Spacewire cabling in an Operationally Responsive Space Environment

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Agenda

- Who am I
  - Me
  - NRL/NCST
- What are we doing
  - ORS
  - TACSATs, TACSAT-4
  - Spacewire
- Why do it
  - Depot concept
- What have we done so far
  - Test Plan
  - Test results
- What’s next
  - Summary and input

My Background

- Electronics Engineer, NRL 2003- present
  - Electrical I&T lead TACSAT-4 / ORS phase-3 bus
- Hardware Design Engineer, Hewlett-Packard Technical Workstation Laboratory 2000-2003
  - USB Subsystem Lead Engineer
- Senior Software Support Engineer, Hewlett-Packard 1995 - 2000
- Masters of Electrical Engineering, Colorado State University, 2003
- Master’s thesis: *Transmission time prediction for meander delay lines in a common PCB geometry*
  - Use of Ansoft HFSS, HPSpice and Matlab to suggest an equation to quantify the actual propagation speed of a signal through a meandering delay line of printed circuit board traces.
- Bachelors of Electrical Engineering, Auburn University 1993

Recent NRL High Speed Data Designs

- NPOES firewire, Ken Wolfram
  - Details TBD
- STEREO (SECCHI)
  - Board Design by Greg Clifford, of SEI.
  - Details available from Greg Clifford (gclifford@silvereng.com) or via SECCHI design review material
  - Of note:
    - SECCHI TVAC cables were created and used with 37P circular connector inline
      - 3 pairs of COTS spacewire (DVI heritage) cables were cut up and a 37P circular connector (D507-37S-059) was attached to the end.
      - A DM5623-37PP was used to penetrate the chamber wall
      - The vacuum portion of the cable assembly was created with 26GA TSP and an overall shield. This terminated in uDs on the UUT end and a 37S Circular on the chamber wall end (13084 37S-5020)
    - No additional qualification, no signal integrity testing was done on the cable solution
    - Cable configuration worked fine at 100Mb/s
    - Only problems encountered were workmanship:
      - The 28GA wire in the COTS cables kept coming loose from the 37-CIR
    - Flight cables were COTS spacewire

What is ORS?

- ORS stands for Operationally Responsive Space
- Trying to make space more accessible to the commanders in the field
  - the UAVs of Space
- Vision is call-up to launch in less than seven days

- This vision requires having inventory of space assets ready
  - Use pre-built busses and payloads
    - Mix-and match
    - Stored in a depot
    - On call up, mate bus to payload, then stack and launch
  - Want to leverage/enable Industry for cost savings
    - Any manufacturer can build a bus or payload
    - Will not be build to point design, is build to requirements
- Satellites are small
- TACSATs (tactical satellites) are part of the ORS effort

TacSat Update: #1 - #4

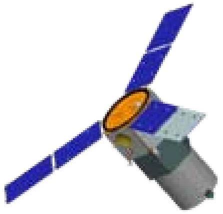
- TacSat-1
  - Navy Led Experiment for OSD's OFT
  - Tactical RF Payloads and UHF Cross-Platform Link
  - Low Resolution Visible (70m) and IR (850m) Cameras
  - Direct Access Via SIPRNET and VMOC Web Site
  - Spacecraft Completed May 04, Within 1 Year
  - Pathfinding a New Launch Process and Vehicle
  - Launch: Falcon-1 Spring 07
- TacSat-2
  - Air Force Led Experiment
  - Tactical Imaging and RF Payloads
  - Tactical CDL and UHF Links
  - Multiple Science Payloads
  - Launch on Minotaur-I, Dec 2006
- TacSat-3
  - Began First Joint Process for Selection,
    - Process Led by AFSPC
  - Air Force Led Experiment
  - AF/Army Hyperspectral Primary Payload
  - Navy Small Data-X Payload for IP-Based Buoy Comms
  - Launch on Minotaur-I, October 2007
- TacSat-4
  - Mission Jointly Selected on Oct 13, 2005
  - Navy Leading With COTM/Data-X/BFT
  - Launch on Minotaur-IV, October 2008

Overall Experimentation Purpose

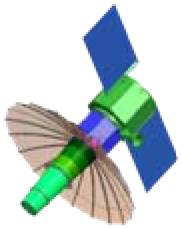
Experiment w/ Key System Elements to Mature Understanding and CONOPS for An Operational System

TacSat-1 at NRL

TacSat-2 / Roadrunner Picture From AFRL & MSI



TacSat-3 Picture From AFRL & Swales



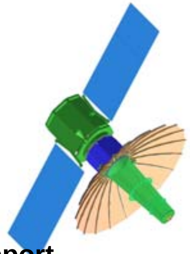
TacSat-4 Picture from NRL & APL

TacSat-4 Mission Summary

Navy Led for Joint Community

Spacecraft and Payload Highlights

- Satellite [Space Vehicle]:
  - 425 kg
  - Payload Power: 200 - 610 Watts
  - Low HEO (4 hr) Orbit
  - 1 Year Life
- Payload Capability:
  - Data-X and BFT
  - COTM
    - Legacy Radio & IP Netted Support
    - MOUS-Like Wideband Capability



Objectives

- Demo High Dwell ORS Capability via a HEO Orbit
  - Augment Poor/No Coverage Areas
- Evaluate & Mature Phase 3, System Level Bus Standards in Realistic I&T, Launch, and Flight Operations Environment
- Provide TACSAT/ORS Comms-on-the-Move Capability (Legacy, Netted, and MOUS-Like)
- Collect BFT Devices in Underserved Areas
- Perform Buoy/Sensor Data-X on Moderate-to-High Power Transmissions

Ground Equipment

- BFT Devices: MTX, Grenadier Brat, Others
- COTM: Legacy Radios and MOUS Compatible UHF Wideband Radios
- Data-X Buoys and Gnd Sensors
- Ground Terminal: One Per 2000 nm Theater Spacecraft Cmd & Cntrl: Blossom Point, Maryland
  - Additional Coverage From AFSCN
  - Payload Tasking on SIPRNET VMOC

Programmatics

- ONR Payload, Flt Ops, Test Bed Sponsor
- OFT Bus Sponsor – “Phase 3” Bus (aka Standard Bus)
- AFSPC, SMC-12 Provided Launch
  - Minotaur-IV
  - Launch Targeting October of 2008
- NRL Program Manager
- STRATCOM to Assign Lead COCOMs as Experiments and Exercises Mature
- Multi-Service Participation

Wearing Two Hats

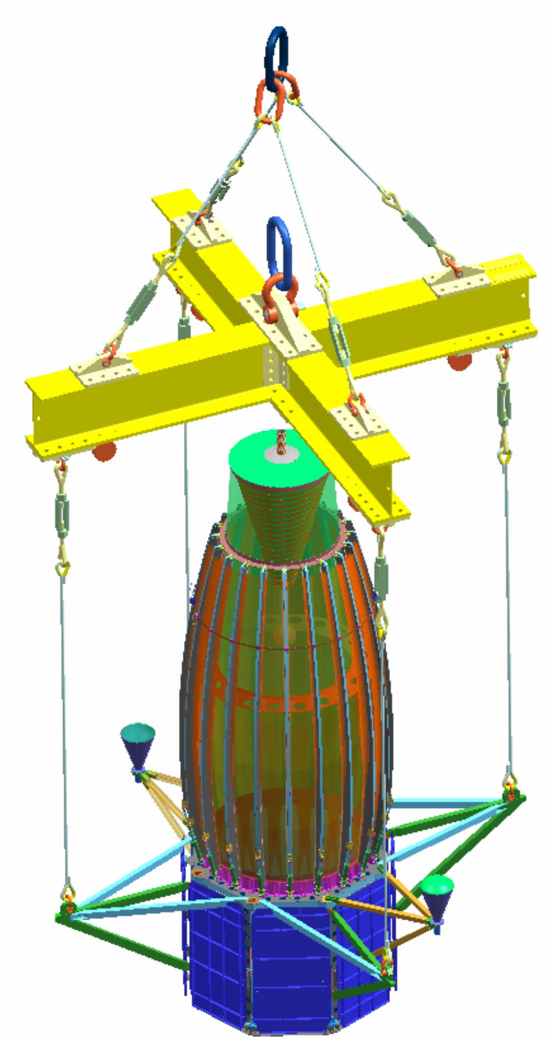
TACSAT-4 Mission

- Deliverables
  - Integrated and fully tested space vehicle
  - Built to meet specific mission
  - Launch in ’09 (TBR)
- Space Wire Implementation
  - Not needed for primary mission; is secondary payload
  - Only added to validate “standard high-speed interface”
  - Is not a native spacewire device.
    - Is 422 converted to spacewire
    - Very low bandwith requirement
    - Very simple network (point to point)
- Constraints
  - Low cost, short development time
  - High risk mission
  - Bus is a “standard bus”

ORS Phase III “Standard bus”

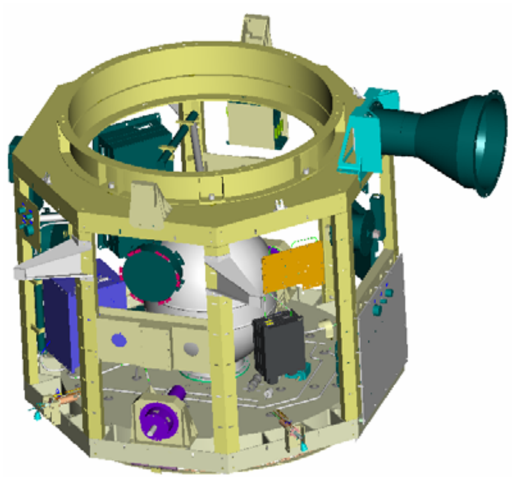
- Deliverables
  - ORS documents
    - Build guidelines for ORS Standard bus
    - Focus on bus to payload interface
      - Four connections:
        - » High –speed data
        - » Low-speed data
        - » Power
        - » deployments
  - Bus built to ORS documents
- Spacewire implementation
  - ORS docs require use of “industry standard interfaces”
  - Spacewire not specifically called out
  - Trade study identified Spacewire as best choice for high speed data interface
- Constraints
  - ORS docs

Depot Concept



Mission specific Payload

+



"Off the shelf" Generic ORS bus

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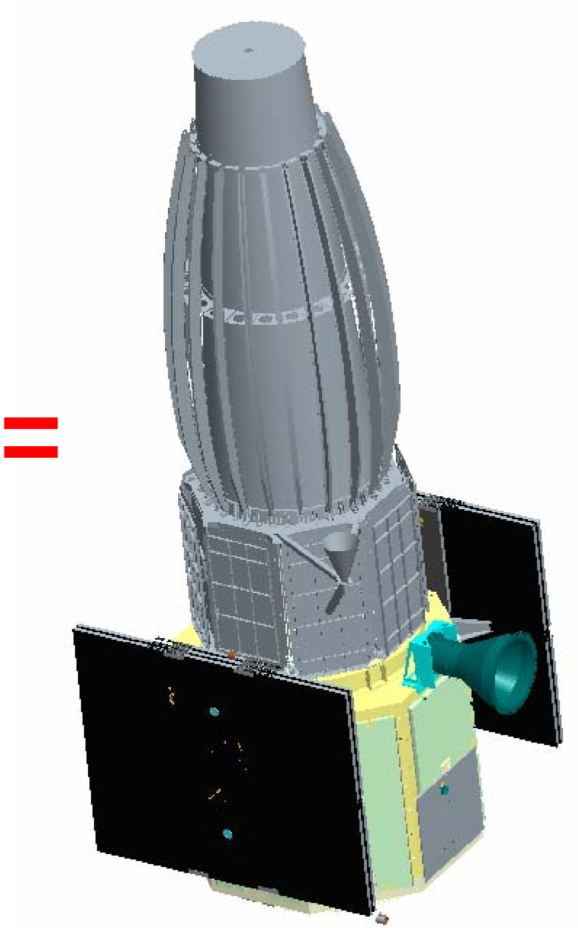


Integrated SV

Operationally Responsive Space (ORS) Requirements for Spacewire Connectors

- Suitable for Space Applications
- Signal Integrity and Impedance control
  - Ability to reliably support Spacewire
- Availability
  - Should be fairly widely available
- Cost
  - Should not be exorbitantly expensive
- Suitable for Depot Operations
  - Quick, reliable connection
  - Usable by minimally trained personnel
  - No torque requirements
  - No need for tools
- Etc.
  - etc.

