Test, Simulation, and Integration of Fibre Channel Networked Systems

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Introduction

Fibre Channel is a high-speed networking technology deployed on a number of military/aerospace platforms and programs. These include F-18E/F, F-16, F-35, B1-B, B-2, E-2D, the Apache Longbow and MMH helicopters, and AESA Radar. Applications for Fibre Channel include mission computers, processor and DSP clusters; data storage; video processing, distribution, and displays; sensors such as radar, FLIR, and video; serial backplanes and IFF.

Basic characteristics of Fibre Channel include a choice of copper and optical media options; 1 and 2 Gb operation, including auto-speed negotiation; and operation on multiple topologies including point-to-point, arbitrated loop, and switched fabric. In addition, Fibre Channel provides low latency to the single-digit microsecond level; address scalability with a space up to 2^{24} ports; broadcast and multicast operation; unacknowledged and acknowledged classes of service; a means for providing variable quality of service (QoS); and multiple upper layer protocols (ULPs).

Test and simulation applications for deployable Fibre Channel networks include the development of board and box-level systems and sub-systems, network integration, production test, and equipment maintenance. For software development and network integration, it's often necessary to rely on Fibre Channel testers and analyzers to simulate unavailable equipment for traffic generation and monitoring.

Some development and integration environments provide demanding requirements for real-time data monitoring, storage, and subsequent offline analysis. For production test and field maintenance, low cost testers are often better-suited than higher-priced analyzers.

Aside from cost and capabilities to support the requisite data rates, topologies, and ULPs, there are a number of factors to consider when selecting Network Access Controllers (NACs) and switches for use in Fibre Channel test and simulation.

Additional considerations include:

- The need to emulate and monitor N_Ports and F_Ports, and monitor E_Ports
- Support for high throughput rates,
- Implicit and explicit login
- Clock sync
- Autonomous scheduling
- Interoperability with military and commercial Fibre Channel products
- Real time operating systems
- Provisions for link statistics
- Built-in-test.

Fibre Channel Upper Layer Protocols

One of the salient features of Fibre Channel is the flexibility enabled by a wide choice of upper layer protocols (ULPs). Following are overviews of four ULPs commonly used in embedded military applications.

TCP/IP and UDP/IP

The mapping of IP over Fibre Channel (IPFC) is defined by IETF documents RFC 2625 for IPv4 and RFC 3831 for IPv6. These mappings stipulate the assignment of unique IP addresses to individual Fibre Channel ports. It is important for IPFC implementations to provide a standard BSD socket in order to support common services. These services include:

- TCP/IP and UDP/IP protocols
- FTP
- NFS
- ICMP
- FARP, ARP, and RARP Address Resolution
- SNMP
- SNTP (client and server)
- BOOTP.

Important requirements for IPFC test/simulation environments include:

- Verifying the status of other IP devices on the Fibre Channel network
- Sending or receiving SNMP messages from a high-level software application
- Capability to read and write data from/to an NFS server
- Ability to “ping” other nodes on a network.

FC-AE-ASM

FC-AE-ASM, or Anonymous Subscriber Messaging, ULP is used on a number of airborne platforms. ASM defines a simple, unidirectional protocol that supports messages (Fibre Channel exchanges) with an allowable range of byte counts of 0 to 2^{24}. ASM defines a 4-word ULP header that includes a 32-bit MESSAGE_ID label, used to identify system-specific functions.

In flyable ASM interfaces, received messages are typically sorted by means of the ASM MESSAGE_ID field. However, for test and monitoring applications, it is more common to filter received messages based on MESSAGE_ID, and store the filtered messages chronologically with an associated time stamp.

Raw Mode

Raw mode upper layer protocol involves the transmission and reception of Fibre Channel frames containing *no* ULP headers. Raw Mode has therefore been characterized as "no" upper layer protocol, "ultimate lightweight protocol," or "pure FC-2" Fibre Channel. As FC-2 encompasses the lower three levels of Fibre Channel, it provides multiple physical layer options, along with encoding/decoding, framing, multi-frame Sequence formation, segmentation and reassembly, and flow control.

