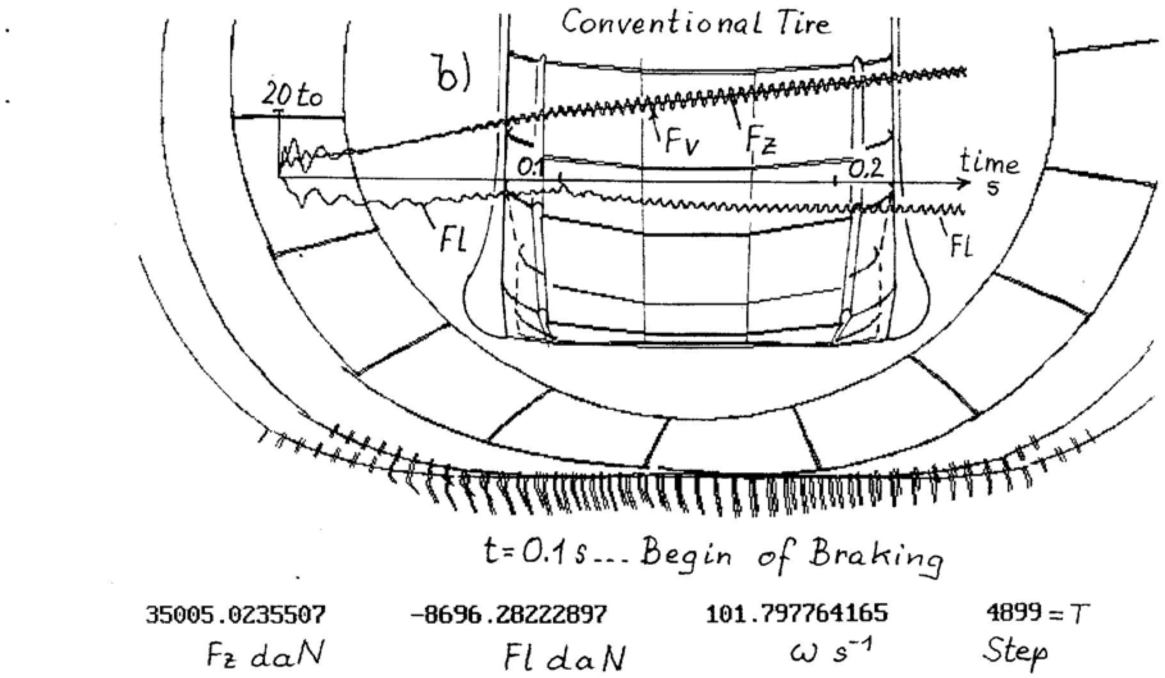


Fig.2a The fast simulation of a conventional tire during landing with v = 240 km/h spin up the non-rotating tire and deflects it so strong that the profile elements are abrasive at the side walls. The beginning of contact in 2a is only in the middle part of the tread with a vertical force of Fz = 10 **to.** This axle-force has a lower frequency as the contact force because it is the sum of all boundary forces of the tire on the wheel rim. The contact forces between Tire and Road have twice the Frequency. The amplitudes overrule the static Load of 21 **to.** Also the Side-Walls are intense sheared Fig.2b.

The side-wall shear deformation of the radial tire is stronger than for a conventional tire, Fig. 3.

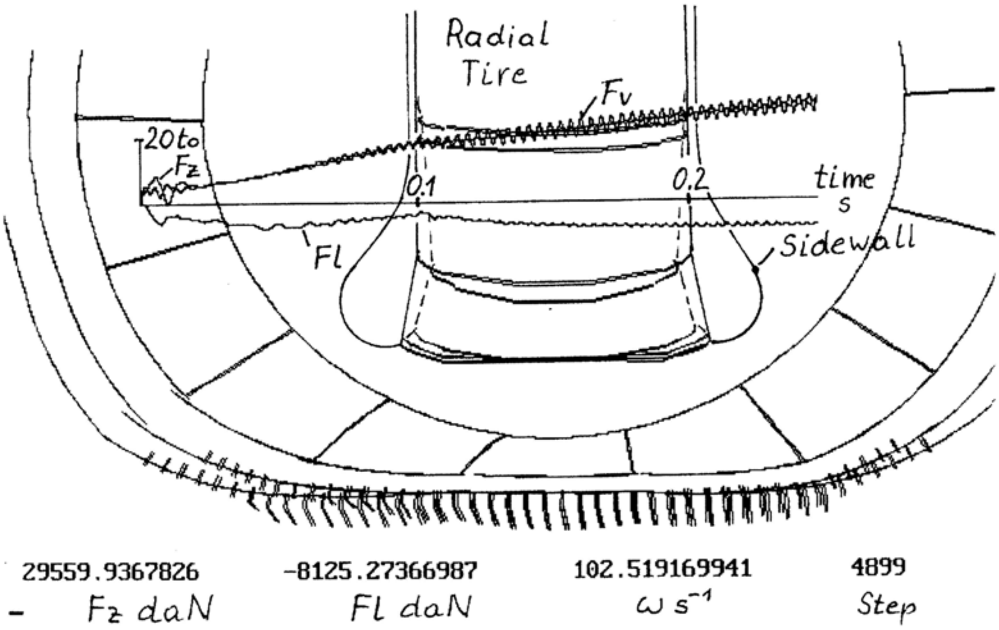


Fig.3 The radial tire is computed under the same conditions than the conventional tire. It isn't vertical so stiff but has a better grip and fewer abrasion.

In order to get a realistic view into the deformations of the layered tire structure, constraints for the cords, an inverse computing method is used [11]. The computed data of external 3D-tire dynamics are the strain and bending tensor-components of each net point. Then, in the tangential field the negative strain of all net-cords are imposed as a kinematic condition. In the next step this strain is reduced by computing the additional tangential shear between the layers together with their reduced strain. This new strain-system can also be used for the next time step of the net-system, but it needs very much computing time. Then it is possible to look for new thickness distribution of the wall, but dynamic thickness variation was not taken into account. Only the Oscillation of tread mass against the net mass was computed.

MEASUREMENTS WITH THE TRIANGULAR FILAMENT DEVICE

To compare 3D tire solutions with measurements, a tetrahedral filament system was invented for measuring dynamic deformations of big agricultural tires. Little drums are used to roll out and tow in the filaments and produce a data field from which one compute 3D tire deformations u,v,w relative to the rim. Because of the mass of the drum this motion is limited to ~50Hz and an amplitude of ~7cm. We compared deformations of tire and also measured axle-forces [13].

