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Implementation of Fiber Channel Avionics Environment Anonymous Subcriber Messaging Protocol and Testing

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Abstract: Fibre Channel is being implemented as an avionics communication architecture for a variety of new military aircraft and upgrades to existing aircraft. The Fibre Channel standard defines various network topologies and multiple data protocols. Some of the topologies(point to point, Arbitrated ,Fabric) and protocols (ASM, 1553, RDMA) are suited for Avionics applications, where the movement of data between devices must take place in a deterministic fashion and needs to be delivered very reliably. All aircraft flight hardware needs to be tested to be sure that it will communicate information properly in the Fibre Channel network. The airframe manufacture needs to test the integrated network to verify that all flight hardware is communicating properly. Continuous maintenance testing is required to insure that all communication is deterministic and reliable. This paper provides an overview of a Fibre Channel Avionics network and protocols being used for Avionics. The paper also discusses a practical implementation of avionics level testing and testing challenges associated with these applications.

Keywords: ASM, Fiber channel, Testing, Avionics.

I. INTRODUCTION

New advanced avionics programs and applications have an increasing need for bandwidth while maintaining the traditional values of low latency, determinism, and reliability as hallmarks of military-avionics requirements. During the past decade, Fibre Channel has emerged as a winning solution from several competing technologies, for example, Scalable Coherent Interface (SCI), and Gigabit Ethernet. One characteristic that all competing technologies share with Fibre Channel is that they are all based on high-speed serial transmissions placed in routed switched architecture.

Although relatively new to the avionics marketplace, Fibre Channel is already a high speed digital data bus for avionics. For example, it is already being implemented on major programs such as the F18, F16, E2C, B1B, and others. Although Fibre Channel is largely not understood, it must fulfill the military avionics market requirements for speed, reliability, determinism, and fault tolerance. Speed, reliability, and determinism issues are relatively easy to address. However, fault tolerance turns out to be dependent on a combination of architectural issues, Upper Level Protocol (ULP) features, and Fibre Channel transport characteristics.

FC-AE-ASM is intended to support bi-directional communication between two N Ports in a constrained and carefully defined environment, typical of avionics applications. The intended usage is avionic command, control, instrumentation, simulation, signal processing, and sensor/video data distribution. These application areas are characterized by a variety of requirements, among them a need for high reliability, fault tolerance, and deterministic behavior to support real-time control/response

II. FIBRE CHANNEL BASICS

Fibre Channel (FC) as a Universal Avionics Network (UAN) candidate solution for the advanced integrated avionics systems can enable high-bandwidth, low-latency, high-reliability and hard real-time communication on aircraft platforms spanning military and commercial applications. The American National Standards Institute (ANSI) has adapted the commercial standard to military avionics applications in the Fibre Channel-Avionics Environment (FC-AE) specification.

In the commercial marketplace, deployed Fibre Channel systems more closely match military avionics systems because the commercial world greatly values the integrity of their core corporate data files and reliable access with ultra-high availability. Fibre Channel was designed to be a communication protocol between host processors and secondary storage elements, like disk drives and tape drives. This means that Fibre Channel has been designed with all the real-time requirements of speed and reliability characteristic of the Input/Output (I/O) market and shared with the military avionics market. Additionally, Fibre Channel has been designed with the concepts of connectivity and interoperability that mark the general networking marketplace. Finally, Fibre Channel has been designed to be a universal carrier of information. The result is that Fibre Channel has been crafted to easily map other protocols. The idea was to allow existing software written for legacy protocols to be easily ported to Fibre Channel. In fact, Fibre Channel does not have a native command set of its own. For an application to utilize Fibre Channel physical and logical transport layers, someone much map an existing command set to it, like SCSI or 1553, or invent one of their own like the Anonymous Subscriber Messaging (ASM) protocol used on some advanced avionics programs.
Fibre Channel is described in the standards as a stack of architectural levels. Although the stack pictured in Figure 1 illustrates seven levels, we will only briefly discuss four of them here.

