Migrating Airborne Instrumentation Systems from PCM to Network

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ABSTRACT

The majority of currently operating flight test programs around the world utilize PCM-based airborne instrumentation systems. Most instrumentation engineers are very comfortable with PCM-based data acquisition systems, and feel uncomfortable when talking about network implementations and the adoption of iNET. In order for these engineers to embrace this new technology, migrating from a PCM to network topology must be done in an evolutionary manner that provides for the preservation of capital investment while introducing new system concepts that enhance current instrumentation systems.

This paper describes hardware components that enable instrumentation engineers to migrate their existing PCM-based instrumentation system to a network-based system. Several of these components are discussed to illustrate how they provide a controlled migration path to a network-based system. These components include time distribution, gateways, network data selectors, network switches, transmitters, transceivers, and recorders.

KEY WORDS

Network, iNET, IEEE-1588, Gateway, Data Acquisition

INTRODUCTION

PCM-based data acquisition systems are commonly used in most flight test programs. This in turn implies the existence of an air and ground infrastructure to support the PCM system. This infrastructure includes large investments in capital equipment, software, and most importantly, decades of engineering experience. A transition from a PCM-based system to a network-based system must be made in a way that that preserves most of the current infrastructure investment, and supplements that investment to transition into a network-based system at minimal cost while providing maximum system flexibility.

The iNET (Integrated Networked Enhanced Telemetry) program, which is sponsored and funded by CTEIP, is chartered to "Determine Feasibility of RF Networks" and to "augment and enhance current PCM technology". The key to iNET's success and the ability of any network-based instrumentation system to make an inroad into current and future programs is the ability of that system to "augment" and "supplement" customer based infrastructure during the transition phase.

Instrumentation engineers must view network-based instrumentation systems as an opportunity to enhance existing systems with capabilities that PCM systems alone cannot provide. The network allows the acquisition of data, the distribution of time, system setup, system status, and control through the network bus as discussed in [1]. Network-based systems also support the infusion of mature commercial technology, tools, and scalability that our industry could not afford to develop on its own due to its relatively small market size. Most importantly, network-based systems can add capabilities and features such as two-way communication with a test article, real time data mining, test article function adjustment and reconfiguration while airborne, and reduction of cost and program test cycle time.

This paper will not discuss the software challenges facing the system provider or the user of a PCM system in transition to a hybrid network/PCM or network only system. These challenges are discussed in [2], [3] and [4]. The paper will primarily concentrate on the basic hardware building blocks of an airborne instrumentation system and the way in which one may go about using a hybrid PCM/Network system, and methods to gain the experience to slowly embrace the network environment while minimizing time and cost of the transition.

PCM-based Data Acquisition System

PCM-based airborne data acquisition systems components are widely known and commonly used in most flight test programs. These components have well understood characteristics. These characteristics include:

Unidirectional data movement – Data moves from the sensor to the onboard recorder and/or the transmitter; these systems have minimal flexibility to redirect data to other destinations, just short of rewiring the system.

Synchronous data movement – Data is highly deterministic due to the precise state machine execution of the PCM format. Data is sampled at the PCM word rate, and data arrives with a fixed delay due to precise data pipelining for all data channels.

Static quality of service – The quality of service for a given system, wiring, and format is static.

Separation of control and data transfers - When control utilizes data path wiring, that data must be interrupted to perform the control function. Additional wiring may be required if data cannot be interrupted.

Separation of time and data path - Units requiring IRIG time must use additional wiring to provide the time base information to local/remote acquisition units.

PCM-based Data Acquisition Components

Most instrumentation engineers are very familiar with the basic components that make an airborne data acquisition system. A brief description of those system components is provided.

Data acquisition remote slave units – These units condition and acquire sensor data, selected avionics data parameters or complete avionics bus data. Some are function specific units such as pressure scanners, thermocouple scanners, and avionics specific acquisition units. These units are generally connected to a PCM controller unit via a CAIS (Common Airborne Instrumentation System) bus, or a vendor proprietary bus. The units use synchronization signals from the PCM controller and have a bandwidth of up to 20 Mbps. Some units provide PCM output directly to a system recorder while selected data is sent to the system controller. If IRIG time is required to time stamp acquired data, additional wiring is used to provide the time base information to the remote unit.

