Introduction

Flight test instrumentation (FTI) architectures are increasingly migrating to airborne “network” systems, comprised of distributed sub-systems of data acquisition, processing, and recorders. One result is that the network switches forming the network switch fabric for these architectures become more critical, as do the FTI recorders that must acquire large amounts of data from different data sources in formats suitable for ground processing. This white paper discusses the factors influencing switch and recorder unit design for a distributed FTI system and a single recorder alternative.

Towards Higher Data Rates

FTI architectures are rapidly evolving to airborne “networks” comprised of various network elements, such as, data acquisition units (DAU), switches, recorders, gateways, and network manager sub-systems/units. Previous architectures, such as CAIS-based using aggregators for PCM outputs from multiple DAUs, are now transitioning to DAUs that are part of the network and multicast acquired data to the network. The network DAUs include traditional measurands, such as, 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 includes data from high-definition or high-speed cameras 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 multicast of different data sets, i.e., all collected data (or “bulk” data) and selected messages/data (or “cherry-pick”) data.

The collected data rates needed to transmit all the data far exceed the available RF bandwidth for real-time telemetry (TM). It is thus necessary to use airborne recorders for storing the collected data and, as applicable, only provide 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 record the collected data and provide selected data sets (DRoD) for TM.

In a networked architecture, PCM data can be generated for telemetry via an RF transmitter. This can be done 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.

FTI architectures can vary depending on the platform, mission requirements, and system integrator preferences. Alternatives include using multiple recorders that provide redundancy and distribute the network units across an entire platform instead of dedicating/sacrificing a single large section of a 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 – requirements 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 scenario, 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 the 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 an FTI network grows 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, such as, from DAUs or 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 will further discuss these factors and their impact on the switches and recorders through a few use cases.

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, a recorder, a recorder control panel (RCP), a gateway, and a transmitter.

The 16-port switch acts as the master reference in this network, with its timing referenced to a GPS signal that it supports. The entire network uses IEEE-1588-2008 (v2) for time synchronization, with other switches, e.g., 5-port switch and 12-port switch providing either boundary clock (BC) or transparent clock (TC) modes of operation.
In this example system, the DAUs acquire analog data and bus data and multicast 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 multicast as Telemetry Network standard (TmNS) (IRIG Chap. 21 – 26), IRIG Chapter 10/11, or as DARv3.

Some protocols, such as, 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 multicast it for devices, e.g., network gateway to convert to PCM for real-time TM. The DAUs may also multicast their status, metrics and, in the future, may support QoS for time-critical data.

Other data sources, like cameras, are also part of the FTI network and multicast IP traffic. The cameras may capture high-definition display data or high-speed event data for onboard 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 10 Gbps, and in the future to 100 Gbps. The capture and processing of these high data rate sources will require improvements to the current FTI capabilities.

The onboard recorder could 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 recorder would ideally support 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 a sensor-suite, may be better suited for recording as PCAP, while other data, especially from DAUs that capture analog data, would be better 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 gateway, the recorder may need to provide data/message selection and conversion to PCM. Thus, the recorder, in this instance, functions as a gateway. The recorder may optionally multicast selected messages to a gateway if one is part of the FTI network. In an FTI architecture, the selected message/data from each data source will be filtered by the gateway for conversion to PCM. The PCM formats would also depend on the data sources within the FTI system.

Figure 1: A generalized FTI network
An FTI system that requires only analog data to be telemetered 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 or 4.

Other functions that the recorders need to perform include DDoS, thus necessitating design and implementation changes on the file formats and journaling for rapid data retrieval. Implementing DDoS, especially with a bi-directional transceiver, e.g., Curtiss-Wright’s nXCVR-3140 that provides an uplink for ground station commands, will have implications on latency, QoS, and, in the 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, which may be optimized to support the entire network for an integrated 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 a ground check out panel (GCOP) interface. The network may also be controlled during flight using a recorder control panel (RCP) or a cockpit control panel (CCP).

One of the critical functions in the FTI architecture definition and management is estimating and managing 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 switch to aggregate all the data from DAUs underneath the left-wing. Additional switches may aggregate the data from multiple switches, culminating in a higher bandwidth switch that supports multiple 10 Gbps inputs/outputs. Any switch port 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.

