Real time and triggered architecture for airborne wide bandwidth analog acquisitions

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Abstract: In the certification program framework for A380 electrical system, wide bandwidth analog acquisitions have to be performed for flight tests.

But recording 64 channels with such performances during an entire test flight was not conceivable. That is the reason why a triggering strategy has been designed. This paper shows the architecture implemented within the flight test installation in order to select interesting time zones. This architecture integrates various real time tasks for each part of the triggering line, and is based on computer processing with both analog and digital data.

This design builds a coherent and programmable system and by this way optimise on ground human and computer data processing.

Keywords: Triggered acquisitions, real time processing, wide bandwidth analog acquisitions

1. Introduction

Airbus Flight Test Installation for A380 certification campaign has been designed in order to acquire many types of signals, coming from various information sources. Based on a common core, this architecture acquires digital data (from discrete up to avionic buses) and analog signals (with a DC to 20 kHz maximum bandwidth and inboard data pre-processing), mixes and transmits them for telemetry and recording.

Like almost all systems in A380, electrical generation and distribution system is new, and certification process for that particular system requires measurements that have never been recorded in flight. In order to meet these requirements, it is necessary to improve analog bandwidth in a very important way.

It is therefore necessary to study how these peculiar needs can match up to flight test architecture, by keeping in mind that global performance must not be altered and without resizing the main flight test architecture.

2. Objectives

2.1 Background

With A380 development program, a technological step has been performed in airborne electrical network :

- Much more equipment include electronics in their power stage. Even consumers that usually were free of it at this level, such as electrical motors for pumps or fans, added electronics in order to enhance their performance. Driving a motor electronically is smarter, more efficient and powerful. But the equipment behaviour on the electrical network will also become non-linear.

- AC network frequency is now variable between 360 and 800 Hz. Some equipments added electronics directly connected to power buses in order to accept that.

- Power needs for commercial loads significantly increased. Electrical power to be provided per passenger strongly increased compared to existing aircrafts.

These different reasons explain why new requirements had been added in Airbus Directives for electrical generating systems and supplied equipments ABD0100.1.8 Issue D [1]. Major modifications consisted in specifying limits on Total Harmonic Distortion Voltage (THDV) and on current harmonics induced by equipments connected to the electrical network. These features must be checked in a frequency range from the fundamental frequency up to 150 kHz.

2.2 Needs

Certification campaign demands therefore to validate the complete respect of this directive directly on test aircraft : voltage and current measurements must be recorded with an 150 kHz bandwidth, and THDV must also be processed in real time, taking an 150 kHz bandwidth signal into account.

Around 55 different channels need to be recorded with a 10% maximum attenuation at 150 kHz. Then data will be digitally processed on ground to perform harmonic analysis.

Another need for electrical measurement is to record around 30 voltages and currents with a 3dB attenuation at 10 kHz. Data will be used in this case to visualize electrical transients on power buses, for example when a bus switches from a generator to one other.

A quick overview of both needs can easily provide an estimation of storage capacity required for these data : 55 channels recorded during 8 hours with a 450 kHz sample frequency (minimum Fs to obtain the attenuation needed)

and coded on 16 bits demand a storage capacity around 1200 GBytes.
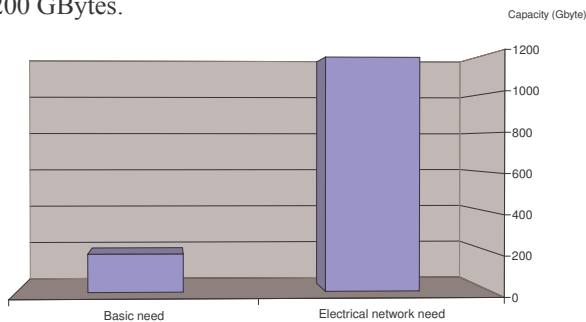

Figure 1 : Storage capacity needs

Compared to storage capacity need for common core flight test installation for a flight, which is around 200 Gbytes, we can clearly detect that electrical network measurements on A380 are a very specific request.

3. Implementation

3.1 Strategy

This previous comparison shows that a specialized process has to be put in place in order to solve storage needs for electrical network measurements. The other problem linked to the first one is that it will necessitate hours and hours to use such a huge amount of data. It will require localizing and extracting interesting time zones in order to process them with an harmonic analysis.

The best way to prevent these two problems can be found by selecting data to store instead of recording everything and extract after flight useful data. It is this global principle that has been chosen for electrical network measurements.

