# Mass reduction and higher data rate transmission with copper based components,

Short Paper


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This paper reports on the major achievements of some Axon' projects to evaluate Nano-D connectors for Space environment for mass and space saving, to develop a Low Mass SpaceWire cable design and to present solutions to achieve very high data rate transmission on copper based cables.

Today, the team has completed the project with the extensive evaluation of Nano-D range of products from 9 pins to 51 pins, with the evaluation of a new variant of Spacewire cable offering a mass reduction by at least 50 per cent retaining similar performances than existing variants, and has evaluated and qualified copper based solutions to carry on signals up to 10Gb/s.

Nano-D connectors allow much higher contacts density keeping a good current rating. The data below regarding the external surface of the connectors illustrates well these arguments: Surface is reduced by a factor of 2.8 between D SUB and Micro-D, by a factor 14 between D-SUB and Nano-D and by a factor of 5 between Micro-D and Nano-D. Such a connector can accommodate a very large quantity of pins. Mechanically they are robust and durable, they present low contact resistance and high current capacity. In addition, they have excellent resistance to shock and vibration. Jumpers, Pigtails, PCB connectors (CBR, BS, SMV) from 9 to 51pins are available. Customized harness can be realized.

The first low mass Spacewire version uses twisted shielded pairs and presents electromagnetic, mechanical and electrical performances at least similar or better to the existing standard, and is therefore recognized by ESA. The second version uses pairs of coaxial cables and presents higher attenuation, thus limiting the usage length, but significantly increased flexibility and an even lower mass. This version, however, is not ESA recognized. The project team additionally concludes on the maximum advisable lengths for the different low mass versions assessed. Therefore, taking all of this into account, the team is currently working with ESA and Star Dundee to feed all of these conclusions into the latest draft of the ECSS-ST-50-12 assembly standard and the ESCC 3902/003 cable standard updates. The screen termination method has been reviewed in depth. The inner and overall shields are terminated together to the connector shell at both ends.

SpaceWire, however, remains limited to 400Mbits/s or its maximum usable length. The new SpaceFibre standard will be a multi-gigabit protocol proposing copper or fiber optic solutions for very high data rates and/or longer cable lengths. A good connector candidate for a copper cable solution is named Axomach®, an Axon' connector previously developed with CNES for transmissions up to 10Gb/s per channel. The latest tests run by Star-Dundee demonstrate that this cable and connector solution works very well for crossover transmission lines running at 2.5Gb/s.



Relevant indexing terms: SpaceWire, SpaceFibre, Micro-D, Nano-D. *(key words)*


## I. Background, Existing Limitations

This short paper intends to provide a brief overview of the recently completed ESA project to evaluate Nano-D connectors range, to develop a low mass alternative to the existing SpaceWire cable, and will discuss continued limitations and possible future developments to carry on higher data rate on copper based assemblies keeping in mind mass and space saving.

Since the need for miniaturization is an ever-growing trend, AXON' has developed high density and ultra-high density solutions ranging from power or single signal transmission line to High Data Rate and high frequencies transmission: Micro-D and Nano-D connectors.

Nowadays a vast majority of satellites use D subminiature connectors as they can be used for many applications. Alternatively, Micro-D and/or Nano-D connectors can be used in wired harnesses for mass and volume saving purposes. Micro-D connectors solutions are based upon ESCC3401/029 and/or Nano-D solutions based on MIL-DTL-32139 & ESCC3401/86.

It is clear that reducing the size of the connectors by a ratio of 14 may cause among users a strong fear and installation problems. This technical issues has been assessed and a user guide has been issued to help users to handle and install correctly the Nano-D assemblies.

The existing SpaceWire cables, recognized by the ECSS-ST-50-12 standard, have a number of limitations. They are relatively heavy, at approximately 80g/m for the lightest (AWG28) version, they are fairly rigid, they are not particularly radiation tolerant, and they have quite a large minimum bend radius, particularly the bigger AWG26 version. All of these limitations reduce the suitability of the current SpaceWire cable for installation and use in spacecraft, although they remain currently the only approved options.