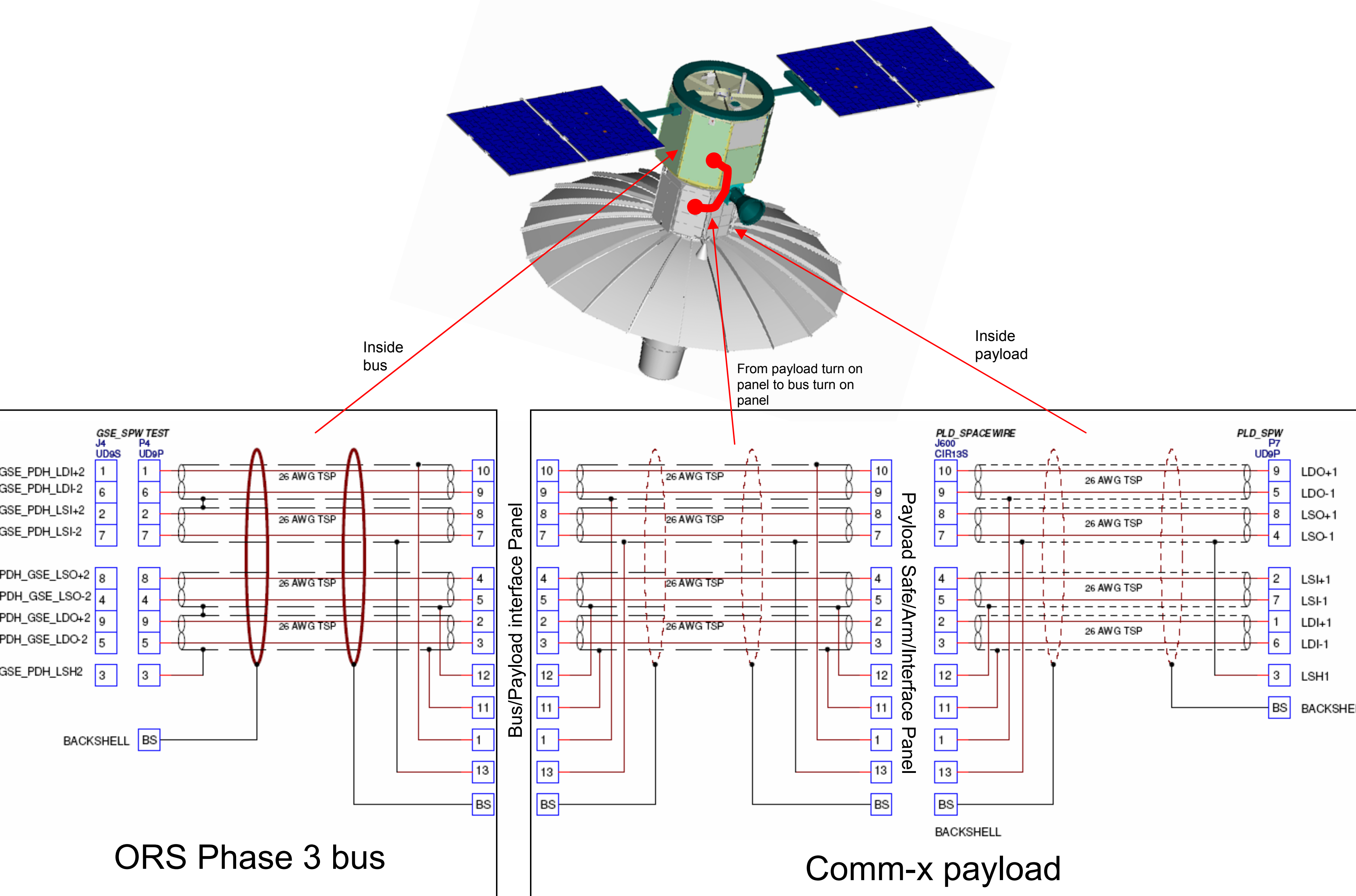
Connectors Considered

	Cost	Lead time	Availability	Depot Assembly	Impedance control	EMI
D connector	Low	Low	High	Fairly easy	Poor	Poor
High density D	Low	Low	High	Fairly easy	Poor	Poor
Micro D	Med	Long	Low	Tricky	Poor	Poor
Gore JWST twinax	High	Long	Low	Fairly easy	Very good	Very Good
38999	Med	Med	Med	Simple	Fair	Ok

TACSAT-4 Spacewire Implementation Notes

- Spacewire “driver” is Payload Data Handler designed by Greg Clifford, of SEI
  - Partial heritage to SECCHI design
  - Details available from Greg Clifford (gclifford@silvereng.com) or via ORS Phase III Bus CDR material
- Spacewire “receiver” is CEASE (TBR)
  - Details TBR
  - Spacewire experiment is a Payload distinct from comm-x
  - Spacewire experiment is (what)?
    - Anticipated operating speed?
    - Driver
    - SPWr heritage?
    - Who owns this space wire experiment?
    - Who tests it?
    - Who builds the flight cable?
    - Who integrates it into TS4 payload?
- Baseline Interconnect configuration:
  - Series 38999 13-pos Circular connector:
    - D38999/46FB35PN (on bus) & D38999/40FB35SN (payload cable)
    - 22 ga contact.
    - 4-8wk lead time to get exact connector
  - Our harness group will build the spacewire cable assemblies using 26GA TSP Tufflite TL med wall pairs.
  - 3 segment cable (as above) with a total length < 6m
    - CDE to interface panel
    - I/F panel to intermediate payload panel
      - payload intermediate i/f also a 38999 series 4
    - Intermediate payload panel to payload Spwr load.
- One path from CDE to Payload (as noted above)
- One path from CDE to EGSE (debug port)
  - Two segment in ambient testing
  - Three segment in TVAC

TACSAT-4 Spacewire bus to payload wiring



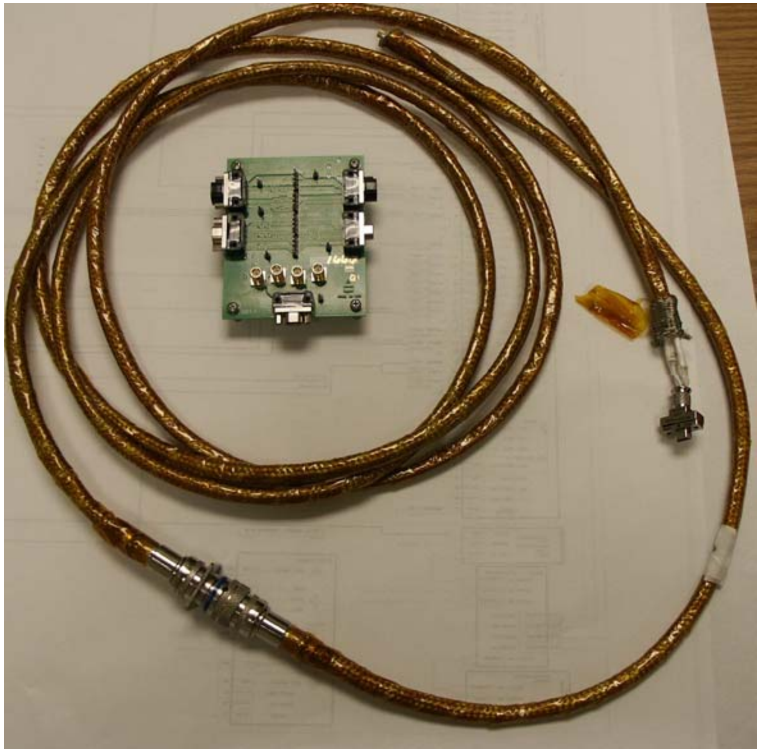
Tacsat-4 /NRL's SpaceWire Testing (starting position)

- NRL will perform testing to evaluate the deviation from Spacewire specifications
- Tests will be baselined against an intact COTS 3m cable
- Testing includes:
  - compare v. baseline
  - Differential Impedance
    - Via TDR
  - Eye Patterns
    - O'scope
  - Bit Error Rate Measurement
    - <10**-7 BER for sucess
- For operational tests (eye and BERT) testing will be done with the existing SpaceWire PMC card
  - In loopback mode
- Test cables will be hand fabricated by NRL's harness group.
  - Using a connector similar –not exactly- to flight
  - Max length per spec (10m, total)
  - Recommend flight follows pinout, length and twisting defined by this study.
- Test will be performed at 3 speeds
  - designed bus speed
  - 2x designed bus speed
  - To failure or 200Mbit which ever comes first.
- All O'scope probing will be done on a Tex TDS644A with a Tex P6246 *400MHz* diff probe.
  - Input Capacitance <1pF
  - Input resistance ~200kOhms
- TDR Testing will be done on a Tektronix DSA8200 with a 80E04 differential TDR head
  - Impedance correction done in Iconnect (80SICMX)
- Additional testing of the cabling will achieved during normal SV qualification
  - Shock, vibe, TVAC, etc. during SV environmental
  - Details of testing in backup slides

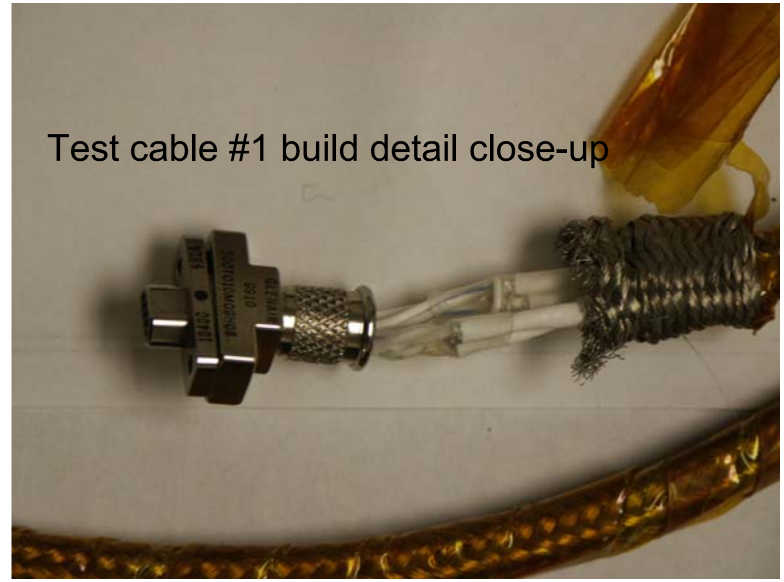
Tacsat-4 /NRL's SpaceWire Testing (To date)

- Tests were base lined against an intact COTS 3m cable
- Testing includes:
  - compare v. baseline
  - Differential Impedance
    - Via TDR
  - Limited O'scope traces
  - Data rate tests
- Data rate testing done with the StarDundee SpaceWire/USB brick
  - In loopback mode (with and without test board inline)
- Test cables were hand fabricated by NRL's harness group.
  - Using a connector similar –not exactly- to flight
    - Flight = D38999/46FB35PN (on bus) & D38999/40FB35SN (payload cable) (TBR)
    - Test = MB929T10F35P (on bus) & JTPQ00RE-1035S (payload cable)
  - Only two segments
  - Segment lengths were randomly chosen (~2m, total)
  - Pinout chosen by graphically using "ORS Spacewire Connector (10-35P) conductor configuration" slide in this presentation
    - Attempted to make conductor configuration for each pair as uniform as possible
    - Attempted to align H fields
- Test was performed at max speed for driver (61MHz)
- All O'scope probing was done on a Tex TDS644A with a Tex P6246 *400MHz* diff probe.
  - Input Capacitance <1pF
  - Input resistance ~200kOhms
- TDR Testing was done on a Tektronix DSA8200 with a 80E04 differential TDR head
  - Impedance correction done in Iconnect (80SICMX)
- A spacewire test board (test fixture) was fabricated to facilitate easier testing
- No BERT testing, no test completed with PDH or PMC card

