DOI 10.5162/ettc2022/1.3

Modern High Speed FTI Recorders and Switches Requirements and Use Cases

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Abstract: As Flight Test instrumentation (FTI) architectures increasingly migrate to airborne "network" systems – comprised of distributed sub-systems of data acquisition, processing, and recorders – the role of network switches that form the network switch fabric become critical. Likewise, the FTI recorders – whether a single large or multiple distributed data sinks – is also increasingly critical as it relates to the data formats suitable for ground processing, given the number and types of data sources. This paper discusses the factors influencing the switch and recorder units, for a Distributed FTI (DFTI) System.

Keywords: DFTI, IEEE-1588, IEEE-1394, 10GBASE-SR, PTP, QoS, TmNS, PCAP, DAR, IRIG, iNET, UDP

1. Introduction

The FTI architectures are rapidly evolving to airborne "networks" comprised of various network elements, i.e., Data Acquisition Units (DAUs), switches, recorders, gateways, and network manager sub-systems/units. The previous CAIS-based architectures, using aggregators for PCM outputs from multiple DAUs are now transitioning to DAUs that are part of the network and multi-cast acquired data to the network. The network DAUs include traditional measurands, e.g., accelerations, temperatures, pressures, and, also increasingly, avionics bus traffic, e.g., MIL-STD-1553, IEEE-1394, 10GBASE-SR, and ARINC-818. The network traffic also include data from cameras, whether high-definition or high-speed, that are delivered as Internet Protocol (IP) messages. The amount of data collected, especially for new airborne platforms, has increased significantly, with the bus traffic far outstripping the data from traditional measurands. The new type of network DAUs allow multi-cast of different data sets, i.e., all collected data aka "bulk" data and selected messages/data aka "Cherry-Pick" data.

The collected data and data rates are far more than the available RF bandwidth for real-time Telemetry (TM), thus necessitating the use of airborne recorders for storing the collected data and, as applicable, providing a subset of safety and time-critical data for TM. In the near-term, the need for Data-Retrieval-on-Demand (DRoD), driven by ground station commands using bi-directional RF links, will require recorders that not only record the collected data, but provide selected data sets (DRoD) for TM.

In an networked architecture, the TM data can be generated as PCM (clock/data) for a RF transmitter, by either a centralized recorder or a Gateway unit that filters all selected messages/data from the various network sub-systems and creates a single PCM for the entire network.

The FTI architectures, even for the network systems, can vary depending on the platform, mission requirements, and the system integrator preferences. Alternatives include using multiple recorders that provide redundancy and a means to distribute the network units across the entire platform, instead of dedicating/sacrificing a single large section of the platform for a centralized recorder.

The dichotomy in the FTI architectures can even extend to the entire FTI system, above and beyond the decision on the recorder type. Does the platform support the Size, Weight, and Power (SWAP) – including thermal management – for centralizing the entire FTI systems of DAUs, switches, recorders, and gateways; or does an alternative method of distributing the various FTI sub-systems throughout the platform, often closest to the measurands and their DAUs, provide better benefits and fully leverage the "network".

In either scenarios, the FTI network requires some key elements for it to be fully functional. These include time synchronization throughout the network with one network sub-system/unit providing the master reference; system wide programming and control e.g., through Simple Network Management Protocol (SNMP); multi-casting of bulk and selected message/data; data aggregation and port mirroring to multiple data sinks (recorders and gateways); and source data type agnostic network paths. As the FTI networks grow larger with potential for latencies, especially for safety and time-critical traffic, the network should provide capabilities to establish a

Quality-of-Service (QoS) for critical data. In the long-term, the FTI networks may evolve to include Time-Sensitive-Network (TSN) capabilities for these types of traffic.

The network recorders should be capable of receiving data from multiple sources with different message types, e.g., from DAUs or from platform sensor-suites, and be capable of recording them in formats that are suitable for ground processing. Depending on the data source, some formats may be better suited for some message types, e.g., PCAP for sensor-suite IP traffic and IRIG Chapter 10 for other traffic types.

The FTI network considerations drive the requirements and use cases for the switches and recorders. This paper discusses these factors and their impact on the switches and recorders, through a few use cases.