PCM Controller Unit – This unit can either be a controller only or a controller with built-in data acquisition capability. The unit utilizes a communication bus (i.e. CAIS or other) to communicate commands and synchronization signals to remote slave units, and to receive selected or all data from the remotes. A controller interface topology with remote units is either daisy-chained or starred, or may rely on a combination of the two. Generally, system configuration is done via the controller unit. Controllers provide system synchronization timing and operate at up to 20 Mbps. Most controllers provide all or a subset of their data for telemetry transmission.

Telemetry transmitter – The transmitter receives PCM data from the PCM system controller unit for continuous data transmission of safety of flight data. Frequency and transmission power varies based on the application. Most transmitters are designed to operate at the lower L-band, upper L-band, or S-band, and provide PCM-FM or SOQPSK modulation.

Data Recorders - Recorders vary in functionality, bandwidth, and integration with the rest of the PCM system. The simple small PCM recorders are either integrated with a system controller or standalone, and record PCM stream at up to 20 Mbps. Newer, more complex recorders (IRIG Chapter 10 recorders) acquire data from multiple PCM streams, avionic busses, video/audio, Ethernet, Fibre Channel, etc. These recorders have a recording bandwidth of up to 1 Gbps. Generally, recorders are not fully integrated with the PCM system, and few of them have the capability to “cherry pick” incoming avionics data parameters for telemetry of safety of flight without re-acquiring the same avionics bus by the data acquisition units. Some data recorder units provide data pass-through using an Ethernet bus with no capability to mine the data, while others may provide data mining capability. Most complex data recorders effectively operate as high speed data multiplexers with either built-in media storage or external storage.

Migrating from PCM to Network

Migrating to a network-based system while reusing existing PCM assets allows the user to start building their confidence and experience with network-based systems. A network-based system provides a different set of characteristics to the user as compared to the PCM systems described earlier. The characteristic elements of a network-based system include:

Packetization of data – a transformation from a continuous stream of data into a discrete data packet movement. Data packets require accumulation of data to create the packets, which create an inherent delay due to the accumulation latency.

Bi-Directional packet movement – A network node has no inherent directionalism. While at one moment it may output a data packet, the next moment it may receive a time packet, node status request packet, etc. A recorder node may receive real time data packets from acquisition nodes for storage, and output previously stored data upon request.

Asynchronous arrival of data – While the sampling frequency of a parameter occurs at a predefined rate, the resources used to transfer that parameter and its data packet are shared among other nodes on the network. If we measured the arrival time of packets from a single source that collected its data in a synchronous fashion, we would find the packets spread out into a normal distribution centered on a mean value.

Dynamic quality of service Parameters – The network can be setup to prioritize data from particular sensor/node. This is particularly important when data packets compete for the same resources as the status packets.

Intermix of Data, Control, and Time – The network has no need for separation between the different type of packets and direction of flow of those packets. The packet header contains addresses that identify the source and destination of the packet. Higher level protocols identify control functions. User applications identify user encapsulation of data payloads for any user specific functions.

Network-based Data Acquisition Components

The transition from a PCM system to a network system does not have to be a decision of either PCM or network. The transition, by its nature, can be an evolutionary one, where the user can have a combination of the two, if reuse of existing PCM assets is of importance. The first important components to be discussed in this section are the various gateways. These components allow the user to transition from one medium to another medium. The second set of components discussed are components that are inherently designed as network components or components that have been converted from PCM by way of replacing some internal communication circuitry.

PCM to Network Gateway – This device receives data and clock from the PCM system, performs data decommucation, frame time tagging, and data packetization for transmission over the network. The gateway supports the programming, verification, setup, and system inventory status of the PCM system by way of converting network packets to RS-232/422 wired signals to the PCM system as shown in figure 1.