As a result, for test applications, Raw Mode provides an extremely high degree of flexibility for sending and receiving Fibre Channel Frames and Sequences. Raw Mode, which may be implemented at either the frame or Sequence level, provides a tool for enabling the transmission and reception of *any* ULP. Raw Mode also includes the capability to interleave messages from multiple sources. Because of its "lightweight" characteristic, Raw Mode provides extremely high performance, including "line rate" throughput (e.g., about 206 MB/s at 2 Gb line speed) and end-to-end latency of less than 10 µS.

Because Raw Mode is capable of sending, receiving, and transferring interleaved Frames and Sequences with multiple ULPs from multiple sources at high throughput rates, it is well-suited for data monitoring, a common application for test and simulation.

SCSI/FCP

For both commercial and military Fibre Channel networks, SCSI/FCP (Fibre Channel Protocol) is commonly used to interface with magnetic and solid-state storage devices. Test applications for SCSI/FCP include reading or writing test data to data recorders and Fibre Channel RAIDS or disks. Common military applications for SCSI/FCP are surveillance and reconnaissance systems, including those compliant with the NATO STANAG-4575 standard, data servers, and computer clusters.

Fibre Channel Test and Monitoring

Figure 1 illustrates a basic Fibre Channel test and simulation scenario, a point-to-point configuration with the tester/analyzer emulating an N_Port or F_Port. In either case, the tester/analyzer needs to perform Fibre Channel link initialization along with implicit or explicit login, depending on the requirements for a particular system. For the exercising and testing of flyable Fibre Channel equipment, it is common for the tester/analyzer to need to emulate a switch F_Port.

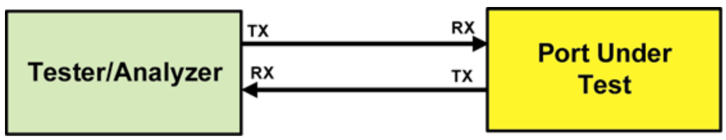

Figure 1. Tester/Analyzer Emulating an N_Port or F_Port

For all protocols, but in particular ASM and Raw Mode, it may be necessary to perform "stress testing," entailing high data throughputs in both directions. This places particular demands on test equipment to be able to generate, receive, and store high-rate streaming data.

To emulate an F_Port, in addition to being able to respond to a fabric login request, a tester/analyzer must be able to transmit traffic from multiple end-points; i.e., including interleaved exchanges with multiple values of S_ID.

Figure 2 illustrates an example of switch port mirroring. In this example, either all traffic input to F_Port A or all traffic transmitted out of F_Port B is routed to the output of I_Port C, where the I_Port is an instrumentation port. If the level of traffic is light, it may be possible to route Port A's input traffic *and* Port B's output traffic (and possibly additional streams) out of Port C.

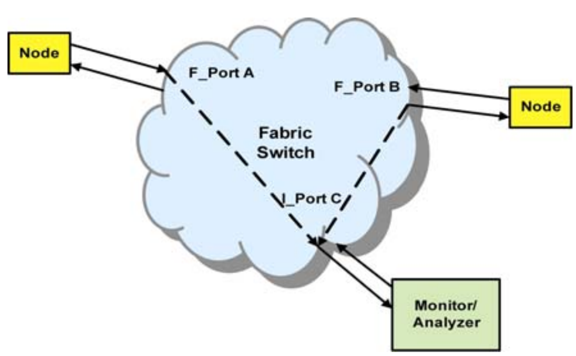

Figure 2. Example of Fabric Switch I_Port Providing Port Mirroring Connection to Monitor/Analyzer

As shown, the data transmitted by the I_Port is received by a monitor/analyzer card for analysis or storage. In this example, the I_Port is a "true" bidirectional Fibre Channel port with flow control capabilities. However, some switches provide capabilities for simplex (output only) I_Ports. The advantage of the latter is that this mode enables "passive monitoring." This eliminates the possibility of input ports "backing up," which could affect the timing operation of the network and attached systems.

Military-Specific Fibre Channel Test Issues

There are a number of considerations for Fibre Channel NACs and switches that are specific to military applications.

Login

Fibre Channel login is a mechanism enabling switch F_Ports and node N_Ports to "negotiate" for the purpose of identifying common characteristics and parameters. This process may be performed by either explicit or implicit login.

