Proton-Induced Bit Error Studies in a 10 Gigabit per Second Fiber Optic Link

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Outline – Pushing the Speed Limit

• High speed fiber links for radiation environments
• Optoelectronics for a 10 Gbps serial link
• A ruggedized autonomous avionic testbed
• Proton Bit Error Rate (BER) test results
  – 10 Gbps Si bipolar mux/demux
  – High speed optoelectronics
• Serial versus parallel link proton BER comparison
Fiber Optics for Digital Satellite Links

- Power-efficient bandwidth
- Electromagnetically quiet
- Leverage with industry standards saves costs
- Growing base of radiation tolerant components and architectures
  - Low loss fibers available (single and multi-mode)
  - High optical power transmitters, e.g. VCSELS
  - Acceptable Bit Error Rate (BER) Receivers
Flexibility Imposes Choices

• Single mode versus multi-mode fiber and optoelectronic parts
  – Highest bandwidth links are forced to single mode operation
  – Multi-mode is subject to modal dispersion which increases BER
  – Single mode solutions have issues with ruggedization due to critical
    ~9 micron core alignments at optical interfaces

• Highly parallel multimode links solve link needs into the >10 Gbps regime- with the requirement of high speed mux and demux
  – E.g. Honeywell Ruggedized Link (C. Marshall, et al., NSREC 2001)

• We examine the speed/distance limits of serial multimode links
10 Gbps Serial Optoelectronics

- Vertical Cavity Surface Emitting Laser (VCSEL) transmitter
  - Focused Research, Inc. H6101-01
  - Bipolar Current Mode Logic (CML) differential inputs
  - AlGaAs operating in direct modulation at 850 nm wavelength
  - -5.8 dBm (50% duty) coupled into 50/125 multi-mode fiber pigtail

- GaAs p-i-n photodiode based receiver
  - Focused Research, Inc. H6111-02
  - 50/125 micron multi-mode fiber pigtail
  - Maximum sensitivity at 10 Gbps measured at -9.9 dBm
  - Bipolar CML differential outputs

- Link included a 100 meter length of 50/125 multimode fiber
10 Gbps Autonomous Testbed

- Fully custom board design provides freedom from “conventional” Bit Error Rate Test (BERT) equipment needs
- Altera APEX® FPGA provided 127 bit pseudorandom pattern generation along with received signal error checking and logging
- GIGA® Si bipolar mux/demux pair converted bussed CML LVDS “low speed” FPGA interface to SONET OC-192 rate at CML levels
10 Gbps Autonomous Testbed

- High speed enclosure contains Altera® FPGA, Focused Research® optoelectronics, and 100 meter NetOptics® BA226363 50/125 micron fiber with FC/FC connectors

- Clock generation and synchronization are described in the paper and fixed at the OC-192 rate of 9.953 Gbps
10 Gbps **Autonomous Testbed**

- A second enclosure provided power conditioning and PC-486 based control and error recording

- Apply 28 Volts and the test is under way!

- Autonomous and ruggedized operations successfully demonstrated in flight in an F-18 wing pod
Proton Test Configuration

- 63 MeV proton tests at UC Davis
- 100 meter fiber deployed for remote operation of the high speed board
- LabVIEW® interface to the PC-486 for error logging and stage control for DUT selection and angle adjustment
Proton Test Objectives and Results

- Characterize high speed bipolar and optoelectronic BER performance
  *without killing the demonstration*

- **GIGA® GD16585 bipolar multiplexer**
  - No degradation after 3.7 krad(Si)
  - 4 errors halted operation and required reinitialization
  - 22 single bit errors and a 36 error burst after $1.20 \times 10^{10}$ 63 MeV p/cm$^2$

  \[ \sigma = 1.8 \times 10^{-9} \text{ cm}^2 \]

- **GIGA® GD16584 bipolar demultiplexer**
  - No degradation after 2.07 krad(Si)
  - 11 single bit errors after $2.49 \times 10^9$ 63 MeV p/cm$^2$

  \[ \sigma = 4.4 \times 10^{-9} \text{ cm}^2 \]
Proton Test Results

• Focused Research® H6101-01 Transmitter
  – No degradation after 1.4 krad(Si)
  – Only 1 single bit error after $1.40 \times 10^{10}$ 63 MeV p/cm$^2$
    \[ \sigma = 7.1 \times 10^{-11} \text{ cm}^2 \text{ (limiting cross-section)} \]

• Focused Research® H6111-02 Receiver
  – No degradation after 9.1 krad(Si)
Serial versus Parallel 10 Gbps Comparison

- Focused Research® H6111-02 Receiver 63 MeV proton cross-sections

![Graph showing proton cross-sections vs incidence angle](image_url)
10 Gbps Serial versus Parallel Link

- Results are consistent previous work showing proton direct ionization
- On-orbit error rate prediction is problematic (CREME-96 is not well suited and other tools have not been validated – RADECS 2001 talk)
- Even so, it is possible to assess relative performance for proton induced errors for 10 Gbps serial versus 10 x 1 Gbps parallel links
  - A separate study (C. Marshall, et al., IEEE NSREC Workshop Proc. 2001) examined the 10 x 1 Gbps/channel Honeywell ruggedized link
- Data comparison must recognize the importance of BER dependence on the link’s optical power
10 Gbps Serial versus Parallel Link

- Cross-sections match when normalized to optical power per bit
  - Parallel link with 10 channels would expect ~ 10x the BER impact
10 Gbps multimode links show promise

- Results are consistent with previous BER analyses describing bit errors due to proton direct ionization in the link’s receiver
- 10 Gbps serial operation of a ruggedized optical link over 100 meters of multimode fiber has been demonstrated in flight experiments
- An autonomous testbed capability through test set design is key to flight demonstration and greatly simplifies radiation characterization
- Proton test results indicate very favorable error rates relative to other 10 Gbps parallel link solutions
  - This includes all high speed electronic and optoelectronic components
- Future plans include demonstration at high altitude in NASA’s WB-57 avionic testbed