Lessons Learned in Microelectronic and Photonic Test Bed (MPTB) Flight Experiment

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ABSTRACT

We present the experiences and lessons learned in design and implementation of NASA GSFC's Dual Rate 1773 (DR1773 or AS1773) Experiment on the Naval Research Laboratory's (NRL) Microelectronic and Photonic Test Bed (MPTB). This includes radiation effects testing, design parameters and possible design recommendations for future consideration.

INTRODUCTION

NASA first began using fiber optics for spaceflight with the MIL-STD-1773 data bus on board the Solar Anomalous Magnetospheric Particle Explorer (SAMPEX), launched in July 1992 [1]. Since that time, the 1773 bus has flown successfully on NASA GSFC missions including the X-Ray Timing Explorer (XTE), Tropical Rainfall Measuring Mission (TRMM) and the Hubble Space Telescope [2]. The AS1773 bus standard, created by the Society of Automotive Engineers (SAE) Avionics Systems Division (ASD) [3], is derived from the MIL-STD-1773 fiber optic data bus and incorporates a reduced radiation-induced bit error rate (BER) as well as implementing a 1 and 20Mbps dual rate capacity. The MPTB, launched in late 1996, proved to be a great opportunity to collect radiation effects data on the AS1773 bus in a harsh radiation environment. The flight experiment has been flying and providing in flight data continuously for more than 5 years. This paper presents some of the lessons learned during the design and implementation of the DR1773 flight experiment. These lessons include discussions of SEUs during ground irradiation and for spaceflight data as well as design considerations.

AS1773 Description and Background

The AS1773 is derived from the MIL-STD-1773 fiber optic data bus which operates at a single data rate of 1Mbps. MIL-STD-1773 is the fiber optic equivalent of the all-electrical MIL-STD-1553 bus using the same communication protocol but a different physical transmission medium. AS1773 maintained the 1773 and 1553 logical protocol heritage, but added greater bandwidth capability by introducing the 20Mbps operation in addition to the 1Mbps 1773 standard [3]. Figure 1 shows the AS1773 A bus in its full capacity 32 node configuration. AS1773 is a star coupled dual redundant bus utilizing two 32x32 buses in its full implementation.

