

# Proton Single Event Effects (SEE) Testing of the Myrinet Crossbar Switch and Network Interface Card

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**Abstract** - As part of the Remote Exploration and Experimentation Project (REE), work was performed to do a proton SEE evaluation of the Myricom network protocol system (Myrinet). This testing included the evaluation of the Myrinet crossbar switch and the Network Interface Card (NIC). To this end, two crossbar switch devices and five components in the NIC were exposed to the proton beam at the University of California at Davis Crocker Nuclear Laboratory (CNL).

## I. INTRODUCTION

The Remote Exploration and Experimentation Project (REE) was part of the NASA's High Performance Computing and Communications Program. An effort was in place to place a commercial-off-the-shelf (COTS) supercomputer in space. The architecture being investigated was a multi-processor system connected to a prime controller that was hardened for space. The network system that was being evaluated for use in this application was Myrinet.

For this system to be useful in the space environment, the network electronics should not place undue radiation susceptibility in the overall system architecture. To evaluate the Myrinet system for space use, crossbar switches and network interface cards were exposed, at room temperature, to the proton environment at the University of

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California at Davis Crocker Nuclear Laboratory (63 MeV beam).

The following sections will describe the details of the devices that were tested, the hardware systems used to evaluate these devices, the software used, and the results of the testing.

## II. DEVICES TESTED

Two devices were tested for this work. The first were crossbar switches manufactured by Myricom, Inc, which provide the interconnectivity in the Myrinet model (as a hub would in star-configuration network model). Secondly, a Peripheral Component Interconnect (PCI)-bus network interface card (NIC) manufactured by Myricom was tested. On the NIC, five devices were arbitrarily chosen to be exposed and the system evaluated for its response to their exposure. The listing of all devices used in this testing is given in Table I below. Official description of the Myrinet standard appears in its entirety in an ANSI document [1].

### A. 16 port Crossbar

The crossbar switch (Xbar) device type is the essential component interconnecting devices residing on the network. The 16-port Xbar switch tested allows 16 devices to connect in any configuration, one with another (no broadcast or group connections). The bandwidth of Myrinet is described as the data rate available in the "forward" direction plus the bandwidth available in the opposite direction.

There are different Myrinet speed standards. The Xbar and the NIC types tested are capable of operating at the Myrinet-2000 data rate of 2 gigabits per second (GBPS) in both directions simultaneously (full duplex). Thus, the data rate is expressed as 2000 + 2000. Each single-direction 2000 MBPS link is referred to as a channel. The opposite-direction pair of these channels is referred to as a link.

TABLE I  
DEVICE UNDER TEST (DUT) TABLE

Device	Vendor	Location	Model Number
Switch 1	Myricom	Switch Board 1	M3-SW16-8S
Switch 2	Myricom	Switch Board 2	M3-SW16-8S
NIC	Myricom	NIC	M3S-PCI64B-2
Lanai9	Myricom	NIC	9.1
SerDeSer	Myricom	NIC	1.1
PCIDMA	Myricom	NIC	1.3
Transceiver	Vitesse	NIC	VCS7146RH
SRAM	Samsung	NIC	K7N803601M

The Xbar Device Under Test (DUT) is a 0.25  $\mu\text{m}$  commercial CMOS ASIC manufactured for Myricom to perform their function. Each DUT acquired was pre-mounted to a printed circuit board (See Figure 1). No other components on the DUT board were irradiated.

Each Xbar Integrated Circuit (IC), shown in Figure 2, has 16 System Area Network (SAN) ports. The Xbar IC and SAN specification for Myrinet is described in [2]. Briefly, SAN is a parallel data and control signals format for short haul (components no more distant than within one rack). Eight of these SAN links are brought to the front panel through a serializer/deserializer for connection to external components. The other eight ports are connected to the backplane connector for SAN connection to other components within the chassis that hold these cards.

