



Applied Space Environments Conference 2019

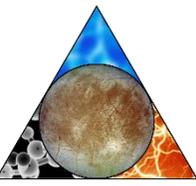
Bit Errors Induced by Internal Electrostatic Discharge on SpaceWire

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

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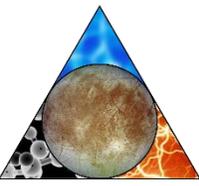
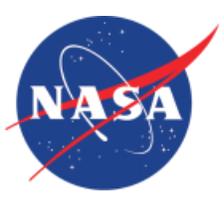


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Outline

- Introduction to planned Europa Clipper Mission
- Introduction to IESD
- Test Plan
- Test Setup
- Results
- Discussion

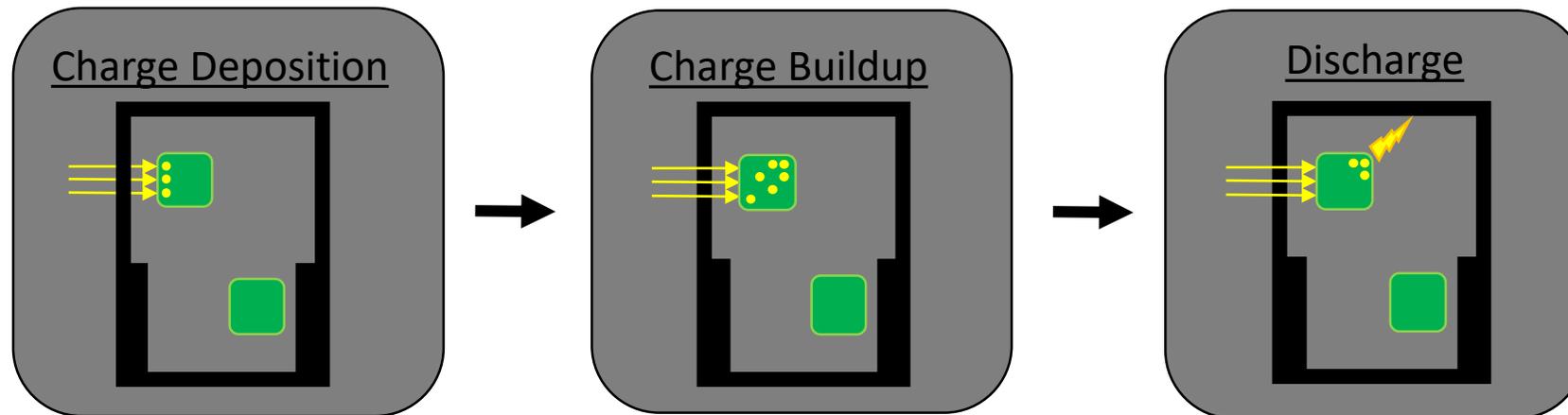


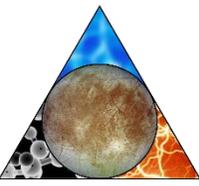
Planned Europa Clipper Mission

- Jupiter orbiter making ~60 flybys of Jupiter's moon, Europa
 - Expected launch date in 2020's
- Objective would be to investigate the habitability of the moon
- Taking measurements to characterize the atmosphere, water ice crust, suspected sub-surface ocean, and rocky interior
 - Temperature, Composition, Interactions at the boundaries between layers
- Radiation environment around Europa's orbit is very high
 - Significant threat posed by internal charging

Internal Electrostatic Discharge (IESD)

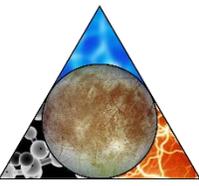
- High energy electrons penetrate spacecraft and deposit internal to electronics
- As charge accumulates, high electric fields develop, resulting in arcing
- Current arcs can damage electronics and jeopardize missions
- For a low voltage data signal, may induce bit errors



