FAST-LOCK ZIF INTERCONNECTIONS AND CONNECTORLESS FLAT CABLES.

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1.) INTRODUCTION

Since the early '90's Flexible Flat Cables (FFC) have been a widely used technology, mainly for automotive and consumer electronics. Now, with the trend towards smaller satellites and mega-constellations there is a real and growing interest in this technology. FFC are emerging in the space sector because they offer advantages versus round wires harness. Compared to bundles of round cable and wires, their lightness and flexibility are elements that can solve complex situations. In addition, their much better heat dissipation allows higher currents to be passed for the same copper cross-section. These particularities are of interest for space industries who have been involved in the presented developments.
As a manufacturer of classic Micro-D connectors and also of a wide variety of round cables and interconnect used in Space but also a leader for FFC commonly used in consumer electronics and automotive applications, Axon' Cable is very well versed in the pros and cons of harnesses used in harsh environment and particularly concerning space environment constraints.
As requested by the ESA ARTES background, the purpose of this paper is to present the development of "connectorless" flat cable link solutions connected to PCB-mounted connectors with fast-lock solutions to meet the growing needs of the space market for quick and easy integration and mass reduction. This solution eliminates the cable-mounted connector and therefore improves the reliability of the link by reducing the number of connection points.
As part of an ongoing ARTES activity, Axon' is developing signal and power FFC cables and various variants of Zero Insertion Force (ZIF) connectors adapted to these flat cables. These connectors are designed for mounting on PCB and equipment panels. Indeed, PCB-to-PCB and PCB-to-panel connections are necessary for wiring inside the equipment and are also necessary for connecting the equipment to each other. In order to offer a complete solution to future users, these space-grade FFC links will be manufactured and evaluated for low voltage and low current applications, as well as for higher current applications.

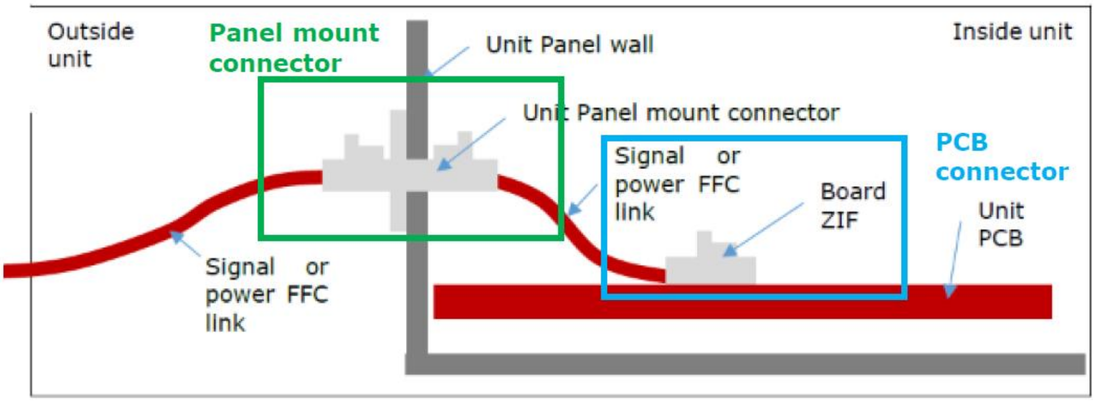


Fig. 1: PCB and Panel mount connector

During this study, the reliability of the locking of the ZIF connector, the quality of the electrical contacts as well as the double insulation rules, which were taken into account and adapted to the flat structure, are optimized to achieve a ZIF connection suitable for use in space.

The aim is to achieve TRL 6 for the development of ZIF connectors for PCBs capable of accommodating flat cables supporting DC or low-frequency signals or a DC power supply (up to 10 A per track).

2.) SURVEY

During a preliminary survey, Axon' identified several FFC connectors in the market, allowing direct connection between FFC and units. These identified connectors are for industrial activities and none are available for space market. The existing suppliers identified are either Asian or American. No European solution is available on the market. Thus there is a double interest of developing an European and a space compatible solution.

3.) FLAT CABLES AND CONNECTOR DESIGN

3.1) Flat cable design

The idea of this study was to develop a concept of connector that could be extended to various types of flat cables. Axon did the choice to select two flat cables already used on ongoing space projects, one for a power transmission application and the second one for signals transmission.
The designs of theses Flat Flexible Cables for Power and signal were made as per the table 1 :

Axon' P/N	Section	Designation
P584261	Power 0.735mm² (#AWG18)	FFC8x3.5x0.21 PI insulation + acrylic adhesive & SPC conductors
P584262	Signal (#AWG26)	FFC20x1.0x0.12 PI insulation+ acrylic adhesive & SPC conductors

Table 1. Type of flat cables to be connectorized.

