Bit Errors Induced by Internal Electrostatic Discharge on SpaceWire

James Chinn[1], Wousik Kim[1], David Keller[1], Sergeh Vartanian[1], Eduardo Martin[1], Dennis Thorbourn[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, 91109, USA (e-mail: James.Z.Chinn@jpl.nasa.gov)

I. Introduction

NASA has planned a mission to study Jupiter's moon, Europa. The mission would place a spacecraft into orbit around Jupiter, performing nominally 60 flybys of the moon. The suite of instruments onboard the spacecraft would investigate Europa's potential to sustain life, studying the moon's atmosphere, water-ice crust, suspected subsurface ocean, and rocky interior.

The radiation environment at Europa's orbit is severe and presents a significant threat to the spacecraft. There are several radiation effects that could be problematic, one of which is internal charging. Problems due to internal charging arise when high energy electrons penetrate the spacecraft and deposit within onboard dielectrics or floating metals. These charges can build up over time, generating electric fields that exceed the breakdown strength of materials in the region. A rapid discharge of the stored charge may occur, sending current pulses into electronics and potentially damaging them.

An Internal Electrostatic Discharge (IESD) design environment was created for the planned Europa mission [1]. The IESD design environment is meant to characterize the part of the radiation environment that poses the largest threat to the spacecraft with respect to internal charging. The environment was based off of electron data gathered by the Galileo spacecraft.

The UVS instrument on the spacecraft uses SpaceWire data-handling network and Gore SpaceWire cables to communicate between the antenna and the electronics housed within the radiation vault. Previous IESD testing demonstrated that with copper tape shielding, the magnitude of discharges on the cable will be below Human Body Model (HBM) Class 1A. The UVS electronics will not be damaged by this magnitude of discharge. However, another less common concern was raised with respect to IESD: because SpaceWire is a high data rate communication protocol using a low voltage signal, small pulses on the cable may induce bit errors, even if they do not damage the electronics. Testing was proposed to evaluate the expected Bit Error Rate (BER) and corresponding data loss for the UVS instrument due to IESD-induced bit errors. This document describes those tests and presents the results and conclusions.

II. SpaceWire Protocol and Gore SpaceWire Cable

SpaceWire is a data-handling network capable of high speed data-links up to 200 Mbps. It sends information using two signals in each direction and is driven using Low Voltage Differential Signaling (LVDS). SpaceWire cable consists of four Screened Twisted Pairs (STP), which are wrapped in a binder, screened, and then jacketed. A diagram of the cable is shown in Figure 1. The UVS instrument uses a Gore SpaceWire cable to carry their signal. The wire insulation and binder material is ePTFE, the filler material is PTFE, the twisted pair jacket material is fluoroplastic, and the bundle jacket material is ETFE. The cable is then wrapped in one layer of Cu tape with 50% overlap for radiation shielding.

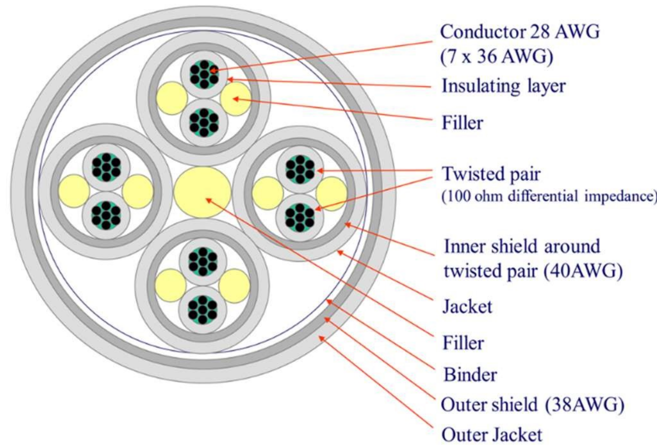

Figure 1. Diagram of SpaceWire Cable [2]

III. Test Setup and Measurement Scheme

The electron beam deposited the same amount of charge in the cable as expected during one flyby of Europa. The rate of charge deposition and duration of the test varied. Details are provided in section IV. Simultaneous to the electron exposure, a random bit stream was transmitted and received on the cable using SpaceWire protocol and the link was monitored for errors. The shields of the twisted pairs were tied together and monitored for discharges with a current probe before being grounded to the chamber. The harness shield was similarly grounded and monitored for discharges. A diagram of the test setup is shown in Figure 2.