Test Cable Images



Test cable (configuration #1), test board

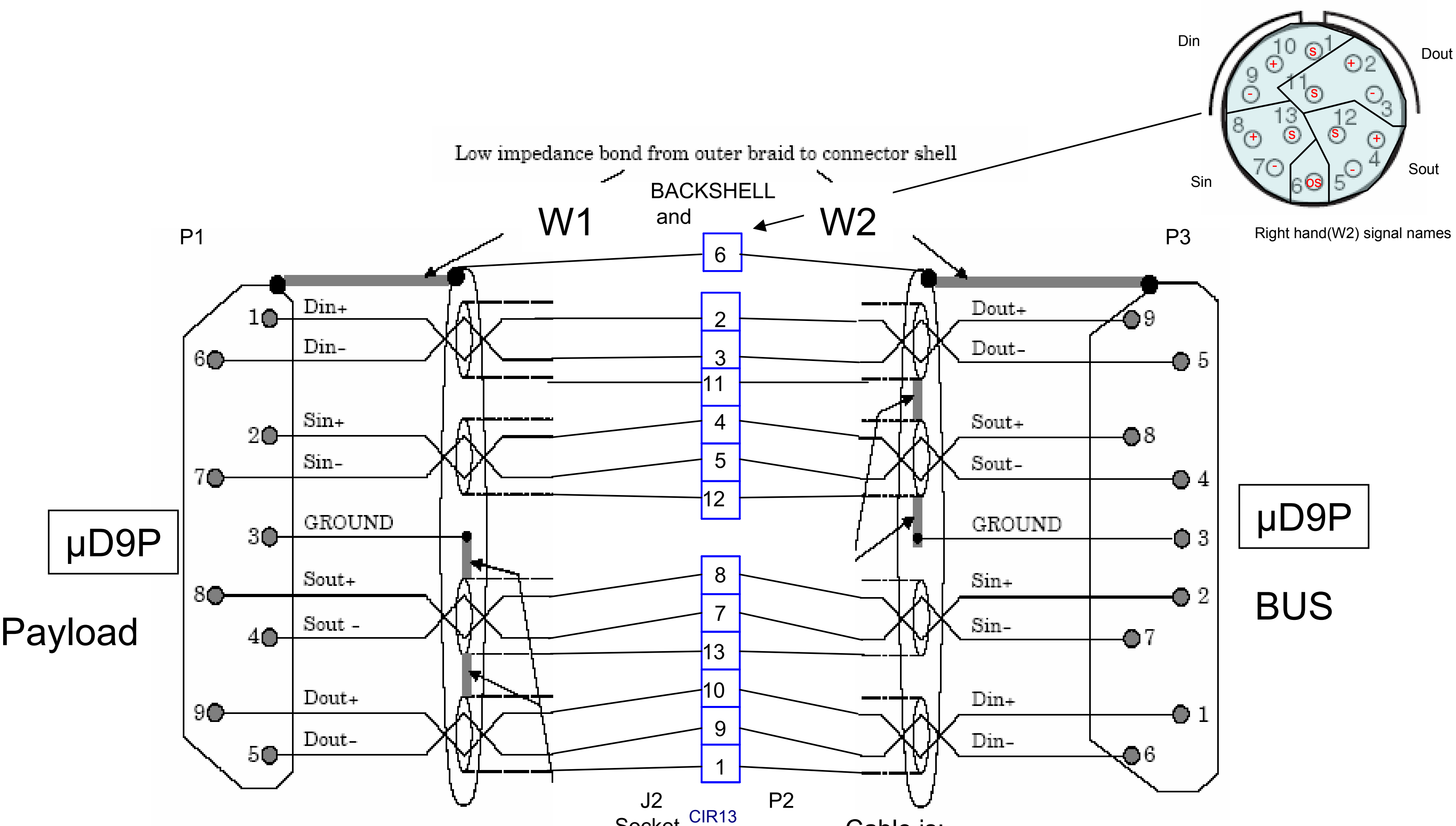


Test cable #1 build detail close-up

38999-series connector in test cable

Baseline Cable

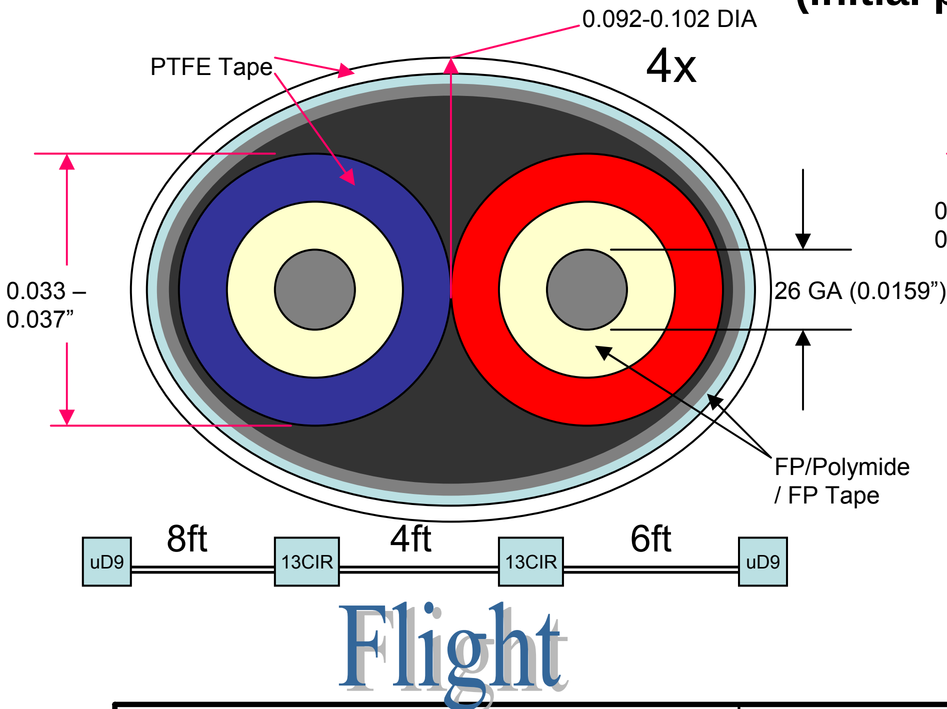
Test Cable (W1, W2) detail

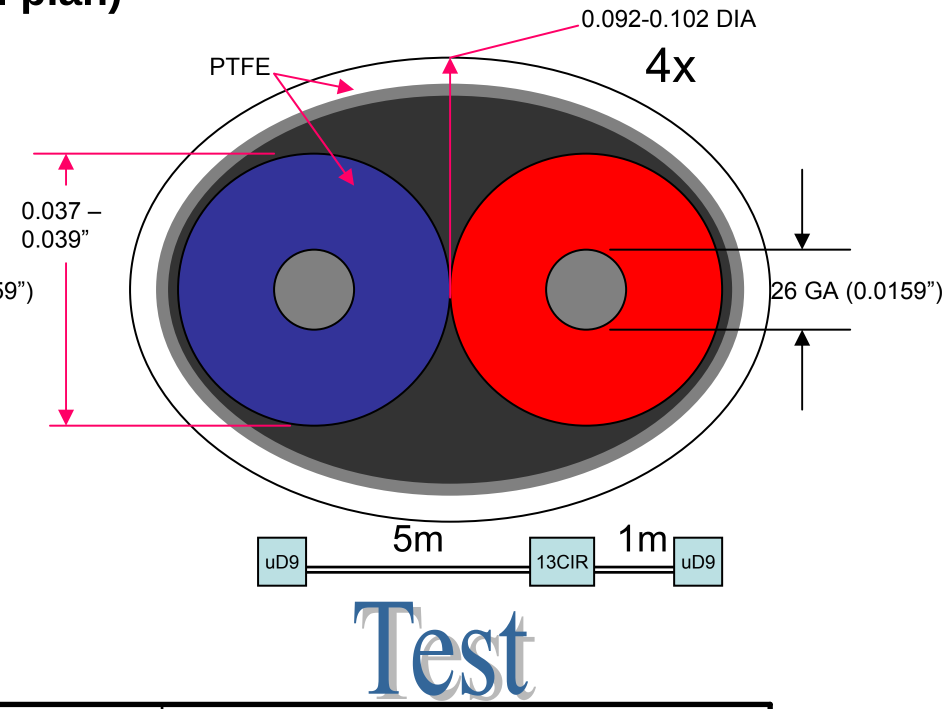


Inner shields are isolated from one another.
Inner shields around Sout and Dout pairs are connected together and to pin 3 of connector.

Cable is:
4@26GA TSP
M27500-26 RC 2 S 06

Comparison between flight and test cabling
(initial plan)

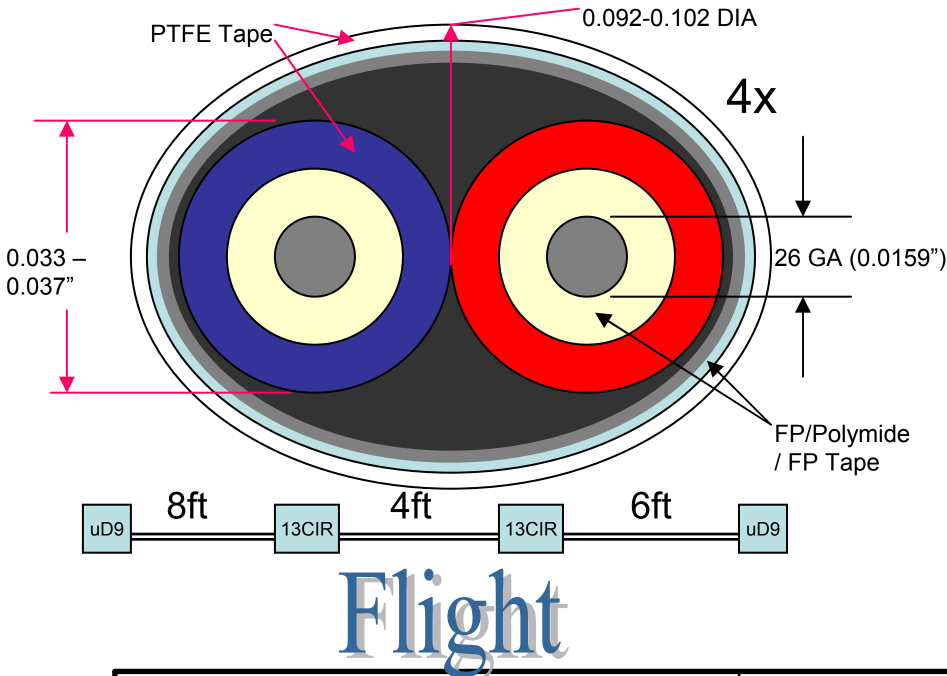


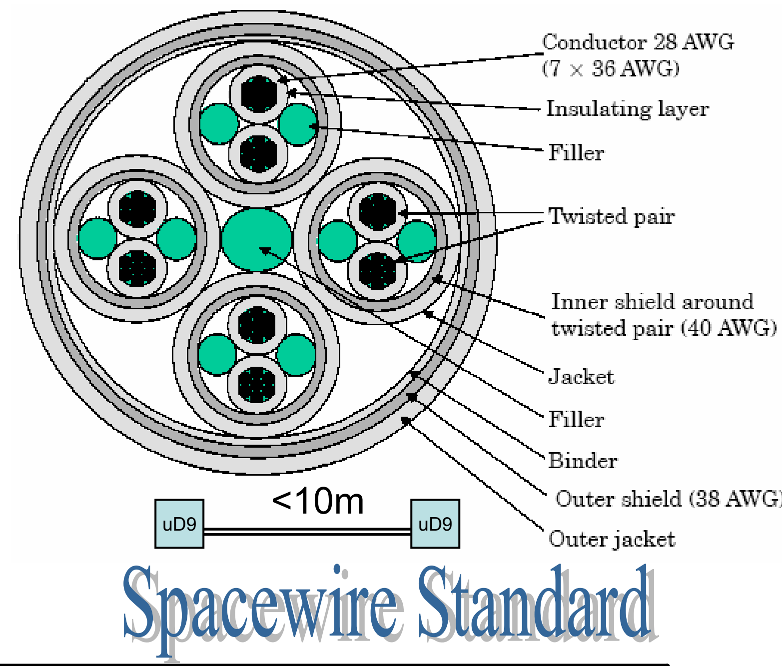


4x (26 GA TSP)	Type	4x (26 GA TSP)
Tensolite	Manufacturer	
??pn??	PN	M27500-26-RC-2-S06
77Ω	Z_diff*	80Ω
6	Number of connectors	4
3	Number of segments	2
6m (est)	Total length	6 m
Tufflite TL(medwall, 26)	Individual components	M22759/11
UT54LVDS031LVE (PDH)	Driver	(STAR-Dundee Spacewire-USB Brick)
<600ps	Driver rise time	

* - Calculated per Johnson and Graham "High-Speed Digital Design: A Handbook of Black Magic," Appendix C (Z_diff = 2*Z_coax || Z_twpr)

Comparison between Standard bus baseline cable design and Spacewire standard: the big four