Silver plated copper conductors (2 µm silver thickness) and 25 µm Polyimide tape insulation are used as a baseline of flat Flexible cable for space application. 76 µm Acrylic adhesive is used to fix the elements (insulation + flat conductors) as it has an excellent adhesion to copper and a good compatibility to space environment (low off gassing, good radiation resistance).
The design of such cables has been done to meet double insulation requirements based on ECSS standard ECSS-Q-ST-70-12C that was issued for flexible PCB but can be applicable a for a large number of requirements to FFC cables. From this observation, it is clear that a generic specification (ESCC) for flat cables is missing.

- For power application we started with a cable part number P584261 with 8 conductors of section 3.5x0.21 mm=0.735 mm², pitch 6 mm as described in the following specification Fig. 2:

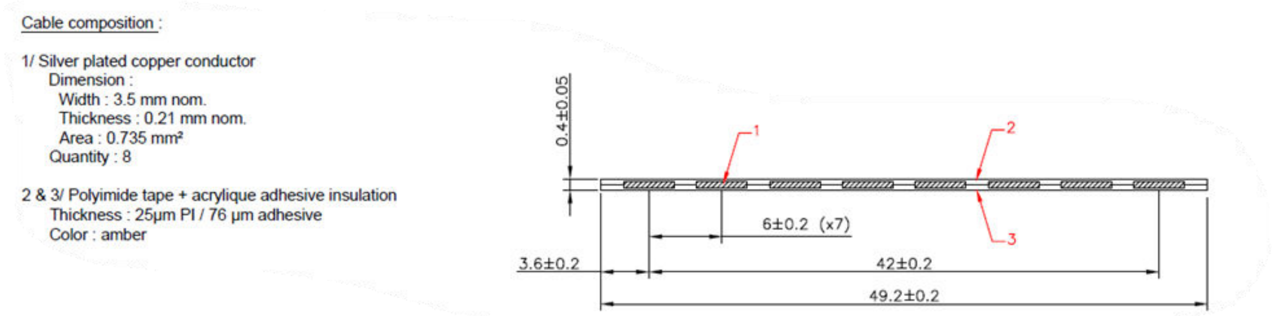


Fig. 2: Power flat cable 8 conductors each close to AWG18

For signal application we started with P584262 with 20 conductors of section 1.00x0.12 mm=0.12 mm² as described in the following specification Fig. 3:

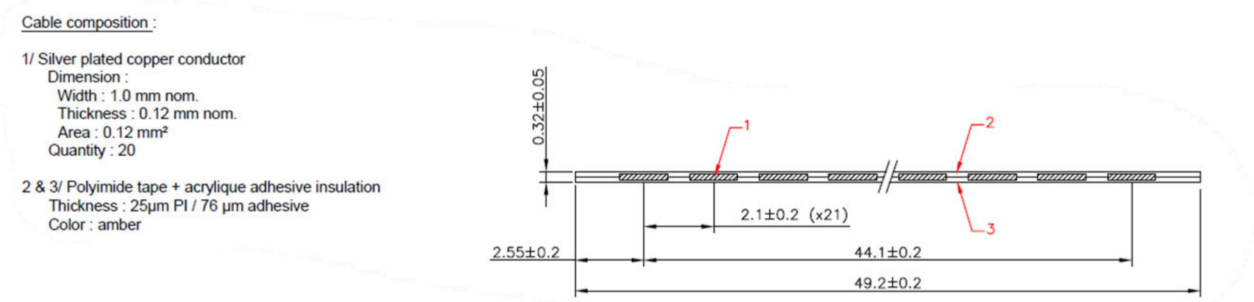


Fig. 3: Signal flat cable 20 conductors each close to AWG26

3.2) PCB connector design

The idea is to have a connector that allows the flat cable to be easily installed or removed without any tools. The pre-stripped cable is inserted directly onto the connector mounted on the equipment PCB (cabling without a connector to save on an interface).
The flat connection of the cable in the connector must have zero insertion force. A force applied by the closing piece part during closing achieves the connection of all the contacts of the connector to the tracks of the FFC.

3.2.1) Power and signals contacts design.

The contacts must allow flat cables to be inserted without force or stress, in accordance with the ZIF "zero insertion force" connector principle.
For the power, we chose a cut-out contact folded into a “clamp shape” to ensure electrical contact on the two sides of the FFC conductors while limiting forces. Numerous calculations were required to determine the material and its condition, as well as the shape and thickness of the contact (see Fig. 4 & 5).

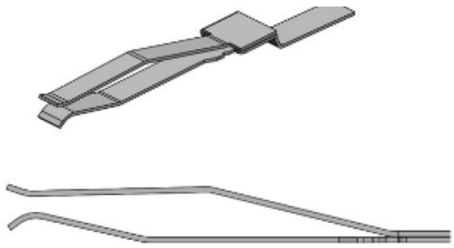


Fig. 4: Final design of the power contact after optimisation coming from mechanical calculations.