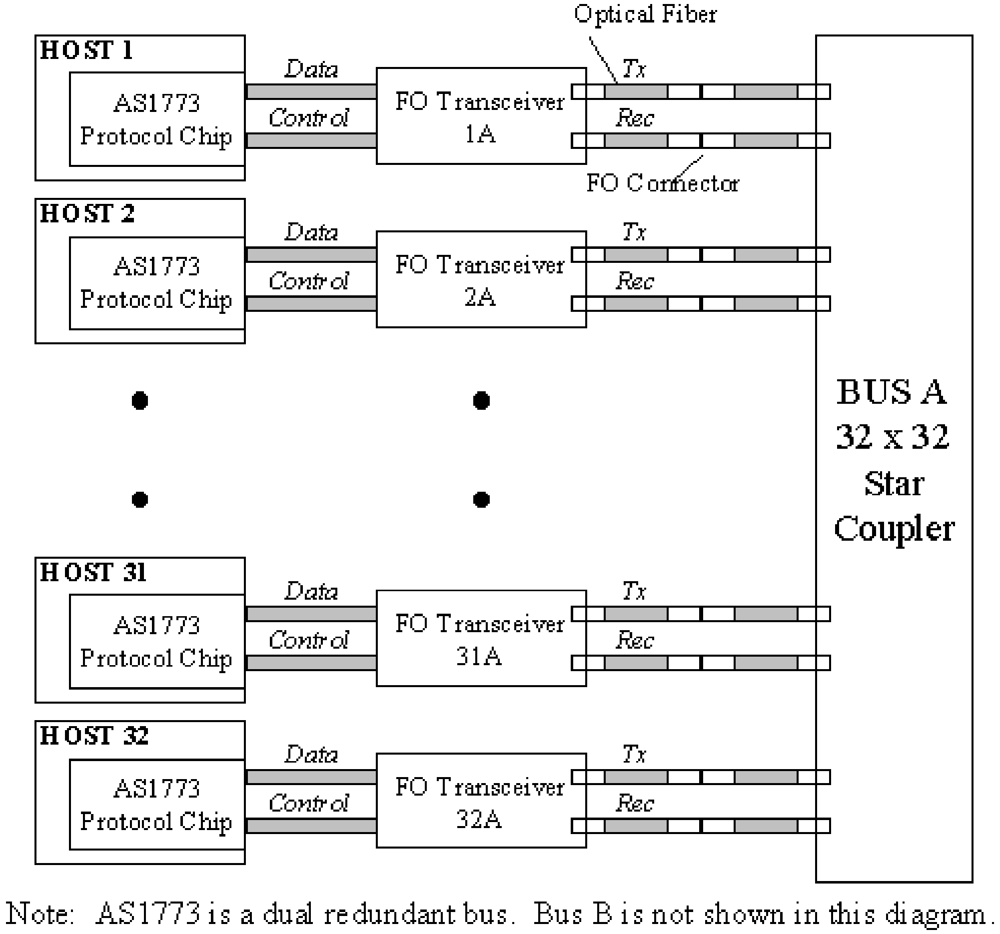

Figure 1. A Representative AS1773 System

Original 1773 transceivers (with Si photodiodes) were sensitive to direct ionization from protons meaning they would exhibit a high BER in space applications. For this reason, the use of 1773 protocol fault-tolerant message retries was implemented in the DR1773. Although this allowed for successful use of 1773 in multiple NASA missions, it reduced effective bus bandwidth by ~50%. This may not be acceptable for high data rate systems. Other hardening techniques were also employed in the DR1773 including reduced volume of the photodiode, receiver filtering, as well as a TID hardening process.

DR1773 Experiment Design

The DR1773 was designed to simulate an AS1773 spacecraft bus. Briefly, the experiment consisted of three sections; the optical section, device under test (DUT) section, and the experiment control section. The experiment control section is located inside an A1280 Actel field programmable gate array (FPGA) which controls the experiment operation and houses the command and telemetry interface to the MPTB motherboard. The optical section consists of 100/140um optical fibers, 8x8 fiber optic star coupler and fiber optic terminations. The DUT section consists of two Boeing 1300nm AS1773 transceivers. A more detailed description of the experiment has previously been published in Jackson [4].

The experiment begins with a mode command from the MPTB host processor. Once this command is received, the control section will generate a Manchester encoded 32-bit pseudo-random message. The control section will then select a DUT transmitter and receiver and send the message out over the bus. The control section then reads the message back for comparison. If the return message is different from the generated message then an error counter is incremented. This process is continued until another mode command is sent, or the experiment is turned off. A total word counter is incremented for each message sent over the fiber optic link. This word counter can be used in conjunction with the error counter for each mode to determine bit error rate information.

The experiment operates at 20Mbps only in one of two defined modes. “ED” mode where transceiver 1 sends messages to transceiver 2 or “DE” mode which reverses the transmission direction between transceivers. As noted in previous publications, the physical optical fiber connections for these two links are different. ED uses a physical contact (PC) polished fiber optic terminal as opposed to DE mode’s flat polished. Data presented over the life of this experiment supports the idea that the PC termini provides a more robust and lower loss scheme of optical connection.

Ground Proton Testing

Results from tests performed prior to flight are summarized below in Table 1. Receiver proton testing was performed with varied optical attenuation using a nominal -17dB, -23 and -25dB. Proton incident angle was varied, and energies used were 63Mev degraded to 38.2MeV. For proton total ionizing dose (TID) no degradation was observed at 35 kRads (Si). No heavy ion testing was performed due to packaging limitations, however, the devices were suspected of heavy ion sensitivity.

Table 1 Boeing DR1773 Proton SEU Test Results- Receiver

Data Rate	1Mbps	20Mbps
Normal Optical Attenuation	No SEUs	1 error total all runs (σ < 1.4 $E^{-10}cm^2$
Additional Optical Attenuation	No SEUs @ -23dB	See graph
Angular Incidence	N/A	See graph
Energy Dependence	N/A	Minimal (10-20%)

Figure 2 shows the error cross section vs. induced optical attenuation. Figure 3 shows the error cross section vs. beam incidence angle.

