This project is funded by the European Union

AHEAD WP 6.5 (Interconnection harness)
Status report
May 2018

1 March 2016 – 1 April 2018

Written by	Xavier de la Broïse	
Checked by		
Distribution List		
Distribution Date		

1 Introduction.

The aim of this project is to develop high-density superconducting harnesses for the readout, in spatial context, of very low impedance detectors. These harnesses electrically link pieces at different temperatures, minimizing the thermal conduction between them. The harness we have designed contains 37 tracks, routed on a signal layer (see Figure 1 and Figure 2). This one is intercalated between two shielding layers made of hatched shielding planes, and this set is again intercalated between two thermal contact layers where large gold pads are designed at both extremities of the harness and at its middle, for its thermalization at three different temperatures (low, intermediate if needed, and "high"). All the grounds of the four top layers are interconnected by microvias, in order to entirely enclose the lines by shielding, and to improve the thermalization.

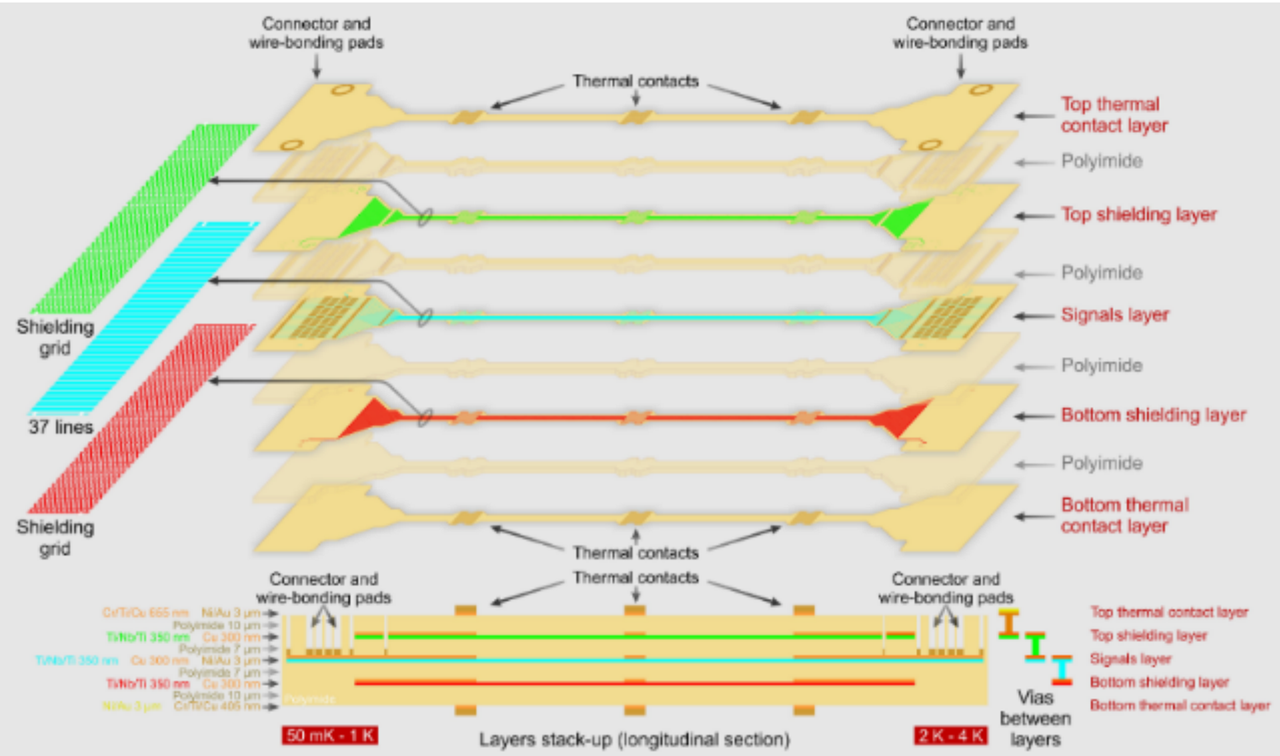

Figure 1 : Stack-up.

