APPLYING RULES FOR ISOCHRONOUS SAMPLING WITHIN ACQUISITION CYCLES TO ALL LEVELS OF FTI SYSTEM DEFINITION

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ABSTRACT

This paper examines two rules for data acquisition that have advantages for today's Flight Test Instrumentation (FTI) systems where:

- Data is acquired from physically separate test equipment
- Deterministic (IRIG-106 (Ch. 4)) and non-deterministic networks co-exist
- Data Acquisition Units (DAUs) from multiple vendors are required
- Signal lists and sampling rates change rapidly
- A time-coherent sampling strategy (even for smart sensors) is required

These rules may aid not only in the selection of the data acquisition equipment but also the definition of the sampling, transmission, storage and analysis strategies.

KEY WORDS

Isochronous, acquisition-cycle, time-tagging, packet-definition, IRIG-G251, smart sensors.

INTRODUCTION

There are many questions asked of FTI vendors today:

Can you supply a 1553, CAIS, NexGenBus, smart sensor controller? ✓
Have you a plan for FC, Firewire, FDDI, 1Gb Ethernet, 1553++, Loadnet? ✓
Have you thought about non-deterministic networks? ✓
Can you send packets of data to a certain Solid State Recorder (SSR)? ✓
Can you guarantee simultaneous sampling? ✓
Have you thought about packet structures and how they may be handled? ✓
Can I change my mind later about any of the above? ✓

Many FTI vendors are content to tick these boxes; and explain later the coherency issues and the problems of stale, skipped and lost packets. This paper argues that there exist some core axioms about which an FTI system must be designed. Obeying these axioms supplies a rigorous solution to these challenges rather than simply ticks in boxes.

This paper outlines some of these rules and illustrates some of the problems these rules solve.

THE GENERIC PROBLEM

Data is gathered from many sources:

- Analog to digital converters (strain, accel., video, synchros, and so on)
- Bus controllers (smart sensors, 1553, 429, CAIS and so on)
- Bus monitors (too many to mention)

Subsets of this data are being sent to many sinks

- A few to a cockpit display (VGA, 1553, 429 and so on)
- A few to a telemetry link (perhaps in packets and hence to a network)
- A lot to a recorder (e.g. SSR via FC-AE or 1Gb Ethernet or whatever)

How do we correlate, with respect to time, the data from the various sources? Furthermore how do we present the data to the various sinks in well-defined, succinct packets across networks with limited determinism?

Next, this paper takes an informal look at some old rules by which FTI programs were defined. This is followed by some new rules and a discussion of how some of the challenges outlined above are met.

THE OLD RULES FOR SOLVING THESE PROBLEMS

I) TAG EVERYTHING - With time, stale, skipped and empty (at least)!

How else can data from the controller gathering data via MIL-STD-1553 be correlated with respect to the data gathered from the smart sensor belt and the myriad A/Ds about the system?

II) AVOID COMMERCIAL BUSSES - There be dragons!

There was a time when MIL-STD-1553 was a better choice than Ethernet, mainly because the latter did not exist, but even when it did, it was not much faster and had "determinism issues". With 1Gb Ethernet is this still the case?

There was a time when we could only dream of "Decomless" telemetry. Again mainly because the commercial world was not sending large packets of data via telephony in real-time? Is this still the case?

III) FORCE "SIMULTANEOUS SAMPLING MODES" - Whatever that is?

In those cases where parameters must be sampled "simultaneously" the FTI vendor must jump through some ill-defined hoops and support a "broadcast" sample command. We won't talk about what that means for parameters at different sampling rates or why we just don't do this for all parameters.

IV) DEFINE DATA PACKETS IN DETAIL - Don't trust the FTI vendor!
How do we specify that all parameters be sent to the recorder and which subset to send to the telemetry link? One problem with old FTI systems is that a small change like adding a new parameter or changing the sampling rate of an existing parameter often meant a big change to the sampling sequence and hence time delays and so on.

THE NEW RULES FOR SOLVING THESE PROBLEMS

I) Define an **acquisition cycle** time during which all parameters everywhere that are **potentially** of interest are sampled at least once.