2. Generalized FTI Network

A generalized FTI network is shown in Figure 1. The network includes DAUs that acquire analog sensor data, e.g., acceleration; switches (5-port, 12-port, and 16-port); recorder (nREC-7000); recorder control panel (RCP); gateway (nGWY-2000); and transmitter.

The 16-port switch (NSW-16GT-1), henceforth NSW-16 acts as the master reference in this network, with its timing referenced to GPS signal that it supports. The entire network uses IEE-1588-2008 (v2) for time synchronization, with other switches, e g., 5-port switch (NSW-5GT-1, henceforth NSW-5) and 12-port switch (NSW-12GT-1, henceforth NSW-12) providing either Boundary Clock (BC) or Transparent Clock (TC) modes of operation.

The DAUs acquire analog data and bus data and multi-cast them on the 100Base-T, GbE, or higher data rate ports. The analog data in each acquisition stack may be formatted as PCM and the PCM frames are packetized and multi-cast as TmNS (IRIG Chap. 21 – 26), IRIG Chapter 10/11, or as DARv3 (Curtiss-Wright proprietary format) that is widely used in the FTI industry. Some protocols, e.g., TmNS and DARv3 are better suited for networking, with Chapter 10/11 becoming more prevalent for some system integrators. The DAUs can also select specific messages and/or data, especially from acquired bus traffic, and multi-cast it for devices, e.g., network gateway (nGWY-2000, henceforth nGWY) to convert to PCM for real-time TM. The DAUs may also multi-cast their status, metrics and, in the future, may support QoS for time-critical data.

Other data sources, e.g., cameras are also part of the FTI network and will also multi-cast IP traffic. The cameras may capture high definition display data or high-speed event data for on board recording, and possible TM of camera pre-view data.

Other data sources may include the platform sensor-suites that are rapidly advancing in dates from less than 1 Gbps to 10Gbps, and in the future to 100Gbps. The capture and processing of these high data rate sources will require improvements to the current FTI capabilities.