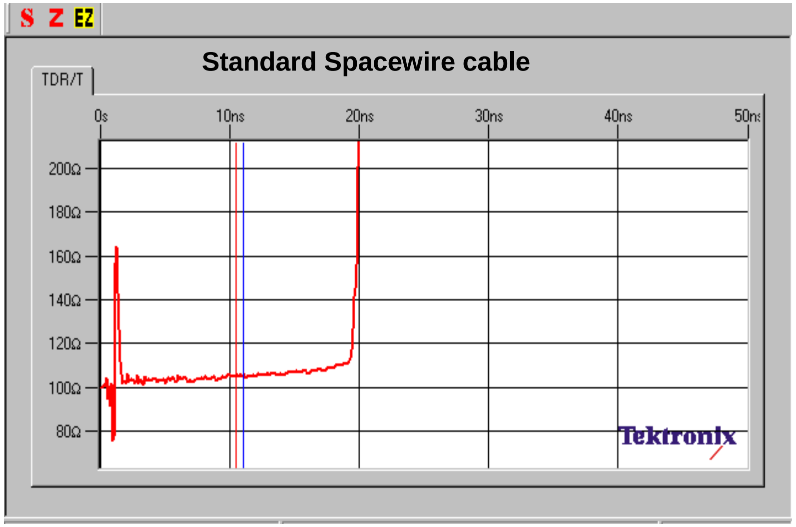


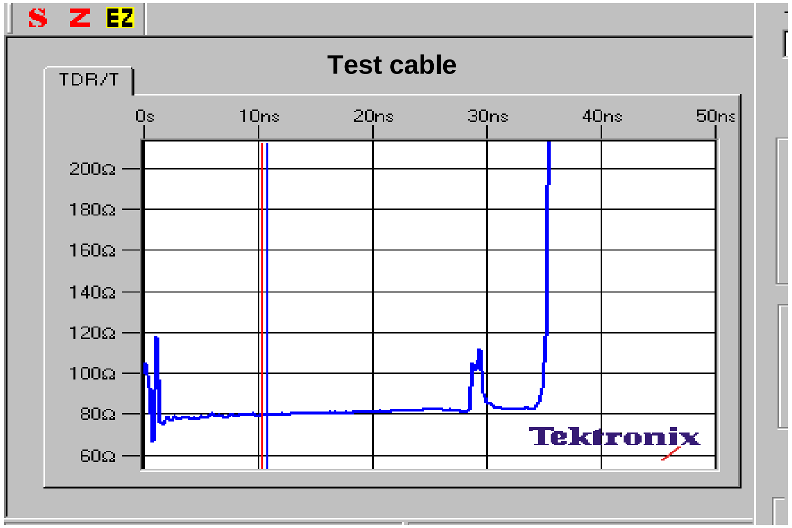


4x (26 GA TSP)	Type	4x (28 GA TSP)
Tensolite	Conductor configuration	7 x 36 GA silver coated copper alloy
PTFE/FP Polymide	Jacket material	PTFE
3, 6	# of Segments, connectors	1, 2
6m (est)	Total length	<10m
80Ω (calc), ->WORSE	Impedance	100 +/- 6Ω
Same dielectric, bigger conductor -> expect same or BETTER	HF loss	c
Same dielectric, bigger conductor, shorter length -> expect same or BETTER	Delay (skew)	+/- 0.1ns/m max
Better shield coverage -> expect same or BETTER	Cross-talk	n/a

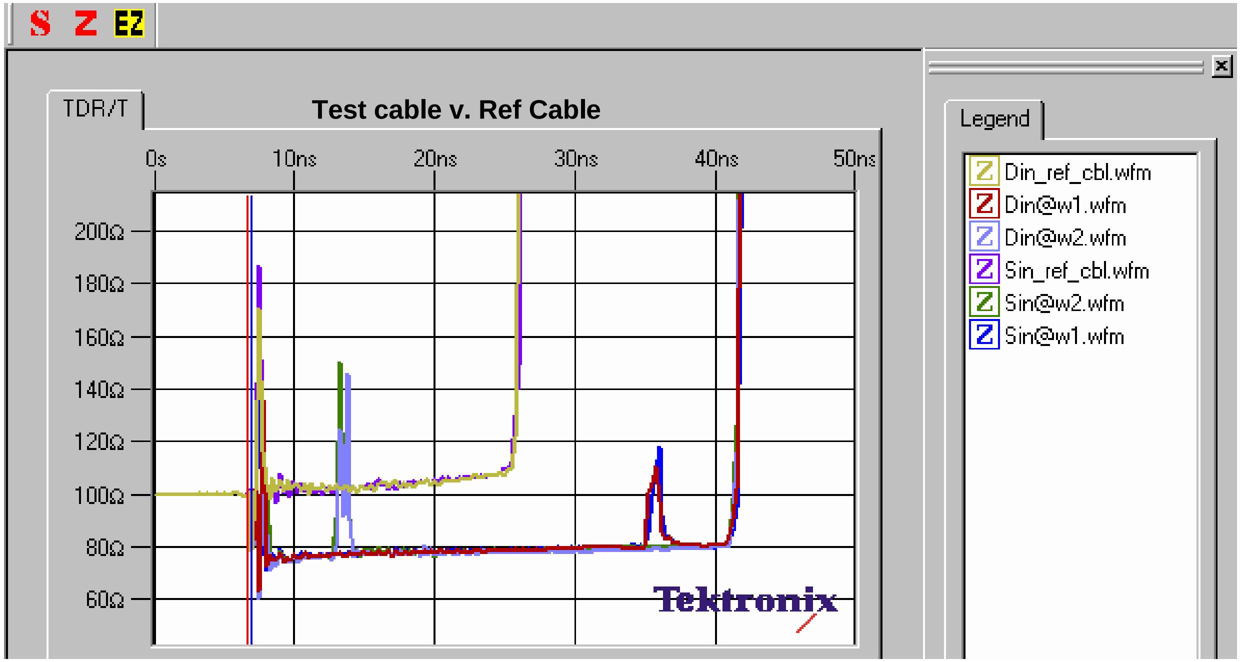
Preliminary Cable Testing Results

- Traces at right
  - taken with Tek DSA8200 series TDR
  - using spacewire test board
  - are differential (Din+ / Din-)
  - Images
    - Upper is standard spacewire cable
    - Lower is test cable with 38999 circular connector
- Preliminary Conclusions
  - Test Cable has wrong impedance 80 vice 100
  - Connector shows promise at ~100Ω
  - Test cable has more consistent impedance than purchased cable





Testing Results (Cable, Impedance)

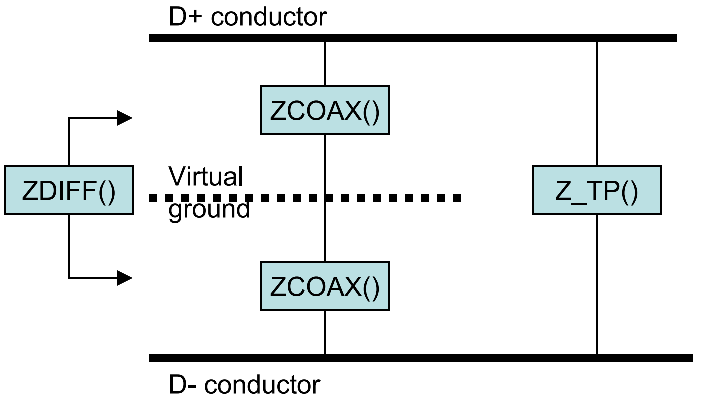


- Conclusions
  - Cable is wrong impedance 80Ω vs. 100Ω
    - Our cable configuration needs to be reviewed as well
      - Now were deviating from spec with cable impedance as well as connector
    - We got here because no-one did the math on the impedance of our cable solution
  - Another test cable was made to get 100 Ω diff impedance (26GA TP kapton (150)
    - Cable unsuitable for flight use, data to follow
  - Curiously, Impedance seems to match a simple formula, shown on next slide.
  - Reference cable is broken…see the impedance discontinuity at the near end (prev slid shows it better)
- Issues/Concerns
  - We have no cable solution (for TS-4) that is 100Ω differential impedance
  - Discovered wire size mismatch with uD9 wile building test cables:
    - uD9 max wire = 28GA
    - 38999 min mire size = 26GA
    - This mismatch was with one specific solder cup connector selected for testing, the other two are ok for up to 24GA

Quick Formulas for Impedance Calculations

ε0 =	8.85E-12	F/m	μ0 =	1.25664E-06	H/m											
	Inner		Outer													
εr	AWG	OD	OOD	Wire Dia	Z_coax	Z_tp	Z_diff_est	Prop delay (ps/in)	Notes	r (mΩ/ft)	l_coax (μH/ft)	c_coax (pF/ft)	l_tp (μH/ft)	c_tp (pF/ft)	l_tot (μH/ft)	c_tot (pF/ft)
2.1	26	36	92	16	145	125	67	120	Tufflite TL medium wall 26GA TSP	40.8	1.1	66.5	0.2	12.2		
2.1	24	40	100	20	133	114	61	120	Tufflite TL medium wall 24GA TSP	25.7	1.0	72.8	0.2	13.6		
2.9	26	36	85	16	118	106	56	141	Kapton (150) 26GA TSP	40.8	1.0	96.2	0.2	16.9		
2.9	26	36	#####	16	16031	106	106	141	Kapton (150) 26GA TP	40.8	136.9	0.7	0.2	16.9		

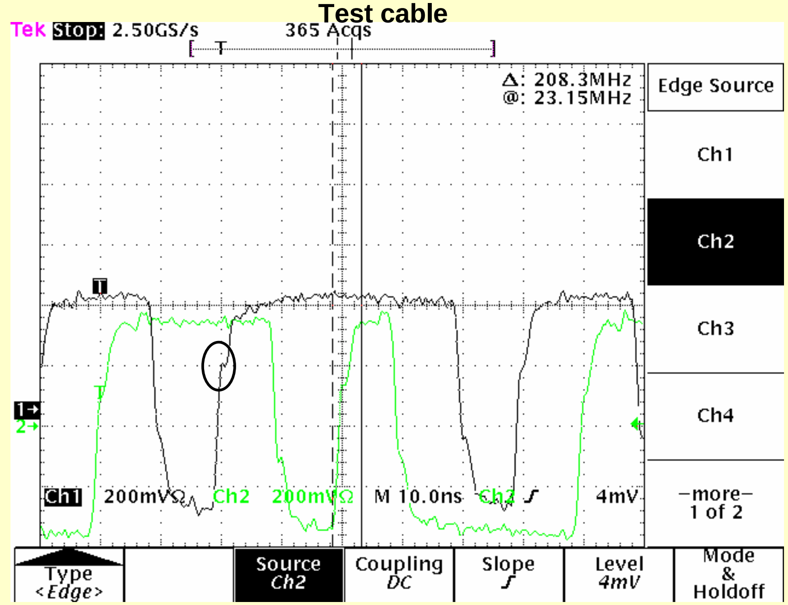
- One of the lessons learned from this testing was a simple formula for calculating differential impedance
- The above spreadsheet has been surprisingly accurate in predicting differential impedance when compared to TDR results
- Formulas are from Johnson and Graham Appendix c, pg 428-429 and 424-425
- They are combined using the logic at right
  - For ZCOAX(), assume one conductor is at the center of the overall shield
  - Z_diff = (2*Z_coax) || Z_tp



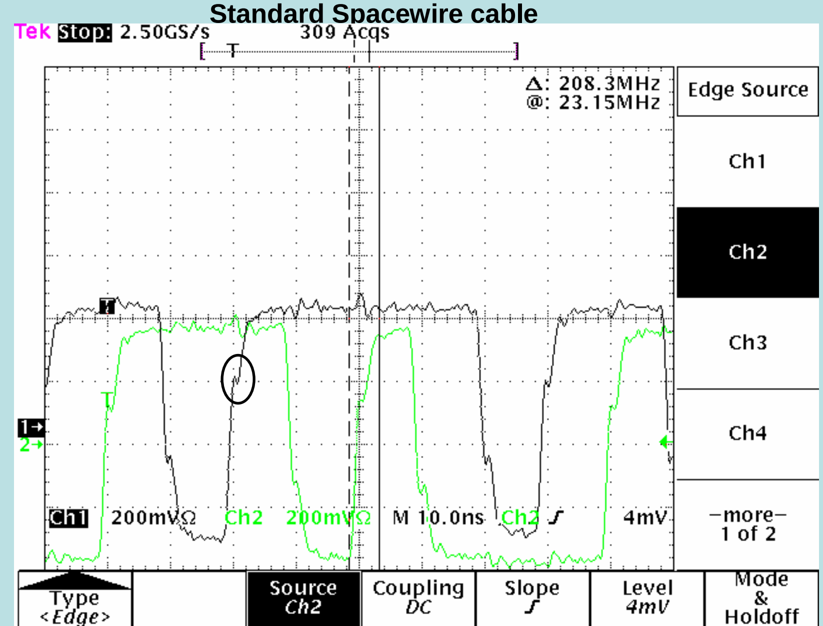
Testing Results ('scope)

