2S Module Assembly Procedure

CMS Module Working Group

EDMS document ID: 2642512 (v.1)
2021-10-13

Contents

1 Introduction

The following sections are a detailed step-by-step description of the 2S module assembly steps. The CAD models of the baseline modules geometries can be found in [1, 2, 3]. The 2S module specifications can be found in [4]

2 Sensor backplane PI isolator and HV circuit gluing

The AlCF bridges of the 2S module are directly connected to the cooling circuitry of the CMS tracker and thus to electrical ground of the experiment. The sensor backsides are on a negative high voltage potential. Therefore, the connection between sensor backside and AlCF bridges must be isolated electrically to up to 800 V, which is done with polyimide strips. The high voltage potential of the sensor backsides is served by HV tails. For best cooling performance the glue joint of the isolator strips should have an as small as possible thermal resistance. This requires thin glue layers with high wetting and thin polyimide layers. The chosen material is 25 μm thick Kapton MT, which has a higher thermal conductivity ($\lambda = 0.46$ W/mK) than the more common material Kapton HN ($\lambda = 0.2$ W/mK) [5]. Two different types of polyimide strips are used to cover either the short stump or long AlCF bridge:

- Long strips: 95.68 mm × 9.8 mm
- Short strips: 17.26 mm × 10.1 mm

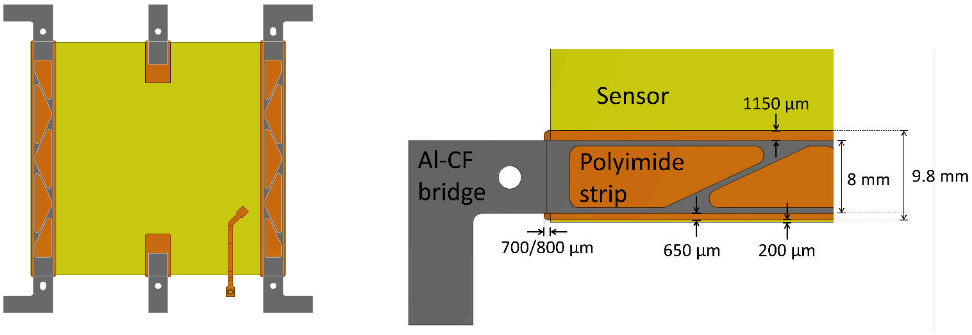
To guarantee the high voltage stability of the module and to avoid problems in subsequent assembly and integration steps the dimensions and position of the strips must meet certain requirements. The dimensional tolerances claimed by the manufacturer are less than ± 0.1 mm.

Figure 1 shows the nominal position of the strip with respect to the AlCF bridges and sensor edges. It is aimed to to have 650/700 μm of polyimide between the high voltage potential (sensor backside and edge) and the AlCF bridges. The minimum distance is 500 μm. Everything below must be reworked. The strips overlap the sensor edge by 700 to 800 μm at the position where the bridges exit the sensor sandwich. This gives a window of ± 200 μm to place the strips in this direction. Along the bridges the strips must be positioned within the sensor area, while it should not move too close to the AlCF bridge, resulting in a window of $+200/-150$ μm.

The HV tails stick out of the sensor sandwich and are plugged into the SEH after the hybrid assembly, explained in Section 4. Therefore, the tails must be positioned accurately to match the plug of the SEH. There are two different kind of HV tails: The top sensor of a 2S module is equipped with a tail containing the HV power connection and a thermistor. The thermistor on the top sensor is used to monitor the temperature of the module. The bottom sensor is equipped with a smaller tail only containing the HV power connection. Figure 2 shows the different positions of the tails depending on the module flavour. Because the 4.0 mm module is thicker, the top sensor tail must be glued further to the sensor edge compared to the 1.8 mm module top tail, to compensate the larger distance towards the plug of the SEH.

In addition to the correct position, glue excess of any kind must be avoided due to different reasons:

- Glue excess over the sensor edge can result in misaligned bare modules.



(a) Placement of polyimide strips and a high voltage tail on the backside of the silicon sensor

(b) Nominal position of a long polyimide strip

Figure 1: Polyimide gluing

- Glue excess on the sensor topside can worsen the electrical performance of the sensors.
- Glue excess/droplets on the polyimide strips can make it impossible to place the AlCF bridges flat on the strips.
- Glue excess on the HV tail wire-bond pad can cause problems in the bonding procedure.

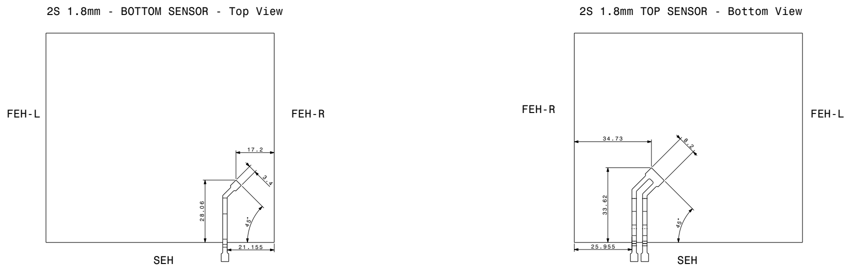
The OT module working group developed and successfully tested multiple techniques and tools for this assembly step. The technique and tooling described in the following was developed at the ETP (KIT). As most of the steps in assembling 2S modules it is mandatory to practice the procedures. The polyimide strip and tail gluing tools are described in more detail in Appendix A.1.

The basic procedure is as follows: The sensors are placed topside down on an assembly fixture, which is then placed below a gantry with a volumentric glue dispenser. After a certain amount of glue is applied in a special pattern, the strips and tails can be placed precisely using pickup tools. After the glue joint is cured the electric connection between HV tail an sensor backside is made with wire-bonds which are protected with a drop of Sylgard 186.

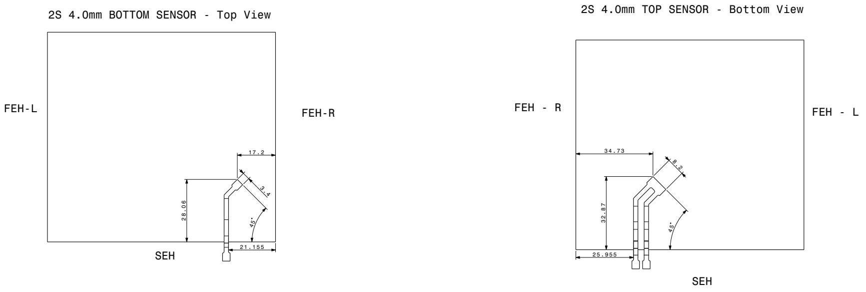
2.1 Step 1: Preparation

The KIT polyimide gluing jig consists of four isles holding one sensor each. The surface of each isle consists of ESD safe PTFE (carbon-filled). The 2 × 2 design allows for a high through-put during production and decreases the sensor handling steps. Gluing, wire-bonding and encapsulation of the tails are done on the same tool without a removal of the sensors. Each station has a dedicated vacuum plate on which the array can be placed.

To prepare the assembly the 2 × 2 array is placed on the vacuum plate of the glue table and on each isle one sensor is placed face down on the PTFE surface. Being the most sensitive part of the sensor, the topside should not be damaged in any way. Therefore, the PTFE surface and the sensor top side must be completely freed of any dirt. The PTFE plateau can be cleaned using dry air flux. Any more resilient dirt must be removed with clean room brushes. At this step most of the sensors (95 %) will be unpacked for the first time from their transport packaging coming from the



(a) 1.8 mm Bottom sensor tail position (b) 1.8 mm Top sensor tail position



(c) 4.0 mm Bottom sensor tail position (d) 4.0 mm Top sensor tail position

Figure 2: Tail positions

manufacturer. After unpacking, the sensors should be placed directly on the fixture to avoid any possible contamination. Usually silicon sensors are shipped in very clean conditions. A dry air flux on the sensor top side right before the placement is usually sufficient to remove possible smaller dust particles. The sensors are positioned by moving them slightly against three PTFE stops on each isle. Afterwards vacuum served from the plate below is applied to fixate the position. During the transport between the stations the vacuum must be released. To still have a fixation plastic springs with a rubber tip are attached to apply a small force on the sensor backsides holding them in place, as is shown in Figure 3.

The polyimide strips are removed from their carrier foils and can be placed on a clean room tissue. The removal of the strips from the carrier foil requires some practice. It is advisable to only wear gloves for this procedure, not using any special tools. The strips are very sensitve to folding and can be poked easily. Therefore, tweezers or similar tools should not be used. Each strip should undergo a visual inspection to detect any contamination or damage.

The HV tail can be removed from their packaging bag and can be mounted after a visual inspection in the corresponding pickup tool, as explained in Section 2.3.

2.2 Step 2: Glue Application

The sensor jig is placed on the vacuum plate below the dispensing gantry. The vacuum is applied and the plastic springs are removed. The polyimide strips are glued with a low-viscosity epoxy resin *Polytec EP 601 LV*.