With explicit login, which is used in most commercial applications, an exchange of parameters takes place over the Fibre Channel network.

Implicit login, which is used in many, but not all, military applications, bypasses the parameter exchange process. Instead, the parameter values for NACs and switches are enforced *a priori* by means of a system specification. This enables simpler, faster network initialization at startup, and faster re-initialization following momentary power outages. For many military Fibre Channel test environments, implicit login is a necessary interoperability attribute for both NACs and switches. However, explicit login is used on some military platforms and is often necessary for interfacing with commercial equipment.

ELS Clock Sync

Fibre Channel's Clock Sync Extended Link Service (ELS) provides a means for sharing a common, highly accurate time base among multiple systems. For test and simulation, it is important to establish an accurate time base to enable the time-stamping of individual messages transmitted and received across a network, and for being able to determine the relative timing of events occurring in a multi-system network.

With ELS Clock Sync, individual client ports on a network can request that a Clock Sync server port located within a node or switch provide periodic updates of network time. For this service, Fibre Channel defines an option for resolution up to 64 bits, with an LSB value of 73 ps., and a rollover time of 43 years. While individual implementations may provide a subset of this resolution with reduced accuracy, it is important for test equipment NACs and switches to provide high resolution (at least 48 bits) and tight accuracy. In addition, for flexibility, it is important for test equipment NACs and switches to support both server and client functions. For one avionics network, the time sync server resides in the network switch and provides updates to all ports every 20 mS.

Two Channels

The inclusion of two independent channels in Fibre Channel testers allows the simultaneous monitoring of *both* links between a switch and a port under test. As illustrated in Figure 3, another example of independent port use is monitoring of a data stream of TCP/IP or ASM traffic on one port, and writing the monitored data to a SCSI/FCP disk drive or RAID by the tester card's other port. For the tester/monitor's back-end interface, 133 MHz PCI-X provides the benefit of being able to support the aggregate throughput of two 2 Gb channels transmitting and receiving simultaneously. In order to facilitate operation on various hardware platforms, it is desirable to provide for auto-configuration for PCI/PCI-X back-end interfaces.

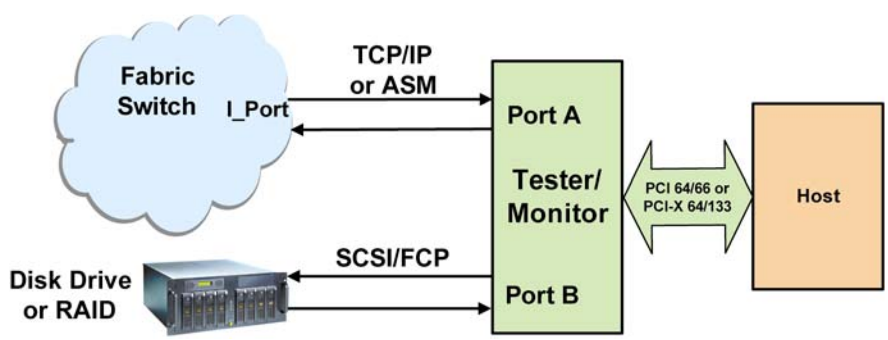

Figure 3. Using Two-Port Tester Card to Monitor and Store Test Data

Autonomous Scheduling

Unlike commercial storage applications, deterministic scheduling can be an important factor for such military Fibre Channel applications as mission computers, DSP clusters, and display processing. For military test applications, deterministic scheduling enables an array of messages to be transmitted reliably in a pre-determined amount of time while offloading the tester host's resources. Tester cards with autonomous scheduling allow the time between the starts of consecutive messages to be programmable, typically with a resolution of 1 μS/LSB.

Interoperability

Assurance of interoperability is a fundamental consideration for Fibre Channel test equipment. Ideally, tester NACs and switches should be able to operate seamlessly with NACs and switches from any and all military and commercial suppliers. Since military-specific NACs tend to use implicit login while commercial NICs generally use explicit login, the need for interoperability emphasizes the importance of supporting both implicit and explicit login.