In fig. 4 an example of the data field got during rolling on a flat bed test rig is presented. At the top is drawn the radial deflection of tire equator v for one point fixed at the inner layer of the tire. One full rotation of that point shows the next maximum of deflection. a.s.o.

There is no stationary rolling observed in the line of 170 mm. The lateral deformation w (t) in the line of 50 mm shows the same behaviour but the effect is from ply-conicity analogy effect as ply steer. In the line of 30 mm the circumferential deformation u (t) is drawn. The measured maximum deformations are: 35mm, 8mm, 12mm.

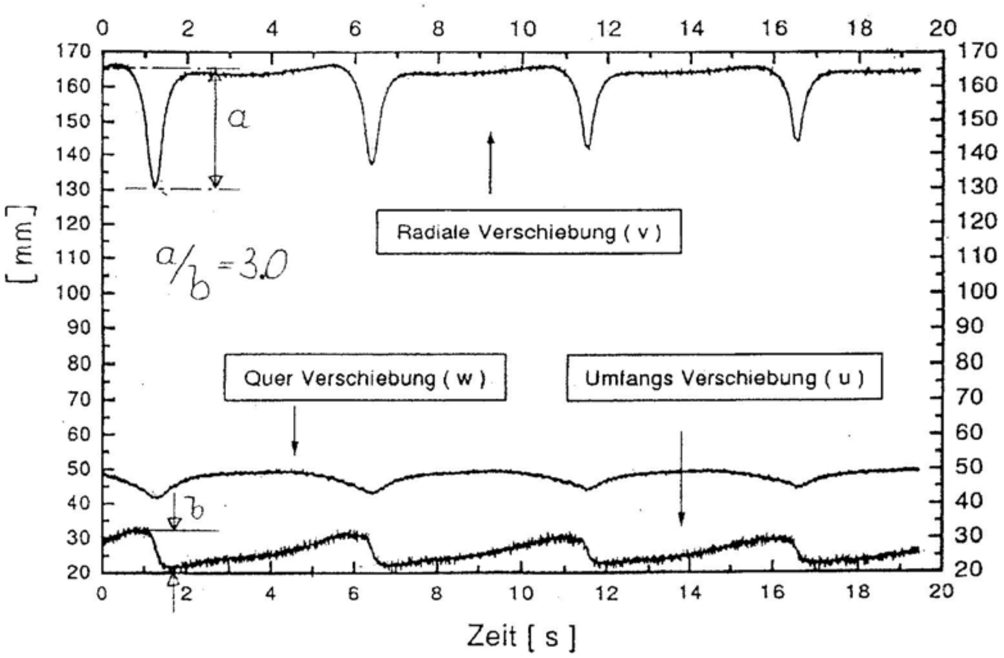


Fig.4 Measurements ofnon stationary deformations of an equator point of a tire AS 18.9 R 34 on the flat bed test rig at TU Berlin.

The tire has a radius of 820 mm and has 14 points for deformation measurements in equidistant distribution at circumference. It should be desirable to develop such a system for fast rolling! The tire is an agricultural radial tire and gave good coincidence with computed 3D-deformation. For six steps of slip the tire driving forces were measured rolling in a deep ground channel. It was found very good coincidence to the computed force characteristics, fig. 5.

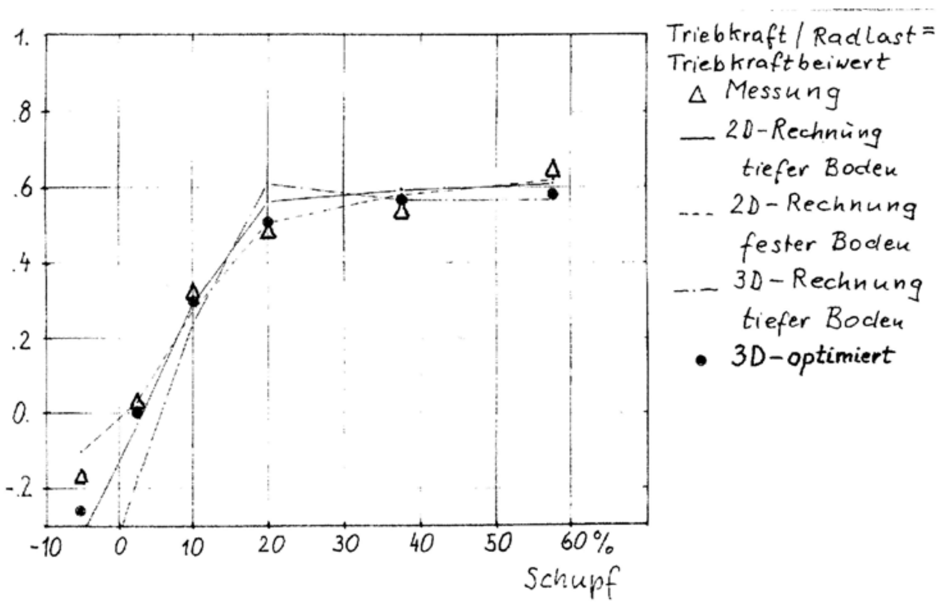


Fig. 5 Measurement and computed of traction characteristics on deep ground channel at TU Munich

In case of high rolling velocities one should change to measurements of 3D acceleration at the inner layer of the tire. An experience exists to put up a hook on the inner layer in a durable manner, this can be done also for a small 3D-acceleration sensor. Then it become possible to use the numerical solution for decomposing the signals of the sensor relative to the rim. Integration in time will give the deformations.

That is we like to get deformation measurement in combination with computed solution. At the beginning we compare an absolute amount of acceleration with a computed one.

LIMITS OF THE TIRE DEFLECTION

When the tire is vertical deflected the sidewalls are extended until the tread is contacting the wheel rim. In this case the tire is very stiff and the computer program switches to a kinematical statement which limits the distance of the gear axle to the ground equal to the radius of the wheel rim. Another problem is the rolling on a step sized roughness which gives rise of a small penetration of the tread into the roughness. The program can only limit the local contact force in consideration. Then the decision is that this contact point is not sliding.

COUPLING OF TIRE TO THE FUSELAGE

The usual landing gear strut has a working interval of more than 40 cm and is strongly nonlinear (progressively) to avoid hard impulses so that the tire contact patch is not completely deflected. There is a oil and a air camber which are separated from one another. The prestress in the air camber is so that the axle force of the tire does not deflect the strut beyond a force of 5.5 **to.** Additionally, a constant friction and a oil damping system are acting. With 5 **to**/cm the main gear strut has a stiff coupling used in computation. The nose gear strut has 10 **to**/cm stiffness. This is done to get fast tire reactions in simulation in view of heavy carriage.