The glue is filled in a 5 cm cartridge with a PTFE coated tip (Inner diameter: 0.84 mm, green). The cartridge is inserted in the dispensing gun which is then

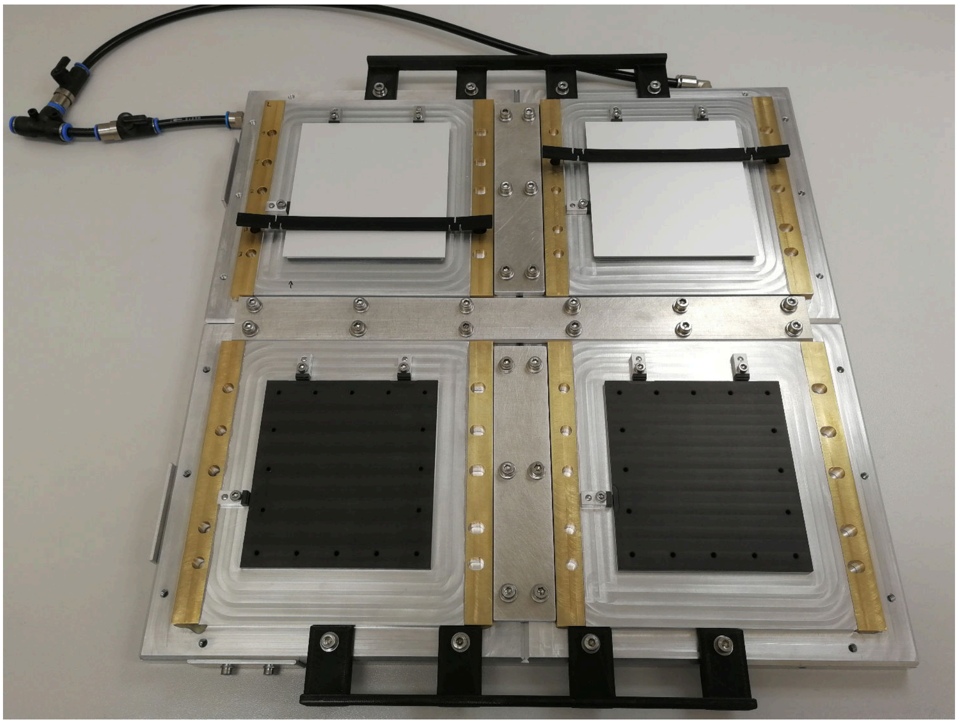


Figure 3: Sensor placement on polyimide gluing jig

mounted on the gantry. Afterwards the dispensing tip is aligned in X, Y and Z. The distance between sensor backside and dispensing tip should be between 50 and $200\,\mu$m. The feeding of the dispensing gun is set to 0.0011 ccm/s.

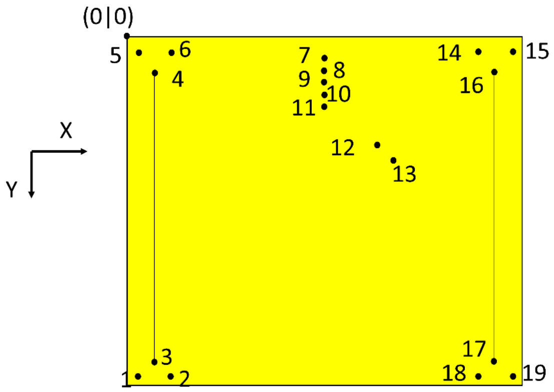
Figure 4 shows the dispensing pattern for the top and bottom sensors in a 2S module. With these parameters the resulting glue layer between sensor and polyimide strip should have a thickness of less than $10\,\mu$m. After the glue is applied the plastic springs are attached and the vacuum can be released to remove the assembly jig.

2.3 Step 3: Placement of polyimide strips and HV tails

After the glue pattern is dispensed on the sensor backside the polyimide strips and HV tails can be placed. The sensor jig is carried back to the glue table and is mounted on the vacuum plate. Vacuum is applied to fixate the sensors during the strip placement. The plastic spring can stay in place. The pot life of Polytec EP 601 LV is four hours. Though, it should not take too long to place the strips, because the dispensed glue lines tend to contract over time, forming droplets. These droplets can - depending on their size - cause glue spills outside the polyimide strip after the placement.

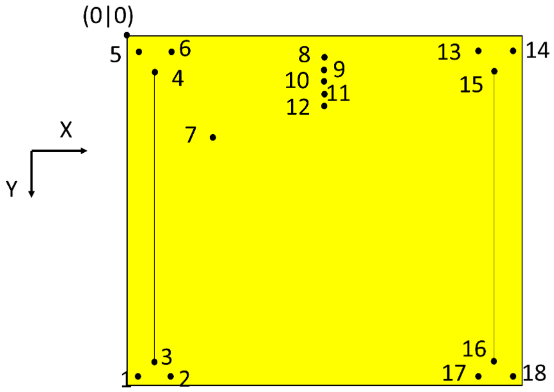
To place the strips and tails each isle has five pairs of precisely drilled alignment bores. In case of the ETP technique there are four pickup tools to be placed on each sensors: Two for the long strips on the outer parts of the sensor, one for the short in the middle and one for a HV tail. To equip the pickup tools with the polyimide strips the surface is slightly wetted with isopropyl. The pickup tool is placed on a plate with an L-shaped stop on it. The strip is placed on the alcohol and then sticks to the wet surface but can still be moved around. As shown in Figure 5a the strip is gently pushed against the L-shaped stop. The stop is machined in such a way, that the

Point	Type	X	Y	Material (mg or µl)
1	Drop	4000	90183	0.15
2	Drop	7200	90183	0.15
3	Line	5600	87183	4.8
4		5600	7000	
5	Drop	4000	4000	0.15
6	Drop	7200	4000	0.15
7	Drop	51300	5600	0.12
8	Drop	51300	7200	0.12
9	Drop	51300	8800	0.1
10	Drop	51300	10400	0.1
11	Drop	51300	12000	0.1
12	Drop	64200	28300	0.2
13	Drop	67400	31800	0.2
14	Drop	95600	4000	0.15
15	Drop	98800	4000	0.15
16	Line	97200	7000	4.8
17		97200	87183	
18	Drop	95600	90183	0.15
19	Drop	98800	90183	0.15



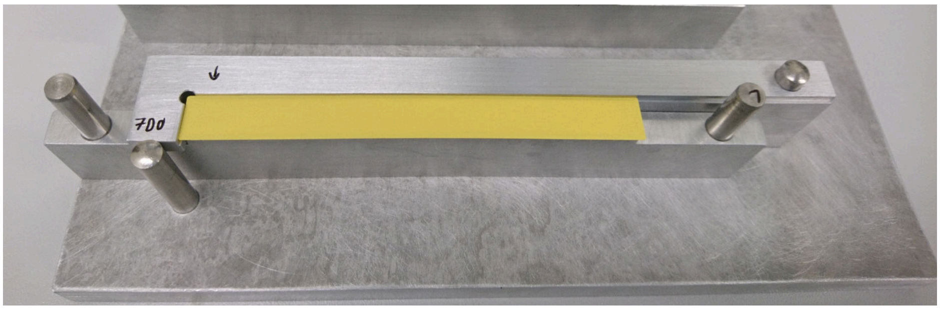
(a) Top sensor

Point	Type	X	Y	Material (mg or µl)
1	Drop	4000	90183	0.15
2	Drop	7200	90183	0.15
3	Line	5600	87183	4.8
4		5600	7000	
5	Drop	4000	4000	0.15
6	Drop	7200	4000	0.15
7	Drop	16900	26400	0.2
8	Drop	51300	5600	0.12
9	Drop	51300	7200	0.12
10	Drop	51300	8800	0.1
11	Drop	51300	10400	0.1
12	Drop	51300	12000	0.1
13	Drop	95600	4000	0.15
14	Drop	98800	4000	0.15
15	Line	97200	7000	4.8
16		97200	87183	
17	Drop	95600	90183	0.15
18	Drop	98800	90183	0.15

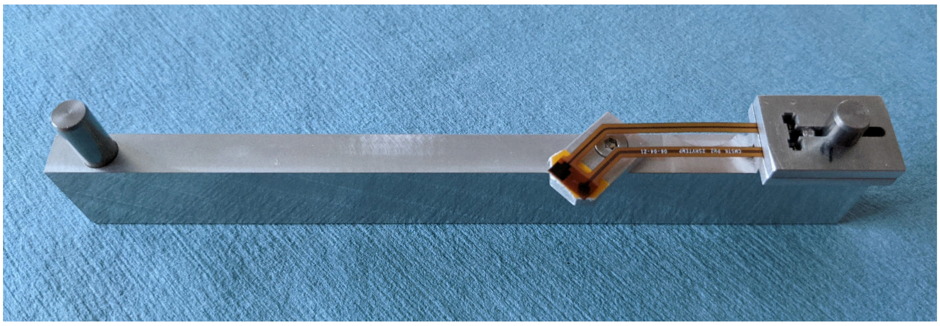


(b) Bottom sensor

Figure 4: Dispensing pattern



(a) Long polyimide strip on pickup tool pushed against L-shaped stop



(b) HV tail on pickup tool

Figure 5: Pickup tools

strip has a certain overhang on the pickup tool. After the strip is aligned, the stop is turned away from the pickup tool, leaving the strip on the wet surface. The whole pickup tool is turned over and carefully placed in the corresponding guides. The placement procedure requires some practice. The pickup tool should not be lowered too fast because this can result in glue splashing out of the glue joint creating glue excess. Once the strip is carefully placed, the glue starts to spread by capillary forces and forms a meniscus at the end of the strip. This process takes about 5 to 10 minutes. It is advisable to check this process to avoid unexpected glue excess at any position. The isopropyl between pickup tool and strip evaporates within 10 minutes.

As shown in Figure 5b, the pickup tools for the HV tails differ compared to the ones of the polyimide strips. The tails are clamped between two aluminium pieces of which one matches the connector(s) of the tails. Small magnets in the aluminium pieces keeps the compound together and it can be easily attached to the pickup tool, which also has a small magnet incorporated. The pickup tool is rotated and placed on the corresponding pair of guides. At the very end of the tail the pickup tool has a small support area to apply some force by the weight of the pickup tool at the glue joint. To cope with the different tail designs and module thicknesses, there are three different kinds of aluminium pieces: 4 mm top, 1.8 mm top and 4/1.8 mm bottom sensor.

Polytec EP 601 LV takes 16 hours at 23C to cure [6]. After the glue is cured the pickup tools can be removed. In case of the HV tails the small aluminium pieces must be kept down, while the pickup tool is removed.


(a) Kaptonized sensors on the sensor array (b) Encapsulated HV tail

Figure 6: Kaptonized sensors with encapsulated hv tails

2.4 Step 4: Wire-bond HV Tails

Each HV tail must be connected to the sensor backside with wire-bonds. For this the vacuum is released and the sensor jig is placed inside the wire-bonder on the matching vacuum plate. Each connection should have at least have 10 bonds. Short (1 mm) and low ($\approx 200\ \mu$m) wire-bonds are favourable.