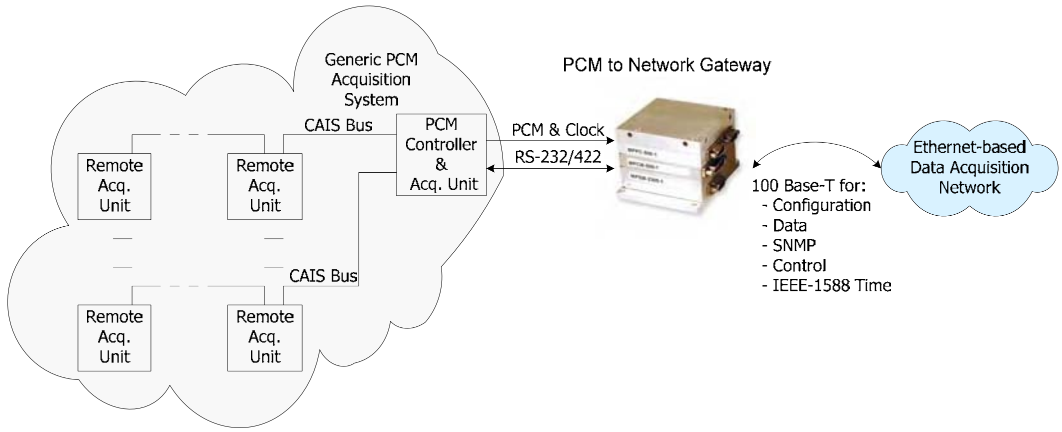


Figure 1. PCM to Network Gateway

Users of a PCM system can immediately experiment with the gateway for many applications while at the same time, the PCM system provides its PCM data to onboard recorders and a TM transmitter. These applications may include:

- Using the gateway to allow the user to program the PCM system using an Ethernet connection.
- Use of the gateway to acquire the data via Ethernet for preflight checkout or an airborne computer without the use of a PCM decomutation card.

Network to PCM Gateway – This device connects to the network side of the acquisition system, performs parameter selection from incoming data packets, and formats the data for a continuous PCM and clock output as shown in Figure 2. The unit operates either as a "parameter data selector/formatter" or as a "converter from network data packets to PCM mode." The first mode assumes that the user provides the gateway only with multicast data packets that include data to be selected. The unit outputs PCM data at up to 20 Mbps. The gateway can optionally convert the PCM back to network packets for transmission over the network for data recording.

The Network to PCM Gateway is a necessary component if telemetry is required in either a PCM/network hybrid system, and in a network only system. iNET is currently defining its RF transceiver for communication to and from an airborne test article to the ground receiving equipment. Additionally, iNET assumes that serial streaming telemetry will coexist with the transceiver communications; the gateway performs the necessary tasks to support this capability.

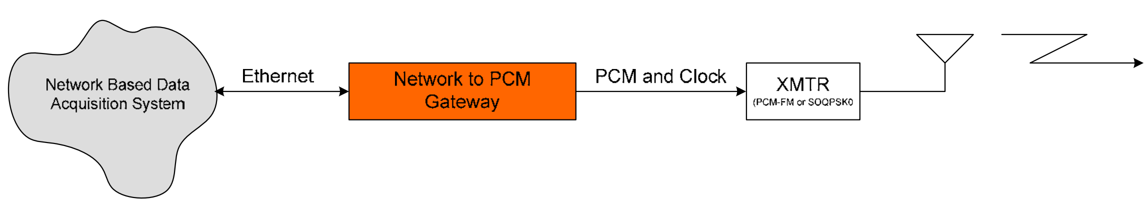
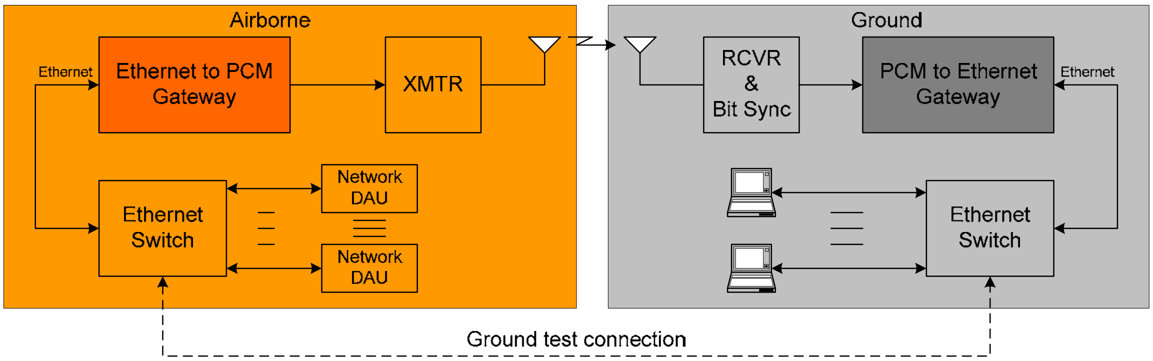


Figure 2. Network to PCM Gateway

In converting a complete set of data packets into a continuous PCM stream, one can imagine an application where a network to PCM unit is used on a test article, and PCM to network is used on the ground to reconstruct the network packets to their original form as shown in figure 3.



