FIBRE CHANNEL TESTING FOR AVIONICS APPLICATIONS

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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 (see T11 web site www.t11.org) defines various network topologies and multiple data protocols. Some of the topologies 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.

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 mil-avionics requirements. During the past decade Fibre Channel has emerged as a winning solution from several competing technologies such as Scalable Coherent Interface (SCI) and Gigabit Ethernet. One characteristic that all the competing technologies shared with Fibre Channel is that they were all based on high-speed serial transmissions placed in routed switched architectures.

You will see that this “shared characteristic” places two important stress points on incumbent testing methodologies and strategies. First, the shear volume of the data makes it impossible to hold onto a philosophy of logging all data on the network so as to not miss something of importance for post-run or post-flight analysis. And secondly, in a switched topology there is no single tap point in the system where all the data may be seen. Perhaps as important is the fact that, since shared media transports have been abandoned for the increased system bandwidth offered by switched networks, there is no single link that can possibly contain all the network traffic.

Although relatively new to the avionics marketplace, Fibre Channel is already a High Speed Digital Data Bus for Avionics. For instance, it is already being implemented on major programs like the F35/JSF, F18, F16, E2C, B1B and others. Although Fibre Channel is largely not understood, it must fulfill the mil-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 and Upper Level Protocol (ULP), and Fibre Channel transport characteristics.

FIBRE CHANNEL BASICS

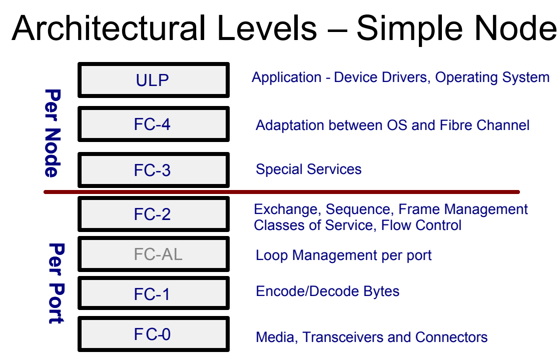
What is Fibre Channel? A very high view of Fibre Channel shows it is an accepted international standard. Within the American National Standards Institute (ANSI) body is a group called the international Committee for Information Technology Standards (INCITS) that is home to a task group called T11. Defining Fibre Channel is the responsibility of the T11 task group committee. Sister sub-committees to T11 would be HIPPI and FDDI as well as T10's work with SCSI.

This means that Fibre Channel is a Commercial-Off-the-Shelf (COTS) technology enjoying all the benefits of a three to five billion dollar commercial marketplace defined as the Storage Area Network (SAN) market. Although mil-avionics requires special environmental packaging and support for deployed architectures greatly exceeds the eighteen months of the commercial marketplace, there are great benefits derived from a marketplace which tests, deploys and supports the basic technology. Even in the commercial marketplace, deployed Fibre Channel systems more closely match mil-avionics systems because the commercial world greatly values the integrity of their core corporate data files and reliable access with ultra-high availability. Witness the Wall Street and banking industries requirements for 99.999% availability or uptime and 100% reliability of data. The billions invested annually into this commercial marketplace accrue directly to the mil-avionics market.

Fibre Channel has been 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 that is characteristic of the Input-Output (I/O) market and shared with the mil-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 the Fibre Channel physical and logical transport layers, someone must map an existing command set to it, like SCSI or 1553, or invent one of their own like the Anonymous Subscriber Messaging Protocol (ASM) utilized 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 7 levels, I will only briefly mention four of them here.

Figure 1

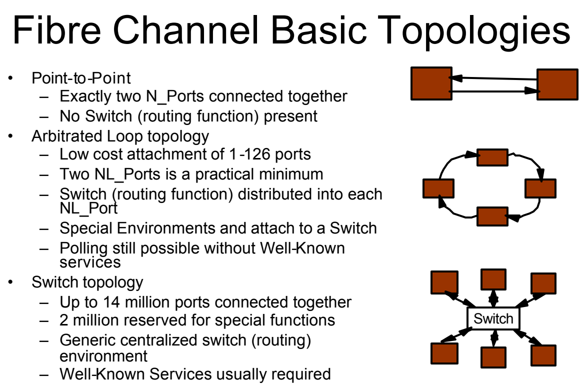


FC-0, the bottom level, describes the Physical Interface for Fibre Channel. This level specifically defines the speeds, transceivers, connectors, and cabling. Currently there are three baud rates shipping in commercial and military avionics Fibre Channel products. These are 1.0625 gigabaud, 2.125 gigabaud, and 4.25 gigabaud. These rates translate to duplex user data rates of 200 Megabytes per second, 400 Megabytes per second, and 800 Megabytes per second respectively.
Although the technology is called "Fibre Channel" the physical media variants include copper along with long-wave and short-wave optics utilizing both single mode and multimode cabling. Fibre Channel systems are flexible enough that every physical link may be chosen based on that link's requirements and not on the presence of other media types elsewhere in the system.