2.5 Step 5: Encapsulate HV Tails

The encapsulation of the HV tail wire-bonds is made with a drop of Sylgard 186, which is the same material used for the encapsulation of the readout wire-bonds after the hybrid assembly explained in Section 6. The encapsulation can either happen with the dispensing gantry or manually with a steady hand.

3 Sensor sandwich gluing

This procedure can be found in a separate document [7].

4 Hybrid gluing

The assembly of hybrids to a 2S bare module requires a set of three fixtures, which were designed and distributed to the assembly centers by KIT. The three fixtures are described in detail in Appendix A.3. The first fixture is named *Bending tool* to pre-bend the SEH tails. The second fixture is named *Skeleton Plate* to connect the hybrids into a Skeleton. The third fixture is the actual *Hybrid Gluing Jig* to attach the Skeleton to the bare module. While the first two are only required once per assembly site the Hybrid Gluing Jig has to be existent multiple times depending on the planned size of the assembly line in the production centre.

The hybrid gluing jig is still under development. A first version was send to the assembly sites to spot possible flaws in the design and handling of the tools. The gathered feedback will be incorporated directly in a succeeding design by the end of 2021.

4.1 Step 1: Bending of SEH Tails

The pre-bending of the SEH tails is necessary to cope with a possible misalignment between the SEH and the FEHs. The tails are bend twice according to an S-shape. If not happened before the SEH should undergo a visual inspection to check for broken components such as a damaged DCDC aluminium shield, loose components or cracks in the polyimide protection layer. In any case the connectors should be checked on possible impurities such as dust or strands. During the whole procedure the operator should be protected against ESD.

To start with the bending procedure all sliders and the protection cap of the bending tools should be removed. Then the SEH can be placed on the aluminium plateau. The position is determined by two 2 mm alignment pins. The hole and the elongated hole of the SEH have nominally 2.0 to 2.1 mm (see Figure 7a). In case the pins do not fit into the SEH holes due to glue residues or minor misalignments in the layers of the SEH, an electric screwdriver with a 2 mm drill can be used to gently enlarge the holes. This should only be done by expert staff and should not be necessary once the quality of the alignment holes improves with future hybrid batches. Once positioned the protection cap is placed on the SEH and secured with the winged M4 nut as shown in Figure 7b. The cap serves as protection for the sensitive components on the SEH during the bending procedure. In addition to that, it fixates the SEH to its position and specifies the first bending shape by the rounded part at the outer most bottom corner.

The first bending is made by moving the tail upwards until it is laying flat on the vertical area of the protection cap (see Figure 7c). Afterwards the orange single pin sliders can be inserted into the corresponding guide ways. The tails should be kept upwards while the slider is moved to its destination, marked with a groove. The slider should engage in that position. Then the tail can be gently bend around the 6 mm pin downwards (see Figure 7d). Afterwards the orange sliders are removed. The tails should have their first S-shaped bend and the tails' end should stay roughly in a horizontal position.

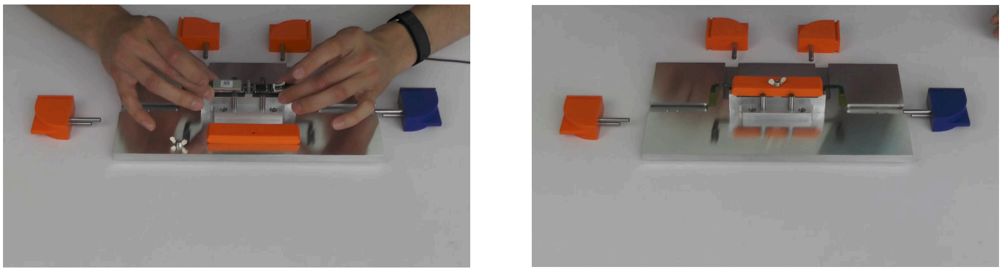
For the second S-shaped bending the green and red double pin sliders are inserted into the corresponding guide ways. They are moved to the first engaging position. During this process the tail must be kept above the alignment pins. Once the first position is reached the tail can be bend downwards. One finger should ensure that the tail stays on top of the pin while the other finger guides the flex downwards (see Figure 7e). In this position the slider is moved to the second position and traps the tail in between the two pins. The last step is to move the remaining tail with the connector upwards (see Figure 7f). Then the slider can be released and the L-shaped tail should have an additional second S-shape.

As last step the protection cap is removed and the SEH should undergo a final visual inspection to check for possible delamination, broken connectors or wires.

4.2 Step 2: Connect Skeleton

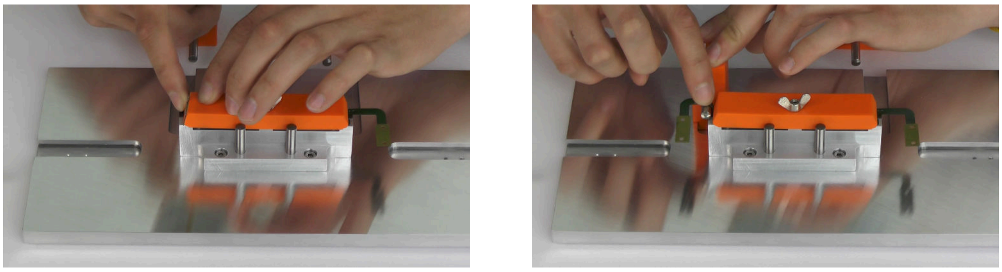
The Skeleton Plate serves as a mounting fixture to connect the SEH with the two FEHs. In addition to that, the Skeleton can be tested on its functionality which could reduce the reception testing of single FEHs and SEHs. For this the Skeleton Plate has the same outer dimensions as the 2S module carrier and can be mounted in the OT module test box. Again the operator should be protected against ESD during the whole procedure.

To connect the SEH with the FEHs the FEHs are first placed on the aluminium plateaus on the left and right side. Their position is fixed by inserting two 2 mm pins ("H"). If the 2 mm pins do not fit in the corresponding holes due to glue residues or misalignments of the hybrid layers, the hybrid gluing jig set contains red "U I" pins, which are undersized by 100 μm having a diameter of approximately 1.9 mm.



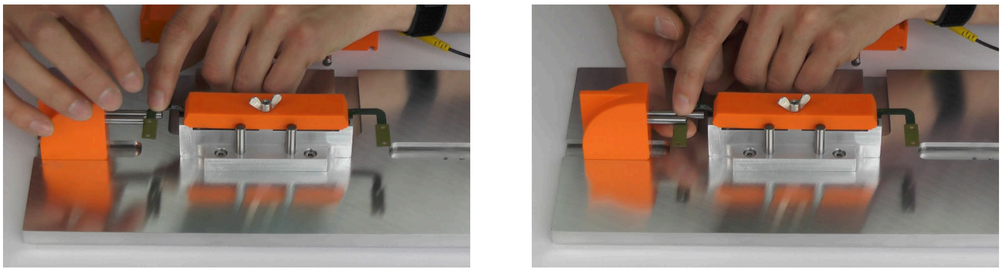
(a) SEH placed on Bending Tool

(b) Protection cap on top of SEH



(c) First bending step

(d) Second bending step



(e) Third bending step

(f) Fourth bending step

Figure 7: Bending steps of the SEH

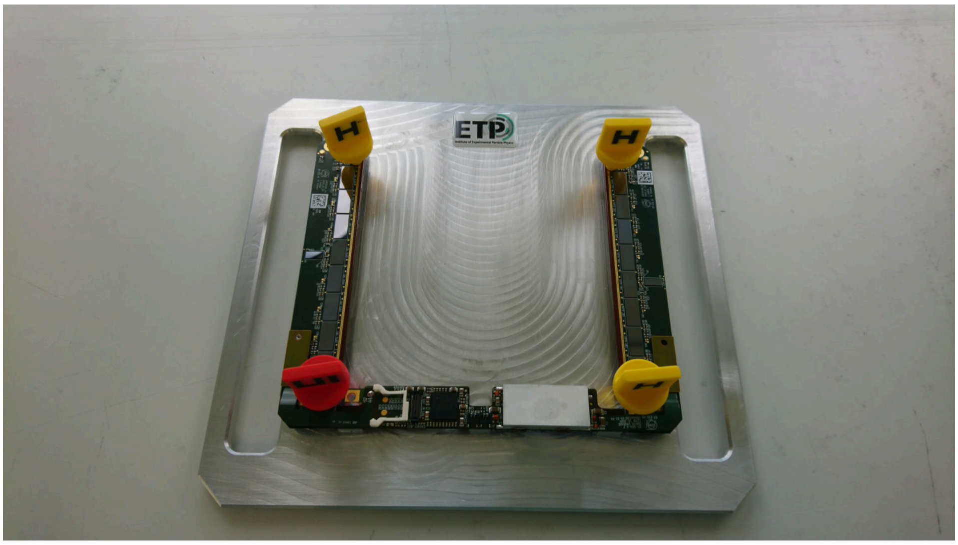


Figure 8: Skeleton on plate

For 1.8 mm Skeletons the three cylindrical height adapters must be placed in the milled grooves to adapt to the difference in height. Then the SEH can be placed on the three plateaus. It is positioned with two 2 mm pins which are already mounted in the plate.

The L-shaped tails of the SEH should rest above the corresponding connectors of the FEHs. The next step is to gently mate the two connectors. The result is shown in Figure 8. Each connection is secured with two specialized M1 screws. The screw is placed on top of the connector and screwed into the thread of the FEH using a torque screw. The torque to be applied is – Nm (to be defined).

4.2.1 Skeleton Readout

To prepare the skeleton for readout the LV must be connected. Before any voltage is applied, the polarity of the cables (GND and +10 V) must be checked! In addition to this the VTRx has to be plugged into the SEH. This is a very delicate procedure and should not be done without valid reason to minimized the mating cycles of this connection. The VTRx is placed loose on the SEH and then pushed sideways below the plastic clamp. Then the plug can be mated with the connector of the SEH. During this the operator should support the SEH using two fingers to avoid a bending of the SEH. It is also possible to place something below the SEH for support with a matching height.