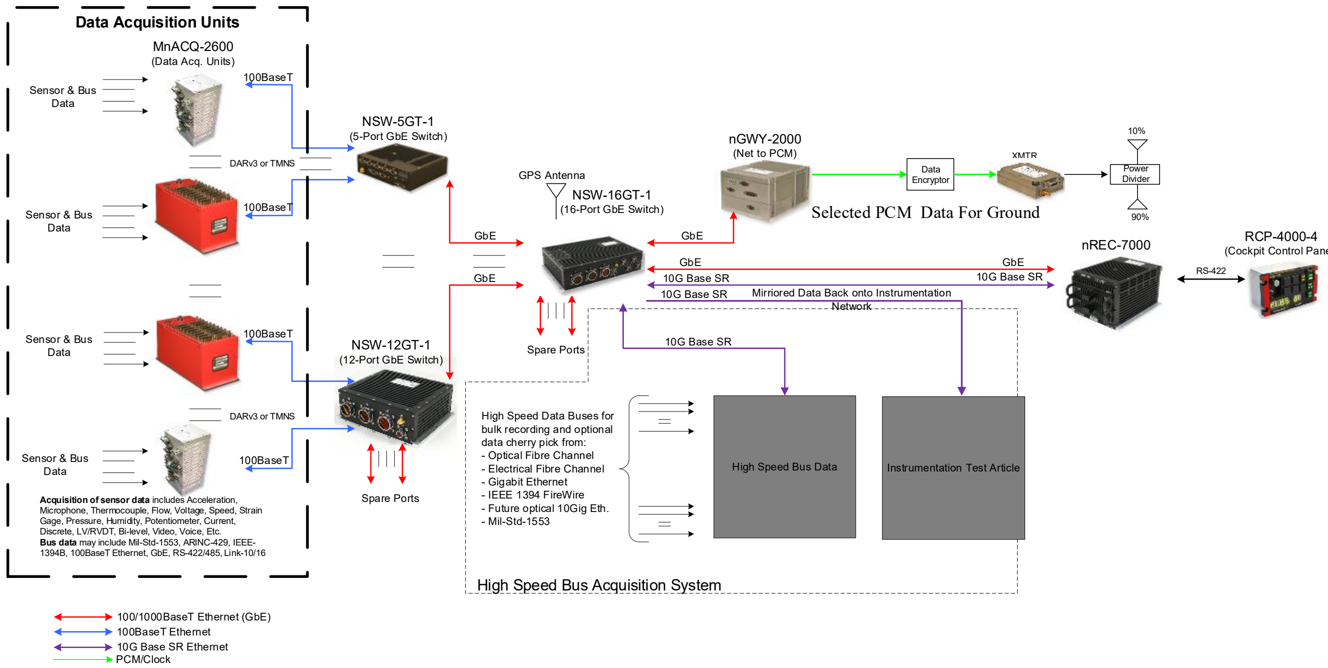

Figure 1: Generalized FTI Network

The onboard recorder (nREC-7000, henceforth nREC) represents one of the of the data sinks of the network. The nREC may be used to record the entire FTI network data including all bulk and selected message/data and the status and metrics of all the network sub-systems/units. Thus, the nREC should be capable of supporting multiple message types from the different data sources and record them in formats suitable for ground processing. The time stamping of the recorded data varies by the specified standard with some formats supporting the 64-bit resolution while others revert to 48-bit resolution. Some message traffic types, e.g., from sensor-suite may be better suited for recording as PCAP while other data, especially from DAUs that capture analog data, preferable to be recorded as IRIG Chapter 10. FTI recorders should provide the requisite flexibility in recording formats.

The recorders may additionally provide other capabilities depending on the FTI system architecture. If there is only one centralized recorder with no nGWY, the recorder may need to provide data/message selection and their conversion to PCM. Thus, the recorder, in this instance, functions as a gateway. The recorder may optionally multi-cast selected messages to a nGWY if the gateway is part of the FRI network. In an DFTI architecture, the selected message/data from each data source will be filtered by the nGWY for conversion to PCM. The PCM formats would also depend on the data sources within the FTI system. A FTI system that requires only analog data to be provide as TM, may use the bandwidth efficient IRIG Chapter 4 PCM format. If the FTI system includes traffic from network sources, e.g., video messages for TM, the PCM needs to be formatted as Chapter 7/4.

Other functions that the recorders need to perform include DRoD, thus necessitating design and implementation changes on the file formats and journaling for rapid retrieval of data. The implementation of DRoD, especially with a bi-directional transceiver, e.g., nXCVR-3140 that provides an uplink for ground station commands, will have implications on latency, QoS, and in future, TSN.

The network configuration, programming, and monitoring also pose requirements for the switches and recorders. The network may be configured, programmed, and managed by SNMP. Other methods include vendor specific software, e.g., TTCWare (Curtiss-Wright software) that supports the entire network for a “Total Systems Solution”. In the future, the FTI industry may adopt the IRIG Chapter 23 Meta Data Language (MDL) programming for the network. In a fully networked FTI system, the entire network will be programmed on the ground using Ground CheckOut Panel (GCOP) interface. The network may also be controlled during flight by Recorder Control Panel (RCP) or Cockpit Control Panel (CCP) units, e.g., RCP-5000 that supports GbE.

One of the critical functions in the FTI architecture definition and management is the estimation and management of the network switch fabric traffic loads, and the required aggregation of data from multiple data sources to one or more data sinks. The network switch fabric may be required to provide a layered aggregation of data, e.g., using a NSW-5 to aggregate all the data from DAUs underneath the left wing. Additional switches may aggregate the data from multiple NSW-5 culminating in the NSW-16 that supports four (4) 10Gbps optical inputs/outputs. Any of the switch ports could also support port mirroring, where data received on one port is copied and mirrored back to another port. These features enable network traffic to be directed to a bulk recorder, while the copy is sent to a unit that carries out data/message selection and/or gateway functions.

3. Recorder Centric Flight Test Systems

There is a growing need to provide a compact recorder unit for FTI applications that may only require the need to capture avionics data buses. There are situations where initial flight testing has been completed and the aircraft has moved into production. In these cases, when there is a need to requalify for a new specification or increased capabilities of the aircraft, a compact recorder unit would suffice, and the data can be pulled from the avionics buses located on the aircraft. The optimal solution is a compact recorder that could easily be inserted into the aircraft, and act as a permanent piece of test hardware. This provides the team with limited wiring to deal with, and a low weight addition to the aircraft. The compact recorder would perform similar operations as a full blown DFTI system, except in a much more reduced size and scale.

