CMS Tracker FE-Hybrid Working Group Document
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# Technical specification and procedures for the final assembly of the CMS silicon tracker front-end hybrids

## Working Draft

## 1 Introduction

This document describes the technical specifications, the procedures, and the QA/QC issues involved in the final assembly of the front-end hybrids for the CMS silicon strip tracker. The described procedures are planned to be carried out primarily at CERN.

What is termed the ‘final assembly’ in this document refers to the mounting of the glass pitch adapter (PA) and the front-end ceramic hybrid circuit (CHC) onto the carbon fibre (CF) carrier plate, or in the case of the TIB hybrids onto the ceramic hybrid itself. The final assembly also includes the wire bonding from the APV25 read-out chips inputs to the PA. It is assumed that the hybrid circuit is fully loaded with components and cable(s), the bonding of the PLL, DCU and control+power lines of the APV25s is done, and the hybrid circuit has been fully tested electronically. It is also assumed that the PAs have been fully tested for opens and shorts.

## 2 Description of the Hybrid Configuration

### 2.1 TOB and TEC hybrids

The TOB and TEC hybrids will have a similar design utilizing four main components: the CF hybrid carrier, the CHC, the PA, and the spacer for the PA. The PA, spacer and CHC are mounted on the CF carrier which has the same thickness as that used for the module frames. The arrangement of the components is shown schematically in Figure 1. The CF carrier shape will vary with module type since it must accomodate the different dimensions of pitch adapters. In addition the PA will have a spacer placed between the PA and CF carrier plate. This spacer serves to raise the height of the PA to the same or slightly above the level of the APV chips. This will automatically make the PA height much greater than that of the sensors. This raising of the PA level is done in order to avoid the possibility that the bond wires from PA to sensor or PA to APV can touch the edge of the sensors or chips. This elevation is also needed to raise the PA high enough to clear the kapton circuits which run on top of the CF legs of the frame under the extreme ends of the PA. The spacer material will likely be carbon fibre. A schematic cross-sectional view of the hybrid and the relevant parts of a module is shown in Figure 2 roughly indicating the heights of the various components and the relative positions of the read-in bond wires that will have to be made on the hybrids of a module.

The thicknesses of the relevant components as currently expected are: TOB/TEC CF frame (600 $\mu$m), CHC (380 substrate + 150 glass and gold layers = 530 $\mu$m), Kapton+glue layer on frame (100 $\mu$m), TOB and rings 5-7 TEC sensors (500 $\mu$m), rings 1-4 TEC sensors (320 $\mu$m), APV chips (320 $\mu$m), CF hybrid carrier (assuming the same as TOB/TEC frame: 600 $\mu$m), PA (550 $\mu$m). Other glue layers are assumed to be 50 $\mu$m thick. The spacer must be at least 400 $\mu$m thick to ensure the PA is higher than the sensor and APV.

The PA, CF frame and spacer will have different dimensions and shapes for the different types of modules (two types for the TOB and ten types for the TEC). However, the TOB and TEC ceramic hybrids are of identical design and dimensions for all module types.