FIGURE 1: ARCHITECTURAL LEVELS – SIMPLE NODE

FC-0: The Physical Layer

FC-0, the lowest of the five levels, covers the physical characteristics of the interface and media, including the cables, connectors, transmitters, and receivers. The FC-0 level describes the link between two Ports. Essentially this consists of a pair of either optical fiber or electrical cables along with transmitter and receiver circuitry which work together to convert a stream of bits at one end of the link to a stream of bits at the other end.

Figure 1

FC-1: The Encode/Decode Layer

This layer, which is the transmission encode/decode layer, defines serial physical transport, timing recovery, and serial line balance. Fibre Channel uses the 8B/10B encode/decode scheme. In the 8B/10B scheme, 8-bit internal bytes are encoded and transmitted on the Fibre Channel link as 10-bit Transmission Characters. The transmission characters are converted back into 8-bit bytes at the receiver.

FC-2: The Framing Protocol Layer

This layer defines the rules for the signaling protocol and it serves as the transport mechanism of Fibre Channel. Included in this layer are the framing rules that define how data is transferred between ports. It also defines the various mechanisms used for controlling the different classes of service. To aid in the Transport of data across the link, defines the following building blocks: Ordered Sets, Frame, Sequence, Exchange and Protocol. Ordered Sets are used for handling such functions as configuration management, error recovery, frame demarcation, and signaling between two ends of a link. A Primitive Sequence is an Ordered Set that is transmitted and repeated continuously until a specific response is received. Frames are the smallest indivisible units of user data that can be sent on the Fibre

Channel link. Frames can be variable in length, up to a maximum of 2148 bytes long. Each frame begins and ends with a Frame Delimiter. Immediately following the four-byte Start of Frame (SOF) is the 24-byte Frame Header. Each frame can carry up to 2112 bytes of FC-4 payload. The payload includes zero to 64 bytes of Optional Headers and zero to 2048 bytes of ULP data. A Fibre Channel Optional Header allows up to 4 optional header fields – Expiration Security Header (16 bytes), Network (16 bytes), Association (32 bytes), Device (64 bytes).The four byte Cyclic Redundancy Check (CRC) precedes the four-byte End of Frame (EOF) delimiter.

FIGURE 2: FIBRE CHANNEL FRAME FORMAT

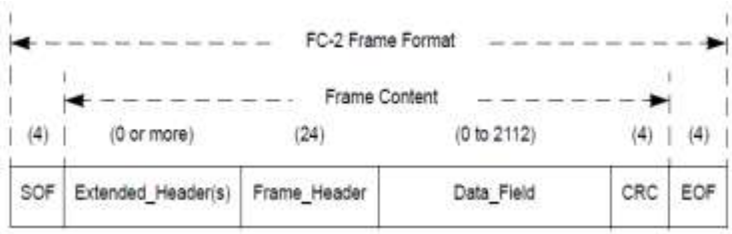

Figure 2

FC-3: The Common Services Layer

The FC-3 level defines a set of services that are common across multiple ports of a node. This layer is not well defined in the standards and is not generally implemented.

FC-4: The Protocol Mappings Layer

This topmost level in the Fibre Channel hierarchy defines the application interfaces that can execute over Fibre Channel. Fibre Channel supports networking and channel protocols, which include SCSI, IP and ASM. Each ULP that is supported by Fibre Channel requires a separate FC-4 mapping. These mappings are specified in separate FC-4 documents.

FIGURE 3: DATA ORGANIZATION HIERARCHY

The individual movements of data like 1553 commands, status, and data – which from the ULP's point of view are typically called information units – are represented in Fibre Channel by sequences. Exchanges are comprised of one to many sequences. Sequences are comprised of one to many Fibre Channel frames. The maximum Fibre Channel frame size is limited to 2,148 bytes, where 2,112 bytes are user defined data. If the information unit to be transferred is larger than 2,112 bytes, the sequence must be comprised on more than one Fibre Channel frame. Finally, frames are comprised of transmission words and transmission words are comprised of four transmission characters. Each transmission character is ten bits; Fibre Channel utilizes an eight-bit to ten bit transmission encoding.