II) Insist that all parameters everywhere be sampled at the start of the acquisition cycle and at even time-intervals thereafter.

These rules are deceptively tricky to understand and implement but are equally deceptively powerful once implemented completely. They describe an isochronous sampling system (Iso = same, chrono = time).

This goes beyond the mere synchronicity of a PCM stream or the type of "simultaneous sampling" boasted of by certain command-response busses. Before looking at the design elements of such a system let's first look at some situations where these rules may provide clarity.

COMMERCIAL NETWORKS – BEYOND MIL-STD-1553

Many ground stations today use networks to share telemetry data among multiple ground stations. As these networks get faster and the chip-sets associated with them get smaller it seems the next step may be to think of the Data Acquisition Systems (DAUs) from which the data was originally gathered as network nodes.

There are a few commercial busses under consideration by the avionics community: FDDI, Firewire, ATM, 1Gb Ethernet, and FC-AE to name but a few. It is also worth mentioning that considerable effort is being spent on faster, "enhanced", usually optic-fiber versions of MIL-STD-1553.

Deciding between the various options is not trivial. There are financial, mechanical and packet delivery time trade-offs. Once a network is chosen the learning curve is just beginning; for example:

- Fiber-channel (FC) is a commercial network standard
  - They want a very fast SCSI bus.
- FC-AE is an Avionics Environment group within FC
  - They want a very fast avionics bus (MIL-STD-1553+)
- NexGenBus is yet another group with an FTI focus
  - They want a very fast CAIS type bus

This paper does not advocate one bus over another. All the busses discussed above can operate comfortably in an environment of isochronous DAUs. In particular, it may be that in environments where more than one network is used then the DAUs *must* be isochronous.

This paper argues that, whatever network or flavor of network is chosen, if each DAU node is isochronous then at least the data collection or sampling is completely deterministic - even if the transfer of that data is not. Now the problem of determinism is purely on the receiver (ground station) side.

Figure 1 shows multiple DAUs operating isochronously (the mechanics of this are discussed later). Each is gathering data packets during each acquisition cycle. The network however transfers these packets in a way that first might appear as anathema to an FTI engineer - the DAUs can be read out of sequence and at varying intervals of time.