After connecting the LV the skeleton can be tested on its functionality in the module test box. HV must not be connected. For more information see: (There will be a short documentation about the readout box which will come by autumn 2021)

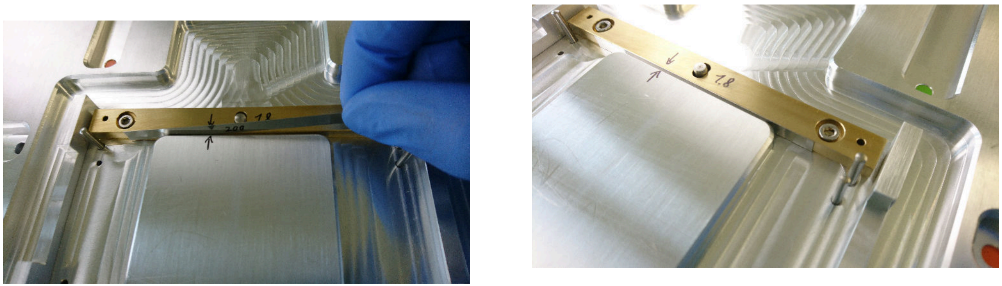
4.3 Step 3: Glue Skeleton to Bare Module

The assembly procedure of the hybrids to the bare module starts by placing the bare module on the jig. Afterwards the glue is applied and the skeleton is placed on the bare module as a whole. Then the front-end hybrids are positioned using alignment pins and the glue joints are secured with magnetic pushers. It was concluded by the OT modules working group to use alignment pins to position the hybrids. This technique requires a less elaborated tooling compared to previous designs that allowed to position the hybrids more freely. Downside is that before the jig is used for its first time or when a new batch of hybrids are available some preparations need to be done.

4.3.1 Prepare Hybrid Gluing Jig

The front-end hybrids are positioned using 2 mm alignment pins (”H”), which are pushed through the hybrids alignment holes into the brass rails below. The jig has a feature that allows to adjust the distance of the FEHs to the bare module by changing the position of the brass rails. The rails are in flat contact with the aluminium plateau in the middle of the jig. By adding feeler tapes between this plateau and the rails, the distance and thus the FEH position can be changed (see Figure 9a). There are two different pair of rails, one for 1.8 mm modules and one for 4.0 mm modules. The arrows on the aluminium plateau and the brass rails should point to each other to ensure that the brass rail is positioned correctly.

Before the first modules are assembled with the jig it is mandatory to go for a *dry run* to figure out the correct brass rail distance to roughly have a gap of 100 μm



(a) Feeler tape inserted between aluminium plateau and brass rail.

(b) Brass rail is pushed against aluminium plateau and then secured with two M3 screws.

Figure 9: Hybrid Gluing Jig preparations

between the FEHs and the bare module. It is assumed that the manufacturing tolerances of the FEHs do not vary too much or at least only batch-wise during the production period. This should allow to build many modules without changing the brass rail position. The dry run should mimic the real assembly sequence but without the application of glue. With the *Gap Tester* it is possible to estimate the distance between the bare module and the FEH on the top side of the module. Afterwards the brass rail distance should be changed accordingly. The distance can be changed by inserting different combination of feeler tapes. There are three pairs of feeler tapes with different thickness: 50, 100 and 200 μm.

Inevitable, there are (machining) tolerances that add up:

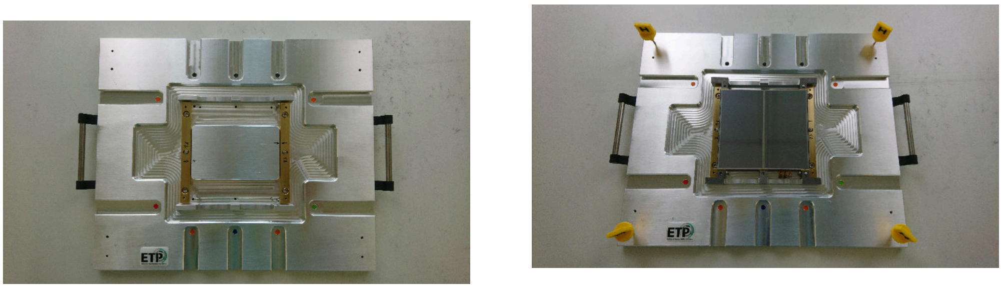
- Plateau milling in aluminium plate
- Position of the 2 mm drilling in the brass rail
- Tolerances on the diameter of the 2 mm alignment pin
- Position of the alignment holes of the hybrid
- Diameter of the alignment holes of the hybrid

Therefore, the thickness of the feeler tape layers can only be estimated, and the value can vary between left and right. A good guess is to start with 150 μm on both sides.

4.3.2 Assembly of Skeleton to Bare Module

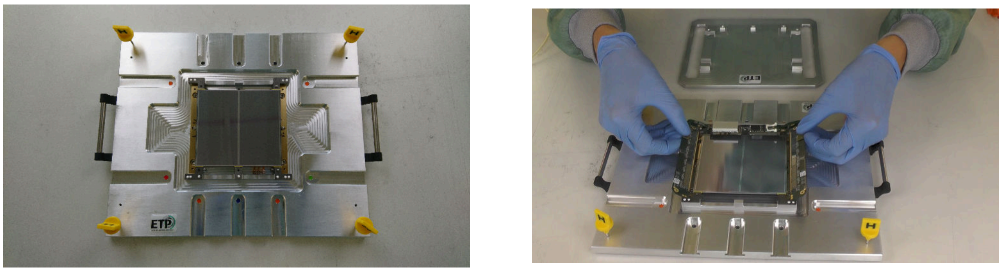
Placing the objects must happen with maximum care. As first step all magnetic pushers should be removed from the hybrid gluing jig to have as much space as possible to place the components as shown in Figure 10a. The bare module is aligned using two 2.5 mm pins on the right-hand side of the jig (see Figure 10b). Make sure the AlCF bridges are lying flat on the aluminium plateaus. Then the glue can be applied as shown in Figure 10c. 11 drops, 4 for each FEH and 3 for the SEH with 3 mg are sufficient. The skeleton placement is the most critical part of the sequence. It can be lifted up holding it at the two connectors or between the connectors and CICs. First focus should lie on the alignment of the SEH to avoid that it bumps against the sensor sandwich.

While the skeleton is lowered, the FEH should be tilted as shown in Figure 10d. This way the risk of touching the sensor edges with the FEH is reduced. The FEH then slide into the sensor sandwich. After the Skeleton is placed the SEH position



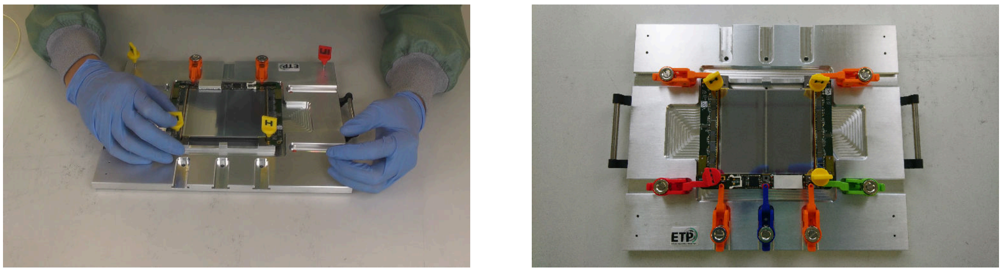
(a) Empty hybrid gluing jig

(b) Bare module aligned with two 2.5 mm pins



(c) Glue application

(d) Placing the skeleton



(e) SEH secured, insert FEH pins

(f) Hybrids aligned and pushers applied

Figure 10: Hybrid Gluing Jig assembly procedure

should be secured with its magnetic pushers (Two orange, one blue) to ensure it does not lift up, loosing its alignment pins while the FEH are positioned.

After the SEH is secured the alignment pins of the FEH can be inserted. In an ideal case this happens with the yellow 2 mm pins. If there are any problems especially that the pins do not fit in the holes of the FEH as mentioned before, one can use the undersized red pins labelled with "U I", which stands for "Undersized 100 μm". They have a diameter of about 1.9 mm. Using this pins give some freedom to move the hybrid, which must me checked with a microscope and can be confirmed with the Gap Tester. As last step the magnetic pushers are engaged to apply pressure on the glue joints. Placing the red and green pusher is a bit tricky to not clash with the grasp of the alignment pin, but doable. After 24 hours the module can be removed from the jig. First the pins are removed, again with maximum care. Then the magnetic pushers can be released leaving the module laying on the aluminium plateaus ready to be placed onto the module carrier.