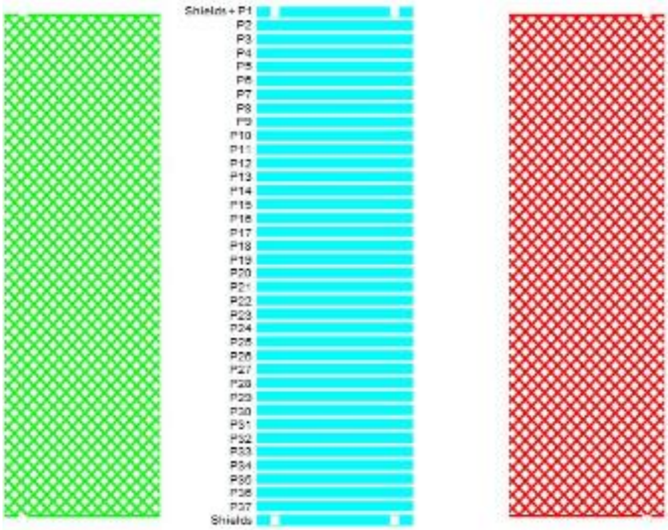

Figure 2 : Section of the design of the top shielding layer (left), the signal layer (middle), and the bottom shielding layer (right).

The width of the signal tracks is 15 µm spaced by 15 µm. The characteristics and theoretical performances of each variant are given in Figure 3.

Characteristics and theoretical performances	Value
Tracks width (µm)	15
Tracks spacing (µm)	15
Shielding filling ratio	0,5
Tracks quantity	37
Minimal harness width (mm)	1,89
Total thermal conduction (W/K)	**1,77E-08**
Critical current at 4 K (mA)	**5,25**

Figure 3 : Characteristics and theoretical performances of the harness.

The length of the harnesses is 100 mm, its maximal width (at connector level) is 19 mm, and its minimal width (between two thermal contacts) is 1.89 mm (see Figure 4). Two interconnection options are available at both extremities : either SMD NanoD connectors, or wire-bonding pads if very low contact resistance or maximal compactness are needed.

AHEAD
This project is funded by the European Union

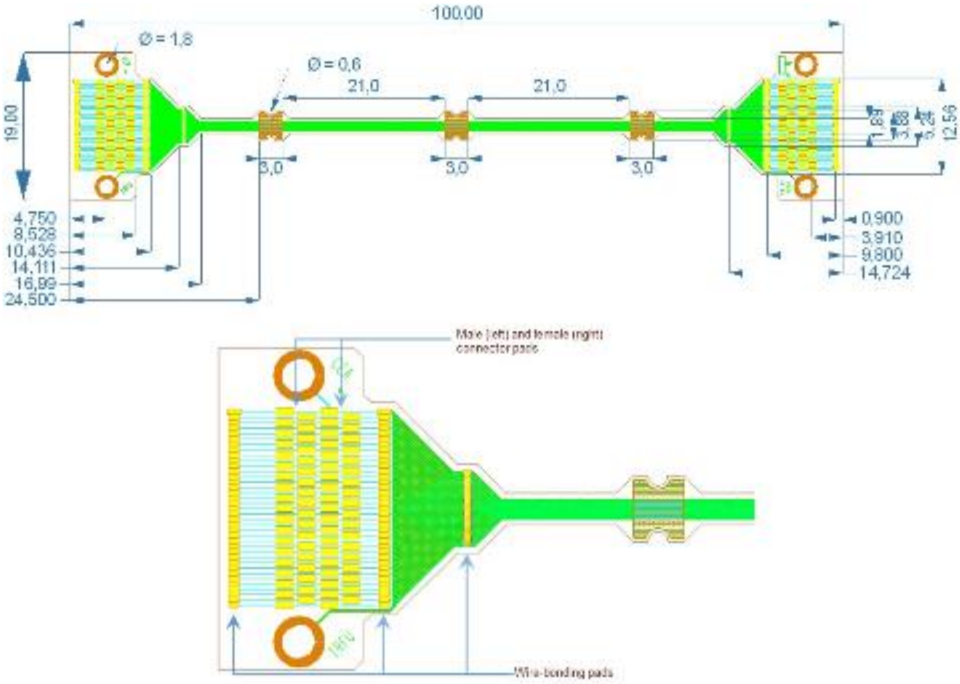

Figure 4 : Dimensions and interconnection.

2 Progress.

2.1 Production history and status.

CEA ended the **design** of the harness in August 2016, and Hightec, the manufacturer, has started the **production** in October 2016.

Hightec delivered a **first batch** on 1st February 2017. The overall result was good, but many local defects have been observed (only three panels over the six produced were partially OK), and critical adhesion defects were detected on a large number of pads (see section 2.3.2).

Hightec delivered a **Second batch** in April 2017. The yield was better, several defects were corrected, but the adhesion defects fully remain.

Then it has been decided to stop the production and, for testing and comparison of new adhesion layers and activation methods, to produce a **special batch** containing test samples and three partial panels (containing only the signal layer). It has been delivered on 15th June 2017. Pullout tests has been performed by Hightec, and cold tests by CEA, in order to compare the different solutions, and finally a new adhesion layer has been validated to solve the problem.