Providing 16 serial ports requires more than one Xbar card; the other eight backplane ports must be made available at the front panel. This is accomplished with a "spline" card, which does not contain an Xbar but merely converts the eight SAN channels to/from serial format. An inefficient arrangement of two Xbar cards can be used in place of one Xbar and one spline. A single Xbar card can be used if the eight backplane ports are not required. Some of this testing involved a single Xbar card and the rest involved two Xbar cards because the proton irradiation was sufficiently penetrating to hit both Xbar ICs, which are one above the other. This gave data on many more paths (described below in the DUT System description).

Messages are transported across a Myrinet as one or more packets. Packets are encoded with routing information that allows it to reach the desired destination. Each pass through an Xbar (in a large network many Xbar transits may be required to reach the destination) involves one byte of routing information, which gives a relative (to the incoming

port) output port. These routing bytes are removed as they are used, and Cyclic Redundancy Check (CRC) is recalculated and appended so that the new packet (1 byte shorter) is correctly formatted. Packets that have inconsistent CRCs are simply dropped. This behavior is hard-wired within each component (within the LANai9 processor within the NIC, and within the Xbar IC). That is unfortunate for SEE testing—events are detectable only by their failure to arrive. No examination of erroneous data is possible.



Figure 1. The Myrinet Xbar card showing the backplane SAN ports at top and serial front panel ports.

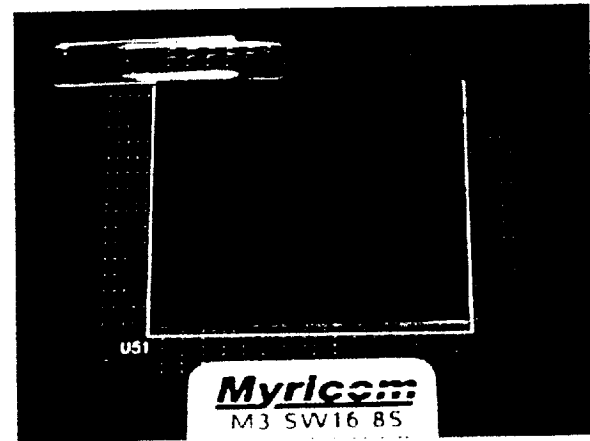


Figure 2. Close-up of the Xbar IC. The total height above the board of the IC is 1.4 mm.

#### B. Network Interface Card

The Network Interface Card (NIC) provides functionality for a device (PCI-bus computer, as are most desktops currently in use) to communicate via the Myrinet-2000 standard [3]. It is a PCI-64 form-factor card that can operate from 32-bit PCI bus as well. It operates at either 5 V dc for PCI32 operation or 3.3V for either PCI32 or PCI64 operation. The card operates at either 33 MHz or 66 MHz PCI bus speed with ICs that provide bus interface (including PCI Direct Memory Access (PCIDMA)), protocol processing, and serialization and deserialization

(SerDeser) functions. The primary focus was on the protocol processing IC, which is called the “LANai 9 processor”.

Operating in typical PC situations (33 MHz PCI32 bus) allows a data rate of 132 MB/s. Operation at maximum data rate (66 MHz PCI64 bus) is still limited by either the host computer’s capabilities or the PCI bus limits. 523 MB/s is the theoretical limit; the actual rate during testing was near that limit. To achieve full 2 GBPS rate 64 bit 200 MHz bus and high speed processors are required. Figure 3 shows the NIC. The additional signals for PCI-64 operation can be seen hanging to the right of the white PCI-32 socket. The black Myrinet cable can be seen at far left.

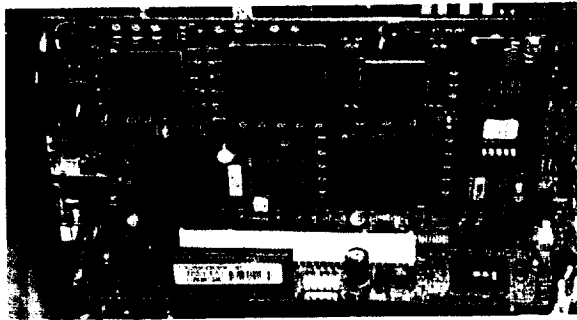


Figure 3. Myrinet NIC installed in PCI-32 motherboard without extender.