For system integration scenarios, known interoperability enables users to proceed with the assurance that testers will be able to operate not only with the specific unit(s) under test but with all other equipment involved in a test lab. At the physical layer, this should entail, as a minimum, compliance with the relevant FC-PI copper or optical specification. For ASM, interoperability requires that test NACs and switches be compliant to the released version of the T11 FC-AE-ASM standard, and that test equipment be able to pass interoperability testing with the deployed NICs, NIUs, and switches on a network.

Statistics

The maintenance and indication of statistical information by NACs and switches is a useful tool for system integrators. This functionality typically provides a “snapshot” of network operation and status, and enables system diagnostics. For both NACs and switches, this information includes such data as the number of frames transmitted and received over individual links, and information relating to the number of various error conditions.

For a NAC operating in a system requiring the use of FARP (Fibre Channel Address Resolution Protocol), the ability to determine the number of FARP requests sent and received can be instrumental in troubleshooting network initialization problems. For a Fibre Channel switch, indications of counter values for invalid D_IDs received; busy destinations, including individual destinations for multicast; and indications of such errors as loss-of-sync, CRC errors, and frames received with no receive frame buffers available provide useful information for system integration.

Built-in Self-Test

To ensure correct equipment operation, built-in self-test is an important feature for test environments. Particularly for production test and maintenance applications, where network testers and switches represent just a portion of complex suites of equipment, it’s important to be able to determine, isolate, and repair equipment failures quickly.

For NACs, self-tests commonly performed following power turn-on include JTAG boundary scan, memory self-tests, and front-end loopback tests. Additional tests such as online memory checking may be performed continuously during operation, while more elaborate tests may include write and read vectors to verify on-board logic, and external loopback tests using jumpers to exercise physical layer interfaces.

For Fibre Channel switches, power-up tests can include self-checks for frame buffers and routing table memory, register read/write tests, and internal SERDES loopback tests. To enable periodic self-tests, it is important that these tests may be performed by user command as well as following power-up, with results reported through either in-band methods and/or configuration interfaces.

Test Platforms and Operating Systems

Test and simulation labs employ a variety of host computers. These include Freescale and Intel-based computers, with form factors including VME or cPCI single board computers, and desktop PCs and workstations. For all of these, PMC form factor for tester cards is generally applicable, sometimes entailing the use of a PMC-to-PCI adaptor. For Fibre Channel switches for test equipment, VME is a commonly used form factor.

VxWorks, Green Hills Integrity, and Solaris are often used for test and simulation applications with more demanding real-time requirements, while Windows NT®, Windows XP®, and Linux are appropriate for less stringent test applications. In most cases, ready-to-use software drivers are available, while in other cases it is necessary to port a driver from a different operating system.

Fibre Channel NACs for Test Applications

Basic Capabilities

For test/simulation applications, NACs should be able to support 1 and 2 Gb data rates, ideally with capability for auto-speed negotiation. For flexibility, tester NACs should be able to support all topologies and all necessary ULPs needed for a specific application.

ASM-Specific Capabilities

NACs for FC-AE-ASM test/simulation applications must be able to send or receive messages containing any 32-bit value of the ASM MESSAGE_ID field. In some instances, there are requirements to send the same ASM message to multiple destinations. When test/simulation NACs receive interleaved ASM messages from multiple sources, these must be reassembled by the NAC hardware and stored in PCI or PCI-X host memory space. Since ELS clock sync is specified for use by FC-AE-ASM, tester NAC cards (like embedded NACs) must be able to receive clock sync updates and update the value of their internal "wall clocks," and to time-stamp individual transmitted and received messages.

ASM Data Monitoring

A common requirement for ASM Fibre Channel test and simulation environments is the ability to monitor and store streams of data coming off a network. These passive monitoring applications typically entail connecting the monitor NAC's input to the output of a "tap" or simplex I_Port, or an output from a physical layer or "static" switch. A physical layer or "static" switch, or "patch panel," is a switch in which the routing is statically established in advance and is fixed regardless of the destination address (D_ID) of incoming frames.