This new adhesion layer has been integrated in the process and a **third batch** has been launched. It has been stopped in early March 2018 due to an Hightec preparation error, but it has been immediately relaunched from zero and its delivery is now planned for the end of July 2018.

2.2 Realization.

Figure 5 shows a photograph of the produced harness, and different details illustrating the quality of the realizations.

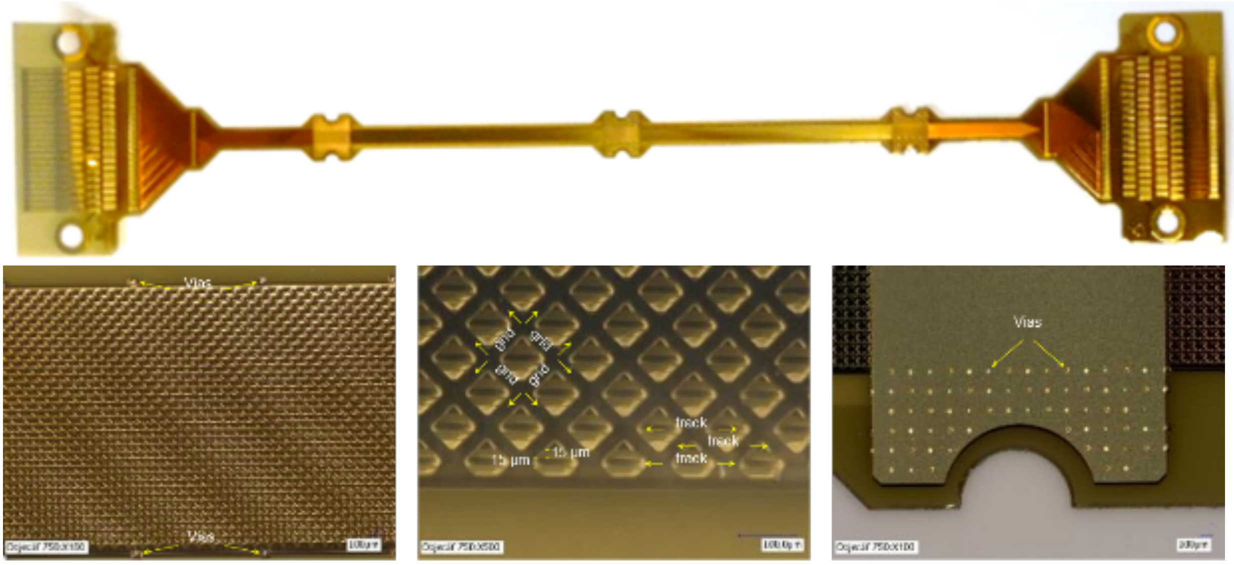

Figure 5 : At top : photograph of the harness. At bottom, left : zoom on the tracks and grids zone ; the shielding grids are closed by vias. Middle : further zoom where 15 µm/15µm tracks appear between the two shielding grids. Right : zoom on a top thermal contact, with vias connecting it to the two shielding planes.

2.3 Characterisation.

2.3.1 Measurements.

The critical temperature of the tracks has been measured, by performing a four-wire measurement of their electrical resistance when the temperature was varying in both directions. The critical temperature measured is about 9.2 K (see Figure 6), i.e. very close to that of the bulk niobium (9.3 K). This excellent result is due to a good deposition quality.

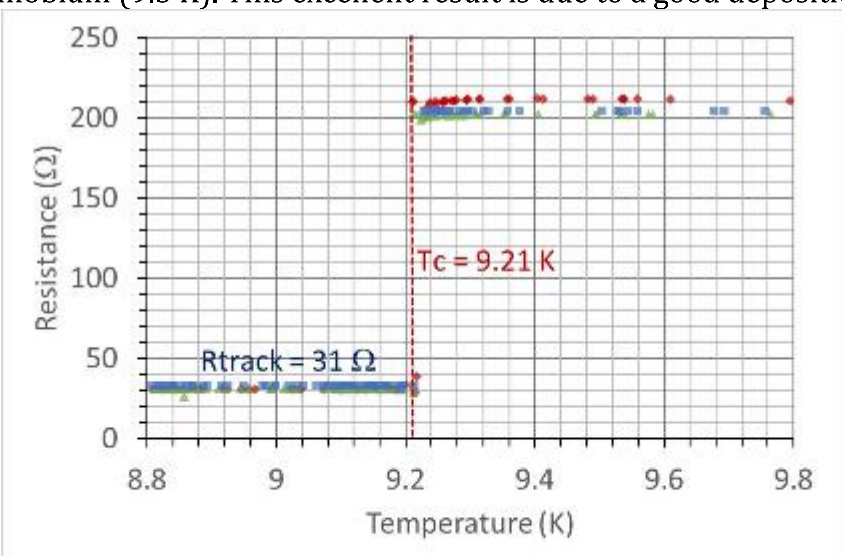

Figure 6 : Electrical resistance of three tracks (blue, red, green) versus temperature : transition around 9.2 K.

