Evaluation of Commercial Communication Network Protocols for Space Application

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Outline of Talk

- Introduction
  - Need and selection criteria
- Survey of Networks
  - Hardware
  - Software
  - Performance
- SpaceWire, Ethernet, FireWire and SFODB
  - Availability
  - Reliability (radiation effects)
  - Hardening approaches
  - Implementation

Introduction

Rational for Network Development

- Need for high-speed and reliable communications between scientific instruments, mass memory, computers and downlinks on spacecraft.
- Develop a network that will support equipment compatibility and reuse at both the component and subsystem levels so as to:
  - Reduce cost of development
  - Improve reliability
  - Increase amount of scientific work that can be done within a limited budget.
  - Simplify integration and test.
- ESA/ESTEC program European Cooperation on Space Standards (ECSS) and JPL (X2000) have selected different networks.

Introduction

Desirable features of a network

- Data rate – high (>100 Mbps)
- Power – low (LVDS)
- Scaleable – increase bandwidth by adding nodes
- Standards available – minimize development effort
- Complexity – simple to implement
- Robust:
  - Radiation hardened components
  - Redundancy

Network Communications Systems

Trade Space	*FireWire IEEE 1394*	*SpaceWire IEEE 1355*	*Ethernet IEEE 802.3*	*SFODB IEEE 1393*
Data Rate	400 Mbps	400 Mbps	100 Mbps	700 Mbps
Physical Layer	LVDS 172 to 265 mV swing	LVDS 1V to 1.5V swing	LVDS 1V to 1.5V swing	Fiber-Optic
Type	LAN	LAN	LAN	LAN
Topology	Tree Half Duplex	Point-to-point Full Duplex	Point-to-point Full Duplex	Ring Half Duplex
Cable Length (m)	4.5	10	10	Depends on speed
Control	Master/Slave	Nodes – Switch/Router	Nodes – Switch/Router	Token Passing
Specification status	Draft	Draft	Complete	Complete
Complexity		Limited test eqpt	Lots of test eqpt	No test eqpt
Redundancy	Not Inherent	Not Inherent	Not Inherent	Yes
Missions	NPP 2006 100 Mbps	Swift 2004 32 Mbps NGST 2010 140 Mbps	GPM 2009 10 Mbps	EO-1 Too late

Single Event Effects in Networks

Ionizing particle radiation produce two types of errors:

- **–"Soft" errors that do not stop communications**
- **–"Hard" errors that do stop communications (SEFIs)**

(Similar to microprocessor testing – registers and logic)