In terms of inputs, the DFTI system interfacing to specific digital buses, e.g., MIL-STD 1553, IEEE 1394, Fibre Channel, ARINC 429, Serial Buses, Ethernet Buses will typically contain the necessary information on aircraft that has completed the initial flight test qualification.

As in the DFTI system, there is typically a need for telemetry or TM in this application as well for some type of safety of flight, or potentially some type of onboard display. The idea in this system would be the ability to select specific data from the input interfaces, and output this data via a PCM output, that needs to be formatted as Chapter 4 or 7 for telemetry. As well as the need to provide a UDP multicast output, a data format that can be sent over the network via UDP multicast traffic as TmNS (IRIG Chap. 21 – 26), IRIG Chapter 10/11, or as DARv3 (Curtiss-Wright proprietary format) that is widely used in the FTI industry.

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In summary, the needs of every aircraft are different. However, by identifying what buses need to be captured, we can tailor a specific recorder box that be used in these specific applications.

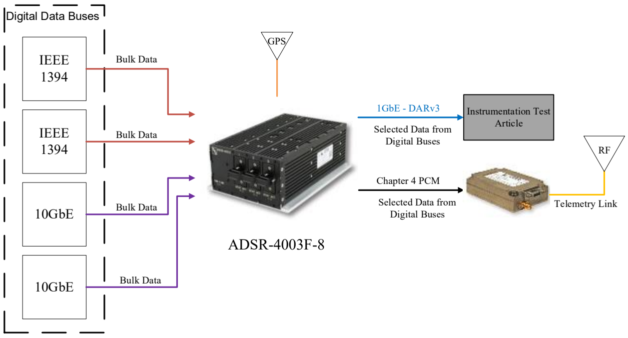

Figure 2: Recorder Centric Flight Test Acquistion System

Figure 2 represents an example of a compact recorder box (ADSR-4003F-8) that is being used to accomplish the above outlined task, of providing a one box solution for a compact recorder box. The unit is interfacing with four different avionic buses – 2-Channels of IEEE 1394, and 2-Channels of 10GbE that are bulk recorded in a Chapter 10/11 format for post processing. In addition, the data from these buses is filtered, and the filtered/selected data is sent to ground via PCM (Chapter 4) output. Moreover, the same stream is sent out over the network as UDP packets to interface with the aircraft devices, e.g., display.

Curtiss-Wright provides several Commercial-Off-The-Shelf (COTS) units, as different ADSR-4003F-x variants for different customer and platform needs. Table 1 below show the currently available ADSR variants

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	ADSR-4003F-1	ADSR-4003F-2	ADSR-4003F-3	ADSR-4003F-5	ADSR-4003F-6P	ADSR-4003F-7	ADSR-4003F-8	ADSR-4003F-10
ADSR Base	1*	1*	1*	1*	1	1	1	1
1 Channel GPS & PCM Output					1	1	1	1
2 Channel IEEE 1394 Card					2		2	
2 Channel 10G Base - SR							1	
4 Channel MIL-STD 1553 Card						2		3
1 Channel HD-SDI Input		4						
1 Channel DVI/ HDMI Input			4					
2 Channel 1GbE Input				1				

Table 1: Supported Interfaces

4. High Speed Camera System

Some DFTI applications have a need to capture images at extremely high rates, e.g., 1000-5000 frames per second. These systems function like the described DFTI network, comprised of the same type of elements: Data Acquisition Units (in this case the cameras themselves), switches, recorders, gateways, and network manager sub-systems/units. As in the DFTI system, the switches (NSW-16GT-1) are responsible for synchronizing to an external time source, such as GPS, and providing 1588 time synchronization to all the high speed cameras (nHSC-36-S1), recorder (nREC-7000), and nMGR-2000. This is to ensure that all cameras can be time coherent when analysing their images in post flight.

The most common application is to capture a separation event from the aircraft. The system is installed as a “distributed, networked architecture”; the customer may install the individual high-speed camera units in a variety of locations throughout the aircraft (in the fuselage, wings, etc). The high-speed camera equipment will be wired to power, network interfaces and control instruments by the customer.

