LESSONS LEARNED FROM IMPLEMENTING NON STANDARD SPACEWIRE CABLING FOR TACSAT-4

Session: SpaceWire Test and Verification

Short Paper

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ABSTRACT

The rapid integration, launch, and deployment of satellites in response to emerging needs has been termed "Operationally Responsive Space" (ORS). 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 with 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, the SpaceWire standard (ECSS-E-50-12A) has been specified as part of such a payload-bus interface for high rate data. The TacSat-4 satellite, part of the USDOD TacSat experiment series, is intended as a combination of a prototype ORS Standardized Bus for small satellite national security missions and an example payload. This implementation includes an instance of the SpaceWire interface called out in the ORS Payload Developer's Guide. The need for non-standard SpaceWire connectors has been established in previous studies. Such deviations are justified to get more performance or better human factors engineering. When these deviations from a standard are undertaken, extra effort is required to validate the implementation. Often these efforts result in valuable lessons learned. Investigation and testing described in this paper details our recent efforts, at the Naval Center for Space Technology, to design and qualify for flight on TacSat-4 a non-standard SpaceWire connector implementation. This paper will also cover performance, details on qualification, and lessons learned from environmental testing performed during TacSat-4 flight qualification.

INTRODUCTION

The SpaceWire link on TacSat-4 connects the Payload Data Handler (PDH) module in the Command and Data Electronics (CDE) on the bus side with the Universal Interface Electronics (UIE) on the payload side. CCSDS (Consultative Committee for Space Data Systems) space packets are used for the higher level protocol as dictated by the document "ORS Standard Data Interfaces: Bus to Payload, Bus to Ground".

Because of the depot concept imbedded in the ORS standards, the SpaceWire link deviated from the physical layer called out in ECSS-E-50-12A (now ECSS-ST-50-

12C). As mentioned in previous papers [Schierlmann, Jaffe] the ORS standards require that an ORS bus and payload are capable of being mated in a depot facility by minimally trained personnel without specialized tools. Thus the point to point cable called out in Sections 5.3 – 5.4 of the SpaceWire standard is not ideal.

Section 5.4 of 12C calls out the use of a single cable assembly of no more than 10m joined by two identical connectors. TacSat-4 needed to implement the cable assembly as three separate cables with a total of six connectors. This arrangement is shown in Figure 1.

In addition to the three segment flight cable, other cables were fabricated to accommodate integration and test activities. The three segment 10m cable used for I&T testing consisted of two bulkhead breaks: one to provide for passing through the thermal vacuum chamber wall, and another for passing through the turn on panel of the bus. Comm-X payload testing required a longer three segment 18.5m cable for payload I&T activities, especially electromagnetic interference (EMI) testing. The ORS bus and payload teams successfully tested SpaceWire across these cabling configurations.

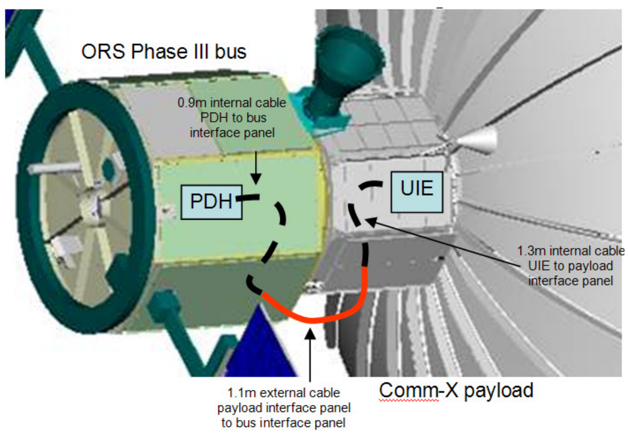

Figure 1: TacSat-4 SpaceWire cabling configuration

Section 5.3 of 12C specified that SpaceWire cables are only to use a 9 position micro-D connector. However, in order to meet depot handling requirements, TacSat-4 chose to use 38999 Series IV connectors (D38999/40FB35SN, D38999/46FB35PN) at the bus/payload interface panels. The choice and validation of these connectors has been documented previously [Schierlmann]. TVAC chamber penetrations were handled with standard hermetic circular connectors from Deutsch (DS07-37S-081, 13084-37S-5020).

