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ATHENA/X-IFU: DCS Cryostat Harness baseline design and road map test

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Abstract

In the framework of the ATHENA ESA mission, a Core Technology Program (CTP) was started to build a flight like cryostat demonstrator in parallel with the phase A studies of the ATHENA X-IFU instrument. As part of the CTP, called the Detector Cooling System (DCS), design, manufacturing and test of a cryostat including existing space coolers will be done based on European technologies. Critical point of this cryostat is the cryogenic harnesses that links the FPA and subkcooler at 2K to the WFEE at 300K. Through this paper, we present briefly the current baseline design and the roadmap tests.

1. Introduction

The Detector Cooling System (DCS) is a project developed under an ESA contract with three main objectives:

- To design a DCS compatible with the instrument X-IFU detection goals and based on European technologies.
- To test the functional and thermal aspects of the cooling chain and the cryostat.
- To determine the performances of the Focal Plane Assembly (FPA)-DM / DCS assembly, mainly in relation with the detection chain/detector sensibility, microvibration sensibility and characterize the EMI/EMC behavior.

Two main assemblies compose the DCS: the Cryostat and the Focal Plane Assembly (FPA), a demonstrator using Transition Edge Sensors (TES) detector technology. The Cryostat is in charge to protect and maintain the operating cryo-conditions of the FPA. A dedicated activity within this CTP-DCS is the demonstration of the 300K–50mK cooling chain in a Ground System Equipment (GSE) cryostat.
The Cryostat has a subassembly, which is the thermal shield and set of active and passive coolers in charge of maintain the cryo-conditions inside the Cryostat.

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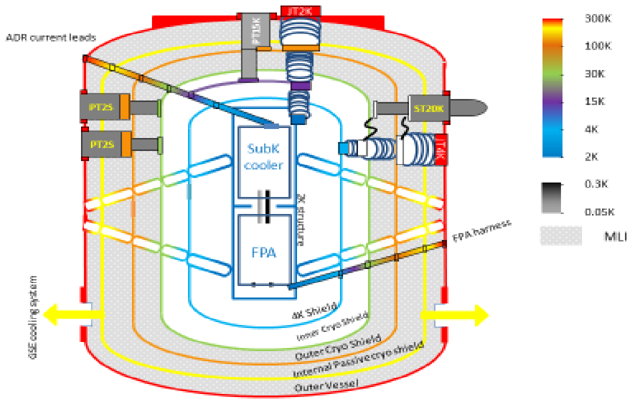

Figure 1 DCS Cryochain

A critical point on the design of the cryostat is the cryogenic cable harness linking the FPA at 2 K to the WFEE (warm from ends electronics) at 300 K and the house keeping harness between the SubKelvin cooler and the vacuum vessel feedthrough.

For all of them, the most critical is FPA harnesses due to the following reasons:

- A large number of wires (order of magnitude 400-500 pairs, i.e. 3-4 pairs per FDM channel include ground/return lines + additional pairs for the CryoAC readout, 50 mK thermistors, heaters, and magnetic field coils) without intermediate connections.
- Low cross-talk between signal pairs to meet both the inter- and intra-channel cross-talk requirements.
- Strong EMC requirements. Therefore, some corrugated tubes (tombacs) to cover the harness are required for isolation.
- Minimum thermal losses through this harness: gauge of the wire shall be greater than 34, and thermalization points of this harness at each thermal stage are required.
- Integration. The 2 K stage, end of the FPA harnesses should be demountable (i.e. with a connector interface) to facilitate its integration and eventual reworking. Housing is consisting of a PCB connected to the associated harness, a PCB connected to the associated flex to FPA, one or two interposers, and some screws to ensure the holding of the assembly.

Among all the constraints of the cryostat harness design, several factors should be taken into account: lack of volume (there are limitation in the allocated volume), all the harnesses should be inside a Faraday cage, using of materials for cryogenics conditions, minimize weight, implementation of some redundant lines, vacuum conditions, integration constrains…all this different requirements should be met in order to fulfil the goals of the DCS demonstrator

2 DCS Harness design description

2.1 DCS Harness layout

DCS harness will be composed of several harnesses and interfaces:

1. Three harnesses for FPA
   - Two for signals and FPA HK between the external IF boxes and the EGSEs.
   - One harness for the AC (cryogenic anticoincidence detector) signals and AC HK between the external IF boxes and the EGSEs.

   These harness will be called **Tombac A**, **Tombac B** and **Tombac C** respectively.
2. Harness for the ADR subK cooler (**Tombac D**) and **ADR coil**.
3. Harness for the cryostat HK. (**HK harness**).

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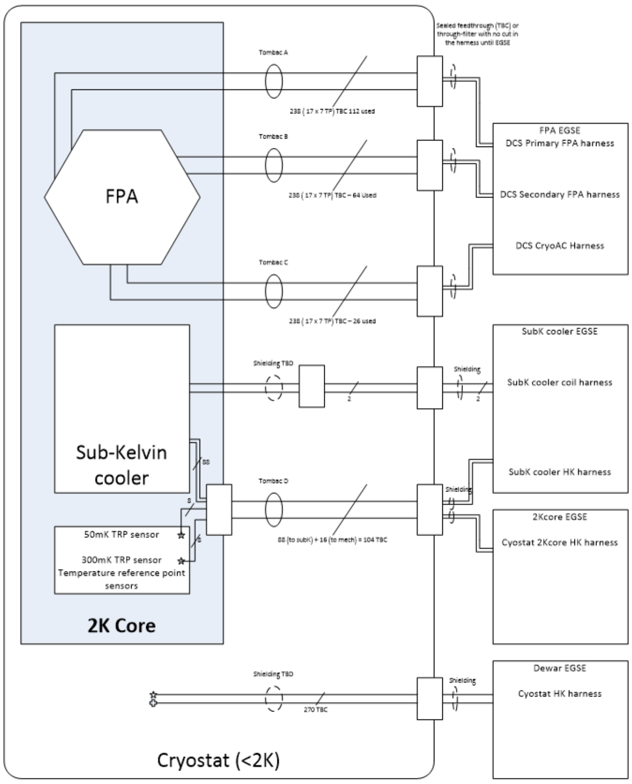