**Recorder Centric Flight Test Systems**

There is a growing need to provide a compact recorder unit for FTI applications that may only need to capture avionics bus data. There are situations where initial flight testing is complete, and the aircraft has moved into production. When there is a need to requalify for a new specification or increased aircraft capabilities, a compact recorder unit is preferable. A compact recorder can more 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 distributed FTI system, except in a much more reduced size and scale.

In terms of inputs, the system can generally gather the necessary information by interfacing to specific digital buses (e.g., MIL-STD 1553, IEEE 1394, Fibre Channel, ARINC 429, Serial and Ethernet buses). There is also typically a need for telemetry in this application for some safety of flight data or potentially for an onboard display. The idea in this system would be to provide the ability to select specific data from 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 a UDP multicast output, a data format that can be sent over the network via UDP multicast traffic, e.g., TmNS (IRIG Chap. 21 – 26), IRIG Chapter 10/11, or DARv3, is required.

However, the needs of every aircraft are different, and it may be necessary to capture some data not on a bus, such as camera or sensor outputs. By identifying what buses, and any other necessary data need to be captured, a decision on whether a specific one-box solution is a viable solution can be made. If there is a lot of additional data from multiple sources, a distributed system may still be more appropriate for a post-test data gathering application.
Curtiss-Wright Compact Recording Solution

Figure 2 represents an example of a compact recorder box (in this case, a Curtiss-Wright ADSR-4003F-8) used to provide a solution for a compact recording. The unit is interfacing with four different avionic buses – two channels of IEEE 1394 and two channels of 10GbE. These are bulk recorded in a Chapter 10/11 format for post-processing. In addition, the data from these buses is filtered, and the selected data is sent to ground via a PCM (Chapter 4) output. Moreover, the same stream is sent out over the network as UDP packets to interface with the aircraft devices, such as, a display.

Curtiss-Wright provides several commercial off-the-shelf (COTS) ADSR-4003F-x units, and those currently available are shown in Table 1. The ADSR has four module slots, and additional inputs can be accommodated using custom-developed modules where required. Contact the factory for more details.

![Figure 2: Recorder-centric system for post-production data gathering](image)

### Table 1: Supported Interfaces

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<th>ADSR Base Features</th>
<th>ADSR-4003F-10</th>
<th>ADSR-4003F-2</th>
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High-Speed Camera System

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

The most common high-speed camera application is to capture a separation event from the aircraft. The system is usually installed as a “distributed, networked architecture”; the customer may install the individual high-speed camera units in various 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 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-S1s).

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 correctly. 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 many 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 sent and the 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.

![High Speed Camera System Diagram](image-url)
In older systems, one would be limited by the 1GbE link of the switch and recorder. When accounting for the combination of limits between the media write speed, and the bandwidth limitations of the switch, the maximum amount of a camera’s high-speed data the user can send to the recorder is limited to three at once, per Ethernet port, when 1GbE limits the link. 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 can eliminate this connection bottleneck. From a bandwidth perspective, this would increase the theoretical transfer capabilities of the high-speed camera network to 30 cameras per Ethernet link.

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

Due to the way most high-speed camera systems are planned, 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 1GbE based switches and rely on the NSW-16GT, and the network manager (nMGR-2000), to properly manage the data being sent to the nREC-7000.

Conclusions

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

Curtiss-Wright designs our products based on applications with system architecture in mind, often in collaboration with customers. This is one reason we have been able to quickly adapt our recorder and switch products in the various ways covered in this paper. It has allowed us to provide existing FTI systems rapidly. These can integrate with high-speed data buses by utilizing our nREC-7000 and NSW-16GT to manage the high-speed data buses, provide permeant fit solutions to post-flight test aircraft by leveraging our ADSR-4003 platform with COTS I/O cards, and decrease the downtime of the high-speed camera system by utilizing the 10GbE pipeline provided by the nREC-7000 & NSW-16GbE link.
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› Multi-band Transmitter
› nGWY-2000EU Network Data Selector with Engineering Unit Processor
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› NSW-16GT 16-Port Ethernet Switch
› nMGR-2000 Network Camera Manager
› nHSC-31-S Network-Based High-Speed Camera with Optional Built-in Recorder