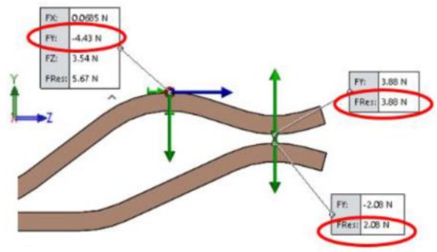


Fig. 5: Calculation of forces and optimisation of the shape, thickness and material state of the contact.

For signals, we chose a cut-out contact folded into a clamp shape to ensure contact while limiting forces. Numerous calculations were required to determine the material and its condition, as well as the shape and thickness of the contact (see Fig. 6 & 7).

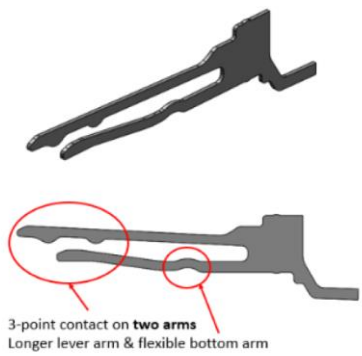


Fig. 6: Final design of the Signal contact after optimisation coming from mechanical calculations: 3 points of connection to secure the electrical contact.

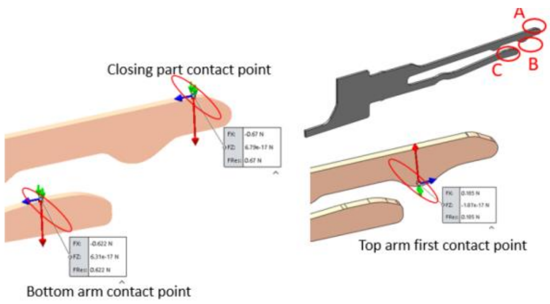


Fig. 7: Calculation of forces and optimisation of the shape, thickness and material state of the contact.

3.2.2) Power and signals connectors design

PCB connector, for both power and signal variant, is built from following components illustrated in Fig. 8:
- Contacts: used to transmit signal from FFC cable conductor to PCB
- Housing: used for positioning and insulation of FFC cable and contacts
- Closing part or slider: used both to secure the FFC cable once put in place, and to apply pressure to the contacts
- Protective cover: late add-on to protect exposed contact area for PCB soldering
- Fixation / brazing pads: used for mechanical fixation of the connector on the PCB.

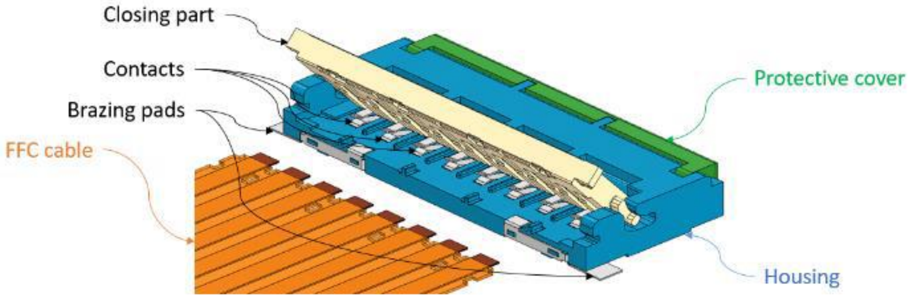


Fig. 8

In accordance with the cables defined in §3.1, the connectors have been designed to accommodate 8 power supply tracks for a copper cross-section close to AWG 18 and 20 tracks for a cross-section close to AWG 26 as shown in Fig. 9

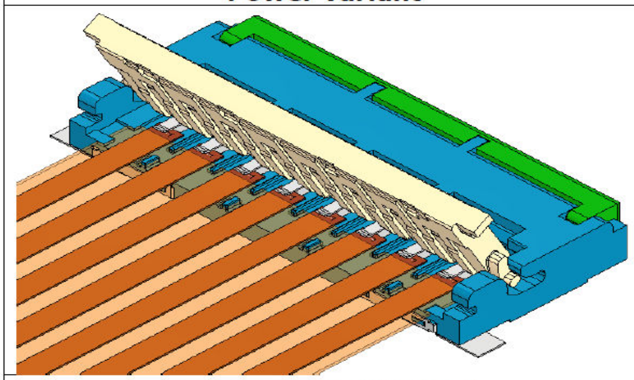
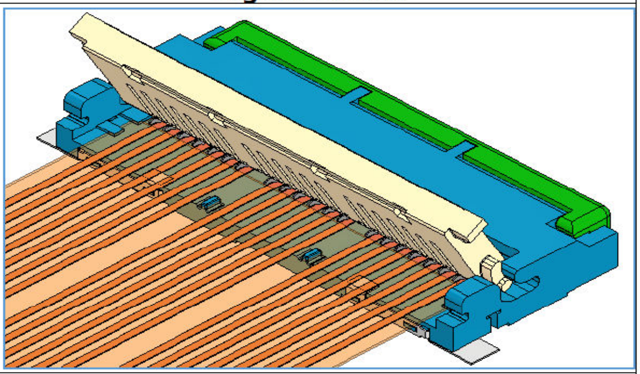
Power variant	Signal variant
	
Number of conductors: 8	Number of conductors: 20

Fig. 9

3.2.3) Locking design.