### III. TEST HARDWARE

The test system consists of two subsystems, the Test Controller and the DUT subsystems. Any cabling not required for the operation of the computer on which the NIC resides or the Xbar switch, along with Myrinet cabling is considered part of the Test Controller subsystem. These subsystems are described below. Figure 4 illustrates the overall test configuration.

#### A. Test Controller Subsystem

The Test Controller hardware is based on the PCI Extensions for Instrumentation (PXI) specification. The PXI subsystem, shown in Figure 5, resides outside the irradiation area and is connected to the DUT at the irradiation point by cabling, approximately 40 feet long. It consists of the PXI components, the PXI Computer ↔ DUT System cabling and the user interface.

The PXI components include the PXI chassis, which contains an embedded controller (running Win98, Labview™ (LV) environment and a custom LV application), a signal switch matrix, and two digital multimeters (DMMs) in the voltage

measurement mode. The switch matrix provides two functions – the multiplexing of analog signals to one of the DMMs, and contact closures (pulling signal levels to ground). One DMM measures all analog values except the value read most frequently or as most important to not be delayed by switch settling time. The other DMM is dedicated to monitoring that value.

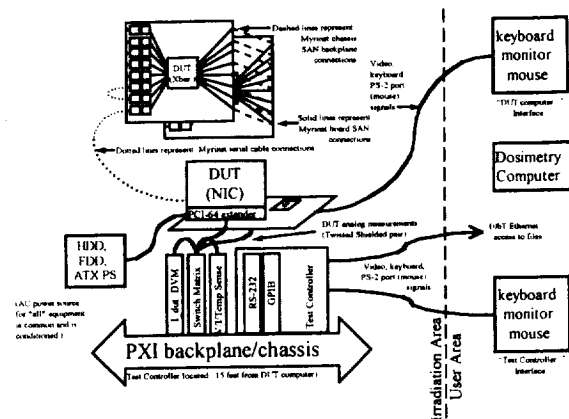


Figure 4. Block diagram of the test system.

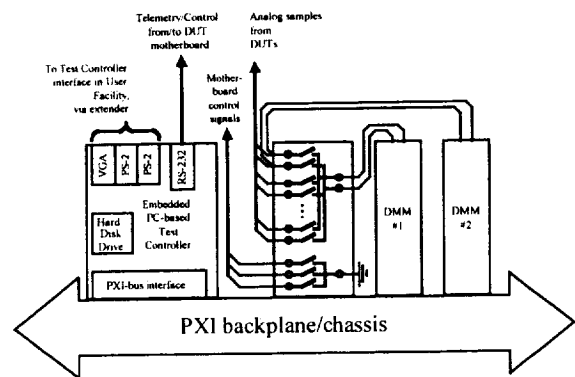


Figure 5. Block diagram of the PXI subsystem.

The PXI Computer’s user interface, network connectivity (for data file access) and AC power feed are also components of the PXI Computer. An extended (via a CAT5 cable based extender from Cybex, Inc.) keyboard/monitor/mouse user interface provides user control of the PXI computer from the user facility (which in this instance is located in the hallway outside the regular, restricted access, user area).

Most of the PXI Computer ↔ DUT System cabling leaves the PXI subsystem from the switch matrix. Exceptions are the AC power cable to power the DUT System and a serial (RS-232) cable for telemetry/command of the DUT System computer (telemetry originates within the DUT System

computer, commands originate within the PXI Controller).

*B. DUT System*

The DUT System consists of the computer in which the NIC resides and to which the Xbar is connected. It includes components mounted directly to the motherboard, components located nearby (e.g. disk drives) and connected via cables, and a Cybex extended keyboard/monitor/mouse user interface.

The DUT system computer motherboard resides in the test chamber, positioned just below the particle beam when the NIC is exposed. The NIC plugs into an extension socket which raises it up by approximately two inches. The dual 1 GHz P3 processors on the motherboard are Flip-Chip Pin Grid Array (FC-PGA) form-factor so they lay very low and well out of the particle beam, as do the low profile (<1”) RAM modules.

Located nearby (approximately 6 feet) are a modified standard PC ATX power supply (PS), a floppy and/or hard disk drive, and a Cybex user interface extension identical to the one used to extend the PXI computer.