As illustrated in Figures 4 and 5, there are two configurations for passive monitoring: (1) simplex operation, and (2) transparent flow-through operation. Figure 4 illustrates monitoring of a simplex I_Port, by a monitor (or recorder) type interface operating in a receive-only simplex mode. This mode may be used in conjunction with physical layer "taps" or switches (static switches), to enable the "eavesdropping" of all traffic transmitted between two Fibre Channel ports. The monitored ports may be N_Ports, F_Ports, or E_Ports. In this configuration, all received messages (or possibly a filtered subset) are transferred across the monitor's PCI (or PCI-X) interface.

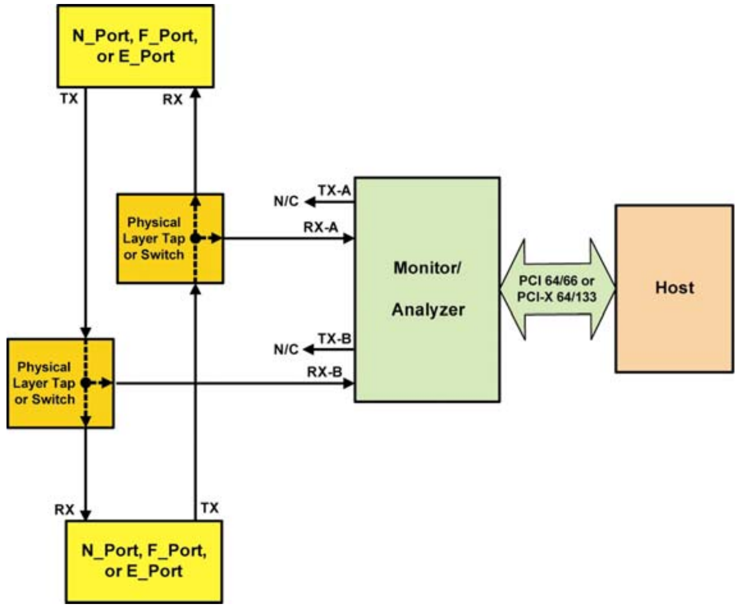

Figure 4. Monitoring Data in Simplex Mode

An alternative configuration, as illustrated in Figure 5, is transparent flow-through mode. In this configuration, a physical layer tap or switch is *not* required, and each of the NAC's two ports connect directly to an N_Port, F_Port, or E_Port. All traffic received on each of the card's two input ports is repeated out of the opposite output port, which then re-transmits the received stream to the destination N_Port, F_Port, or E_Port. That is, traffic received on Port A is transmitted out of Port B, while traffic received on Port B is transmitted out of Port A.

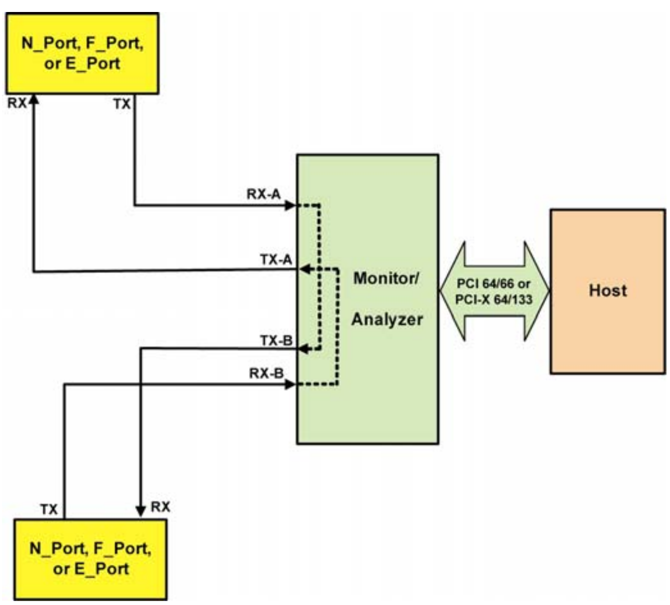

Figure 5. Monitoring Data in Transparent Flow-Though Mode

Since the monitor does not provide buffer-to-buffer flow control, the repeater delay time is minimal, thereby *not* significantly affecting the operation of the monitored network. As in the receive-only simplex mode, all received messages (or possibly a filtered subset) are transferred across the monitor's PCI (or PCI-X) interface.