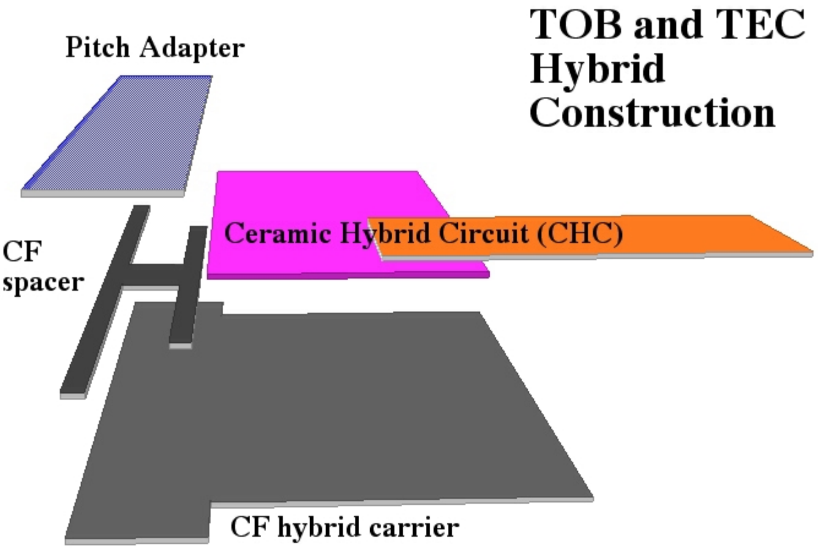

Figure 1: *Exploded view of the components which comprise a TOB or TEC hybrid.*

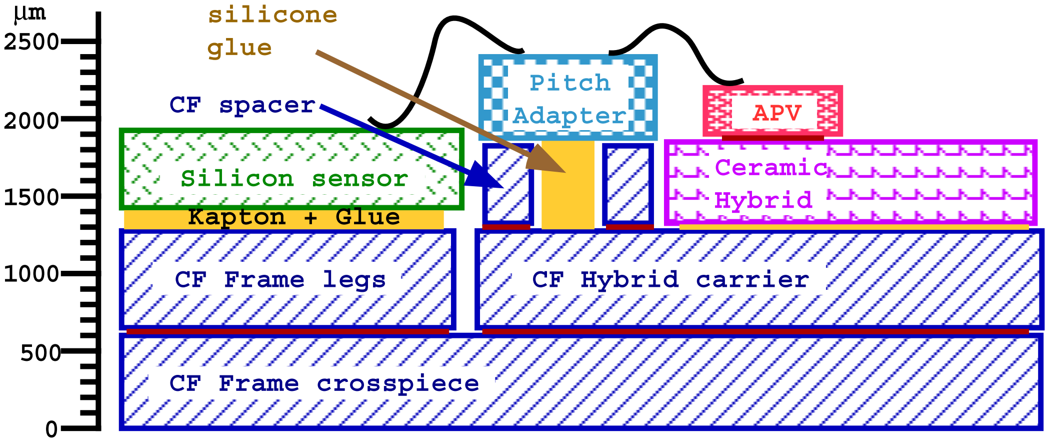

Figure 2: *Cross-sectional view of a cut through a TOB or TEC module at the hybrid.*

## 2.2 TIB hybrids

The TIB hybrids will consist of three components: the CHC, the PA and its spacer as shown schematically in Figure 3. The reason it will not be mounted on a CF carrier is because the TIB modules are made from a one piece CF frame instead of a three piece frame as for the TOB and TEC. As can be seen in the cross-sectional schematic of Figure 4, the height of the sensors is lower in the TIB module with respect to the CF frame under the hybrid by the thickness of the CF frame material (nominally 500 $\mu$m). The inclusion of a CF hybrid carrier would lead to an even greater height mismatch between the PA and the sensor. In addition the extra thickness of the CF of the hybrid carrier would further degrade the heat conduction from the APV chips to the cooling system. This is also an issue for the TOB and TEC modules but to a lesser degree owing to the lower density of APV chips and less restrictive heat conduction path in those modules. Instead of mounting the PA and CHC on a CF carrier, the PA will be mounted directly on the CHC. This requires that the CHC be extended forward by several mm along the edge with the APV25 chips. This extra ceramic will not have any printed circuit so will be the thickness of the bare ceramic with no metal or glass layers.

The PA will again need a spacer to support it under the edge facing the sensor. Although this support is needed only when bonding to the sensors, it is proposed to have the spacer glued to the back of the PA during the hybrid assembly. This will make it easier to work with the hybrid on a simple flat surface and should reduce somewhat the risk of breaking the glue joint between the PA and CHC.

The thicknesses of the components for the TIB are as for the TOB/TEC with the following exceptions: TIB CF frames (500 $\mu$m), TIB sensors (320 $\mu$m), and ceramic substrate spacer (380 $\mu$m).

