High Data Rate Solutions with new cable and connector technologies

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INTRODUCTION

Axon' Cable was selected to carry out the development of a new, impedance-matched SpaceWire (SpW) connector under a ESA Technology Research Project (TRP). The classic existing SpaceWire connector, the 9 way micro-D, whilst having the advantages of being both small in size - and common to most projects - is not electrically adapted to SpaceWire, nor is it particularly efficient for EMC protection. As application data rates start to increase there is, therefore, a need to develop an improved connector interface.

In a supplement to the original scope of the project, Axon' has also designed and manufactured a number of different cable constructions in order to evaluate whether the existing 4 shielded twisted pairs configuration is indeed the best option for the SpaceWire LVDS transmission.

Both of these activities fit nicely into Axon's strategy of seeking to increase the data rate capability and more generally the overall performance of the full assembly by working on all of the components in the link. Not only SpaceWire, but a wide range of protocols are demanding ever greater efficiencies and currently there are no suitable solutions on the market for space applications.

In the next short section Axon' presents a brief background of their high data rate (HDR) experience. The main body of the paper is a detailed presentation of the new prototype compact, impedance-matched SpaceWire connector, which discusses the various trade-offs performed in order to achieve a desirable size coupled with significantly improved performance. The penultimate section deals with an internal survey carried out on possible new cable constructions for high data rates, and this is followed by a brief conclusion.

HIGH DATA RATE BACKGROUND AT AXON' CABLE

Axon' has gained extensive experience in developing custom and compact matched impedance connectors and cables for the Space and Aeronautics industry, most of which have become, or are in the process of becoming ESA qualified parts. This experience began in the late 80's and early 90's with the supply of Space grade Mil-Std-1553B Databus looms for all the onboard network for Ariane V and many other platforms, and takes us to today's developments including solutions for SpaceWire, SpaceFibre, TT Ethernet and many more.

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In particular, Axon' has developed, through a Research & Technology (R&T) project (development & evaluation study) with CNES, a range of HDR assemblies. The ensuing AxoMach® family with data rates of up to **10 Gb/s** per channel has a flight heritage since 2012 on a number of programs. Additionally, this family has successfully been adapted to create a **SpaceFibre** version (Fig. 1.) through an ESA-led development under contract with the University of Dundee.

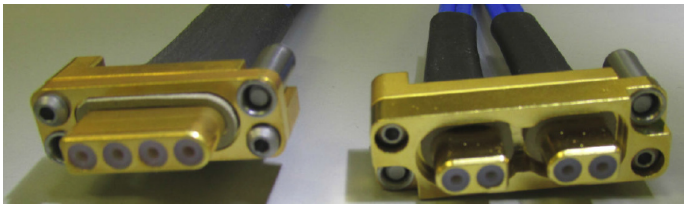

Fig.1. SpaceFibre Demonstrator connector (left) and equivalent AxoMach® 2 way connector (right)

Axon' has also developed, under a separate ESA TRP project, a low mass variant of the classic SpaceWire cable (ESCC 3902/003) which was qualified in 2015. The main achievement of this development was a cable mass reduction of 50% whilst retaining the same level of performances as the qualified, heavier cable, albeit with some restrictions regarding temperature rating and a different screening arrangement. The new AWG28 Low Mass SpaceWire is now qualified as ESCC 3902/004.01.

SPACEWIRE ADAPTED CONNECTOR

Note: To avoid repeating the lengthy phrase "compact impedance-matched SpaceWire connector" throughout this paper and elsewhere, Axon' has adopted the working name "**MicroMach SpW**" for this connector family, drawing on its twin heritages of Micro-D and AxoMach® ('mach' meaning high speed) technologies.

Existing Market Connectors Survey

Among a variety of existing connectors on the market dedicated to interconnect high speed links, only a few appear to have the required electrical performance levels, but these tend to be much larger in size than the 9 way Micro-D solution (see example in Fig.2). Other than its compact size, however, the Micro-D offers the least electrically compliant results of the study - unsurprising in that it was originally chosen for its size and robustness rather than its HDR capability. Put another way, typically when a connector is of a desirable size, the electrical parameters tend to be compromised - particularly in terms of EMC performance. Additionally, the various available connectors on the market, along with their contacts and accessories, are not always well matched to the cable size and can therefore create a degree of electrical mismatching, generally manifested by deviations in characteristic impedance and shielding efficiency.