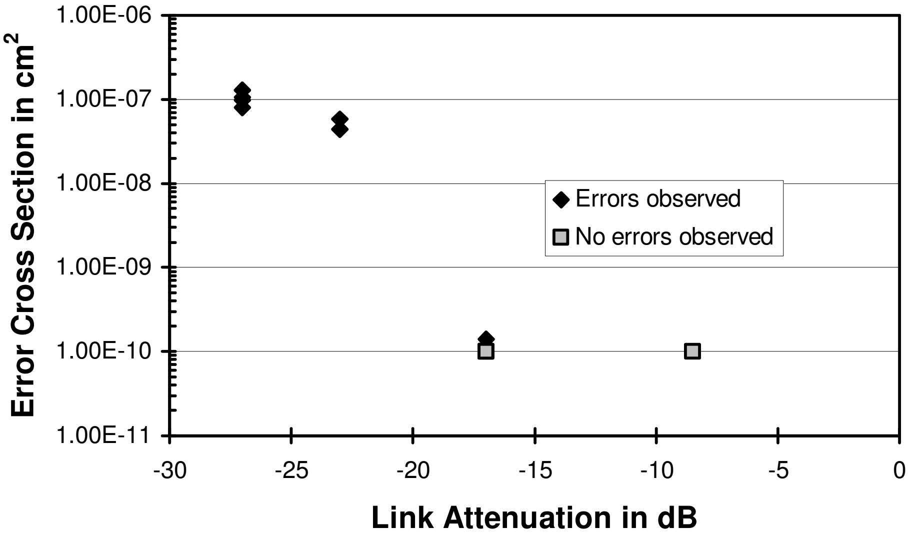

Figure 2 Error cross section vs. attenuation 90 degrees incidence

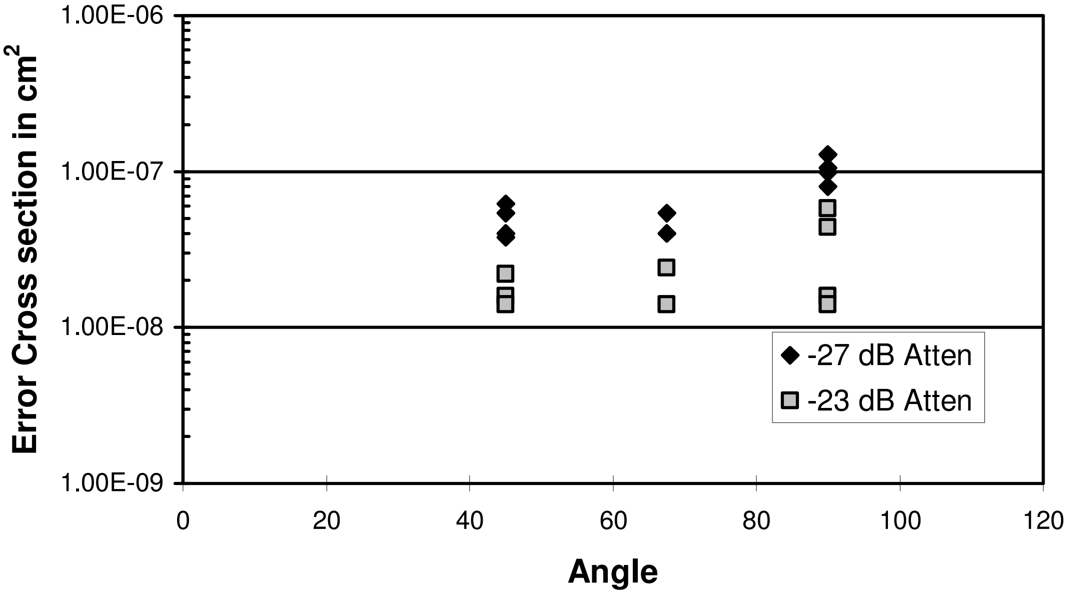

Figure 3 Receiver error cross section by beam incidence angle

In-Flight Experiment Results

As previously mentioned, the number of errors on each of the two fiber optic links is being captured. Note that these modes are mutually exclusive (only one link is active at a time). For this reason, results for each of the modes are presented separately. Figure 4 shows the daily number of errors for mode 1 or "ED" mode over ~5 years of collected data. This mode uses the PC fiber optic termini and has performed robustly with an overall bit error rate BER=2.118E^{-14} errors/bit.

Figure 5 shows the daily number of errors for mode 2 or "DE" mode for a lesser period of time. This is in part due to the fact that the experiment was commanded in DE mode less of the time and for shorter periods of time. The data shows this mode, which utilizes the flat connection termini has a much higher susceptibility to errors. A BER of 6.609E^{-11} errors/bit was calculated for the time spent in this mode. Table 2 summarizes the breakdown of BER per year by mode.