Figure 2 Cryoharness synoptic

2.2 FPA Harness: Tombac A, Tomac B and Tombac C

2.2.1 Tombac design description

To avoid high frequency perturbations, the use of a tombac (corrugated tube) for the most sensitive cold harnesses is required. These tombacs should be electrically connected to the structure at both ends, on the FPA housings and on EGSEs.
The tombac is a stainless steel corrugated tube with an external diameter of at least 200 microns thickness. That thickness is the necessary to perform a good shielding of the harness and avoid frequency perturbations.

In the initial trade off of the tombac design and manufacturing, three different options are being investigated:

Table 1 Tombac options

Heat trace hose (180 µm)	**Vacuum bellow**	**Heat trace hose (300µm)**
 Figure 3 Heat Trace Hose 180 µm	 Figure 4 Vacuum Bellow	 Figure 5 Heat Trace Hose 300 µm
✓ weight No 200 µm	✓ thickness Bad Integration	✓ thickness ↑ Weight
✓ volume	✓ volume	✓ integration ↑ Volume
✓ integration	✓ weight	

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Option 1 Heat trace hose (180 µm): this option is the preferred one in terms on weight, volume, integration issues but it has 180 microns, so it does not have the required thickness for shielding. If this is the final solution EMC shielding test should be performed.

Option 2 Vacuum Bellow: This option is a good compromise between thickness, weight and volume, but as it does not stay in a predefined position, this corrugated tube could bring integration problems. One solution for that, an in order to maintain the harness in a defined position is to have some parts with a non-corrugated tube solded to the tombac part. That option could have some impact in the heat conductivity.

Option 3: this possible solution would allow to fulfil the integration issues and thickness requirements but have a big impact on the weight and in the allocated volume required.

For all the options, inside this tube the wires shall be maintained in a relative position to avoid movement in the tube and also movement relative to each other. This issues could cause microphony and triboelectricity effects which could modify the electrical characteristics of the lines. The shielding efficiency of the tombac overshield shall be at least 100dB from 30MHz up to 18GHz.

Finally, the solution adopted will be mainly focused in terms of integration aspects, critical bending radius are foreseen and the lack of space are the main drivers in the Tombac selection more than EMC shielding constrains.

2.2.2 Loom description

A loom is a set of N twisted pairs harness arranged in a flat braided packaging. A technical solution is already available and provided by the company “Tekdata” and regularly used by SRON as some of those products are qualified for cryogenic usage in space applications.
The main downside of this technology is that while shielded twisted pairs are possible to implement, they are incompatible with the vacuum tightness requirements at the feedthrough. To create a shielding ersatz guard lines are used, they offer a partial shielding in some directions.
On the figure below is depicted a 12-pair loom. Each pair is twisted separately and assembled into a ribbon with the help of the white fabric.
A pair is composed of two single 38AWG wires that are isolated with a thin enamel layer.

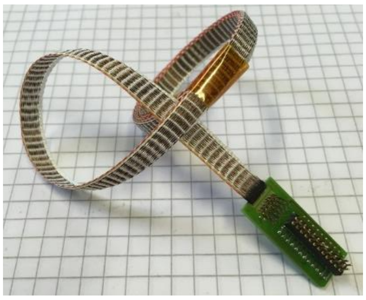

Figure 6 Loom

For the FPA harness, the packing philosophy is using 12 twisted pair looms. Each tombac has 12 looms grouped in 4 groups.
As differential signaling is used, a signal uses 2 or 4 wires, thermometer readings are 4 wires, heater lines use 2 wires and coil power lines use 4 wires (to help with joule losses).
To create separate shielding zones, the harness is sub-divided into 4: the two channels have their own simili-360° shielding and the thermistor/heater/coil lines are spatially separated. This is seen on the example below as loom 1 and 3 forming the top and bottom “shielding” of channel 1 housed on looms 2.

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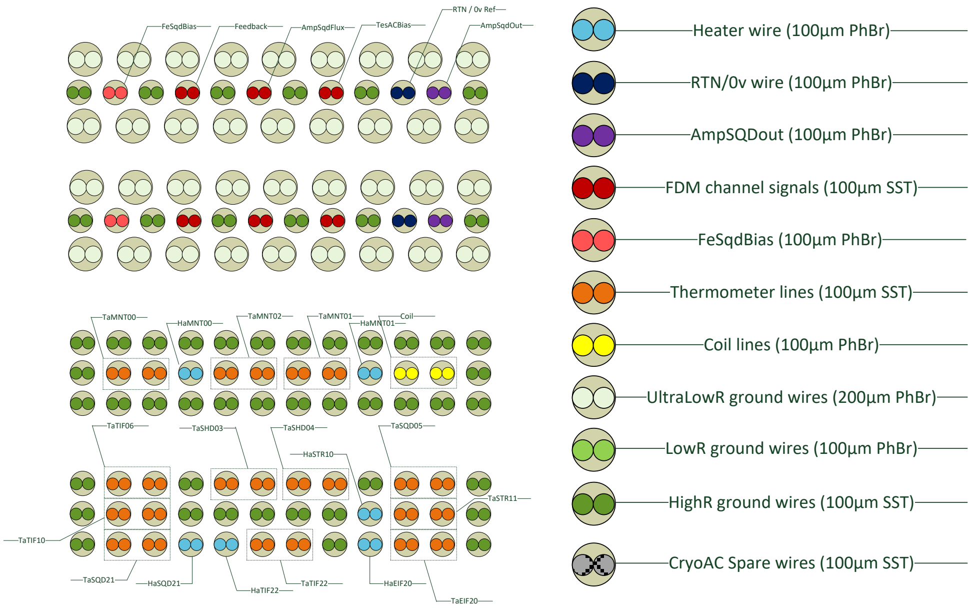