- Conclusions
  - Both cables run at 61MHz with the spacewire brick in loopback mode
    - Adding/removing the test board doesn't affect link speed
  - Scope traces look almost identical
- Issues/Concerns
  - The impedance mismatch should have caused a reflection, where is it?
  - Non-monotonic leading edge (in circle)
    - Is on both traces, so is probably from the test set-up
  - These traces were captured with a 500MHz scope using 400MHz probes…doubtful that was enough bandwidth.
- Recommendations
  - Do a bounce diagram on the system:
    - Ref cable with and without test board
    - Test cable
    - TS-4 Flight config
    - SECCHI config

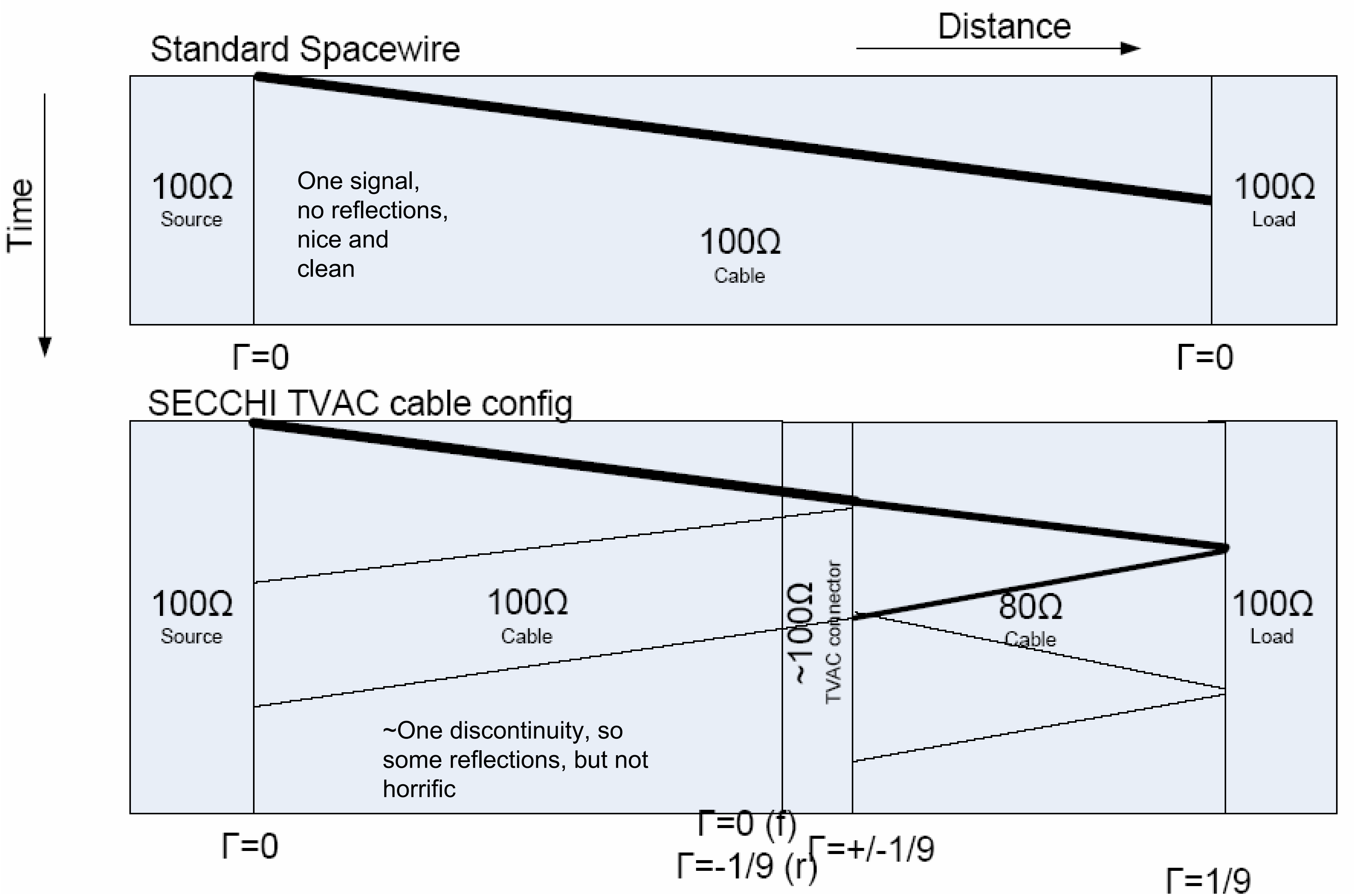
Test cable



Standard Spacewire cable

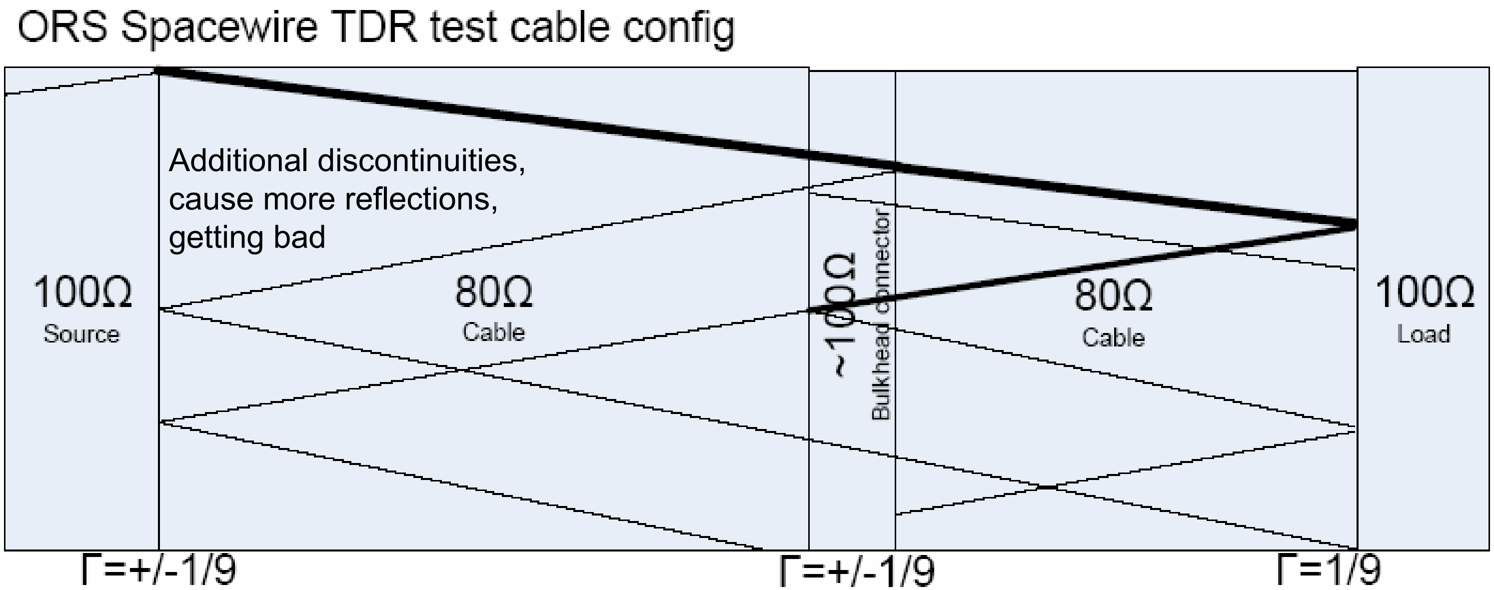


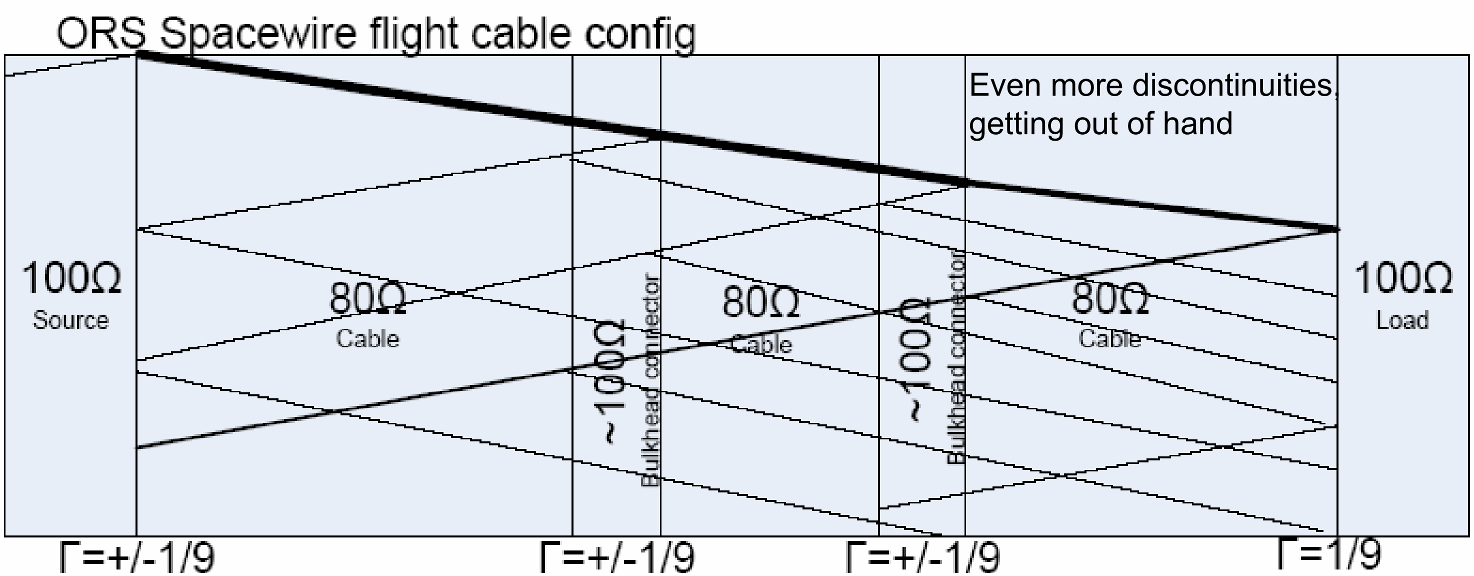
Bounce Diagrams (Spacewire and SECCHI TVAC)



Bounce Diagrams (TS-4 Test and flight configuration)

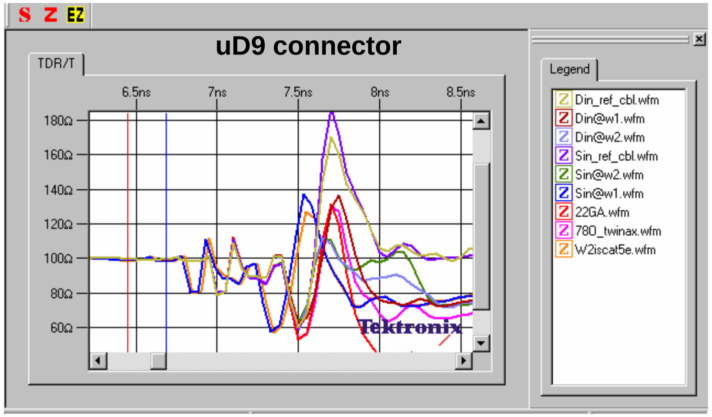
Note that we're starting with <90% of our signal now

