SpaceWire cabling in an Operationally Responsive Space Environment

Session: SpaceWire Test and Verification

Short Paper

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Abstract
Rapid integration, launch, and deployment of satellites in response to emerging needs have been the focus of various organizations. This concept has been termed "Operationally Responsive Space" (ORS) by the United States Department of Defense. One vision of ORS calls for the positioning in a depot of interchangeable satellite payloads and spacecraft buses with a common interface. Upon direction to deploy a particular mission, the appropriate payload would be selected and integrated to a bus, and the space vehicle would be launched. To support such a system, standardized hardware and software interfaces are needed between the payload and bus. For the development of ORS Bus Standards, SpaceWire has been specified as part of such a payload-bus interface for high rate data. Data interfaces can be modelled in a number of ways, such as with the OSI layer model. SpaceWire offers the appeal of standardization of physical, data, and network layers. However, the physical standards specified in the SpaceWire standard (ECSS-E-50-12A) regarding connectors are not ideal for the depot environment. The need for quick connection, use by minimally trained personnel, and few or no required tools combines with the usual mission considerations of cost, availability, signal integrity maintenance, and space worthiness in driving connector selection. The preliminary investigation and testing described in this paper details our recent efforts at the Naval Center for Space Technology concerning possible SpaceWire connectors for ORS. Proposed ORS test and flight cables were fabricated, tested, and analyzed using time-domain reflectometry, and compared with existing SpaceWire standard cabling.

Introduction
The commonplace cost and schedule overruns associated with space missions [Powner et al, 2006] have resulted in a focus on the development of meaningful capabilities that are achievable relatively inexpensively and on shorter timeframes. It is desirable to have the capability to deploy space assets rapidly, both in the sense of reducing durations between call-up and launch, and in minimizing the time it takes to field new technology in orbit. The US Department of Defense has undertaken a multi-phase effort to establish the feasibility, requirements, architecture, and standards involved with an Operationally Responsive Space (ORS) system.

For this approach, the space vehicle is split into two components: the spacecraft bus and the payload. One or two different types of spacecraft buses could support the variety of a dozen or so different interchangeable payloads.

The concept of operations outlines the existence of a launch depot, where launchers, spacecraft buses, and payloads are stockpiled. Upon call-up, a given payload is mated to a spacecraft bus, forming the space vehicle, and the space vehicle is integrated with the launcher for launch, the whole process perhaps being shorter than several days. SpaceWire was selected as the standard to be employed for the high rate data interface between the payload and spacecraft bus [Jaffe 2007].

Problem
The cabling and connectors specified in the SpaceWire standard (ECSS-E-50-12A) are not ideal for ORS and the depot concept. The standard is insufficient for ORS for two reasons: 1) the lack of provision for an intermediate or bulkhead connection and 2) the specification of micro-D connectors, which have burdensome handling requirements.

The standard allows only for point-to-point cabling. This would force ORS busses using SpaceWire as their high-speed link to either restrict placement, routing, or access of SpaceWire devices, or perhaps necessitate the use of a hub placed on an external surface of the spacecraft. Such situations would add to the complexity and cost of an ORS bus and should be avoided.

Micro-D connectors have many advantages, but are not the best choice for a depot environment. In an ORS depot, a satellite will be created by mating a standard bus to a mission package-payload. This assembly will be undertaken by mid-level armed forces enlisted personnel whose expertise will most likely not be spacecraft engineering. The micro-D connectors called out in the SpaceWire standard are somewhat delicate and require small tools and conscientious handling. We would prefer something more ruggedized.

A SpaceWire connector for ORS requires signal integrity and impedance control fine enough to reliably support SpaceWire communication. The connector should be widely available for a reasonable cost. Such a connector should provide quick, reliable connection even when used by minimally trained personnel. It should not have torque requirements and ideally should not require tools.