Figure 7 Tombac A loom layout

As it can be seen 264 lines are for tombac A. Most of them are ground lines that are used rounding as shielding the signal lines.
On figure 6:

- Green wires are connected to ground.
- Red are FPA inputs, pink is FPA output, dark blue is FPA zero volt reference line ($\neq$ GND)
- Orange are thermometer polarization and readout lines
- Light blue are heater lines
- Yellow is the coil

To avoid microphony effects every three looms are hand stitch between them:

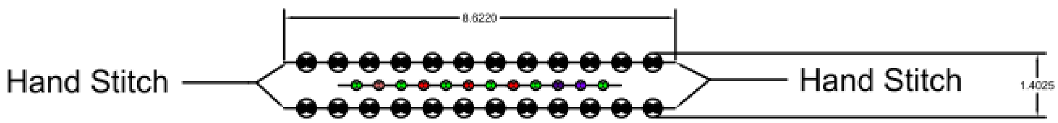

Figure 8 Group of 3 looms hand stich

Oher relevant characteristic of these looms is the material that are used in every line, stainless steel (SS) or phosphor-bronze (PhBr), the material depends if the line is low or high ohmic.

In the complete configuration, there will be for one over shielded harness:

- One TOMBAC overshield
- 144 (12 times 12 pairs looms) twisted pairs

Hence two stages of shielding will be implemented whenever possible: extra pairs grounded at each end serve as shield lines (thought to deal with lower frequencies and protection versus crosstalk), the TOMBAC over shield (protection versus high-frequency E-field f>10MHz).

Looms from tombac B and tombac C are defined in a similar way:

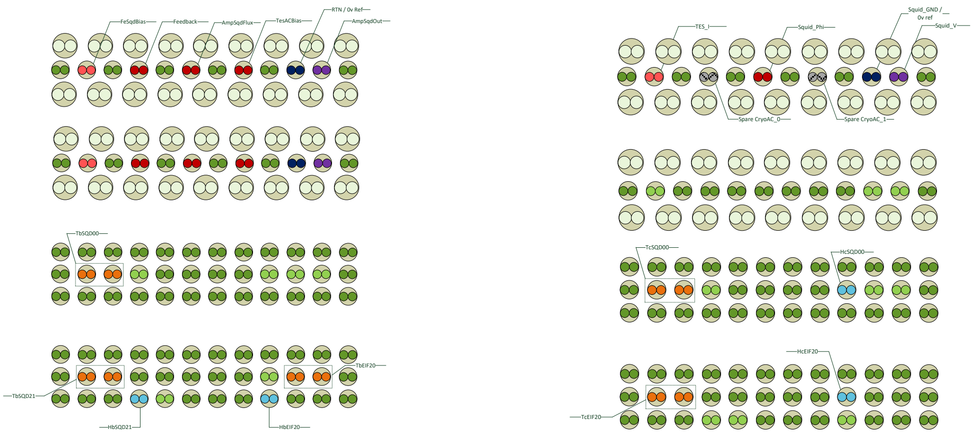

Figure 9 Tombac B (left) and C (right) layouts

2.2.3 Cold I/F

One of the main design parameters of the FPA harness is to minimize the crosstalk effects. Connectors remove the twisting of the pairs and therefore make the readout sensitive to crosstalk. At the same time connectors introduce unbalances to the readout circuit, which might lead to crosstalk issues as well (as more common mode current can flow). That is why connectors should be avoided as much as possible in the FPA harness design.
However, typically it cannot be avoided all connectors from mechanical/AIV/wire mapping constraints so this is the reason that some I/F connectors should be in the cold FPA I/F and in the warm electronics I/F outside DCS.
The cold FPA connection is made via a PCB and an interposer.