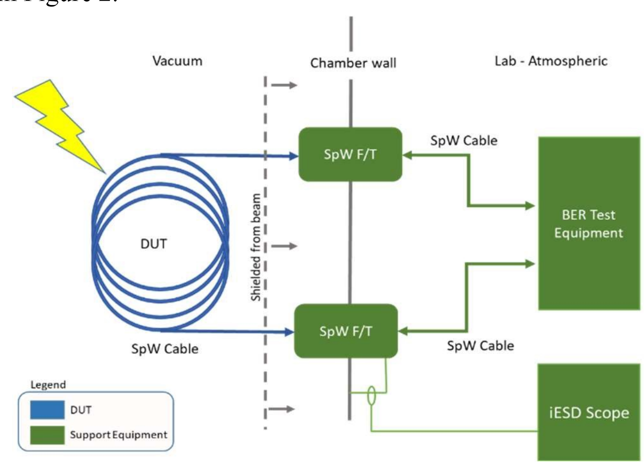

Figure 2. Diagram of Test Setup

The nominal test conditions were determined using the 1D radiation transport code, TIGER. The radiation environment was the IESD design environment [1], described in the introduction. A 1D description of the geometry was generated, and this geometry and the radiation environment were input into TIGER to determine the expected charging and dose rates during flyby of Europa. Then, a series of monoenergetic electron beams were simulated with the 1D geometry to determine what electron beam energy and flux would deposit that same amount of charge and energy in the dielectrics of interest, namely the insulation of the wires. The reason the wire insulation was targeted is because of the expected differential-mode error mechanism, described in section V. Again, details of the beam conditions for each particular test are given in section IV.

IV. Description and Summary of Each Test

Before the beam was turned on, a baseline test of the BER detection system was performed. The sample and chamber were set up as they would be during the test and the accelerator was powered up to high voltage, but no current was run through the filament so no electrons were emitted. The BER detection system was running as it would be during the test, and no errors were recorded after four hours of running a 200 Mbps data-link. The system was established to be working correctly, and any errors that occurred above this base rate with the beam on could be attributed to internal electrostatic discharges.

A total of six tests were performed with beam on. The tests are listed in Table 1 along with several parameters of interest and the results of each test.

The first test was performed to evaluate the performance of the monitoring equipment. Specifically evaluated was the triggering system between the discharge monitoring oscilloscope and the bit error detection scope. The test wasn't intended to evaluate the BER due to IESD, nevertheless, the sample received the total electron flyby fluence. The test flux was 40x the nominal expected flux and the test was run for 1 hour, or 1/40th the nominal expected exposure duration. The sample was at room temperature (approximately 25° C) and the data rate was 200 Mbps. No errors were observed during this test, though many discharges were observed, with a maximum current of 90 mA.

The second test was the baseline test. This was a 4x accelerated test, meaning the flux was 4x the expected rate during flyby and the duration was 1/4th as long, or 10 hours. The temperature of the sample was held at -50° C for the first 7 hours

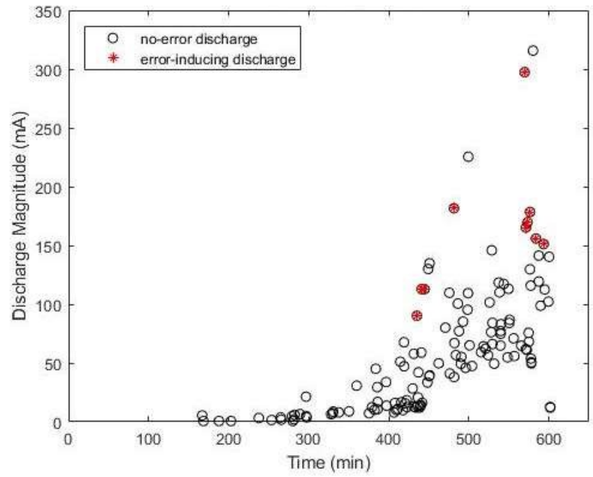

Figure 3. Data for Second Test (Baseline Test)

of the test, then lowered to -90° C for the last 3 hours. The expected lowest temperature during flight is -90° C, and it is known that IESD phenomena are more extreme at colder temperatures. Many discharges were observed, with a maximum current of 315 mA. 10 bit errors were recorded, and were tightly correlated in time with discharge pulses. The data rate for this test was 200 Mbps. A plot of discharge magnitude vs. time is shown in Figure 3.