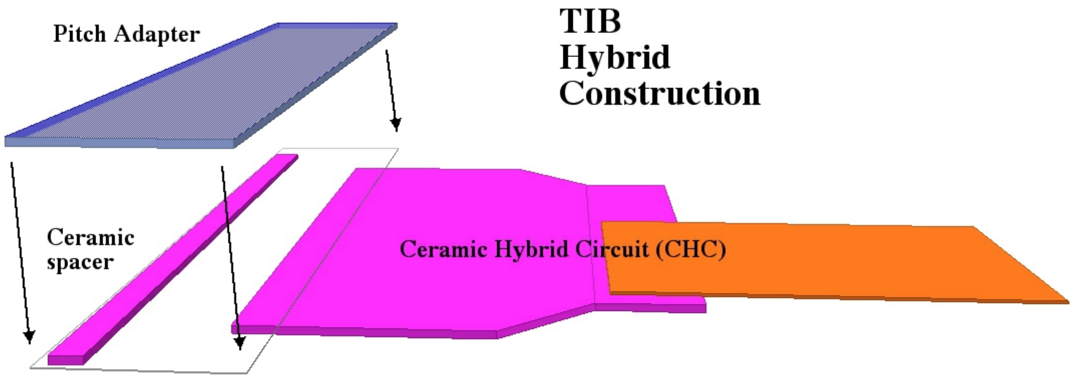

Figure 3: *Exploded view of the components which comprise a TIB hybrid.*

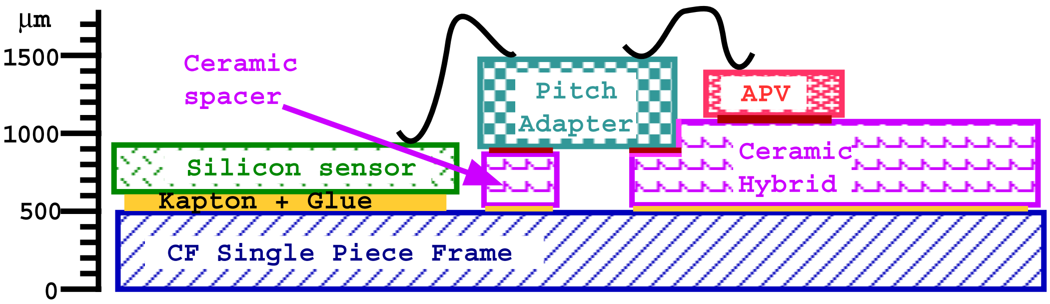

Figure 4: *Cross-sectional view of a cut through a TIB module at the hybrid.*

## 3 Technical Specifications for the Hybrid Final Assembly

The specifications of the front-end hybrid printed circuit are described in the separate front-end hybrid working group document. The drawings of the module design with details for the frames, PA, and sensors can be found in the EDMS document system. The specifications here pertain only to the final assembly of the hybrid.

## 3.1 TOB and TEC hybrids

The following subsections describe the specifications for the gluing and mounting steps to be performed on the TOB and TEC hybrids.

### 3.1.1 Ceramic hybrid circuit mounting

The mechanical specifications relevant to the final assembly of the hybrid concern the placement and gluing of the CHC onto the CF hybrid carrier plate are as follows:

1. CHC placement accuracy in X-Y: $< 50$ $\mu$m from nominal
2. type of glue used: CMS approved room temperature cure silicone glue
3. glue surface area of contact: complete coverage of CHC surface, no bubbles
4. thickness of glue layer: $< 50 \pm 20$ $\mu$m

Notes:

The alignment of the CHC to the CF plate will be done with respect to two pre-defined orthogonal edges of the plate or to two precision drilled holes in the plate.

It is not clear what type glue should be used for the ceramic to CF joint but the silicone based glue used for the sensor to CF frame is taken as default. The choice will depend on the analysis of the stresses and reliability of joints for the different candidate glues.