Locking principle is the same for power and signal variant, and can be described as following:

STEP 1

- Closing part (Slider) open
- Cable insertion

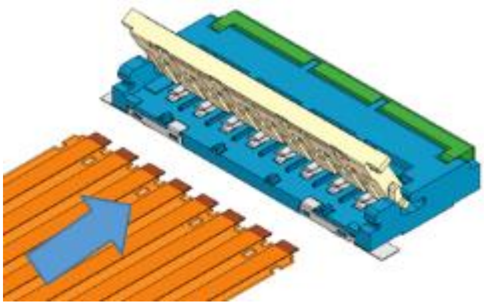


Fig. 10

STEP 2

- Cable inserted
- Slider rotated downwards
- Progressive pressure applied on contacts

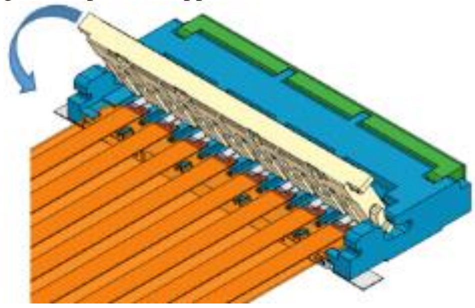


Fig. 11

STEP 3

- Slider in contact with cable
- To be pushed backwards to lock the connector

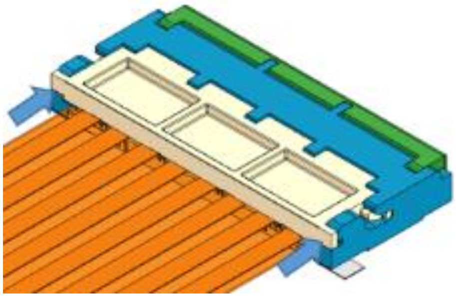


Fig. 12

STEP 4

- Connection complete, connector locked

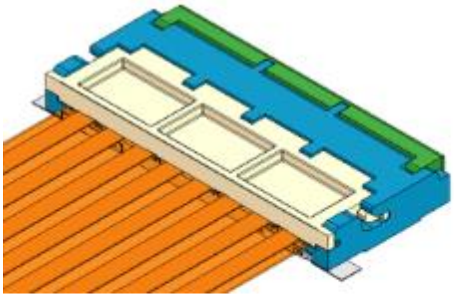


Fig. 13.

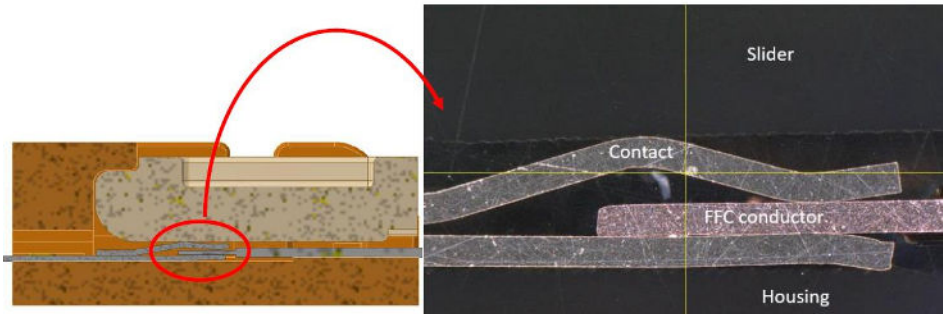


Fig. 14: Microsection of power contact closed on FFC conductor

3.2.4) Raw materials:

Housing is made by LCP polymer. LCP: "Liquid Crystal Polymer" is a high-performance crystalline, thermotropic (melt-orienting) thermoplastic that can deliver exceptionally precise and stable dimensions, high temperature performance and chemical resistance in very thin-walled applications.

Contacts and pads are in gold plated Beryllium copper.

3.2.5) Mechanical retention

The number of cut edges and retention ears was obtained during a series of experimental trials in which we tested several different configurations.

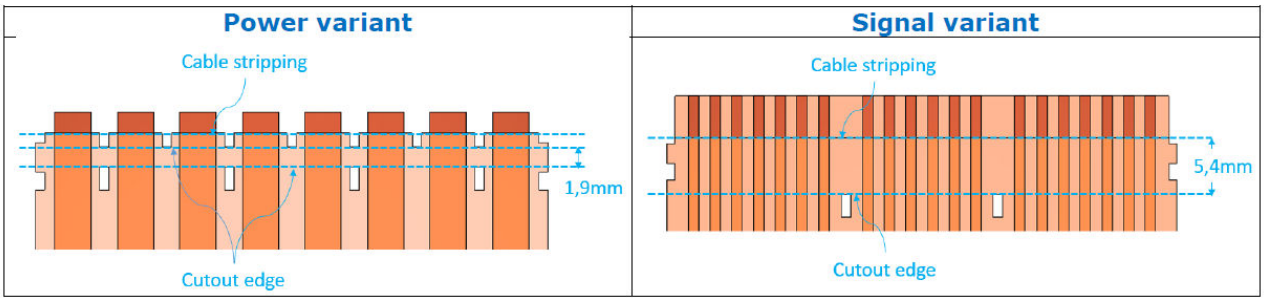


Fig. 15: Preparation of FFC cables using stamped process or laser stripping.