Typically, the monitored, or "eavesdropped" data will be stored to a magnetic disk, RAID, or solid-state storage for subsequent analysis. For monitoring and recording of ASM data streams, it is important to be able to filter based on the ASM_MESSAGE_ID field, along with any combination of source and destination Port_IDs.

The value of filtering is the ability to limit the monitored and stored data to a specific set of MESSAGE_IDs, each of which maps to an individual system-level function. The benefit of this is the reduction in the amount of data that needs to be stored, which in turn simplifies and accelerates the operation of subsequent analysis software. In addition, for monitoring the output of an N_Port or E_Port, the filter reduces the amount of data stored by only passing a single "copy" of messages that are transmitted to multiple destinations.

Since there is no flow control on simplex connections, it is important that data monitors include sufficient input frame buffers and are able to transfer data across PCI or PCI-X quickly enough so as not to lose received messages. Other important considerations for monitors include time-stamping of all messages with the card's ELS Clock Sync time, validating all received messages, and identifying all errors detected. These errors include missing or out-of-sequence frames, CRC errors, lack of on-card memory, and lack of host memory. In particular, the last two conditions reflect a "lost data" condition. If any of these conditions occurs, it is imperative to issue host interrupts.

ASM data traffic can include a large number of short messages. Hence, reducing the number of interrupts so that requests are issued only following the reception of "N" (a programmable number) messages, rather than following every message, provides the benefit of a potentially large reduction in the level of host resources needed to deal with servicing interrupts.

Raw Mode

Raw Mode ULP provides a high degree of flexibility for Fibre Channel test, data monitoring, and simulation applications. For example, a Raw Mode NAC can transmit and/or receive and store Fibre Channel exchanges for *any* ULP. Raw Mode ULP can operate on either the Frame or Sequence level.

With Frame-level Raw Mode, it is possible to emulate (transmit) the stream of Frames coming from a switch F_Port or E_Port, with interleaved frames and Sequences originating from *different* (simulated) source IDs. For simulation using Raw Mode, the autonomous scheduling feature may be used as a means of emulating various real-time system scenarios.

Raw Mode Sequence mode provides a “pure” FC-2 level interface, in which Fibre Channel Sequences may be transferred between test application software and the analyzer card.

For Raw Mode, received Frames or Sequences may be stored into large host circular buffers, with interrupts issued for either every “N” Frame or Sequence stored, or following a buffer overflow condition. Similar to ASM, for each Frame or Sequence transferred, the value of the ELS Clock Sync time stamp, a Frame/Sequence status indication, and total byte count indication is stored for each Sequence or Frame.

The status information normally indicates either that a received Frame or Sequence was valid, or provides an error notification. The latter may include loss-of-sync conditions, CRC errors, code violations, out-of-sequence Frame, E_D_TOV timeout, R_CTL error, and out-of-memory errors.

Fibre Channel Switches for Test Applications

As stated, one of the common requisite characteristics for NACs and switches operating in avionics environments, which includes test and simulation, is implicit login. For the case of switches, this encompasses bypassing not only Fabric Login (FLOGI) with individual connected N_Ports, but also having all switch Domain_IDs and switch-to-switch routing information inherently “known” at the time of power-up. However, for the case where NACs based on commercial controller chips are used on a network, there may also be a need to support explicit fabric login.

In a test/simulation environment, it may be necessary to increase the total number of ports on a network. When the total number of ports exceeds the number of ports on a network switch, it is necessary to attach additional switches to the network. Switch E_Port capability provides this scalability. In this case, the number of E_Port ISLs (inter-switch links) between pairs of switches will depend on the anticipated level of traffic between switches. For example, as shown in Figure 6, if there’s originally a single 16-port switch on a network, the number of N_Ports that can attach to the switch fabric may be increased from 16 to 24 by cascading a second 16-port switch, and establishing four inter-switch links between the two switches.

In a multi-switch test environment, one switch may be assigned as the Master switch, thus enabling it to assign the Domain_ID(s) to any cascaded switch(es) automatically. As a means for improving aggregate throughput performance in a multi-switch network, some switches provide support for hunt groups. In Figure 6, traffic may be routed from one of the N_Ports connected to the left switch to one of the N_Ports connected to the right switch. With hunt groups, the routing table for the left switch may be programmed so that this traffic travels through either ISL #1, ISL #2, ISL #3, *or* ISL #4, whichever port(s) is operational, but currently not in use.

