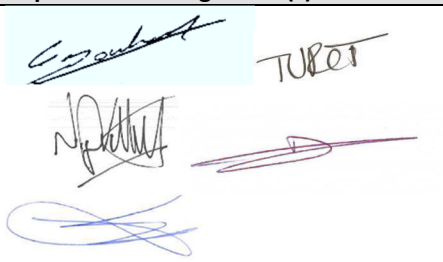
Axon' Cable **Minutes of Meeting**

14027-MIN-FP-A01 rev 1 11/12/2019

Meeting	**Final Presentation: MicroMach Connector** (Compact, impedance matched SpaceWire Connector)

Participants:

Company	Name	Representative Signature(s)
Axon' SAS, France	Gilles Rouchaud, Dimitri Angénieux, Stéphane Hermant, Lindsay Turot, Kevin Lefez, Laetitia Marrec, Antoine Faucher	
Axon' LTD, UK	Nigel Kellett	
ESA	Denis Lacombe, Laurent Trougnou (partial)	
STAR-Dundee	Steve Parkes	
University of Leicester	Julian Thornhill, Chris Bicknell	
IWF	Manfred Stellar	

Conclusion
The Final Presentation was declared successful, and Axon' can go ahead and submit all remaining deliverables, along with Contract Closure Summary. Final milestone invoice can be posted once all deliverables are submitted.

Axon' presented a Final Presentation PowerPoint File (attached to these minutes) with the following agenda:

1. Introduction
2. Summary of Work Logic
3. Overview of Evaluation Test Plan
4. Results of complementary tests
5. General conclusion of the evaluation
6. Comparative MicroMach® vs Micro-D
7. ESCC Detail Specifications
8. First mission: SMILE
9. Development and future concepts

For the sake of brevity in these minutes, they are to be read in conjunction with the PowerPoint slides, and comments are noted here only where there was related discussion during the presentation.

1. Introduction [slides 1-9]

During initial overview of the PCB connector styles (Wired, SMT and Flex [slides 6-8]) S. Parkes indicated that it would be good to have the possibility of screen termination through to the PCB. Axon' confirmed that this is already integrated in the Flex variant, but that it does not currently exist within the Wired or SMT variants. Axon' will consider this as a possibility or option for future iterations.

2. Summary of Work Logic [slides 10-11]

No comments

3. Overview of Evaluation Test Plan [slides 12-13]

No comments

4. Results of complementary tests [slides 14-18]

ESA agreed that in the case of the 3 anomalies discovered during the initial ETP testing, the delta testing carried out was reasonable given the nature of the anomalies in question.

5. **General conclusion of the evaluation [slides 19-25]**

Side 25 generated the most discussion, about whether the theoretical data rate v length & AWG plots could be incorporated usefully into the detail specification or not. It was agreed that there are other elements in play apart from just insertion loss (e.g. skew, jitter, etc.) and therefore it could be misleading to present this theoretical chart as a given. It was agreed that the chart was nevertheless useful as an indication, possibly for inclusion in an annex, as long as the user bears in mind that other factors may deteriorate these theoretical performances.

6. **Comparative MicroMach® vs Micro-D [slides 26-29]**

Slide 28 generated some discussion about how Axon' tested the relative EMC performance, and shortly post-meeting, Axon' agreed to lend their EMC test boxes to ESA (J. Ilstad) for some related EMC testing.

7. **ESCC Detail Specifications [slides 30-34]**

Slide 33, it was agreed that Axon' should clarify the proposed maximum Operating Data Rate. i.e. specify at least one length and AWG size for the max data rate in question, then possibly refer to the aforementioned annex for a theoretical max compared to length and AWG size.

8. **First mission: SMILE [slides 35-39]**

No specific comments, although there was some general discussion about the project and grateful recognition of University of Leicester's and their partner's role in promoting this new technology and allowing it to gain flight heritage. (Mission Launch planned for 2023)
Note: The participants from University of Leicester and IWF specifically attended this presentation as they will be first to fly this new SpaceWire interconnect.

9. **Development and future concepts [slides 40-46]**

- **SBS (Short Backshell) version.** [slide 41-42] All agreed that this looks to be a promising option for reduced space, it could indeed even become the default version as it would also be lower cost. Axon' just needs to evaluate if they can achieve the same impedance results as it is more difficult with the SBS to continue the inner screens as close as possible to the dielectric
- **Right angled backshell.** [slide 43] Generally of interest for space-constrained applications
- **Reduced cable skew.** [slide 44] Axon' indicated that they have made great improvements recently in cable skew reduction, all of which helps overall performance
- **MicroMach® Flat.** [slides 45-46] All parties found this development very interesting. STAR-Dundee would be interested in having samples to test for SpaceFibre applications; Axon' to provide samples
- **Solderless PCB termination** [slides not included] Axon' also presented a concept in development for high data rate, solderless connection to the PCB. The slides are not included in the MOM annex as this is very confidential and patent applications are pending. S. Parkes indicated that the option to extend this concept to be able to terminate both above and beneath the PCB at the same time could be very interesting.
- **MicroMach® for SpaceFibre** [no slides] General discussion that a MicroMach® connector, together with 8 off suitable adapted coaxial cables, could potentially be used for two channels of SpaceFibre over relatively short lengths. (Potentially possible to achieve 3.125Gb/s per channel, for example.

Overall Summary and additional comments

Axon' pointed out that they had also tested performance on hybrid MicroMach to 9pin Micro-D harnesses, both for ground test purposes, using existing test equipment fitted with micro-D connectors, and also for flight, in case any user wanted to connect legacy to new equipment. The general conclusion of this work is that the performance is limited by the Micro-D connector, therefore there is no performance benefit in replacing one end only with MicroMach®.

ESA (D. Lacombe) thanked Axon' for all the work done to date, and for sharing the associated developments planned.

Actions: (Final milestone can be invoiced once blocking action is complete)

A1. Axon' to submit Contract Closure Summary along with Final Deliverables Data Pack (blocking)
A2. Axon' to include in the data pack an order confirmation number for shipment of demonstration samples to be kept by ESA
A3. Axon' to send EMC test boxes to J. Ilstad for related EMC testing
A4. Axon' to organise samples of MicroMach® Flat for STAR-Dundee SpaceFibre testing

Annex 1: Final Presentation PowerPoint file

Final presentation at ESTEC

Compact impedance matched connectors for SpaceWire Links

10th December 2019

- **Gilles ROUCHAUD** (Project Manager)
- **Stéphane HERMANT** (R&D Engineer)
- **Lindsay TUROT** (Project Manager)
- **Kevin LEFEZ** (R&D Technician)
- **Nigel KELLETT** (Business Development Manager)
- **Dimitri ANGENIEUX** (R&D Engineer)

axon' cable & interconnect

Agenda

- Introduction
- Summary of Work Logic
- Overview of Evaluation Test Plan
- Results of complementary tests
- General conclusion of the evaluation
- Comparative MicroMach® vs Micro-D
- ESCC Detail Specifications
- First mission: SMILE
- Development and future concepts

Introduction

From Micro-D to MicroMach®

New connector purpose : Refresher

- No connectors on the market reached the requirements of the SpaceWire protocol ECSS-E-ST-50-12C
  - Best option until now has been the ESCC3401-029 9 pin Micro-D connector
- ESA Technology Research Project (TRP) launched in 2015 to develop a more adapted connector:
  - Compact (as close as possible as 9 pin micro-D)
  - 100 ohms matched impedance connection
  - Improved cable screen terminations to connector (for 360°protection)
  - Higher data rate performance (at least 400Mb/s)
  - Low crosstalk between ways
- Axon' selected (in consortium with STAR-Dundee)

SpaceWire MicroMach®

Male

Male with Low Mass SpW cable

9w µD vs. µMach

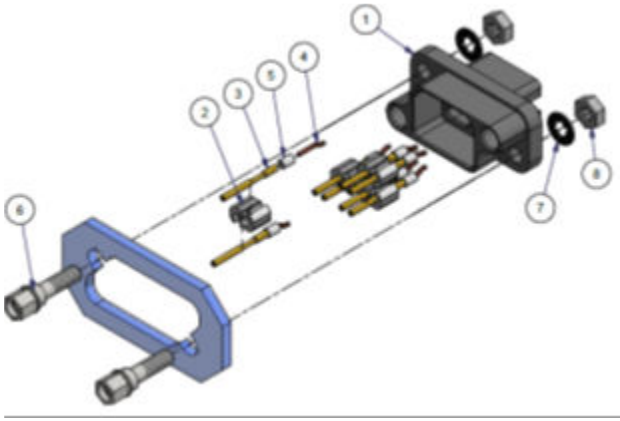
Main features:

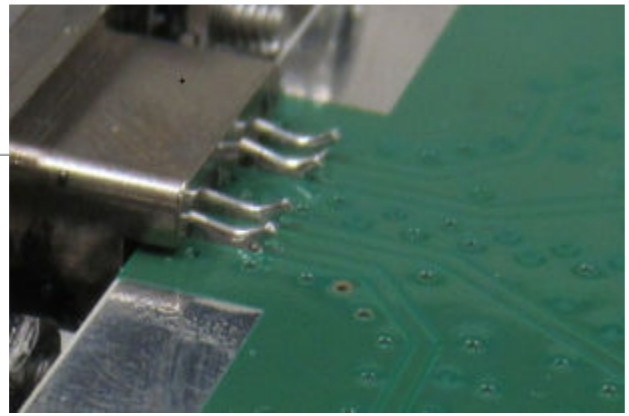
- 1 cavity by transmission line → Improved crosstalk
- Inner and outer shield termination → Improved EMC
- 100Ω differential impedance throughout the line → Improved data rate
- Integrated guide pin → Improved mechanical robustness
- Twist pin MicroD contacts → well known technology
- Size → close to a 9pin microD