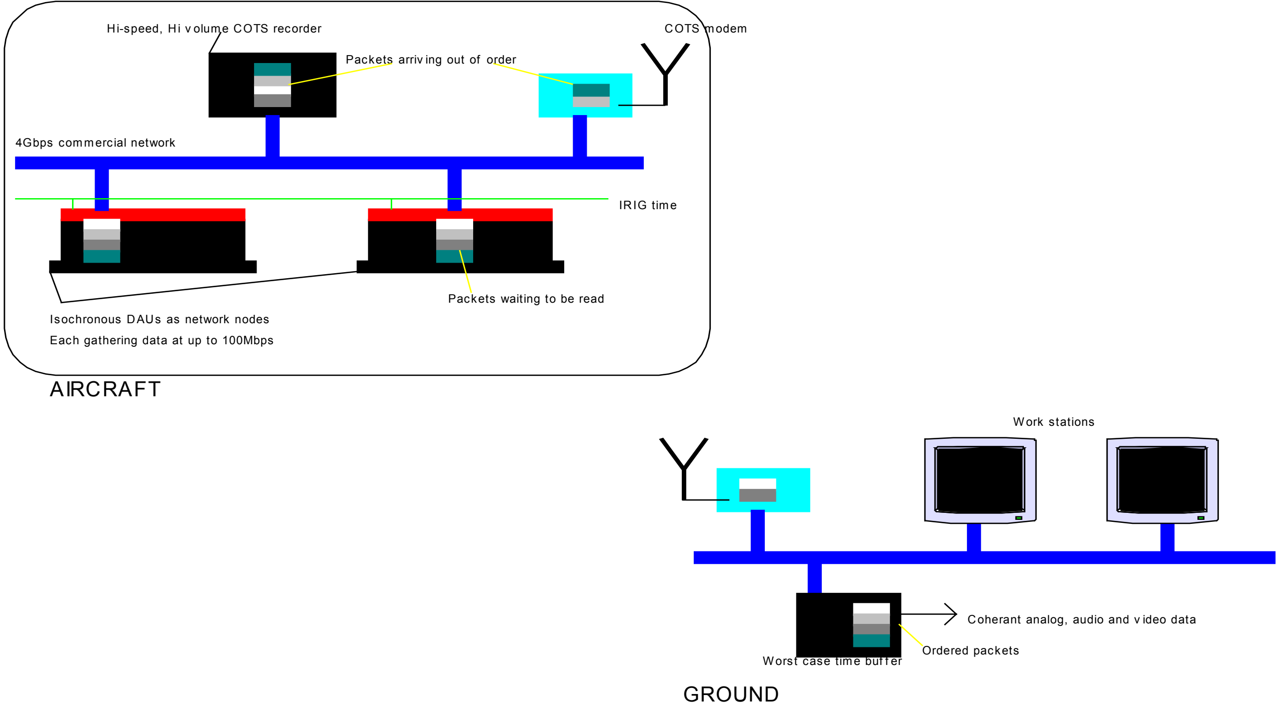

Figure 1 - Commercial networks – Beyond MIL-STD-1553

All is not lost! Remember all the data is sampled isochronously within, for example, ±100ns. The large (super-set) packets going to the recorder can be sorted in time later. Also it may be that the even though the order in which the smaller (sub-set) packets are transmitted to the ground may change, the worst-case delay may be within some acceptable window, for example 300ms. In this case the design task on the ground becomes one of building a 300ms buffer on the ground - if a packet is received within 10ms; delay it by 290ms. For this to work each packet must have a time tag - axiomatic for an isochronous DAU network.

PACKET DEFINITION

It may not be obvious that isochronous systems have advantages with respect to packet definition. In particular once the two core axioms of isochronous operation are understood then significantly less communication is required when discussing topics such as:

- Sub-packets
  For example, a parameter sampled at 20kHz to an on-board recorder is also sent at a much slower rate to the ground and at an even slower rate to a cockpit meter. Which samples are sent where?
  Another request often made is - only send "interesting data" - if data is reduced, the structure of the new packet must be defined (or must it?).
- Time tagging
  Wouldn't it be great if one time tag tagged all parameters?
- Packet structure
  What information is needed in a packet?

Below there are two packets of data acquired during one acquisition cycle. One packet is going to a solid-state recorder and another, smaller one, is going somewhere else. The first element in each file is the packet identifier, the second is the packet's time tag. Each row after that contains samples of a particular signal.

```
P1234
2002 03 27 23 59 5999 9999
0001    0002    0003    0004    0005    0006    0007    0008    0009    000A
1001    1002
2001    2002    2003    2004    2005    2006
3001    3002    3003    3004    3005
4001    4002    4003    4000    4005
```

First (super-set) packet

```
P1234
2002 03 27 23 59 5999 9999
0001    0006
1001    1002
2001    2004
3001    3002    3003    3004    3005
4001
```

Second (sub-set) packet

In an isochronous acquisition system there is a lot of information in these packets.

The **packet identifier** points to a header packet that need only be sent occasionally. This packet contains information on the acquisition cycle time and signal names, ranges, units, delays and so on for each row.

The **time tag** (Tc0) is the precise time that all the samples in the first column of the packet were sampled. If the acquisition cycle length is Ta and there are only two samples in a row then the second sample was taken at exactly Tc0 + Ta/2 and so on.

Some observations:
a) It may be worth considering having the packet identifier and time-tag incorporated into any file name associated with the packet, as it would make sorting easier.

b) One time tag tags everything - while this greatly reduces the tag information that must be transmitted it also means that even if the sampling rate changes or extra signals are added the engineers analyzing the data need not care.

c) Defining data reduction subsets becomes axiomatic. Each set must contain the first sample and all samples must be evenly spaced in time. For example see the third row of each packet.

d) In the first packet the parameter in row 5 is sampled at 50Hz and row 6 at 60Hz. Time correlation of these signals is straightforward. Remember the first sample of each row was taken at the same time.

e) In the first packet the parameter in row 7 is also sampled at 60Hz, that means every sample in row 6 was taken at precisely the same time, as those in row 7.