SpaceWire

IEEE 1355

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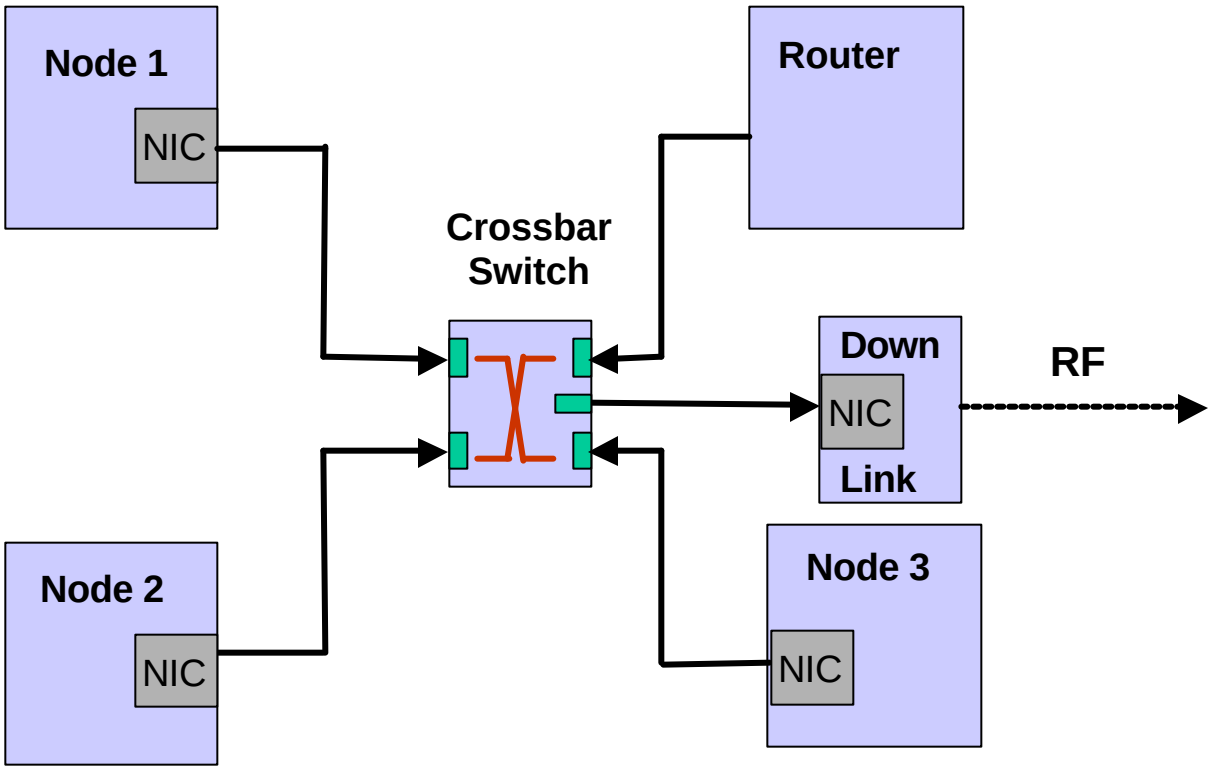
