

# Characterization of Transient Error Cross Sections in High Speed Commercial Fiber Optic Data Links

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## Abstract

This paper presents data on the single event transient (SET) response of several high speed commercial fiber optic links (FOLs). We show that commercial-grade technologies may be robust to SET in the natural space environment encountered in many satellite missions even for data rates in the 1 Gbps regime. In addition to characterizing the error cross section as a function of optical power and data rate, the angular dependence of the SET behavior is also quantified as a function of optical power. Note that receiver angular response has some similarity to behavior observed in optocoupler technology and must be quantified for accurate predictions of on-orbit link error rates [1,2].

## I. INTRODUCTION

Tremendous effort has been invested into the demonstration, radiation hardening, and the transition of FOL technology to the commercial and military sectors for data transfer on board satellites [3-5]. In addition, protocol standards issues have been actively addressed to make sure the interests of the space community are represented. The first aggressively hardened hardware for the medium data rate busses, and the second generation hardware for the AS 1773 1/20 Mbps busses are now available. The Boeing transceiver is currently flying on the MPTB space experiment, and the on-orbit SEE results demonstrate the viability of this technology even in a demanding orbit [6].

In recent years, we have also evaluated a number of higher speed (up to 1 Gbps) commercial links, some of which are expected to be suitable for missions with requirements below  $\sim 30$  krad(Si) [7,8]. The use of vertical cavity surface emitting lasers (VCSELs) in commercial FOLs provides enhanced performance from a commercial yet very robust technology. In this paper, we present the latest 63 MeV proton-induced error cross section data for four links that show promise for many satellite missions:

1. Honeywell Ruggedized Link (12 channels at 1.062 Gbps per channel with 850 nm VCSEL array transmit / 850 nm GaAs p-i-n array receive).
2. Hewlett-Packard HFBR-53D5, a Gigabit Ethernet transceiver with 850 nm VCSEL, Si p-i-n detector, and a Si bipolar transimpedance amplifier (TIA).
3. Lasermate TTC-155M4, a 155 Mbps transceiver (850 nm VCSEL transmit / 1300 nm receive)
4. Lasermate TTC-155M2, a 155 Mbps transceiver (850 nm VCSEL transmit / 850 nm Si p-i-n receive).

## II. EXPERIMENT DESCRIPTION

Tests were performed at the Crocker Nuclear Laboratory Cyclotron Facility at the University of California at Davis. The beamline has been described previously[5]. The dosimetry measurement uses a 5-foil secondary emission monitor calibrated against a Faraday cup. Ta scattering foils located several meters upstream of the target establish a beam spatial uniformity of 15% over a 2 cm radius circular area. We employed a 67 MeV internal tune that is degraded to 63 MeV as it passes through the scattering foil, the beamline exit window, and reaches the device under test. Beam currents from about 5 pA to 50 nA provided proton fluxes from  $10^6$  to  $10^{11}$  protons/cm<sup>2</sup>/s. For *in-situ* measurements of data transmission with bit periods of only a few ns, one must consider the beam temporal structure and its relation to the data stream. We have examined the impact of the 22 MHz cyclotron frequency (at 67 MeV) that provides micro-pulses of approximately 1.3 ns duration every 44 ns. The experiments are conducted in a manner to assure the beam microstructure did not influence bit error cross section measurements.

### A. Honeywell Ruggedized Parallel Link

Proton testing was performed with a transmitter and receiver board configured as shown in Figure 1. Bit error cross sections were measured using a commercial 4 GHz bit error rate tester (BERT) from Synthesis Research, Inc. The bit error rate was measured as a function of optical power, data rate and incident proton

angle. Angular control of the transceiver was achieved using an automated 4-axis stage. The optical power was varied by placing an optical attenuator in between the transmitter and receiver, and was monitored by an external lightwave meter. The proton radiation response of both the transmit and receive circuitry was evaluated.

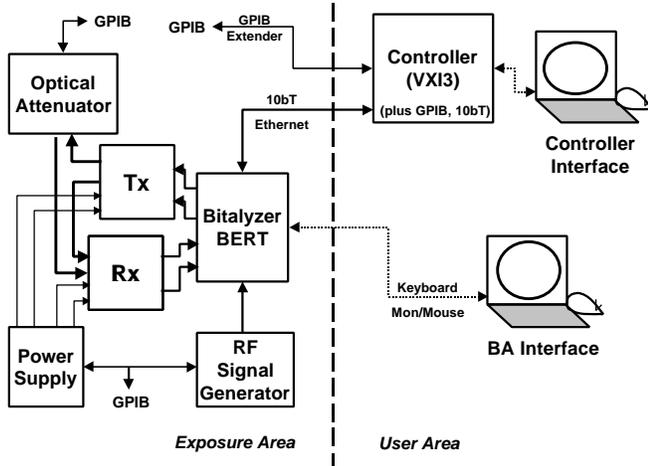


Figure 1 Test configuration for Honeywell Ruggedized Link. The MT connector on both the detector and source arrays were joined to ST single multimode fiber connectors in order to insert a variable optical attenuator between the transmitter and receiver, and to permit independent testing of the 12 parallel optical links.