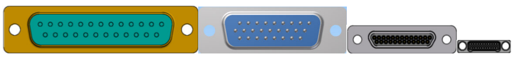
In addition to these physical constraints with the cable itself, the standardized interface connector, the 9 way Micro-D, is not impedance-matched (not a big issue when used up to 400Mb/s), not EMC optimized and as the 4 pairs are not separated through a couple of connector creating, a poor crosstalk is achieved. In addition standardized wiring schedule is not optimized for EMC.

The ESA ITT sought to address many of these issues, the principle one of which was weight reduction, and Axon' Cable, the winner of the tender, has therefore been developing such optimized solutions along with their consortium partners, Star Dundee in Dundee, Scotland and EADS Astrium in Toulouse, France.

## II. Ways to reduce mass, connector higher density, low mass Spacewire version

### II.a Migration of connector packages using Nano-D:

The reason of choosing Nano-D connectors for wired harnesses is the mass and volume saving. Theses connectors allow much higher contact density keeping a good ampacity. The table 1 and the drawings below illustrate well these arguments.
Surface is reduced by a ratio of 2.8 from D-SUB to Micro-D.
Surface is reduced by a ratio of 14 from D-SUB to Nano-D.
Surface is reduced by a ratio of 5 from Micro-D to Nano-D.



| | **D SUB SD** ESCC.3401.01 | **D SUB HD** ESCC.3401.02 | **Micro-** ESCC.3401 29 &77 | **Nano-D** ESCC3401 086 |
|---|---|---|---|---|
| Pitch | 2.74 | 2.41 | 1.27 | 0.635 |
| Dimensions (mm) | 53.04x12.55 for a 25 ways | 39.14x12.55 for a 26 ways | 30.1x7.82 for a 25 ways | 14.61x3.18 for a 25 ways |
| Surface (mm²) | 665 for a 25 ways | 491 for a 26 ways | 234 for a 25 ways | 46.5 for a 25 ways |
| Weight (g) | 13 for a 25 ways | 7.6 for a 26 ways | 3.6 for a 25 ways | 0.5 for a 25 ways |
| Wire Awg | 28 to 20 | 26 to 22 | 28 to 26 | 30 |
| Removable | Y | Y | N/Y | N |
| Screwlocks size | 4-40 UNC | 4-40 UNC | 2-56 UNC | 0-80 UNF |
| Work. Volt. (Vrms) | 300 | 250 | 150 | 250 * |
| Rated current (A) | 3 to 7.5 | 3 to 5 | 1.5 to 2.5 | 1 * |

Table 1: Comparison between D-SUB, Micro-D & Nano-D

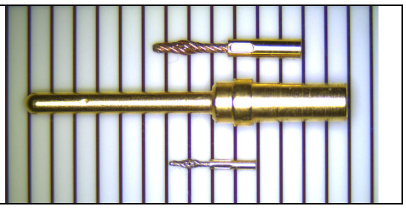
| | |
|---|---|
| **Micro D twist pins**<br><br>**D-SUB AWG20 pins**<br><br>**Nano D twist pin** |  |

Table 2: Size comparison between contacts.

These connectors have been designed according to MIL-DTL-32139 and are at the origin of ESCC3401/086. Extensive evaluation including 6 groups :Group 0, "Exomars cycling tests"; Group 1, "Mechanical"; Group 2, "thermal and mechanical Endurance"; Group 3 "Temperature tests"; Group 4, "Voltage and current overload test"; Group 5: "Contact group" were performed. Limit of the connectors were determined.
The test vehicles withstand:

- space thermal, environment (EXOMARS 333 cycles from -124 to + 80°C),
- mechanical vibrations (20Hz to 2000Hz, with a spectral density of 0.4g²/Hz during 2 hours);
- Mechanical shocks (30 half-sine shock pulse of 50g amplitude and 8ms duration);
- mechanical endurance (700 cyles);
- 1695 hours of thermal endurance (1695 hours at +150°C); - 1205 rapid change of temperature cycles (from -55°C to +150°C ); …