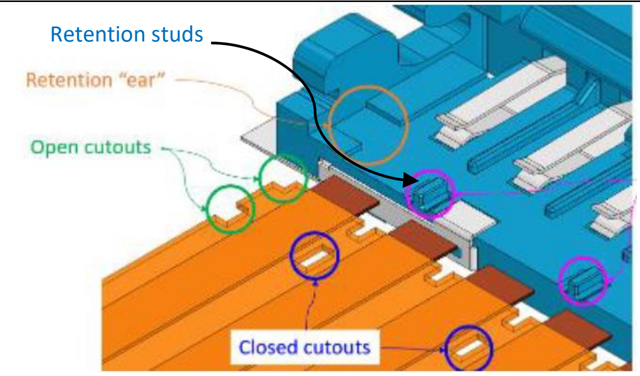


Fig. 16: Retentions studs on the connectors. Open ears and cutouts on the flat cable.

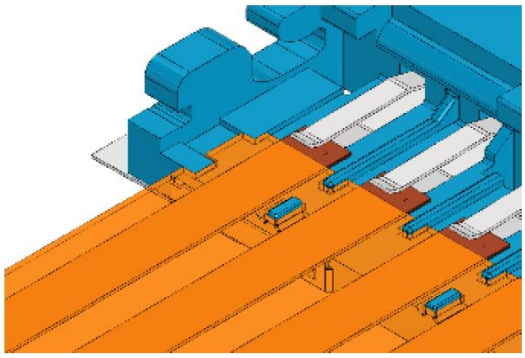


Fig. 17: Retention studs inserted in the FFC in the cutouts windows.

3.2.6) EMI protection.

Shielding is also considered to be optional on this connector.
When needed, shield folded parts can be added to cover the connector housing and the closing part.
These shield parts are bonded to the PCB ground by extra soldering pads. On FFC side, connection fingers allow electrical contacts between PCB shield and connector shell.
To allow connector fixation on PCB in case we were not using shielding, soldering pads are present and mechanically secured on the housing.

On Fig. 18:
Rep.1: pad placed each side on housing shield – for both connector fixation and top shielding termination.
Rep.2: extra pad is located on each side of the housing for mechanical fixation.
Rep.3: Connection fingers

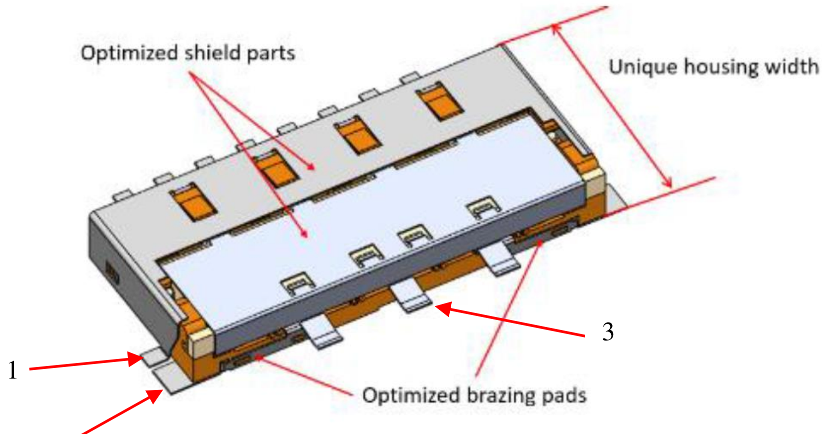


Fig. 18

3.2.7) Double insulation.

This section will detail dispositions implemented to both signal and power connectors to make insulation as reliable as possible at connector's level. Insulation barriers/walls have been set at connector interface to avoid any direct access between conductors after cable installation. Looking from the side cut view, connector is also fitted with different shapes to prevent any direct access to contacts once locking part is closed. Those insulation barriers are fitted between closing part and connector housing as illustrated in Fig. 19 & 20.

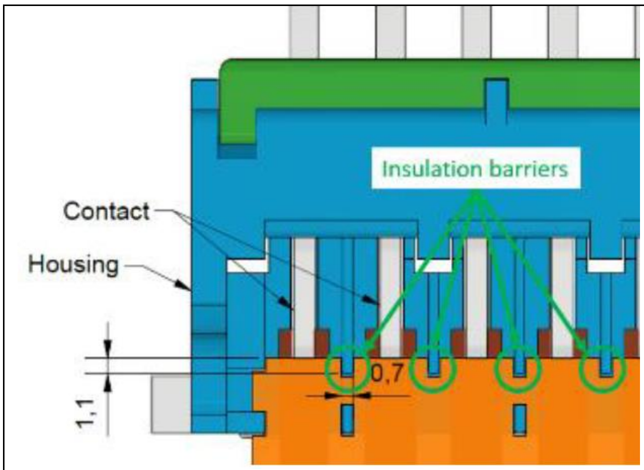


Fig. 19: View with locking part removed: Walls used as insulation barriers are present from the top to the rear of the cavity to keep insulation between contacts.