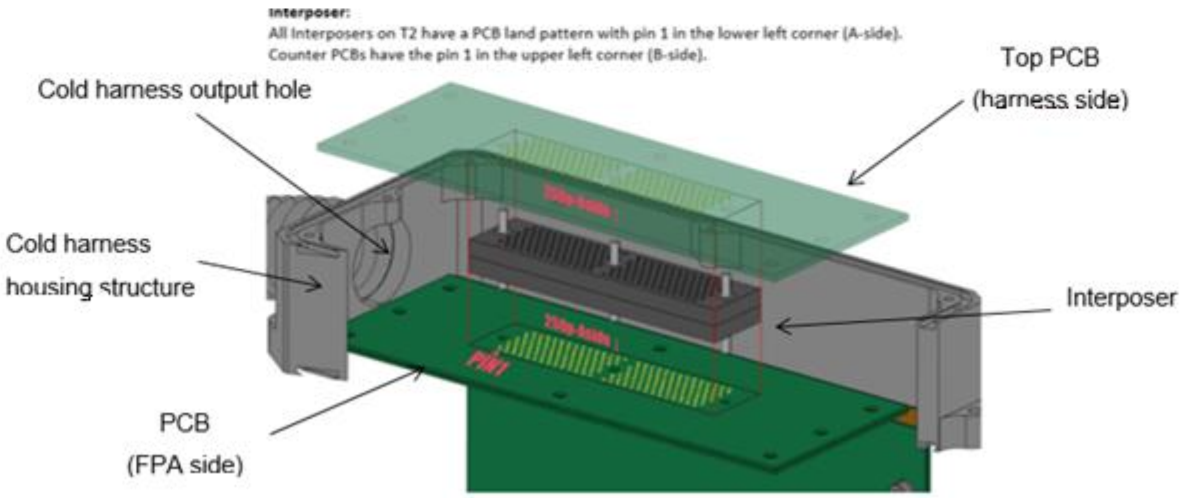

Figure 10 Cold I/F

The FPA looms would be soldered in a PCB, like done in Figure 6. This PCB would be connected to other PCB via an interposer.

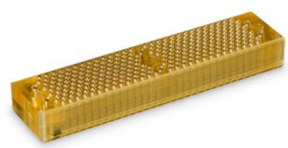

Figure 11 Interposer

The interposer connector provides a very large density of pins so it is rather efficient in volume/area. Other positive points for using an interposer are related to crosstalk (connector height vs pin pitch) and flight representativeness. The

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spring contacts solve some differences in thermal contraction. The material selected is matched as much as possible to the polyimide PCB.

2.2.4 Warm I/F

In order to minimize the number of connexions a feedthrough with no connectors is used. The philosophy can be seen in the next figure:

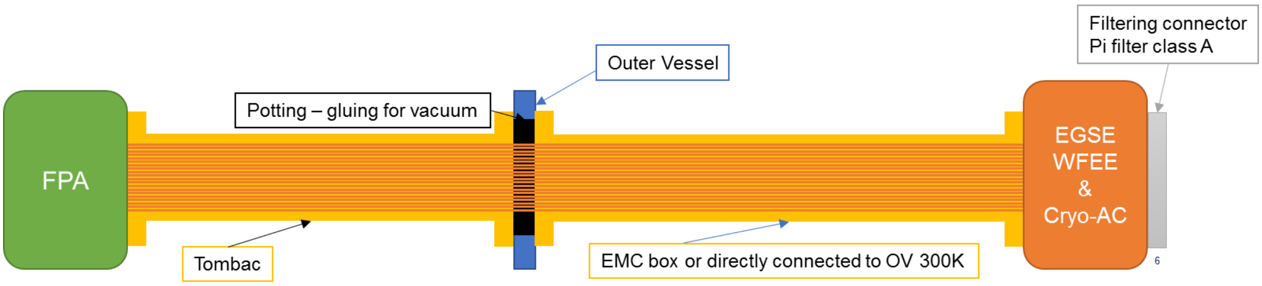

Figure 12 FPA Warm I/F

This feedthrough should assure:

- Maintaining signal integrity.
- Maintaining the hermeticity of the cryostat against the atmospheric pressure.
- Ensure that the faraday cage remains closed and clean.

The feedthrough design is using a potting like the one in the following picture:

Figure 13 Potting feedthrough

The current design of the feedthrough for the 12 looms (4 groups of three looms) can be seen below:

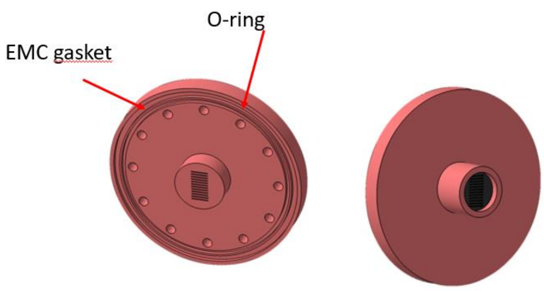

Figure 14 Warm FPA I/F feedthroughs

The manufacturing process of the feedthroughs has to be validate prior DCS integration. The main parameters that has to be controlled during the process are the following:

- Surface impregnated by the glue, check different glues (stycast…); prior the glue: nusil should be applied.
- Eliminate the bubble formation.
- Time to cure.

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To integrate the looms in the feedthrough, looms has to be separated from the handmade stitch. Some of the enamel parts has also to be removed in order to guarantee that the glue impregnates all the wires and there are no any empty spaces that could cause bubbles formation.
To check that the feedthrough fulfil their requirements vacuum test should be performed in a vacuum chamber and with a leak detector.

The warm connexion between the looms and the outside electronics (an intermediate PCB to route all the signals inside the electronics, EGSE WFEE) is performed via a Fischer connector (see Figure 6).

2.2.5 FPA Harness thermalizations

In order to be able to guarantee that in every step of the cooling chain the target temperature is reached and there are no thermal loses, all the harnesses that goes from the 2K core to the 300 outer vessel of the cryostat has to be routed and thermalized along the different shields that forms the cryostat. The thermalizations would be performed at 4k, 15k, 30k and 100k.