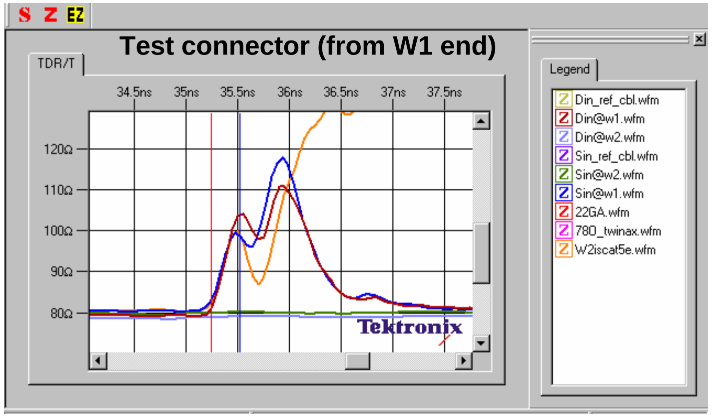


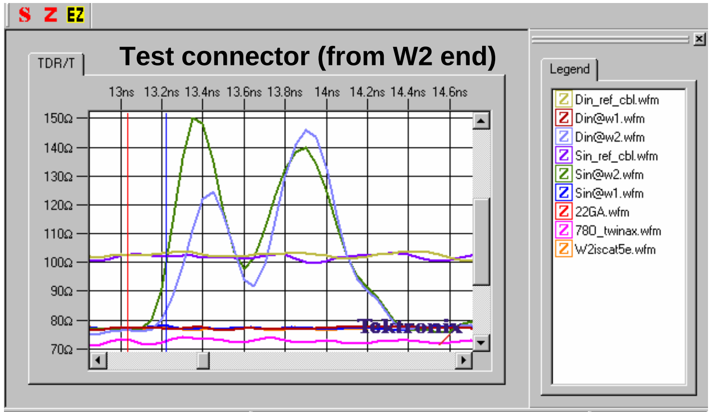


Testing Results (Connector, Impedance)

- Conclusions
  - Connector looks better than our cable
    - Its impedance is in the ballpark of 100Ω
  - Less of an impedance perturbation that the uD9
  - Doesn't appear to contribute to skew (TDR results)
- Issues/Concerns
  - The connector doesn't appear to be symmetrical?!?!
    - W2 images show more impedance variation than W1 images
- Recommendations
  - Connector shows promise, if a 26GA cable is added to space-wire standard, this could be an acceptable alternative



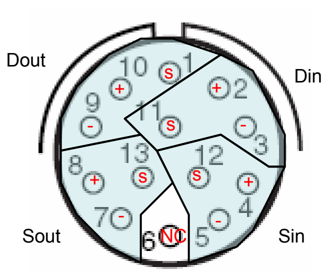




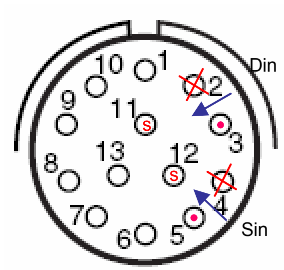
Asymmetrical Connector Impedance?

P1 to P3 (@W1)

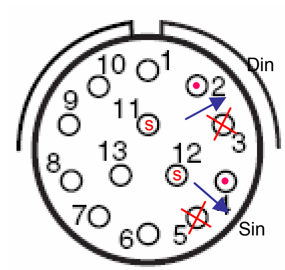
rear of J2, front of P2



Pin names



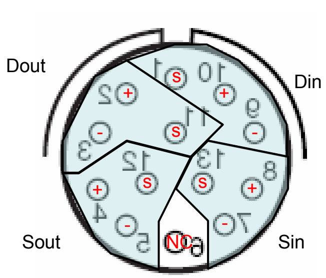
As Tested



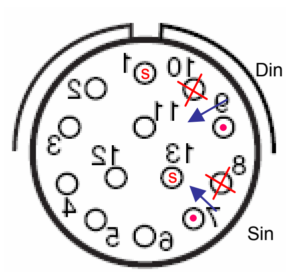
Flight configuration

P3 to P1 (@W2)

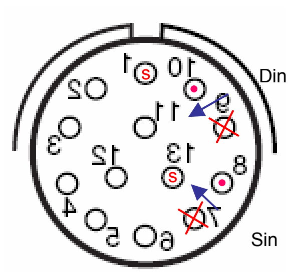
rear of P2, front of J2



Pin names



As Tested



Flight configuration

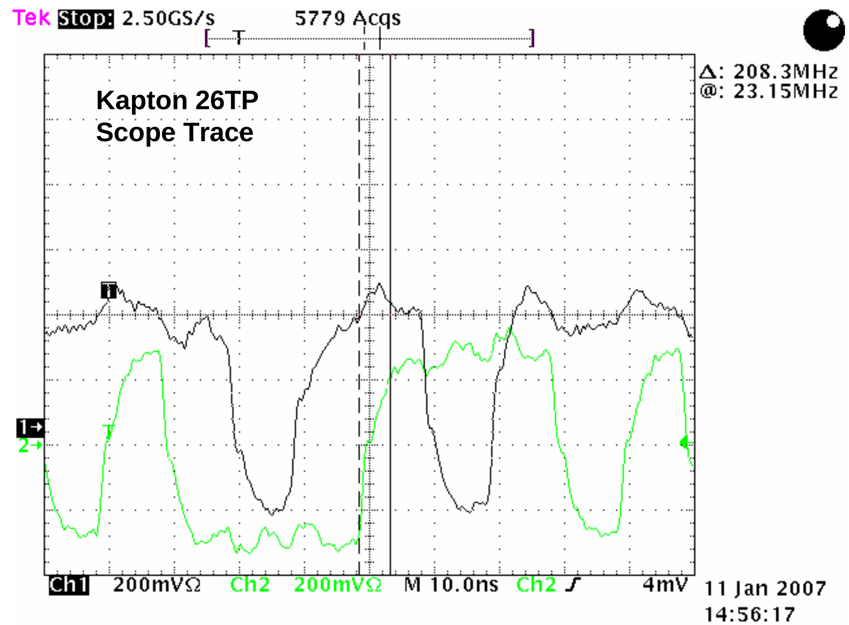
- Drawings on right show that there is no difference in conductor geometry for the Sin pair when viewed at W1 to that when viewed at W2
- Yet the scope traces above vary significantly depending on which end of the cable the TDR is taken from
- This difference in scope traces remains regardless of which pair is viewed
  - Din varies significantly when viewed from W1 as opposed to W2
  - Din at W2 varies from Sin at W2
  - Yet Din and Sin at W2 look very similar
- Doesn't appear to be a workmanship issue.
  - Traces taken on the all pairs show same asymmetry
  - As do traces taken on a completely different cable (kapton version)
- Scope traces above clearly show a difference, why?
- Only differences appear to be
  - that traces taken @W2 go from pin to socket and traces @W1 go from socket to pin
  - Material on socket side of 38999 looks different that material on pin side
    - Do they have different εr?

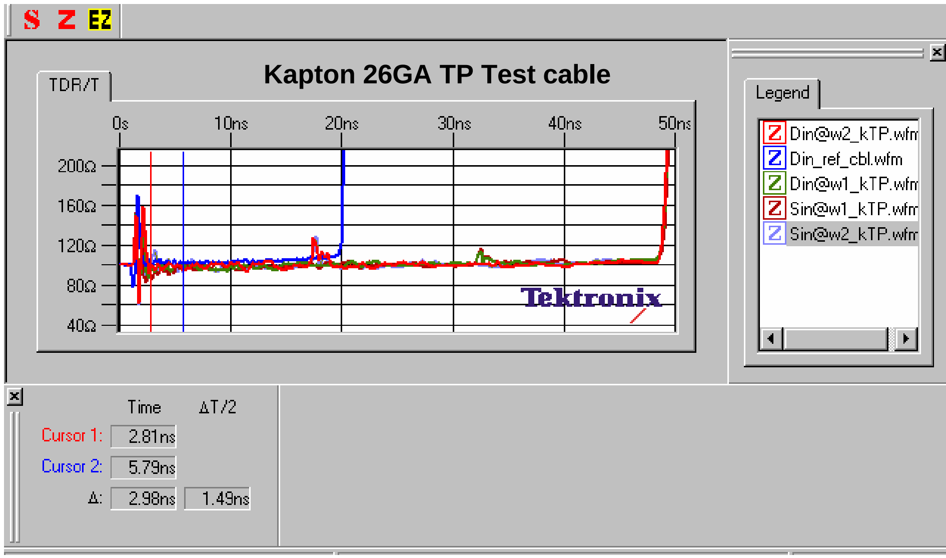
Key

H vector — Current entering page — Current leaving page — s Shield

Testing Results (Cable #2)

- Conclusions
  - 100Ω isn't 100Ω.
    - Kapton solution has very poor scope traces
  - TP solution is not a consistent impedance
  - 80Ω TSP scope traces look better
  - (not shown) 38999 connector impedance looks slightly better
    - 125Ω max impedance versus 150Ω.
  - Surprisingly, this cable ran at 61Mb/s as well
- Issues/Concerns
  - Is the poor edge caused by the increased inductance (relative increase) resulting from lowering c?
- Recommendations
  - Some day, it would be nice to run a spice model on this. Till then, stay away from this configuration
  - For the lessons learned, remember that adding/ removing shield messed with the impedance of a cable.
  - Find a 100Ω TSP solution and rerun these tests to check out the connector





TACSAT-4 Spacewire Interconnect Design (Current Status)

- We have a connector AND a cable issue
- Current plan is to look into other options:
  - The JWST solution is attractive because:
    - The significant engineering and evaluation effort put forth so far
    - The ability to purchase (somewhat) off the shelf cables and connectors. In the future, ORS busses will be built to standards, so it is attractive to call out the spacewire interface cable as a XXX part number.
  - Possible hybrid solutions exist:
    - Purchase Gore 26GA Spacewire assembly and modify in house
    - Still use 38999s
    - Purchase 26GA TSP (GOR-TEX) wire and build cable here
  - Cost is deciding factor (to a point)
- Collect input from Spacewire working group
  - Other options?
  - Impact assessment of 80Ω cable and/or 38999s
  - Suggested further testing
    - Tests, Test equipment, and test Jigs
  - Mitigation strategies
- Fallback plan
  - Use 80 Ω cable with 38999s
  - Delete one or more of the bulkhead connectors
  - Delete all bulkheads and go back to a standard spacewire cable
- Important to know that a Spacewire 38999 will be on TACSAT-4 regardless of this study
  - S/C Controller to EGSE mates to bus with a 38999.

Backup slides

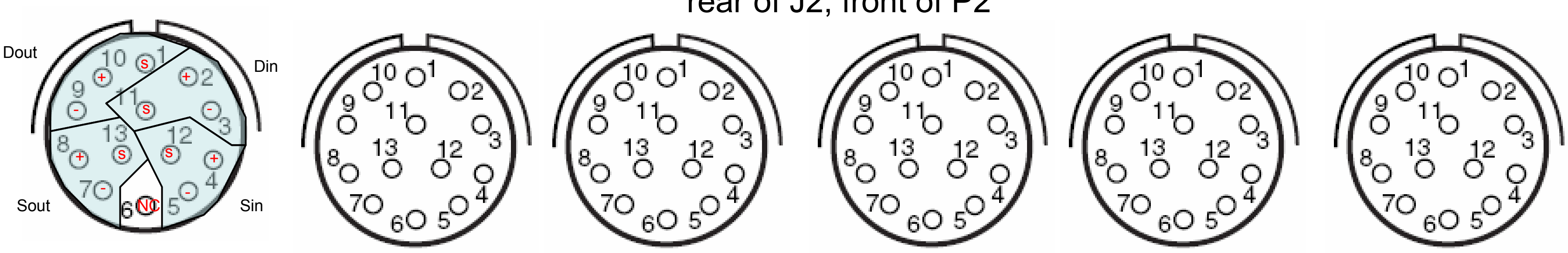
References

- Brooks, Douglas. “Differential Impedance: What’s the Difference?” Printed Circuit Design. August, 1998.
- Heikkila, Tuomo. “Differential Impedance Measurements with the Tektronix 8000B Series Instruments.” [Online] Available http://www.tek.com/Measurement/cgi-bin/framed.pl?Document=/Measurement/App_Notes/85_16644/eng/&FrameSet=oscilloscopes , 2004
- Johnson, Howard and Graham, Martin. High-Speed Digital Design: A Handbook of Black Magic. New Jersey: Prentice Hall PTR, 1993.
- Johnson, Howard. “A transmission line is always a transmission line“. [Online] Available http://www.sigcon.com/TransmissionLine.htm, 2002
- Johnson, Howard. “Differential Reflections“. [Online] Available http://www.sigcon.com/2_21.htm, 1998
- Johnson, Howard. “Differential Signaling“. [Online] Available http://www.sigcon.com/3_12.htm, 1999
- Johnson, Howard. “Differential TDR“. [Online] Available http://www.sigcon.com/differentialtdr.htm, 2002
- Johnson, Howard. “Differential Trace Impedance“. [Online] Available http://www.sigcon.com/5_2.htm, 2002
- Johnson, Howard. “See Beyond the Edge“. [Online] Available http://www.sigcon.com/SeeBeyond.htm, 2005
- Johnson, Howard. “So Good it Works on Barbed Wire“. [Online] Available http://www.sigcon.com/SoGoodBarbedWire.htm, 2001
- Johnson, Howard. “Transmission Lines/Gate Delay “. [Online] Available http://www.sigcon.com/1_19.htm, 1997
- Paul, Clayton R. Introduction to Electromagnetic Compatibility. John Wiley & Sons, 1992.
- Sadiku, Matthew N. O. Elements of Electromagnetics 2nd Edition. Saunders College Publishing, 1994.