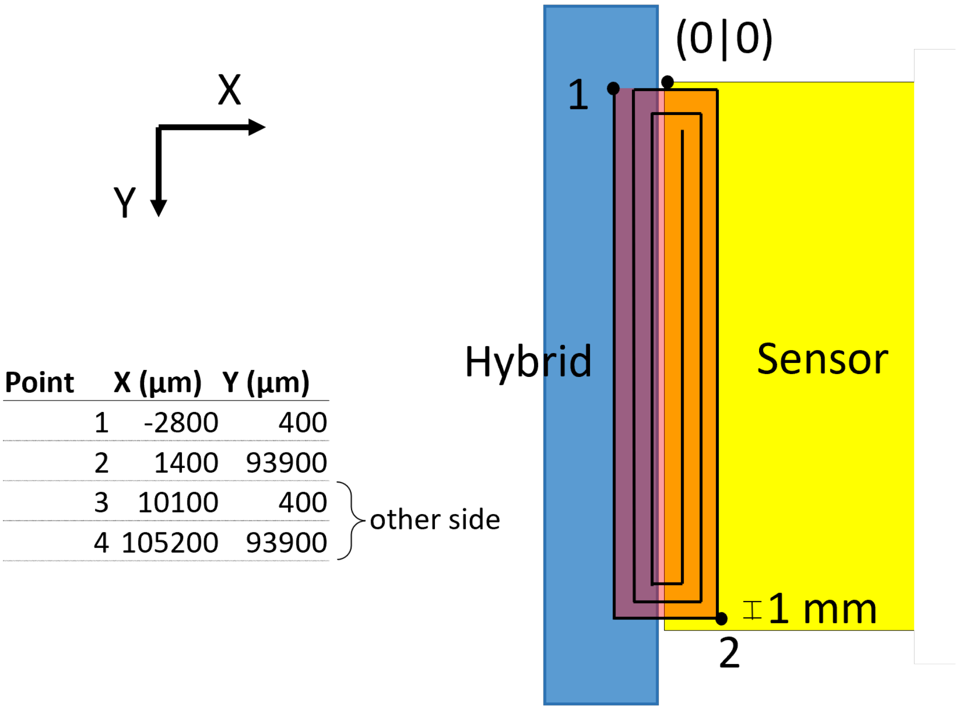
5 Wire bonding

6 Wire-bond encapsulation

Each 2S module has more then 4000 readout wire-bonds. To protect them from mechanical damage and electrochemical corrosion the wire-bonds are encapsulated with a silicon elastomer. The material used is Dow Corning Sylgard 186 [8]. Mixing and filling procedure of the cartridge is documented . The application requires a volumetric dispenser mounted on a gantry. To have proper protection each wire-bond should be fully covered by at least 150 μm of silicone. After wire-bonding, the modules are sitting on their carriers. Therefore, the gantry must have a matching fixture to mount one or more carriers.

The OT module working group developed a reliable dispensing pattern yielding nicely covered wire-bond rows. The readout wire-bonds of a 2S module are 4 to 4.5 mm long and have a height of 500 to 700 μm. As shown in Figure 11, the dispensing pattern developed consists of a spiral containing six lines with equal distance. The spiral is dispensed starting from the outer region going inwards with a distance between tip and sensor/hybrid of 1 mm. For the opposite module side the dispensing pattern is mirrored. The used dispensing tip and feeding values vary among the assembly sites. Figure 12 shows an encapsulation process using a blue tapered tip (inner diameter 0.41 mm) and a feeding value of 0.005 cm/s.

It takes 0.55 g to encapsulate one wire-bond row. Having four wire-bond rows the overall encapsulation mass on the module is 2.2 g, which is roughly 6 % of the modules' mass. Although the curing time of Sylgard 186 is 48 hours at room temperature, it can be handled safely after 24 hours, enabling a full encapsulation of both module sides in two working days. After one side is encapsulated the module can be removed from the gantry and stored in a cabined to proceed the next working day with the second side.



Point	X (µm)	Y (µm)
1	-2800	400
2	1400	93900
3	10100	400
4	105200	93900

Figure 11: Dispensing pattern to encapsulate one wire-bond row of a 2S module

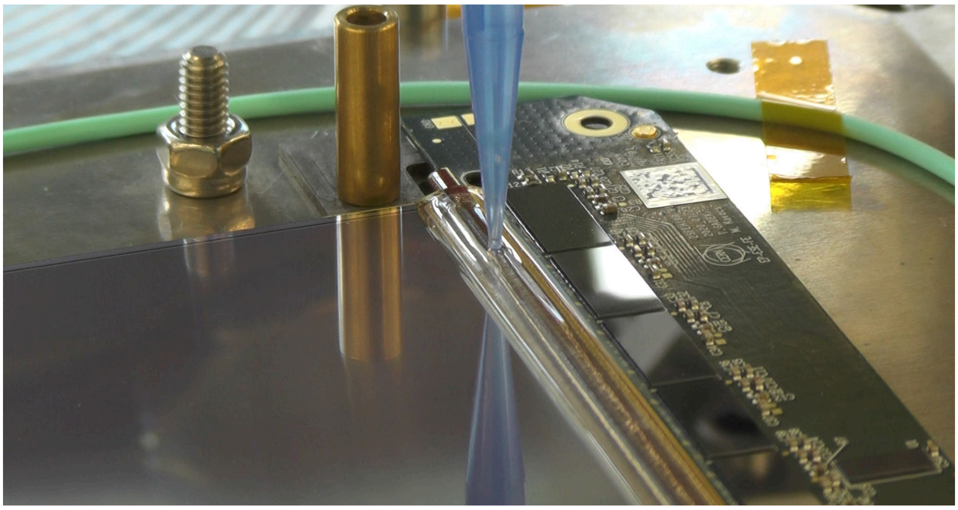
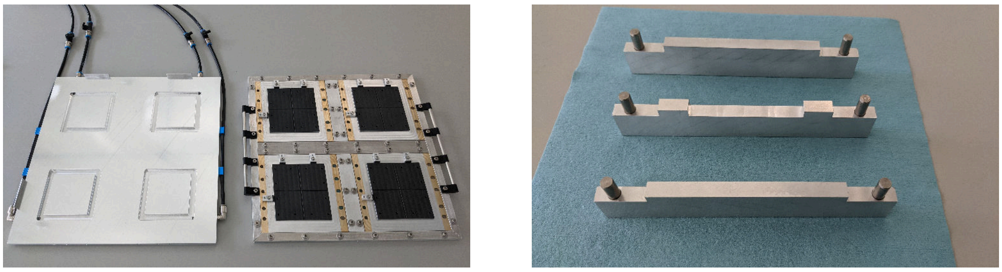
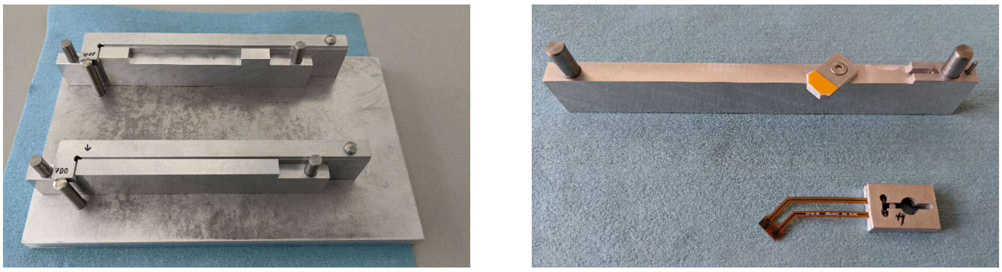


Figure 12: Encapsulation of a 2S module wire-bond row



(a) Vacuum plate and sensor array (b) Polyimide pickup tools



(c) L-shaped stops (d) HV tail pickup tool

Figure 13: Polyimide gluing jig set

A Tooling

A.1 PI isolator and HV circuit gluing jig

The polyimide gluing jig at KIT has several components. As shown in Figure 13a, four sensor isles form a 2 × 2 array. Each isle is machined from distortion free aluminium. To place the sensors on the jig, ESD-safe PTFE plates are glued on the aluminium and machined afterwards. PTFE stops align the sensor on the jig. These stops are milled at the same steps as the alignment bores. The 2×2 array can be placed on a vacuum plate, also machined from distortion free aluminium. With vacuum holes through the PTFE and aluminium the sensors are sucked down and kept in place on the PTFE surface. The vacuum plate has four valves, one for each sensor isle.

The polimide strips and HV tails are positioned and placed with pickup tools. To match the precision drills in the sensor isle, all pickup tools have the same outer dimensions and pin distances. For each sensor isle there are two pickups for the long polyimide strips, one for the short strip and one for a HV tail. The strips are positioned on the pickups with L-shaped stops (see Figure 13c), which come in two variants. One for an polyimide overlap of 700 m with respect to the AlCF bridges (long strips) and one for 1000 m (short strips). The HV tail pickup has additional positioners pieces holding the HV tails (see Figure 13d). There are magnets incorporated in the pickup tool and the positioners pieces to keep them together.

A.2 Sensor sandwich gluing jig

This fixture is designed to integrate top and bottom sensor subassemblies into a single unit, creating an epoxied subassembly with the modules mechanical mounting features sandwiched between the two sensor subassemblies. In earlier steps of the production process, each of these sensors has had insulating Kapton sheets epoxies to

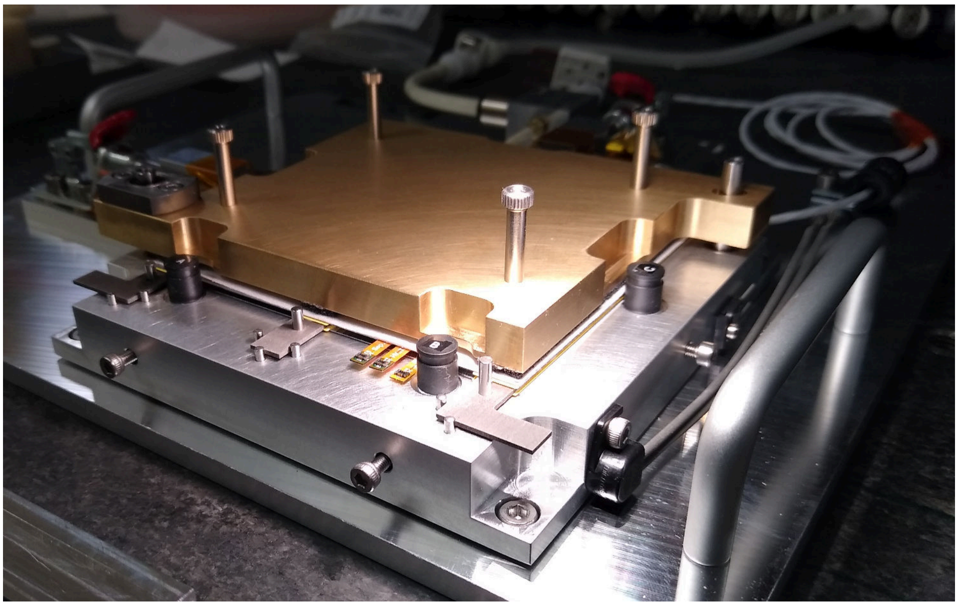


Figure 14: Sensor alignment fixture.

areas of the sensor bottom surface to prevent electrical contact with the mechanical mounts. In addition, small Kapton circuit pigtails have also been epoxied into place and wirebonded to the back surface of the sensors for bias voltage connection. These wirebonds have been encapsulated prior to beginning this assembly step. After completing the sensor assembly steps, the module is to be stored at a slightly elevated temperature while the epoxy is curing. Afterwards, the sensor subassembly is visually inspected and then taken to the next assembly station for inspection of the sensor alignment. A detailed description of the assembly procedure for this production step is included in [9].