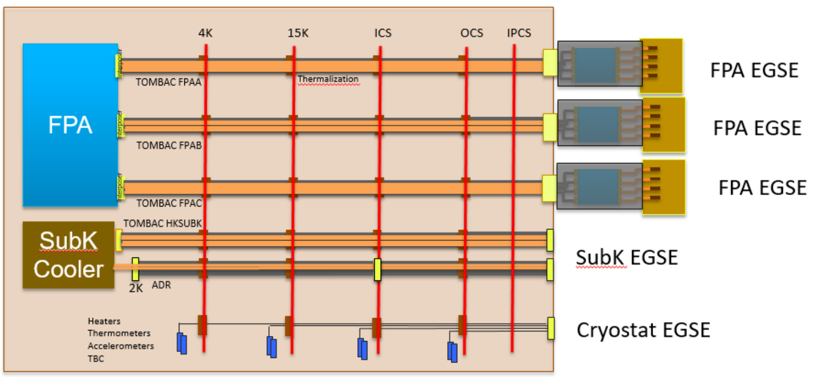

Figure 15 Harness configuration

The thermalizations must ensure the harness continuity, the Faraday cage and provide enough length to have a uniform temperature range.
The baseline design of the FPA harness thermalization would be to stack the 12 looms in groups of 3 looms, so the hand stitch is not removed.
To have the best thermal contact the looms have to be glued:

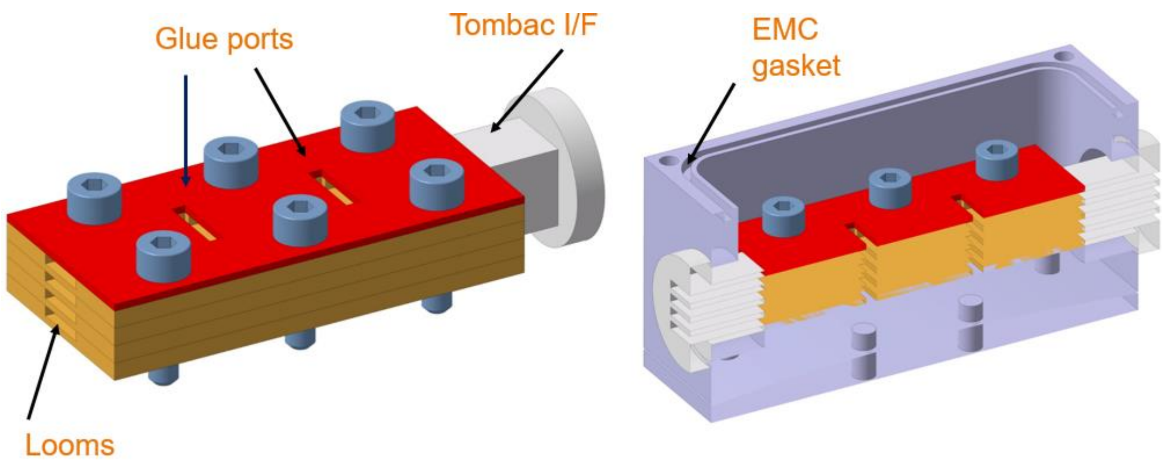

Figure 16 FPA Thermalization concept

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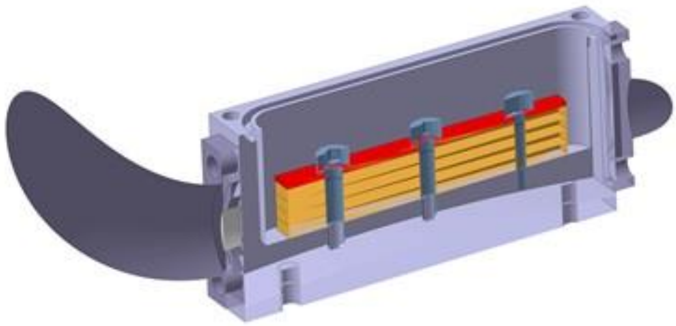

Figure 17 Thermalization and Tombac view.

2.2.6 FPA Harness integration

The FPA harness integration is driven by the following parameters:

- Continuous looms are required from 2K to 300K (they cannot be cut).
- In the cold end the looms are soldered into a PCB that connects to an interposer.
- Tombacs and thermalizations need to be integrated in the middle of the looms.
- To go through the outer vessel a potting feedthrough is needed: Looms need to be impregnated with potting in a metallic feedthrough.

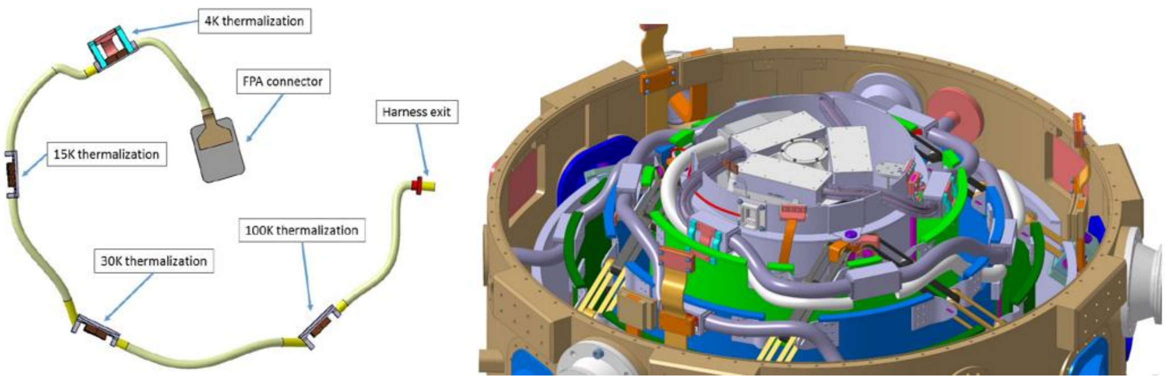

Figure 18 FPA Harness, Tombac A, B or C (left) and harness integration in the DCS.

Different integrations options have been considered:

Table 2 FPA harness integration trade off.