Main strategy consists in using data collected by common core installation, and processing them to detect particular events on the plane and specifically on the aircraft electrical network.
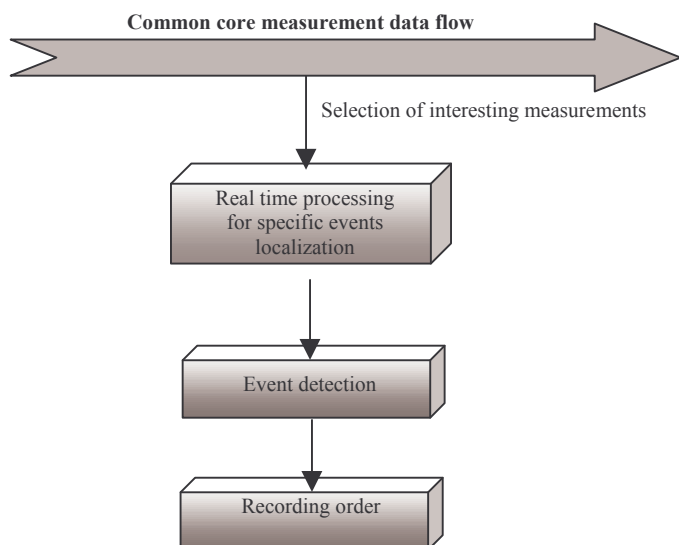

Figure 2 : Time zone selection

Data extracted from common core measurements are globally defined, but can be changed from one test to another depending on flight test phases. They are mainly information coming from :

- discrete states (bus bar configuration, equipments starting …)

- analog values (RMS voltages, RMS currents, frequencies, actuator positions, THDV…)

- digital buses (specific orders to equipments)

All these data must be analysed in real time, as we need to know quickly if time zone has to be stored or not. But nothing can be instantaneous, neither processing nor transmitting orders. Acquisition and storage tool for electrical network measurements must include ability to keep data for a few instants. By this way, requirement on latency time due to processing and transmitting chain is not very restricting, and all useful data can be stored without any chance to lose part of it.

3.2 Flight test architecture

Airbus flight test installation for A380 is called IENA architecture. It is based around a switched Ethernet Local Area Network. It uses IP Multicast protocol for data transfer.

This network has special features due to embedded requirements, such as static multicast configuration, dynamic protocol de-activation, IP address pin programming, network redundancy and special physical links.

The architecture is divided into four different levels of data handling :

- Level 1 is sensors level, where a physical input (pressure, temperature, acceleration, stress...) is converted into a measurable electrical value

- Level 2 consists in acquisition from analog, digital or discrete data. Analog filtering, data sampling and analog to digital conversion are performed.

- Level 3 deals with data concentration, commutation, and duplication. It dispatches data from level 2 systems to level 4 equipments without modification

- Level 4 is a recording and analysis level, with mass data storage, on board analysis, displays and telemetry.
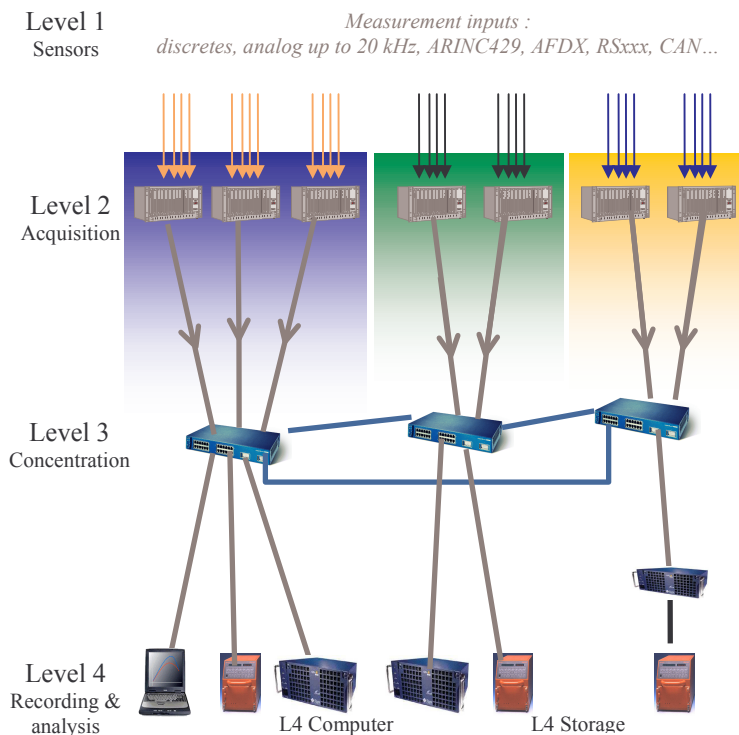
Figure 3 : Airbus IENA flight test installation

Level 1
Sensors

Measurement inputs :
discretes, analog up to 20 kHz, ARINC429, AFDX, RSxxx, CAN...