2.3.2 Defects.

Defects of different natures have been observed on the produced harnesses. Some are critical, because they prevent to use properly the harness. Others are not critical, and are more appearance defects.

The category of critical defects is composed of the delamination of large pads. This problem occurred in the first batch and persisted, even to a larger extent, in the second batch.

This delamination appears on the connector large pads (see examples in Figure 7), where pads are completely or partially delaminated. It appears also on the thermal contact pads (see example on Figure 8). Concerning the connector pads, the microscope photographs shows also pads with a bubble forming below the metallisation, what can be confirmed when the harness is observed from the bottom side. The bubble formation indicates that the adhesion is deteriorating over time or during processing. It is obvious that the harness became unusable and the stability of remaining sticking pads was to be questioned.

Hence, Hightec and CEA have agreed that this adhesion problem has to be controlled or solved before continuing with the fabrication of the whole batches. This is the reason why a special batch has been produced to test solutions (see section 2.1). A solution has been validated and a new batch is being produced.

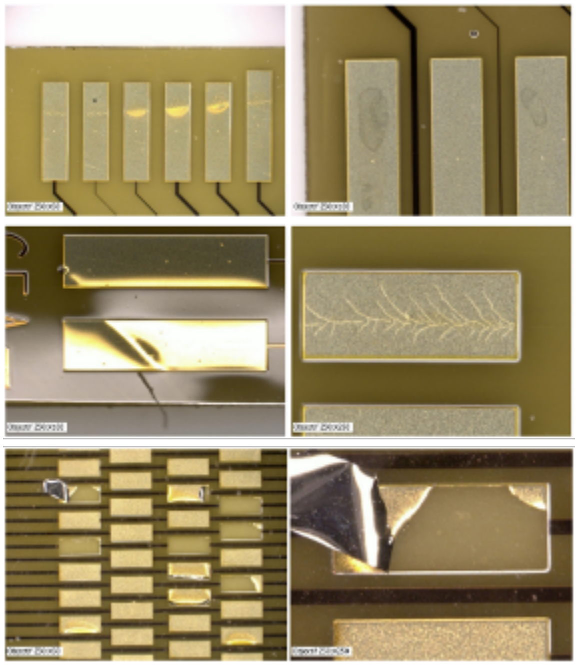

Figure 7 : Delamination on connector's pads

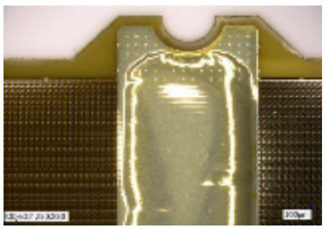

Figure 8 : Delamination on thermal contact pads.

Other not critical defects have been also observed, but do not prevent to use the harness and are relatively infrequent. Nevertheless, efforts will be produced to further decrease their frequency in next batches. A typology of these defects is shown in Figure 9.