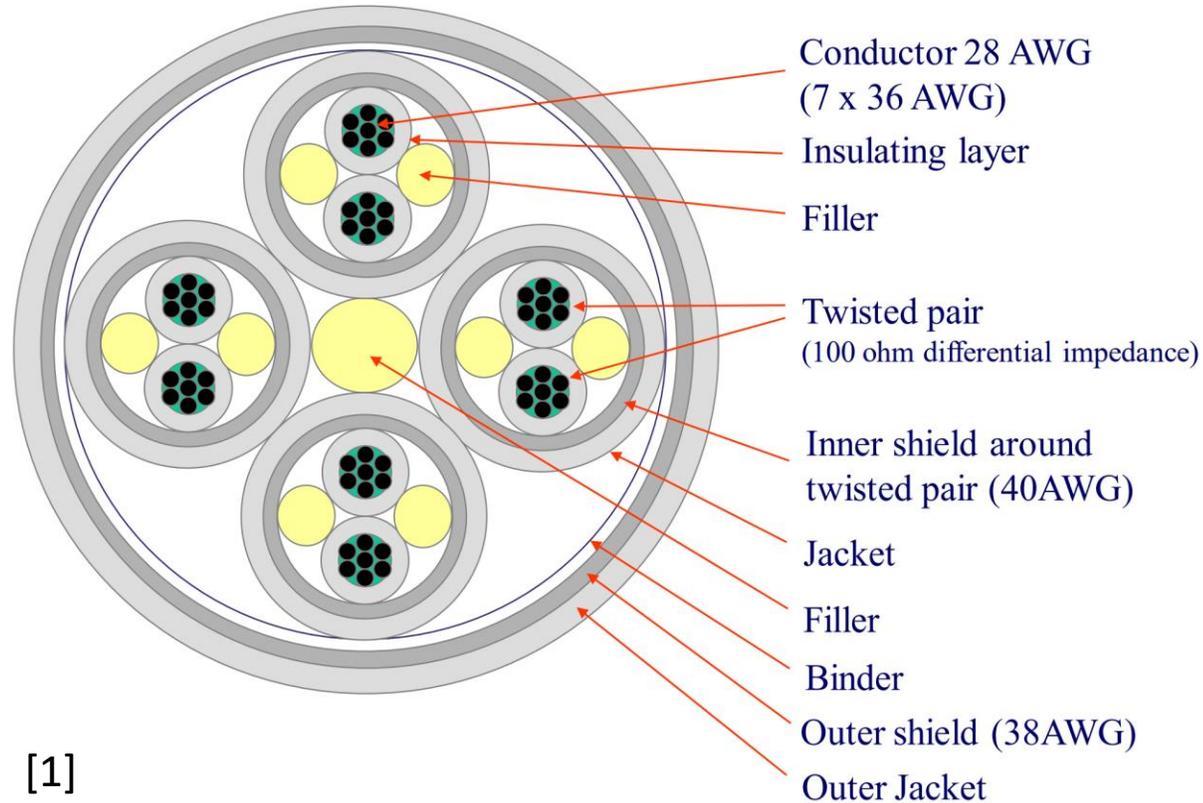


Overall Summary (details for each test follow)

- This test campaign was intended to determine whether or not the number of bit errors induced by iESD events would be problematic for SpaceWire on Europa Clipper.
- Six total tests were performed to check the effects of flux level, temperature, data rate, and dose on the bit error rate.
- Tested the setup for several hours in the chamber pumped down without beam – this control configuration produces zero errors
- **The conclusion is that we can expect roughly 10 bit errors or fewer due to iESD during each ~40-hour flyby of Europa.**



Gore SpaceWire Cable

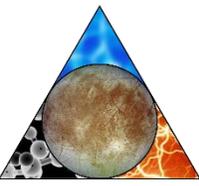


[1]

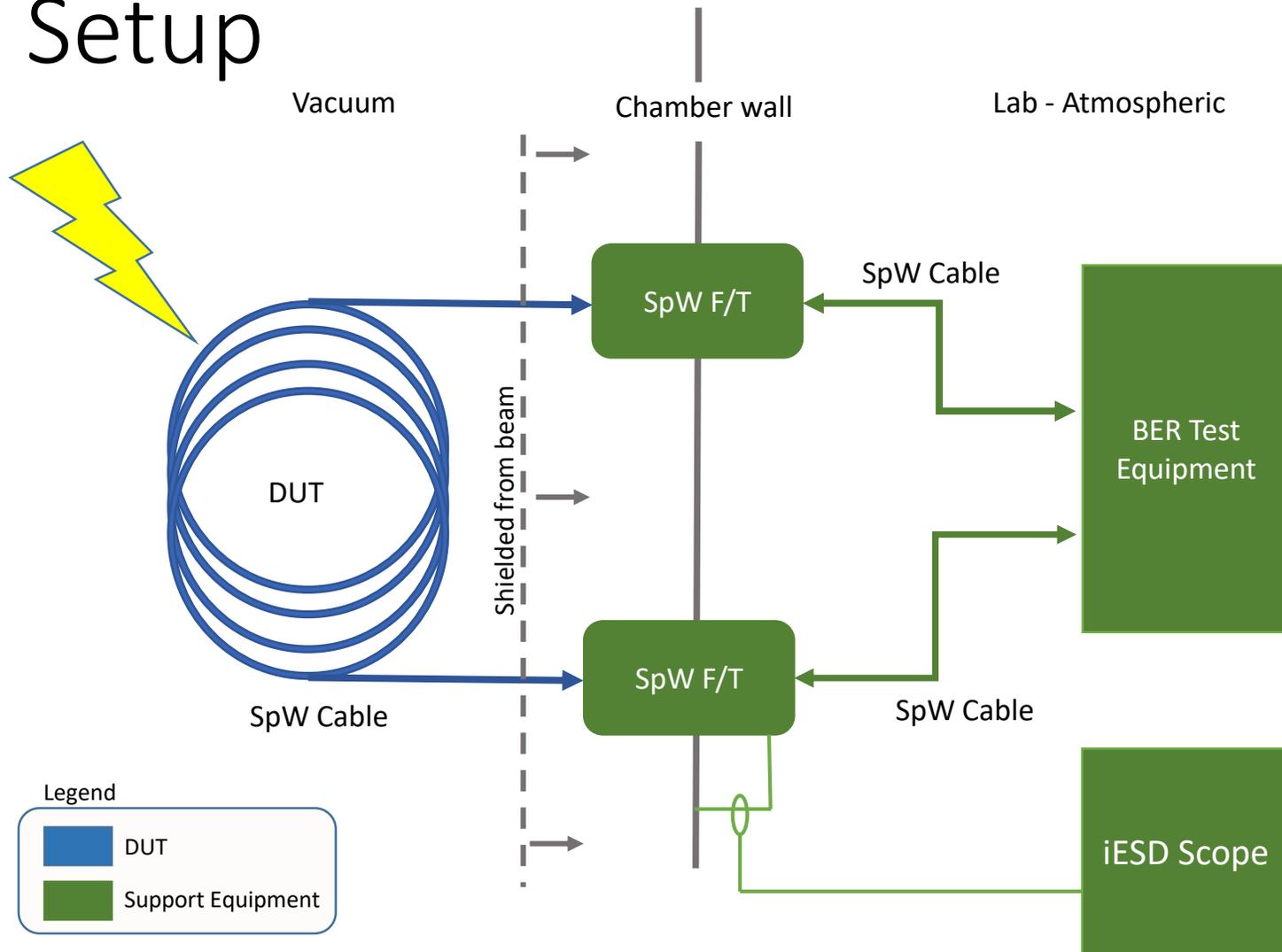
Wire insulation and binder material is ePTFE, the filler material is PTFE, the twisted pair jacket material is fluoroplastic, and the bundle jacket material is ETFE.