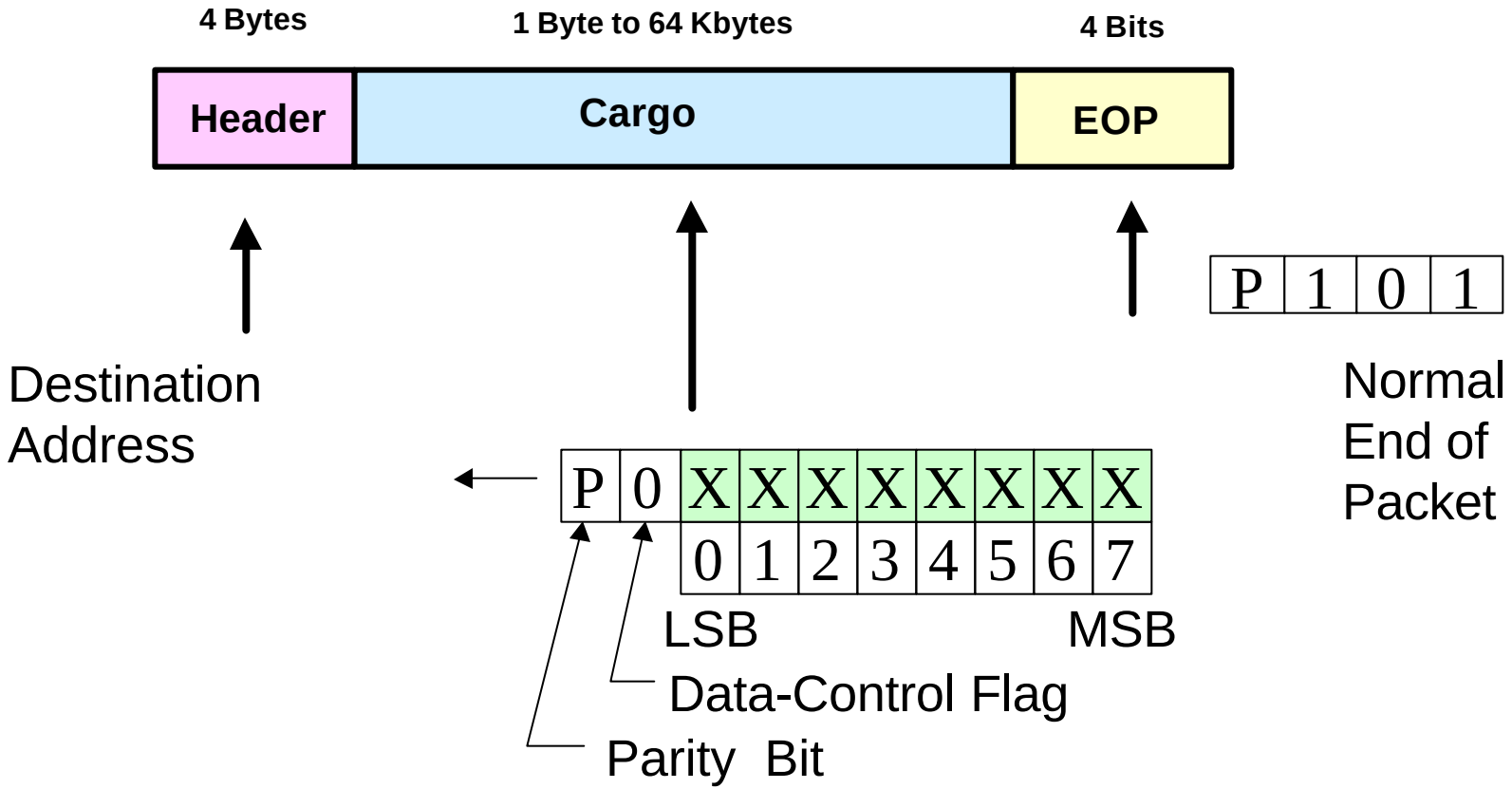
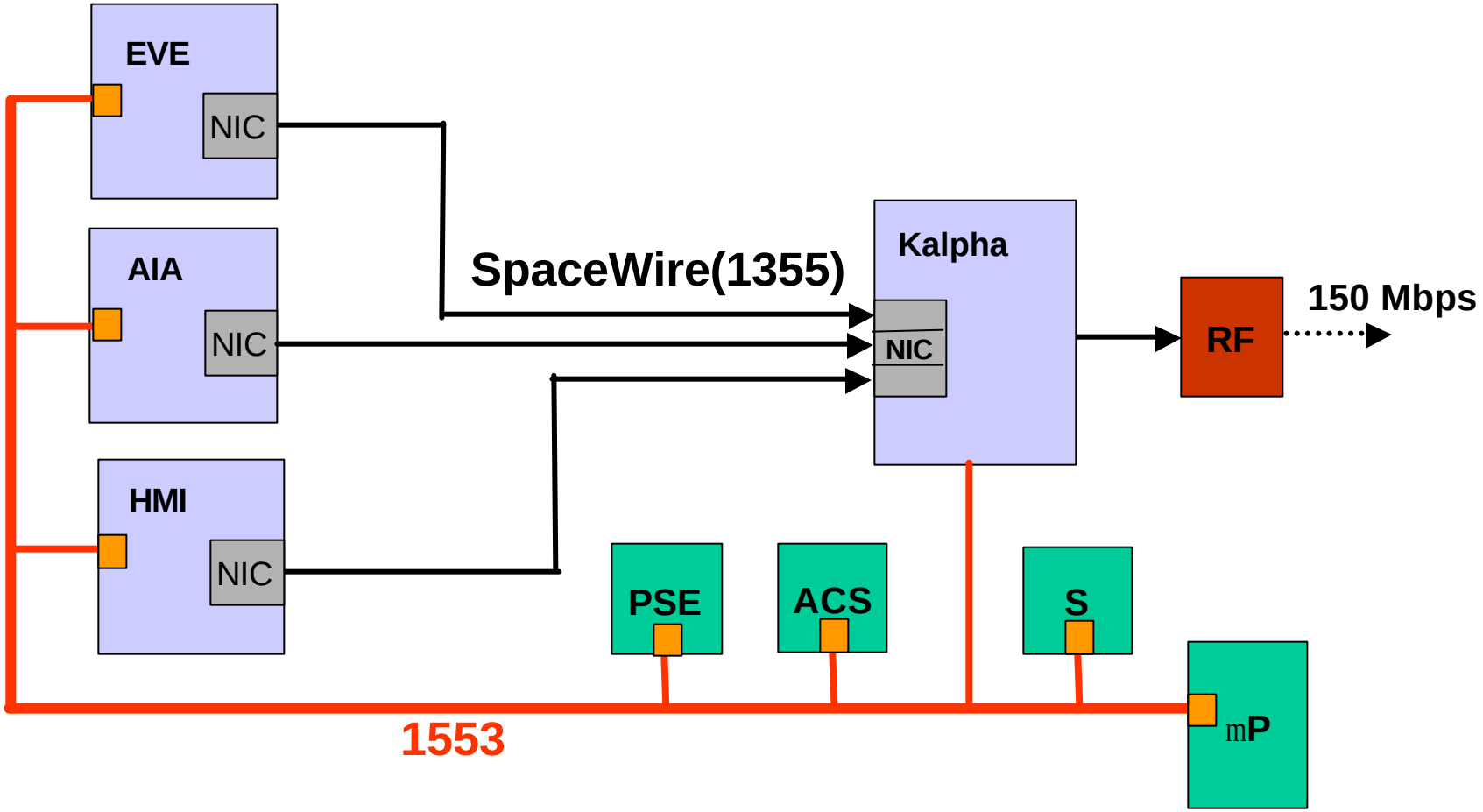
SpaceWire Topology