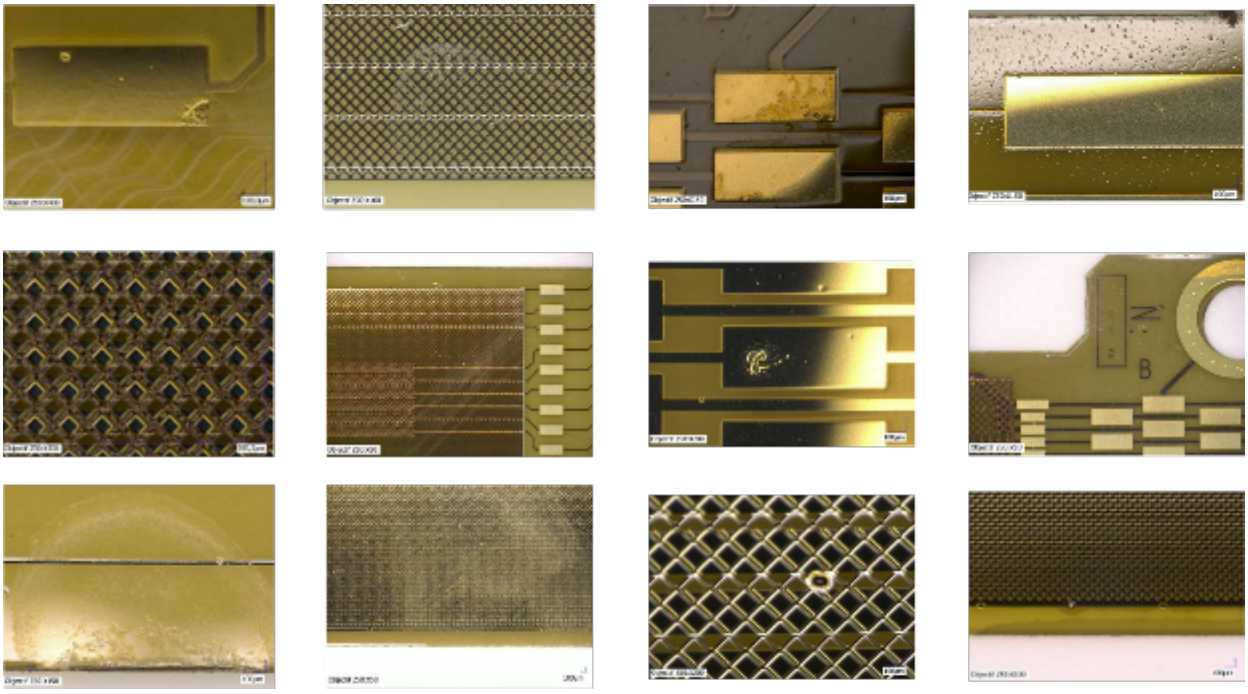

Figure 9 : Typology of non-critical defects.

2.4 Assembly.

The harnesses should be equipped to be usable. Connectors or wire bonding should be implemented at both extremities, for electrical interconnection of the harness. To allow this, stiffeners should be glued at both extremities. These stiffeners are also used to thermalize the harness.

2.4.1 Stiffener gluing.

The stiffeners are composed of gold platted OFHC copper. They are mechanically bonded to the flexible PCB by deep cryo-epoxy. To this aim, a specific pressure and heating controlled press has been developed (see Figure 10 and Figure 11).

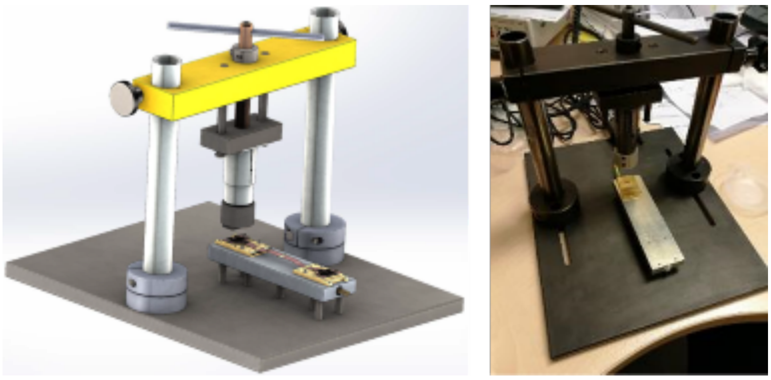

Figure 10 : Heating press.

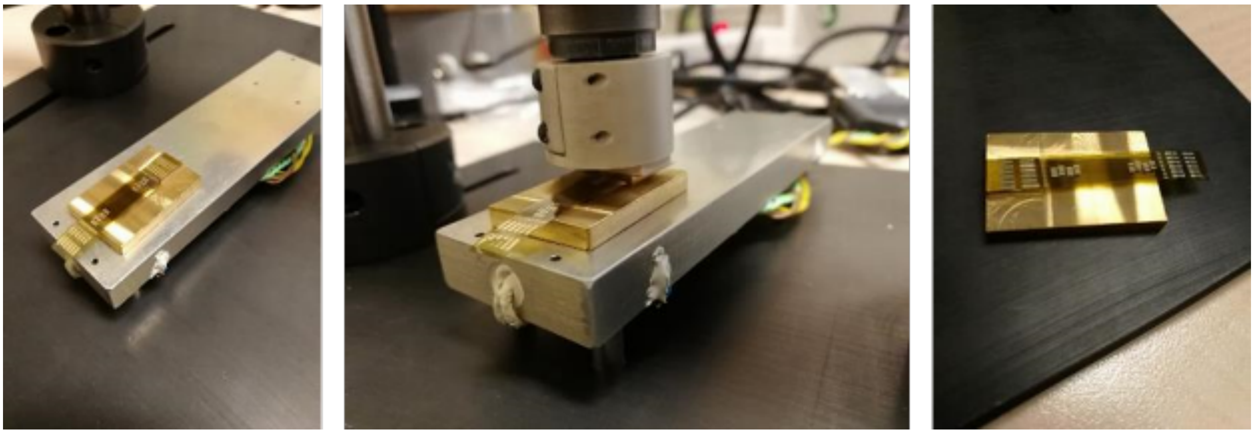

Figure 11 : Gluing test.