### B. Hewlett-Packard and Lasermate FOLS

These tests were configured with a pair of transceivers on a card connected with multi-mode optical fiber. ECL inputs and outputs connected the link with a commercial BERT from Broadband Communications Products, Inc. that generated a serial pseudorandom numeric (PN) sequence of  $(2^7-1)$  bits in length. The bit error rate was measured as a function of optical power, data rate and incident proton angle as described above. With protons incident on a given transceiver, we monitored the BER and the number of errors. Measurements of BER were typically made with  $> 100$  total errors to assure good statistics. This usually covered a time interval of minutes, and the error free interval feature provided information to assure that we were monitoring individual events and not contiguous errors from a single strike.

## III. EXPERIMENTAL RESULTS

### A. Honeywell Ruggedized Link

Proton testing of the parallel 850 nm Honeywell Ruggedized Link was performed at the UC Davis cyclotron facility using the 4 Gbps bit error tester from Synthesis Research, Inc. The bit error characterization

was performed as a function of optical power, data rates (up to 1.2 Gbps per channel) and incident proton angle. During testing, we operated well above the theoretical noise floor (estimated to be on the order of -27 dBm at 1 Gbps).

We see in figure 2 that the error cross section decreases dramatically with increasing optical power. This trend is independent of data rate and is characteristic of receivers with automatic gain control circuitry. At lower optical power levels, the error cross-section approaches the physical area of the  $80 \mu\text{m}$  diameter GaAs p-i-n diode. A GaAs diode was selected for this link in order to achieve a lower error cross section for a given optical power as compared to a Si detector as explained in [9]. Measurements on a second ruggedized link showed no significant variations.

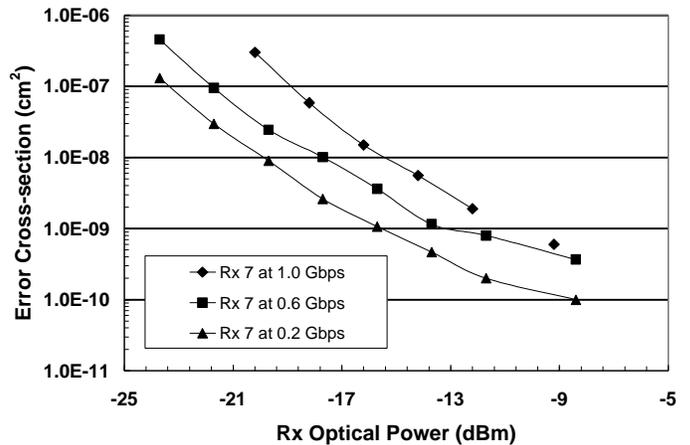


Figure 2 The error cross section decreases dramatically with increasing optical power, and increases with increasing data rate. This trend is exploited to mitigate the on-orbit bit error rate.

Figure 3 illustrates the significant increase in error cross section versus incidence angle for three levels of optical power. The sizeable increase around grazing incidence is present at all levels of incident optical powers, and the enhancement factor between optical powers is roughly independent of incidence angle. This behavior is very similar to previous results in fiber optic link receivers and also to high speed optocoupler diode based receivers [1,2]. As explained in [1], this follows from the upset sensitivity of the link to direct ionization from protons, and demonstrates the increase in the effective LET with angle. Such data is essential for performing on-orbit bit error rate calculations that are also described in [1,2].

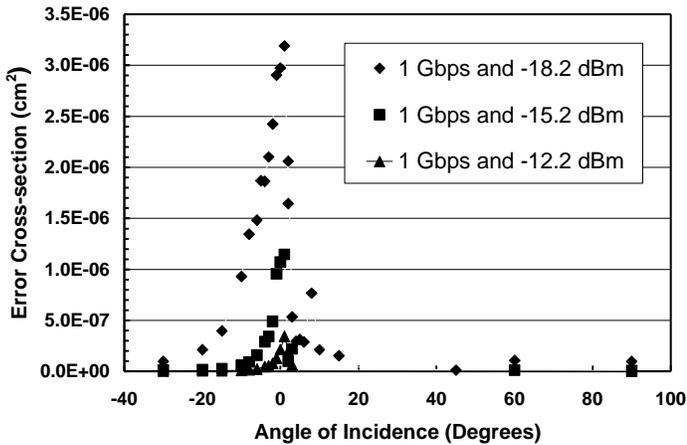


Figure 3 The dramatic increase in error cross section versus incidence angle is present at all levels of incident optical powers. At zero degrees, the proton traverses the plane of the detector and the maximum path length is obtained.