SpaceWire MicroMach ® \ PCB Variants

1. Edge panel mount

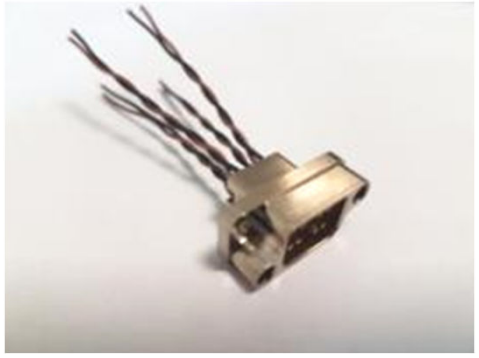
- Compact solution for card edge variant
- Termination as a SMT
- Matched impedance

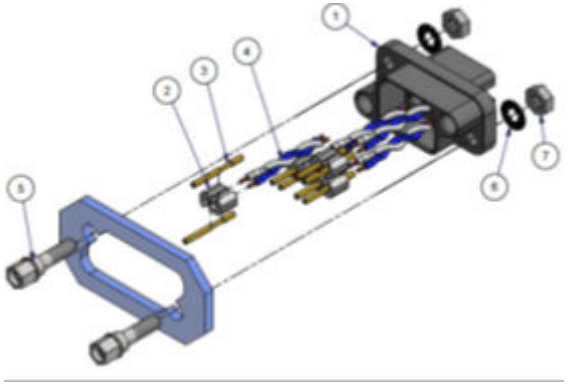


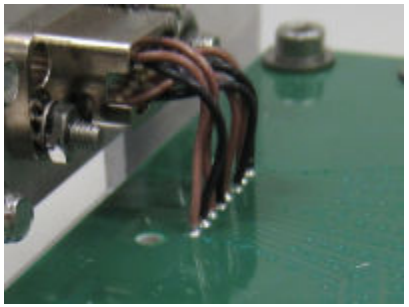


SpaceWire MicroMach \ PCB Variants

2. Wired panel mount



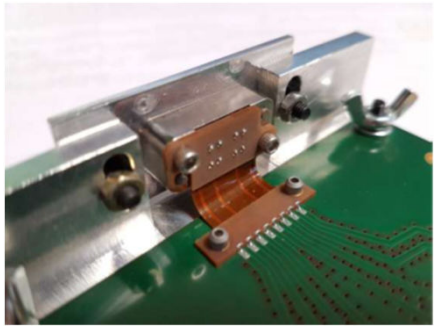


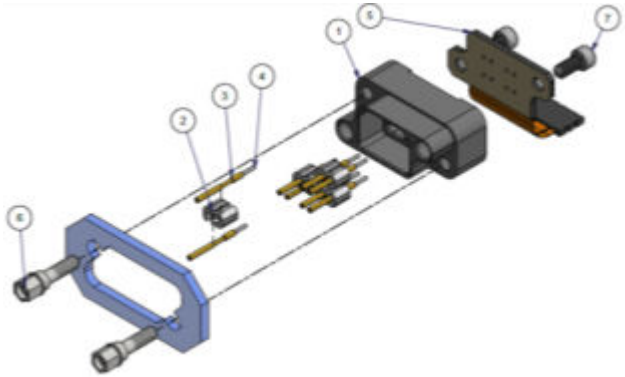


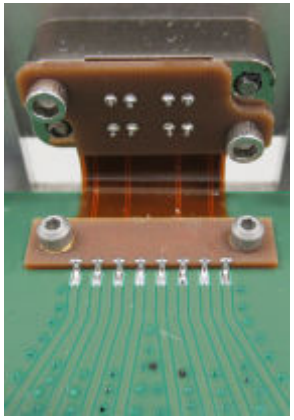
- Easy to integrate
- Flexible
- Matched impedance but without shielding

SpaceWire MicroMach ® \ PCB Variants

3. Flex PCB panel mount



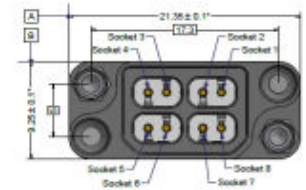


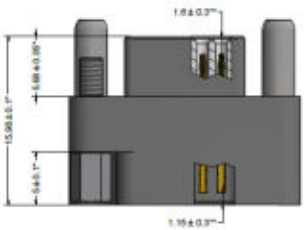


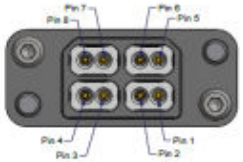
- Compact
- Flexible
- 4 x 100Ω differential impedance with a full ground plane

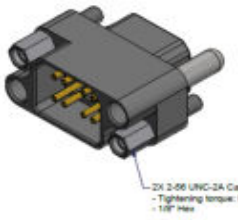
SpaceWire MicroMach® \ Saver

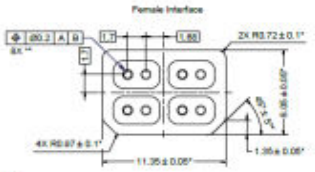
- Used during AIT phase to save the connector interfaces from too many matings

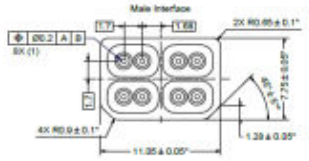












Summary of Work Logic

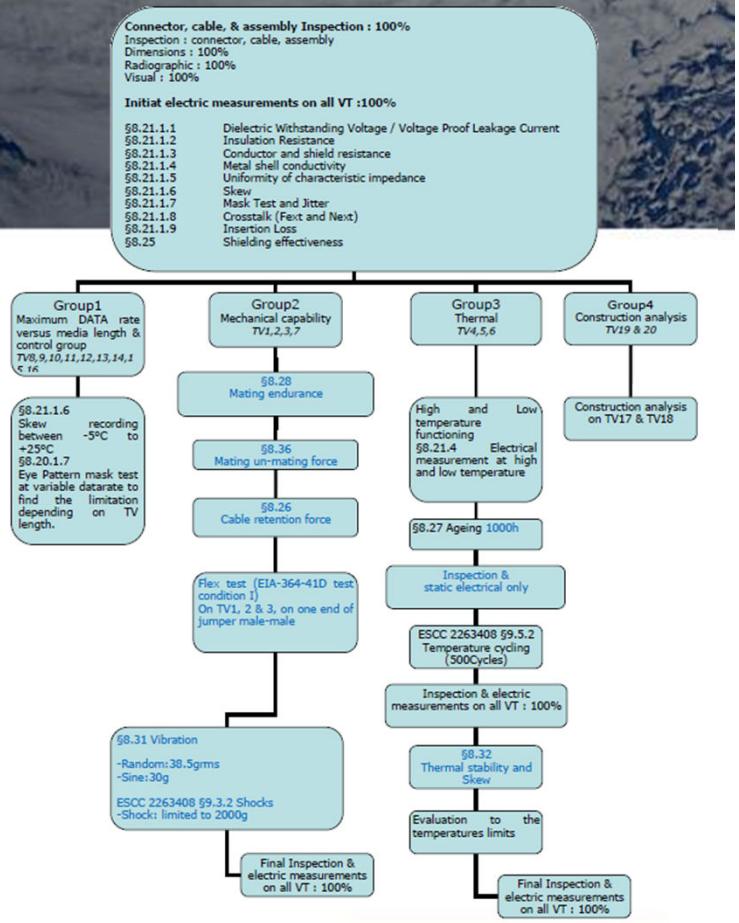
Work Logic

- Market survey and analysis of existing products
- Preliminary Design
- Customer survey and feedback
  - Including dedicated session at Customer Seminar in 2017
  - Including presentation during SpW working group at ESTEC
- Detailed design and prototype manufacture
- CDR and review of EVT
- Manufacture of Test Vehicles then Evaluation testing
- Delta Evaluation testing & drafting of ESCC specifications
- Final Presentation
- Submission of ESCC specifications for review

Overview of Evaluation Test Plan

ETP written with ESA & CNES

- 4 groups:
  - *Group 1 dedicated to the maximum electrical performances (9 TVs)*
  - *Group 2 dedicated to mechanical capability (4 TVs)*
  - *Group 3 dedicated to thermal solicitations (3 TVs)*
  - *Group 4 dedicated to the construction analysis performed by ESA (4 TVs)*

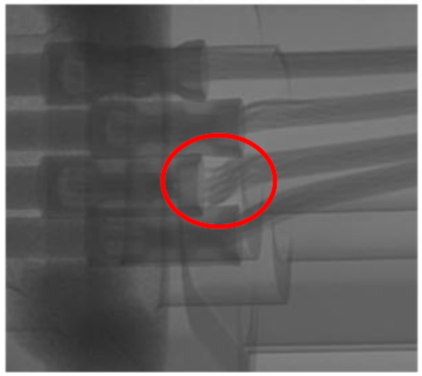


Results of complementary tests

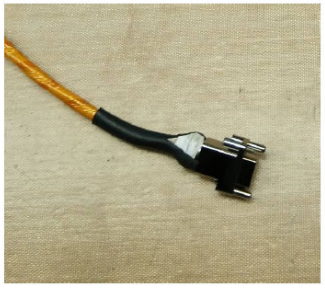
Anomalies met during the evaluation

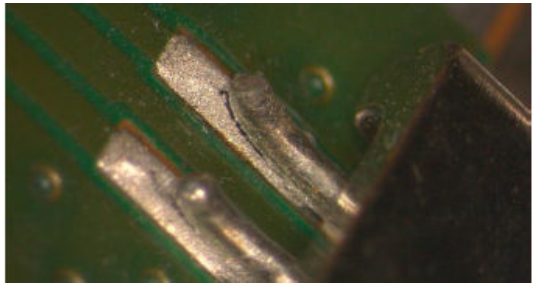
3 anomalies:

- On group 2 (Mechanical)
  - A broken wire on the Parallel Pair Vehicle during vibrations test



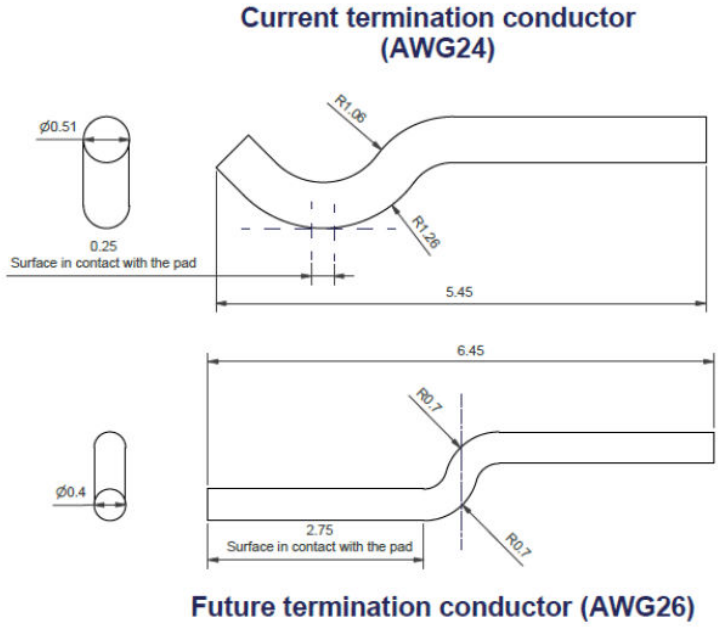
- On group 3 (Thermal)
  - Cracks on the sleeves
  - Damaged soldering joints on SMT connectors





Corrective actions taken

- Replacement of RNF-100 sleeves by Viton sleeves ➔Higher thermal resistance
- Design of a new termination conductor ➔A new shape and a new section (From AWG24 to AWG26)
- Cabling of parallel pairs improved ➔More slack is let after crimping of the contacts

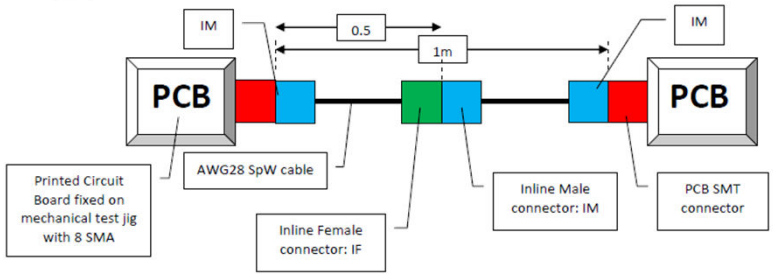


Complementary test plan: test vehicles

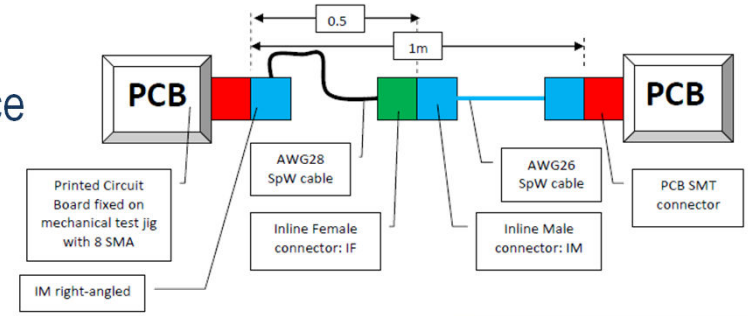
- Two new TVs have been submitted to 200 Thermal cycles (-55°C to 125°C)

- On those TVs are embedded a few additional design changes such as:
  - ✓ Blind holes guide pins (EMI improvement)
  - ✓ Front male dielectric modifications (Better guidance of contacts)
  - ✓ New locking system (ESA components)
  - ✓ Right-angled male version (LM-AWG28)

TVα:

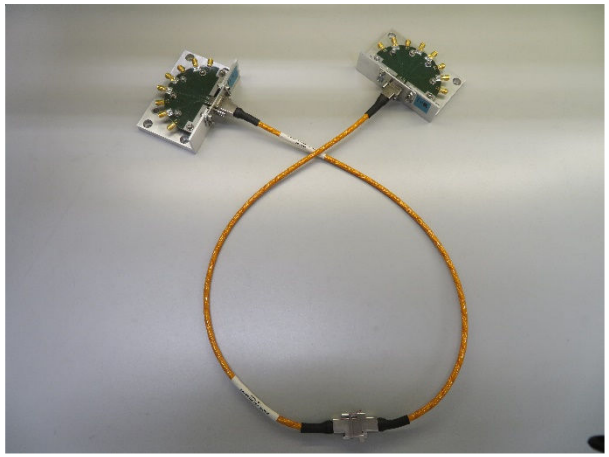


TVβ:

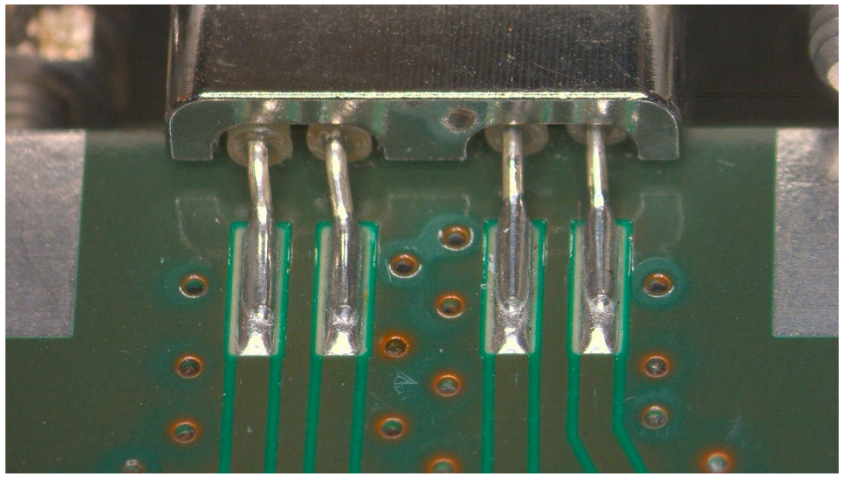


Results of the complementary tests

- The 8 Viton sleeves have passed the 200 Thermal cycles without any damage



- The 32 soldering joints have also passed the 200 Thermal cycles without any damage



- There is no significant drift on the electrical performances (Static and dynamic) after the 200 Thermal cycles

General conclusion of the evaluation

MicroMach® Harnesses: Maximum data rate per TV

TV N°	Cable	Length (m)	Max Data Rate (Mb/s)	Max Skew (ps/m)
8	ESCC3902.003.02 (AWG26)	1	>3200	19
9		4	1600	17
10		8	400	27
11		10	200	17
12	ESCC3902.004.01 "Low Mass" (AWG28)	1	>3200	6
13		2	1600	14
14		4	800	7
15	Parallel Pairs (AWG28)	1	>3200	10
16		4	800	5

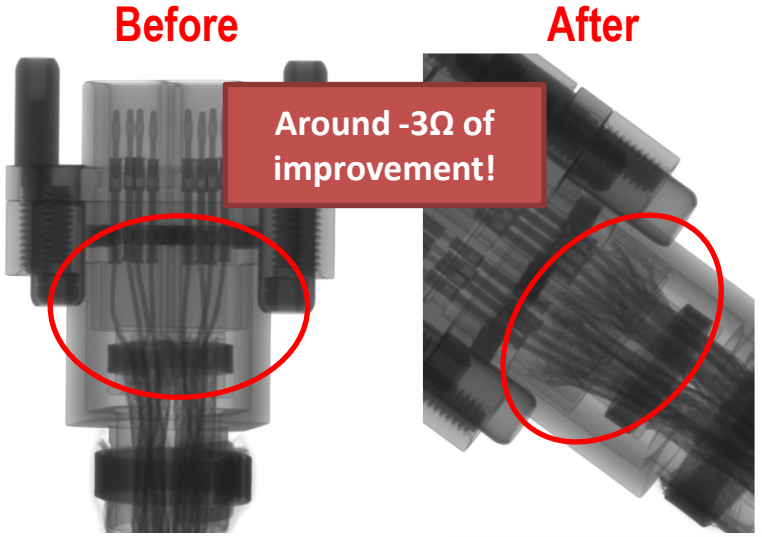
MicroMach® Harnesses: Electrical performances

Very satisfying results on the skew, the Crosstalk and the Insertion Losses

Electrical performances			
	Min	Max	Average
Characteristic Impedance	96,07 Ω	116,89 Ω	102,93 Ω
Skew for ESCC3902/003	17 ps/m	27 ps/m	20 ps/m
Skew for ESCC3902/004	6 ps/m	14 ps/m	9 ps/m
Crosstalk Fext (at 1GHz)	-50,82 dB	-73,87 dB	-60,53 dB
Crosstalk Next (at 1GHz)	-53,43 dB	-83,18 dB	-64,49 dB
Insertion Losses (At 500MHz) for ESCC3902/003	-0,71 dB/m	-0,94 dB/m	-0,77 dB/m
Insertion Losses (At 500MHz) for ESCC3902/004	-0,84 dB/m	-1,16 dB/m	-0,98 dB/m