2.4.2 Connectors soldering.

For the implementation of the connectors, a low temperature solder paste (96°C) and an « almost » classical PCB solder brazing process (solder paste through stencil) are used. To this end, many developments, tools and trials for setting the soldering process have been performed (see Figure 12 and Figure 13).

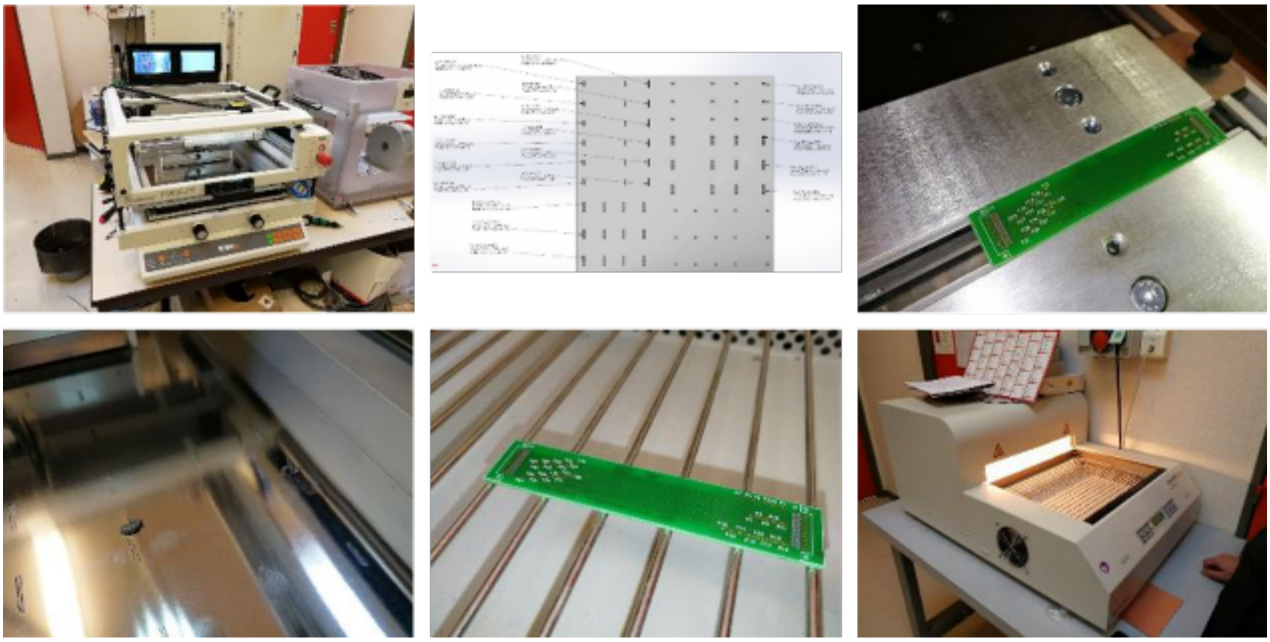

Figure 12 : From left to right and top to bottom : brazing machine, stencil, dummy harness in FR4 PCB, spread of solder on stencil, passing in the oven,oOven.

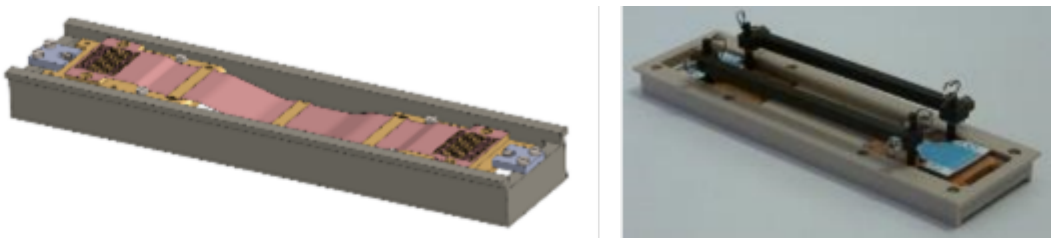

Figure 13 : Support for the harness in the brazing machine. At right,in black, the top part of the handling tool is laid.

Once assembled, harnesses remain very fragile, which imposed the development of a transport support and handling tools (see in black the top part of them on Figure 13, right).

2.5 Measurements tools.

Once equipped, many tests should be performed on the harnesses to validate them. For these tests, tools should be designed and manufactured.

For example, we have designed eight different interconnection boards (see Figure 14) for the measurement of the transition temperature (Tc) and of the access resistance of the harness, including both configurations of interconnection devices (connector or wire-bonding). These boards allow the (4-wires) measurement of the electrical resistance of the 37 tracks in parallel when the temperature is varying (with fine measurements around Tc), and the chaining of the 37 tracks for the precise measurement of the access resistance bellow Tc.