These tests provide requirements listed in the draft ESCC specification (rated current, rated voltage, insert retention…).
Range of products: 7 shell sizes :9-15-21-25-31-37-51
Contacts, Nickel 15-18 µm over aluminium plating

### II.b Reducing weight with „Low Mass Spacewire"

Mindful of the electrical performance requirements dictated by the standard, it was necessary still to use certain minimum dimensions and materials. However, three main areas were focused on to bring about improvements:

- The use of lighter materials. Essentially broken down into conductors and insulators, the use of lighter conductors such as aluminium, was proposed where appropriate, as opposed to copper; and for the insulators or dielectrics, the use of expanded or alveolar materials was selected, as being lighter than their solid counterparts.
- Constructional changes. The existing SpaceWire cable is a construction consisting of four individually screened and jacketed twisted pairs all laid together in an assembled bundle, which itself then has an overall braided screen and an overall extruded outer jacket. The project members sought to explore other constructions which could achieve the same or similar electrical performances while using a "lighter" combination of elements.
- Flexibility. While considering weight reduction, the project team also gave consideration to possible ways of increasing the flexibility of the finished cable.

In all, some 12 suggested constructions were put forward for initial analysis and testing, following which two constructions of interest were finally selected.

The first of these, known initially as Variant 03, and then given the project designation C-OA-TPA-A-2819, is similar to the existing SpaceWire AWG28 cable, with the following key differences:

- The silver plated copper conductor is a 19 stranded AWG28 conductor, giving it more inherent flexibility than the existing 7 stranded version.
- The primary insulation is of an aleveolar PTFE (or aPTFE) construction, where the material is not solid but has a number of air gaps in a lattice-like structure, see Fig 2. This has the twin advantages of improving the dielectric constant whilst also reducing weight.

Fig. 1. Cross sectional view of an alveolar PTFE insulated conductor.

- The inner screens of each twisted pair are silver plated aluminium instead of silver plated copper, thus substantially reducing weight (and not requiring termination)
- The filler between the four screened pairs is of expanded PTFE, for which Axon's trade name is CELLOFLON, a material which is inherently very flexible,
- An outer screen has been retained, also in silver plated aluminium, but which, very importantly, is in contact with the four inner screens,
- And finally an outer insulation is constructed by the use of a CELLOFLON expanded PTFE inner tape and a polyimide (KAPTON) outer tape, providing an excellent combination of lightweight flexibility and good radiation tolerance.

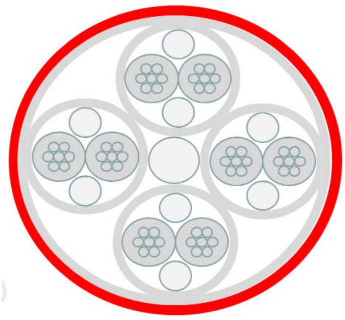


Fig. 2. Variant 03 (C-OA-TPA-A-2819) Low Mass SpW cable (Outer shield in contact with inner pair shields, all shields in silver plated aluminium)

Having been proven to have acceptable performance results in all tests, this variant has been accepted in principle by ESA as a potential lightweight "drop in" replacement to the existing SpaceWire variants, and is in the process of being added to the latest revision of the standard.

The second construction of interest, known as Variant 09, (C-OC-CPC-P-3407) takes a completely different constructional approach, based on four pairs of coaxial cables. Although these are not 100 ohm impedance pairs each coaxial has a 50 ohm impedance, and therefore under the required SpaceWire tests as defined by the Project scope they nevertheless perform satisfactorily. An enhanced version of this variant employs an overall shield for improved EMC underneath an outer insulation of similar construction to that of Variant 03. The mechanical advantages of this variant are substantial;

- Mass of around 33 g/m – almost 70% weight saving,
- Outer diameter of around 4.5 mm as opposed to over 7 mm for existing SpaceWire,
- Extremely small bend radius – the cable can almost be bent double during installation and still perform satisfactorily, see Fig 3.