### 3.1.2 Spacer mounting

This is not fully worked out. This step will probably be done by the gantry but could be done by hand if the spacer is to difficult to handle (i.e. too small for the gantry pickup tooling). Assuming gantry mounting of a CF spacer, the mechanical specifications would be:

1. spacer: CF 500-600 microns thick, size and shape to match pitch adapter support requirements, large holes or voids in central areas away from regions under the PA bond pads to allow for silicone glue of the PA mounting
2. spacer placement accuracy in X-Y: $< 200$ $\mu$m from nominal
3. type of glue used: standard room temperature cure Araldite
4. thickness of glue layer: $< 50 \pm 20$ $\mu$m

The spacer could be made from either the TIB CF material (500 $\mu$m thick) or TOB/TEC CF material (600 $\mu$m thick). An economical solution would be to use the TIB CF excess material coming from the central hole cut-out.

### 3.1.3 Pitch adapter mounting

The mechanical specifications relevant to the final assembly of the hybrid concern the placement and gluing of the PA on the CF hybrid carrier plate are as follows:

1. PA placement accuracy in X-Y: $< 50\ \mu$m from nominal
2. PA top surface height with respect to CF hybrid carrier surface: 1100-1200 $\mu$m
3. PA surface parallelism with respect to CF surface: <5mR
4. type of glue used: CMS approved room temperature cure silicone glue
5. glue surface area of contact: to be specified when spacer is designed but the glue should be not be allowed into the spacer-PA interface

Notes:

X-Y placement accuracy is needed for alignment of the bond pads of the PA with respect to those of the APV25 chips. Also, there must be correct placement such that the gap between APV and PA is sufficient to allow access to the power bond pads on the ceramic hybrid surface in the case of repair. However, bonding to those pads may require a deep access bonding machine. The placement accuracy is defined as for the CHC, namely, with respect to the specified edges of the CF plate or to the precision alignment holes.

The parallelism specification is important in that a ‘tilted’ PA will make the fiducial marks difficult to find for the pattern recognition program of the module assembly gantries and of the bonding machines. The reflectivity of the metal pattern is very sensitive to the angle between the surface normal and the optical viewing axis.

The choice of glues is not definitive but will depend on the results of irradiation, mechanical and thermal tests that are in progress. A silicone based glue is chosen for gluing the PA so as to avoid thermally induced mechanical stress between the glass PA and the carbon fibre carrier plate. The spacer will likely have a skeleton-like form allowing for large glue drops to be placed at intervals but without allowing the glue to make a joint between the spacer and the PA. The spacer should be glued only to one of the two surfaces it contacts; that surface should be the one of the same material so there is no bi-metallic effect produced. Thus in the case of a glass spacer, the spacer may be glued to the PA a previous step. Similarly for a CF spacer, it may be glued to the CF carrier in a previous step. Another way to reduce the bimetallic effect would be to use low CTE borosilicate glass, which has a CTE of 3.25 ppm/C compared to 7-9 ppm/C of standard glass. It may be possible to glue the glass directly to the CF with silicone glue or even with standard araldite in that case. Tests will be carried out to find an optimal solution for the spacer.

A one-piece moulded CF frame for the TEC and TOB modules is currently under investigation. If this development is successful and is chosen to be the definitive frame design, the TOB/TEC hybrid design will be reviewed. The CF hybrid carrier would no longer be necessary for bringing the height of the PA above that of the sensors, so a TIB-like design may be feasible and desirable.

## 3.2 TIB hybrids

The following subsections describe the specifications for the gluing and mounting steps to be performed on the TIB hybrids.

### 3.2.1 Spacer mounting

This is not fully worked out. The spacer is needed to keep the PA parallel to the CF frame when the hybrid+PA package is to be glued to the frame by the module assembly gantries. It also serves to support the PA under the bond pads of the sensor side of the PA. This step will probably be done by the gantry but could be done by hand if the spacer is too difficult to handle (i.e. too small for the gantry pickup tooling). Assuming gantry mounting, the mechanical specifications would be:

1. spacer: same thickness as raw CHC substrate, size and shape to match pitch adapter support requirements (likely to be about 3mm x 60mm)
2. spacer placement accuracy in X-Y: $< 200$ $\mu$m from nominal
3. type of glue used: standard room temperature cure Araldite
4. thickness of glue layer: $< 50 \pm 20$ $\mu$m

Notes:

The best way to ensure the correct thickness for the spacer would be to use the same CHC substrate material (alumina) itself.