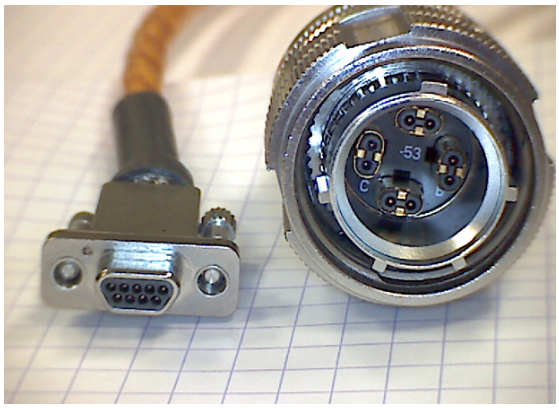

Fig.2. Comparison in size between classic 9 way Micro-D connector and one of the top HDR performers in the connector survey

As no connector on the market currently meets both the electrical performances and the dimensional aspirations of the study, the development of a dedicated connector was commenced, focusing on the twin targets of remaining as close as possible to the size of the 9 way Micro-D whilst significantly improving the overall electrical performance.

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New Connector Design

The shape of the proposed new connector was rapidly chosen in accordance with customers' needs to be a rectangular design with 4 separate cavities. Each cavity is separated by a metallic wall to improve crosstalk performance. The 4 ways are designed to all be fully 100Ω adapted throughout the complete transmission line.

To secure the mating sequence, 2 special guide pins are used which, as well as securing the backshell to the connector, help accurately guide the male and female connectors together during mating.

The electrical contacts are assured by the very well-known and reliable Twist Pin technology used on Micro-D connectors, which can boast decades of successful flight heritage. These contacts are inserted by first fitting them into dielectrics which are then press-fitted into the connector shell. This design prevents the contacts moving backwards or forwards within the connector.

A SpaceWire cable consists of 4 inner shields (around the twisted pairs) and one overall shield. One of the main challenges of this new development, therefore, was to design a connector with 4 effective inner shield terminations in an overall size as close as possible to that of a 9 way Micro-D. The choice, made jointly with ESA and STAR-Dundee, was to work on a connector with "good-but-not-360°" inner shield termination (as illustrated in Fig.3) in order to make it more compact. The purpose of this design was to guarantee sufficient electrical contact between the braided shield of each pair and the metallic shell of the connector whilst saving space and significantly reducing crosstalk.

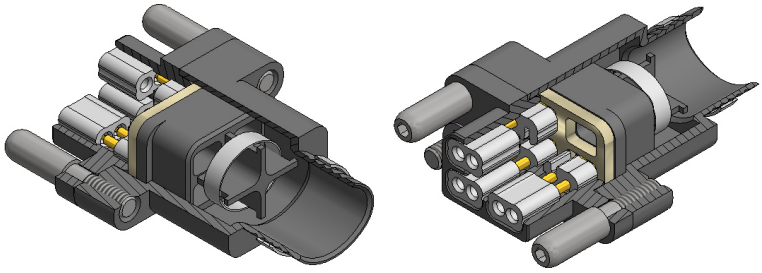

Fig.3. 3D cross-section of the in-line male MicroMach SpW connector

The contact of all 4 inner shields is achieved using a metallic 'nano' band tightened around a special feedthrough insert with the 4 shielded inner pairs in situ (Fig.4). The cruciform shape at the rear of this inner shield insert ensures a solid electrical contact by maintaining a degree of pressure over the 4 cable braids. This Axon-designed insert has been dubbed internally, "**aXiform**"

The overall (outer) shield of the cable is then crimped over the backshell funnel with an axoclamp® (or equivalent) banding adaptor.

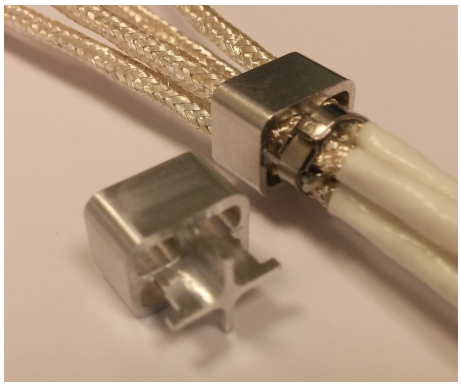

Fig.4. twisted pair shield connection demonstration with "**aXiform**" inner shield feedthrough insert

The MicroMach SpW connector is currently designed for both AWG26 and AWG28 SpaceWire cable variants with a specific "aXiform" insert for each size. Other cable constructions could be achieved simply by adapting the insert as required.