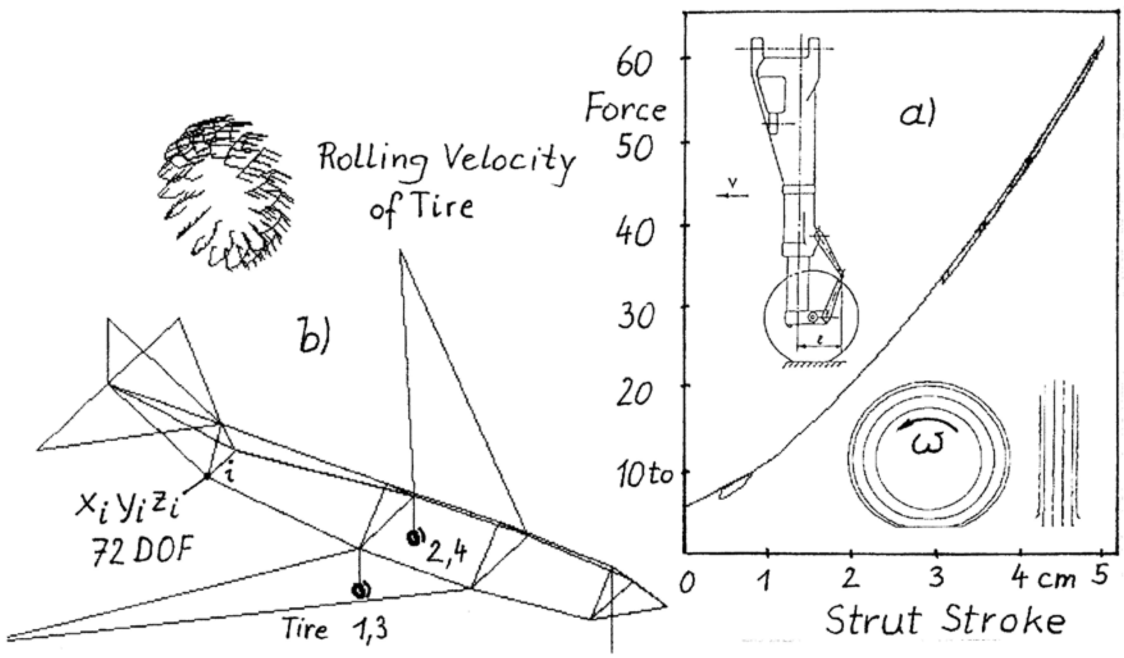


Fig 6 a) The strut force is nonlinear and belongs to the maximum loaded main gear of Fig 10 example.
Fig 6 b) The computer model of the airplane consists of 72 DOF and has bending and shearing stiffness in addition with hysteresis-

DISCUSSION OF START AND LANDING COMPUTATION

A simplified computer-model for a 41.4 to elastic airplane with four main-gear tires and a front gear as a spring-strut is shown in Fig 6a with start-position and velocity distribution of the rolling tire. Fig.6b is the nonlinear characteristic of the main gear strut. Fig 7 shows a start beginning with Vo = l0m/s at touch down to get a quasi static start. The tire rotation ω increases from $20s^{-1}$ to $27.3s^{-1}$, the airplane velocity to 13.3 m/s in 0.25 s by aid of thrust of 2x 10 **to** of two engines.

In the beginning of computation there is not an equilibrium situation of the airplane and the tires. In case of a starting run the velocity is 10 m/s, a small vertical deflection of airplane and tires is given. A transition of contact forces, gear forces and airplane structural forces arise. Acceleration of 0,25 g the airplane by engine thrust is included. The sink-rate is the same as for a landing situation: -50 cm/s. The small rolling velocity coincides with the rotational velocity of the tires . By virtue of engine thrust, this velocity increases up to a lift up which needs very long computer running time. In practical use of computation the wavelength of the road roughness is coupled with the length of tire contact elements [9], [12], Chapter 4.5.

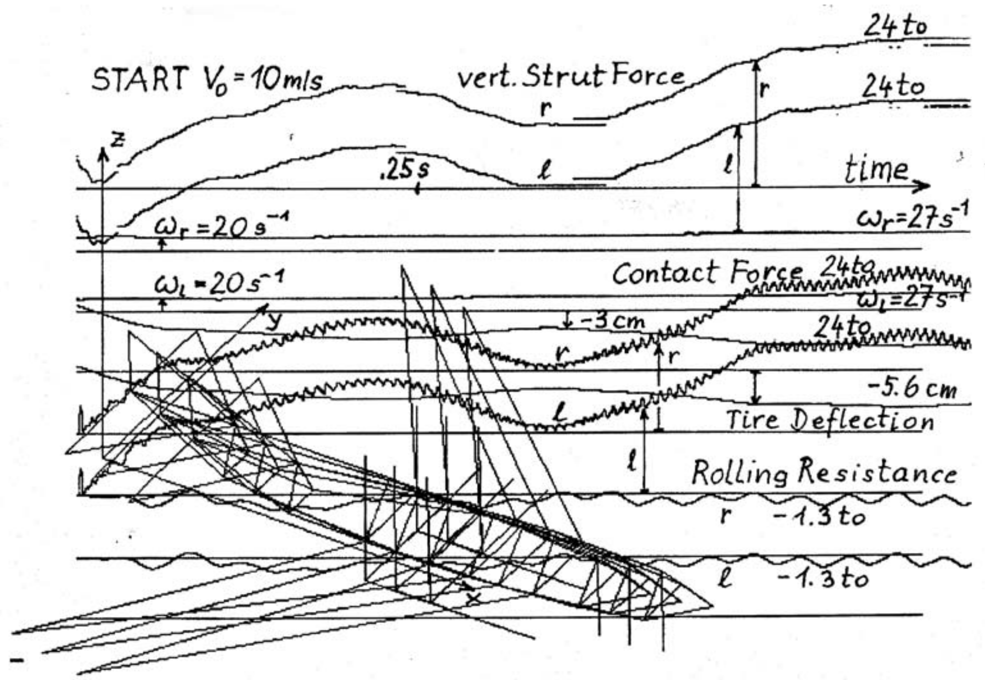


Fig 7 At first the tire is in air but is expanding by inner pressure acting. Then it touch the ground and gets a vertical impulse. It looses again contact and develop a rough linear increasing contact force. The strut force comes down from -5.5 **to** prestress and then increases also. The tire deflection is only the mean value - of axle high minus nominal tire radius of 50 cm which increases by inner pressure for ~ 1 cm. Contact forces are drawn for two tires.