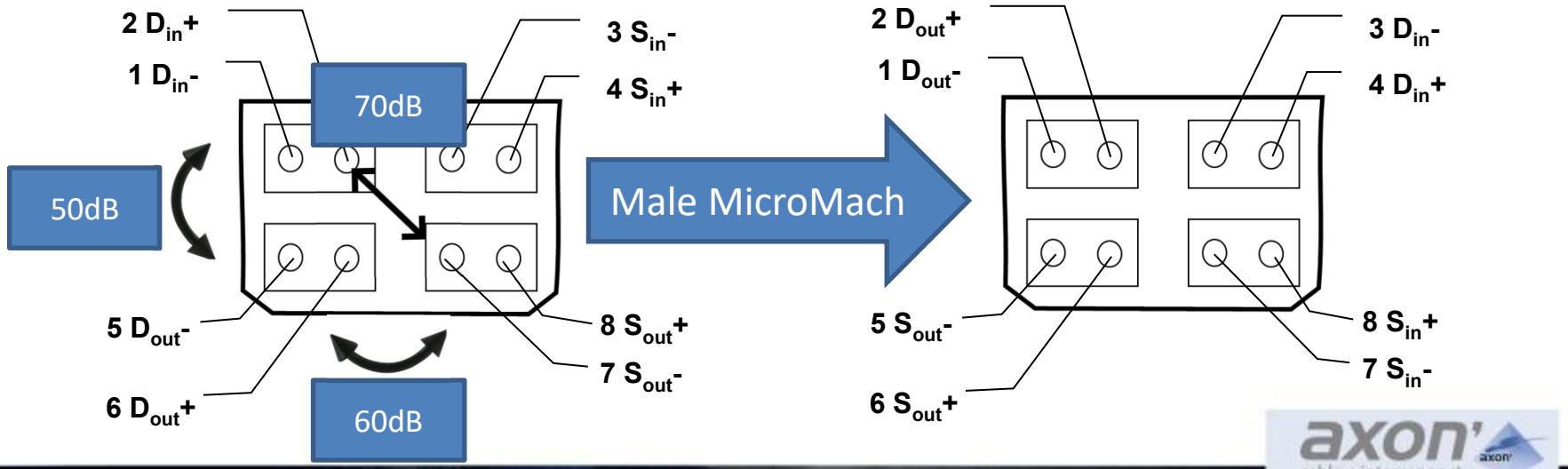
As for the ZC, we wanted to lower it to 115Ω…

A slight improvement has been made on the cabling, reducing the maximum ZC of a few Ohms



Modification of the pins allocation

- Given the results of the evaluation concerning the Crosstalk, Axon' has decided to change the pins allocation of the MicroMach in order to minimize the disturbances between IN and OUT signals



MicroMach® Equipment Connectors

- All equipment connectors have given satisfying results on the ZC

Maximum mismatch (Time rise 150ps)	SMT	Wired	Flex
	115Ω	115Ω	105Ω

- The wires used on the Wired variant have been replaced by an ESCC twisted pair (3901.012.13) 2xAWG26 ➔Lower ZC + ESA wires

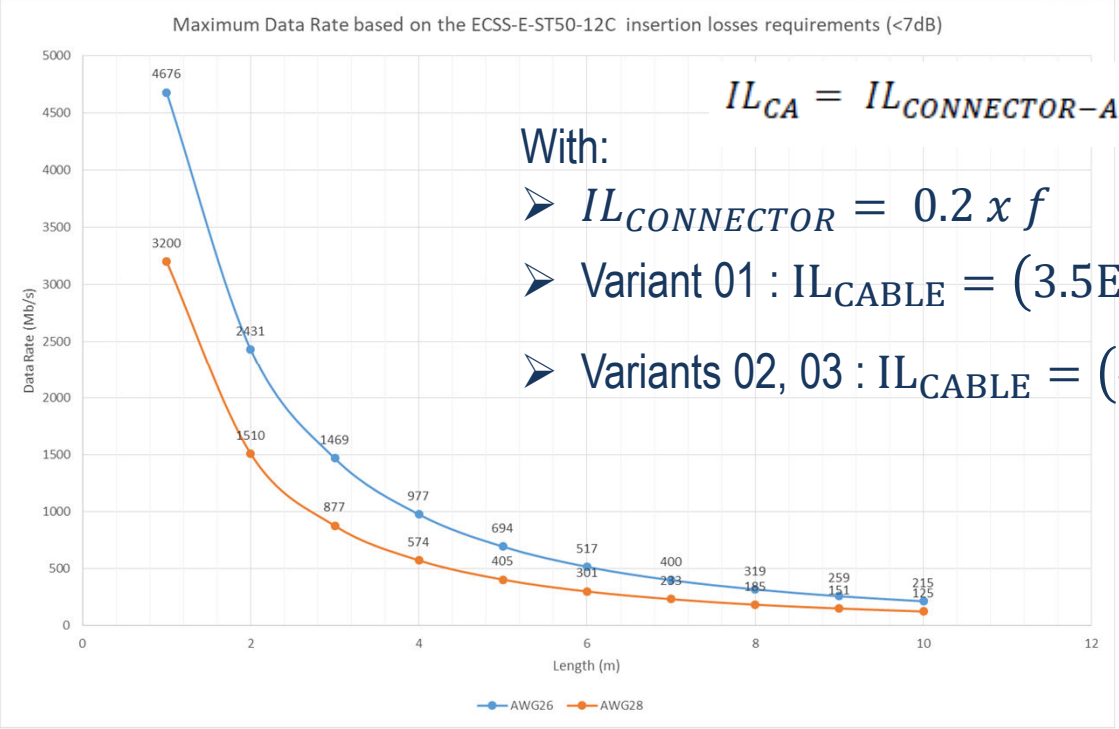
- Apart from the resolved SMT anomaly, all the equipment connectors have withstood both the mechanical and the thermal campaign

MicroMach® performances vs ECSS-E-ST-50-12C

➢MicroMach links fulfill the requirements of the Cable assembly Type B described in the SpaceWire ECSS standard

	ECSS-E-ST-50-12C requirements	MicroMach worst performances on the Evaluation vehicles
Shield bonding between outer shield of the cable and the connector	<10mΩ	<5mΩ
Shield bonding between inner shields of the cable and the connector	<10mΩ	<5mΩ
Shield resistance (Between the two connectors of a harness)	<1Ω	<25mΩ/m
Insertion Losses	<7 dB at frequencies up to 1,5 times the data signalling rate	Refer to the next slide
Inter-pair skew	0,17ns	AWG26: 27ps/m LM AWG28: 14ps/m
Intra-pair skew	0,5 ns	
Crosstalk (FEXT and NEXT)	<-50dB up to 1GHz	<-50dB up to 1GHz

MicroMach® performances vs ECSS-E-ST-50-12C



$$IL_{CA} = IL_{CONNECTOR-A} + IL_{CONNECTOR-B} + (IL_{CABLE} \times L)$$

With:

- $IL_{CONNECTOR} = 0.2\ x\ f$
- Variant 01 : $\mathrm{IL_{CABLE}} = \left(3.5\mathrm{E}^{-2}\ \mathrm{x}\ \sqrt{\mathrm{f}}\right) + \left(1.8\mathrm{E}^{-4}\ \mathrm{x}\ \mathrm{f}\right) + \frac{5\mathrm{E}^{-4}}{\sqrt{\mathrm{f}}}$
- Variants 02, 03 : $\mathrm{IL_{CABLE}} = \left(4.5\mathrm{E}^{-2}\ \mathrm{x}\ \sqrt{\mathrm{f}}\right) + \left(4\mathrm{E}^{-4}\ \mathrm{x}\ \mathrm{f}\right) + \frac{5\mathrm{E}^{-4}}{\sqrt{\mathrm{f}}}$

This requirement could be used to define the maximum data rate per length and gage.
At least for SpaceWire applications…

MicroMach® vs Micro-D

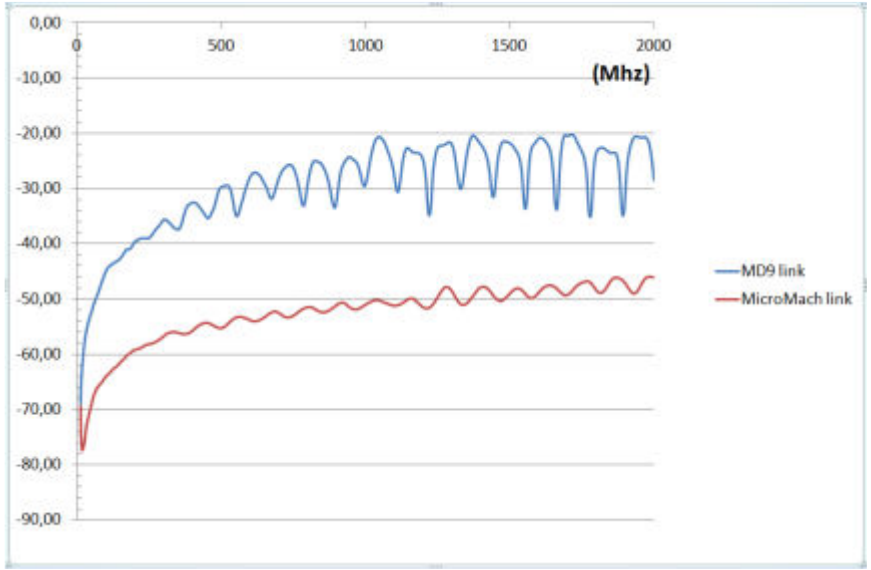
axon' cable & interconnect

MicroMach® vs Micro-D: Crosstalk

Crosstalk:

- MicroMach® link offers a significant crosstalk improvement
- Tables below give the dB difference between all the values measured during the evaluation on the two Micro-D TVs and the 9 MicroMach® TVs:

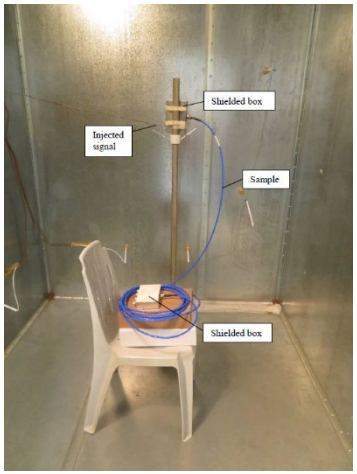
Delta FEXT			
	500MHz	1GHz	2GHz
Max	-24,64 dB	-25,48 dB	-35,36 dB
Min	-24,88 dB	-21,77 dB	-17,57 dB
Average	-19,46 dB	-21,27 dB	-23,89 dB
Delta NEXT			
	500MHz	1GHz	2GHz
Max	-30,27 dB	-41,29 dB	-31,34 dB
Min	-33,99 dB	-34,77 dB	-30,94 dB
Average	-26,81 dB	-33,40 dB	-26,31 dB

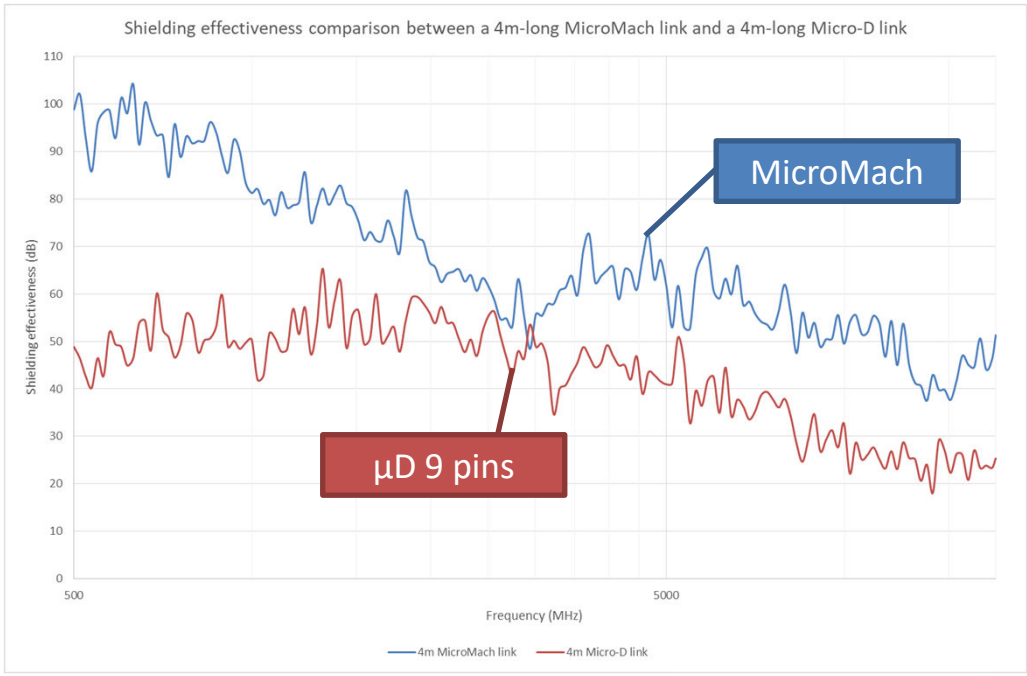


MicroMach® vs Micro-D: Shielding Effectiveness

- In comparison to standard Micro-D cabling, the MicroMach® variant offers a noticeable improvement in shielding effectiveness

  ➔around -25dB better up to 5Ghz!



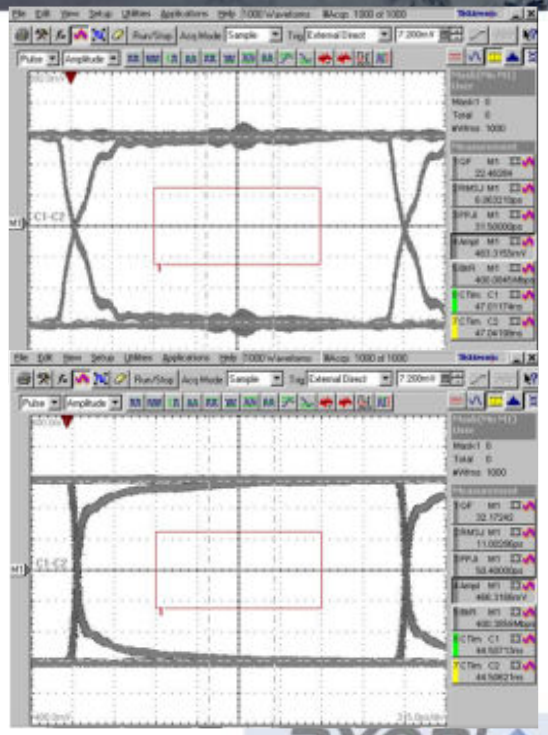


MicroMach® vs Micro-D: Signal Integrity

- Top screenshot shows the signal measured on the Micro-D terminated link
- Significantly better with MicroMach® (Bottom screen) and more with the parallel pairs configuration
- 100 Ohm matched characteristic impedance between the twin signal pins delivers better signal integrity on MicroMach®

Micro-D terminated 1m link @400Mb/s

MicroMach® Terminated 1m link @400Mb/s



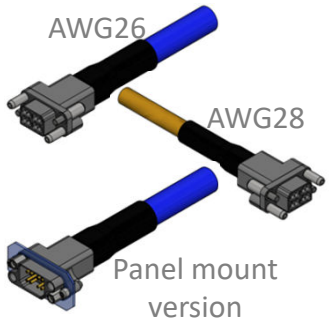
MicroMach® ESCC Detail Specifications

axon' cable & interconnect

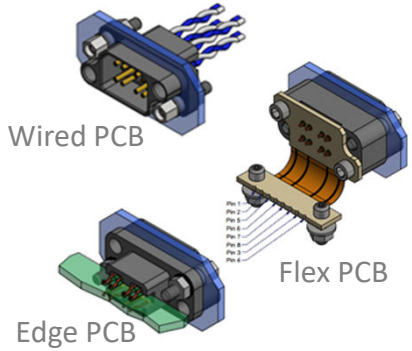
A set of new ESCC Detail Specifications

↳ Based on the AxoMach set of ESCC Detail Spec.

Cable Assembly 3409/00x

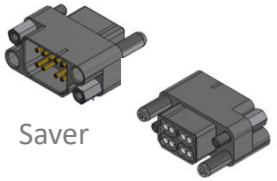


PCB Connectors 3401/xxx



Extensive evaluation done ✓
Next step: **EPPL2** in 2020

Accessories 3401/xxx



Focus on MicroMach® Cable Assembly ESCC D.S.

↳ Construction proposal: **3 variants → selection of cable type**

Variant Number	Designation (See Note 1)
01	HDR Cable Assembly with cable, "SpaceWire", AWG26: ESCC 390200302
02	HDR Cable Assembly with cable, "SpaceWire", AWG28: ESCC390200301
03	HDR Cable Assembly with cable, Low Mass, "SpaceWire", AWG28: ESCC 390200401

⇨ 01 : SpaceWire, AWG26
⇨ 02 : SpaceWire, AWG28
⇨ 03 : Low Mass SpaceWire, AWG28

↳ To combine with: **4 connector codes MicroMach (in-line plug or panel mount jack)**

Connector Code	Connector Type
01	MicroMach, AWG26, Male, In-line Plug
02	MicroMach, AWG28, Male, In-line Plug
03	MicroMach, AWG26, Female, Panel Mount Jack
04	MicroMach, AWG28, Female, Panel Mount Jack

Available combinations:

Connector Code Side A	Connector Code Side B: 01	02	03	04	00
01	01		01		01
02		02, 03		02, 03	02, 03
03			01		01
04				02, 03	02,03

Ex: 3409002**01**0**1**D0**3**2000

⇔ *MicroMach® SpW assy, Classic AWG26 SpW cable, Male – via direct wiring to - Female, 2 meters long*

Limits proposal for ESCC specifications

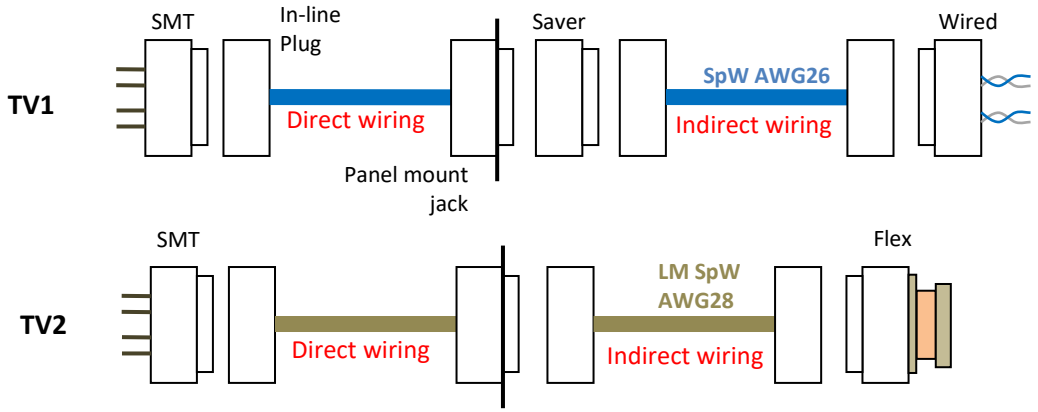
- With the current design, MicroMach® links and equipments could provide satisfying performances.
- However, we believe that slight adjustements can be made in order to do even better

Main characteristics	Limits proposal
Maximum Operating Data Rate	3 Gb/s
Mating Force	MF < 25N
Unmating Force	3N < UF < 25N
Shield resistance	11mΩ/m + 10mΩ/m per couple of connectors
Mated shell conductivity	5mΩ
Characteristic Impedance	95Ω < ZC < 115Ω
Intra-pair Skew	AWG26 & AWG28: 80ps/m Low-Mass AWG28: 50ps/m
Inter-pair Skew	AWG26 & AWG28: 130ps/m Low-Mass AWG28: 100ps/m
Crosstalk FEXT and NEXT	<-50 dB up to 1 GHz
Insertion Losses	Refer to the 25th slide
Shielding Effectiveness	<-80 dB up to 1GHz

