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**

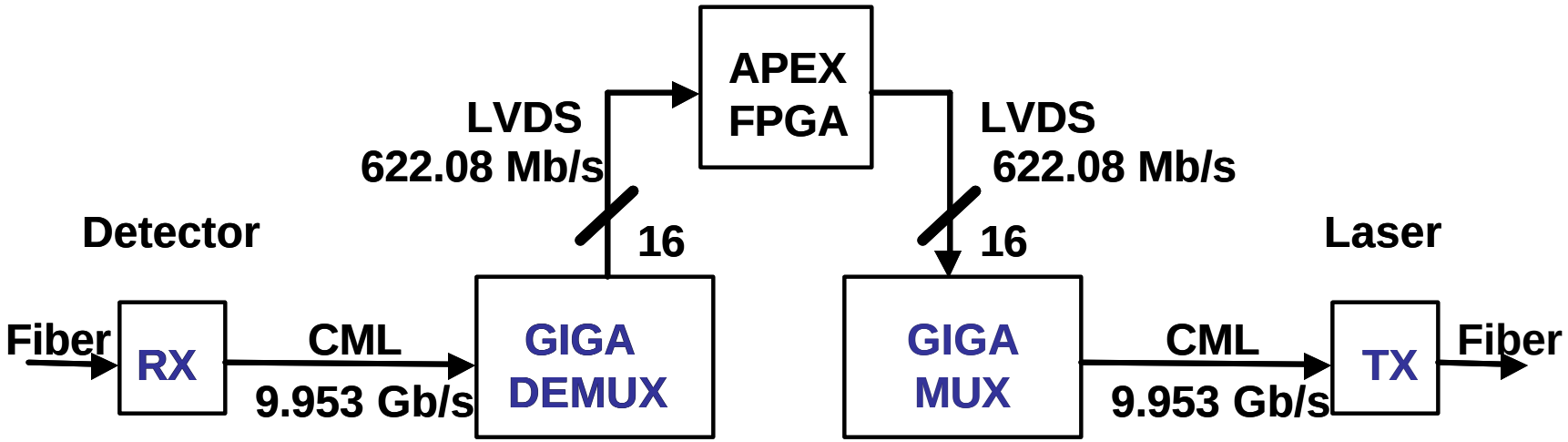
- **Highly parallel multimode links solve link needs into the >10 Gbps regime- with the requirement of high speed mux and demux**
  - **E.g. Honeywell Ruggedized Link (C. Marshall, et al., NSREC 2001)**