Additional Cu tape overwrap using 50% overlap results in HBM Class 1A discharges or better from cable.

Remaining question is: will these small discharges cause an undesirable number of bit errors on the link?



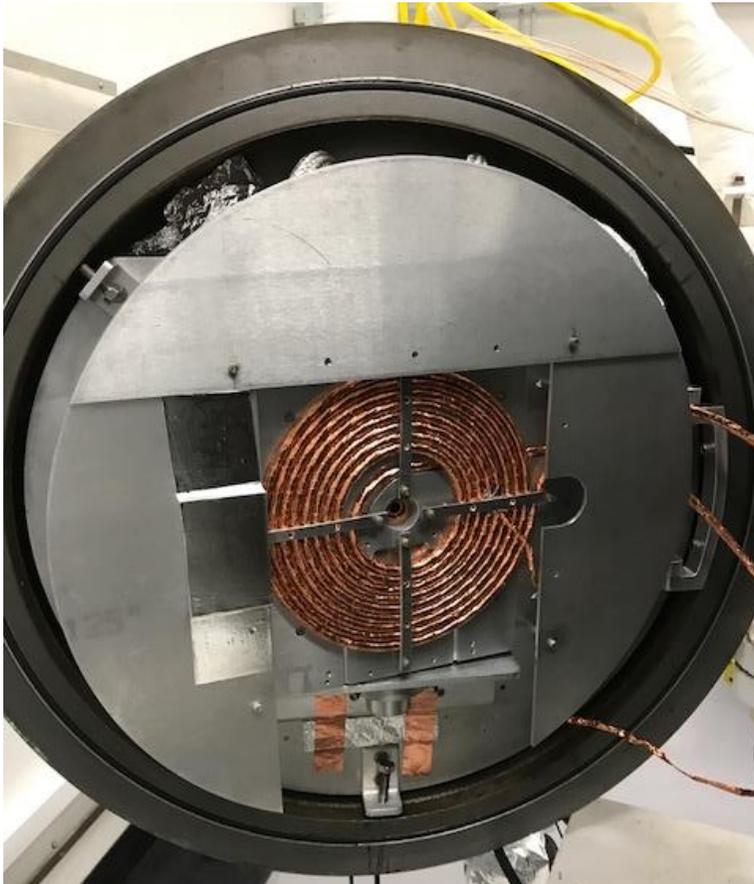
Test Setup



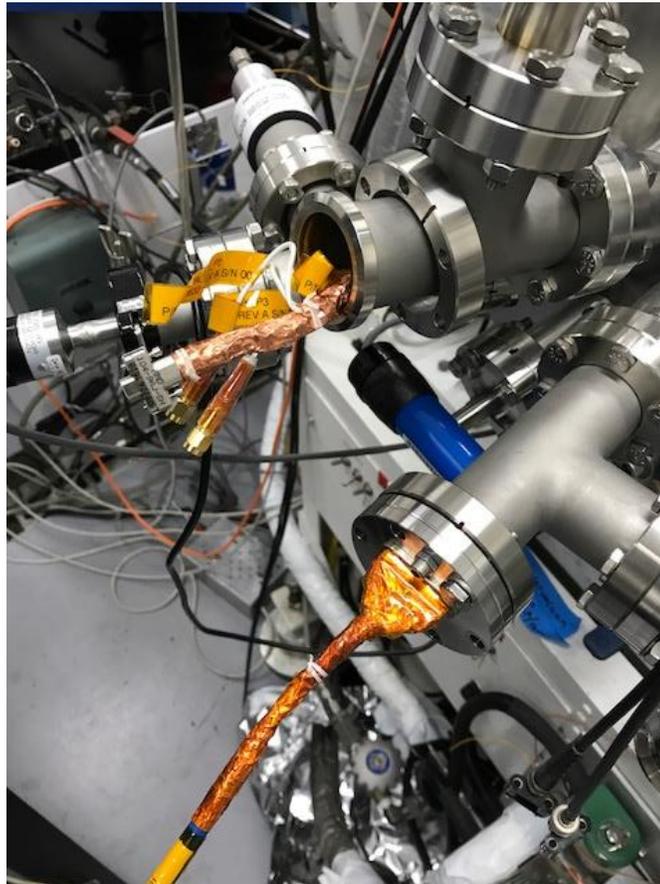
Two current probes at each feedthrough (only one pictured). Measuring current in TP shields (combined) and in bundle shield to ground.