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Finite Element Simulation

To identify the best compromise between the hardware design and the resulting electrical performance, Axon' carried out Finite Element simulation on 3D models using CST software. These analyses were principally focused on characteristic impedance in order to determine the optimum size of all the inner connector elements. As can be seen in Fig. 5, the main mismatching is where the cable is terminated to the contacts. At the crimped contact interface the Zc variation may be around 20Ω for AWG28 and 15Ω for AWG26 cable.

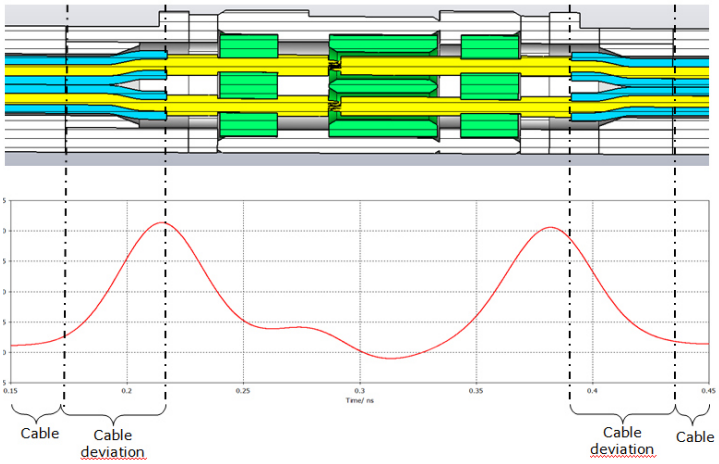

Fig.5. CST simulation with Finite Element Model

Key Mechanical Specifications of the MicroMach SpW Connector

Dimensions: **21.4mm x 9.3mm** → Fairly close to a 9 way Micro-D (19.7 x 7.6 – comparative photograph in Fig.6.)
Female weight : **6g**
Male weight : **7.5g**

Fig.6. 9 way Micro D next to New *MicroMach SpW* connector

Preliminary Electrical Results

1. Ground contact between Male & Female bodies **< 5mΩ**
2. Next/Fext **< -50dB up to 1Ghz**
3. Return loss **< -20dB up to 1Ghz**
4. Characteristic Impedance:

The following Characteristic Impedance plots (Fig.7) were measured on a Micro-D mated pair terminated with AWG28 Low Mass SpaceWire (ESCC 3902.004.01) versus the MicroMach SpW connector mated pair terminated with classic AWG26 SpaceWire (ESCC 3902.003.02). The differing cable types are not particularly relevant – they were simply the available test samples to hand at time of writing – but the results show clearly that the new MicroMach SpW connector is highly adapted even in full band (around 20GHz).

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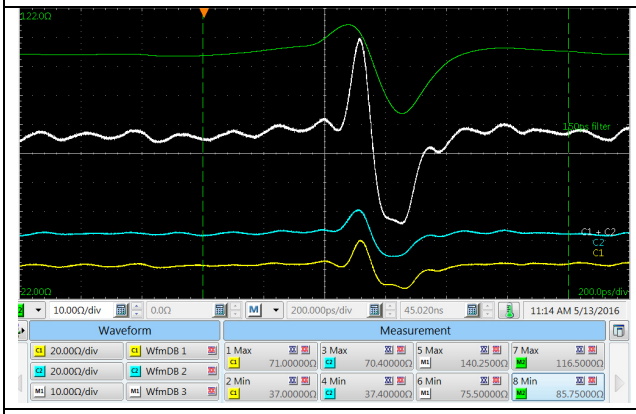
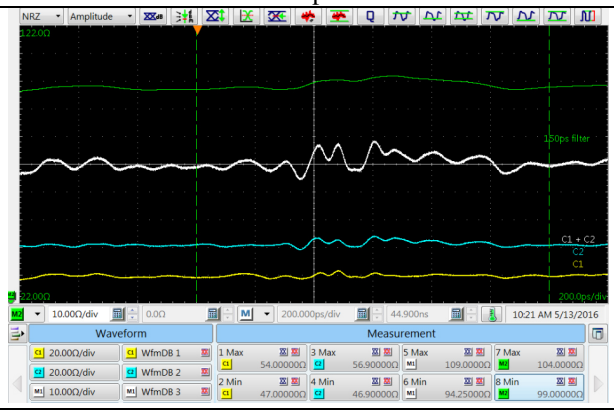
Micro-D connector	MicroMach SpW connector
	