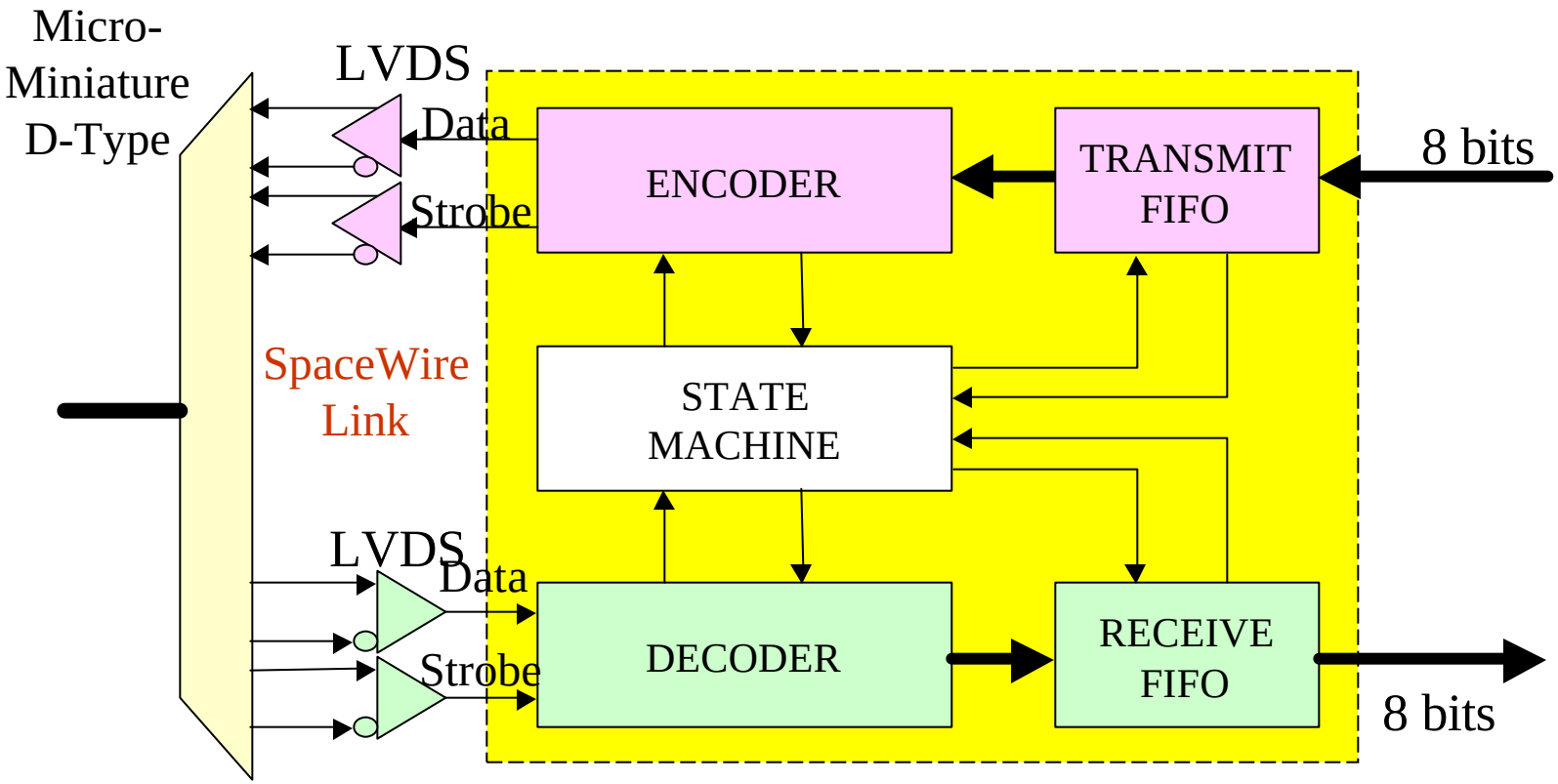
SpaceWire Packet



SpaceWire Topology for SDO



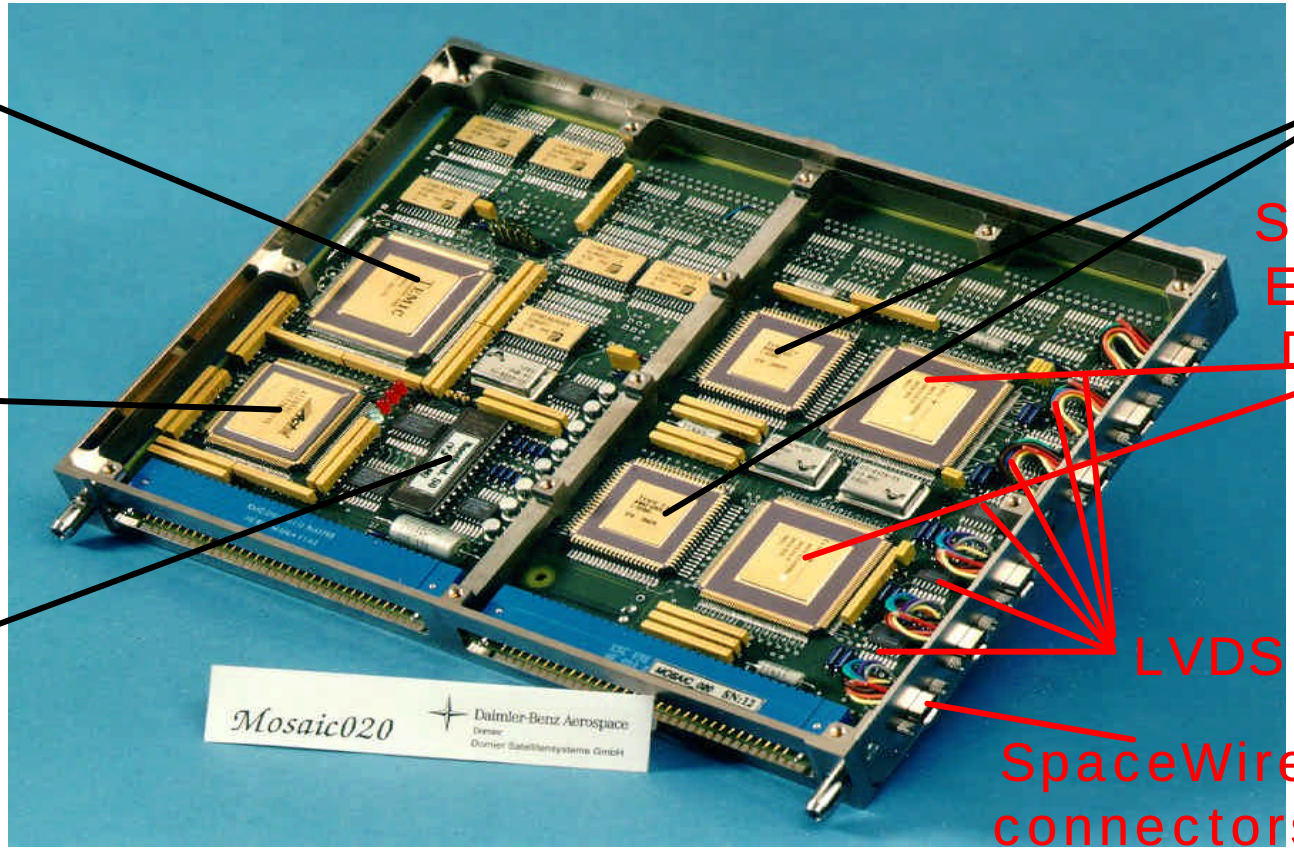
SpaceWire – Chip on NIC



Protocol Generator, FIFO and Drivers must be radiation hardened

Network Interface Card

In red : 1355 / SpaceWire related modules



SpaceWire

- Being developed by ESA/ESTEC and others.
- Serial digital links: Up to 400 Mbps (length not specified – depends on skew and jitter)
- Full duplex with 4 twisted pairs of wires (Data and Strobe)
- Low power (0.5 Watt per link interface for LVDS).
- Scaleable network - add bandwidth by adding cables – possible because of routing switches, at a price of increased complexity.
- Low latency, low cost (for commercial, but not for space).
- Suitable for integration into ASICs
- Packet level delimited by “end of packet markers” allows transmission of any kind of data in “cargo”.

SpaceWire

- Can recover from network failures. If no transition detected in 850 nsec., something went wrong => Links need to re-start, and they will re-synchronise
- Able to detect and recover from following errors:

  Link Errors:
  - Disconnect
  - Parity
  - Escape Error
  - Credit Error
  - Empty Packet Error

  Network Errors:
  - Link Error
  - Erroneous End-of-Packet received
  - Destination Address Error
- Not able to detect double-bit errors
- Not inherently redundant. Redundancy implemented by using switches providing alternate routes. Not available in FireWire and cumbersome to use in Ethernet.

SpaceWire

- NICS contain radiation-hardened Atmel ASICs designed by Astrium on 4Links Boards.
- Two types of Atmel ASICS – one and three channel
- TID>100 krads, SEL – none, SETs have LET threshold of ~20 MeV.cm^2/mg. PLL not tested
- Atmel no longer making these parts but has a supply for about 3 years.
- Can be implemented in other ASICS.