The motherboard is modified to allow power cycling and reset via the PXI switch matrix. The ATX power supply is modified to allow force power shutoffs. The PCI-64 extension board, which the NIC plugs into, is modified to sample DUT current via the PXI switch matrix and DMMs.

The NIC is connected via a Myrinet cable to the rest of the DUT system, the Xbar switches. (Figure 6). These are housed in a chassis containing its own AC power supply.

The motherboard is modified to allow connection to two controlling signals, both momentary contact closures. The motherboard front panel power on/off (MotherPonoff) input signal is controlled by the PXI switch matrix, as is the motherboard front panel soft reset (MotherSR) input signal.

ATX PS on/off state is normally controlled by a constant signal from the motherboard (The ATX SP supplies a standby +5V to power such motherboard functions). This signal (PS\_ON#) is, approximately, a latched toggle of the front panel signal, MotherPonoff. This motherboard PS\_ON# signal is disconnected from the ATX power supply’s PS\_ON# input so that it can be controlled directly from the PXI. This additional control is necessary because the computer can hang to the extent of not responding to the normal on/off commands. The ATX PS AC power is extended back to the user facility.

The DUT Computer runs the Windows-NT™ operating system and a software application that

access Myrinet NIC drivers. Commands from the PXI computer are received via an ethernet cable and responses are transmitted back via the same link.



Figure 6. Close-up of Myrinet serial cable ends.

Currents and voltages, from as many as three devices (one NIC and two Xbars), were monitored. System cabling was designed to allow four current/voltage samples in one subD 15-pin connector cable. A cable assembly was added to trifurcate three signals to separate locations.

DUT system signals that are controlled by the PXI subsystem, as described above, or by the user from the user facility are shown in Table II.

DUT computer signals that are monitored by the PXI or directly by the users in the user facility are shown in Table III.

Name	Destination	Description
PS_ON#	ATX Power supply	Hold low (0 V) for PS on; Open = High = Off
MotherPonoff	Motherboard power switch connector	Pulse low (0 V) to toggle power on and off
MotherSR	Motherboard reset switch connector	Pulse low (0 V) to initiate reset
Command	DUT system computer	CAT-5 cable, ethernet, 10/100 mbps rate. Same cable that carries Telemetry data.
Keyboard/mouse	DUT system computer	PS-2 keyboard ports

*C. Test Software*

The DUT software for Myrinet testing was written in Microsoft C++ Professional version 6.0. It was designed to run in Windows 2000 Professional service pack 2. The driver for the Myrinet network

adapter was GM 1.1. This driver was downloaded from the Myricom website (<http://www.myri.com/>).

The Network Interface Card (NIC) takes data packets from the driver and sends/receives the packets through the cables and network switches. The receive function of this card rejects data packets when errors are detected. The method used for detecting errors is a CRC check byte at the end of each packet.

Name	Source	Description
V_NIC, I_NIC	NIC extender card	Voltage and current samples of the NIC primary supply. Twisted shielded pair (TSP).
V_Xbar, I_Xbar1	First Xbar card	Voltage and current samples of the first/only Xbar switch card supply. TSP.
V_Xbar, I_Xbar2	Second Xbar card	Voltage and current samples of the second Xbar switch card supply, if installed. TSP.
Telemetry	DUT system computer	CAT-5 cable, ethernet, 10/100 mbps rate. Same cable that carries Command data.
GUI output	DUT system computer VGA card.	Video carrying output to the user facility.

The DUT Software sends packets with an incrementing packet # and data which is a function of the packet #. If the packet number/16 is odd, then the data is a stream of bytes with the value hex 55; otherwise, it is a stream of bytes with the value hex AA. After each packet is sent, the program waits until either a packet is received or approximately 10 microseconds, whichever comes first. There are two physical setups supported. The first setup uses one NIC for both sending and receiving. The second setup uses two NICs, one for sending and one for receiving.