Zc variation around 86Ω to 116Ω (150pS rise time filter) & 76Ω to 140Ω (full band)	Zc variation around 99Ω to 104Ω (150pS rise time filter) & 94Ω to 109Ω (full band)

Fig.7. Zc on 9 way Micro-D connector vs. MicroMach SpW connector

5. Eye pattern / SpaceWire mask compliancy

The Eye Pattern in Fig. 8 is a 1 metre link using Low Mass SpW cable (ESCC 3902.004.01) terminated to 2 MicroMach SpW mated pairs and run successfully at **4Gb/s** with respect to the SpaceWire mask.

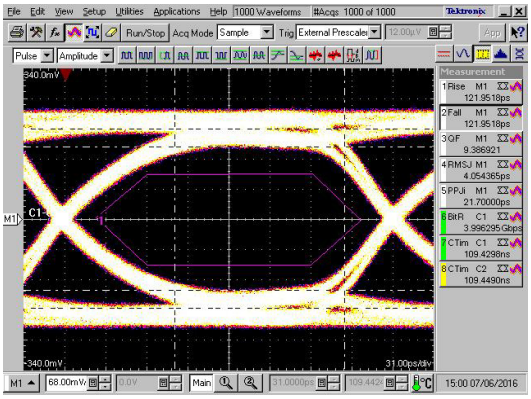
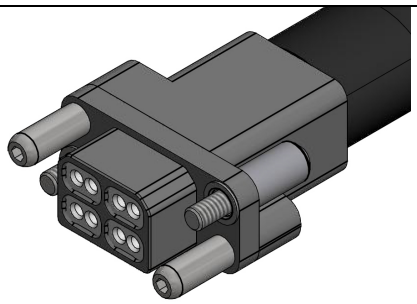
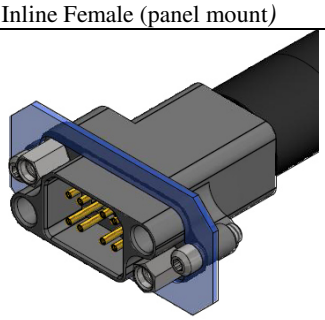


Fig.8. MicroMach SpW connectors with Low Mass SpW cable: Eye pattern @ 4Gb/s, 1m link

Presentation of a Possible MicroMach SpW Range

Axon' has also worked on a number of different possible connector variants as presented briefly below (Table.1). Some additional PCB connectors will be developed according to the need.

Inline Male	Inline Female (panel mount)
	
This connector will be used mainly for normal links between equipments or between equipment and router.	This variant will be used to add a break point in a link. It could be fixed to a dedicated bracket or on a panel.

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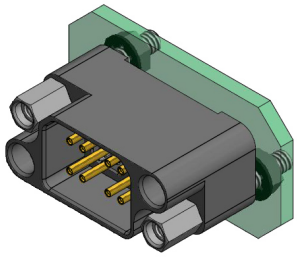
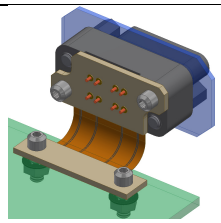
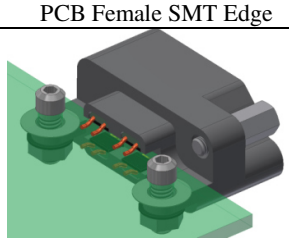
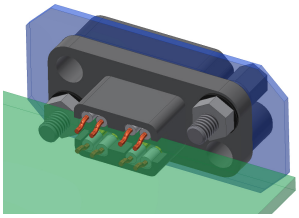
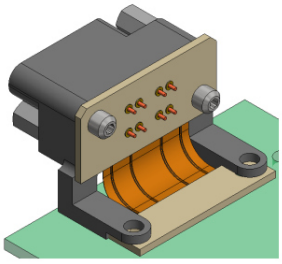
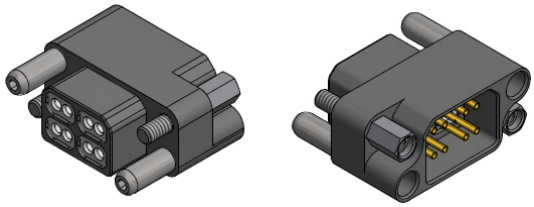
PCB Female Board Straight	PCB Female Flex
 Basic PCB version to connect to a board with limited mismatching and crosstalk.	 Allows a good mechanical decoupling between PCB and equipment panel while maintaining impedance matching and crosstalk reduction. The skew is also very low.
PCB Female SMT Edge	**PCB Female SMT Edge**
 This variant saves a lot of space on the PCB and allows a significant crosstalk reduction between the two connection sides.	 Adds the possibility of mounting the connector on a panel (rear mount)
PCB Female CBR	**Saver**
 This variant allows a right angle mount while maintaining impedance matching. Offering limited crosstalk and skew.	 Savers are often needed during the AIT phase.