In case of a landing run the velocity is high and the tires are non-rotating. Intensive slipping forces arise even when contact deflection is small. After an interval of 0.375 s the spin up of the tires is enough for beginning of breaking without strong abrasion. Thrust is not taken into account in computation. The computation of roll out is also lengthy. There are two further examples which are interesting : Firstly, the question what happens when only one main gear is breaking, secondly, when a strong side-wind of 72 km/h is acting. In the first case it is shown that no big influence in deviation of straight rolling occurs, in the second one, strong influence and very critical situations could arise. In this worst case, a computation of elastic "plastic deformation can be done as it was done for a agricultural truck "crash with 3D-tires against a wall.

For slow taxiing conditions simpler tire models can be used together with measured lateral and longitudinal slip/force characteristics or computed by Magic Formula after H. Pacejka [5]. In this case it is only necessary that the paths of contact point should have a wavelength lO-times longer than the contact length. Together with a very small rolling velocity one gets difficulties in computing stable integration steps of longitudinal slip conditions. That is why one should go back to a rigid wheel with stationary slip forces or use simple dynamic tire models [4], [7], [8]. In situations, where slip is small mid rolling velocity is high one has to take into account sticking and possibly slipping parts of the contact patch. The decision to do so is the fact that the tread of the tire has inertial force and every contact point is working as an Oscillator, nonlinear because of friction.

The landing of this model with v_0 = 50 m/s and a vertical velocity of~50cm/s shows a spin up of the tires in 0.25 s. Fig 8 Therefore it is possible to begin with breaking after 0.375 s with a force of 2x5 **to** and a deceleration of 0.25 g:

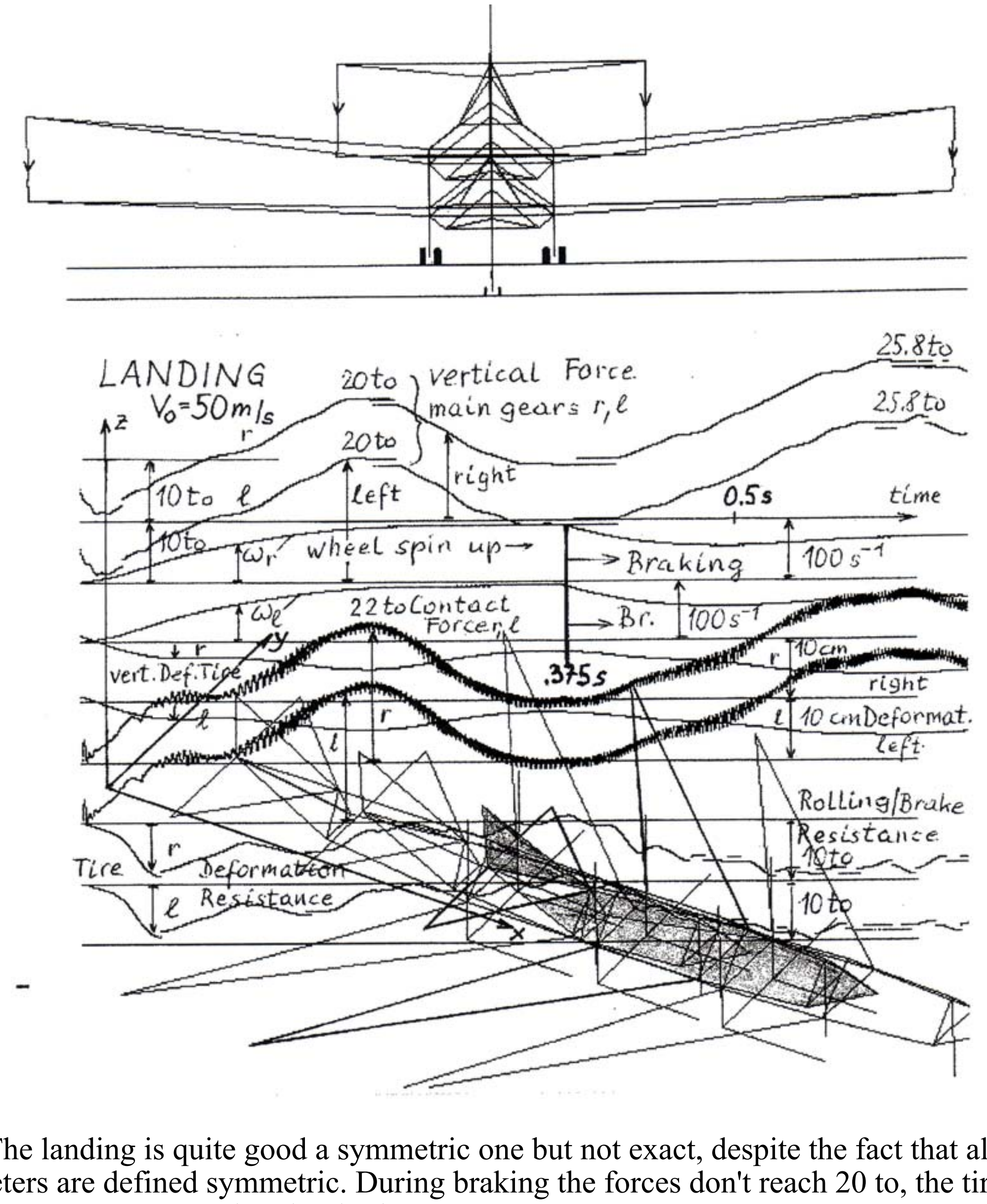


Fig.8 The landing is quite good a symmetric one but not exact, despite the fact that all parameters are defined symmetric. During braking the forces don't reach 20 to, the tire rotations aren't constant. On top animation is shown.