From the cold to the warm side:		From the outside to the cold side:		From the outside to the cold side and modifying the FPA box:	
✓ Easy soldering	Difficult in the feedthrough potting and manufacturing process	✓ Easy feedthrough potting	Bad PCB soldering, no space	✓ Easy feedthrough potting ✓ Easy soldering	FPA box to be modified, check Farady cage design

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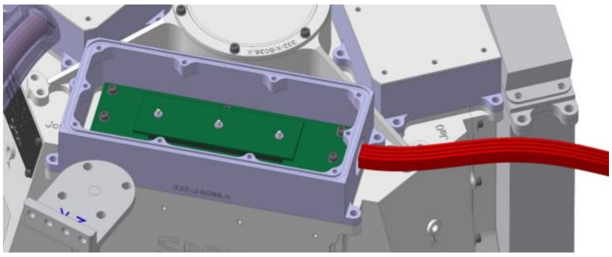
Figure 19 view of the FPA box and PCB

Finally, the main driver for the integration is the feedtroughs manufacturing process. The I/F box will be redesign in order to allow easily integration of the PCB with the looms soldered.

2.3 Tombac D

This harness goes from the Subkcooler to the Subk EGSE. It is composed by 5 different looms and surrounded by the same Tombac as the previous ones.
As some of the signals requires an extra shielding, the looms are manufactured as explained in the next picture:

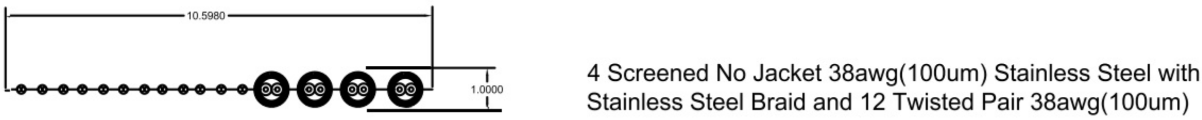

Figure 20 Shielded loom for Tombac D

Looms configuration for Tombac D are the following:

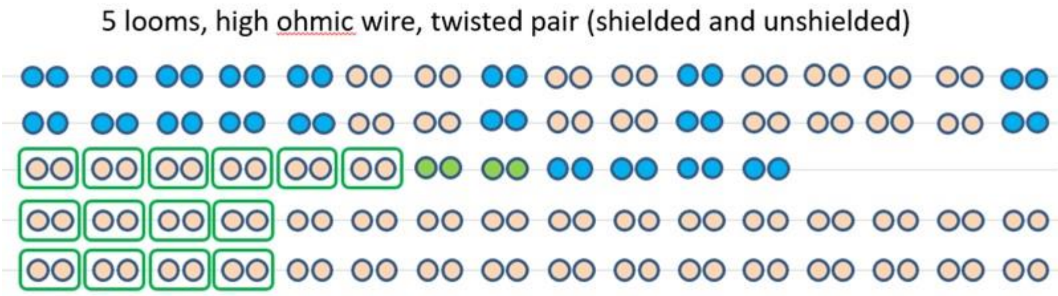

Figure 21Tombac D loom configuration Upper ones with no shielding

These looms have also thermalizations at the same points (4k, 15k, 30k and 100k). In this harness connectors are allowed, therefore Micro D connectors (3x31 pins and 2x37pins) are used in the cold and warm I/F.

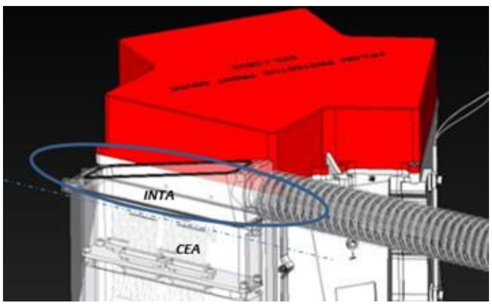

Figure 22 Cold Tombac D Interface 1

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Figure 23 Cold Tombac D Interface 2

For the warm I/F a socket to socket hermetic feedthrough connector has been design, this solution is much better in terms of integration constraints.