SpaceWire

Recent SEE Experimental Results

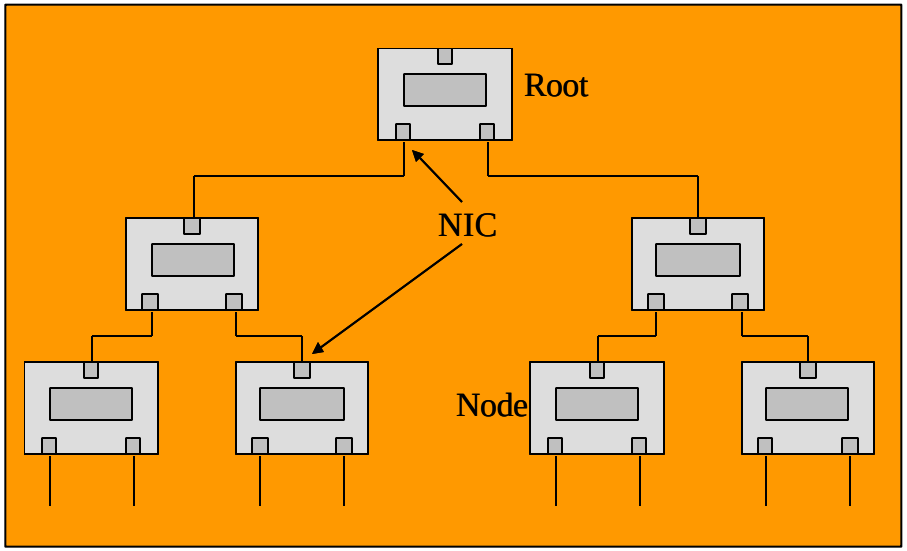
- Recent testing of ASIC included PPL.
- Two computers communicated with each other during testing.
- Errors were observed in both computers when the DUT was irradiated, regardless of whether the DUT was the master or the slave.
- Three types of errors with LET_{th} = 12 MeV.cm^2/mg:
  - data errors alone
  - loss of link alone
  - data errors together with loss of link
- Recovery involved manually restarting the software.
- One SEFI observed - required power reboot of both computers.

FireWire

(IEEE 1394)

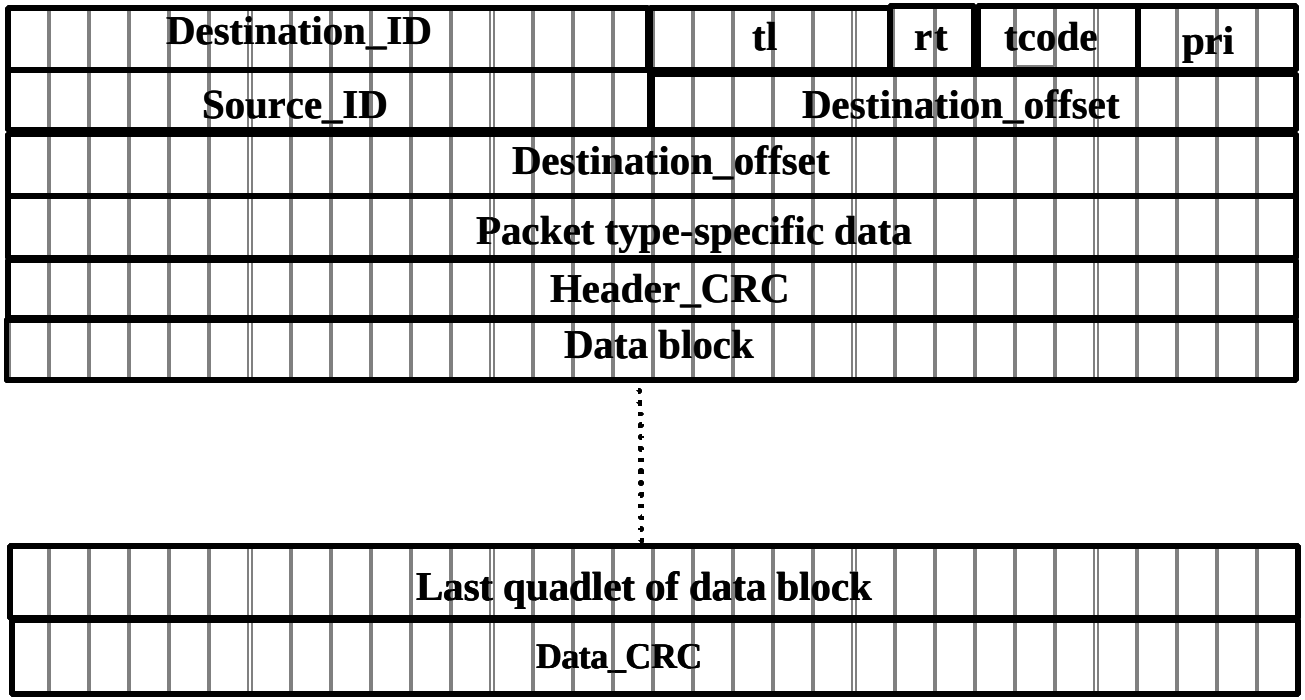
FireWire Topology

“TREE”



NPP Working on Redundant Version using two channels in a peer network.