In all examples the touch down produces tire frequencies of ~ 130 Hz but during rolling the contact frequency is of ~ 580 Hz. At the beginning of contact the tire in air deformation is ~ 0 cm, defined by start conditions, when tire load of 20 **to** is in free rolling , deformation is ~ 5 cm. Also in all examples at first the tire is in air but is expanding by inner pressure acting. Then is touching the ground and gets a vertical impulse. It looses again contact and develop a rough linear increasing contact force. The strut force comes down from -5.5 **to** prestressed and then increases also. The tire deflection is only the nominal figure of axle high minus nominal tire radius which increase by inner pressure ~ 1 cm. The next case is non symmetric breaking:

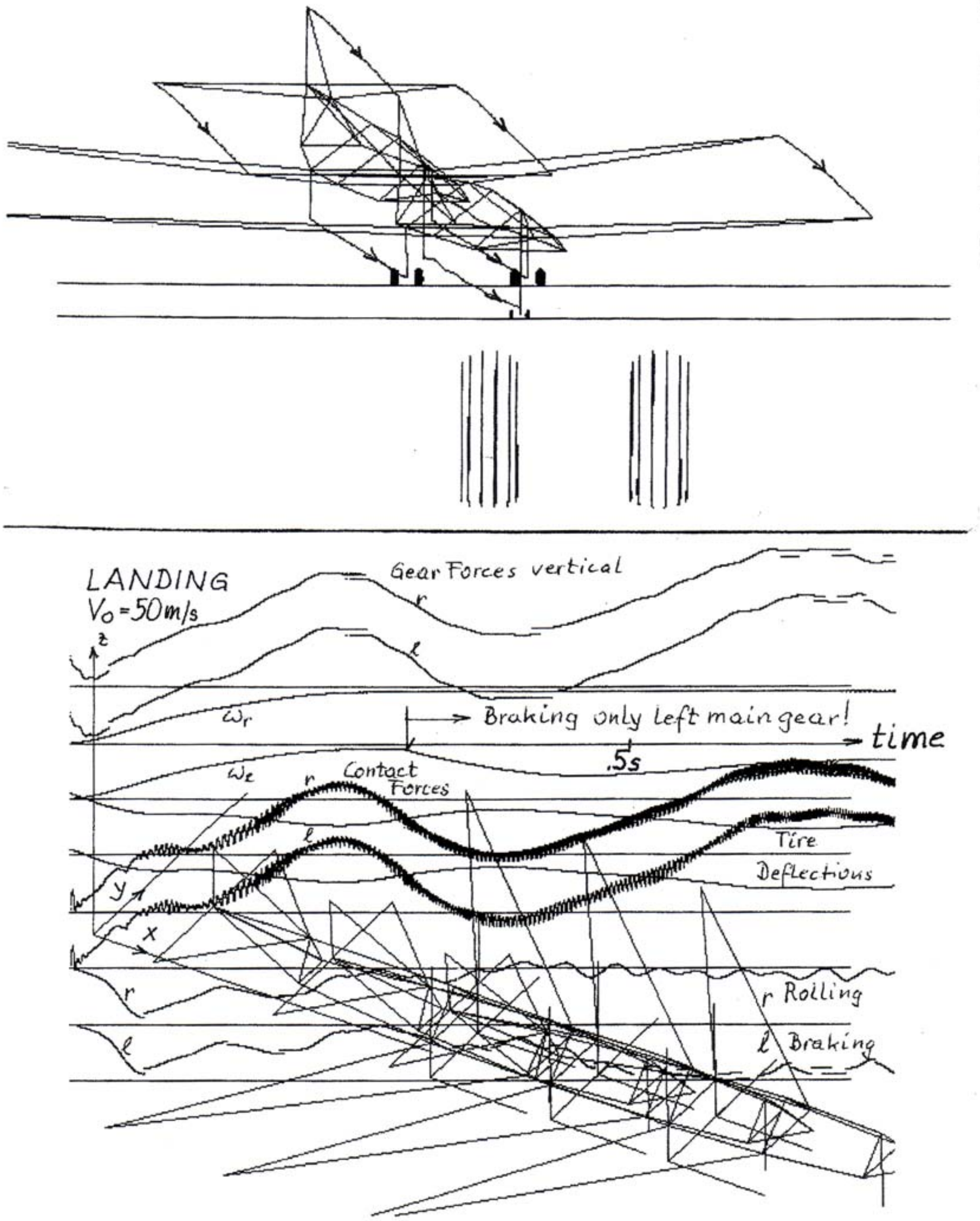


Fig. 9 In this computation the influence ofnon symmetric braking is documented. The deviation from straight run is very small, but by longer computer run may be of interest.

The worst case of landing with strong sidewind produces more than 50 **to** contact force on the right main gear and the right two tires. The left one have zero contact. In the animation the tire deformation is shown, also the deviation from straight rolling is catastrophic. The rolling resistant forces in x-direction are strongly oscillating with amplitudes of 20 to. This forces are acting at the axle of the two tires. They are inertial forces of tire and main gear Fig 10.