Future ESCC Qualification

↳ Based on the AxoMach Qualification philosophy: ***qualify a complete solution (cable assembly + opposite equipment connectors) following ESCC 3409 chart F4A***

All MicroMach range of products represented (chart F4A, gr. 1&2):



QTP Ref :
18044-QTP-A01-Axon
PID : CNES-PID-15-21

Schedule :
After lessons learned from AxoMach ESCC Qualif and design adjustements.
Planned start early 2021

First mission: SMILE

axon' cable & interconnect

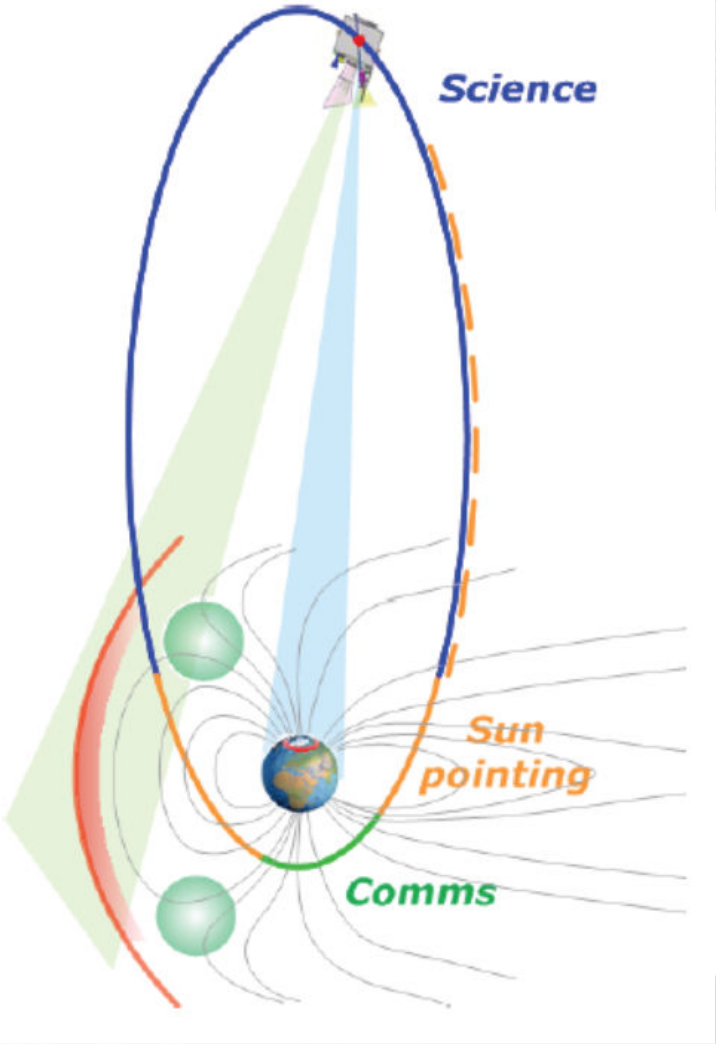
What is the SXI?

- **Soft X-ray Imager**

- Major instrument on ESA – CAS **SMILE** mission
  - Joint mission between ESA and China (CAS)
- Designed to observe X-ray emissions at Earth's magnetopause

- Two large X-ray sensitive CCD detectors
- Highly elliptical orbit - between ~ 5,000km and 121,000km
- ~51 hours per orbit

- Passes through radiation belts, therefore need for **door** to protect CCDs



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SXI Interconnect

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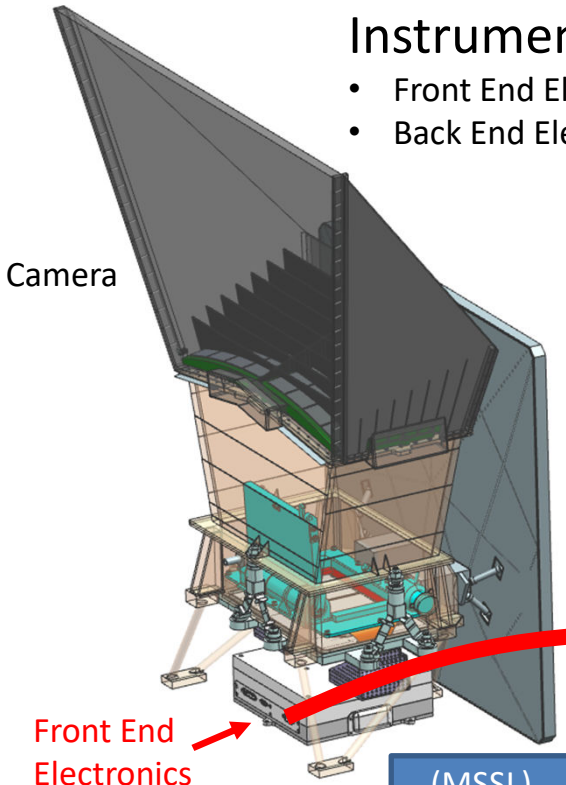
Instrument is in two major parts

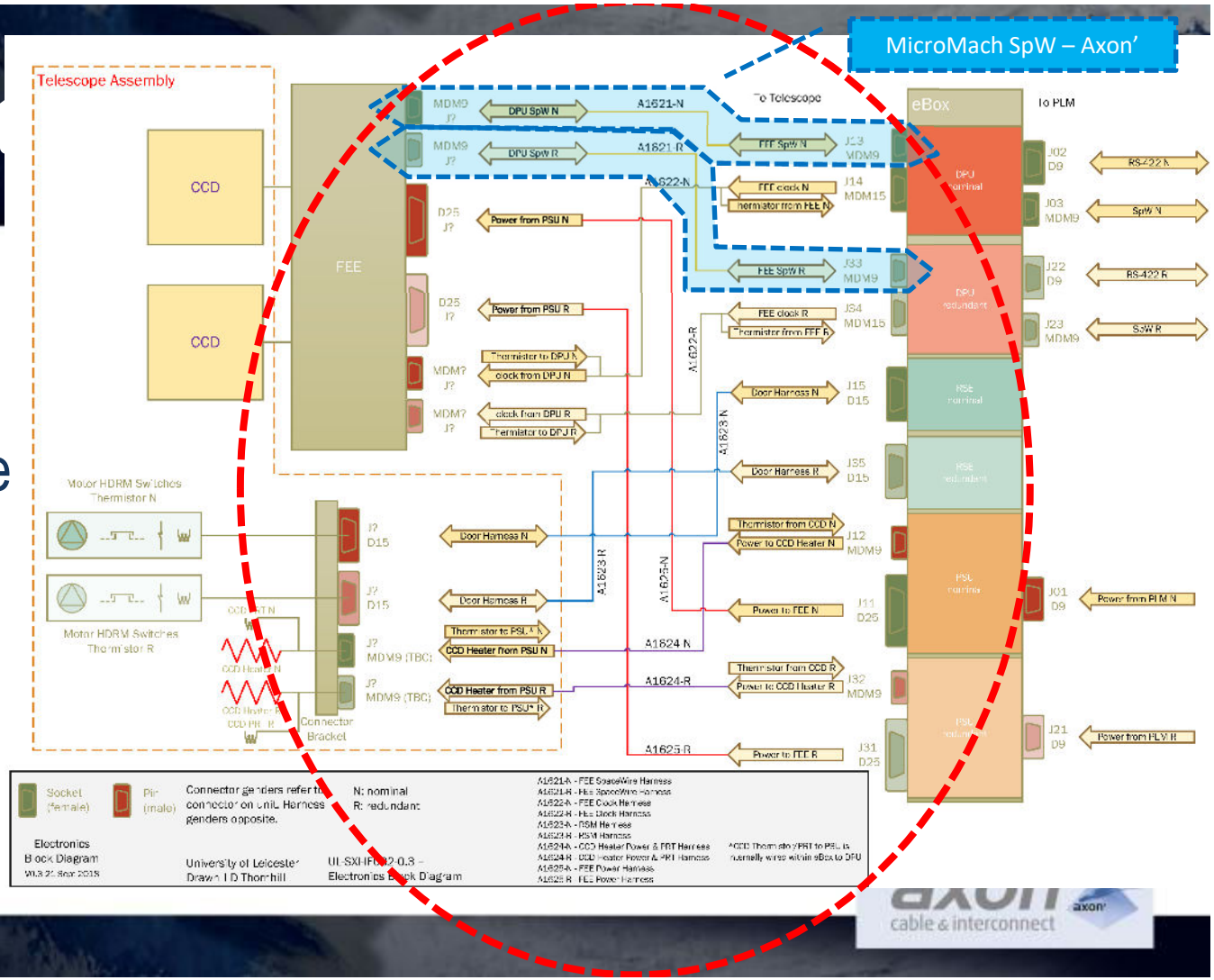
- Front End Electronics (FEE) by **MSSL (UK)**, controlling the camera
- Back End Electronics (BEE or eBox) by **IWF (A)**, interfaces with the platform