FireWire Packet

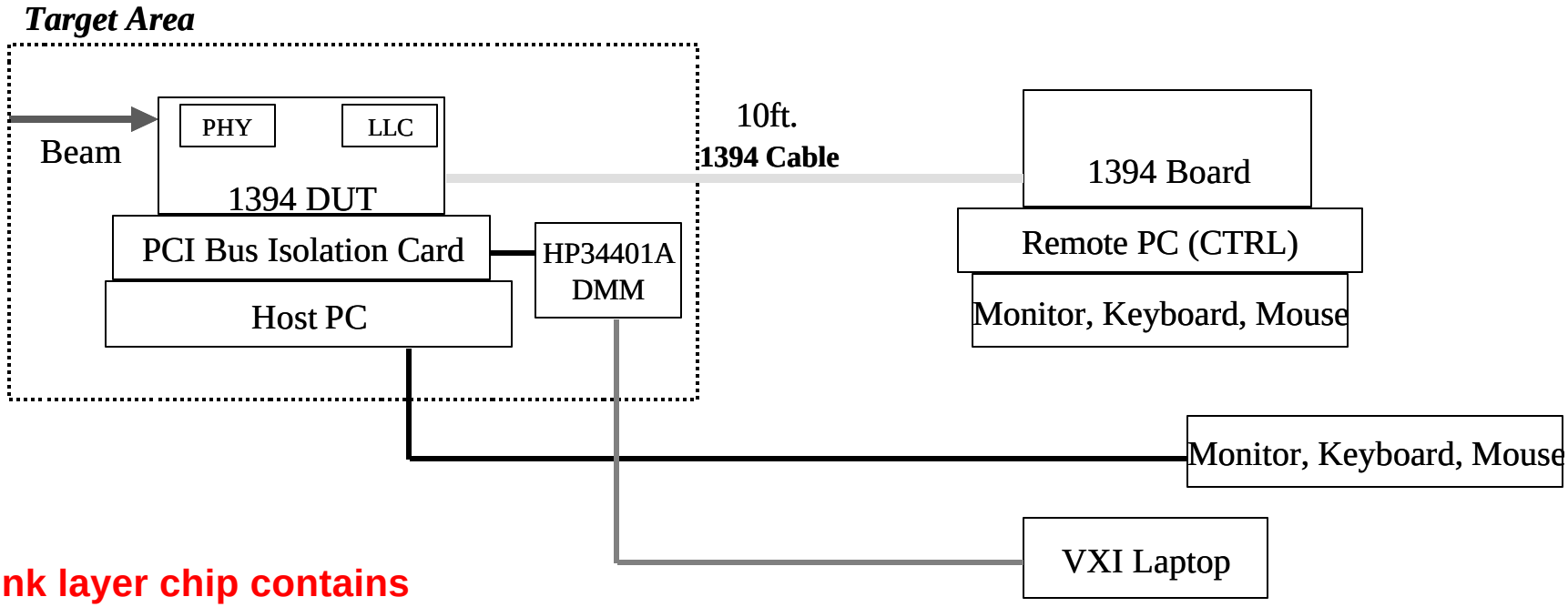


FireWire (IEEE 1394)

- Currently 100, 200, 400 Mbps.
- Relatively power hungry
- Half-duplex (cannot transmit and receive data at the same time) – limits bandwidth, similar to bus rather than network.
- Not scaleable, i.e., bandwidth does not increase when adding additional nodes – no routers or switches.
- Redundancy difficult to add but is being tried for NASA Program by using 2 parallel channels.
- X2000 program at NASA/JPL has selected it for future missions.
- Very complex and might be abandoned by NASA/GSFC
- Rad-hard version using Actel FPGA or UTMC ASICs.
- Attempts to increase bandwidth by using cables and backplanes – BAE makes a radhard backplane chipset.

FireWire Radiation Testing

Radiation Test Hardware Diagram



Link layer chip contains

- **102 OHCI registers**
- **22 PCI registers**
- **FIFO**

Physical layer chip contains 16 internal registers.

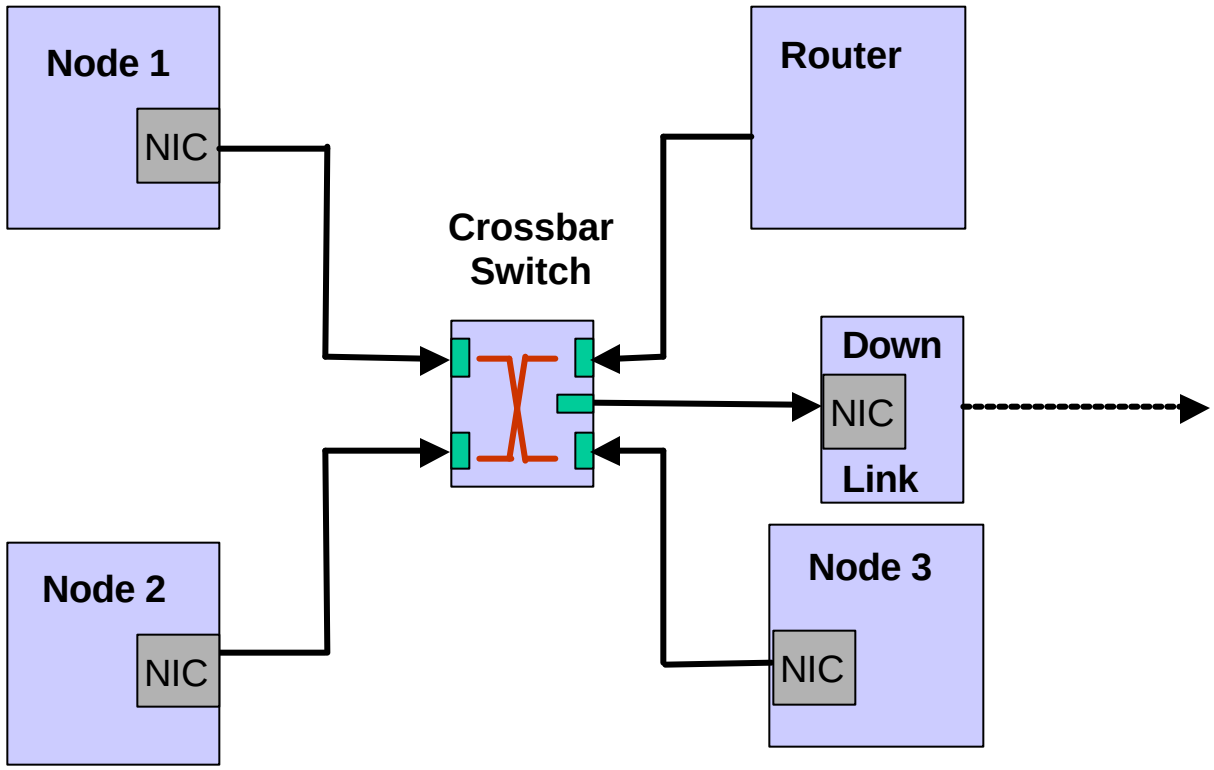
IEEE 1394 – SEE Test Results

Step	Action
1	SEU test loop restarted on CNTRL i.e. packet sent to DUT requesting register information.
2	Software bus reset, i.e., force CTRL to be root, initiate bus reset in the PHY, and reset Link to restore OHCI registers and flush FIFOs.
3	Reload Software application, which refreshes lockdown memory region shared by the software and hardware. Implies steps 2,1.
4	Controller cannot see the register data response packet. Power cycle the CNTRL followed by steps 3,2,1.
5	Disconnect/reconnect 1394 cable. Causes hard bus reset and tree ID process.
6	Step 5 followed by steps 3, 2, and 1.
7	Step 5 followed by cold rebooting only DUT followed by steps 3, 2, and 1.
8	Cold reboot DUT followed by steps 3, 2 and 1.
9	Reboot both CNTRL and DUT PCs, followed by steps 3, 2, and 1.