- **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**

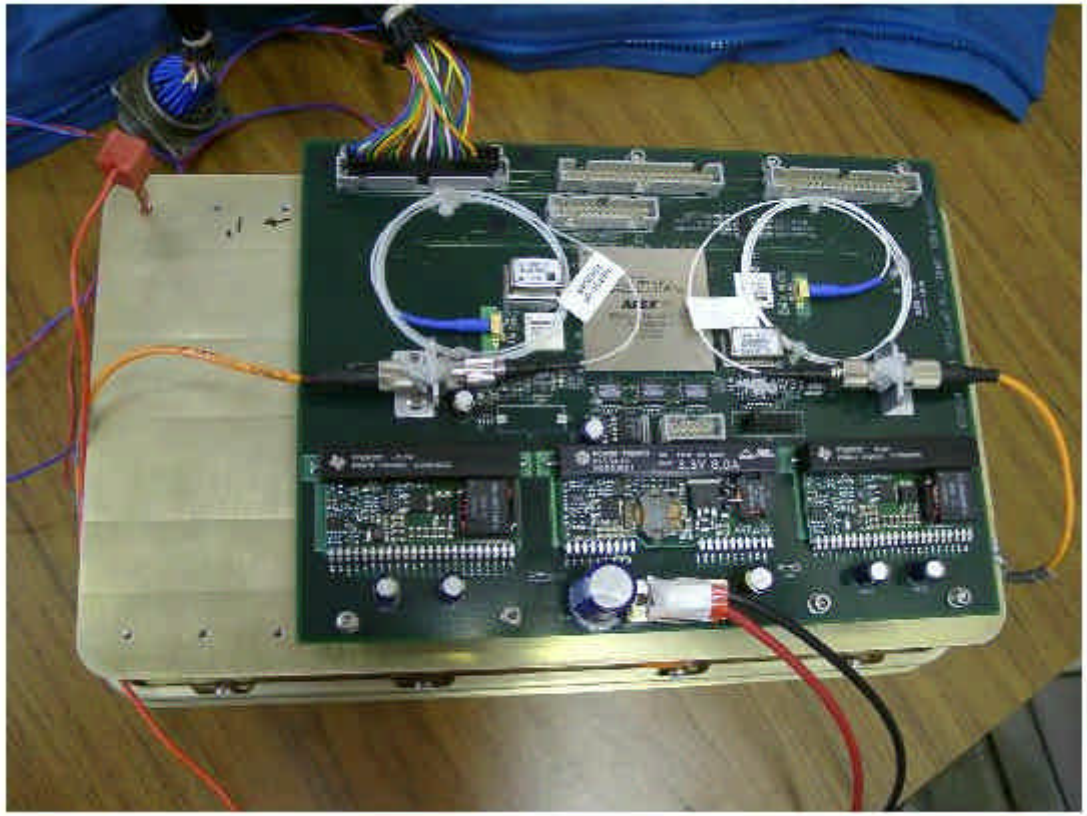
10 Gbps Autonomous Testbed



- 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

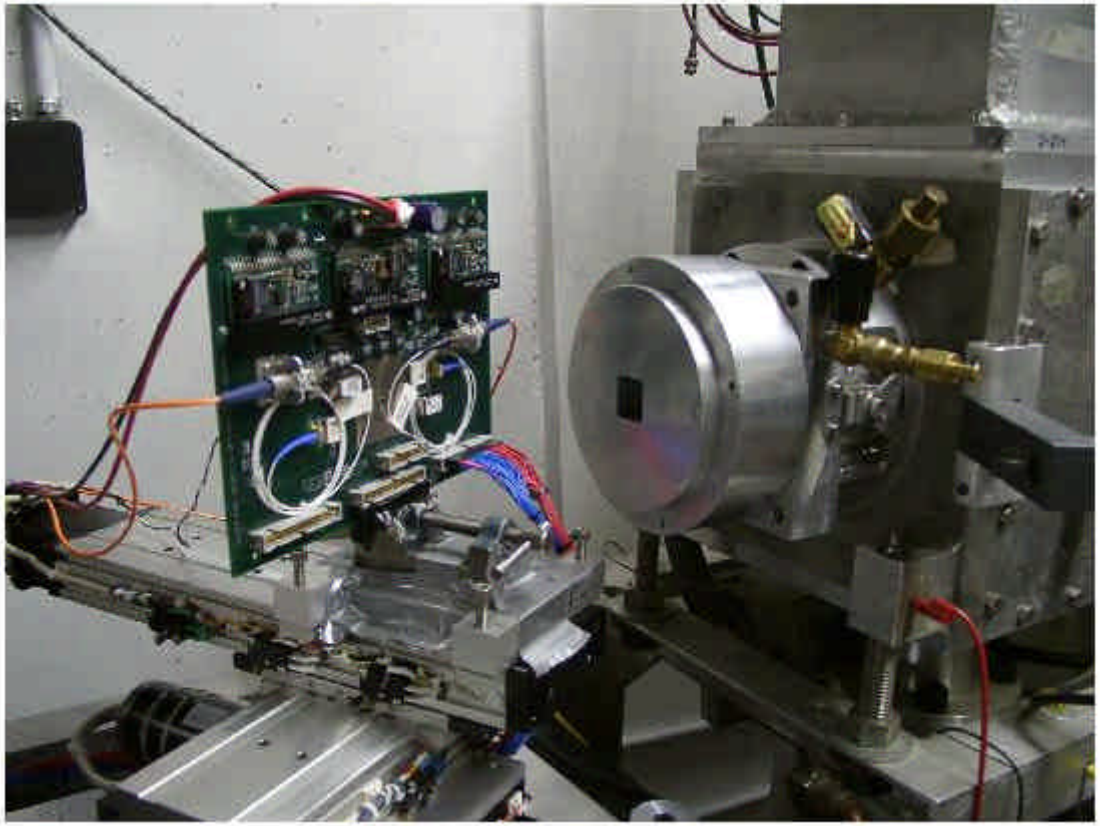
- **A second enclosure provided power conditioning and PC-486 based control and error recording**