Test Setup (Continued)

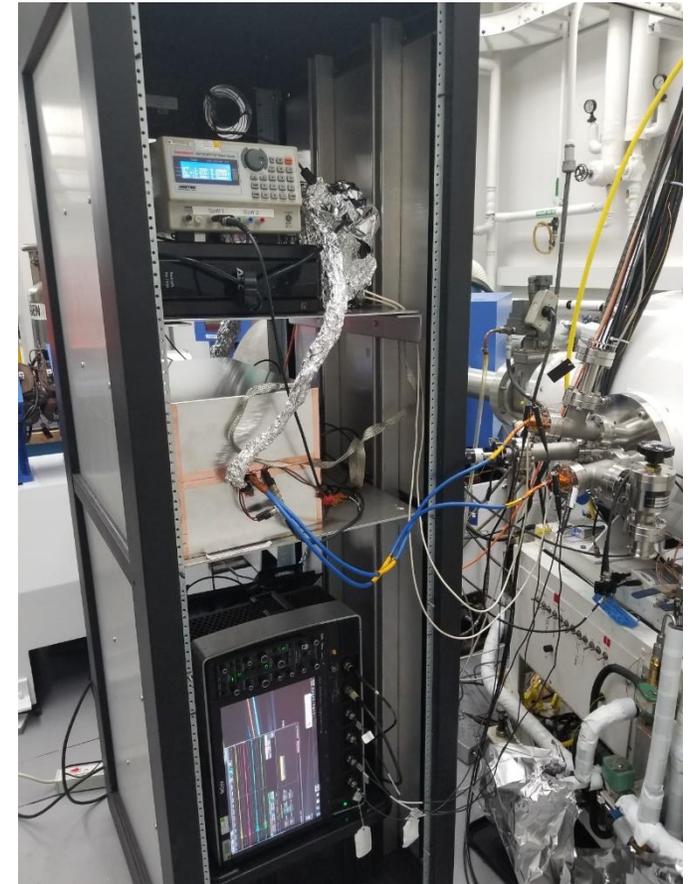
DUT in chamber with shielding

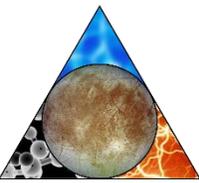


Feedthrough



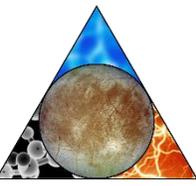
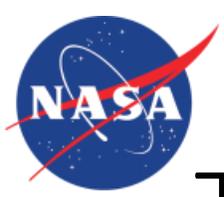
BER Tester & iESD Scope





Other Notes

- The number of discharges (and hence, number of errors) increases with the length of the cable exposed to the beam. This test campaign exposed 12.5 feet of cable to the beam, which is approximately the longest length expected to be used during flight. Total cable length is 25 feet (including unexposed cable and cable outside the chamber).
- The number and magnitude of discharges typically increase as temperature decreases. $-75\text{ }^{\circ}\text{C}$ is the lowest expected operating temperature for Spacewire. As recommended in the ERD, we tested at $15\text{ }^{\circ}\text{C}$ lower than this temperature ($-90\text{ }^{\circ}\text{C}$).
- All the TP shields were tied together and the current from them to ground was monitored. The current from the harness shield to ground was also monitored. Both ends of the cable were monitored for a total of 4 channels.



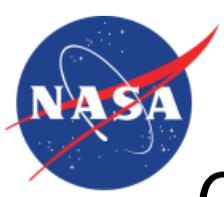
Test Overview

| 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 occurrence of an error doesn't depend entirely on the magnitude of the ESD event; the same size discharge in one case induces an error and in another case does not. There is no known definitive reason why at this point.
- It appears there is a threshold discharge magnitude of approximately 95 mA, below which no bit errors are induced by iESD.

* Flux Condition refers to how accelerated the test was. i.e. a 40x flux condition means the flux was 40x higher than that expected in flight and the test was run for 1/40 as long. Each condition delivers 1 iESD design environment's worth of electrons; the higher flux conditions do it faster and tend to be more conservative (produce larger discharges).

** Discharge magnitudes are reported as one-sided amplitude, not peak-to-peak. Reported magnitude is maximum of all recorded channels.

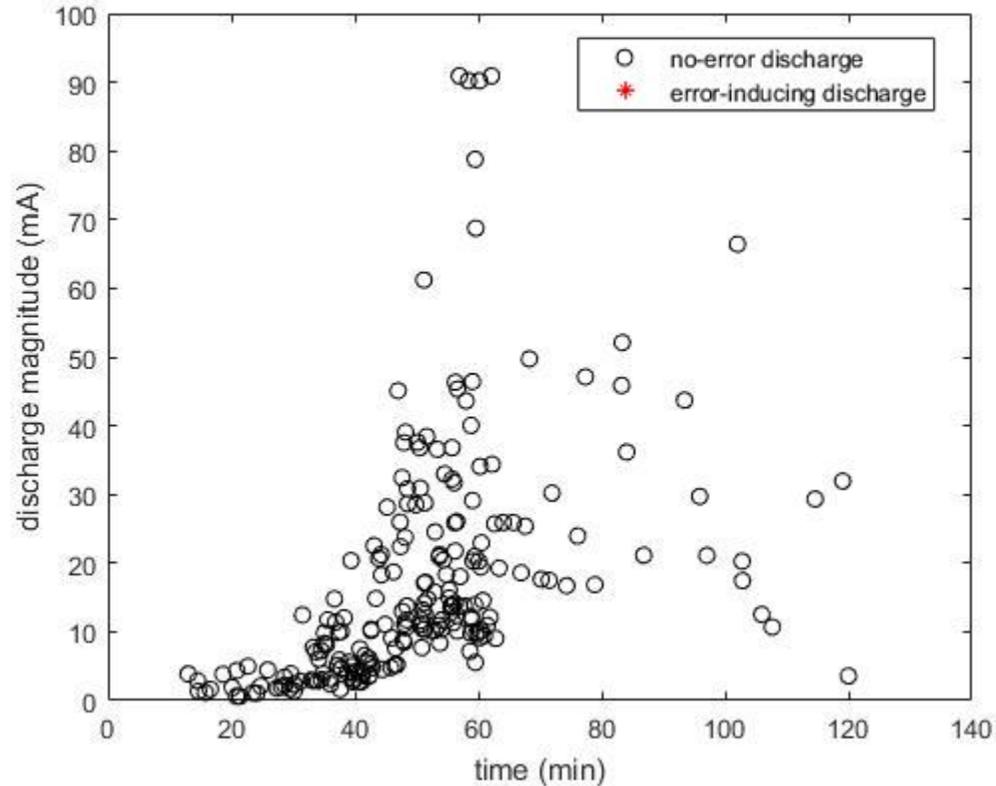
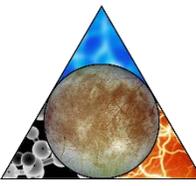