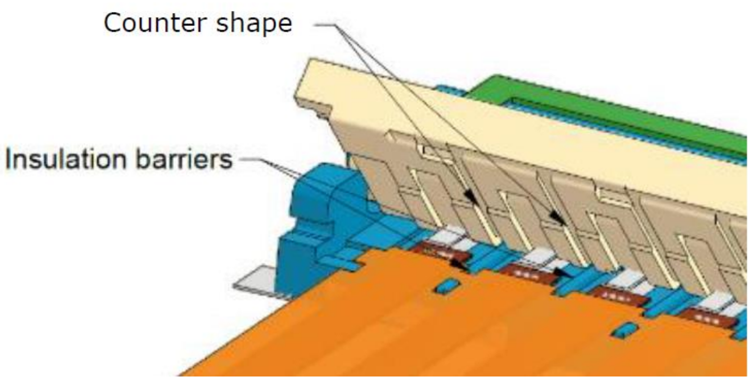


Fig. 20: View with locking part closed: Counter shapes are present on the bottom side of the locking part, to avoid any direct access between contacts once locking part is closed.

To improve insulation at soldered joints area, we designed a dedicated closing part. This device is open during soldering, cleaning and inspection phases and finally closed to protect and isolate the connector terminations.

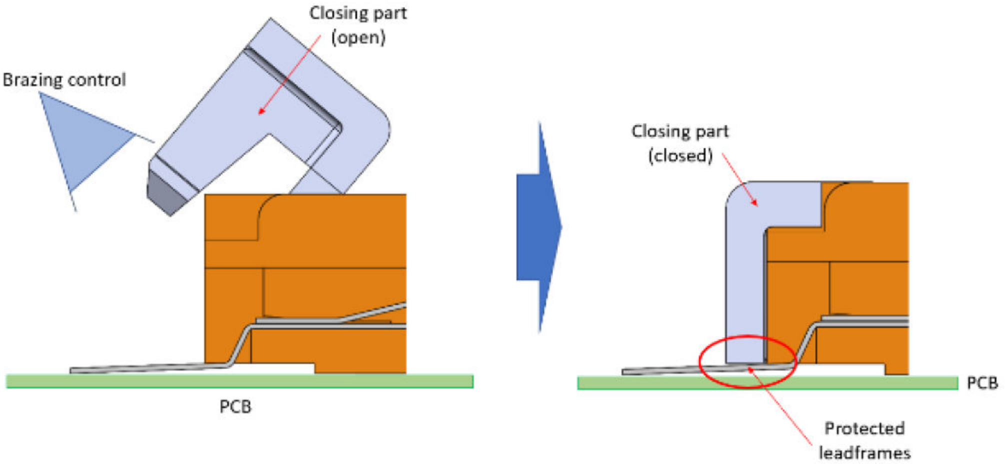


Fig. 21

3.3) Equipment connector

Equipment panel feed-through connectors for power and signals have been designed with the same ZIF interface for flat cables.
The idea is to have a panel connector with the following functions:
- Outside of the equipment, a shielded ZIF interface bonded to the chassis of the equipment.
- Inside of the equipment, an unshielded ZIF interface.

Fig. 22 described the designed solution for power and Fig. 23 for signal application.