axon' cable & interconnect

SXI Interconnect

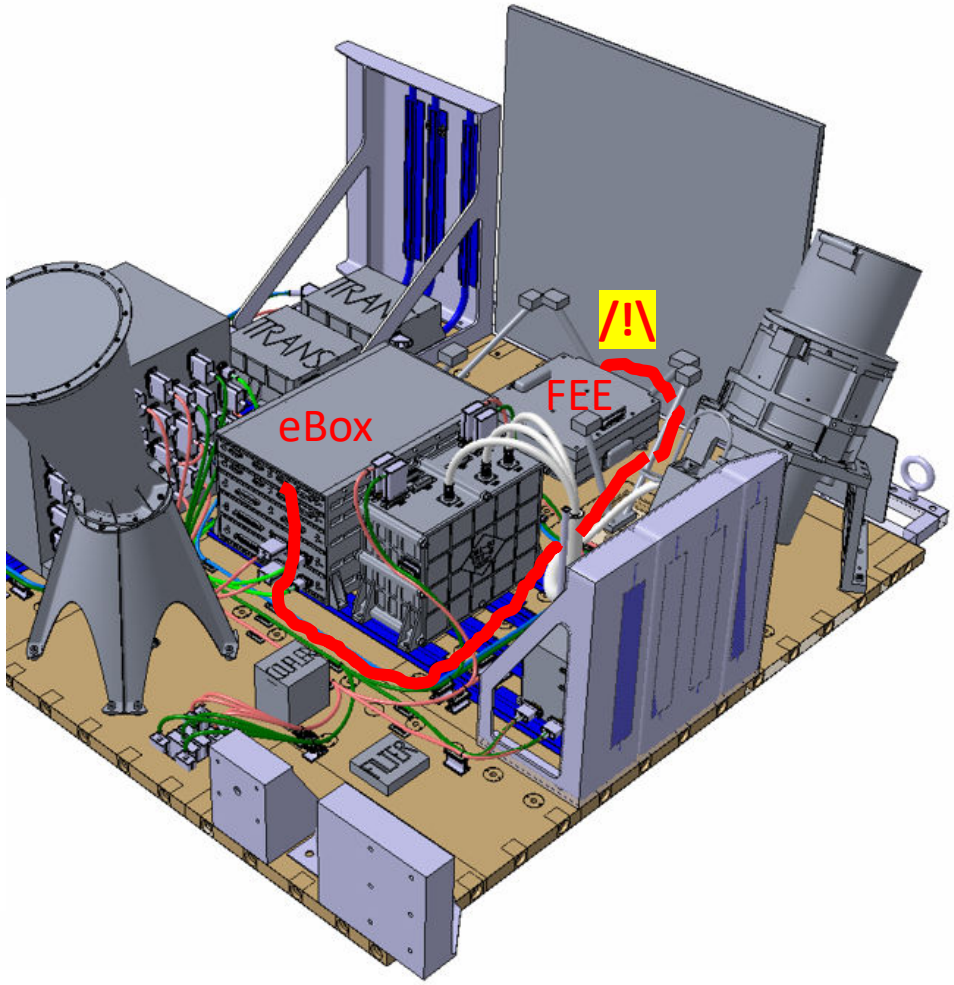
- 2 x SpW links
  - Nom & Red
- Not a high data rate
  - 10Mb/s
- Good candidate mission
  - To promote new technology



SXI Challenges

- Radiation belts
- Reduced magnetism preferred

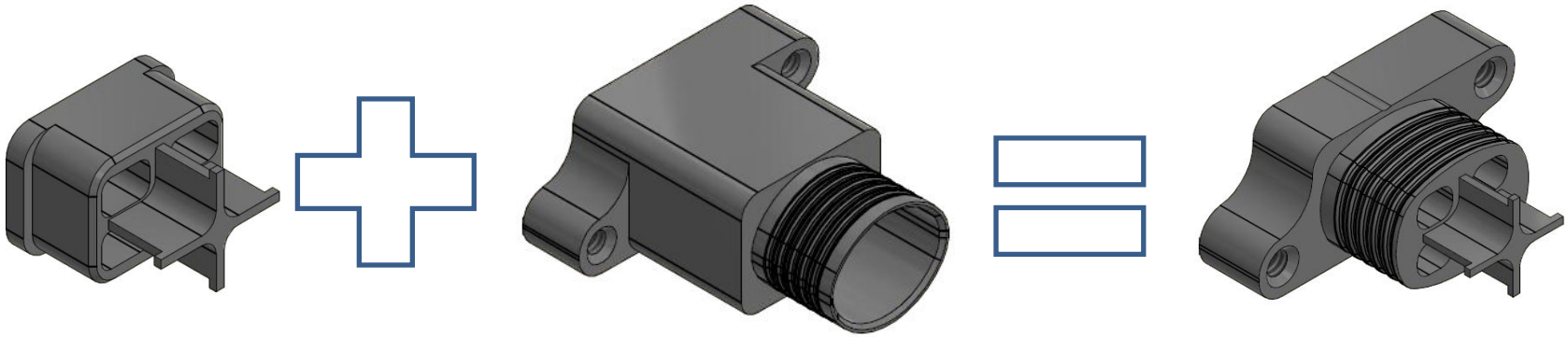
- /!\ Limited space at FEE
  - Possible need for right angled backshell



Developments and future concepts

MicroMach® SBS (*Short Backshell)*

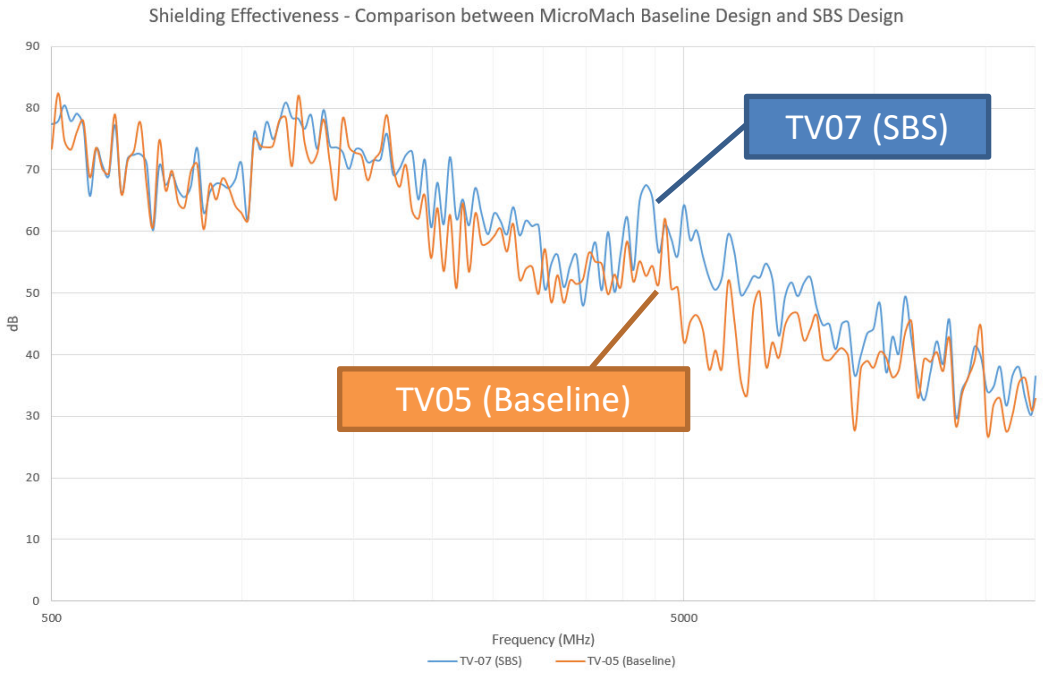
- In order to reduce the number of components on the MicroMach® , and thus to reduce the overall cost of a MicroMach® link, Axon' has developed a new component combining the roles of the AxiForm (Shield bonding of the pairs) and the Backshell (Shield bonding of the overall bread)



- Evaluated during the mechanical campaign (TV07 – LowMass SpW) ➔Same electrical performances.

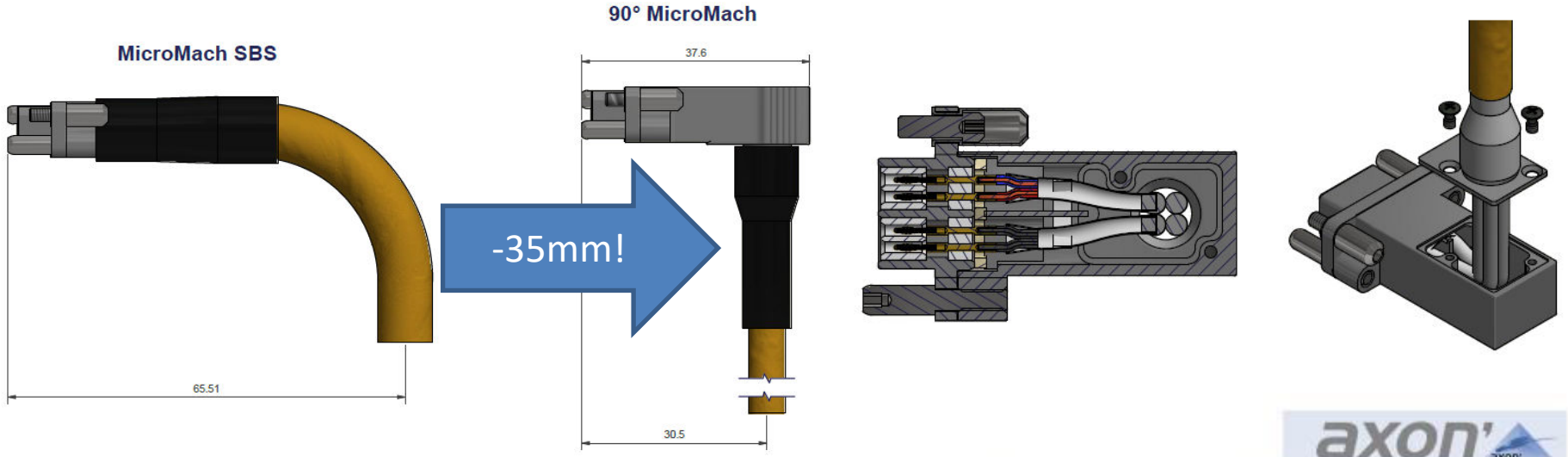
MicroMach® SBS (*Short Backshell*)