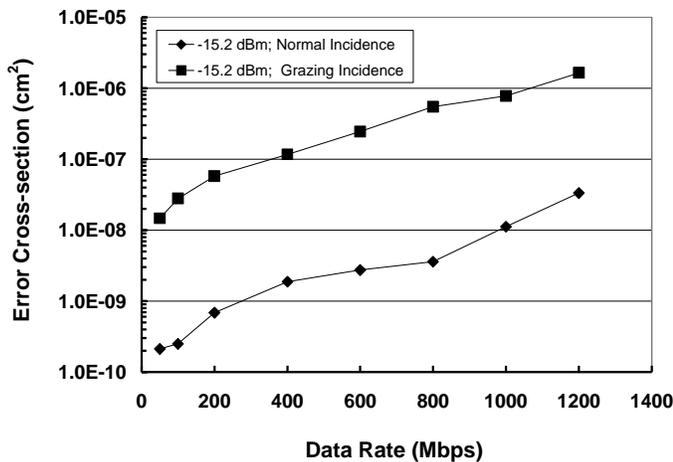


Figure 4 The trend of increasing error cross section with data rate is expected, but we do not know a reason for the greater-than-linear increase. Similar trends were observed for both normal and grazing incidence angles.

In figure 4, the trend with increasing data rate is compared at normal versus grazing incidence and appears similar for the two angles. Generally, we observe an approximately linear increase with data rate for fiber data links, but note a greater than linear trend in this case. The data appear well-behaved indicating that both the packaged part and test set are broadband, so that bandwidth limitations has not affected the data. (The transceiver chips were manufactured by Helix.)

Other highlights of the test results are:

1. The VCSEL based transmitter is immune to single event effects, and did not show any signs of radiation-induced degradation to a 63 MeV total ionizing dose (TID) of 77 krad(Si).
2. The receiver functioned well throughout testing to an integrated TID of 259 krad(Si) with the noise floor remaining constant to within  $\sim 0.5$  dB.

## B. HP and Lasermate FiberChannel Data Links

Generic (no higher protocol) proton SET tests on three high-speed fiber link transceivers. In each case, the nominal optical power incident on the receiver diode is 10.5 dBm (no attenuation inserted in the link).

### 1) HP HFBR-53D5 Transceiver

Extensive 63 MeV proton testing of this optical fiber based transceiver indicate that the bit error cross section is dominated by the photodiode. As seen in figure 5, the error cross section increased approximately linearly with data rate, and decreased with increasing incident optical power ( $\sim 10X$  increase in cross section for a 10 dB increase in incident power). Significant increases in the error cross section were observed for protons incident on the receiver photodiodes at grazing angles as illustrated in figure 6. The qualitatively different angular dependence as a function of optical power can be explained in terms of the threshold for upset sensitivity by proton ionization, and will be described in the final paper. No catastrophic failures were observed to an exposure level of  $\sim 25$  krad(Si) at 63 MeV.

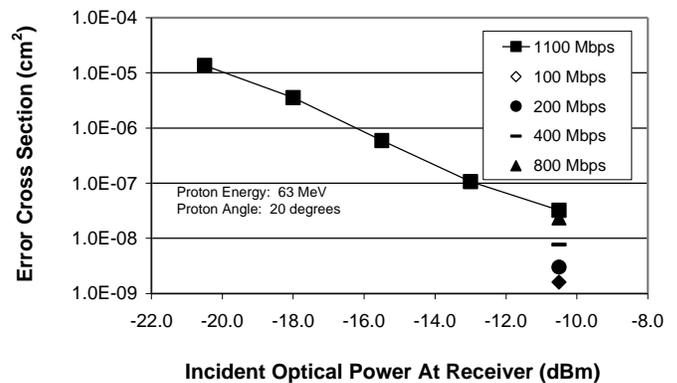


Figure 5 HP HFBR-53DE transceiver bit error cross section versus optical power and data rate. Sensitivity of receiver at 1.1 Gbps (i.e. lowest optical power with no errors in 1 minute of operation, yielding a limiting error rate of  $1.5E-11$ ) is  $-21$  dBm.