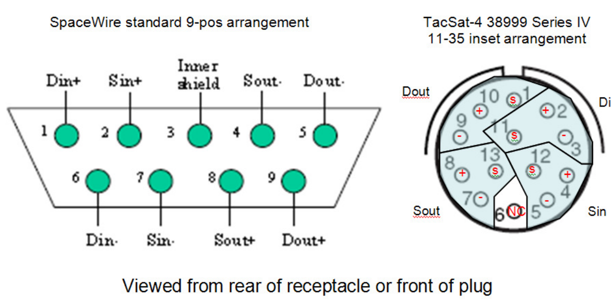

Figure 2: TacSat-4 pin assignments vs. standard Spacewire

The final deviation from ECSS-ST-50-12C was with regard to cable construction as called out in section 5.2. Previous work [Allen, Mueller] has shown that 26 AWG cable outperforms the cable called out in the specification. TacSat-4 chose to use 26 AWG SpaceWire cable manufactured by W.L. Gore & Associates GmbH.

DATA

SpaceWire at the CDE box level and system level was simulated using a PMC spacewire card purchased from Dynamic Engineering. This particular card was able to interface directly onto the VME Power 7E card which was already located in the SES (space environment simulator) chassis. This ability, though at first seemed most beneficial for saving space in the chassis, proved to make interfacing the cables to the PMC card more difficult. The small work area made it difficult to physically connect the cables to the card itself. A couple of mating instances resulted in cable wire to pin connections separating and having to rework the cable. It is important to note that this issue only occurred with the microD solder cup type connectors and did not occur with the potted flying lead connectors.

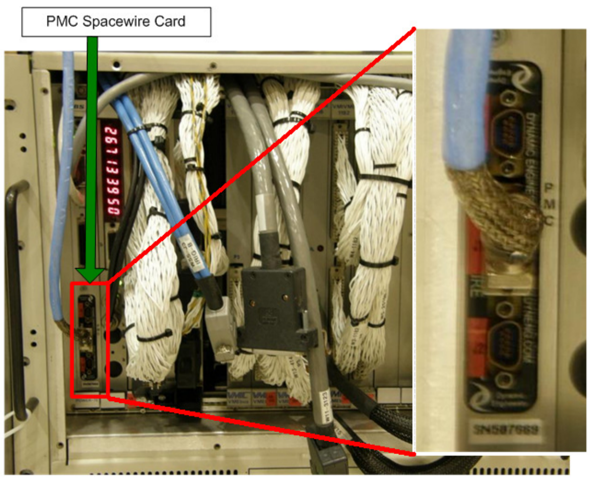

Figure 3: TacSat-4 SES chassis w/ PMC Spacewire Card

Developing GSW (ground software) for utilizing the new PMC card to test the PDH board proved to have a significant learning curve. Knowing the SpaceWire protocol was helpful, but until data was actually flowing across the interface it was difficult to predict what the data would look like and how the PMC card would behave. A breakout box and logic analyzer proved to be critical tools to help understand and troubleshoot the interface. Loopback connectors also proved very useful for stand alone testing of both the PDH and PMC cards.

During ORS bus system level testing, the PMC card simulated the Comm-X payload SpaceWire interface and a SpaceWire test interface to accommodate for testing both channels from the PDH card. The tests performed across the SpaceWire link were run at 25Mbps. Upon completion of the Comm-X payload the ORS bus and Comm-X payload will be integrated to form the TacSat-4 space vehicle. Full space vehicle system level testing will be performed across the SpaceWire link at that point.