- **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 1.20×10^{10} 63 MeV p/cm^2**

    $S = 1.8 \times 10^{-9}$ cm^2
- **GIGA® GD16584 bipolar demultiplexer**
  - **No degradation after 2.07 krad(Si)**
  - **11 single bit errors after 2.49×10^{9} 63 MeV p/cm^2**

    $S = 4.4 \times 10^{-9}$ cm^2

Proton Test Results

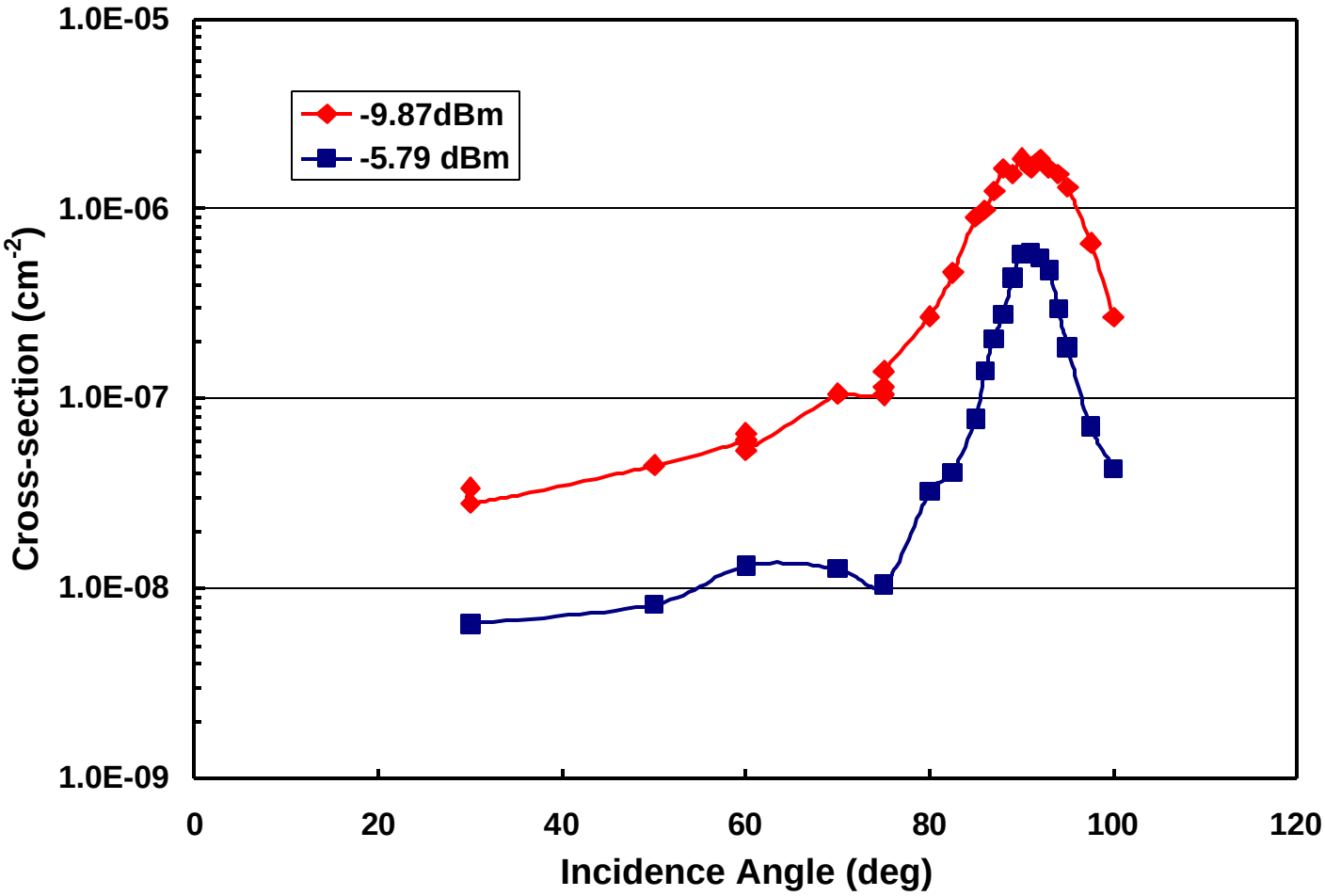
- **Focused Research® H6101-01 Transmitter**
  - **No degradation after 1.4 krad(Si)**
  - **Only 1 single bit error after 1.40 x 10^{10} 63 MeV p/cm^2**