The FC-2 level is interesting because it describes how Fibre Channel manages the flow of information between two ports. This level was designed by the Standards body to allow ease of mapping to Upper Level Protocols (ULP) through an intermediate mapping level (FC-4).

Fibre Channel supports three pure topologies, illustrated in Figure 2, and one hybrid. Fibre Channel supports the Point-to-Point, Arbitrated Loop, and Fabric Switched topologies. The hybrid topology supported is Arbitrated Loops attached to Switch ports. Take note, in all topologies a Fibre Channel port's transmitter is only ever physically attached to one other port's receiver. This simplification of the link allows for highlyreliable transmissions lowering the system error rate in even ultra-high-speed links to acceptably low rates.

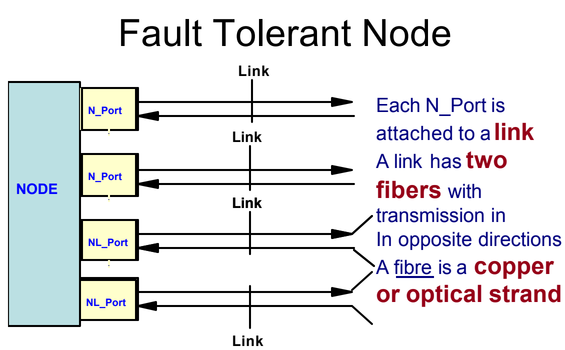
Figure 2



A simple solution for higher availability and greater fault tolerance utilizing any of these topologies is to have redundant physical ports on a node attach to redundant topologies.

For instance Figure 3 depicts a single node with four Fibre Channel physical port connections. Two of the connections can be to two redundant switches and two can be tied into two redundant Arbitrated Loops. This would be a very fault tolerant system.

Figure 3



You may notice that the figure also illustrates that a single physical Fibre Channel link is comprised of two independent fibers: a dedicated transmit and a dedicated receive. This means that the port is full-duplex capable of receiving and transmitting concurrently. In fact, in a switched topology a port can be receiving data from a source port while sending data to a completely different destination port.

To the attached Fibre Channel ports called N_Ports for Node-Ports, the switched fabric looks like a cloud (see Figure 4) that takes care of all destination routing. The N_Port is uninvolved in the process of routing and really has no idea of the physical destination since packets of data, called frames, are routed based on a network assigned address.

Figure 4

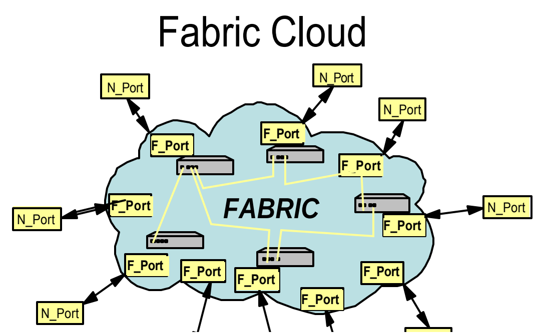
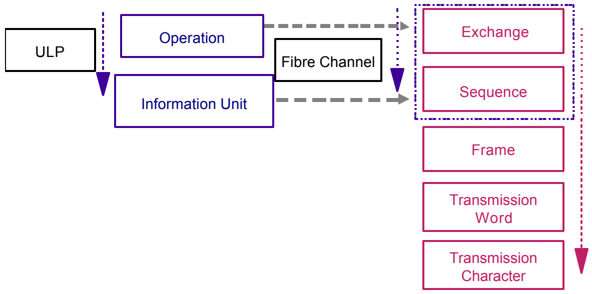


Figure 5 illustrates the Fibre Channel data hierarchy. A ULP command represents an operation. For instance, a 1553 Remote Terminal (RT) to Bus Controller (BC) transfer command represents an operation comprised of several movements of data beginning the BC sending a command to the RT. Then the RT sends a status message to the BC followed closely by the RT sending the data to the BC. In Fibre Channel this operation is called an Exchange. The importance of this is seen in that Exchanges are Fibre Channel's mechanism for mapping half-duplex protocols like 1553, SCSI, and others. The individual movements of data like 1553 commands, status, and data, typically called Informational 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 then the Sequence must be comprised of 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 5

Data Organization Hierarchy



Another valuable Fibre Channel basic relates to user classes of service that Fibre Channel offers. Generally, there are four user classes of service defined in Fibre Channel. However, only two of them are widely deployed. Classes of service has to do with the Quality of Service (QoS) with which data is sent across the media. Typical QoS features include guaranteed bandwidth, guaranteed latency, acknowledged delivery, notification of non-delivery, end-to-end flow control, and guaranteed in-order delivery of frames within a Sequence.