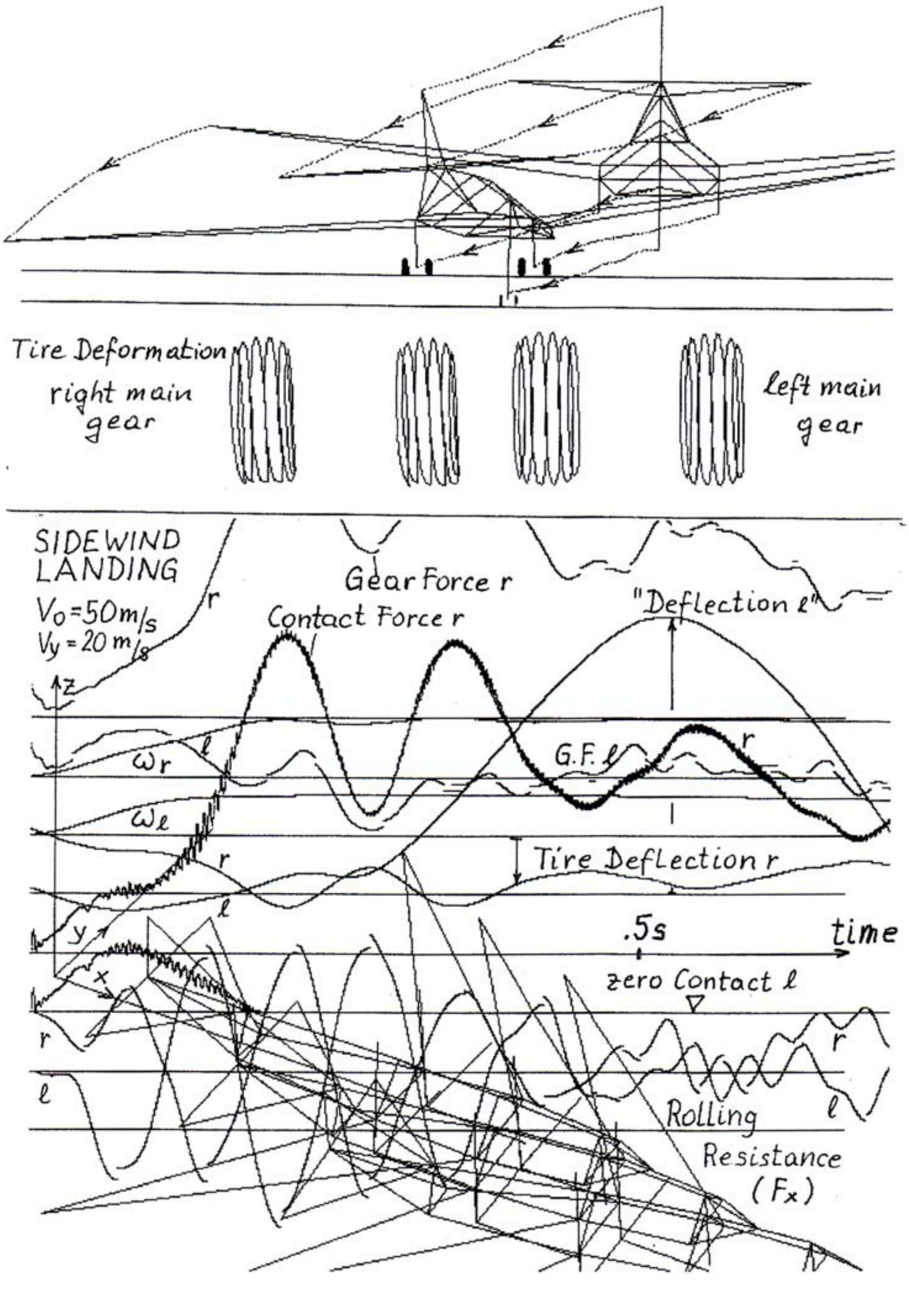


Fig 10: Side-Wind landing of 72 km/h when landing velocity is 180 km/h is a strong demand of the gears by shifting the vertical forces to one side and also the horizontal forces producing a gear-walk. The longitudinal forces have amplitudes bigger than 20 **to.**

CONCLUSION

For modern and future flight the tire is an inevitable part of the airplane. It fulfils a heavily dynamic work during start and landing. Up to now there exist no possibility to sense continually acceleration stress and strain in contact time. It is well known that in the 2 .world war nearly 40 % of all military airplanes where damaged during start and landing. At the end of the war stable rolling gears where invented to increase the loads. Tire radius of big main gears tires can't be increased because of too big stresses of rubber and cord material. So it was necessary to increase the number of tires for one gear. Carriages are growing and also number of gears. A limit of rolling stability is reached for big airplanes. It isn't only a question of linear stability theory. This is the necessary condition to came ahead. The remaining question is the nonlinear stability of the free moving system. Using acceleration measurements inside the wall of the tires in combination with nonlinear numerical computation, that is the successful way of solving the problem of finite dynamic tire deformation for high rolling velocity and heavy load.

LITERATURE

[1] F.Böhm, AIMS 1998
[2] F.Böhm, AIMS 2000
[3] S.K. Clark, Mechanics of Pneumatic tires
US government Printing Office Washington D.C. 20402
[4] F. Böhm and H.P. Willumeit, AGARD-R-800
[5] H.B. Pacejka, RBakker: The Magic Formula Tyre Model. In: Tyre Models for Vehicle Dynamics Analysis, H.B. Pacejka (Eds.), Proc. 1st hit. Colloquium on Tyre Models for Vehicle Dynamics Analysis, dift. The Netherlands 1991; Supplement to Vehicle System Dynamics, Bd. 21, S. 1-18,1993
[6] F.Böhm zur Mechanik des Luftreifens. Habilitationsschrift, TH Stuttgart 1966
[7] F.Böhm: Zur Statik und Dynamik des Gürtelreifens. ATZ 96 (1967), 255-261
[8] H.B. Pacejka: The Wheel Shimmy Phenomenon - A theoretical and experimental investigation with particular reference to the nonlinear problem, PhD thesis (reprint), Delft University of Technology, 1966
[9] F. Böhm Theorie schnell veränderlicher Rollzustände fiir Gürtelreifen. Ingenieur-Archiv 55 (1985), 30-44.
[10] F. Böhm: From Non-holonomic Constraint Equation to exact Transport Algorithm for Rolling Contact. Periodica Polytechnica ser.Trans.Eng.Vol.24, No. 1.
[11] F. Böhm: Dynamic rolling process of tires as layered structures. Mechanics of Composite Materials 32 (1996) N0,6, p.824-834
[12] F. Böhm and K. Knothe, Hochfrequenter Rollkontakt der Fahrzeugräder. Wiley-VCH, 1998
[13] Deutsche Forschungsgemeinschaft DFG Reports BO-648/5,6

ETSC Annual Activity Report

to the Plenary Meeting 2004

Gerhard Mayer
German Society of Telemetering
Arbeitskreis Telemetrie e.V.
Email: gerdvitus.mayer@t-online.de

1. General Information

The European Telemetry Standardisation Committee (ETSC) was founded in 1994 by

- SEE (Club 17) and AAAF (Test Commission), France
- AKTM and DGLR (Panel 4.1 Telemetry), Germany

The ETSC shall serve as a focal poin to receive, review, coordinate and dissaminate information concerning standards, methods and procedures with relevance to Telemetry and Remote Control.
Main tasks of the committee are

- inform/ comment on existing and coming standards
- coordinate reviews of new standards
- act as an information link between users and industries
- establish committees for addressing specific needs

The ETSC is linked to the Telemetry Standards Coordination Committee (TSCC) to ensurean information and interest transfer between the US and Europe.
The present active member countries , represented in the ETSC are

- Austria, France, Germany and the UK

Contacts and information exchange are in existence with organisations in

- Australia, Brasil,India, Indonesia, Israel, Italy, Norway, South Africa, Spain and Sweden.

The ETSC was structured into three subpanels

- SC-1 : RF-Spectrum & Frequency Management
- SC-2: Data Acquisiton & Processing
- SC-3: Data Recording & Storage

2. Main Activities

SC-1: RF-Spectrum & Frequency Management
Chairman: Jean-Marie Berges, SEE, France
Email : jmberges@voilà.fr

The main task was to support the work of the
International Consortium of Telemetry Spectrum (ICTS).

In a coordinated action to the national (France, Germany, UK) preparation of the WRC 2003 the preliminary agenda point 2.12 for the WRC 2007,
"to consider spectrum requirements for wideband aeronautical telemetry in the band between 3 and 30 GHz",
was supported successfully. It was implemented into the ECP and is now definitely agenda point 1.5 of the WRC 2007.
A Newsletter is spread out by internet on a regular basis, informing on matters related to Radio Spectrum and Telemetry /Remote Control in a broad sense.