### 3.2.2 Pitch adapter mounting

The mechanical specifications relevant to the final assembly of the TIB hybrid concern the placement and gluing of the PA onto the CHC are as follows:

1. PA placement accuracy in X-Y: $< 50$ $\mu$m from nominal
2. PA surface parallelism with respect to CF surface: <5mR
3. type of glue used: standard room temperature cure Araldite
4. glue surface area of contact: 3mm width, 47mm length
5. thickness of glue layer: $< 50 \pm 20$ $\mu$m

Notes:

X-Y placement accuracy requirements are the same as for the TOB and TEC hybrids. The placement accuracy is defined with respect to reference marks on the CHC.

As for the TOB and TEC hybrids, the parallelism specification is critical for the pattern recognition program of the module assembly gantries and of the bonding machines.

In the case of an alumina spacer, the glass used for the PA should have a matched CTE to avoid bimetal effects. This should not be a problem since standard glass has a CTE of about 7 ppm/C compared to 6.5 ppm/C for alumina. There is, of course, no problem if the spacer is made from the same type of glass as the PA. There will be a problem later when the CHC+PA+spacer is glued to the CF frame during module assembly. It must be checked if the CTE difference (the CTE of CF is about 0 ppm/C) will create problems for those glue joints. Unlike for the TOB/TEC, the glue choice (Araldite) can be made definitive since it has been qualified as radiation hard and there is not a CTE mismatch where it is proposed to be used.

## 3.3 Wire bonding

The wire bonding specifications are common to all hybrid types (TOB, TEC, TIB). The specifications apply to the wire bonds between the PA and the APV25 chip inputs and to the bias wire bond(s) between the PA and the hybrid circuit.

1. bond wire type: 17.5 $\mu$m diam. Al (1% Si), medium hardness
2. loop height and form: Not critical but must not touch the edge of APV chip. Typically 300 $\mu$m higher than the highest bond pad surface and with >100 $\mu$m height separation between rows.
3. tail length: Short enough to avoid shorts to neighbors (typ. <50 $\mu$m)
4. pull strength: >2g

5. allowed number of failed read-in connections: 1 per hybrid (<0.02%)

Notes:

The wire diameter choice of 17.5 $\mu$m is motivated by the very small bond pad size on the APV25 chip and by the fact that rebonding on used bond pads is often possible with 17.5 $\mu$m but is rarely possible with 25 $\mu$m wire. Since the APV25 chip has only one (small) pad per input channel, with 25 $\mu$m wire, one has only one chance to obtain a successful bond.

Although not too critical, the bond loop height and form must allow for movement of the two ends of the wire due to thermal expansion/contraction of the mechanical structures and substrates.

Wire bond pull strength will be measured on test bonds made on the pitch adapter's metallized test areas. One may be able to test the strength of the bond at the APV25 by using test pads on the sides of the chip. In general, bond tests will not be made systematically on the APVs but done only if doubts of bondability exist or if problems are found.

# 4 Overview of the final assembly procedure

The following basic steps describe the final assembly work needed to produce working front-end hybrids. The first step will be to receive the basic components: the CHC, PA, spacer, and CF carrier (TOB and TEC). A visual inspection for damage and other anomalies will be performed for all components and then they will be repackaged or returned to their original containers (the handling containers are not yet determined). There is the possibility for a quick read-out test of the hybrid if it is considered necessary. However, it should be noted that the connectors on the hybrids have a finite number of connections and disconnections before they will likely fail, so it must be clear that any tests that require these connections are necessary.