The fixture design for the tooling involved in this step is included in [10] and is primarily composed of two sections: the jig that is used to align the parts during assembly (see Fig. 14), and a separate tool used to help dispense epoxy onto the face of the larger of the two mounting bridges (see Fig. 15).

Basically, the sensor alignment fixture relies on the excellent dicing accuracy of the silicon by Hamamatsu to accurately positioning the sensor edges relative to the hole and slot features designed into the mounting supports that are sandwiched into the sensor subassembly during this step of the process. Sensor edges are spring-loaded against three precision pins, and the location of those edge pins relative to the pins used to register the location of the mounting bridges is controlled by the accuracy of the machining of the top plate of the fixture. The drawing for that fixture plate is shown in Fig. 16.

After the sensor-bridge sandwich has been arranged on the fixture, a guided weight plate is used to hold the parts together while the epoxy is curing. A protective sheet of lens paper is included both above and below the module subassembly to protect the surface of the top and bottom sensors.

After epoxy curing, the fixture pins are removed allowing easy transfer of the module off of the tooling. A visual inspection is performed to check for any excess epoxy runout and the module is then transferred to the next assembly station for inspection of the sensor-to-sensor alignment.

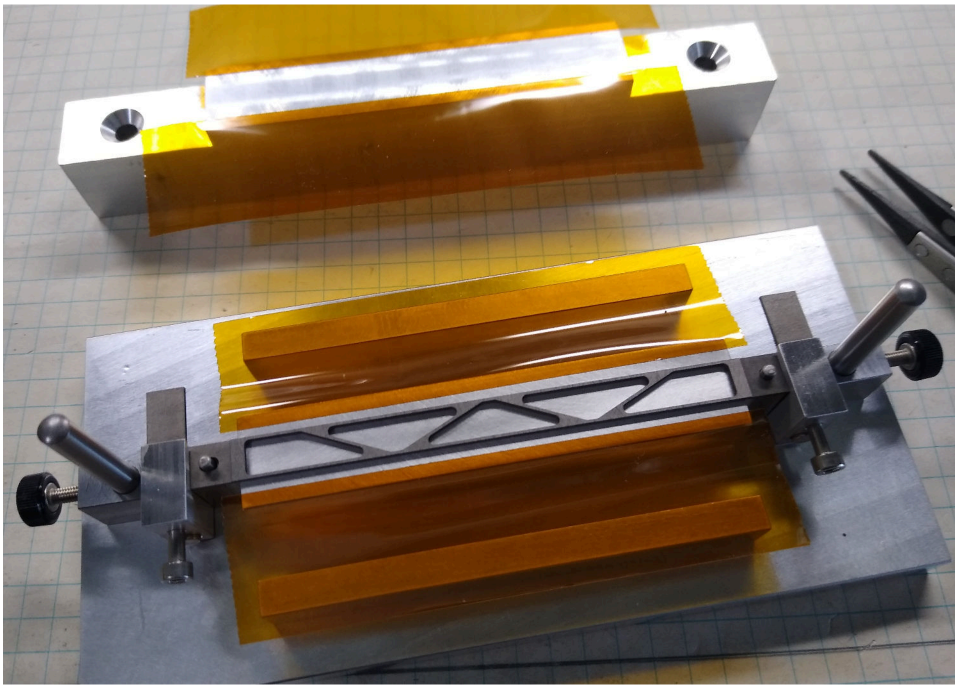


Figure 15: Bridge epoxy application tool.

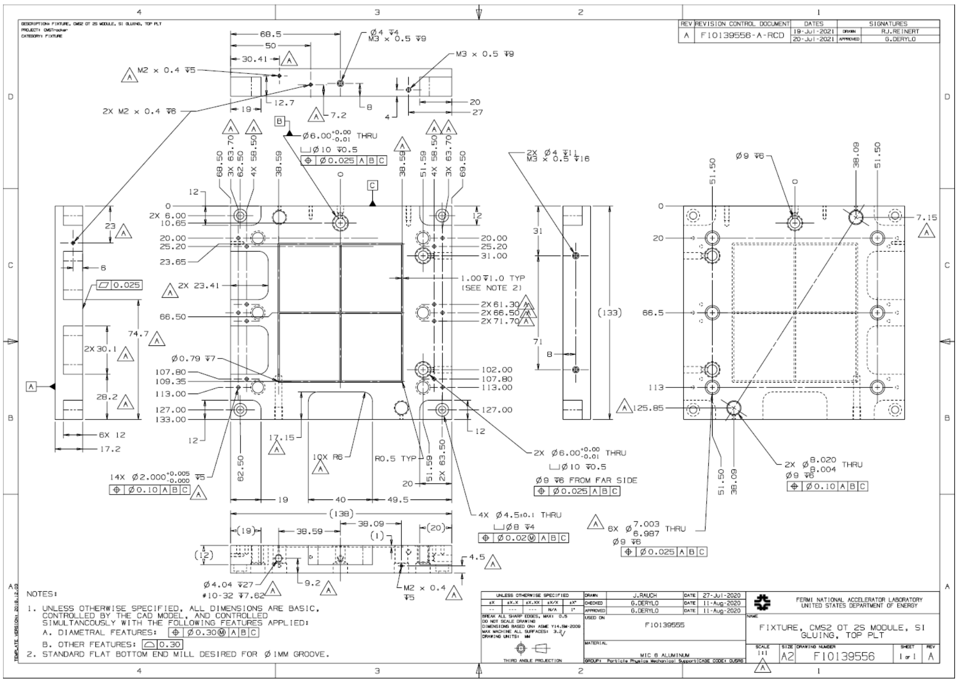


Figure 16: Top plate of the sensor gluing fixture used to align the sensor edges to the hole/slot features in the mounting bridge supports.

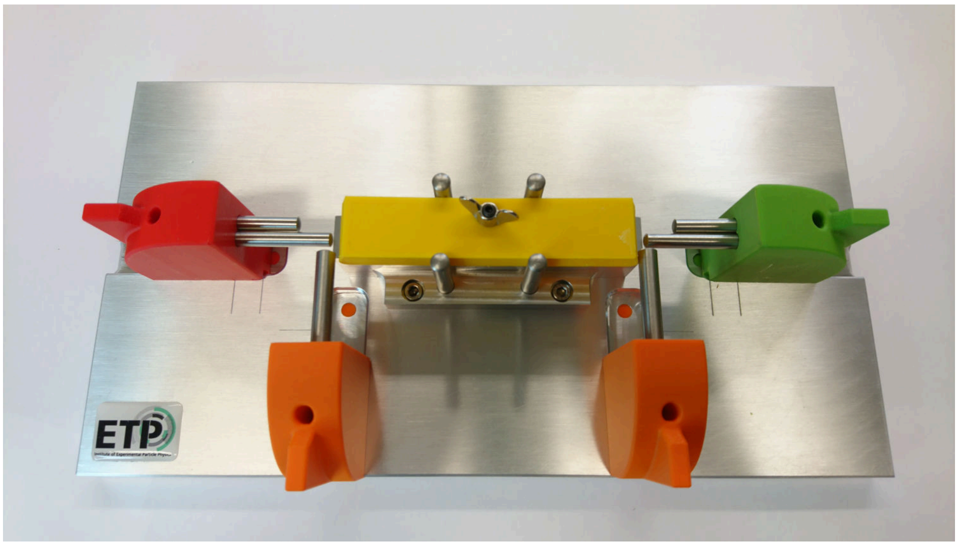


Figure 17: The Bending Tool

A.3 Hybrid gluing jig set

There are three fixtures for the hybrid assembly of 2S modules: Then bending tool, the skeleton plate and the hybrid gluing jig itself.

A.3.1 The Bending Tool

The SEH of the 2S module has L-shaped tails with connectors that mate with the FEHs. The L-shaped design absorbs most of the stress that could be introduced in the connection by misalignment of various parts and components:

- Assembly tolerance of the connectors on the flexes
- Assembly tolerance of flexes on the carbon fibre stiffeners.
- Assembly tolerance of the hybrids

Coming from the manufacturer the SEH has a flat shape. To have more flexibility the L-shaped tails must be pre-bend before the assembly starts. The tool is shown in Figure 17 and consists of:

- 1 Distortion-free aluminium plate with an attached aluminium plateau
- 1 Protection cap (3D print, yellow)
- 1 Winged nut (M4)
- 2 Single pin (6 mm) slider units (3D print, orange)
- 1 Double pin (5 mm) slider unit ”left” (3D print, red)
- 1 Double pin (5 mm) slider unit ”right” (3D print, green)

The pushers can move in the milled guide ways and contain a pressure pin below. This pin engages in pre-defined marks in the guide ways giving the correct position for the assembly procedure. The force the pressure pin applies on the guide way can be adjusted with a hex key inserted through the hole on the top.