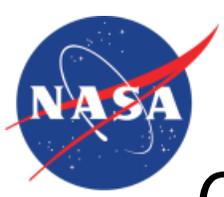
01/30/18

The purpose of this test was to check that the error-monitoring system and discharge-monitoring system were working and could communicate.

This test wasn't intended to evaluate the BER due to iESD. Nevertheless, the sample received the total flyby flux without any errors (at room temperature).

| | |
|-------------------------|---------------------------|
| Flux Condition | 1 hr at 40x; 1 hr at 4x |
| Temperature | Room Temperature (~25° C) |
| Bit Rate | 200 Mbps |
| Number of Errors | 0 |
| Min Discharge w/ Error | N/A |
| Max Discharge w/o Error | 90 mA |



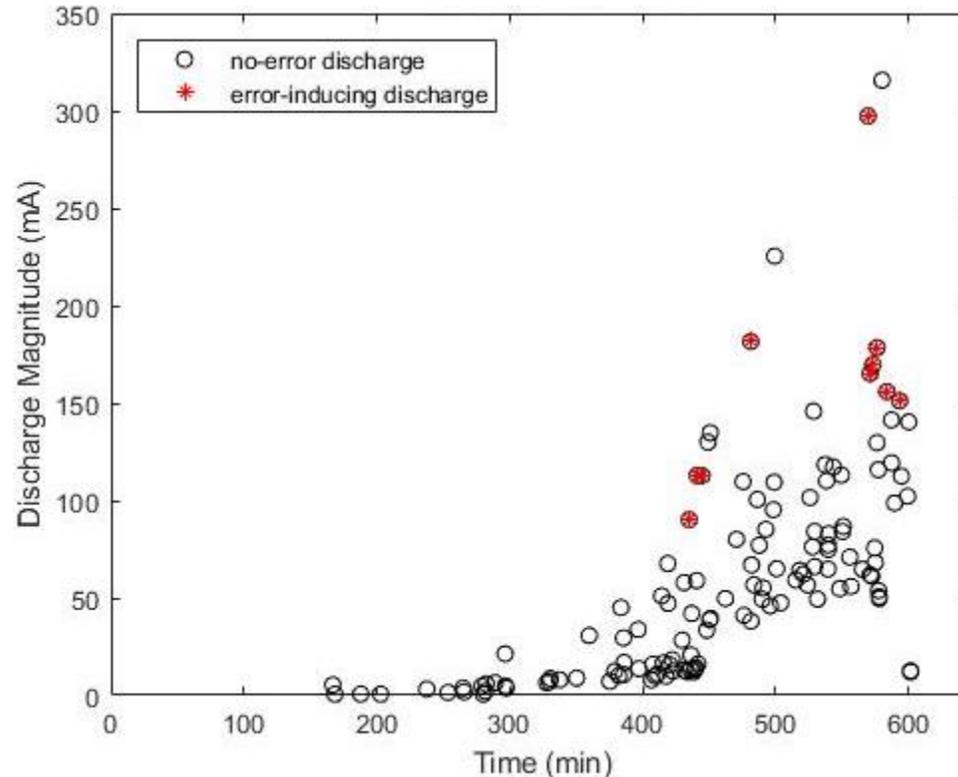
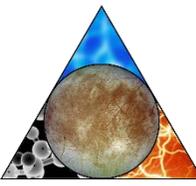


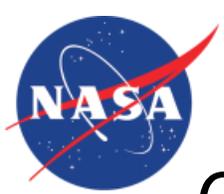
02/28/18

This was the baseline test: nominal beam conditions (4x accelerated flux compared to the expected environment flux for ¼ of the duration) and maximum bit rate of 200 Mbps.