The components then go to the CERN gantry assembly area for the component mounting step described in section 5. After the glue curing is complete, the hybrid is taken to the bonding area and placed on a bonding jig. This jig will likely be a polished aluminium plate of size slightly larger than the hybrid CF carrier plate (or in the case of the TIB, the combined CHC+PA area) with holes and grooves on the upper face to allow vacuum to hold the hybrid in place. In addition small pillars or other structures will be attached to the plate to position the hybrid on the jig. Initially, the jig will be designed to hold one hybrid. Multiple hybrids on a single jig could be considered if it is found that there is a significant gain in time by avoiding the movement of the jig to and from the bonding machine. Normally, the time to install and remove a jig should be small and thus may not be worth the effort and expense of making a multi-hybrid bonding jig. Bonding is carried out as described in section 6.

After bonding, a number of tests will be performed to test the quality of the bonding. These tests should be sufficiently rigorous so that wire bond failures are detected now rather than in later tests. This allows problems to be fixed before further bad bonds are made and also will prevent extra transport of defective hybrids. Also, as mentioned in the specifications section, repair bonding of the APV25 inputs will likely not be possible with 25 $\mu$m wire which will be the standard for the module bonding centres. This series of tests is described in detail in section 7. Hybrids passing the tests are prepared for transport to the module assembly sites. Failed hybrids are considered for repair as explained in section 8.

# 5 Component Mounting

## 5.1 TOB and TEC hybrids

Here it will be assumed that the spacer is made of CF and can be handled by the gantry pick-up tooling. The assembly first involves the application of araldite to the areas to hold the spacers. Then the pick and placement of the spacers are made. Since the accuracy of placement of the spacers is not critical, no special tooling is envisaged to prevent the spacer from shifting slightly from it initial position. Then comes the application of silicone glue to the area of the CF hybrid carriers which will receive the PAs and

CHCs. Then the pick and placement of the PAs and CHCs are made. There will likely be some special tooling made that ensures that the PA and CHC cannot move from their placed positions. At least 8 hours is then needed for the room temperature glue curing step. This assembly will be performed by the CERN gantry system which was used to develop the automated assembly of the modules. Depending on hybrid type (TOB or TEC and which endcap ring), between 8 and 15 hybrids can be assembled in one batch. The detailed assembly procedure goes as follows:

These steps done by the assembly technician:

1. initialize gantry machine
2. load components (CF carrier, CHCs, PAs, spacers) on assembly platform
3. prepare glues

This step done by the technician interacting with the gantry:

4. run glue dispensing tests, modify parameters if necessary

These steps done automatically by the gantry:

5. find fiducial marks on all PAs and all CF carrier plates
6. dispense araldite glue
7. pick and place spacers
8. dispense silicone glue
9. pick and place PAs
10. pick and place CHCs

These steps done by the technician:

11. remove assembly platform for glue curing, visual inspection
12. go to step 2

## 5.2 TIB hybrids

Here it will be assumed that the spacer is made of ceramic. The assembly platform will have positioning elements (pins or milled regions) to allow pre-placement of the spacers and CHCs in their correct relative positions. The assembly first involves the application of araldite to the top surface of the spacers. Then comes the application of silicone glue to the area at the edge of the CHCs which will receive the PAs. Then the pick and placement of the PAs are made. There will likely be some special tooling made that ensures that the PAs cannot move from their placed positions. At least 8 hours is then needed for the room temperature glue curing step. This assembly will be performed by the CERN gantry system. It is estimated that between 15 to 24 hybrids can be assembled in one batch. The detailed assembly procedure goes as follows:

These steps done by the assembly technician:

1. initialize gantry machine
2. load components (CHCs, PAs, spacers) on assembly platform
3. prepare glues

This step done by the technician interacting with the gantry:

4. run glue dispensing tests, modify parameters if necessary

These steps done automatically by the gantry:

5. find fiducial marks on all PAs and all CHCs
6. dispense araldite glue on spacers
7. dispense silicone glue on CHCs
8. pick and place PAs

These steps done by the technician:

9. remove assembly platform for glue curing, visual inspection
10. go to step 2

As noted previously, spacer design and handling for both the TOB+TEC and for the TIB is not yet certain and may change from the above-mentioned procedures.