We examined several commonly used spaceflight qualified connectors to determine their suitability for ORS. This investigation included the non-standard SpaceWire connectors used on the James Web Space Telescope and the International Space Station. We ultimately selected a circular 13 pin 38999 Series II connector similar the one chosen for the European Drawer Rack (EDR) of the ISS [Lanza 2002]. EDR chose a D38999/ 20FB35SN, however we chose a D38999/40FB35SN (447HS166M11-10-4 backshell) for the bulkhead connector and D38999/46FB35PN (same backshell) for the cable side.

The design of the TacSat-4 spacecraft dictates that the SpaceWire cable has two bulkhead connectors for a total of 6 connectors and 3 segments. The pin assignments for the connector were chosen graphically in an attempt to make the conductor configuration for each pair as uniform as possible and attempting to align **E** and **H** fields. The overall design of the cable is shown in Figure 1.

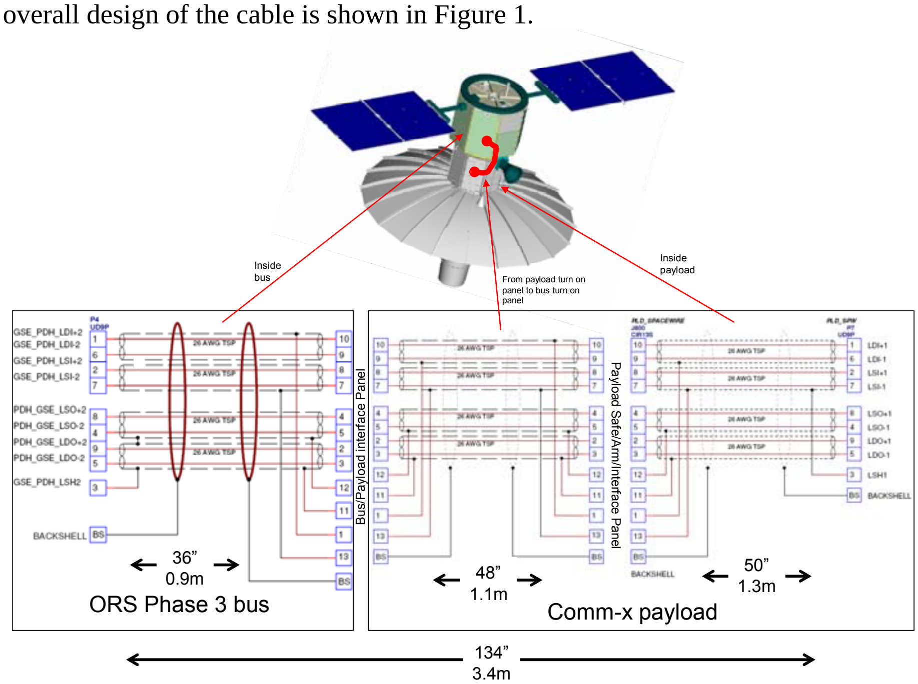

Figure 1: TacSat-4 SpaceWire cable drawing

The cable tested was the flight SpaceWire cable to be used on TacSat-4. The cable was hand fabricated by NRL’s harness technicians in compliance with engineering drawings (2047249) developed by NASA GSFC for the James Webb Space Telescope. The cable assembly is made from Gore-Tex 26AWG (GSC-05-82730-00) SpaceWire cable (W. L. Gore & Associates GmbH). The Gore-Tex wire used to make this cable assembly has undergone extensive qualification and testing to prove its suitability for SpaceWire applications [Mueller 2006].

METHODOLOGY

NRL performed testing to evaluate the deviation from SpaceWire specifications. These tests will be compared to two intact, off-the-shelf, SpaceWire cables (0.5 m and 2 m). The testing included: evaluating the differential impedance (via time-domain reflectometry), comparing data and strobe waveforms, and bit error rate (BER) measurements. TDR traces and scope waveforms were analyzed qualitatively for pass or fail. Successfully passing TDRs traces were close to 100 ohms and had few discontinuities. Oscilloscope waveforms needed sharp, monotonic edges with minimal ringing to pass. An engineering team of SW, hardware, RF, and I&T engineers decided that bit error rate of less than 10^{-7} was required for BER test success. Operational testing (waveform capture and BER) testing was be done with a STAR-Dundee SpaceWire-USB brick in loopback mode. These operational tests were performed using slightly modified versions of the scripts that ship with the STAR-Dundee brick.