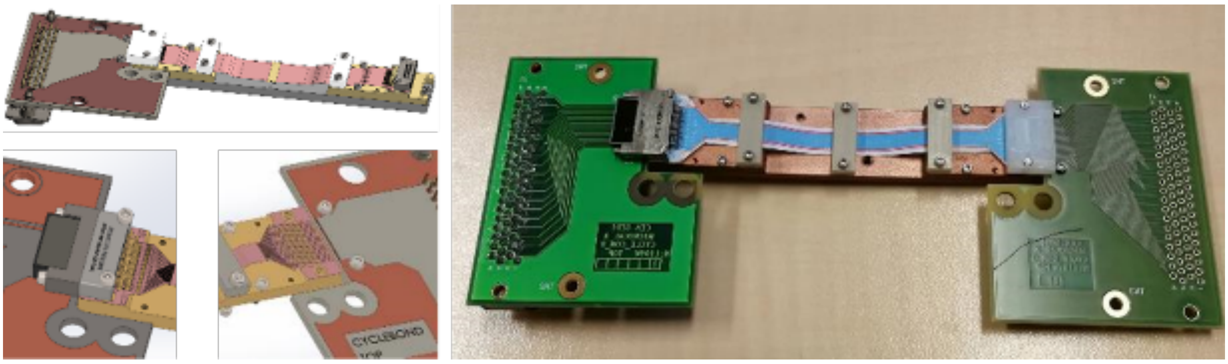

Figure 14 : Interconnection of the harness : connector configuration (left) and bonding configuration (right).

To perform these tests, a cryo-generator has been equipped with tools and cabling specially designed for it (see Figure 15).

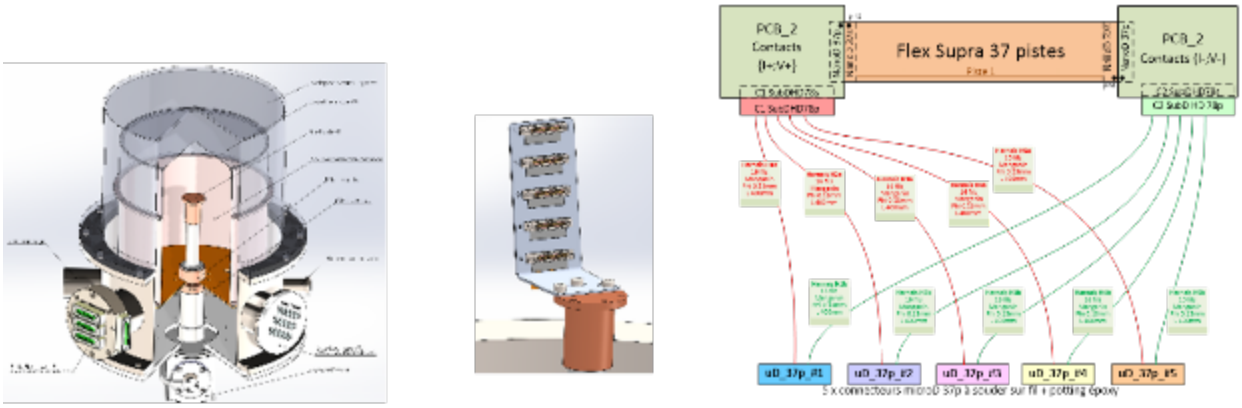

Figure 15 : Cryo-generator for the cycling of the harnesses. Cabling for the 4-wires measurement of the electrical resistance of the 37 tracks of an harness.

2.6 Summary of the assembly and test facilities readiness.

The readiness of the assembly and test facilities can be sum-up as below :

- **Stiffeners assembly at both extremities :**
  - The stiffeners are designed and manufactured.
  - The tools for handling of assembled set are designed and manufactured.
  - The heating press is manufactured and validated.
  - *The gluing process has been tested and validated.*

- **Connector assembly at both extremities :**

- The tools for positioning of harness (mobile support) and spreading of solder (stencil) have been designed and manufactured.
- A dummy harness (FR4 PCB), for process trials preserving harnesses, has been designed and manufactured.
- First tests of solder spreading and then connector soldering in oven have been performed on dummy harnesses.
- *Still to do* : the same steps should be now performed on true (and not dummy) harnesses. This is expected to be achieved in the next few months.

- **Resistance measurement at room temperature** :
  - It is performed systematically for all tracks of all harnesses by the manufacturer, using its mobile probe tester. This is a good witness of the metallization quality.

- **Critical temperature measurement** :
  - It is performed for every batches for a set of tracks of flexible PCB samples (see the set-up in Figure 16).

Figure 16 : Cryo-cooler for the measurement of the critical temperature of set of tracks.