10 bit errors were observed during the 10-hour test. Because the flux is accelerated by 4x, the 10-hour test represents the entire 40-hour iESD flyby environment. Therefore, we expect 10 bit errors during the flyby.

| | |
|-------------------------|------------------------------------|
| Flux Condition | 10 hr at 4x (baseline) |
| Temperature | -50 °C for 7 hrs, -90 °C for 3 hrs |
| Bit Rate | 200 Mbps |
| Number of Errors | 10 |
| Min Discharge w/ Error | 95 mA |
| Max Discharge w/o Error | 315 mA |



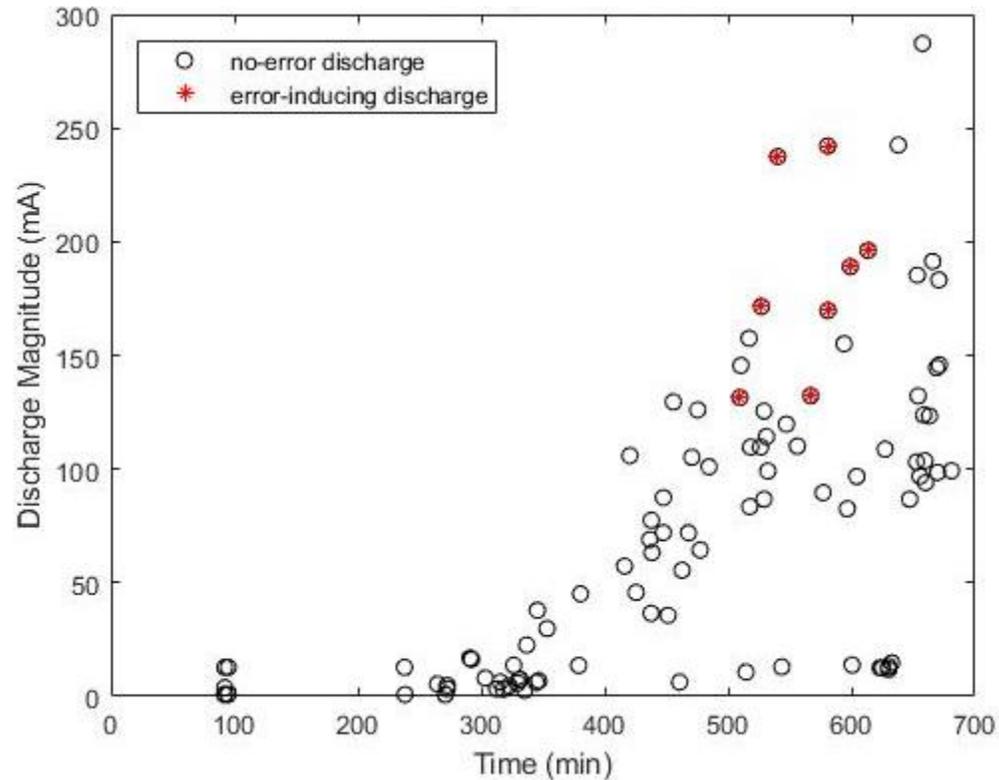
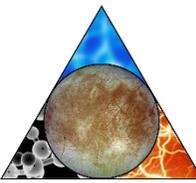


03/13/18

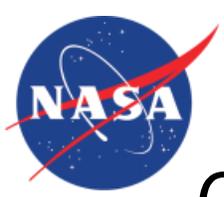
The purpose of this test was to check the performance at a lower bit rate.

The performance was similar to that at 200 Mbps. 8 bit errors were observed during the equivalent flyby environment exposure.

| | |
|-------------------------|------------------------|
| Flux Condition | 10 hr at 4x (baseline) |
| Temperature | -90° C |
| Bit Rate | 40 Mbps |
| Number of Errors | 8 |
| Min Discharge w/ Error | 130 mA |
| Max Discharge w/o Error | 290 mA |



*extra time added because beam was brought down a few times. Total exposure time still 10 hrs.



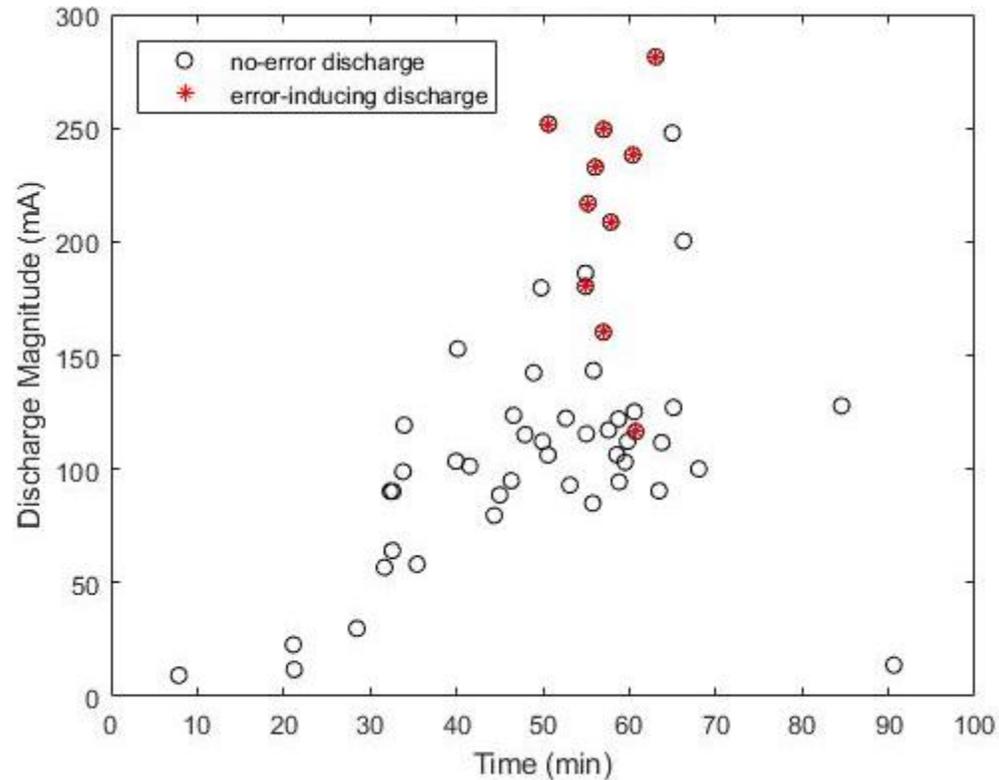
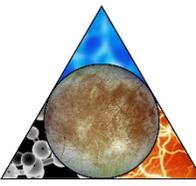
03/14/18

The purpose of this test was to check whether the lack of bit errors during the 01/30/18 test was due to the accelerated flux condition or the higher temperature.