All scope probing was done on a Tex TDS644A with a Tex P6246 400MHz differential probe. This probe has input capacitance of less than 1pF and an input resistance of approximately 200kOhms. The probes were connected to the system using a test board developed for this program. The board is known to introduce a discontinuity, but since test results are compared against a baseline cable, the effect can be subtracted. TDR testing was done using a Tektronix DSA8200 with a 80E04 differential TDR head. Impedance correction was performed using IConnect (80SICMX) software. The TDR analysis also required the use of the SpaceWire test board. Additional testing of the cabling will be achieved during normal flight vehicle qualification. These tests include, but are not limited to shock, vibe, EMI, and TVAC.

RESULTS AND ANALYSIS

Figure 2: Picture showing the flight (left, in unmated configuration) and baseline cables (middle is 2m DVI heritage cable and right is 0.5m 'blue' cable).

The cables shown in Figure 2 were tested as described above. The results and analysis are presented below and grouped according to test.

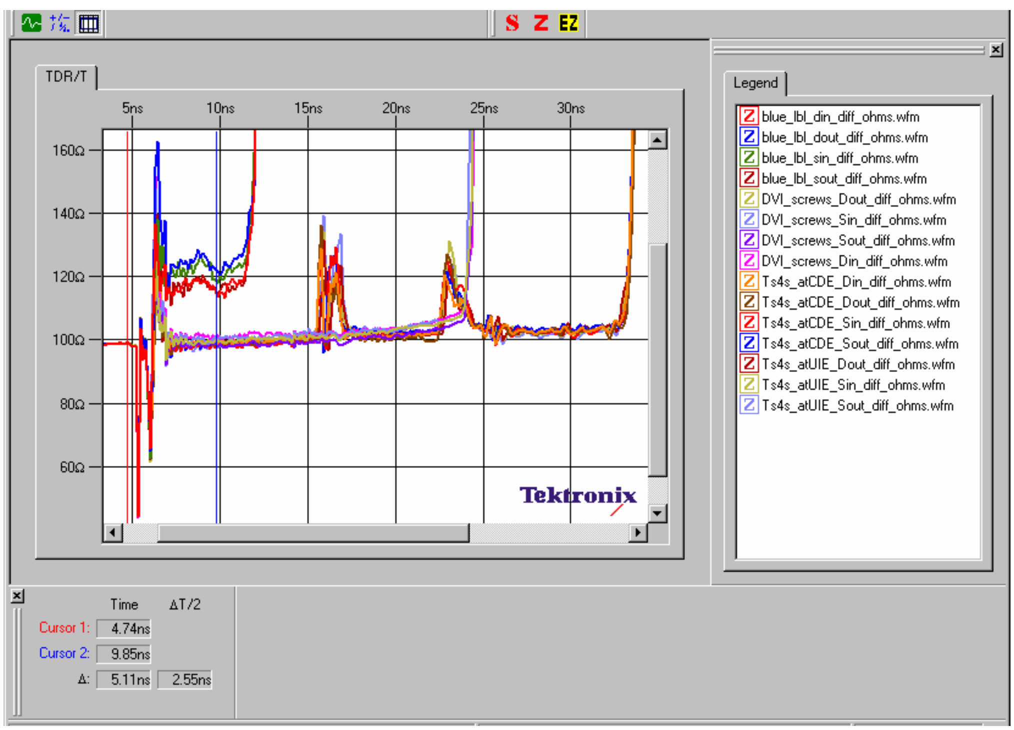

Figure 3: Raw (uncorrected) TDR traces for both reference cables and the TacSat-4 SpaceWire cable

As shown in Figure 3, the 38999 Series II connector has an impedance ranging from 98Ω to 140Ω. The discontinuities are approximately 2 ns wide. An impedance discontinuity of up to 40Ω would seem to be a failure, but the 38999 Series II impedance control is as well as and perhaps better than the standard micro-D

(60Ω to 180Ω for 1.5ns, not shown). It is clear that this connector is not perfect, but it appears to be good enough to support some SpaceWire communications.