ORS Spacewire Connector (10-35P) conductor configuration

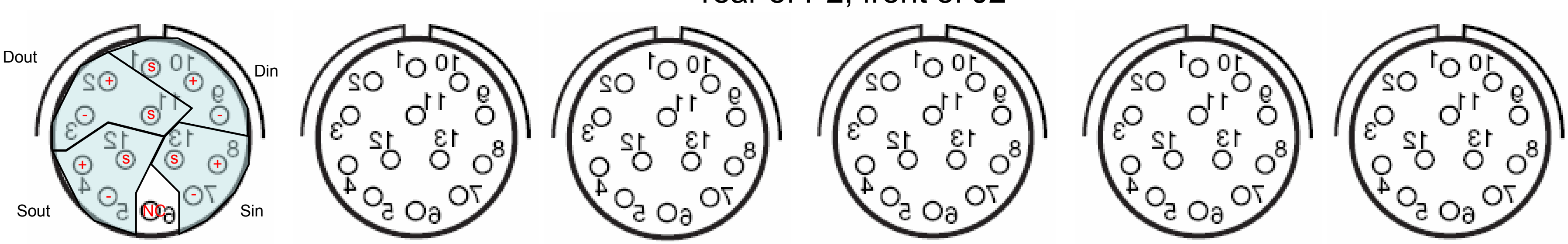
P1 to P3 (@W1)

rear of J2, front of P2

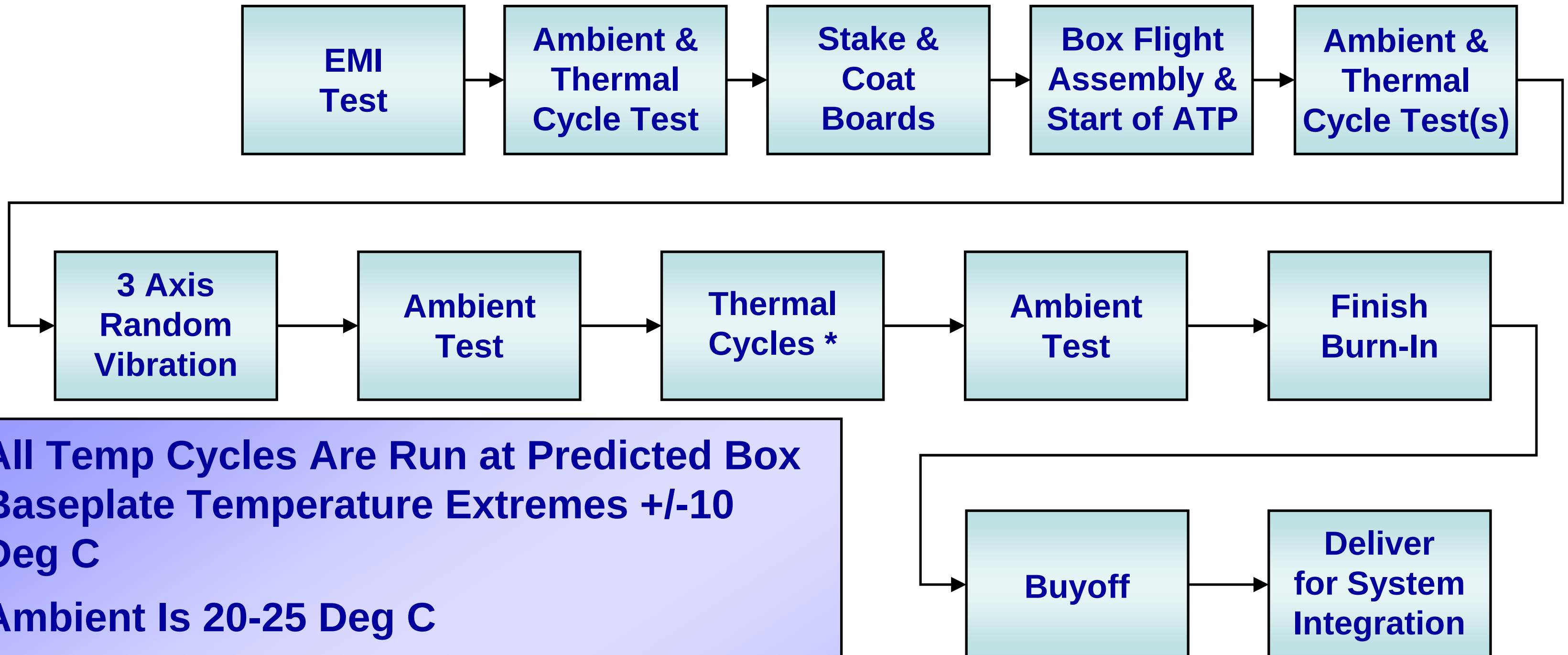


P3 to P1 (@W2)

rear of P2, front of J2



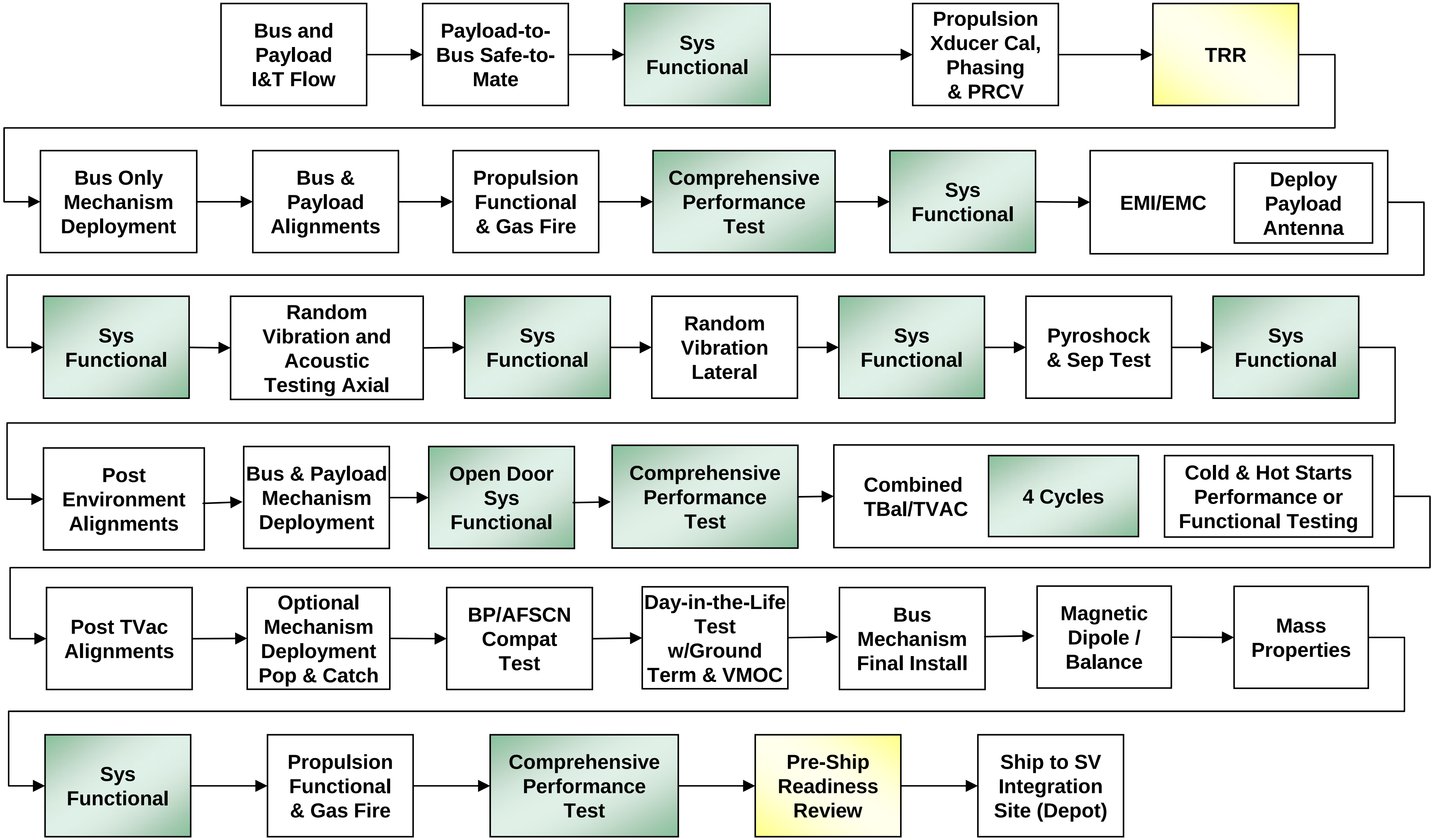
ORS BUS Generic Component Testing Flow



- All Temp Cycles Are Run at Predicted Box Baseplate Temperature Extremes +/-10 Deg C
- Ambient Is 20-25 Deg C
- 9 ATP Temperature Cycles
- 2 Hour Dwells at Extremes
- Minimum of 200 Hours ATP Test Time
- Final 50 Hours Failure Free
- Static Loads Qualification by Analysis or by Sine Burst Testing

* TVAC for Battery & Transponder

Integrated SV Test Flow



Space Vehicle Testing

System Level Structural Verification

- Random Vibration Test Levels, 1 min. Duration

Frequency	PSD
20 - 250	0.004
Overall	0.96 g_{rms}

- Acceleration Response Limiting Allowed for Random Vibration
  Acceleration Responses Not to Exceed Coupled Loads Responses

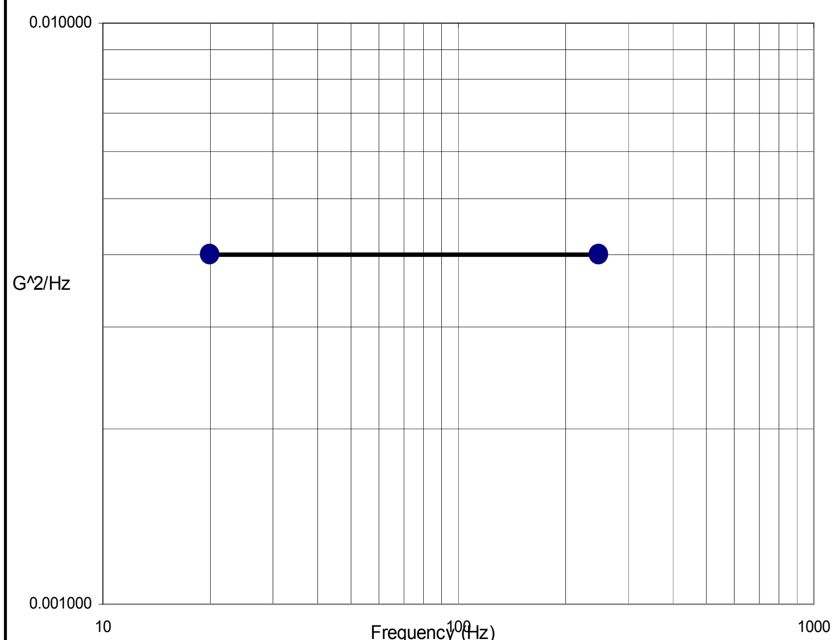
- Acoustic Test: Test Level: Overall SPL 139.2 dB
  Test Duration: One Minute

- Shock Test: Two Clamp Band Firings
  Two Solar Array Releases (Pop and Catch)

Test Levels and Durations

	Protoflight
Random Vibration	Flight + 3 dB Minimum of One Minute (Notch to Insure Responses Do Not Exceed CLA Results)
Acoustic	Flight + 3 dB Minimum of One Minute
Pyrotechnic Shock	Fire Ordnance Two Times
Thermal Vacuum	10 Degrees C Above and Below Design Range

Random Vibration Spectrum



TacSat 4 Space Vehicle Level Random Vibraton Spectrum
(To be Used in Conjunction With an Acoustic Test)