The third test was intended to check performance at a lower data rate. The flux and duration of the test were the same, and the temperature was similar; this time the sample was held at -90° C for the full 10 hours. The main difference between this test and the previous test was that this time, the data rate was 40 Mbps. 8 bit errors were recorded, again closely correlated in time with discharge pulses. There does not appear to be an error rate dependence on data rate between 40 Mbps and 200 Mbps.

The fourth test was intended to check whether the good performance of the first test was because of the accelerated flux or because of the higher temperature. This was a 1 hour test at a 40x flux condition. The temperature of the sample was held at -90° C and the bit rate was 40 Mbps. There were many discharges observed during this test, with a maximum amplitude of 250 mA. 11 Bit errors were observed, making this test consistent with the other cold-temperature tests and indicating that the cold temperature was the reason for the larger discharges and number or errors.

Table 1. Summary of Tests

Date of Test	Flux Condition	Duration	Bit Rate	Temperature	# of Errors	Number of pulses > 95 mA	Min Discharge w/ Error	Max Discharge w/o Error
01/30/18	40x	1 hr	200 Mbps	-50 °C	0	0	N/A	90 mA
02/28/18	4x	10 hr	200 Mbps	-50 °C / -90 °C	10	32	95 mA	315 mA
03/13/18	4x	10 hr	40 Mbps	-90 °C	8	40	130 mA	290 mA
03/14/18	40x	1 hr	200 Mbps	-90 °C	11	37	110 mA	250 mA
03/15/18	1x	40 hr	40 Mbps	-90 °C	1	5	120 mA	180 mA
04/18/18	4x	10 hr	100 Mbps	-90 °C	0	0	N/A	140 mA

The fifth test was intended to check performance at the actual expected flux, data rate, and temperature. This test was a 40 hour test with a 1x flux condition. The sample was held at -90° C, and the data rate was 40 Mbps. Many discharges were observed and the largest pulse was 180 mA. One bit error was observed, indicating that a lower flux reduces the magnitude of discharges and the number of bit errors.

The sixth and final test was intended to check performance after Total Ionizing Dose (TID) exposure. The cable will accumulate ionizing dose during the course of the mission, and this test was intended to capture the performance of the cable at the end of the mission. The cable was exposed to its expected TID and then set up for the IESD test. The nominal 4x flux condition was used, the sample was held at -90° C, and the data rate was 40 Mbps. There were noticeably fewer discharges and they were smaller in magnitude. Also, no bit errors were observed. The SpaceWire insulation is made of expanded PTFE. Experiments performed by Nishi et al indicate that the conductivity of PTFE increases with accumulated dose [3]. This may explain why the number and magnitude of discharges, and hence the bit error rate, decreased after the cable was dosed.

V. Discussion of Results

There appears to be a minimum threshold of approximately 95 mA on the shields below which no errors occur. However, a discharge above 95 mA on the shields does not guarantee an error. It isn't obvious what characteristics of the discharge cause an error. For instance, essentially the same pulse cased an error in one case and did not cause an error in another case; see figures 4 and 5.

One theory for this behavior is based on the fact that SpaceWire measures differential voltage between the two lines of a twisted pair, so it is more robust to common mode disturbances (when the voltage on both lines change together, ~1.2 V is tolerable [3]) than it is to differential mode disturbances (when the voltage on one line changes relative to the other, ~0.4 V is tolerable [3]). A discharge pulse to any of the shields would result in mostly common mode on the data lines, and a discharge pulse to one of the cores of the twisted pair would result in mostly differential mode on the data lines of that pair. This means that the same magnitude discharge may cause an error in one instance and not cause an error in another instance. Unfortunately, because only the shields could be monitored and because they had to be tied together, it isn't possible to know when a differential mode pulse occurred. Additionally, if this were the only explanation, then one would expect either both figure 4 and 5 to trigger errors, or neither figure 4 nor 5 to trigger errors. This was not overserved so there is likely some other unknown phenomenon at play in determining whether or not an error occurs.