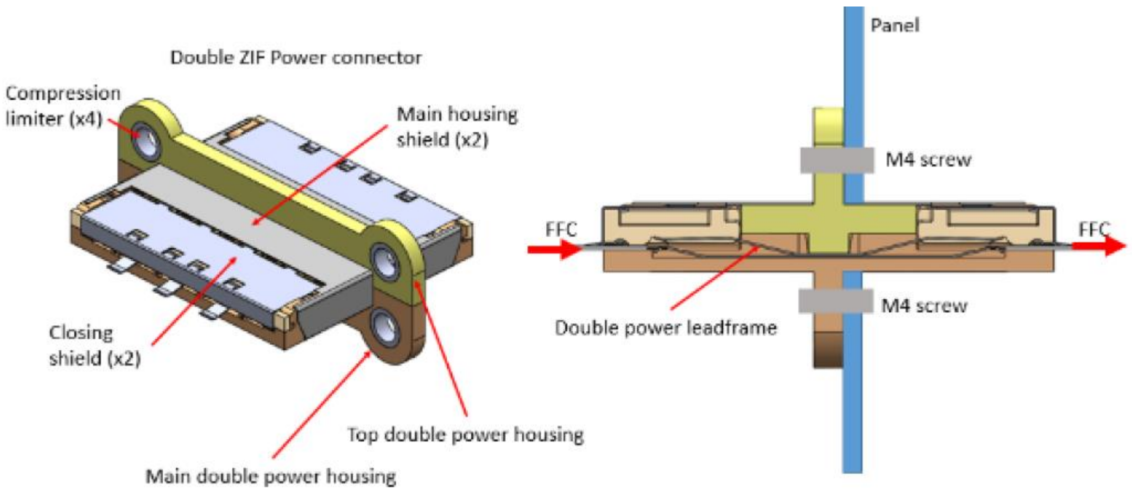


Fig. 22

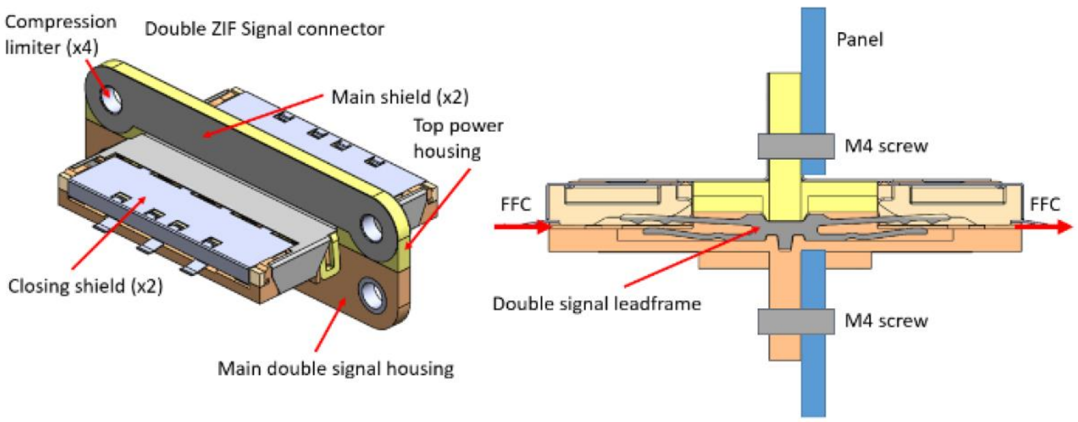


Fig. 23

Same principle is kept for contact design and duplicated to offer two interfaces as shown in Fig. 24 for signal and in Fig. 25 for power.

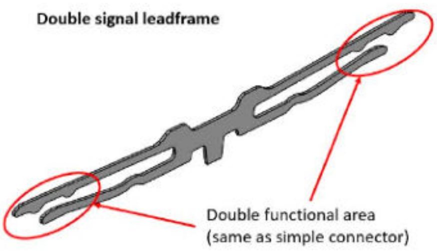


Fig. 24: Signal contact for panel feedthrough connector variant.

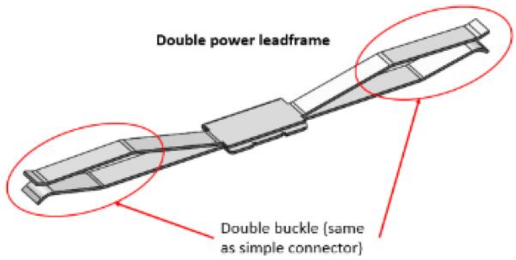


Fig. 25: Power contact for panel feedthrough connector variant.

4.) PREMILINARY RESULTS

4.1) First prototypes

Fig. 26 is a picture of the two prototypes (power connector on the left and signal connector on the right) made with 3D printing with a good surface finish (Epoxy Powder + LASER technology) and compatible with standard soldering process.
Contacts and pads are made with beryllium copper made by chemical machining process.
These connectors are soldered on PCB test jig using SMT style termination (manual iron soft soldering process) see Fig. 27 for pictures.