Class 3 is the dominant user-class of service deployed in both the commercial and mil-aero markets. It is a best effort packet-switched service that resembles a datagram service with no attendant QoS features. Class 2 has been implemented by many vendors of fibre Channel hardware with a view to the future. It also is a packet-switched service but it has end-to-end flow control with acknowledged delivery and notification of non-delivery. It does not guarantee bandwidth or latency of messages.

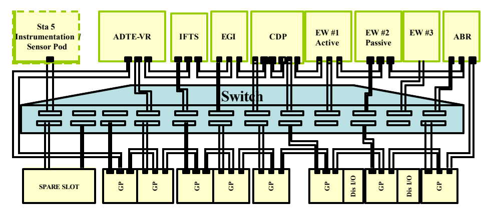
If, at this point, you are excited enough to want to learn more about Fibre Channel or become an expert, then you will want to know where you can obtain the appropriate ANSI Standards. Completed Standards may be obtained through Techstreet in Ann Arbor, Michigan. You may email them at service@techstreet.com or telephone them at (734) 302-7801. If you do not mind looking at draft revisions of the standards you may download them in PDF format from the T11 web site at WWW.t11.org.

AN OVERVIEW OF A FIBRE CHANNEL AVIONICS NETWORK

Figure 7 illustrates one possible avionics architecture. Redundancy for fault tolerance and high-availability is secured by each node containing three ports. One port attaches directly to a Fibre Channel switch and the other two ports attach to Fibre Channel Arbitrated Loops connected in reverse directions. The idea is that if a switch port fails then the loops which are independently connected will support the avionics traffic. Even if one loop fails the other loop is present.

Figure 6

Fibre Channel Avionics Architecture



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 are connected with bypass elements that allow a failed port to be bypassed.

POPULAR AVIONICS PROTOCOLS

Within the T11 Fibre Channel Standards group is a technical committee dedicated to the definition of profiles for the mil-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.

One trick for those already familiar with a legacy protocol like 1553 is to mentally separate the command set from the means of the transport. Also, 1553 Bus features like Bus Controller timeouts on responses to commands from

Remote Terminals is not necessary to carry over to Fibre Channel. In a similar manner the limitations of the 1553 Bus like, allowing only one active BC at a time and the small message sizes of 1553, are not limitations that need to be carried over to Fibre Channel.

Once again, the fault tolerance of a system is derived from a combination of the architecture, the topology, the physical transport protocol, and the application protocol. For instance, 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.

The following discussion shows how avionics protocols assist in providing QoS characteristics to the system.

Figure 7

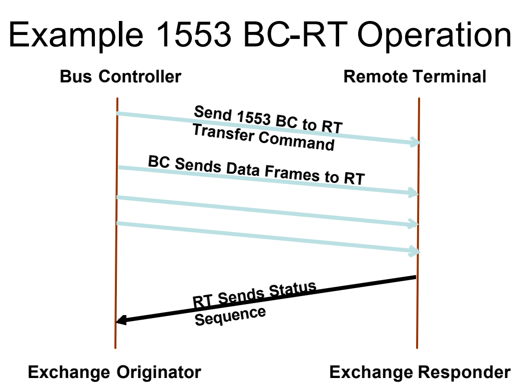
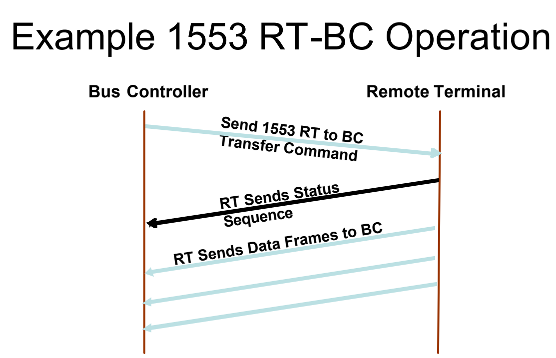