It appears that accelerated flux and lower temperature increase the number and magnitude of discharges and the number of errors, with a diminished sensitivity to flux after increasing beyond a 4x condition. The data rate appears to have no effect on the number of errors.

It appears that 11 bit errors or fewer should be expected during any one flyby of Europa, and that this number should decrease as the mission progresses. The number of discharges, and hence the number of errors, will increase with cable length. The length of cable exposed to the beam was 12.5 feet, which is approximately the longest length expected to be used during flight.

SpaceWire has the property that if there is a bit error, the link is dropped and the entire packet is discarded. The maximum

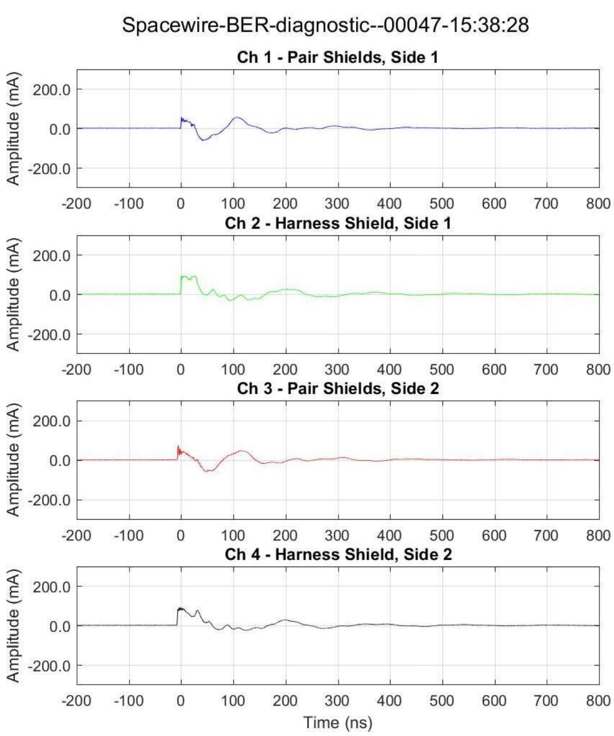

Figure 5. Discharge Pulse that Caused an Error

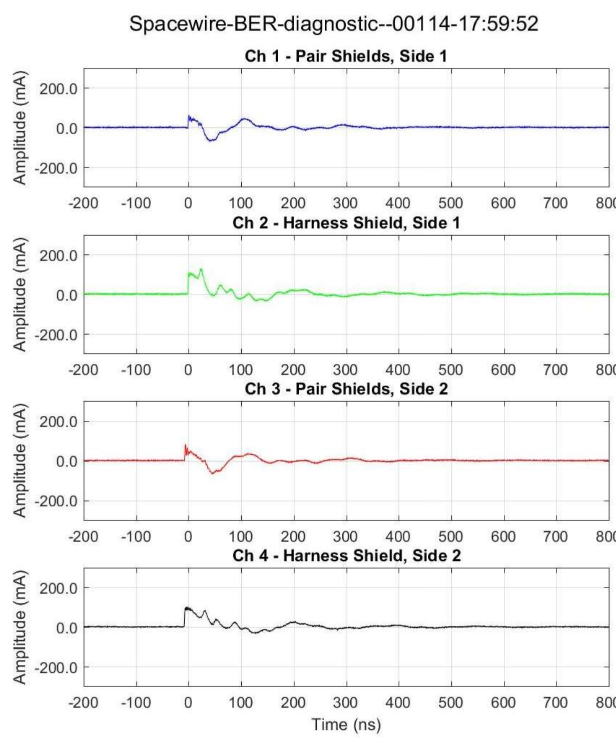

Figure 4. Discharge Pulse that did not Cause an Error

packet size is 2^{16} bytes = 5.2E5 bits. So 11 packets lost is 5.8E6 bits. The number of bits transmitted at 40 Mbps bi-directionally for a 40 hour flyby is 1.15E13, so 11 lost packets translates to a data loss fraction of 5E-7. This conservative data loss estimate is better than the nominal allowed data loss fraction of 1E-6.

ACKNOWLEDGMENT

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