A.3.2 The Skeleton Plate

The Skeleton Plate is used to connect the SEH to the two FEHs. The resulting object is called Skeleton which can be tested in the module readout station. The Skeleton Plate is shown in Figure 18 and contains:

- 1 Distortion-free aluminium plate in the size of a 2S Module carrier
- 3 Height adapter cylinders
- 4 Alignment pins with grasps "H" (2 mm h8, yellow)

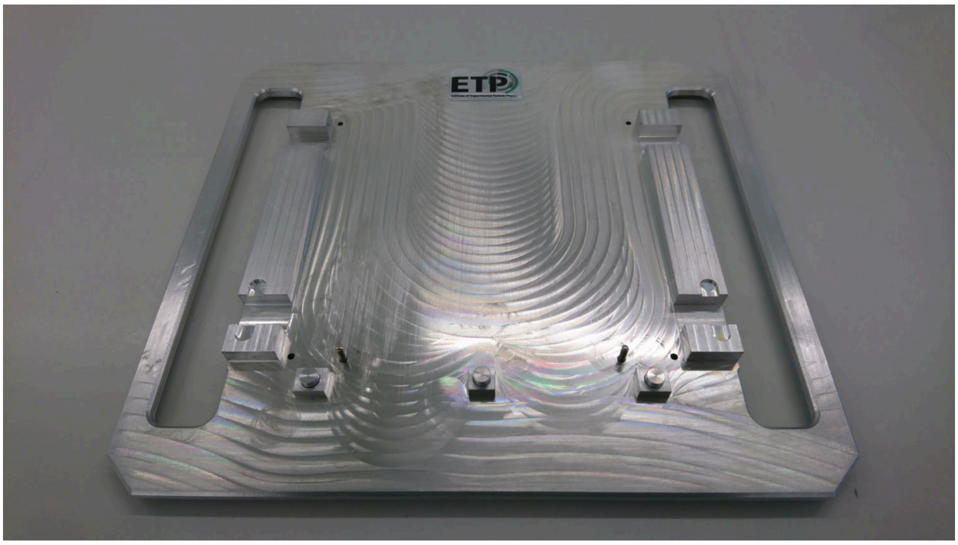


Figure 18: Empty Skeleton Plate

A.3.3 The Hybrid Gluing Jig

The Hybrid Gluing Jig is used to attach the Skeleton to the bare module. It is shown in Figure 19 and consists of

- 1 Distortion-free aluminium plate with grasps
- 8 Alignment pins with grasps "H" (2 mm h8, yellow)
- 4 Alignment pins with grasps "U I" (1.9 mm, red)
- 4 Magnetic pushers with centred round tip (3D print, orange)
- 1 Magnetic pusher with centred flat tip (3D print, blue)
- 1 Magnetic pusher with left round tip (3D print, red)
- 1 Magnetic pusher with right round tip (3D print, green)
- 2 Brass rails to assembly 1.8 mm modules
- 2 Brass rails to assembly 4.0 mm modules
- 6 feeler tapes to adjust distances
- 1 "Gap Tester"

There are four pins permanently mounted in the jig. Two 2.5 mm pins (m6) to position the bare module and two 2 mm (m6) pins to position the SEH. The two FEHs are positioned with two 2.0 mm "H" (h8) or two 1.9 mm "U I" pins each.

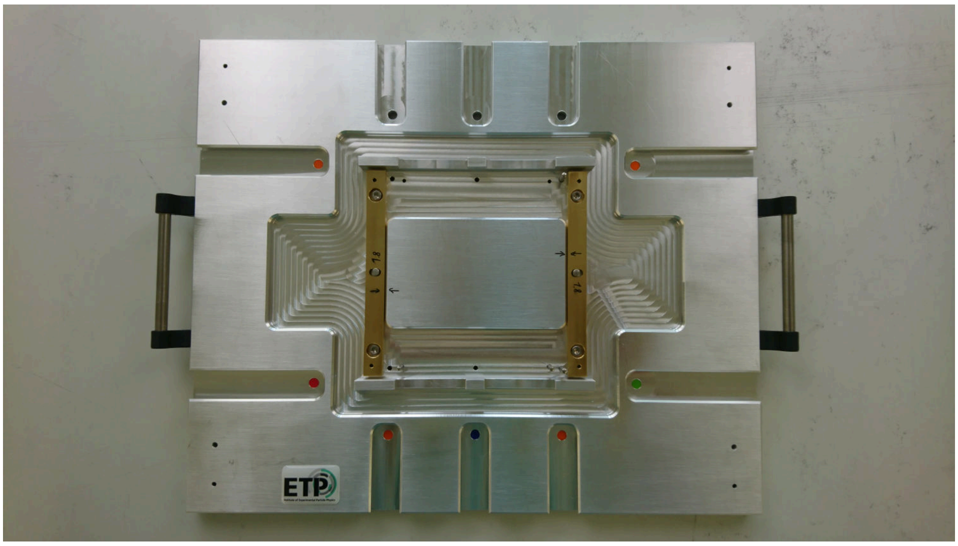
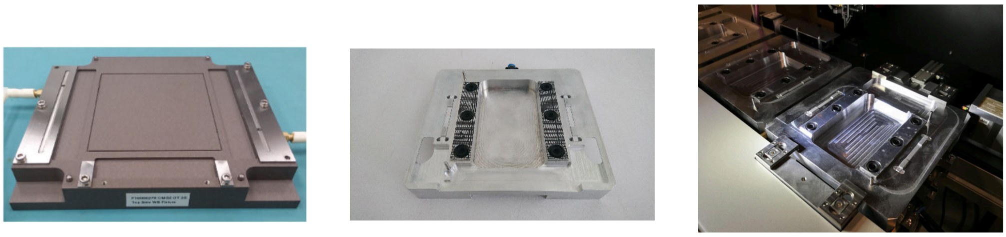


Figure 19: Empty Hybrid Gluing Jig



(a) FNAL wire-bonding jig (b) KIT wire-bonding jig (c) RWTH Aachen wire-bonding jig conveyor system

Figure 20: Wire-bonding jigs among assembly sites

A.4 Wire bonding jigs

The wire-bonding jig of 2S modules was initially designed at CERN. Due to different conditions among the assembly site it was decided by the OT module working group that each assembly site is in charge of its own 2S module wire-bonding jig. The different developments can be separated in three approaches:

- Separation of fixture for bottom and top side of the module: Developed at FNAL, originated due to problems with breakages of Al-CF bridges by aligning the module on the jig. The design is shown in Figure 20a. There are separate fixtures for the top and bottom side of the 2S modules. The fixture is coated with Nituff and a static-dissipative polyester film (MMC 8189K12) for ESD safety
- Modified CERN design: Shown in Figure 20b. The design is based on the initial CERN design to wire-bond both, the top and bottom side of a 2S module. The lower sensor is sucked down with suction cups onto a flat aluminium surface coated with an ESD-tape. Support rods can be moved upwards to support the FEHs during wire-bonding. Due to the design changes of the 2S modules (L-shaped tails, ...) some parts were removed on the jig, freeing some space. The diameter of the alignment pins was reduced from 2.5 to 2.4 mm. This reduces clamping and thus the risk of bridge breakage during placement and removal of the modules. The final design of this jig is planned to be available by the end of 2021 (KIT).
- Conveyor system: Developed at the RWTH Aachen to feed a Delvotec G5 machine with up to 4 modules in a row. As shown in Figure 20c, it also uses a modified version of the initial CERN design.

A.5 Carrier plate

Due to the fragile nature of the module, a handling frame is to be used to minimize the risk of damage to the module. The module is to be transferred onto the carrier after hybrid installation and it is taken out only during the wirebonding steps. Other process steps, such as testing and wirebond encapsulation, can be performed while the module is on its carrier, thus minimizing handling risk.

The design for the carrier is included in [10] and is primarily composed of three sections: the aluminum base plate, the transparent covers, and the interfaces for both the electrical and fiber optic services.

The module is mounted to the carrier plate by using undersized screws that project upwards from underneath the plate as alignment pins that pass through the mounting holes and slots in the modules structural bridges. Tall plastic nuts, easily manipulated by hand, are then installed on the projecting screws to tighten the module mounting points to the carrier plate. The plate also has built-in spacers installed on its surface (shown in light purple in Fig. 21) to provide support under the readout and service hybrid sections that are positioned off the surface of the carrier, and these spacers limit hybrid motion that may occur when mating electrical connectors or during other module handling. The aluminum carrier plate is Alodine coated in order to allow reliable electrical grounding.

Transparent covers are installed above and below to protect the module from accidental contact. These are machined from a transparent poly material with a built-in static-dissipative surface coating to help ensure ESD safety. The bottom cover is hermetic but the top cover is offset with spacers, thus allowing the routing of electrical and fiber-optic services. The top cover also is open over much of the service hybrid due to the height of the components there and the need to access the fiber optic services.

Connections at one edge of the carrier assembly act as an interface point between the module services and testing systems. A small electrical board is mounted here, allowing the connection of the high and low voltage lines to the service hybrid. This board also contains an RTD on its underside, so temperature of the carrier plate can be monitored during module testing. A fiber-optic connector is also mounted to the edge of the carrier. Either of the modules two fiber-optic pigtail lengths can be accommodated, although for the longer pigtail a loop of excess length must be made and then constrained with tape to the surface of the top cover. For both fiber pigtails, an additional sacrificial pigtail is also included here (shown in blue in Fig. 21) in order to minimize cycling of the production MT connector. Small commercially available restraints are used on the carrier to control the routing of both the electrical and fiber-optic services. The assembly drawing for the carrier is shown in Fig. 22.