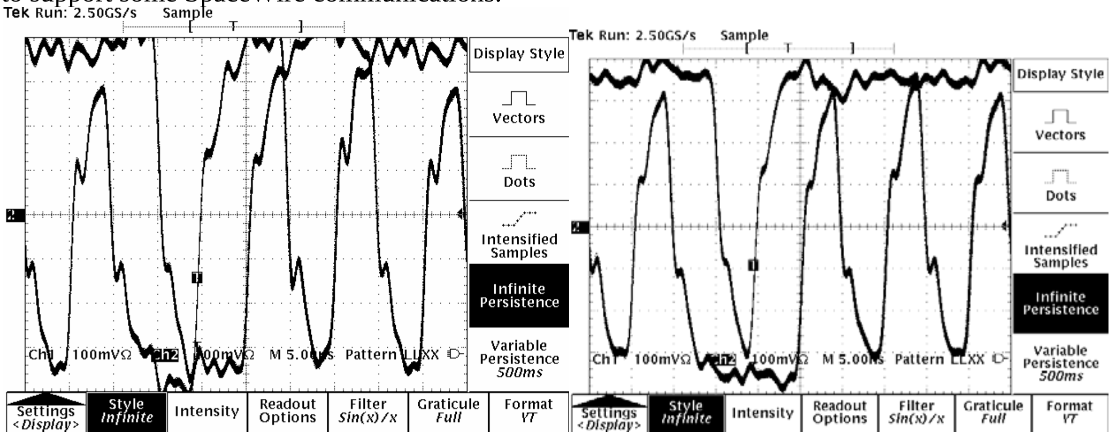

Figure 4: Comparing the reference cable (left) to the TS4 cable (right) Note that waveforms were *NOT* taken simultaneously.

Figure 4 shows typical scope traces comparing the flight and reference cables. As is seen in the image, there was no appreciable difference between scope traces taken of data transmitted on the flight or reference cables when evaluated using the criteria stated above. Although the scope traces show non-monotic edges and some ringing, these effects appear in all traces and may be attributable to the test set-up. The traces taken on the TacSat-4 cables show less ringing and are slightly attenuated when compared to the reference cable. This attenuation is most likely attributed to the difference in length between the TacSat-4 (134"/3.4m) and the reference cable (18"/0.5m) and actually improves the signal slightly.

The bit error rate test used in this study was designed to be a pass or fail test; meaning that there is no feedback from the test other than to say that it passed at the specified speed. Both reference cables and the TacSat-4 cable passed when running at the maximum rate of the SpaceWire device (136 Mbit/s). The 2m DVI heritage reference cable passed BERT testing, but would not run when inline with the SpaceWire test board. In bit error rate testing, there was no difference between the cables.

All testing performed to date has shown that 38999 Series II connector performs reliably in SpaceWire applications up to and above 100 Mbit/s. Furthermore, the concept of a depot-style multiple-segment SpaceWire cable is valid and we will continue to design ORS busses with SpaceWire bulkhead connectors.

FURTHER WORK

It is important to note that no effort was made to characterize the insertion and reflection losses, skew, crosstalk or eye pattern as performed in previous studies [Mueller 2006]. Such work would be useful in further characterizing the proposed cable solution.

The drivers used in this study were speed limited. It would be interesting to see how this cable performs at higher bit rates. How much will the quirks of this cable assembly affect its performance? This study suggests that the cable assembly should perform as good or better at higher rates, but where is the limit?

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