SC-2: Data Acquisition and Processing
Chairman: Werner R. Lange, Lange-Electronic, Germany
Email : rwlange@lange-electronic.de

Decentralized, bus oriented data acquisition is getting more and more popular..
Numerous data busses, standardized or in a sort of way for it, are in existence.
The subcommittee 2 tries to track changes and modifications in existing systems and to follow the evolution of new products..
Based on practical experience and available literature the performance of data busses is analysed and compared (e.g. data transport capacity and speed, data integrity, time correlation).
Presently the work is concentrated mainly on coming Avionics data busses (like AFDX et al.), on Field Bus Systems of the industrial environement and the future potential of wireless network technologies and their application for data acquisiton and collection.

SC-3: Data Recording & Storage
Chairmen: Steve W. Lyons, QinetiQ, UK, Balázs Bago, Heim Systems Germany
Email: swlyons@QinetiQ.com Email: bbago@heim.zodiac.com

Tasks include the dissemination of information on recording systems & techniques applicable to aerospace telemetry and the review of relevant standards / standardisation tasks (e.g. IRIG-106, Chapter 10).
Users are tried to be encouraged to participate in proposing future standards.

TSCC-Meetings

ETSC delegates and TSCC members are:

Jean-Claude Ghnassia, Airbus France
Email :jean-claude.ghnassia@airbus.com

Gerhard Mayer, AKTM, Germany
Email: gerdvitus.mayer@t-online.de

They did participate in the TSCC Meeting , 20 October 2002 , held in
Las Vegas, NV.
Various IRIG and IEEE standardisation documents, under review in the US have been made accessible to the ETSC-subcommitttees, too.

European Telemetry Standardisation Committee
ETC'04 briefing SC3 - acquisition and storage

S.W.Lyons, QinetiQ U.K.
B. Bagó, Heim-Systems Germany

swlyons@QinetiQ.com, bbago@heim.zodiac.com

Abstract

This report, presented under the auspices of the European Telemetry Standardisation Committee (ETSC) – sub committee 3, cites data acquisition & storage issues facing the telemetry user community and reports upon associated standardisation activities. The briefing includes an update upon ongoing Range Commanders Council standardisation tasks.

Tasks

The ETSC Sub committee 3 - acquisition and storage - defines its current tasks as follows:

- Dissemination of information on recording systems & techniques applicable to aerospace telemetry.
- Reviewing relevant standards / standardisation tasks
- Encouraging user participation in proposing future standards.

Standardisation Success on Data Recording

Acquisition and storage for telemetry data in the past meant magnetic tape based recording technology. One of the great successes in this field was the standardisation of the IRIG-106 compatible multi-track recording system with a number of European and U.S. companies manufacturing these in quantity for several decades. The change from recording pure analogue data to recording higher quality PCM data led to a need for high-density digital recorders, which were at the outset engineered around IRIG -106 28 track tape transports. The IRIG -106 telemetry standard achieved further successes through:

- Standardisation of PCM formats (Chapter 4)
- Standardisation of encapsulating MIL-1553 bus communication embedded in a PCM data stream (Chapter 8)
- Using a description language for defining the size, format and coding of physical values in PCM streams and MIL 1553 bus data (Chapter 9).

Increasingly, since the 1970's, digital data storage devices have been available as commercial off the shelf products from the professional and commercial audio, video, and computer data storage Industry. These new systems offered an astonishing high performance / price ratio, rendering the large and expensive IRIG multi track recorders obsolete.

Equipment vendors started to use the technologies offered by the new digital tape storage systems, modified and ruggedised devices for telemetry ground station or on-board data recording purposes. The diversification of tape recording technologies meant the end of the IRIG-106 instrumentation tape media standard – however the RCC incorporated the technologies offered by the commercial industry standard SVHS and D1 videocassettes.

First Digital Data Recording Standard

Storage media in use today includes a wide variety of incompatible longitudinal and helical scan tape formats, optical disks, CD and DVD formats, hard disks, RAID arrays, and a complete range of solid state media. Standardisation on media is unimaginable because of the speed of the product evolution in the commercial and professional digital world. The RCC decided in 1994 to take a different approach: instead of standardisation of the media format, the data format should be defined; creating a "common" data interface. A new standard was released in 1998, called IRIG 107–98 based on the well-established time division multiplex packet telemetry standard of the NASA: the CCSDS. Contrary to the recent announcement by the RCC dated February 2004, this standard was not only targeted for Digital On-board Recording Standard (former name: DORS), but it was also ideal as a data packetisation standard for Telemetry applications.

The normal life of any standard is only as long as the vendors and users actively support it. The IRIG 107-98 was not a success, basically for 3 reasons: From the vendors side only a few companies followed the standard, the other companies didn't see any benefit of changing their existing proprietary data formats to an open – and new data format. Secondly, the standard was not finished. It was a good framework, but the detailed packet formats for different data types were not included. That should have happened, but for the leading engineer of the IRIG 107-standardisation initiative leaving the RCC prematurely. From the users side the push to adopt the standard was not compelling. Other areas were taken as higher priority than a standard data format. Most of the data recorded was still reproduced in the traditional "analogue" way, and there remained a need for the data reduction facilities to manufacture a new "data converter" whenever a new type of recorder was purchased.

The real need for a standard data format otherwise remained. First there was an attempt to complete the unfinished IRIG 107 standard – with a new packet format - version 1 packets – in order to correct a mis-match with the earlier Packet 0 format; it being low-endian against the original CCSDS high-endian data format. Finally a new member of the RCC Telemetry Group Recorder and Reproducer Committee took the lead, took the Version 1 packet format and created a new Chapter in the IRIG-106, the Chapter 10. The last four years of standardisation effort brought the RCC a possible new success: the IRIG-106 Chapter 10 was released in October 2003 as the result of the TG – 56 Solid state recorder standard task.

Current Status of IRIG-106 Chapter 10

The IRIG 106 Chapter 10 is significantly further developed than the previous IRIG-107. The packetised data format only being a part of it – albeit a significant one. Originally it is defined for a Solid State On-Board Recorder Standard, containing the following sub-chapters:

- 10.4 Data Download And Electrical Interface

    Fibre Channel interface and the necessary SCSI commands are defined.

- 10.5 Interface File Structure Definition

    The STANAG 4575 file format is adapted.

- 10.6 Data Format Definition

    The data format definition includes data formats for PCM, MIL-1553, ARINC-429, Time, Voice, Analog Data, Compressed Video, UART, Ethernet, Discrete and Computer generated data.

- 10.7 Solid State Recorder Control And Status

    Definition of the functions of four simple discrete controls and five status lamp drivers.

- 10.8 Declassification

Another two Chapters of the IRIG-106 has been added or significantly extended during the Chapter 10 work:

- 6.18 Recorder Command and Control Mnemonics (CCM)

This Chapter has been added as a result of the TG – 47 recorder command & control standard task.