BUS CONTROLLERS

FTI equipment is often the glue between high-speed busses used to transport all FTI data and slower sub-system busses such as MIL-STD-1553,
ARINC-429, CAIS, smart sensor arrays or legacy 10-wire interfaces.

These sub-systems are typically command-response type architectures not designed for isochronous operation. However they can be adapted to co-exist in such an environment with immediate advantages with respect to time-tagging and coherency.

Figure 2 shows multiple bus controllers gathering data about their respective busses. For completeness data from an analog channel is being sampled along with data from an external analog multiplexer or scanner.

The analog signal is sampled at the start of the acquisition cycle and at equal intervals of time thereafter. The first sample is stored in address X of a current value table (CVT) the second in address Y and so on. So far so good - this would be expected from an isochronous channel. However in real life systems there must be an anti-aliasing filter and all filters have delays. So even though the A/D sampled the signal at the start of the acquisition cycle there is a fixed delay that must be noted.

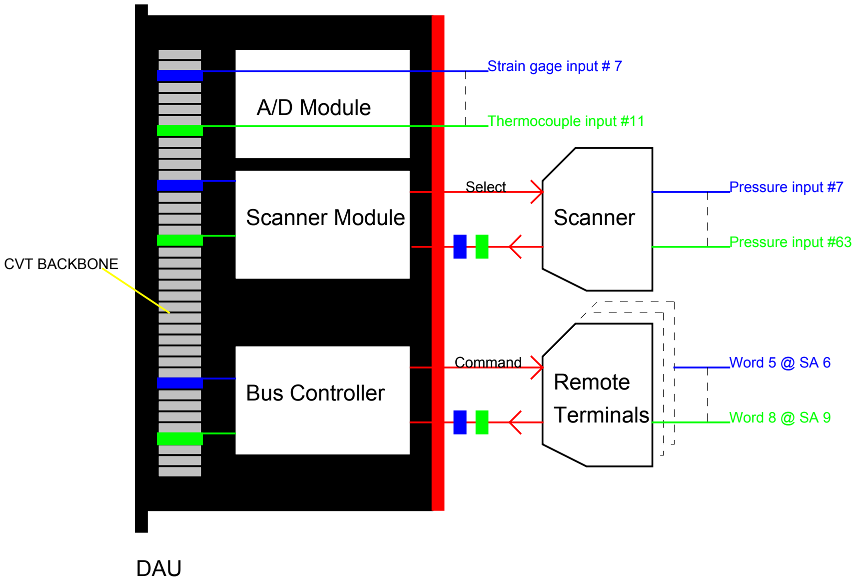

Figure 2 - Different modules in an isochronous environment

The external multiplexer at first seems to violate the rule of sampling all parameters at the same time - this cannot be done with a multiplexer. However think of each channel of the multiplexer as being sampled after a fixed delay. Design the multiplexer controller to step through a sequence of channels at the start of the acquisition cycle and at equal intervals of time thereafter. The first sample from channel 1 is stored in CVT address A, the second sample from channel 1 in B and so on.

This concept (delays + sequences + equal sample intervals) is then extended to the case of the bus controllers. At the start of the acquisition cycle the MIL-STD-1553 controller requests data from a given remote terminal and sub-address and each data word is stored in a specific address in a CVT.

All this data from a myriad of analog channels and busses is stored coherently in a CVT, a snap-shot of which at the end of the acquisition cycle forms a super-set of all the data packets for that DAU. Even if the sampling sequence changes radically on one module, the other modules do not change, providing the acquisition cycle has remained the same.

With multiple data banks these packets can be stored for as long as it takes the network(s) to read the packets.

Furthermore, all these acquisition modules need not be in the same DAU providing all the DAUs are operating isochronously. It is very important to note that only the bus controllers were affected by the move to isochronicity - none of the remote terminals had to be redesigned. One hidden advantage of isochronous systems is that if they work once, they work always because everything that happens, happens always.