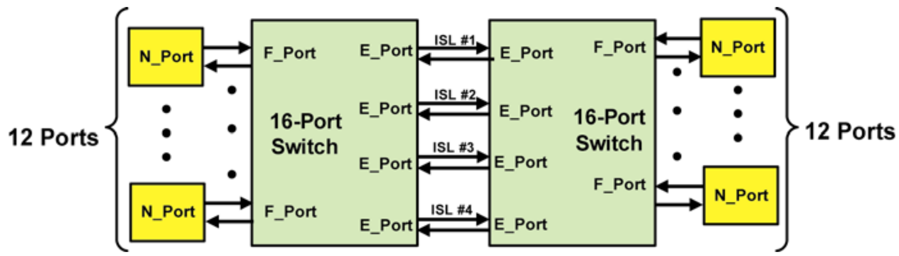

Figure 6. Cascading Switches

In addition to hunt groups and unicast (sending to a single destination), some switches also support multicast (sending to multiple destinations) and/or broadcast (sending to all destinations). As discussed, multicast may be used for routing multiple incoming and outgoing streams to I_Ports, in order to send data to instrumentation.

Switch configuration interfaces may be RS-232 serial links, 10/100 Ethernet connections, or other types. For a Fibre Channel test/simulation lab, these provide flexibility by enabling users to program routing tables, E_D_TOV and R_A_TOV timeout values, configuring ports for F_Port, E_Port, or I_Port operation, and programming implicit login parameters for connected N_Ports.

Configuration interfaces may also be used for providing switch statistics. In a test environment, this enables users to determine quickly the “health” of network nodes, the level of traffic in each direction, and indications of various error conditions.

For test and simulation, switches should be non-blocking, and, where Fibre Channel priorities are used, should always route higher priority frames ahead of lower priority traffic. Switches with only one or two Frame input buffers per port can sometimes result in a “head-of-queue” blocking condition, in which it’s possible for a low priority frame to block the routing of higher priority frames transmitted later by the same source port. This problem may be eliminated by providing a sufficient number of input buffers and strict enforcement of priority levels.

For Fibre Channel, various servers' functionality typically resides in network switches. For example, some military networks deploying ELS Clock Sync require that the Clock Sync server function be performed by a switch. In addition, for situations requiring explicit login, the Fabric Server function will be needed. Another switch server function that may be advantageous for test environments is Name Server. This allows any port on a network—which would include test/instrumentation ports—to be able to interrogate about the Port_IDs and other characteristics of other ports on the network.

Solutions

Following is an overview of DDC's products for Fibre Channel test applications.

FibreACCESS Network Access Controllers

DDC's FC-75100 FibreACCESS Fibre Channel Network Access Controller (NAC) cards (Figure 7) are suitable for use in a wide variety of test applications. These cards provide two copper or optical ports operating at 1 or 2 Gb, and support TCP/IP, UDP/IP, ASM, SCSI/FCP, and Raw Mode upper layer protocols. They include software drivers and sample code for VxWorks, Linux, and Windows. The FibreACCESS NACs provide line-rate throughput with end-to-end latency of under 10 µS. In addition to supporting multiple ULPs, the FibreACCESS NACs provide features applicable to military test and simulation applications, including both implicit and explicit login, ELS clock sync server and client, priorities, autonomous scheduling, and link statistics.