Tests to be performed in the assembly step are the visual inspection of the completed hybrids and strength tests of glue samples made at the beginning of the assembly procedure.

# 6 Wire Bonding

The wire bonding will involve 1 set of bias bond wires from pitch adapter to hybrid circuit bond pad (probably 2 or 3 wires for redundancy) and either 4 or 6 sets of 128 bonds wires from APV25 input pads to pitch adapter pads. The bond pads on both the APV25 and pitch adapter are arranged in two rows with a pitch of 88 $\mu$m and the 2nd row staggered by 44 $\mu$m with respect to the first.

Steps in bonding:

1. initialize the bonding machine
2. load the bias and test bond program
3. place hybrid on bonding jig and place jig on bond table
4. run bias and test bonding program
5. pull test of test bonds on PA (if necessary)
6. run read-in bond program
7. upon completion of bonding, do a quick visual inspection of bonds with bond machine microscope
8. remove jig from bond table, move hybrid from bond jig to test jig
9. go to step 2

It is assumed that the operator will be watching the bonding operation at all times and will intervene in the case of problems. Missed bond wires can be added by stopping the bonding and adding the missed wire. All other faults will require some judgement as to the seriousness and likelihood of successful repair and are discussed further in section 8.2.

# 7 Completed hybrid testing

After bonding, the hybrid is removed from the bonding jig and placed on the test jig. This jig should allow for complete access to the bonding areas for inspection under a stereo microscope and for manipulation of the bond pull tester. The jig is likely to be a flat aluminium sheet with clips or pins to hold the hybrid in place. It may also have a connector mounted on it, into which the cable from the hybrid is plugged for the read-out tests.

## 7.1 Air jet test

This test is not yet specified or even certain to be feasible. The idea is to make a air jet 'gun' which can be used to direct a small burst of air at the bond wires. The force of the burst should be sufficient to move or displace broken or very weak bond wires so that they are readily visible in the optical inspection. The difficulty will be to control the maximum force of the jet so as not to break otherwise good bond wire connections.

## 7.2 Visual inspection

The bonded hybrid should be placed under an inpection stereo microscope with adequate lighting so that any broken bonds can be seen. In addition, the quality of the bond foot (weld), the loop height and shape, the bond tail length, and the general state of the APV chips and PA can also be checked.

## 7.3 Bond pull tests

The test bonds made on the PA at the start of hybrid bonding should undergo a standard bond strength pull test using either a manual or automated pull tester. The pull strength should exceed 2g for every test bond. If the bonds fail this tests, further examination of the bonds and of the bonding machine should be performed before continuing production bonding. This frequency of this test can be reduced if it found that the test bonds never fail. In fact, it is likely that only one PA per wafer (assuming many PAs are made on the same glass wafer or sheet) need be tested. The pull test frequency on the assembled hybrids could be reduced to the extent of making the test only at the start of the days bonding or in one of the following cases:

- there is a suspected problem with the bonding (as a result of visible inspection or from the measured bonding deformation curves)
- the bond wire has been changed
- the bond tool has been changed
- the bonding program parameters have been changed
- the bonding machine has been modified or serviced

## 7.4 Read-out tests including PA pulsing and thermal cycling

The hybrid is taken to the read-out test station. There the hybrid goes through a standard series of read-out tests which assure that the functionality and performance has not changed since the last read-out test (other than a slight increase in the noise expected for the additional capacitance due to the PA). This will include measurements of:

- pedestal value
- single channel noise

- common mode noise
- response to (internal) calibration pulse
- the above will be performed in peak and deconvolution mode

The test station will be equipped with an input pulser device which can inject a charge into all input channels by means of capacitive coupling to the bond pads (sensor end) on the PA. This device is an insulated metal tape which can be placed on the PA surface to give the capacitive coupling. The metal tape is connected to a triggerable voltage step which is controlled by the read-out DAQ system. The pulse injected should be seen as a large signal in every channel. If the signal is not present it indicates either a bad read-out channel, a failed bond, or an interrupted trace on the pitch adapter. This check should be very fast as only a few events need be read to verify properly connected input lines.