.Figure 3. Application of Ethernet to PCM and PCM to Ethernet gateways

Time distribution Gateway - When operating in a network-based system only or a system that includes PCM and network, one must satisfy the requirement to achieve time distribution to all subsystem components. For some systems the time source is IRIG-B time, and for others the time is provided via an antenna hookup to a GPS receiver. The Time Distribution Gateway is built into the network switch and receives time in the form of a GPS signal, IRIG-B modulated or non-modulated time, or IEEE-1588 time over the network. The gateway generates IRIG-B time modulated or non-modulated time, and distributes time over IEEE-1588 as a master or as a slave unit.

Network Switch – Network switches interconnect and route data, control, time, and status between all network nodes as described in detail in [5]. The nodes may include gateways, data acquisition units, avionics acquisition units, recorders, RF transceivers, processors, workstations, etc. Selecting the right switch is not a simple task. The user must be aware of the many choices and decisions that need to be made to select the right switch. The following are some of the key considerations:

- Data bandwidth – Maximum bandwidth aggregation as measured from a few megabits/sec to several gigabits/sec
- Packet switching rate – Maximum number of packets passing through the switch per second. It is measured as a few tens of thousands of packets per second to millions of packets per second
- Multicast address switching – Is the switch capable of switching large amounts of multicast addresses, and large amounts of multicast packets (most commercial switches are not capable of doing either).
- Number of ports per switch – 4, 8, 16, or more
- Maximum data rate per port
- Port interface medium – Electrical (10/100BaseT or 10/100/1000BaseT) or Optical (100Base-FX or 1000Base-X), and the number of electrical vs. optical ports per unit.

- IEEE-1588 Time support – Operation as a boundary clock only or capable of operating as a grand master clock.
- Operation as a time gateway- Built-in GPS, Accept IRIG-B time, Generate IRIG-B time, etc.
- Environmental requirements.

Network Data Acquisition Unit – Network DAUs vary in size, capability, rate, and functionality. All network DAUs should be IEEE-1588 time capable. Some DAUs are identical to their PCM counterpart with the exception of the network interface. Other DAUs are highly specialized to acquire and filter vast amounts of data such as ARINC-664 and Ethernet. The following are some of the choices:

- **Miniature DAU vs. Large DAU –** The miniature DAU can be used in small tight spaces, and very rugged environment. The miniature DAU may provide fewer channels per circuit card as compared with the large DAU.
- **General Purpose DAU –** Acquire data from a wide variety of analog signal conditioners, Bi-Levels, synchro/resolver, temperatures, selected data from avionic busses (MIL-STD-1553, ARINC-429, SDLC, Cross channel Data Link, RS-232/422, etc.), Video and Audio. These DAUs generally operate at rates of up to 20 Mbps.
- **High Speed DAU –** Acquire 100% data or filtered data from one or more asynchronous sources for packetization and transmission over the network. These DAUs operate at 50 Mbps or higher and acquire data from ARINC-629, Ethernet, MPEG-2 Video/Audio, JPEG-2000 Video, JPEG-2000 High Resolution (1600x1280) Video, MIL-STD-1553, ARINC-429, LINK-16, FAAD, Link-11, and other custom buses.

Network Recorders – Network recorders are vastly different from IRIG-106 Chapter 10 recorders, which are effectively their counterpart in the PCM world. One should think of a Chapter 10 recorder as a single integrated multiplexer and data recorder, whereas, the network system can be seen as a large distributed multiplexer and data recorder. This view is taken from the hardware architecture point of view, and leaves out the data packet format. The Network recorder acquires data packets over one or more network ports, and operates as a data destination and data source for data mining simultaneously. The recorder must be IEEE-1588 capable, be configured, controlled, and allow data to be downloaded over the network as shown in [6]. The recorder data rate and capacity must take into account the overall network bandwidth, the need for data mining, storage of measurement metadata, and other data generated by onboard flight test engineers (where applicable).