The DUT is connected through a Transmission Control Protocol/Internet Protocol (TCP/IP) socket to the test controller system where the test controller system acts as the host and the DUT acts as a client. The IP address and port used for the test controller connection are hard-coded. When not connected, the DUT tries once every 3 seconds to make a connection. The DUT sends telemetry information to

the test controller system and records the same telemetry to a file on the DUT hard disk drive. The telemetry consists of a stream of 4-byte long integers sent LSB first with the following format:

```
// The last byte of 4 is a data
// code. The table below shows the
// definitions for each code:
// FF timestamp and beam info
//   xx xx yy FF
//   xx xx relative timestamp
//   yy 01 for beam on, 00 for
//   beam off
// FE Error in data packet
//   xx xx yy FE
//   xx xx location within packet
//   yy data read
// FD Skipped Packet(s)
//   xx xx xx FD
//   xx xx xx Number of skipped
//   packets
// FC Skipped Packet(s) (Large/-)
//   00 00 00 FC
//   xx xx xx xx
//   xx xx xx xx Number of skipped
//   packets
// FB Buffer overflow
//   00 00 00 FB
// FA Header
//   AA AA AA FA
//   aa aa aa aa
//   tt tt tt tt
//   rr rr rr rr
//   rr rr rr rr
//   rr rr rr rr
//   ff ff ff ff
//   ff ff ff ff
//   ff ff ff ff
//   ff ff ff ff
//   pp pp pp pp
//   aa aa aa aa Ascii Version
//   tt tt tt tt Time Stamp
//   rr rr rr rr... Route info
//   ff ff ff ff... Filename
//   pp pp pp pp Packet Size
// F9 Reconnect
//   00 00 00 F9
// F8 Packet Number
//   xx xx xx xx
//   xx xx xx xx Packet Number
```

The DUT software utilizes two methods of data transfer. The first method of data transfer is the standard `gm_send_with_callback()`. The second is the undocumented `gm_raw_send_with_callback()`.

The standard method of transfer uses handshaking that ensures that the data is received without any detected errors before the send is completed. If any errors are detected the data is resent until the data is received without detected errors or a timeout of about a minute is reached. Before running the DUT Software in this mode, the GM utility program gm\_mapper\_service must be executed. This cannot be executed while the DUT software is running. In this mode the speed of data transfer can be set using gm\_set\_speed. This method was not used in this testing.

The undocumented method of transfer (Raw Mode) uses no handshaking. If the data is received with detected errors it is rejected by the NIC and is never seen by the user software. The user software detects when a packet is skipped or any errors that are not detected by the NIC are received. When packets are skipped, the packet number of the packet received after the skip and the number of skipped packets are recorded. When errors are found within a packet, the packet number, the locations within the packet and the actual values of the bytes in error are recorded.

The DUT software is controlled through buttons and checkboxes on the DUT console. All of these can be manipulated through the keyboard and mouse of the DUT computer. Some of these can be controlled through the TCP/IP connection by the test controller system. These are controlled from the test controller by sending a one-byte command to the DUT. The following can be controlled both by the DUT and by the test controller system (The values at the end are the values for the command byte from the test controller system):

1. The button called "Run" is pressed to start logging data and to start sending data when "Loopback" is checked. (1-Run)
2. The button called "End" is pressed to terminate logging and to stop sending data when "Loopback" is checked. (2-End)
3. The checkbox on the console called "Beam" is checked when the beam is on. (3-Check; 4-Uncheck)
4. The checkbox on the console called "Loopback" is checked when using one NIC and not checked when using two. (5-Check; 6-Uncheck)
5. The checkbox "Raw Mode" is checked when using the raw data transfer mode and not checked when using the standard transfer mode. (7-Check; 8-Uncheck)

The following can only be controlled from the DUT:

1. The "Route" button and edit box are used to set the route that the data takes through the switches when using the raw data transfer mode.
2. The "Packet Size" edit box is used to set the data packet size (4088 is the default, 4096 is the max).
3. The "Directory" edit box is used to select the directory into which the telemetry files are stored.
4. The "Suffix" edit box is used to select text which is appended to "Run\*", where "\*" is the run number, when forming the file name for the telemetry file. The run number is incremented each time the "End" button is pressed.