- 9. Telemetry Attributes Transfer Standard

Chapter 9 needs extending by including some new attributes. The Recorder and Reproducer Committee proposed them to the Data Multiplexing Committee, who *own* this Chapter. Unfortunately the update of Chapter 9 is not yet released due to the necessary reformatting process of the whole IRIG-106.

Ongoing IRIG-106 Tasks

As a usable standard should not stop evolving, the RCC TG Recorder and Reproducer Committee has continued the work on the Chapter 10. In the current phase the following extensions are under discussion:

- IEEE 1394b as standard download interface,
- Real-time clock included in the solid state cartridges for synchronizing aircraft without external time sources,

- New 32-bit PCM structures,
- Adding new data types: IEEE 1394, MPEG-2 Program Stream, Parallel (DCRSi) data,
- Adding Event and Index Packets for speed-up debriefing process,
- Correction of misprints and ambiguities in the previous versions.

These changes should be released soon as a pink-sheet.

Other RCC Activities

- Ground-based Recording, Reconstruction and Archiving

The RCC Recorder and Reproducer Committee is preparing a new task which is based on the Chapter 10.6 data format and gives some guidelines how to store, reconstruct and archive data on various media including disks, tapes, DVD, etc. These guidelines should later replace the IRIG-107 Chapter 7. When this happens, the Chapter 10 will no longer be a pure Solid State Recorder Standard, but a universal data format for multiple type, time aligned data streams, freely transportable in the digital recording world between different media.

- TG - 63 Telemetry networks

The topic of networks was earlier outside the scope of the data acquisition and storage domain. However, it will not take long to appreciate how telemetry networks could take over the role of the traditional telemetry data collection and transmission tasks. Earlier RCC activities like: Joint Data Acquisition Network System (JDANS) and Real Time Telemetry Network (RTTN) has been replaced with a unified concept called: iNet. The first study is about to be released in 15th May 2004.

Networking is becoming a core technology everywhere, including real-time data acquisition systems. Recently a new IEEE standard (1588) was approved, which allows for the synchronisation of subsystems over networks down to one microsecond accuracy. Large data acquisition systems will soon be based on standard networking technologies. The special needs of telemetry applications must be considered and standardised.

Discontinuation of TRIUMF

In 1981 the Recording Industry Users and Manufacturers Forum was established in the UK. TRIUMF was modelled on the American Tape Head Interface Committee. Attendance at TRIUMF by both users and manufacturers was healthy for many years and the forum proved to be a successful vehicle for sharing knowledge and resolving recording related problems.

It is regrettable that following a meeting of the TRIUMF committee in December 2003, and a concentrated effort by the committee to establish sufficient user interest in continuing with TRIUMF, a decision has now been taken not to continue with the forum. TRIUMF's remaining funds are to be disbursed to the University of Manchester to assist recording projects, or students studying aspects of data recording. A full statement has been placed on the TRIUMF web site - www.triumf.org

New European Forum ?

TRIUMF was definitely a great meeting place between users and manufacturers – and possibly those resident in other European countries didn't understand its usefulness. In spite of some overseas visitors at TRIUMF meetings, it remained for over 20 years a UK based and focused forum.

Some topics for this ETSC SC-3 meeting discussions:

- Should a European wide data acquisition and storage forum replace the role of TRIUMF?

- Is it enough to follow the RCC standardisation activities, or should ETSC be more active? Is the European Aerospace Industry strong enough to have a role? The answer is surely: yes! Then what stops us being leaders in some areas in standardisation?

ETSC – Meeting at ETC2004, Garmisch-Partenkirchen

Group 2, Data Acquisition and Processing

Werner R. Lange / Lange Electronic GmbH

Thoughts About the Data Handling in Distributed Data Acquisition Systems.

Bus Systems:

Organisations like MILBus 1553, ARINC 429 or the CAN Bus in automobiles are a good example for busses used in distributed Data Acquisition systems. The “field bus” is also an example, although it is not too often used nowadays.

Todays the TCP/IP protocol is widespread in such systems. The advantage of this protocol is that data can be transferred from each participating user (= Client or Host or Server) with extremely inexpensive modules from a wide variety of vendors at very high speeds. Mixed structures using wires, fiber optics and RF transmission are available. The data rates are high and the data can be used easily in a computerized telemetry front end – it is already the language a computer understands.

Examples for protocols and standard used are 802.11, 802.11a, 802.11b , 802.11g (wireless LAN, 2,4 GHz), 802.16 (wireless LAN, point to point, 2 to 11 GHz) and 802.3ae (fiber optic)

There are a few constraints:
If the correlation of data gathered at different places is important, the present structures of TCP/IP time correlation is not “at the leading edge” of technology. One has to remember that TCP/IP is not made for real time applications. There are some tools available to “synchronize” different clients to the same time, the best known is NTP (Network Timing Protocol).
Synchronisations of a few Milliseconds can be achieved in Local Area Networks, if there are only very few routers and switches to go through this number may be enhanced to about 1 millisecond, but not further.

If synchronisation accuracies in the microsecond range has to be achieved, other ways of synchronisation have to be used; this requires usually a separate timing network distributing 1 pps, time information and/or IRIG-type time.

International Consortium For Telemetry Spectrum

General Session Agenda

Garmisch-Partenkirchen, Germany (24-27 May 2004).

Tuesday, 25.May 2004 **Meeting Room: Wetterstein**

1400	**Welcome, ICTS Overview**	**T. Chalfant**
1415	**Business Reports** Secretary/Treasurer — Darryl Holtmeyer Region 1 Coordinator — Jean Marie Berges Region 2 Coordinator — Mike Ryan Region 3 Coordinator — Viv Crouch	
1440	**Economic Impact of Telemetry**	**C. Kahn**
1500	**3-30GHz telemetry Research Projects**	**S. Ortigoza**
1520	**WG 1 Report, 3-30GHz Spectrum Studies**	**D. Ernst**
1540	**Global Spectrum Utilization Matrix**	**M. Ryan**
1600	**Break**	
1610	**Unmanned Aerial Vehicles: TM Spectrum Concerns**	**M. Ryan**
1630	**Data Growth in Aeronautical TM**	**D. Ernst**
1700	**Preparations in Europe within the Conference Preparatory Group (CPG) of the CEPT**	**J. Strick**
1720	**WRC 07/1.5 Preparation in the USA**	**S. Jones**
1740	**WRC 07/1.5 Preparation in other Countries** **Discussion** **How the need is Validated** **How candidate bands are being proposed**	**Open**
1800	**Final Remarks, Next Meeting Announcement**	