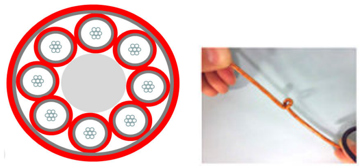


Fig. 3. Alternative variant based on 8 x coaxial cables, with picture showing the tight bend radius possible whilst maintaining electrical performance

However, it is important to note that according to ESA, the coaxial construction is not theoretically suitable for a floating load LVDS application such as SpaceWire, and as such ESA does not currently endorse its use.

This cable can be terminated using existing 9 way Micro-D connectors, or indeed the much smaller 15 way Nano-D connectors, thereby saving even more space and weight (but clearly that would then require devices with Nano-D mating halves). It is not suitable for re-work, however, being based on AWG34 wires, significantly smaller than the minimum acceptable gauge size recognized by ESA, AWG30.

## III. Comparison between both versions

Both cable types meet the SpaceWire performance criteria, although because of the smaller gauge size it would not be appropriate to use the coaxial version in longer lengths. If we assume that an "acceptable" value for Insertion Loss over the whole assembly is 6dB, then we can calculate maximum usable lengths for each type, (not including connectors) and summarize as follows:

TABLE I. Insertion Loss comparison

| **Part number/ Bach N°** | | P551259A / X19623 | P551260A^ / X19371 |
|---|---|---|---|
| **Comments** | | *43g/m, twisted pairs, ESA endorsed* | *33g/m, coaxial pairs, not ESA endorsed* |
| **Code** | | *C-OA-TPA-A-2819* | *C-NO-CPC-P-3407* |
| **Performance at 250MHz** | *S21 (dB/m) @ 250MHz* | 0.7 | 1.3 |
| **Data rate 100Mb/s** | *Max length to reach 6dB in m* | **10** | **4.6** |
| **Performance at 500MHz** | *S21 (dB/m) @ 500MHz* | 1 | 1.8 |
| **Data rate 200Mb/s** | *Max length to reach 6dB in m* | **7** | **3.3** |
| **Performance at 1000MHz** | *S21 (dB/m) @ 1000MHz* | 1.4 | 2.6 |
| **Data rate 400Mb/s** | *Max length to reach 6dB in m* | **3.7** | **2.3** |

## IV. SpaceWire screen terminations

The screen termination and wiring schedule for the current SpaceWire cable is not optimized, but rather was adopted at the time due to the constraints imposed by a combination of the construction of the cable (where all the inner screens are isolated from the outer screen) and previous EMI rules which recommend to not connect shields at both sides to avoid current loop. We therefore have the existing standard wherein two of the inner screens are short circuited together and terminated to pin 3 at one end, and the other two inner screens are similarly terminated to pin 3 at the other end, meaning that no inner screen is continuously connected from one end to the other. The outer screens are terminated to the shell of the connector (or backshell).

Assuming, for backward compatibility reasons, we wish to retain the 9 way Micro-D connector for some time to come, we can now substantially improve this wiring schedule with the new (ESA endorsed twisted pair) cable construction. Here, because all the inner screens are now directly in contact with the outer screen, we can simply terminate the outer screen to the body of the connector or backshell, thus effectively terminating all screens together in one go. For EMC purposes, it is highly recommended to employ a backshell at the rear of the Micro-D connector, with a cable entry funnel optimized to be only slightly larger than the inner bundle of four pairs, and then to terminate the overall shield over this funnel with some recognized form of 360° screen termination, such as a EMC band clamp. This simplified, but improved, wiring schedule will now resemble Fig. 4.