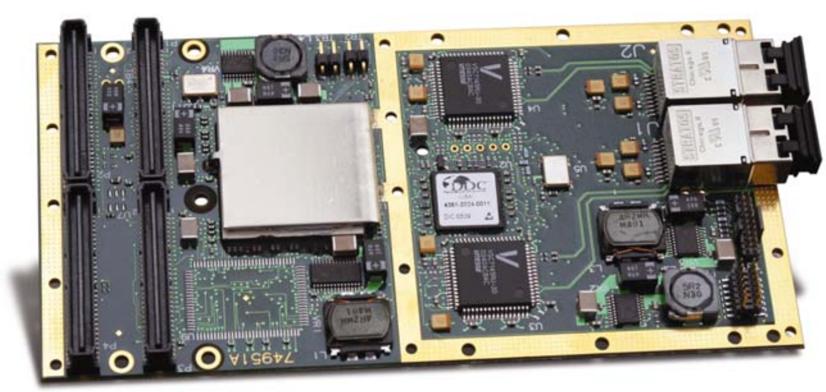

Figure 7. FibreACCESS PMC NAC Card

FibreMATRIX Switch

DDC's FC-76000 FibreMATRIX switch, shown in Figure 8, provides 16 ports operating at either 1 Gb/s or 2 Gb/s, with front panel optical media interfaces on a conduction or air-cooled VME64x form factor. All FibreMATRIX ports are programmable to operate as F_Ports or E_Ports. For lab applications, it's also possible to configure for full-duplex or simplex I_Port operation.

FibreMATRIX Supports Class 2 and 3 Fibre Channel service. Other features targeted for military test applications include a choice of implicit or explicit login; ELS Clock Sync server and client operation; programmable routing tables providing unicast, multicast, broadcast, and hunt group routing; and support of 127 priority levels. RS-232 serial and 10/100 BASE-T Ethernet configuration ports allow user programming of various parameters, and provide statistics indicating the number of transmitted and received frames, along with counters of various error conditions for each port.

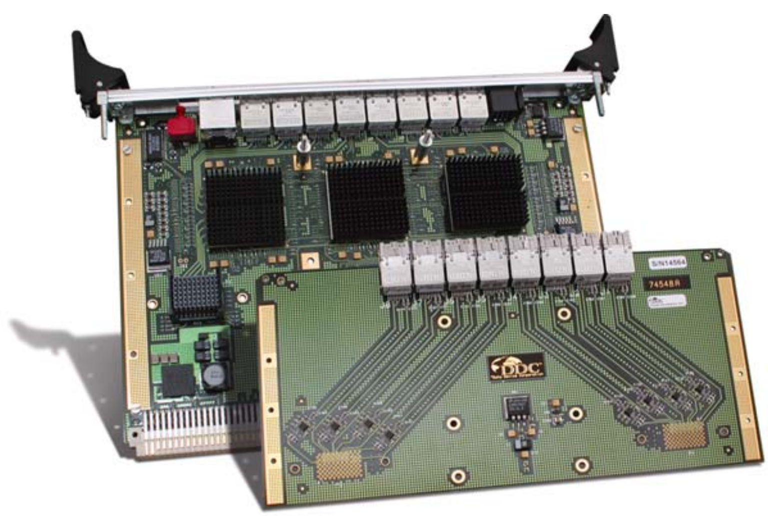

Figure 8. FibreMATRIX Switch

ASM Data Monitor

DDC's ASM Data Monitor Fibre Channel NAC card provides a low-cost solution for capturing Fibre Channel ASM data streams. The Data Monitor provides a flexible tool for lab applications, including system integration, data recording, and system test. The ASM Data Monitor is available with a choice of fiber optic or copper media interfaces, and provides two ports that can operate at 1.0625 or 2.125 Gb data rates.

The ASM Data Monitor is a conduction or convection-cooled PMC card capable of operating in either receive-only simplex mode or in transparent flow-through configuration to allow eavesdropping, monitoring the outputs of N_Ports, F_Ports, or E_Ports. The monitor can filter messages based on combinations of ASM MESSAGE_ID, and S_ID, and D_ID addresses. The ASM Data Monitor cards include a 64-bit master/target 66 MHz PCI interface, which can also operate as a 133 MHz PCI-X interface.

Mike Glass
Principal Marketing Engineer
Data Device Corporation

Data Device Corporation (DDC) is recognized as a leading international supplier of high-reliability data interface products for military and commercial aerospace applications for over 40 years and MIL-STD-1553 products for more than 25 years. DDC's broad product line consists of advanced data bus technology for high-speed Ethernet and Fibre Channel networks, MIL-STD-1553 data bus boards and components, synchro/resolver technologies, and solid-state power controllers and motor drives. The company's design and manufacturing facility is located in Bohemia, N.Y. For additional information, contact Mike Glass at glass@ddc-web.com, or visit DDC's website at www.ddc-web.com.