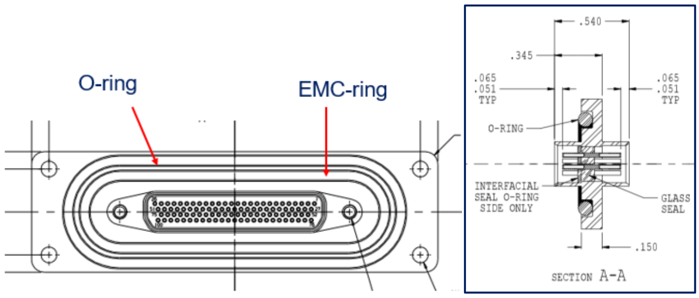

Figure 24 Tombac D Feedthrough 1

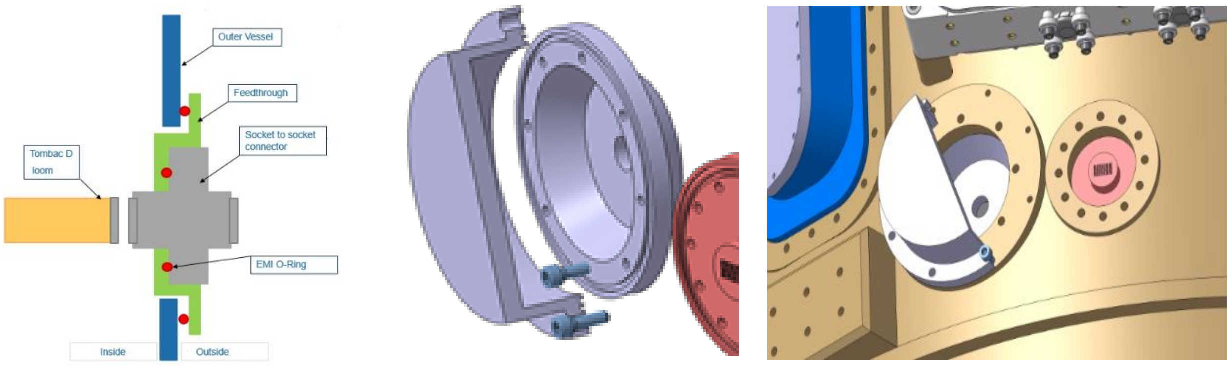

Figure 25 Tombac D Feedtrough 2

The solution presented ensures the Faraday cage required and the vacuum conditions and the soldering/crimping of the connectors before the integration in the DCS.

2.4 ADR Coil harness

This harness connect the ADR subkcooler with the outer cooler warm electronics box. The main functionality of this harness is to provide power to the ADR coils. A total of 2 Amps of current is required for this harness so in order not to have a big Joule Thomson loses a connector that also is a thermalization is used.
This harness is divided in two parts:

- From 2K to 30 K, superconductive, made of MgB2
- From 30k to 300K, made of PhBr

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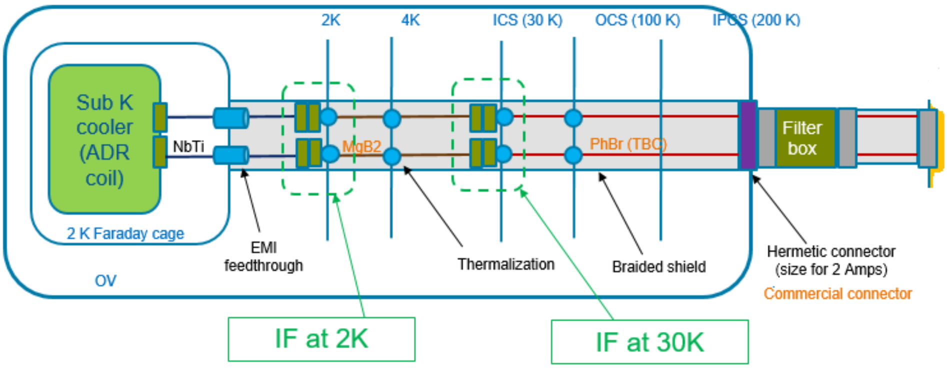

Figure 26 Schematic of ADR coil harness

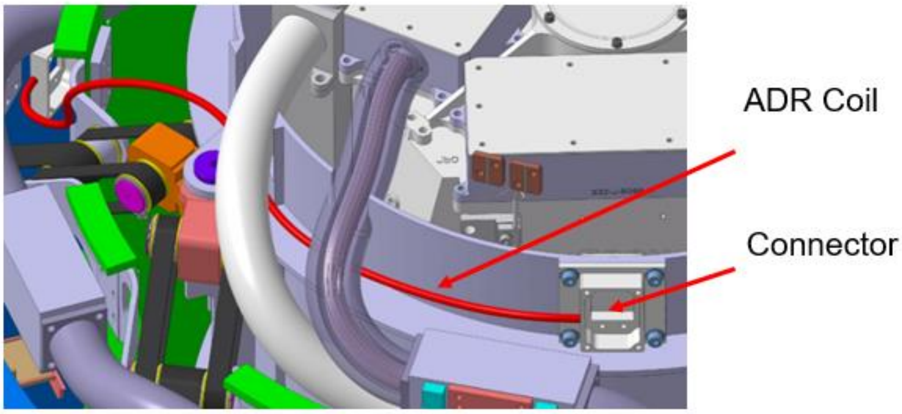

Figure 27 ADR coil harness routing and connector

The main design requirements of the ADR coil harness are:

- Connection of NbTi wires and MgB2 wires should be dismountable easily.
- The wires and connector should be protected from radiative EMI:
  - The wires will be StSt braided shielded and the connection should maintain electrical continuity.
  - The connector should be put into a close box.

    Note: the requirements are less stringent than on other harness type (ADR coil less sensitive due to its high inductance)
- The connections should allow to remove heat from MgB2 wires conduction and from Joule dissipation into the connections with a limited thermal gradient to the 2 K temperature.
- As far as possible the capacitive coupling between the ADR coil harness and the structure should be minimized (contradictory from last point).
- The parts should be attached to a cryostat mechanical structure.
- The MgB2 wire should have a low bending radius.

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2.5 HK harness

DCS cryostat is a demonstrator model which main objectives are to test the functional, thermal, mechanical (including microvibrations) design aspects, as well as characterize the EMI/EMC behaviour. To achieve some of these goals it is necessary to correlate the thermal and mechanical models of the DCS, perform some thermal functional test (via heaters) to check gradients, uniformities, unsteady states… this is done by thermometers and heaters.
Accelerometers to measure the mechanical response and microvibrations are also required for the vibration tests.
A first approach of this HK harness has led to 700 lines. This big amount of harnesses has to be routed carefully using the cryostat shields to thermalize and minimizing the heat conductivity. Tree outer feedthroughs equally separated are foreseen to get the bigger symmetry as possible. Also connectors in every shielding are required in order to guarantee the integration.

3 Roadmap test

In the AIV harness process and to get a functional harness two different goals have to be validated:

- Validate the manufacturing process
- EMC tests harness validation

3.1 Manufacturing validation

In the manufacturing and integration process of the DCS harness there are tree critical points that should require a validation process.