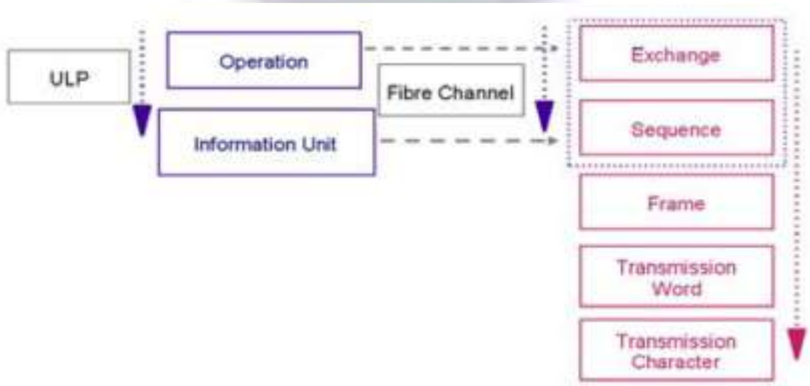

Figure 3

III. OVERVIEW OF A FIBRE CHANNEL AVIONICS NETWORK

Figure 4 illustrates one possible avionics architecture. Redundancy for fault tolerance and high-availability is secured by each node containing three ports. One port attached directly to a Fibre Channel switch and the other two ports attach to Fibre Channel arbitrated loops connected in reverse directions. With this configuration, a switch port fails, then the loops will support the avionics traffic. Even if one loop fails, the other loop is present.

FIGURE 4: FIBRE CHANNEL AVIONICS ARCHITECTURE

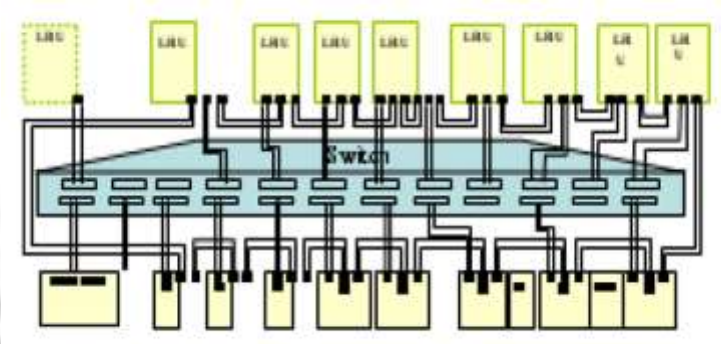

Figure 4

Loop topologies are inherently lacking in fault tolerance because the failure of a single port can cause the entire loop to become inoperable. In commercial as well as military implementations, Fibre Channel loop ports may be made fault tolerant by connecting them with bypass elements that allow a failed port to be bypassed.

IV. AVIONICS PROTOCOLS

Within the Fibre Channel Standards group is a technical committee dedicated to the definition of profiles for the military-avionics community. Three of the profiles published to date include a mapping of the 1553 Command Set to Fibre Channel, a totally new protocol called Anonymous Subscriber Messaging (ASM), and Remote Direct Memory Access (RDMA), which is a SCSI light protocol.

Once again, the fault tolerance of a system is derived from a combination of the architecture, the topology, they physical transport protocol, and the application protocol. For example, a loop topology guarantees in-order delivery by virtue of its single path for all frames. In a complex switch topology where multiple paths are possible, the topology does not guarantee in-order delivery; in-order delivery of frames must be handled by other means, such as a routing protocol.

FC-AE-ASM Protocol

Fibre Channel Avionics Environment (FC-AE),is a group of protocols and profiles that specify Fibre Channel options for devices connected by fabric and/or loop topologies that are pertinent to their use in commercial and military aerospace industries.

ASM is a deterministic, secure, low-latency communication protocol derived only from FC-FS-2 constructs. The Type code is hex ’49’.

Every message in FC-AE-ASM is originated in a single Sequence unidirectional Exchange. The recipient may be expecting the message to arrive at a predetermined rate and does not know where the message is physically originating, only that it will arrive. Therefore, all messages shall use the Unsolicited Data Information Category (Routing Bits hex '0' and Information Category hex '4'). The ASM Header shall be removed on all Frames before reassembly occurs.