For SECCHI, SpaceWire cables of DVI heritage were used. When they were modified for environmental test, we found these cables difficult to work with and prone to breakage. The same was found to be true of the DVI heritage cables used during initial TacSat-4 studies. No such problems were found while using the 26 AWG Gore & Associates SpaceWire cable and the potted flying lead microD connectors used on TacSat-4.

With the addition of the TVAC chamber wall, and to a lesser extent at the bus and payload interfaces, ambiguity arose as to where the out-to-in twisting was to be done. A suggestion from the TacSat-4 bus team was to twist once in each cable, so that an odd number of cables resulted in proper in-to-out assignment. Preliminary designs for the TacSat-4 SpaceWire cable dedicated a pin to carry the outer shield but since the outer shield is chassis ground, this was unnecessary and ill-advised.

Initial qualification of the TacSat-4 implementation of the SpaceWire standard was taken from a previous study [Schierlmann]. This paper extends the work based on feedback received. Eye diagrams were taken using a digital serial analyzer scope (DSA70604). The scope was unavailable for flight cable qualification, but the images were useful as a quick validation of the I&T fabricated cable. The DSA was also helpful in diagnosing a problem with the SpaceWire test board.

The original study used potentially bandwidth limiting 400MHz differential probes when rules of thumb suggest that probes with a bandwidth of at least 1GHz should be used. Further testing was performed with 1GHz probes and no difference was found between results taken with the 400MHz and 1GHz probes.

Table 1: 4-wire (above ground) source - victim cross talk model [Allen]

			Victim						
Connector	Source->Victim	Pins	h (mils)	s (mils)	D (mils)	D/s	D/h	dB	Test group
uD9	Dout->Sout	9/5->8/4	70	50	50	1.00	0.71	-24	2
uD9	Dout->Sout	9/5->8/4	70	50	50	1.00	0.71	-24	2
uD9	Sout->Sin	8/4->2/7	70	50	75	1.50	1.07	-24	2
uD9	Dout->Din	9/5->1/6	70	50	175	3.50	2.49	-40	1
uD9	Dout->Din	9/5->1/6	70	50	175	3.50	2.49	-40	2
11_35P	Dout->Din	10/9->2/3	74	90	223	2.47	3.00		N/A
DB9	Dout->Din	9/5->1/6	98	124	378	3.04	3.86	-30	1
HDD15	Dout->Din	1/2->14/15	76	90	312	3.46	4.10	-47	1

TacSat-4 relied on the crosstalk, jitter and skew analysis performed in previous studies, however, tailored analyses should be used when validating a new interconnect. In the absence of sufficient time or equipment to a complete cross-talk study, one can apply first principles in order to extend to existing data. TacSat-4 chose to look at data in the JWST Connector Choice Study [Allen] and fit the data to a simple cross talk geometry as described in texts[Paul, Johnson 1993]. With some simplification, one finds –as expected- that the cross talk noise shows a strong correlation to the distance (from source to victim) divided by distance to ground (D/h). Given this correlation, one could expect the 11-35 connector chosen by TacSat-4 to perform similarly to the High density D connector investigated. This cross-talk performance is at least as good as the SpaceWire micro-D.

The previous paper incorrectly states that the tests were not run at the full speed of the driver (200Mb/s). However this came from a misunderstanding of the results returned by the SpaceWire driver. A conversation and a quick check of the scope traces confirms that the tests were indeed run at full 200Mb/s speed. Also, the previous paper incorrectly referred to a 38999 Series II with a 10-35 insert arrangement when the connector is really a 38999 Series IV with an 11-35 insert arrangement.

CONCLUSIONS

The 10m and 18.5m cables fabricated for environmental test performed well. The extra length helped to dampen ringing induced by the discontinuities of two inline connectors (bus and chamber wall).

After qualifying SpaceWire cables on two occasions, we still see opportunities for improvement with the test board. Our attempts resulted in noticeable reflection in the signal. One effective option to capture waveforms without an impedance mismatch was to solder to the internals of the SpaceWire brick from Dundee. Given the features and cost of the brick, this approach was risky. In the future we may use a modified DESWBO from Dynamic Engineering for examining waveforms.