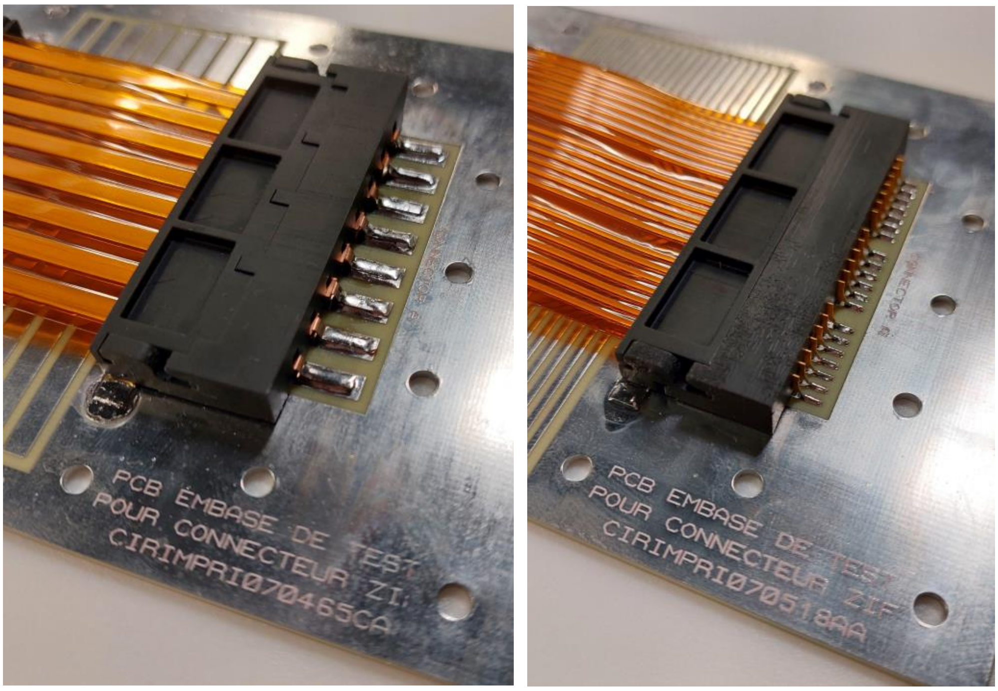


Fig. 26: From left to right, power and signal connector’s prototypes

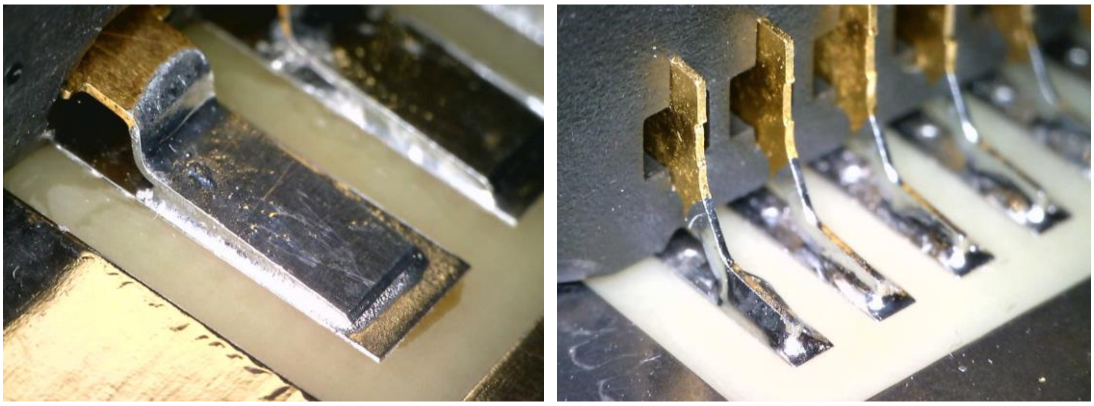


Fig. 27: From left to right, power and signal contacts terminations at soldering area (magnified)

4.2) Mechanical Results: Pull tests

We performed initial pull test measurements on representative prototype with the final retention shapes made with machined PEEK. Based on this design we passed the following pull test limits with margin:

	pull force (N)
Power variant	>120 N
Signal variant	>75 N

4.3) Electrical results

Even though the body parts and contacts are not made from the final materials and the shapes are still slightly to be optimized, we have carried out preliminary measurements on the prototypes.

Contact resistance shows values <20 mΩ for Signal connector and <10 mΩ for Power connector.

Concerning electrical insulation and Dielectric Withstanding Voltage (DWV), measurements results are:
For Signal connector

- >30 GΩ with 500 V_{DC}*
- >2000 V_{RMS} with threshold current of 0.5 mA

For Power

- >30GΩ with 500V_{DC}*
- >3000 V_{RMS} with threshold current of 0.5 mA

The Table 2 summarizes the measurements:

	Contact resistance With 1 A test current	Insulation resistance with 500 Vdc test voltage	Dielectric Withstanding Voltage with threshold current of 0.5 mA
Signal connector	<20 mΩ	>30 GΩ *	>2000 V_{RMS}
Power connector	<10 mΩ	>30 GΩ *	>3000 V_{RMS}

Table 2: Results of continuity & insulation behaviour of signal & power prototype connector.

ECSS-Q-ST-12-C ask the following values: Insulation resistance >10E10 Ω (10 GΩ) and DWV >1000 V_{RMS}/mm for track to track. - *maximum measurement range of the equipment.

5.) CONCLUSION

This article presents the development work carried out by axon as part of an ESA TDE to propose new solutions for making highly flexible electrical connections in satellites based on the use of flexible flat cables. This study mainly concerns the development of innovative technologies for connecting these flat cables directly to PCBs or equipment, for both power and weak signals. Some optimizations and improvements had to be taken into account in the design after feedback from development tests and assembly trials by operators. But the results are encouraging and it is clear that this design will be robust and reliable enough for the space sector.
The design phase is currently nearing completion and we have scheduled the Critical Design Review for Q4 2024. After that, Axon will produce evaluation prototypes and carry out all the necessary tests to prove that these technologies from the automotive and industrial sectors can be used, with certain modifications, in the space sector.