FIGURE 5 – ASM HEADER

Bytes	0		1	2	3
0-3	Message ID				
4-7	Reserved - Security				
8-11	Reserved				
12-15	L	Priority	Message Payload Length (Bytes)		

Figure 5

The first four words (or 16 bytes) of the Payload of each FC-AE-ASM Frame are reserved for the FC-AEASM header. In multi-frame sequences, all frames shall contain a copy of the FC-AE-ASM header. The ASM Header shall have the same content in each frame in a multi-frame Sequence.

Figure 5 illustrates the ASM protocol that was invented for use of modern avionics programs. It is a very simple Producer-Consumer paradigm. The idea is that avionics applications are designed to be run at periodic rates. Applications, by design, expect to consume certain data elements at well-known periodic rates. They will also generate data elements at well-known rates. These applications do not need to be instructed by a master controller when to consume and generate data; they will do it by design. Also inherent in the design is that both the producers of data and the consumers of data are anonymous. As Figure 5 illustrates, the ASM exchange is a very simple single sequence.

FIGURE 6: EXAMPLE ASM EXCHANGE

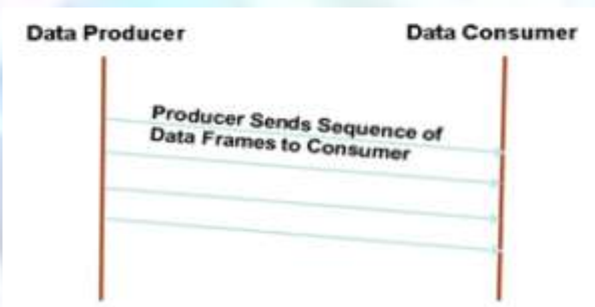

Figure 6

V. TESTING CHALLENGES

Avionics systems designed around Fibre Channel present some new challenges to those tasked with maintaining, testing, and validation. For 1553 bus testing, it is not uncommon to log all network traffic. Consider carrying that practice over to a Fibre Channel-based system. A single Fibre Channel link operating at 1.0625 Gbps will generate 200 MBps of data. To log one hour of traffic amounts to collecting and storing just under seven TB of data. Further complicating the situation is that Fibre Channel topologies are not shared in the sense of offering a single point in the system where all traffic may be monitored. So in a typical avionics system utilizing a 24 port switch, there are 24 links to monitor, meaning the total system data capability is just under 168 TB of information in one hour.

Another challenge is the notion that testing and instrumentation should be completely unobtrusive. Unobtrusiveness is achievable in 1553 systems designed around multi-drop buses; but in fibre optic systems with point-to-point and switched fabric topologies it is not possible. There are three options for tapping into a Firbe Channel switched fabric topology:

1. You can optically tap into a fibre optic link at the cost of power to the destination.

2. You can schedule traffic to be routed to a test system, but this means the test system is no longer in-line with the destination.
3. You can insert an instrument between the source and destination on a link causing the data to the destination to be delayed and retimed.

VI. TESTING STRATEGIES

There are three basic types of test instrument apparatus useful in testing Fibre Channel systems: two-channel pass-through protocol analyzers, data or pattern generators, or emulators.

The two-channel pass-through protocol analyzer is useful in debugging the correctness of the Fibre Channel transport protocol on the physical links as well as assisting in debugging the user applications running on the link. It can also be used to stream data to secondary storage for post run analysis.

Data or pattern generators are used to stimulate avionics modules under test. A pattern generator should be able to stress the link's ability to handle data, send legal and illegal user application data, and perform illegal Fibre operations. Since avionics systems have a large component of periodic data, it would be useful if the data generator had the ability to schedule periodic data transfers. Building onto the data generator the ability to respond to link inputs in real time makes a useful tool for hosting applications under test or for emulating systems to other Devices-Under-Test (DUT). In short, this "emulator" can provide a complete, flexible lab environment in which to stimulate and test a DUT.

AIT is the leading supplier of Fibre Channel testers for military-avionics market. Our PCI Fibre Channel tester card, APG-FC2/4, meets and exceeds all the requirements for each of the three test apparatus.

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