- **Interconnection resistance measurement at cold temperature** :
  - The aim is the 4-wire measurement of the critical temperature and of the interconnection resistance of all the tracks of an harness.
  - The interconnection boards are designed and manufactured, as well as the mechanical pieces and cables.
  - *Still to do* : the assembly of the test bench, and the writing of the acquisition and control software.
  - This test facility will be able to be fully validated only when equipped harnesses (with connectors) will be available.

- **Thermal conduction measurement :**
  - The test bench has been designed and manufactured (see Figure 17, left), and first measurements have been performed.
  - *Still to do* : the calibration of the test bench for absolute measurements. This achievement is expected in the next months.

- **Detailed visual inspection of the harnesses :**
  - An advanced digital microscope has been supplied (see Figure 17, right).
  - Each sample is inspected in detail to list all major or minor defects.

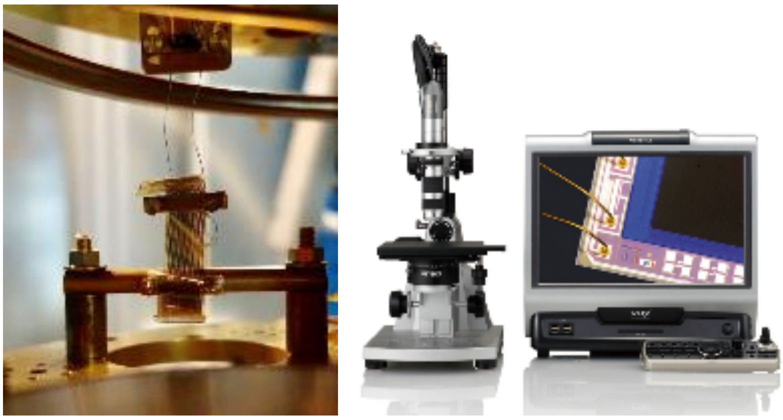

Figure 17 : Left : test bench for the thermal conduction measurement. Right : advanced digital microscope for detailed visual inspection.

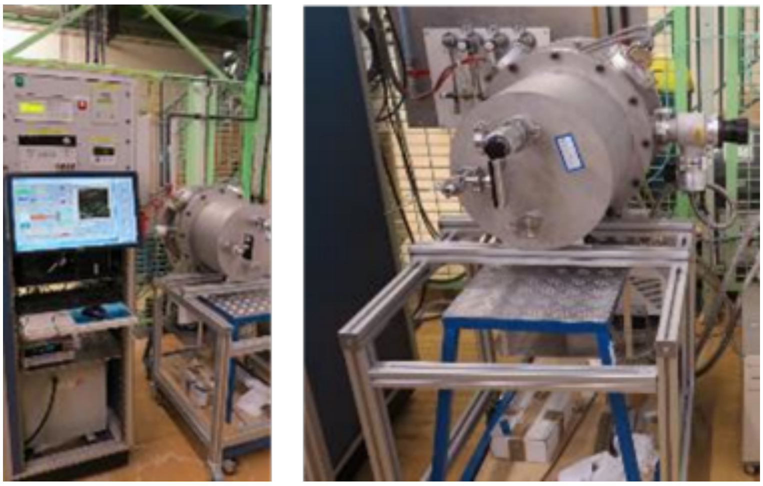

Figure 18 : Cryo-cooler for the 4-wires measurement of the electrical resistance of the 37 tracks of an harness, according to the temperature.

3 Conclusion.

The progress of the manufacturing has been delayed by the occurring of **critical defects of adhesion (delamination)** for large pads (connector pads and thermal contact pads). But a **good cooperation** has been performed with Hightec to identify and solve the problem. Two extra samples and three special (partial) panels have been produced for the comparison and the (thermal) control of the envisaged solutions to fix the problem. A **modified process** has been validated and **a new production using it is in progress** ; the delivery is planed for July 2018. Hightec is confident that this will solve the problem.

We have made in March 2018 a **visit at Hightec**. We have visited the production rooms, we have made a detailed review of the processes (inspection of the full "product manufacturing instruction files"), we have discussed about the production and quality assurances, and we have made a detailed review of all the production defects, major or minor. We have had a good overall impression.

In parallel, we have developed all the **mechanical parts** needed for the **equipment** of the harnesses (stiffeners, handling tools, storage tools, heating press), for the **soldering** of the connectors (stencil, support for brazing, trial board), and for the **cold tests** (thermal resistance test bench, electrical resistance test bench, interconnection boards), etc.

Very first tests of connector soldering have been performed on dummy harnesses (low temperature solder layout, oven tests), and test on true samples will be performed very soon. But the final tests on the final samples will be carried out when the new production, with pad delamination problem solved, will be available.