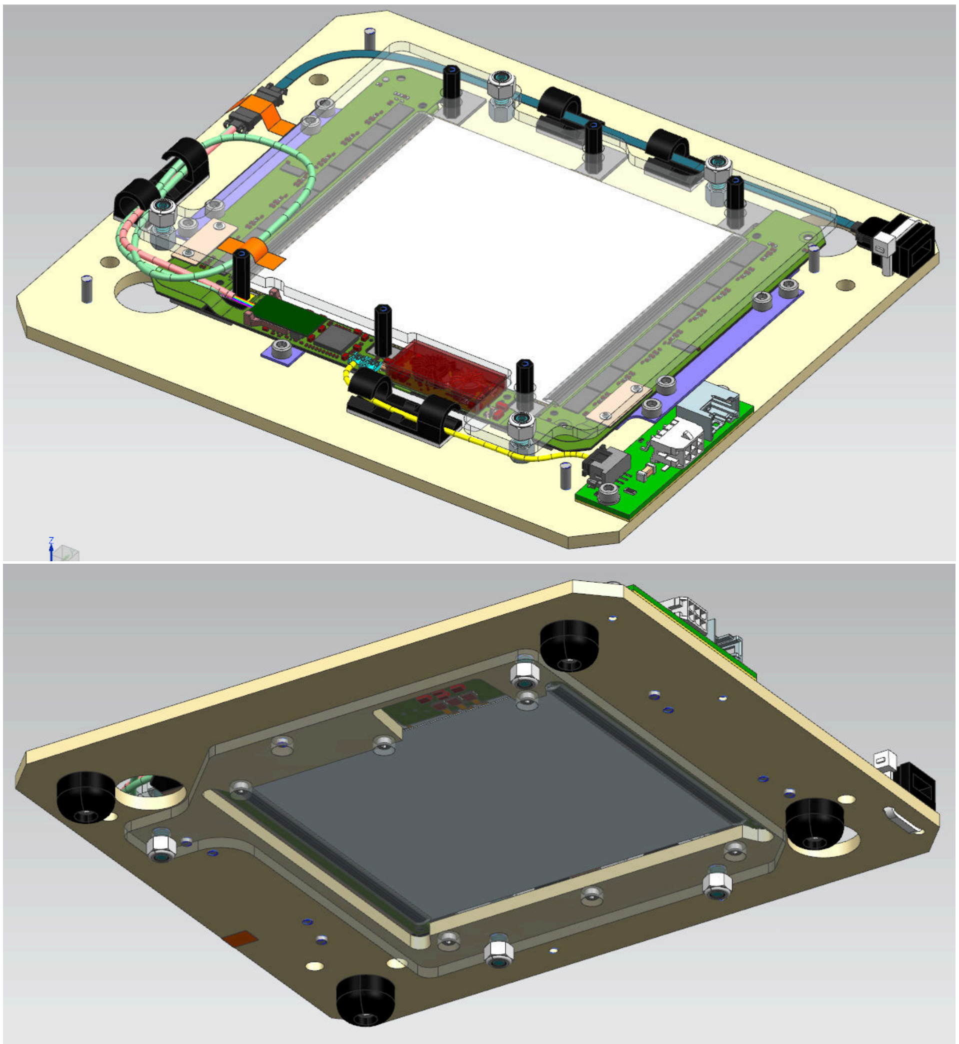
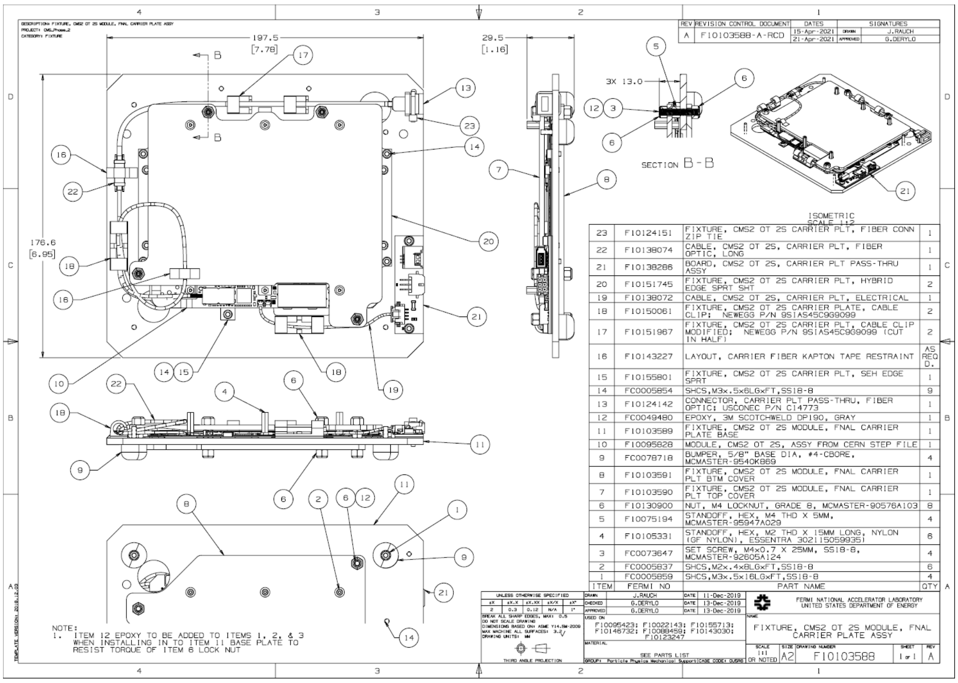


Figure 21: Top and bottom view of the carrier plate assembly.


DESCRIPTION: FIXTURE, CMS2 OT 2S MODULE, FNAL CARRIER PLATE ASSY
PROJECT: CMS_Phase_2
CATEGORY: FIXTURE

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES	
A	F10103588-A-RCD	15-Apr-2021	DRAWN	J.RAUCH
		21-Apr-2021	APPROVED	G.DERYLO

ITEM	FERMI NO	PART NAME	QTY
23	F10124151	FIXTURE, CMS2 OT 2S CARRIER PLT, FIBER CONN ZIP TIE	1
22	F10138074	CABLE, CMS2 OT 2S, CARRIER PLT, FIBER OPTIC, LONG	1
21	F10138286	BOARD, CMS2 OT 2S, CARRIER PLT PASS-THRU ASSY	1
20	F10151745	FIXTURE, CMS2 OT 2S CARRIER PLT, HYBRID EDGE SPRT SHT	2
19	F10138072	CABLE, CMS2 OT 2S, CARRIER PLT, ELECTRICAL	1
18	F10150061	FIXTURE, CMS2 OT 2S CARRIER PLATE, CABLE CLIP; NEWEGG P/N 9SIAS45C9G9099	2
17	F10151967	FIXTURE, CMS2 OT 2S CARRIER PLT, CABLE CLIP MODIFIED; NEWEGG P/N 9SIAS45C9G9099 (CUT IN HALF)	2
16	F10143227	LAYOUT, CARRIER FIBER KAPTON TAPE RESTRAINT	AS REQD.
15	F10155801	FIXTURE, CMS2 OT 2S CARRIER PLT, SEH EDGE SPRT	1
14	FC0005854	SHCS,M3x.5x6LGxFT,SS18-8	9
13	F10124142	CONNECTOR, CARRIER PLT PASS-THRU, FIBER OPTIC; USCONEC P/N C14773	1
12	FC0049480	EPOXY, 3M SCOTCHWELD DP190, GRAY	1
11	F10103589	FIXTURE, CMS2 OT 2S MODULE, FNAL CARRIER PLATE BASE	1
10	F10095828	MODULE, CMS2 OT 2S, ASSY FROM CERN STEP FILE	1
9	FC0078718	BUMPER, 5/8" BASE DIA, #4-CBORE, MCMASTER-9540K869	4
8	F10103591	FIXTURE, CMS2 OT 2S MODULE, FNAL CARRIER PLT BTM COVER	1
7	F10103590	FIXTURE, CMS2 OT 2S MODULE, FNAL CARRIER PLT TOP COVER	1
6	F10130900	NUT, M4 LOCKNUT, GRADE 8, MCMASTER-90576A103	8
5	F10075194	STANDOFF, HEX, M4 THD X 5MM, MCMASTER-95947A029	4
4	F10105331	STANDOFF, HEX, M2 THD X 15MM LONG, NYLON (GF NYLON), ESSENTRA 302115059935)	6
3	FC0073647	SET SCREW, M4x0.7 X 25MM, SS18-8, MCMASTER-92605A124	4
2	FC0005837	SHCS,M2x.4x8LGxFT,SS18-8	6
1	FC0005859	SHCS,M3x.5x16LGxFT,SS18-8	4

NOTE:
1. ITEM 12 EPOXY TO BE ADDED TO ITEMS 1, 2, & 3 WHEN INSTALLING IN TO ITEM 11 BASE PLATE TO RESIST TORQUE OF ITEM 6 LOCK NUT

UNLESS OTHERWISE SPECIFIED

±X	±X.X	±X.XX	±X/X	±X°
2	0.3	0.12	N/A	1°

BREAK ALL SHARP EDGES, MAX: 0.5
DO NOT SCALE DRAWING
DIMENSIONS BASED ON: ASME Y14.5M-2009
MAX MACHINE ALL SURFACES: 3.2
DRAWING UNITS: MM
THIRD ANGLE PROJECTION

DRAWN: J.RAUCH DATE 11-Dec-2019
CHECKED: G.DERYLO DATE 13-Dec-2019
APPROVED: G.DERYLO DATE 13-Dec-2019
USED ON: F10095423; F10022143; F10155713; F10146732; F10088459; F10143030; F10123247
MATERIAL: SEE PARTS LIST
GROUP: Particle Physics Mechanical Support
CAGE CODE: 0U5R6
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
NAME: FIXTURE, CMS2 OT 2S MODULE, FNAL CARRIER PLATE ASSY
SCALE: 1:1 OR NOTED
SIZE: A2
DRAWING NUMBER: F10103588
SHEET: 1 of 1
REV: A

Figure 22: Carrier plate assembly drawing.

References

[1] Outer Tracker Modules WG. Baseline 1.8 mm 2S Module 5 Cooling Contacts. `https://edms.cern.ch/document/2642676`, 10 2021.

[2] Outer Tracker Modules WG. Baseline 1.8 mm 2S Module 6 Cooling Contacts. `https://edms.cern.ch/document/2642678`, 10 2021.

[3] Outer Tracker Modules WG. Baseline 4.0 mm 2S Module. `https://edms.cern.ch/document/2642679`, 10 2021.

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[8] Dow. Sylgard 186 Datasheet. `https://edms.cern.ch/document/2638759`.

[9] Abhishek Bakshi and Greg Derylo. Phase 2 OT Module 2S – Fermilab Assembly Procedures. CMS-doc-13973 `https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13973`.

[10] Abhishek Bakshi and Greg Derylo. Phase 2 OT Module 2S – Fermilab Fixture Drawing Copies. CMS-doc-13443 `https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13443`.