Table.1. Illustration of likely members of the MicroMach SpW range

CABLE SURVEY

In parallel, Axon' has carried out an internal cable survey to try to improve SpaceWire cable features, mainly focusing on skew reduction and size.

The approach was to study the possibility of manufacturing parallel pairs using the same low loss a-PTFE® dielectric as is used in the Low Mass SpaceWire cable in order to increase the maximum data rate whilst assuring a reduction in intra pair skew and insertion loss. In parallel pairs, the skew is better controlled due to the low variation of mechanical length in the individual wires along the length of the cable. Moreover, as the wires are not twisted, the length of all the wires is the same as the length as the overall cable assembly (not the case for the twisted pair). This translates into a significant reduction in the cable insertion losses.

From a mechanical point of view, the cross sectional area of the cable bundle is smaller in a parallel construction than in a twisted one because there is no need for any fillers between wires.

If we are using discrete pairs only (not assembled into a bundle), we can also significantly reduce the bend radius when bending the cable in the flat plane.

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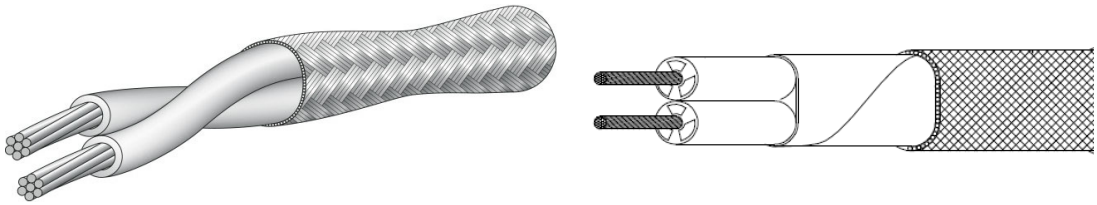

Fig.8. twisted pair versus parallel pair

Key electrical results of a-PTFE® parallel pair:

- skew **< 20ps/m** @ 5GHz
- Zc max. delta variation **< 3Ω**
- Insertion loss **< 1.2db** up to 1GHz

To further reduce the dimensions, quad cable constructions have also been studied. The wire baseline is equivalent to that of the parallel and twisted pairs but matched to offer 100Ω differential impedance between diagonally opposing wires on the cable diameter. See Shielded Quad Cable in Fig.9. This cable needs a dedicated connector with 4 pins in the same cavity to maintain the electrical performance in the connection area.

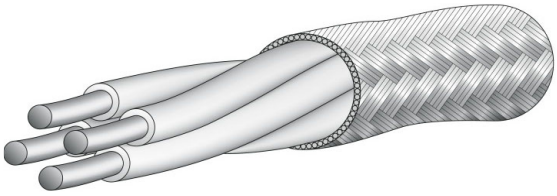

Fig.9. Shielded Quad Cable

CONCLUSION

Axon' continues to develop high performance HDR links by working on both cable and connectors in parallel, as well as on the overall termination methods. The new MicroMach SpW connector range, which will be available by end 2017 offers, in a size only slightly larger than the current 9 way Micro-D, significantly improved performances in data rate, EMC and crosstalk compared to any of the current market solutions.

An important outcome of this project will be the update of the generic specification No. 201 (2263xxx) for the harness plus a new ESCC detail specification characterising these new SpaceWire in-line and PCB connectors. At the same time the latest revision of the SpaceWire standard, ECSS-Q-ST-50-12 has been issued incorporating the possibility to use this new "MicroMach SpW" connector as a type B.

The Axon' internal cable survey, still in progress, will also propose new possibilities for cabling. Parallel pairs are already showing promising results and could be used with the MicroMach SpW connector to achieve high data rates where other restrictions, such as limited available space, may apply.

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