    σ = 7.1 x 10^{-11} cm^2 (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**

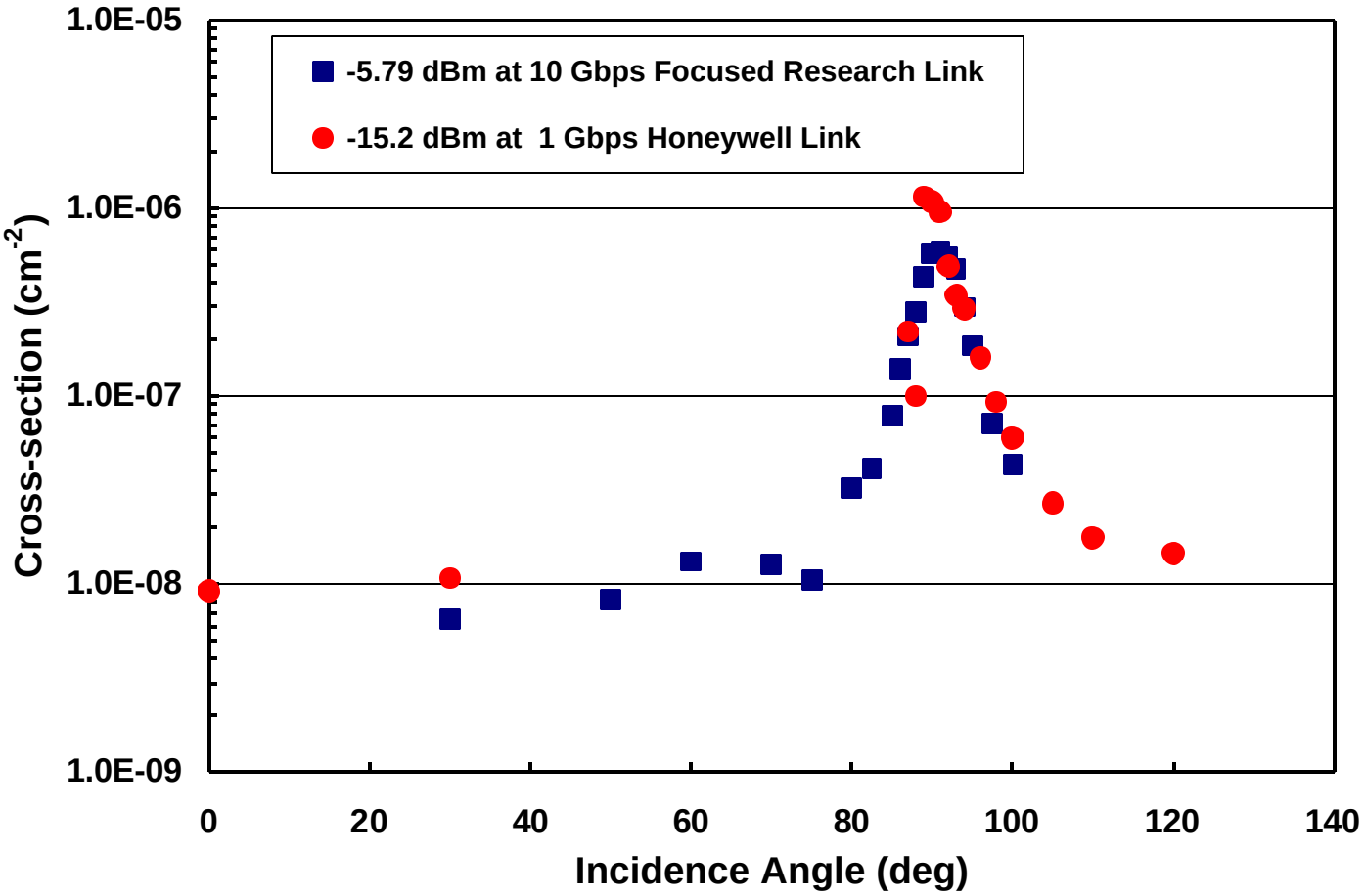


10 Gbps Serial versus Parallel Link

- **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**