The network packet recorder may take many forms as shown in figure 4a, 4b, and 4c.

Figure 4a shows the simplest and most efficient way to implement a network packet recorder. This recorder provides the system architect with the maximum flexibility in defining the data packet format optimized for a network architecture, and real time data mining while in record mode.

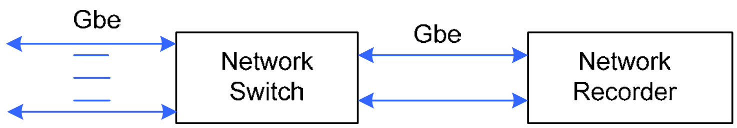


Figure 4a. Network Recorder attached to a Network Switch

Figure 4b is similar to figure 4a with the addition of a high speed data multiplexer. The multiplexer may be necessary when acquiring very high speed data such as Fibre Channel, IEEE-1394, and others. The multiplexer allows for bypassing the network for transmitting large amounts of data.

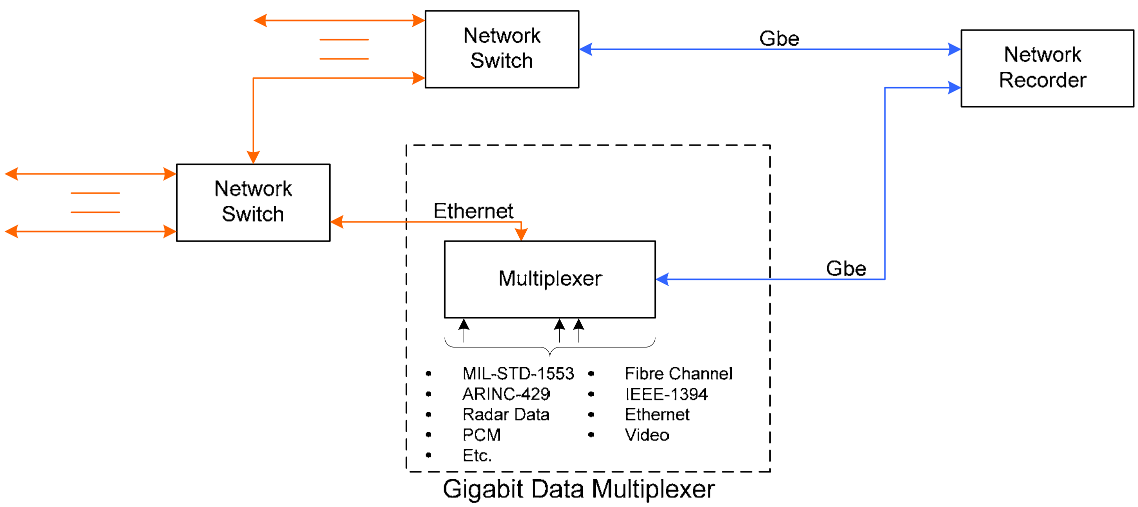


Figure 4b. Network Recorder attached to a Network Switch and High Speed Multiplexer

Figure 4c shows the use of IRIG-106 Chapter 10 as a network recorder. This approach is possible, but highly limited in terms of packet format, absence of IEEE-1588 time representations in Chapter 10, efficient use of network bandwidth, and most importantly the lack of absolute time within every data packet for use in data mining. An additional limitation of this configuration is that Chapter 10 does not require the recording of system metadata, but rather only the TMATS configuration used for the multiplexer recorder.