The test station is also a hermetic and thermally insulated cold box (cooled by a Peltier element). The volume will be flushed with dry nitrogen to avoid condensation. The final test will have the hybrid cycled to operating temperature (-20°C). The type of test performed will depend on whether the hybrid circuit has already been tested at the (low) operating temperature. If it has been tested cold, the it is probably sufficient to take a few events with the input pulser tape to verify that the input bonds are OK. If it has not been previously tested cold, then the standard read-out test should be performed since the hybrid circuit traces as well as the power and read-out bonds have not been thermally stressed. They could fail only when cold and so as many connections as possible should be tested. It is recommended that the hybrid be first unpowered when brought to operating temperature and then powered and run with a realistic DAQ sequence in this test so that the temperature distribution on the components is as realistic as possible. The temperature on the APV chips will be significantly different powered versus unpowered and thus a thorough test should include both cases.

After returning to ambient temperature, the input pulser should again be used to test the input bonds. In addition, the standard read-out test should be repeated to assure that the other bonds (notably the calibration signal line bond) did not fail. After removing the input pulser tape at the completion of this test, the PA should be pushed lightly to check the soundness of the glue joint after the thermal cycle. This glue joint check can be skipped if no failures are observed after an initial large sample is checked.

# 8 Quality Control and Assurance

## 8.1 Summary of tests and acceptance criteria

Tests are listed below but acceptance criteria are not yet determined. It is assumed that the results from each test will be entered into the standard CMS tracker construction data base.

1. visual inspection of received components
2. read-out test (optional)
3. glue quality test
4. bonding successfully completed?
5. bond pull tests (if necessary)
6. air jet test (if possible)
7. visual inpection of bonding
8. 1st read-out test + input pulsing (warm)
9. 2nd read-out test + input pulsing (cold)
10. 3rd read-out test + input pulsing (warm)
11. visual inspection and mechanical glue joint test

### 8.2 Quality assurance procedure

Hybrids failing the final tests will be classed into categories: good, easily repairable, repairable with difficulty or uncertainty, and unrepairable (or would require unreasonable effort to repair). Good hybrids will be prepared for packing and shipping to the module assembly centres. Easily repairable hybrids are defined as those expected to take a similar time to repair as would the take the final assembly of a new hybrid. It is likely that repair work would be grouped so as not to interrupt the smooth flow of production. It may also be that repair work is handled only by certain qualified technicians or physicists. The difficult or uncertain failures will be set aside and worked on only when free time exists. However, these failure types and the unrepairable ones must be understood immediately as to the cause of the failures so that more failures are not produced.

Details on the QA procedures to ensure safe handling, storage, packing and transport are still to be worked out.

## 9 Manpower and production rates

In order to produce enough assembled hybrids to meet the production schedule for modules, a mean production of rate of 40 hybrids/day must be met. This assumes 400 working days for hybrid assembly rather than the scheduled 500 in order to take into account the ramp up in production rate at the start of production. Estimates of throughput are as follows:

1. receiving and pre-assembly testing: 5 minutes/hybrid → 12 hybrids/hr
2. gantry assembly of hybrids: 30 minutes/batch → 16 hybrids/hr (TOB,TEC) or 30 hybrids/hr (TIB)
3. bonding of hybrids: 12 minutes/hybrid/machine → 5 hybrids/hr
4. testing of completed hybrids: 30 minutes/batch(4 hybr) → 8 hybrids/hr

Note that if sufficient manpower exists, the four tasks can be done in parallel. We will likely have 1 technician for 1+2 and 2 technicians for task 3+4. Thus the first technician would spend 3.5 hours on task 1 and 1.5 to 2.5 hours on task 2. It is anticipated that two technicians would be capable of doing the wire bonding. The bonding facility is assumed to have 2 Delvotec 6400 bonding machines with an availability of 50% for CMS, i.e. 8 machine hours per day. It is likely that each technician would spend 4 hours/day on bonding and the rest on testing. This plan would meet the requirements for the tasks but with no contingency for the bonding task.