Level 2
Acquisition

Level 3
Concentration

Level 4
Recording &
analysis

L4 Computer   L4 Storage

With this strategy, we use all the advantages of the common core architecture without slowing nor saturating other data transfers by sending massive data quantities on the network.
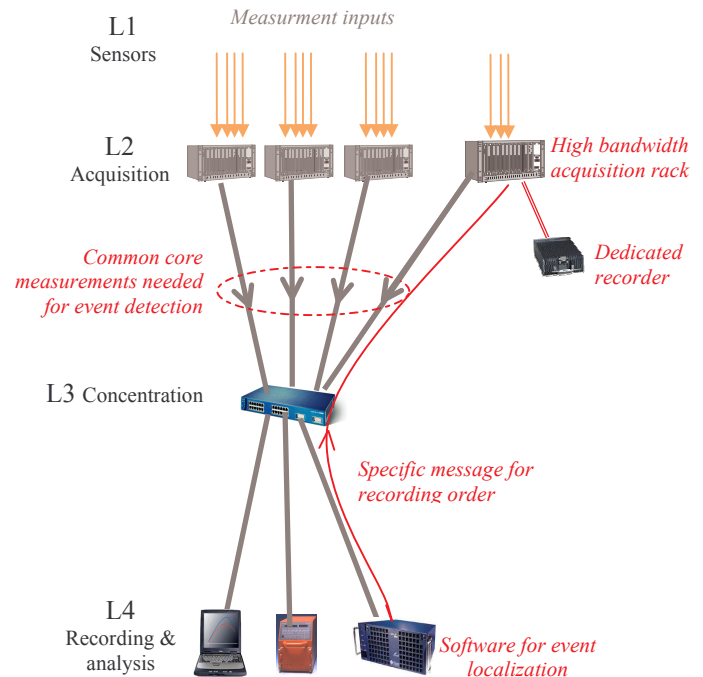

L1
Sensors

Measurment inputs

L2
Acquisition

High bandwidth acquisition rack

Dedicated recorder

Common core measurements needed for event detection

L3 Concentration

Specific message for recording order

L4
Recording &
analysis

Software for event localization

Figure 4 : System integration in existing IENA installation

3.3 Integration in existing architecture

The wide bandwidth data acquisition system is also part of this flight test architecture. This architecture has indeed been designed in the way that any kind of acquisition system can be added or removed easily, and without any modification for other systems.

As shown before, the main functions for our system is to acquire, i.e. filter and digitally convert, measurements coming from various sensors, and to store it. Acquisition part is considered as one of the systems constituting Level 2.

But data flows and quantity for this particular need are too important to be routed on the common Ethernet flight test architecture. A specific data recorder is dedicated to this acquisition system. Because of this point, it can also be considered as a part of Level 4.

But integrating fully this system in the Airbus IENA flight test installation has one major advantage : a real-time loop for event detection can easily be made.

Event detection needs to collect and to process data coming from various Level 2 systems. All these data are available in Level 4, thanks to Level 3 data concentration.

An application for event detection is implemented in one of the On-Board Computers from Level 4.

By this way, it can send an Ethernet message to the wide bandwidth acquisition system on Level 2 to inform it that recording must be made.

4. Specific developments

Building an integrated solution for high bandwidth data acquisition can be done by re-using existing systems, but needs also to develop new equipments, when specific needs can not directly be matched.

4.1 Acquisition racks

Specific acquisition racks has been designed for high bandwidth needs.

Acquisition cards are based on a Sigma-Delta Analog/Digital Converter. With this technology, a 400kHz frequency sample is only needed in order to meet the 10% maximum attenuation at 150 kHz. A "slow" analog filter for anti-aliasing is also implemented on each channel. Cards are based on VME technology, and are synchronised each other's.

The core system works on a PCI platform powered by a 1GHz Pentium and 1Gbytes RAM, on Red Hat operating system. Its goal is not only to dialog with external systems, but also to store temporarily acquired data in a ring buffer. If a recording order arrives from the network,

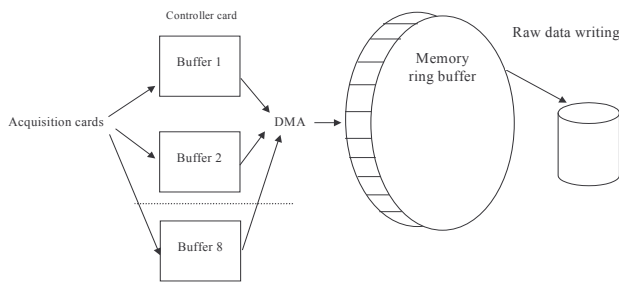a pre-trigger buffer of 1 second maximum can be recorded, followed by a user-defined post-trigger buffer.

Figure 5 : Acquisition principle

Each rack contains 4 acquisition cards, with 8 channels on each : 32 channels can be acquired on one rack. For A380 electrical generation measurements, two racks are used. The two racks are linked together in a master / slave organisation, so that it appears as an unique 64 channels acquisition system from outside (one Ethernet link and one storage device link).