#### **D. Test Methodology**

In this simple test, the main objectives were to observe what effects would be induced by proton irradiation, with specific concern to latchup sensitivity of any parts. Therefore, to achieve these goals, the main devices of both the crossbar switch and the network interface card (NIC) were placed in the proton beam.

During their exposure, the DUT computer was running software that was generating data to be passed along the network and watching for the arrival of these packets of information. While no direct evidence of upsets was possible, as explained previously, if data within the packet was corrupted, the Myrinet hardware would drop the packet. The missing packet would then be noticed by the DUT software and recorded. This is the main type of error observed. During exposure of the NIC it was also possible to induce errors in the data stream once the NIC accepted a package as valid. The methodology and software were also in place to observe these types of errors as well.

The methodology flow was to place the device to be exposed in the beam, start the DUT and PXI software systems, turn the proton beam on, and, finally, observe the effects. The proton beam remained on until either a preset amount of fluence was achieved or a functional interrupt or latchup was observed. Initially, the preset fluence was set to a smaller amount due to the uncertainty in the total dose response of any of the devices. As the testing proceeded and the devices appeared to withstand the dose sufficiently well, preset fluences were set to levels such that there was typically a functional

interrupt prior to the preset fluence level being reached.

For the errors that were observed, the test software recorded all pertinent information about the errors, including the manner in which they were received (e.g., did a single packet get dropped or were a sequence of packets lost in a very short time span). For functional interrupts, as much information, that could be gleaned from the test system, was recorded. In some instances it was simply that the DUT computer rebooted while in others it was detailed information about which switch in the crossbar devices induced the interrupt. If any latchup currents were observed, the device, the peak current seen at the device, and the functionality after the latch would have been recorded.

#### IV. RESULTS

##### A. Network Interface Card

###### 1) Single Event Latchup

For the simple test being performed on this system, the NIC current was monitored for the entire board. Therefore, determination of a latchup event in an individual component would have to generate sufficient current to be observable above nominal NIC current. For all five components exposed to the proton beam on the NIC, no high NIC currents or destructive events were observed. There were events on all five devices that led to functional interrupts (to be discussed next). These events could possibly be produced via a high current condition in the respective part, as a power cycle of the DUT computer was required to reset after the interrupt. However, since no events were destructive, it is impossible to say that latchup did or did not play any role in these events.

###### 2) Single Event Functional Interrupts (SEFI)

When any of the five devices were exposed to the proton beam, the DUT computer system would experience a SEFI event at some point. This could be seen as the DUT computer either freezing or initiating a self-reboot. In all instances observed for all five devices, a power cycle of the DUT computer that housed the NIC was required to regain functionality. The SEFI cross-sections measured for the five devices are shown in the last column of Table IV.

###### 3) Single Event Upsets

As discussed in the software section, missed packets are the normal mechanism for errors to display themselves for the test setup used here. For

all but the Samsung device, this is the upset mechanism that was observed. For the Samsung SRAM part, the second upset possibility arose. These are errors that are received that are not detected by the NIC. In other words, data was correctly received by the NIC, processed by the Lanai9 processor and stored into the Samsung SRAM. While in this stored location, it is altered and that difference is detected. The upset cross sections measured for the five devices are shown in the third column of Table IV.

Part	Accumulated Dose (krad)	Upset Cross Section (cm <sup>2</sup> )	SEFI Cross Section (cm <sup>2</sup> )
Lanai9	59.2	6.81E-12	1.14E-11
SerDeSer	53.1	1.52E-11	5.07E-12
PCIDMA	45.7	2.94E-12	1.18E-11
Vitesse	50.7	4.03E-10	7.95E-12
Samsung	9.1	8.84E-11	7.37E-11

It should be noted that two of these Samsung SRAM parts are exposed during the testing (one on each side of the board). It is not clear from the Myricom documentation how much of both of these parts are used and if their usage is equal. Therefore, the cross section is left as a total cross section for both parts (not per bit or per device).

###### 4) Total Dose

While total dose testing was not explicitly included in this testing, proton dose is accumulated over the course of the test. No parametric measurements of the devices are feasible with this test setup. However, no functional loss or functional performance degradation was observed throughout this entire test. Therefore, it can be stated that the devices are total dose functionally survivable to at least the maximum proton dose during this test. These dose levels for the five devices on the NIC are shown in the second column of Table IV.