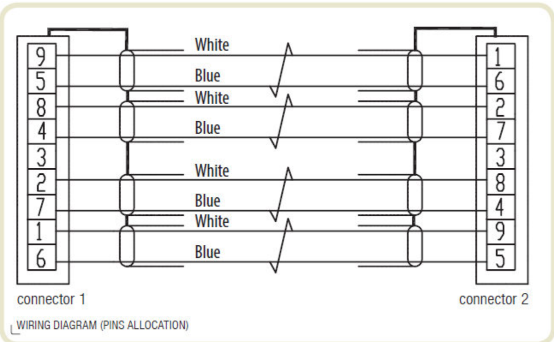
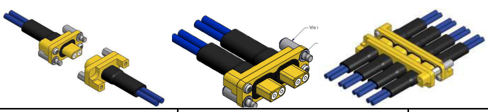



Fig. 4. Proposed Low Mass SpaceWire Wiring Schedule

## V. COPPER CABLE SOLUTION FOR 10GB/S - SPACEFIBER

Out with the Low Mass SpaceWire project, work is ongoing to develop the multi-gigabit SpaceFibre protocol, with potential media solutions in both copper and optical cable. Axon' has already developed a space grade copper based solution in association with the CNES, which (cable and connectors combined) is capable of operating at up to 10Gb/s per 2 channel. Single , double and fourth channels have been developed to be compatible with the largest number of high data rate existing today. A four channel version of this exists permitting total data transfer rates across the link of up to 40Gb/s. This solution is based on pairs of high frequency coaxial cables.



| Single way | Double ways | Four ways |
|---|---|---|

Main features of this connector is

- 2 coaxial space cables media ax2.4S per way
- 100 Ohm differential impedance
- Up to 10Gb/s per way (1,2 &4 ways)
- Low size
- E.M.I. improved
- Surface mount & parallel gap PCB terminations
- -55 to +125°C (Space Environment)
- Up to 10Gb/s per way (L<4m)
- Skew <10ps per connector couple
- Xtalk between ways < -35dB up to 10GHz
- Shielding effectiveness < -60dB up to 10GHz

In order to comply with the intended SpaceFibre requirements, a two way version of such an assembly, trade name, AxoMach®, would be required in a crossover configuration, permitting full duplex operation servicing transmitter and receiver at both ends. Such an assembly has been tested by Star Dundee at 2.5Gb/s with satisfactory results, see Fig. 6.

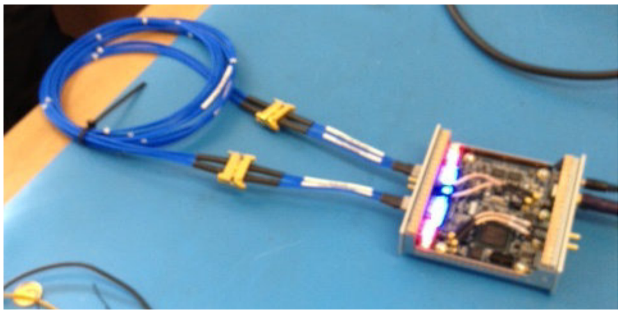


Fig. 5. AxoMach crossover 2 way link connected to a Star Dundee SpaceFibre test unit at 2.5Gb/s (with eSATA adaptors)

## VI. CONCLUSIONS

A low mass alternative to the current SpaceWire cable now exists at approx. 50% of the standard weight, and can be used as a drop-in replacement with existing 9 way Micro-D connectors for compatibility with most systems. This cable is currently being added to the updated SpaceWire standard.

An ultra-low mass version, (70% weight saving) based on coaxial cable pairs also exists, but is not ESA-endorsed for LVDS-based applications such as SpaceWire.

The most common SpaceWire interface connector, the 9 way Micro-D, is neither impedance-matched nor EMC optimized, and there is no European solution ready for an improved SpaceWire connector. Therefore there is a scope to develop a matched impedance connector standard for SpaceWire, particularly if it can also provide forward compatibility for SpaceFibre operation.

A fully compatible copper-based cable and connector solution already exists for SpaceFibre transmission, and indeed can support much higher data rates of up to 10Gb/s per channel.

## ACKNOWLEDGMENT

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