Ethernet

IEEE 1355

Ethernet Topology



Ethernet

- 100 Mbps – fixed
- Interface of choice for software because already developed.
- Scaleable due to switches and routers.
- Current status of development at NASA – breadboard operating at 10 Mbps, can do 100 Mbps
- Software drivers based on LINUX have been developed
- Radiation-hardened components selected:
  - Protocol chip FPGA (Actel)
  - Switch (Actel)
  - FIFO and SRAM (UTMC)
  - Drivers (UTMC)

Ethernet

- Error Handling:
  - CRC detected, drop packet (Best delivery effort)
- Redundancy:
  - Not inherent
  - GSFC is studying the feasibility of a redundant system with
    - 2 NICS at each node
    - 2 Switches
    - 2 Ethernets
- No radiation testing of Ethernet

Crossbar Switch

AD 8151

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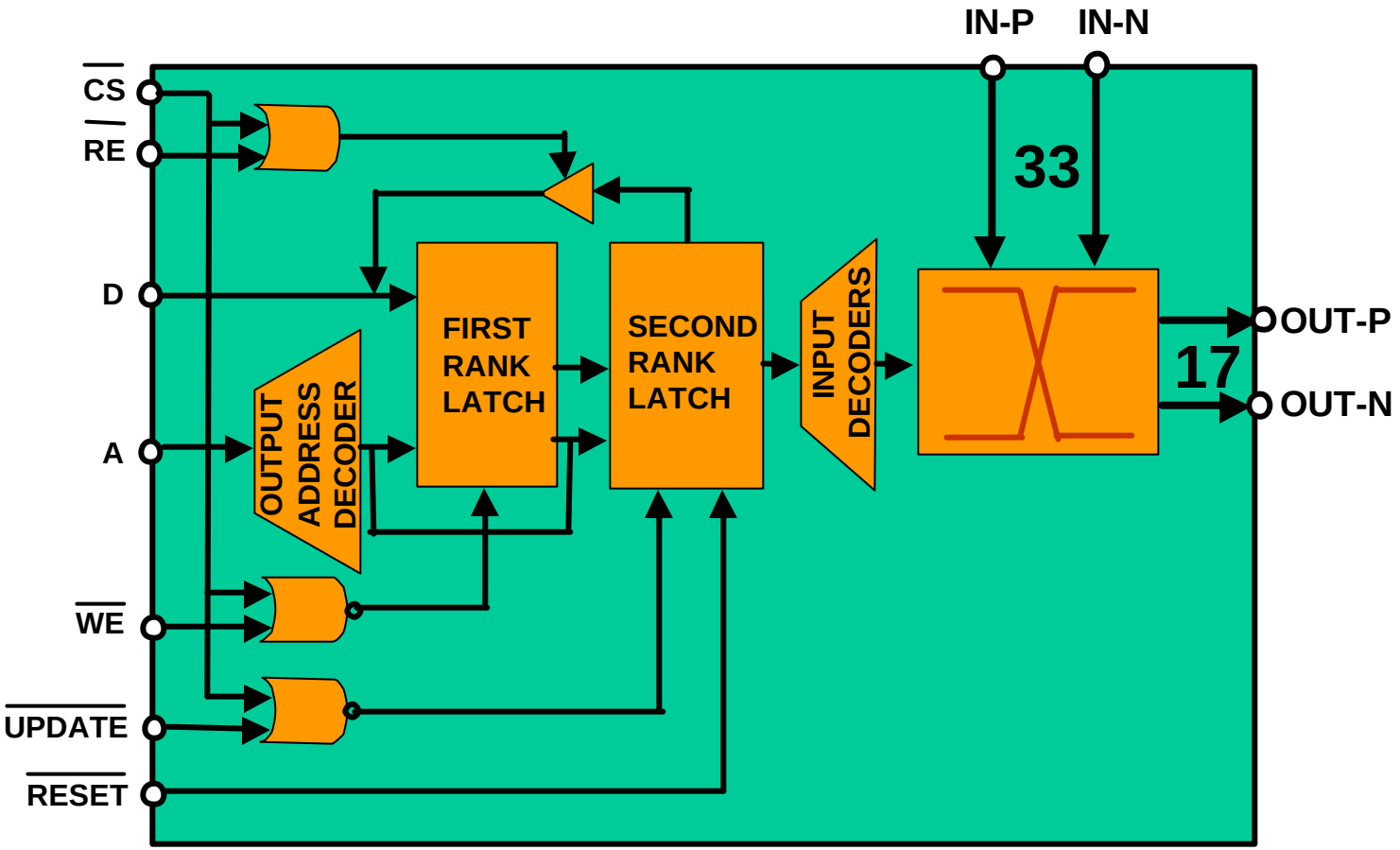
Crossbar Switch



Crossbar Switch – SEE Testing

- Two types of errors produced by proton and heavy ion irradiation:
  - SEFIs – required reprogramming latch to restart comm.
  - Bit errors that came in bursts of up to 30 bits – originated in switches, drivers and amplifiers. Effect depends where in the packet the bit errors occur.
- Bit error rate increased with increasing ion LET and with increasing data rate.
- Used pulsed laser to show that cross-section depends linearly on the number of connections between inputs and outputs.