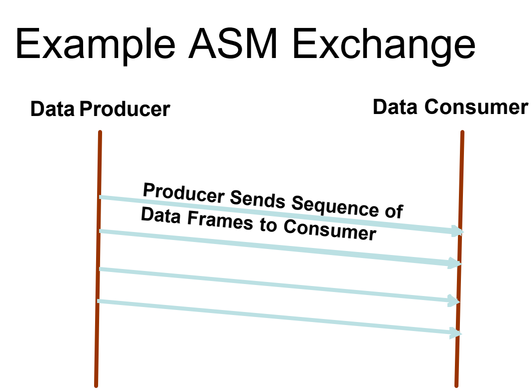
Figure 8



Figures 7 and 8 are latter diagrams that illustrate two common 1553 commands as Fibre Channel Exchanges. Generally, the industry uses Class 3 which is the unacknowledged datagram service. Since class 3 is a best effort delivery, there is no indication provided by the Fibre Channel transport that a frame has been lost. So how does the BC know if the RT has received the BC to RT command sequence? The answer is, in time the RT will send a status Sequence in response to the received data sequence. So the 1553 command set is a self-acknowledging protocol from the ULP level. Since the ULP level sets higher up the protocol stack than the network transport level, it is in fact a more reliable means of acknowledgment than if Fibre Channel class 2 were used and the network were to send an Acknowledgement Frame for every frame received. If the BC does not receive the status sequence from the RT then it can choose some recovery mechanism.

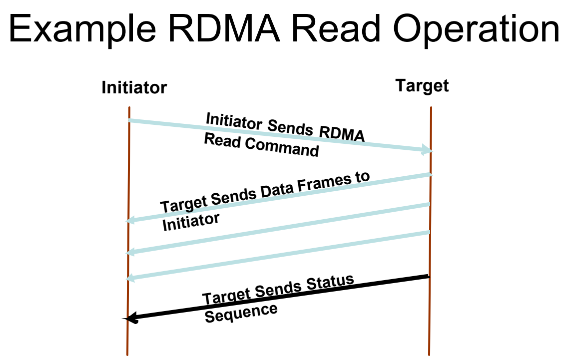
Figure 9 illustrates the ASM protocol that was invented for use on modern avionics programs. It is a very simple Producer-Consumer paradigm. The idea is that avionics applications are designed to be run at periodic rates. Applications, by design, expect to consume certain data elements at well-known periodic rates. They will also generate data elements at well-known rates. These applications do not need to be told by a master controller when to consume and generate data; they will do it by design. Also inherent in the design is that the producers of data do not need to know who the consumers of their data are; therefore the consumers are anonymous. By the same token, consumers of data do not need to know who the producers of their data are, again anonymous. As Figure 9 illustrates, the ASM Exchange is very simple single Sequence.

Figure 9



Figures 10 illustrates the RDMA protocol. RDMA is really exactly like the commercial SCSI FCP protocol with only slight modifications to enable low latency transfers. In terms of fault tolerance the protocol is similar to the 1553 mapping to Fibre Channel already discussed.

Figure 10



TESTING CHALLENGES

Avionic Systems designed around Fibre Channel present some new challenges to those tasked with maintaining, testing and validation. It is not uncommon on legacy systems to log all network traffic. Consider carrying that philosophy over to a Fibre Channel based system. A single Fibre Channel link operating at 1.0625 gigabaud will generate 200 megabytes per second of data. To log one hour of traffic amounts to collecting and storing just under seven terabytes 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 terabytes of information in one hour.

Another challenge is the notion that testing and instrumentation should be completely unobtrusive. Unobtrusiveness may be achievable in systems designed around multi-drop Busses; but in fibre optic systems with point-to-point and switched fabric topologies it is not possible. There are generally three options:

1. You can optically tap into a fiber optic link at the cost of power to the destination.
2. You may schedule traffic to be routed to a test system meaning the test system is no longer in-line with the destination.
3. You may insert an instrument between the source and destination on a link causing the data to the destination to be delayed and retimed.

TESTING STRATEGIES

There are three basic types of test instrument apparatus useful in testing Fibre Channel systems. First, is the two-channel pass-through protocol analyzer: it 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.

A second apparatus is the use of Data or Pattern Generators 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 Channel 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.

Thirdly, building on 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.

The leading supplier of Fibre Channel testers for the mil-aero market today is AIM-USA. Their PCI Fibre Channel tester card (APG-FC2) meets and exceeds all the requirements for each of the three test apparatus.

REFERENCES

[1] *Fibre Channel Framing and Signaling Protocol (FC-FS) Rev 1.7 Feb 8, 2002*
[2] *Fibre Channel Avionics Environment (FC-AE Rev 2.6 Feb 7, 2002*