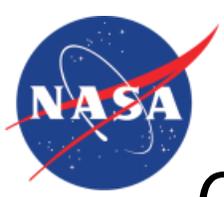
The performance was similar to the previous tests at -90 °C. The discharge magnitudes were higher than the 01/30/18 room temperature test and there were more errors. This indicates that the lower temperature was the cause of the errors, not the lower flux rate. 11 bit errors were observed during the equivalent flyby environment exposure.

5/2019

| | |
|-------------------------|---------------------------|
| Flux Condition | 1 hr at 40x; 30 min at 4x |
| Temperature | -90° C |
| Bit Rate | 200 Mbps |
| Number of Errors | 11 |
| Min Discharge w/ Error | 110 mA |
| Max Discharge w/o Error | 250 mA |



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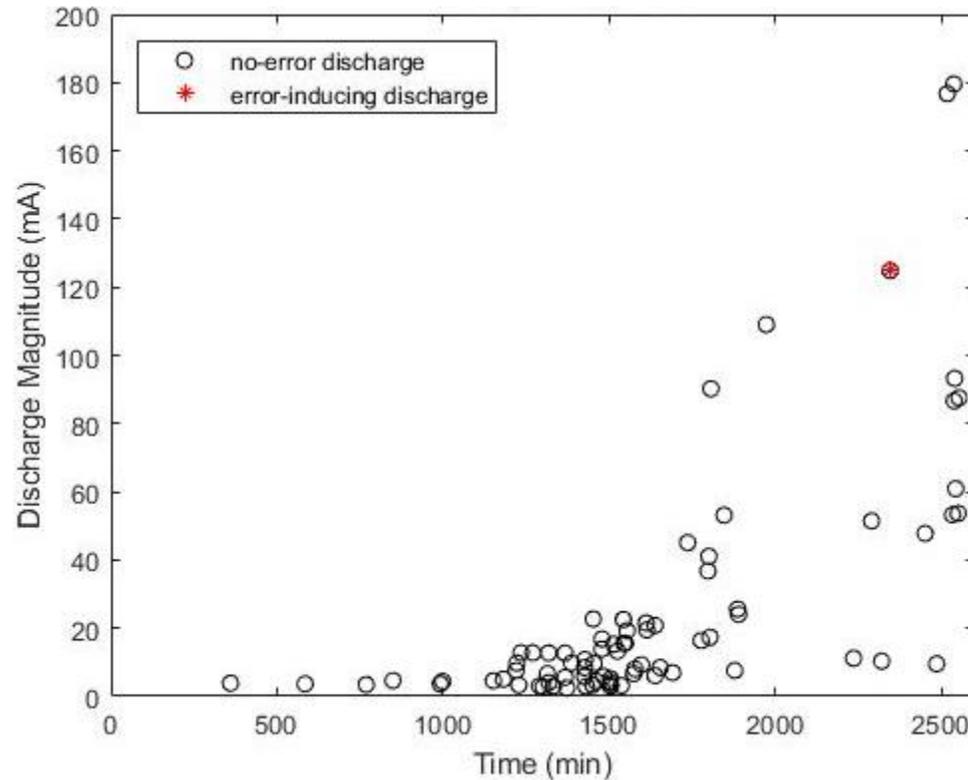
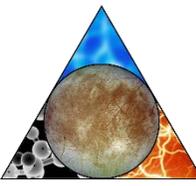


03/15/18

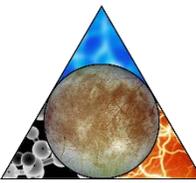
The purpose of this test was to check the performance at the actual expected flux (1x condition), bit rate, and temperature.

At the lower flux, the magnitudes of discharges were ~30% less than the 4x condition. 1 bit error was observed during the equivalent flyby environment exposure.

| | |
|-------------------------|-------------|
| Flux Condition | 40 hr at 1x |
| Temperature | -90° C |
| Bit Rate | 40 Mbps |
| Number of Errors | 1 |
| Min Discharge w/ Error | 120 mA |
| Max Discharge w/o Error | 180 mA |