The bandwidth of a TDR is 20-30GHz, at which frequencies the padstack, stack-up, and foot prints become critically important. The TDR test board had an excessive discontinuity because the antipad around the SMA connector was too large [Bakel]. This discontinuity was large enough to prevent Iconnect from converging to an impedance solution. When commissioning test boards, it is important to know your frequency of interest. For this study was related to TDR bandwidth (30GHz) and not SpaceWire knee frequency (<1GHz) [Johnson, 1993]. Ensure that your layout engineer is familiar with designing to the frequency of interest. For future testing, we may try the Gore test board described in [Allen].

REFERENCES

Connectors, Electrical, Rectangular, Microminiature, Polarized Shell, General Specification for (w/Amendment 1), MIL-DTL-83513. Revision: F, Dated: 30 June 2008. Available: http://www.dscc.dla.mil/Programs/MilSpec/listdocs.asp?BasicDoc=MIL-DTL-83513

Connectors, Electric, Rectangular, Nonenvironmental, Miniature, Polarized Shell, Rack and Panel, General Specification for, MIL-DTL-24308. Revision: F, Dated: 25 June 2007. Available: http://www.dscc.dla.mil/Programs/MilSpec/ListDocs.asp?BasicDoc=MIL-DTL-24308

C. R. Paul, *Introduction to Electromagnetic Compatibility*, John Wiley & Sons, 1992.

D. A. Powner, C. Cha, N. Doherty, N. Glover, K. Malhotra, C. Phillips, K. Richey, "Geostationary Operational Environmental Satellites: Steps Remain in Incorporating Lesson Learned from Other Satellite Programs," US GAO, Washington, DC, Rep. GAO-06-993, Sep. 2006. Available: http://www.gao.gov/new.items/d06993.pdf

D. Schierlmann, P. Jaffe, "SpaceWire Cabling in an Operationally Responsive Space Environment," Proceedings of the International SpaceWire Conference 2007.

H. Johnson, G. Martin, *High-Speed Signal Propagation: Advanced Black Magic*, New Jersey: Prentice Hall PTR, 2003

H. Johnson, G. Martin, *High-Speed Digital Design: A Handbook of Black Magic*, New Jersey: Prentice Hall PTR, 1993

Insert Arrangements for MIL-DTL-38999, MIL-DTL-27599 and MIL-C-29600 Series A Electrical Circular Connectors Revision: B, Dated: 20 July 2007Available: http://www.dscc.dla.mil/Programs/MilSpec/ListDocs.asp?BasicDoc=MIL-STD-1560

J. Bakel, "Diff Pair Routing," Unpublished, April 2004.

J. Mueller, "Design Challenges Of An Advanced Spacewire Assembly For High Speed Inter-Unit Data Link," 2006 MAPLD International Conference, Washington, DC, September 2006.

Operationally Responsive Space (ORS) General Bus Standard (GBS), ORSBS-002/NCST-S-SB001 Revision 3, Jan. 2008. Available: http://projects.nrl.navy.mil/busstandards/

Operationally Responsive Space (ORS) Payload Developer's Guide (PDG), ORSBS-003/NCST-IDS-SB001 Revision 3, Jan. 2008. Available: http://projects.nrl.navy.mil/busstandards/

ORS Standard Data Interfaces: Bus to Payload, Bus to Ground, ORSBS-004/NCST-ICD-SB008 Revision 2, Dec. 2007. Available: http://projects.nrl.navy.mil/busstandards/

P. Jaffe, G. Clifford, J. Summers, "SpaceWire for Operationally Responsive Space as part of TacSat-4," Proceedings of the International SpaceWire Conference 2007.

S. Allen, "SpaceWire Physical Layer Issues," 2006 MAPLD International Conference, Washington, DC, September 2006.

S. Allen, "SpaceWire/Synchronization Connector Choice," Unpublished, October 2004.