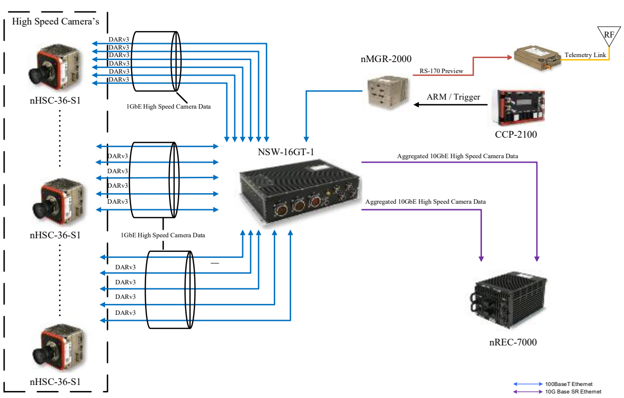

Figure 3: High Speed Camera System

Figure 3 shows a system that uses a manager (nMGR-2000) to configure and control the cameras. The nMGR-2000 sends the capture command when initiated by the control panel via SNMP commands to the High-Speed Camera (nHSC-36-S1’s).

Once the camera captures the images, they will be held in the camera’s internal buffer memory until a transfer request is initiated by the nMGR-2000. This is mainly to manage the traffic on the switches properly. The high-speed cameras will typically be transferring GigaBytes of data, with each camera potentially sending a full buffer of 8GB. One of the issues with the current generation of high-speed network camera systems with large number of cameras (greater than six) is the speed required to transfer the images from the high-speed camera to the recorder. Due to the amount of data being sent, there needs to be a balance between the rate at which the data is being sent, and what is an acceptable time to wait for an entire buffer to be cleared. Typically, the two other factors in this is the pipeline or bandwidth of the Ethernet link, and the media write speed of the recorder.

In our previous systems we would be limited by the 1GbE link of the Switch & Recorder. When accounting for the combination of limits between the media write speed, and the bandwidth limitations of the switch, the maximum amount of camera’s high speed data the user can send to the recorder is limited to 3 at once, per Ethernet port, when the link is limited by 1GbE. This port limitation is both a factor on the switch, and the recorder.

By providing a switch that can support 10GbE such as the NSW-16GT-1, and a recorder such as the nREC-7000 that has the capabilities to link at 10GbE, we eliminate this connection bottle neck. From a bandwidth perspective this would increase the theoretical increase the transfer capabilities high speed camera network to that of 30 camera's per Ethernet link.

The advantage of this allows the 10GbE system to be ready for another set of captures significantly faster than a 1GbE system. The bottleneck could then be put on the recorder's media, which typically was not being hit on a 1GbE network. This development would allow users to theoretically be able to utilize more camera's when imaging events due to the fact that the camera system could be ready significantly faster then what was previously possible in a 1GbE based system.

Due to the way most high speed camera systems are planned out, this capability would typically only require the addition of a 10GbE switch (NSW-16GT), and a 10GbE Recorder (nREC-7000) that has the capabilities of reassembling, and recording the images of the high speed cameras. The user could simply leverage their existing hardware of a 1GbE with the various 1GbE based switches, and simply rely on the NSW-16GT, and the network manager (nMGR-2000) to properly manage the data being sent to the nREC-7000.

7. Conclusions

As discussed, the planning of an FTI system requires a lot of planning to determine the needs of not only the current goals of the system, but potentially the need to provision for increased data rates, or an adaptation of requirements.

By designing our products based on applications with system architecture in mind, we have been able to quickly adapt our recorder and switch products in various ways covered in this paper. It has allowed us to provide existing DFIT systems to quickly integrate with high speed data buses by utilizing our nREC-7000 & NSW-16GT to manage the high speed data buses , provide permeant fit solutions to post flight test aircrafts by leveraging our ADSR-40003 platform with COTS I/O cards, and decrease the down time of the high speed camera system by utilizing the 10GbE pipeline that is provided by the nREC-7000 & NSW-16GbE link.

7. Glossary

DAS: Data acquisition system
EMC: Electromagnetic compatibility
EMI: Electromagnetic interference
FPGA: Field programmable gate array
FTI: Flight test instrumentation
GCOP: Ground Checkout Panel
GPIO: general purpose input output
HD: High definition
IP: Internet Protocol
NTP: network time protocol
PCM: Pulse code modulation
PTP: Precision time protocol
RF: Radio frequency
RTP: real-time protocol
RTSP: real-time streaming protocol