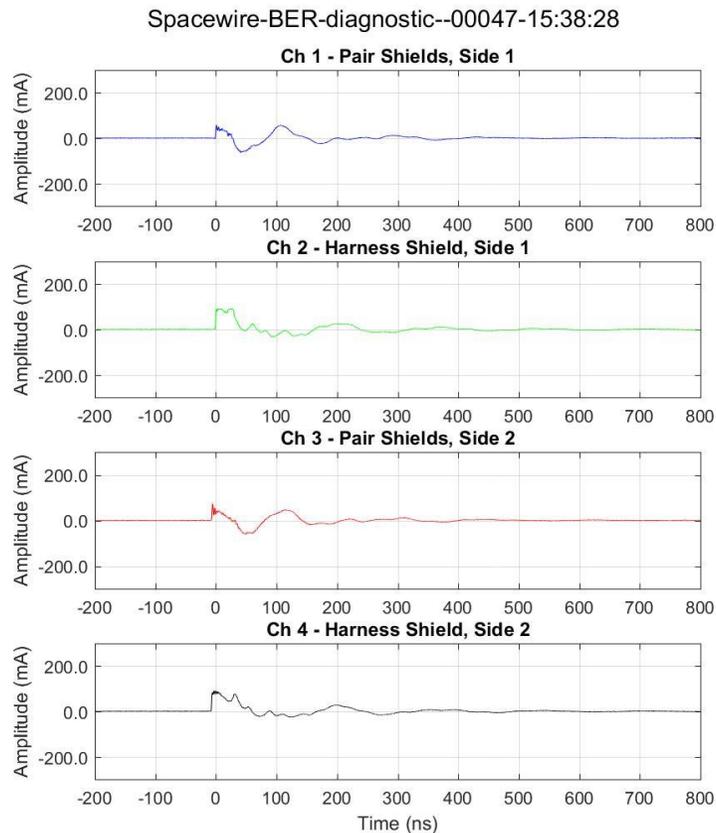


*extra time added because beam was brought down a few times. Total exposure time still 40 hrs.

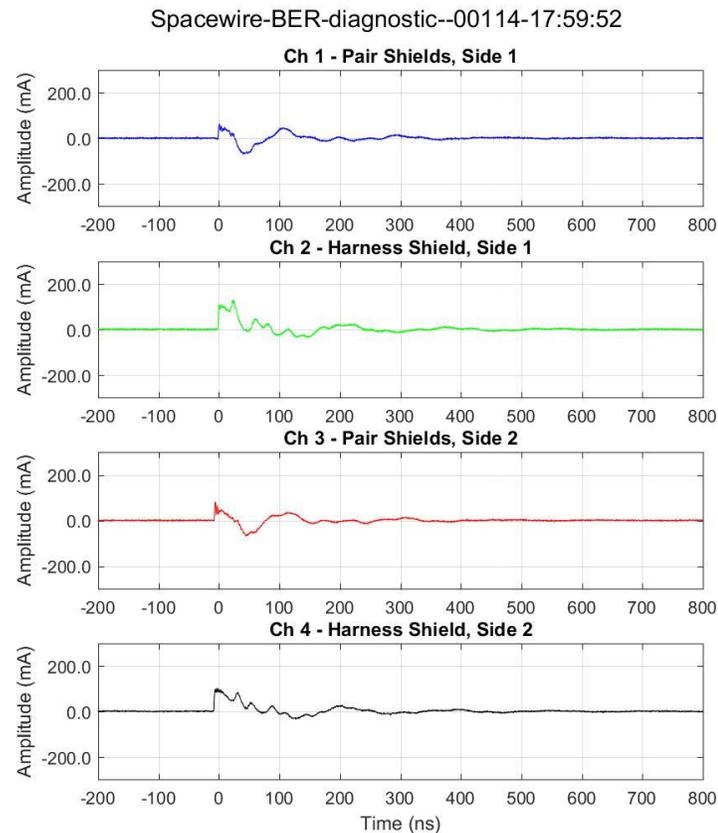


Example Discharge Pulses

Caused Error

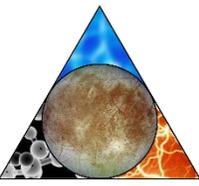
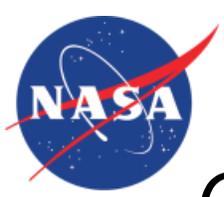


Did Not Cause Error



Looking at the discharge profiles, there is nothing that stands out to indicate why the left discharge pulse caused an error and the right discharge pulse did not. In general, there is no clear feature that reliably predicts what discharge pulses caused errors. Some speculation includes:

- Some discharge pulses may have been more common mode than others of similar magnitude. SpaceWire uses low voltage differential signaling and is more robust to common mode (~ 1.2 V) than it is to differential mode (~ 0.4 V).



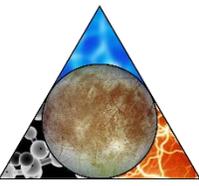
Conclusions

| Date of Test | Flux Condition * (slide 6) | 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 | 280 mA |
| 04/18/18 | 4x | 10 hr | 100 Mbps | -90 °C | 0 | 0 | N/A | 140 mA |

- The occurrence of an error doesn't depend entirely on the magnitude of the ESD event; the same size discharge in one case induces an error and in another case does not. There is not a definitive reason why known at this point.
- It appears there is a threshold discharge magnitude of approximately 95 mA, below which no bit errors are induced by iESD.
- The maximum number of errors to expect during a flyby is ~10. More likely it will be ~1. These errors will occur within the latter ~20 hrs of the flyby.
- A warmer operating temperature appears to reduce the number of errors.
- As dose increases throughout the mission, it appears the number of errors per flyby will decrease.
- Higher flux rates appear to induce more errors.
- Maximum packet size = 2^{16} bytes = $5.2E5$ bits; Maximum errors = 10 -> $5.2E6$ bits lost; Bits transmitted during 24 hr flyby @ 200 Mbps = $200E6 * 3600 * 24 = 1.7E13$; Maximum data loss fraction = $3E-7$ <- better than $1E-6$ requirement
 - This configuration has no common mode choke



References



- [1] S. Parkes, SpaceWire User's Guide, STAR-Dundee, 2012
- [2] Y. Nishi et al, "Electrical Conductivity Enhancement of PTFE (Teflon) Induced by Homogenous Low Voltage Electron Beam Irradiation", Materials Transaction, Vol 53, No. 5, pp. 940 to 945, 2012