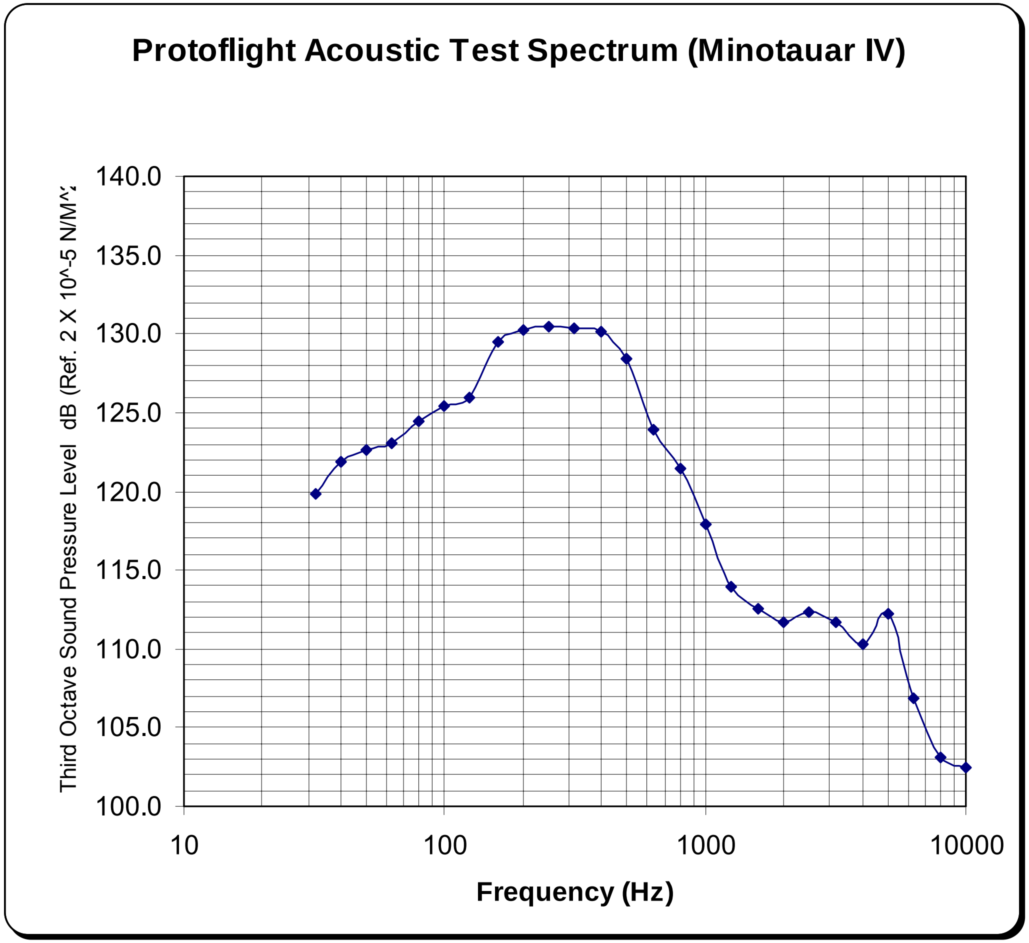
Workmanship SV Level

0.96 Grms

Frequency (Hz)	G^2/Hz
20	0.004000
250	0.004000

Apply in 3 Orthogonal Axes
One Minute per Axis

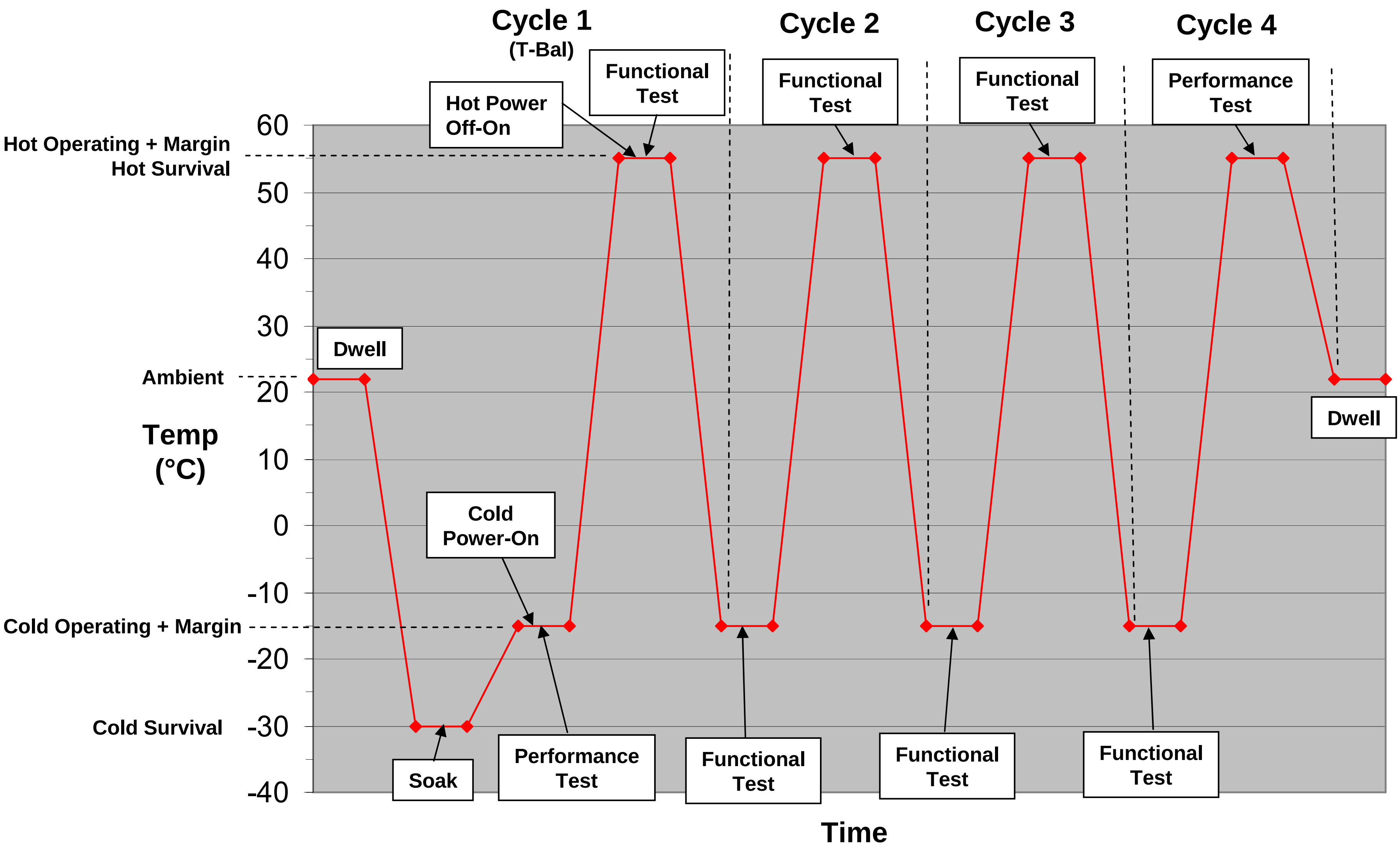
Acoustic Environment



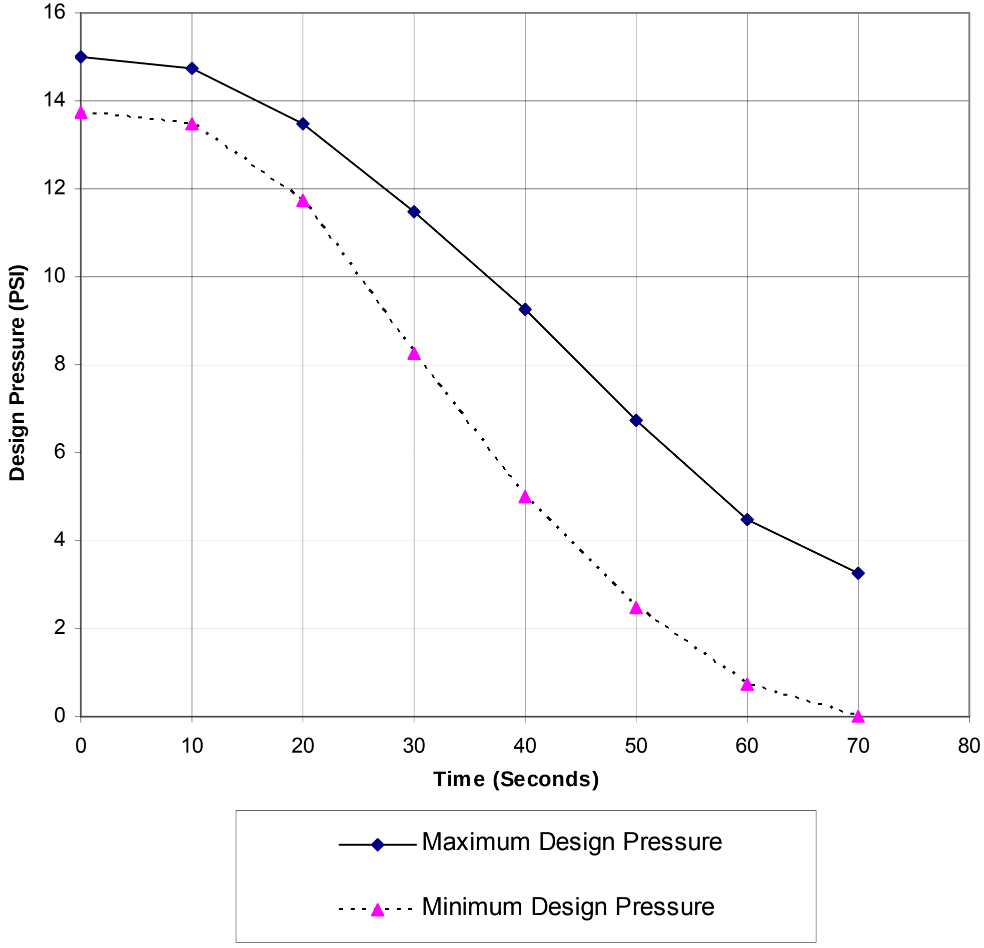
One Third Octave Frequency (Hz)	Flight Level SPL (dB)
32	119.8
40	121.9
50	122.6
63	123.1
80	124.5
100	125.4
125	125.9
160	129.5
200	130.2
250	130.5
315	130.4
400	130.1
500	128.4
630	123.9
800	121.5
1000	117.9
1250	113.9
1600	112.5
2000	111.7
2500	112.3
3150	111.7
4000	110.3
5000	112.2
6300	106.9
8000	103.1
10000	102.5
OA	139.2

Test Levels	Duration (Minutes)
Flight Unit (Protoflight Acceptance Level)	1

Thermal Balance - TVAC



Pressure Environment



Pressure History During Ascent
Maximum Decay Rate = .6 PSI / Second

Bus Integration and Test
Definition of Test Terms Continued
Mechanical Test Terminology

– *Modal Testing*
  - Characterize system’s modal response relative to a reference response
– *Loads Testing/Qualification (Not shown in test flow)*
  - By Analysis With No Test Factors of Safety, or
  - Static or Quasi-Static Test at 1.25 x Design Limit Loads for the Bus
– *Vibration and Acoustic Testing*
  - Acceptance Test Levels = Expected Flight Environment for 1 Minute
  - Protoflight Test Levels = Flight +3 dB for 1 Minute
  - Qualification Test Levels = Flight +6 dB for 1 Minute
– *PyroShock and Separation Testing*
  - Twice on Flight Spacecraft
  - Light Band
– *Thermal*
  - Acceptance Test Range = 5 Deg C Above and Below Design Range
  - Protoflight Test Range = 10 Deg C Above and Below Design Range
  - Qualification Test Range = 15 Deg C Above and Below Design Range

ORS Bus Integration and Test Definition of Test Terms Continued

Electrical Test Terminology

- *Health Test :*
  - Test Port only, most flight like configuration
  - Typically performed at one voltage
  - Performed with the ELSE
  - Open loop testing
- *System Functional* :
  - Performed with EAGE
  - Typically performed at one voltage,
  - Partly closed loop, for ACS test cases.
  - No RF testing
- *Comprehensive Performance Test (CPT):*
  - Equivalent to System Functional
  - Performed at 3 different voltages.
  - Scripts may exercise components further than System Functional Tests
  - Includes open loop testing e.g. RF, EPS, TCS, mechanisms, and payload sim telemetry
- *Day in the life test :*
  - Performed with EAGE
  - Typically performed at predicted beginning of life voltage
  - Testing script reflects expected orbital environments
  - System is exercised and reacts as it would be on orbit for a given orbital day