##### B. Crossbar switch Device

###### 1) Single Event Latchup

For the test being performed on this system, the crossbar switch current was monitored. For both crossbar switch devices exposed to the proton beam, no high currents or destructive events were observed. There were events that led to functional interrupts. These events did require a power cycle of the crossbar power supply to reset after the interrupt. However, since no events were destructive and no

high currents were observed for the switches, it is possible to say that latchup did not likely play any role in these events.

### 2) Single Event Functional Interrupts (SEFI)

Figure 7 and Figure 8 show the per-switch SEFI cross-section for the crossbar switch devices tested. In Figure 7, it is assumed that all switches have the same sensitivity whether they are on the in Xbar frontplane (FP) or backplane (BP), or on either Xbar #1 or #2. This cross section is plotted as a function of the number of switches active during that test (there are different percentages of the switch locations for these four cases). The squares and error bars are the average overall cross section, assuming all switches are the same, and the one-sigma standard deviation. The triangles are the cross sections within each of the four cases. The four data points almost lie within one sigma.

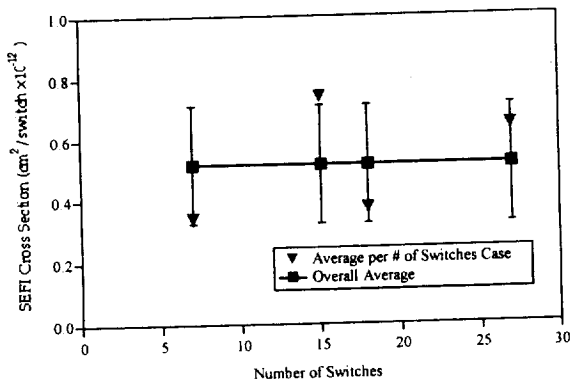


Figure 7. SEFI Cross section as a function of the number of switches.

Figure 8 looks at the same data set but with the thought that the SEFI rate could be different between frontplane and backplane switches. The four cases shown here are the two frontplanes of the two Xbars, the backplane switches, independent of which Xbar houses them, and the overall cross section (the same as the squares of Figure 7). While all of the data points lie within the one-sigma error bars of the overall cross section, there does appear to be a difference between the frontplane and backplane switches.

### 3) Single Event Upsets – Non-SEFI

Single Event Upsets (SEU), for the crossbar switch devices, are only evident as dropped packages. Data was collected to include the number of dropped packages, whether they arrived as a single dropped package or in a rapid sequence of dropped packages. This data was collected for four different switch

quantities, that also had varying quantities in the frontplane and backplane.

Figure 9 shows the per-switch cross section as a function of the number of switches in the test configuration. It shows data for both single package loss and for multiple package loss. It is evident that the multiple package loss appears to be within approximately one sigma of an average value for the multiple events. The same cannot be said for single package loss, as the two higher switch count cases (those with backplane switches in the test configuration) have substantially higher cross sections.

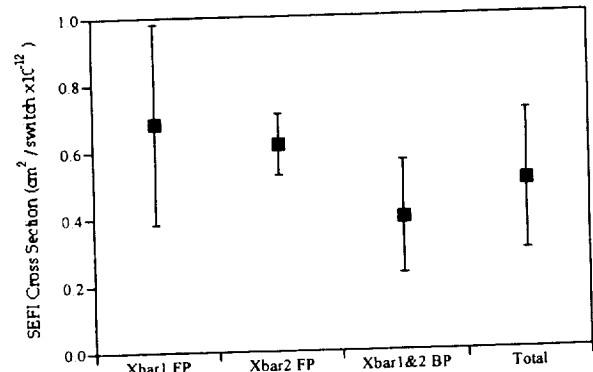


Figure 8. SEFI cross-section as a function of the location of the affected switch.