- Manual soldering process in the PCB
- Thermalization manufacturing
- Potting feedthrough manufacturing

After all these process electrical test to check continuity are necessary.

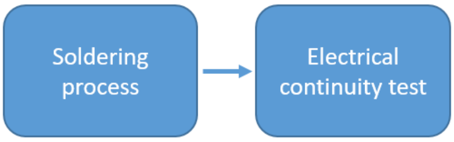

Figure 28 Soldering validation

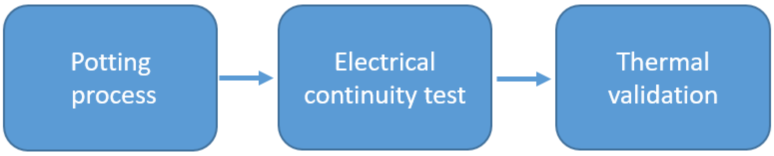

Figure 29 Thermalization

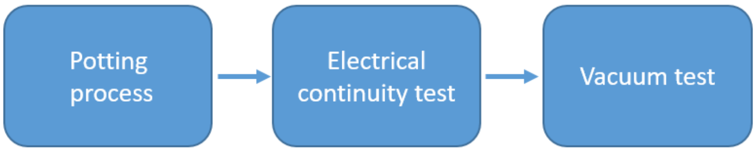

Figure 30 Feedtrough manufacturing validation

3.2 EMC test

The main goal of the DCS demonstrator harness is to characterize the EMI/EMC behavior. Some of the most important requirements that should be fulfilled are:

- Tombac shielding:
  - The shielding efficiency of the tombac overshield shall be at least 100dB from 30MHz up to 18GHz.

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- The transfer impedance of the TOMBAC overshield shall be measured in the frequency range [10kHz-75MHz] for a 2m-overshield. (2m = DCS harness length).
- The transfer impedance of the TOMBAC overshield shall be measured in the frequency range [75MHz-1GHz] with a 15cm-overshield. (15cm = outer vessel harness length).
- The test shall be performed with a simple wire inside the TOMBAC.

• Loom shielding and crosstalk:
  - The pseudo-shield of the loom stack is dedicated for low frequency protection (f< 10MHz) and crosstalk protection (requirement in the 1-6MHz science bandwidth).
  - As a reminder the intra-channel crosstalk requirement is < 60dB. The inter channel crosstalk requirement is < 116dB.
  - Crosstalk measurements shall be performed at ambient temperature:
    - Within 2 neighbour STP of one loom for the inside channel crosstalk characterization
    - Within 2 STP of 2 neighbour looms for the crosstalk inter channel
  - If representative loads are available, they shall be used as terminations of the tested pairs (with the interposer if possible as well).

• Impedance measurements: common mode and differential mode characteristic impedance determination. The transfer impedance shall be measured in the frequency range [10kHz-75MHz] for a 2m-TP.

For the complete FPA harness PCB interface +1 loom signal with 2 looms as shielding + Tombac +thermalization + potting feedthrough the previous requirements have to be fulfilled.

All the different parts of the harness have impact in the final measurements, so only some dedicated measurements at elementary level will be performed to check the element impact on the final measurement.

Focus on shielding and crosstalk measurements and no impedance characterization on elementary level will be performed.

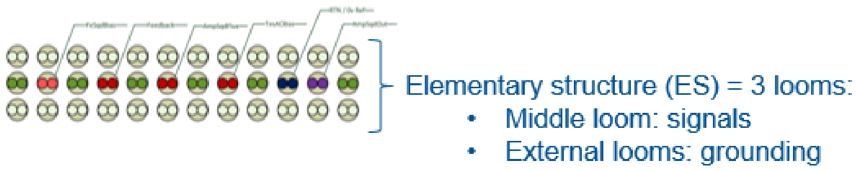

Figure 31 EMC Elementary Test Structure

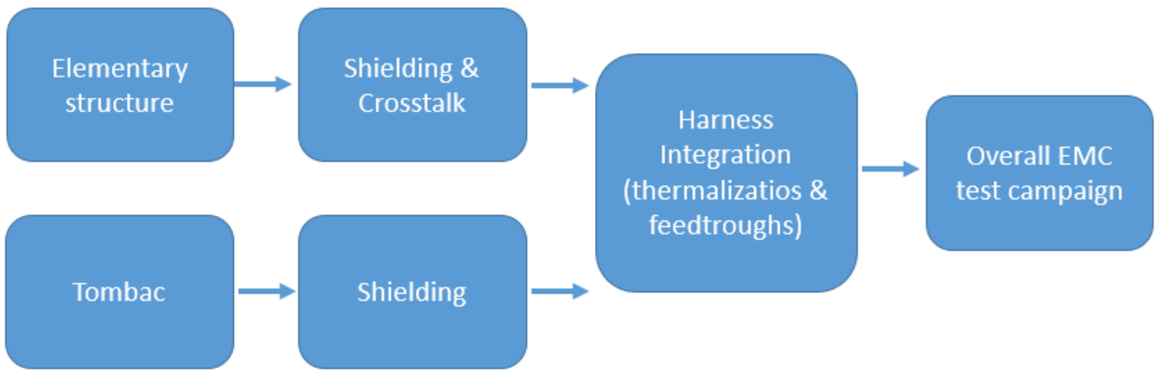

Figure 32 EMC Test campaign

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4. Conclusions

The preliminary baseline design of the DCS cryostat harness has been presented and the main critical aspects that have to be tested and required a manufacturing verification process are shown. EMC and electrical test like shielding and crosstalk effects are needed for characterizing the harness design.

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