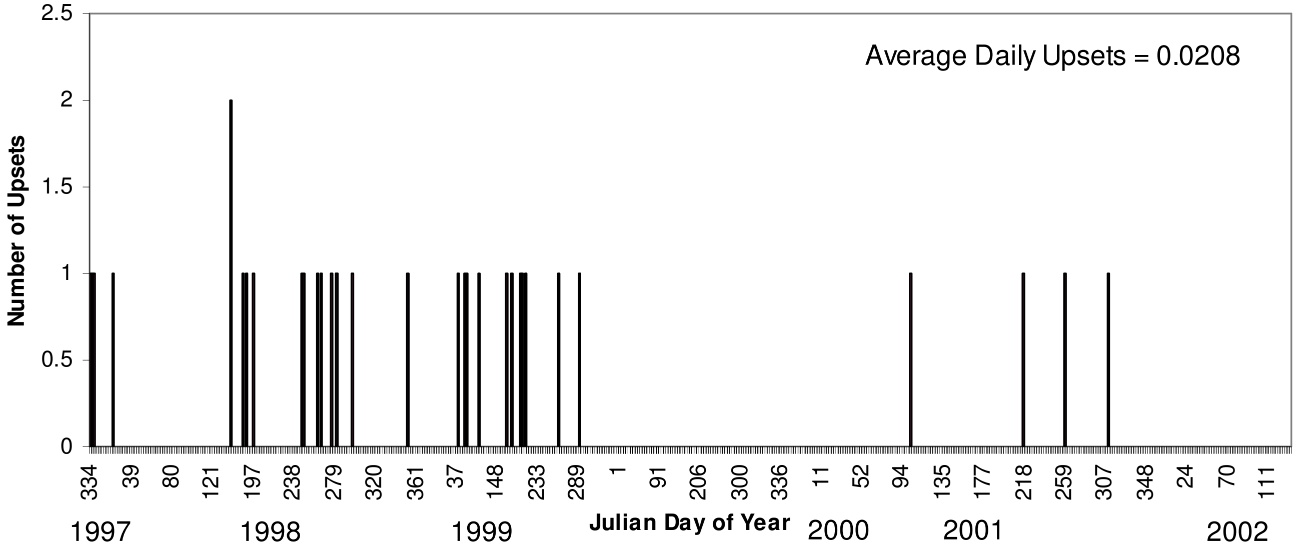

Figure 4 MPTB Transceiver Errors ED Mode 1997-2002 Orbits 0036-3321

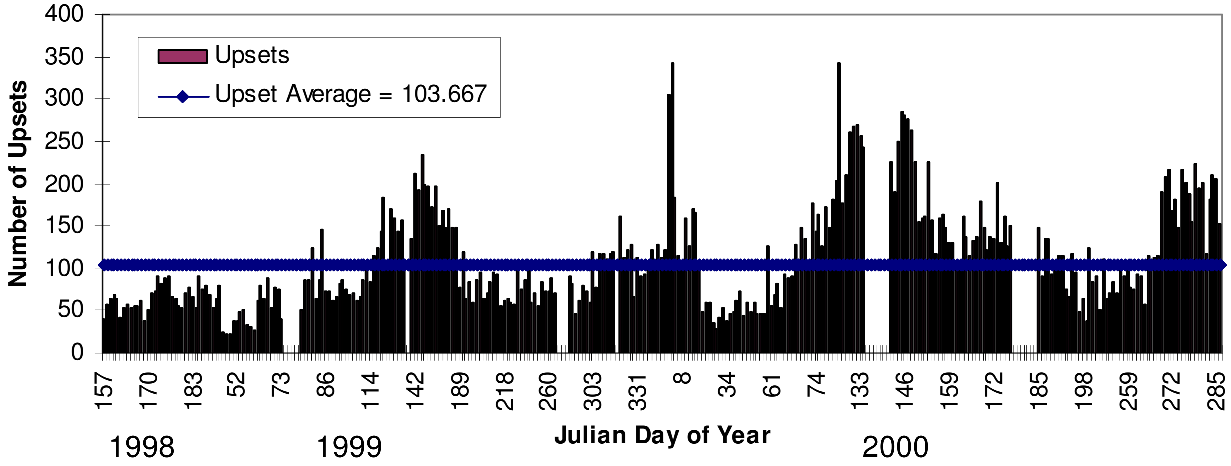

Figure 5 MPTB Transceiver DE Mode 1998-2000 Orbits 0036-3111

Table 2 ED and DE bit error rates by Year

Year	ED BER	DE BER
1997	$1.738E^{-12}$	N/A
1998	$4.224E^{-14}$	$3.787E^{-11}$
1999	$3.855E^{-14}$	$5.303E^{-11}$
2000	0	$8.501E^{-11}$
2001	$8.168E^{-15}$	N/A
2002	0	N/A

References

[1] M. Flanegan, K. LaBel, “Small Explorer Data System MIL-STD-1773 Fiber Optic Bus”, NASA Technical Paper 3227, June 1992.

[2] P.J. Luers, H.L. Culver, J. Plante, “GSFC Cutting Edge Avionics Technologies for Spacecraft”, AIAA Defense and Civil Space Programs Conference, Paper 98-5238.

[3] “Interoperability Requirements for AS1773”, AIR-4957 Draft 2.1, May 1996.

[4] G.L. Jackson, K.A. LaBel, C.J. Marshall, J.L. Barth, J. Kolasinski, C.M. Seidleck, P.W. Marshall, “Preliminary Flight Results of the Microelectronics and Photonic Test Bed (MPTB) NASA Dual Rate 1773 (DR1773) fiber Optic Data Bus”, GOMAC Conference, 1997.