The next section discusses some of the design implications in designing an isochronous distributed data acquisition system.

MAKING DAUS ISOCHRONOUS

At first glance it may appear that a simple broadcast at the start of an acquisition cycle to all DAUs is all that is required to make multiple DAUs operate isochronously. However even with 3ppm oscillators this would require a broadcast every 30ms to guarantee jitter of less than ±100ns. This may be an excessive overhead on many networks. By the way, 100ns jitter is not an unreasonable tolerance for oversampling digital filtering systems.

So an indication of the start of an acquisition cycle, and a regular metronome beat would be ideal. Also it may be desirable to have different sampling strategies or modes or formats. For example CAIS has program, verify and acquisition modes. Also, it may not be possible to always sample everything that might possibly be of interest in every stage of the flight - for this reason IRIG-106 Ch.4 supports format switching.

One solution to all three problems has been around the FTI world for decades. IRIG time can be connected to all DAUs with control function bits indicating the end/start of an acquisition cycle and the format to use during the next acquisition cycle.

The downside of this solution is, at worst, an additional single twisted pair looped to each DAU. The advantage however is that all DAUs are now gathering data coherently even across multiple airframes.

Remember that it is only bus controllers that are affected - not remote terminals. Also it is only network sources that are affected - not the sinks. In other words, the DAUs are affected - not the recorders. For example, a COTS SSR that supports an acceptable flavor of FC-AE (for example) need not be modified to gather data from multiple DAUs. However, each DAU must have enough buffer space to handle any lack of determinism in the network.

The final section looks at the various decisions that must be made in choosing an acquisition cycle length.

SOME THOUGHTS ON THE ACQUISITION CYCLE

Imagine an FTI system with multiple PCM streams, some CAIS equipment and a MIL-STD-1553 controller talking to a cockpit display.

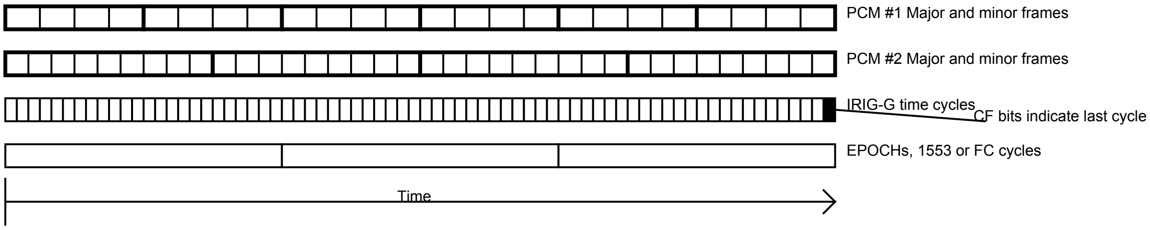

Figure 3 - An acquisition cycle and various sub-cycles

PCM streams are often defined using power-of-two rules such as 512 words per minor-frame, 128 minor-frames per major-frame and 8 major-frames per second.

Fifty cycles per second are often found in MIL-STD-1553 busses. With these two criteria alone, 500ms may be the optimum choice for acquisition cycle (500ms = 4 major-frames and 25 MIL-STD-1553 cycles). By the way, some smart sensor systems talk of EPOCHs - another word for acquisition cycle - that may also have to be factored into the choice of acquisition cycle length.

If 500ms is chosen then IRIG-G time (10ms/cycle) would be a better choice than IRIG-B (1s/cycle).

If the data packets are too big then the delay in gathering the data might be unacceptable (for example audio to ground). Also with a large file losing a small proportion of the file means losing a lot. Finally larger acquisition cycles mean that the recovery time from a power brown-out is longer.

On the other hand if the packets are too small then the protocol overheads (e.g. packet headers or file names) may be excessive, also sampling rates may be pushed too high.

CONCLUSION

Forcing various elements of an FTI system to operate isochronously with respect to IRIG time requires some investment from each vendor, some training of program groups and may require a twisted pair to the controller of whatever network or bus is used to gather data.

However, when adhered to, these simple rules provide many advantages with respect to interoperability, network independence, future-proofing and packetization.

REFERENCES

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