Spaceborne Fiber Optic Data Bus

IEEE 1393

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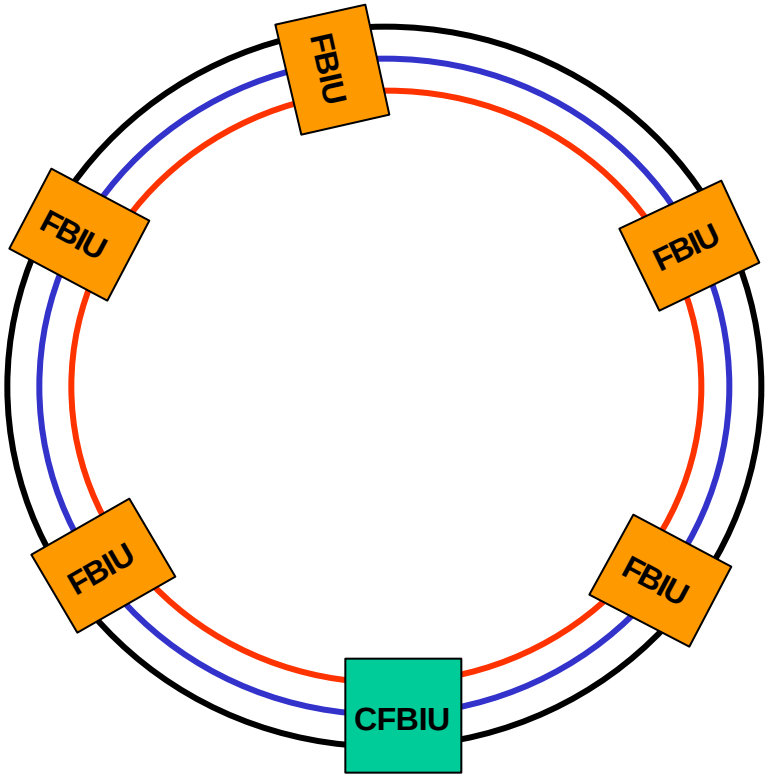
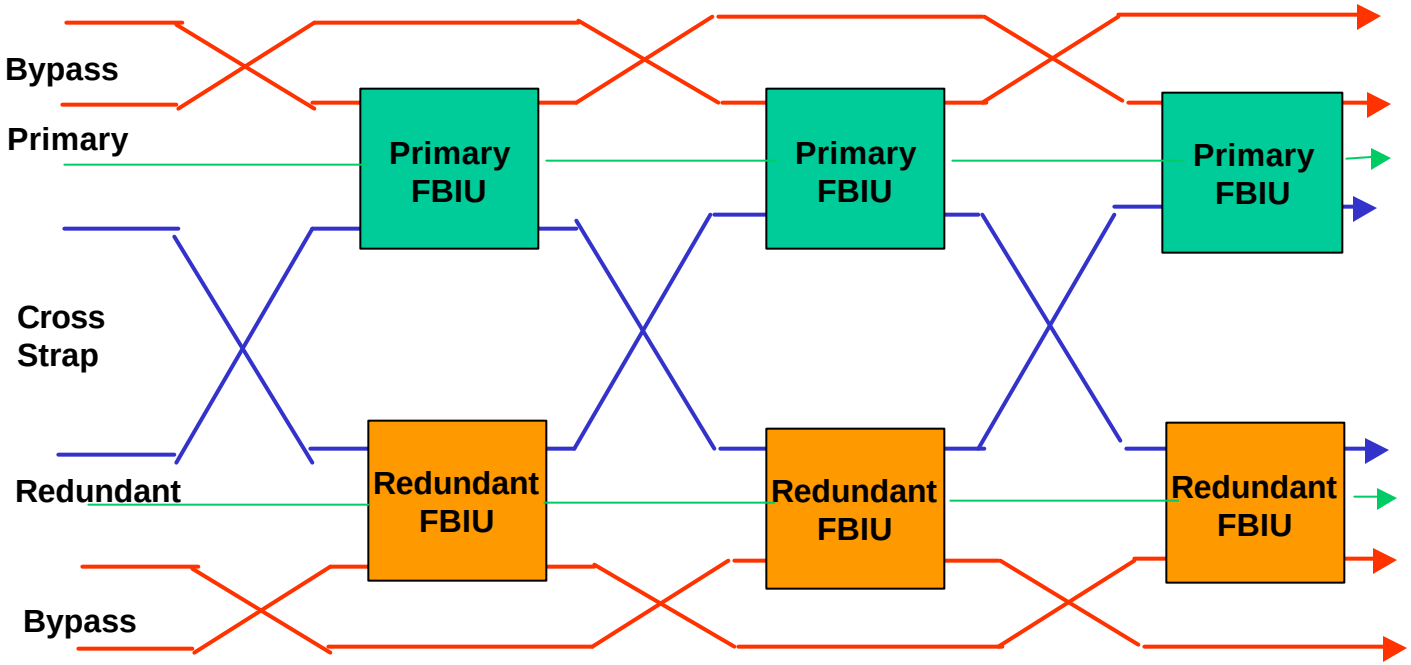
SFODB Topology

Redundant Ring with Cross Strap and Bypass Links



SFODB Topology



FBIU = Fiber Bus Interface Unit

Spaceborne Fiber Optic Data Bus SFODB – IEEE 1393

- Developed by NASA-GSFC and DoD.
- Redundant, cross-strapped Fiber-optic ring with passive bypass.
- Up to 127 nodes.
- IEEE 1393 standard.
- Up to 1 Gbps. Not fully duplex.
- Inherently redundant – 3 fibers cross-strapped.
- Frame consists of 32 slots. Each slot contains 3 bytes of control overhead and a 53-byte ATM Cell.
- Ring network with Token passing to establish control of network.
- Scaleable data rate – 200 Mbps to 1 Gbps

Spaceborne Fiber Optic Data Bus SFODB – IEEE 1393

- Fibers are Rad-Hard multimode graded index fibers (1300 nm).
- Optical receivers and VCSELS.
- Lack of funding to improve GaAs receivers lead to dropping of effort. Was being considered for EO1.
- No radiation testing of SFODB.

Summary

- Various high-speed networks are being modified for space at NASA/GSFC:
  - FireWire
  - SpaceWire
  - Ethernet
  - Spaceborne Fiber Optic Data Bus
- No clear leader at this time because each has its own particular set of advantages and limitations.