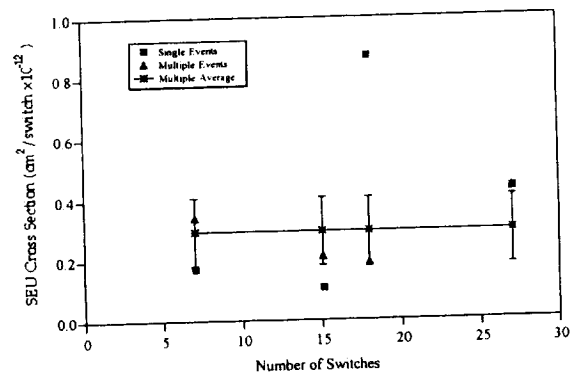


Figure 9. SEU cross section as a function of the number of switches for both single dropped packages as well as multiple dropped packages.

The same data as shown in Figure 9, can be viewed in another way by looking at the total cross section (both single and multiple package losses and not per-switch). This data is shown in Figure 10.

The two cases, with the lowest number of switches (the cases with only frontplane switches), have a cross section that is nearly an order of magnitude lower than the two cases with higher number of switches. Both of these higher switch



count cases have the full sixteen switches from the backplane incorporated in the path for the data packages. The highest switch count case does have a slightly higher cross section than the next lower case as it does contain nine additional frontplane switches (again, these cross sections are not per-switch).

This SEU data appears to imply that having the backplane switches in the data path will substantially increase the data package loss as compared to running without backplane switches. It is possible that there are physical differences between backplane and frontplane switches in dealing with packages that is not immediately evident from the Myricom documentation.

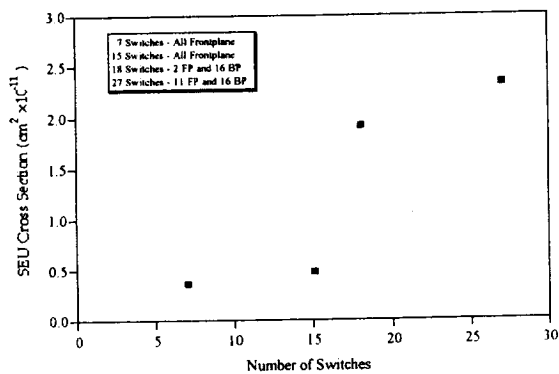


Figure 10. Total SEU cross section as a function of the number of switches with details of switch locations.

#### 4) Total Dose

As with the NIC, total dose testing was not explicitly included in the testing. However, proton dose is again accumulated over the course of the test on the crossbar switch devices (Xbar). No parametric measurements of the devices are feasible with this test setup. However, no functional loss or functional performance degradation was observed throughout this entire test. Therefore, it can be stated that the devices are total dose functionally survivable to at least the maximum proton dose during this test.

For this test setup, however, some amount of uncertainty exists for the dose levels of Xbar #2. This is because the proton beam passes through Xbar #1 and then the board for Xbar #1 before impinging on Xbar #2. While there is an unknown amount of material between the two switches, it does not appear to be substantial and it is assumed that the incremental doses on Xbar #1 are the same for Xbar #2 when it is in place (Xbar #2 is only used when more than seven switches are used in the routing). These dose levels for the two crossbar switch devices tested are 400 krads and 285 krads, for Xbar #1 and #2 respectively.

## V. SUMMARY

The Myricom Myrinet network system was evaluated for proton single event effects response. No indication of latchup was observed. Functional interrupts and data loss upsets were observed and their cross sections determined.

Total dose numbers seen during the testing indicate a good tolerance to total dose. Single event upset and functional interrupt rates were substantial and all interrupts required a power cycle to regain functionality. Further testing of this technology needs access to the bit level information to more accurately assess the single event upset sensitivity and the possibilities of any mitigation techniques.

## VI. REFERENCES

- [1] "American National Standard for Myrinet-on-VME Protocol Specification", VMEbus International Trade Association, ANSI/VITA 26-1998, November 2, 1998.
- [2] "Myrinet M3-SW16-8S Specifications", Myricom Web site: <http://www.myri.com/myrinet/m3switch/m3-sw16-8s/index.html>
- [3] "Myrinet NIC Specifications", Myricom Web site: <http://www.myri.com/myrinet/PCI64/m3s-pci64b.html>