Racks also contain batteries and a power keeping management, because data must be recorded even during electrical transients (and electrical transients can occur on power buses that supply acquisition racks !).

Figure 6 : High bandwidth analog acquisition rack

The last function, but not the least, provided by these racks is to perform a real-time THDV calculation. Thanks to processor performance and source code optimisation, 8 channels on each rack can be processed simultaneously.

These data are sent via the Ethernet link on the common core flight test installation, in order to be stored on global recorders and to participate in event detection.

4.2 Period by period THDV calculation

This information is mandatory to detect every interesting time zones, especially if harmonic analysis is needed. This information is Total Harmonic Distortion Voltage (THDV), which can be seen as a good indicator of network pollution.

THDV is the ratio between quadratic sum of each harmonic amplitude and the fundamental amplitude :

$$ TDH = 100 \times \frac{\sqrt{\sum_{k=1}^{\infty} H_k^{\,2}}}{H_0} \qquad [1]$$

The main difficulty is not the calculation by itself, but the fact that a THDV value for each period of fundamental frequency must be obtained. It is indeed necessary as power consumers can make very quick variations and pollution on voltage.

No averaging can be done on this calculation, for example by using several signal periods. THDV values are an important part of the event detection, and must vary very fast.
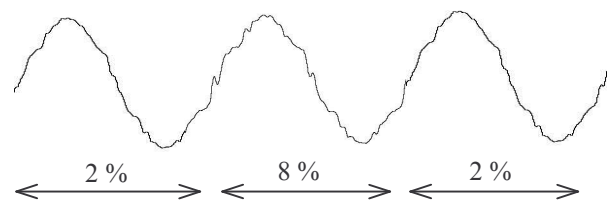

Figure 7 : Quick THD variations simulation

Since electrical network voltage has a variable frequency and since this frequency can be different from one voltage to another, a period detection has to be done for each channel. THDV data are individually dated with the period last sample date, in order to identify clearly to which period is linked a THDV value.

High bandwidth analog acquisition racks compute their eight THDV calculations independently each other's. A reflective memory is shared between the two racks, via a fibber optical link. By this way, 16 THDV calculation results are available at the same time in this memory. Master send then all THDV data of one memory buffer on the Ethernet network to Level 3 and 4, so that On-Board Computer could process it with all other interesting measurements for event detection.

4.3 Event detection software

Many On-Board Calculators are used in the Airbus IENA flight test installation, and specific software, implemented in one of these, has been elaborated in order to treat interesting data coming from various L2 acquisition systems.

This software is fully programmable by electrical specialists, who can before each test flight change the triggering conditions.

It is based on logical equations between several conditions. Each condition is a rising or falling edge and

is executed on a maximum and on a minimum threshold for every interesting parameters.

A real-time task checks cyclically all the defined conditions and send a specific message on the Ethernet link. This message is addressed to the acquisition racks and contains also information about triggering condition and about aircraft electrical configuration.

A problem on a sensor or on an acquisition system could involve a wrong value, and then could generate useless triggers. In order to prevent that, the software inhibits itself any parameter that create a lot of triggers in a too quick period.

4.4 Recorder

A ruggedised hard disk drive is used for this function. It is installed on a cartridge that can be quickly inserted or extracted from its rack.

It is connected to the acquisition racks by a Fiber Channel link at 40 Mbytes per second.
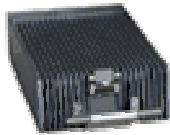

Figure 8 : Removable Hard Disk Drive

5. Conclusion

Airbus flight test installation is historically designed and built to acquire and record data continuously during flights. The new flight test installation created for A380 and future aircrafts is also based on this concept. But its flexibility and its opened architecture enable to integrate without modification a triggered system.

Embedded analog acquisitions were limited to a 20 kHz bandwidth, not because of technology limitation, but because of storage capacity and processing time restrictions. Now, with this new recording approach, analog acquisition bandwidth can be greatly improved.

This system will be used for A380 electrical generation certification, but will certainly be needed for other applications in the next future for high bandwidth airborne analog acquisitions. The challenge will be therefore to design and to adjust smart triggering software for new applications, in order to optimize recorded data size.

6. Acknowledgement

7. References

[1]   JP. Chaussonnet, T. Garcia, C. Montret, S. Tregine-Regent: "*Electrical and Installation Requirements*", ABD0100.1.8 Issue D, AIRBUS, 2002.

8. Glossary

IENA: Installation d'Essais Nouveaux Avions (New Aircrafts Test Installation)

PCI: Peripheral Component Interconnect

RMS: Root Mean Square

THDV: Total Harmonic Distortion Voltage

VME: Versa Module Europa