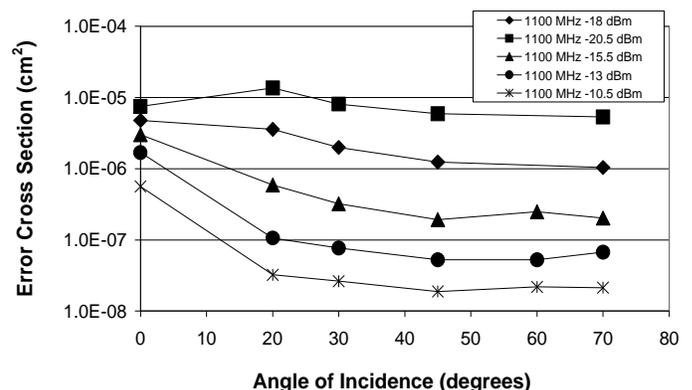


Figure 6 HP HFBR-53DE transceiver bit error cross section versus incident proton angle and optical power.

## 2) Lasermate TTC-155M2 & TTC-155M4 Transceivers

Qualitatively similar trends in the error cross sections versus optical power, data rate and incident proton angle were obtained for both the HP and Lasermate transceivers. Figures 7 and 8 provide a summary of the bit error cross section versus optical power for the two Lasermate optical links. In the full paper, we will also provide the error cross section results as a function of data rate and incident proton angle for both Lasermate transceivers which performed well up to a total ionizing dose level of  $\sim 25$  krad(Si) from the integrated 63 MeV proton exposure.

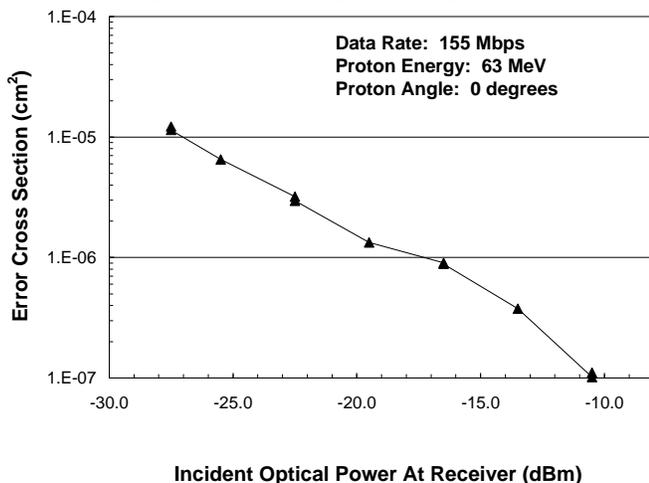


Figure 7 Error cross section versus optical power for Lasermate TTC-155M4 (850 nm VCSEL transmit /1300 nm receive) FOL. Sensitivity of receiver at 1100 Mbps (i.e. lowest optical power with no errors in 1 minute of operation, yielding a limiting error rate of  $1.5E-11$ ) is -21 dBm.

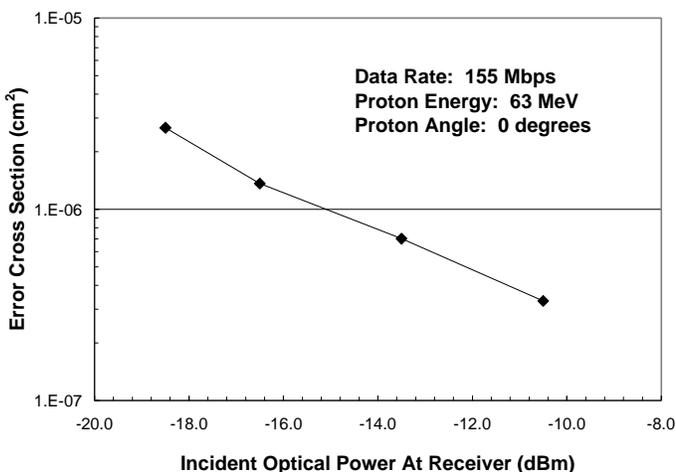


Figure 8 Error cross section versus optical power for Lasermate TTC-155M2 (850 nm VCSEL transmit/ 850 nm Si p-i-n receive) FOL. Sensitivity of receiver at 1100 Mbps (i.e. lowest optical power with no errors in 1 minute of operation, yielding a limiting error rate of  $1.5E-11$ ) is -20.5 dBm.

## IV. CONCLUSIONS

Commercial optical fiber-based Ethernet 1.062 Mbps data links are readily available with reasonable bit error cross sections and total ionizing dose hardness levels sufficient for many satellite missions. Parallel links using VCSEL and GaAs p-i-n arrays operating at 1.062 Gbps/channel provide a promising path to achieve very high data throughput in a robust data link.

## V. REFERENCES

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