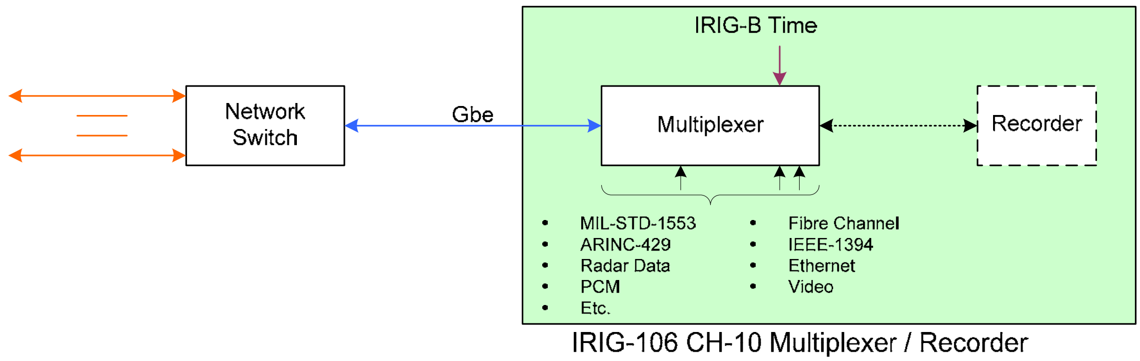


Figure 4c. IRIG-106 Chapter 10 Recorder configured as a Network Recorder

Serial Streaming Transmitter – This is a standard PCM-FM or SOQPSK transmitter for transmitting safety of flight data to the ground. The transmitter requires the use of a “Network to PCM Gateway” to generate PCM from incoming data packets.

Network Transceiver – This device allows for two way IP-based communications between the airborne test article and the ground. The primary goals of the network transceiver are to allow for data mining of the recorder and to retransmit data needed to augment lost information from drop-out in the transmitter. It provides test engineers the capability to mine the flight recorder, reconfigure some airborne settings, and perform many other functions not available in today’s systems. See [7] for further details.

Network System Architecture

We reviewed the basic components of the PCM and the network systems. We have some basic understanding of the functionality of each component. Figure 5 shows a generic system diagram that makes use of a PCM system, PCM to network gateways, Time distribution gateways, Network to PCM gateway, Network switches, Network DAUs, Network Recorder, Network Transceiver, and High-Speed Multiplexer.

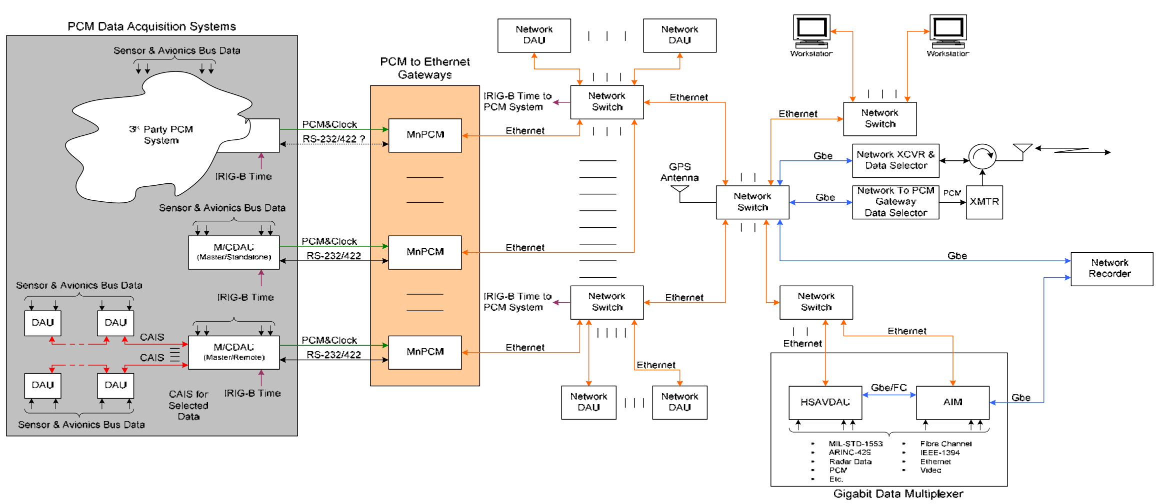


Figure 5. Typical Hybrid PCM/Network System

Conclusions

This paper demonstrates a potential road map for migrating from a PCM data acquisition system to a network-based data acquisition system. Users can already start experimenting with taking small steps in using network components to build knowledge, experience, and capabilities using their existing PCM assets with minimal cost. This paper shows how the functionality of gateways and other network components can ease the transition from a PCM data acquisition system to a fully network-based solution.

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