- -0,5g on a 8,5g connector
- -10mm on a 55mm long connector



Right-angled Male MicroMach®

- Axon has also developed a right-angled Male MicroMach®. At the moment, It can only be used for the Low-Mass SpW (AWG28).
  - Instead of bending the whole cable, the pairs are bent separately, allowing a huge win of space



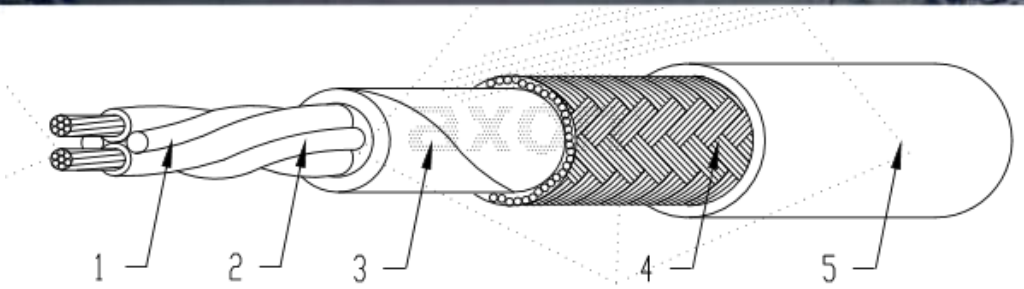
Cable skew reduction

- Intra-pair skew reduced from 80ps/m to 15ps/m allowing us to use MicroMach links at higher data rates

- 30 samples of 6m-long cables (AWG26) measured:

	Total skew (ps)	Skew/m (ps/m)
Maximal	30,4	5,07
Minimal	0	0,00
Average	11,7	1,95

➔-22ps/m compared to the maximal skew measured during the evaluation (i.e. 27ps/m)

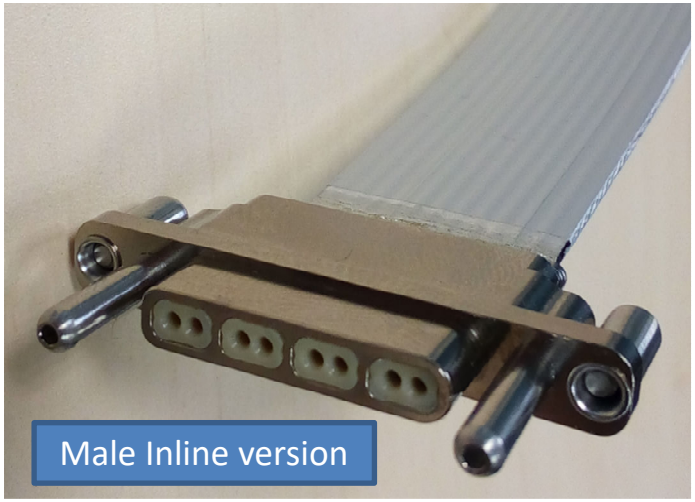


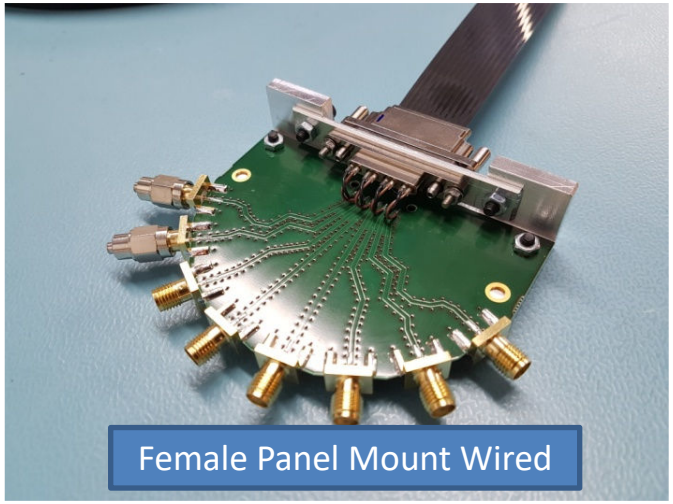
MAIN CHARACTERISTICS:

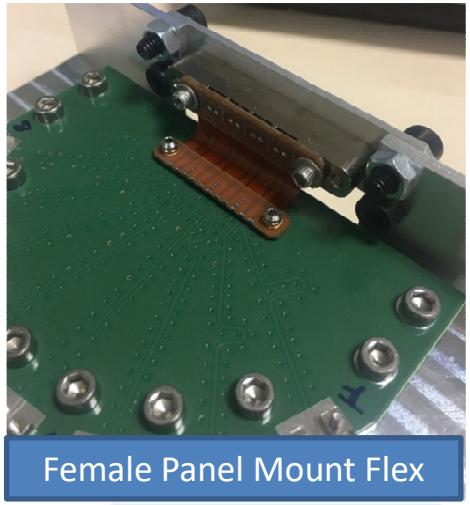
TEMPERATURE RANGE: −90°C / +180°C
OUTER DIAMETER: 2.95 MM NOM.
APPROXIMATIVE WEIGHT: 16 G/M
CHARACTERISTIC IMPEDANCE: 100 (−6/+10) Ω @ 400 MHz
CAPACITANCE BETWEEN WIRES: 45 pF/M MAX.
TIME DELAY: 4.4 nS/M MAX
SKEW: 15 pS/M MAX

Flat cable MicroMach®

- Axon' has developed a new range of connectors for **Airbus DS**, using the lessons learnt from the MicroMach® ➔Those connectors use the same dielectrics, the same contacts, and the same locking system

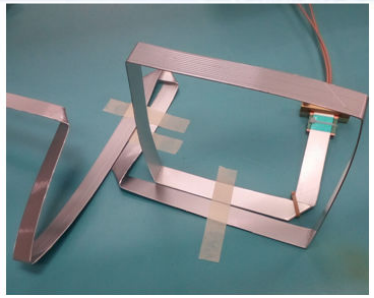

Male Inline version

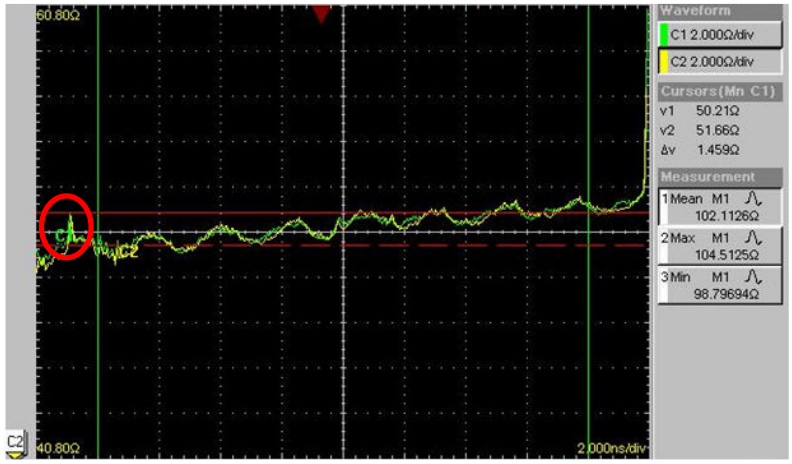

Female Panel Mount Wired

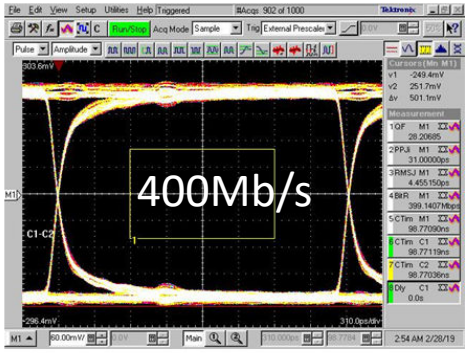

Female Panel Mount Flex

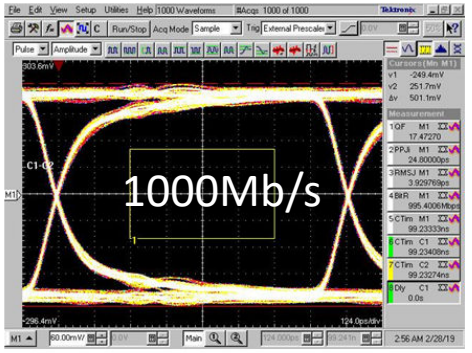
Flat cable MicroMach®

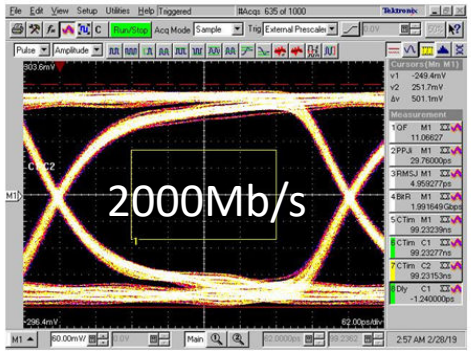
10 folds (90°) did not affect the 2m link !
➔1 fold creates a <2Ω mismatch

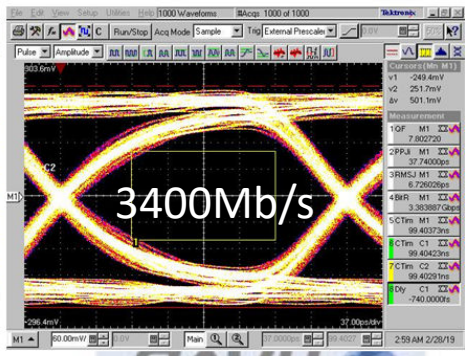












Thank you

For further discussion, please contact:

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Specifications: Lindsay Turot: l.turot@axon-cable.com