ATLAS project	ATLAS SCT Barrel Module FDR/2001				
SCT-BM-FDR-7	*Institute Document No.*	*Modified:*	28/5/2002	*Rev. No.*	

SCT Barrel Module FDR Document

SCT Barrel Module : MODULE QA

Abstract

This document describes the quality assurance procedure to be applied for the SCT barrel module production.

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1 SCOPE OF THE DOCUMENT

This document describes the QA procedure to be applied to barrel modules during the construction process. The QA procedures for the individual components are dealt with in other documents (see SCT-BM-FDR-5). Tests are made during assembly to check that the components have not been damaged, for example in transport or in the first stages of module construction. Post-assembly testing validates the quality of the completed module: most tests will be performed on all produced modules, but some destructive or very time-consuming tests are performed on a sample subset of modules.

The procedures and tests described here aim to investigate a wide range of potential failures and problems. This extensive testing will be applied during the first part of the module series production (order of 100 hybrids or modules), but is time consuming. In the later parts of the production, where the production rate is higher and experience of previously produced modules has been gained, the procedures will be reduced in areas that do not show failures.

The results of all tests will be logged to the SCT database. In some cases a simple yes/no result is obtained, for most tests characteristic performance data will be logged in addition to the flag of whether the module passes the relevant QA criteria.

The aim of the QA procedures is to ensure that each SCT Barrel Module fulfils all aspects of the specification. The same QA procedures and criteria will be applied at all the four barrel module production sites.

2 QA DURING MODULE ASSEMBLY

The following QA steps are performed during the assembly of a module. The criteria for accepting a module as ‘good’ are for initial use, and will evolve with experience.

2.1 Assembly of ASIC's onto hybrids

Before delivery to the assembly site, the individual components have already been subject to QA procedures as described in SCT-BM-FDR-5.3 for the Hybrids and in SCT-MB-FDR-5.4 for the ASIC's.

2.1.1 Tests of Distributed Passive-Component Mounted Hybrids

Hybrids with passive components mounted but without ASIC's are distributed to the hybrid assembly sites. After transport a subset of the acceptance tests for hybrids are repeated to check that no damage has occurred in transport. For similar reasons, a visual check is made of each hybrid. The glass fan-in on the hybrid is also checked visually for any damage.

Before ASIC attachment, pull-tests are also made at the four scratch pads, one wire per pad, on each hybrid. The minimum pull strength required is the values of 6 gm for 30% height to distance ratio setting.

The height of the large capacitors, C73, C53, C54 (link0), C74, C55, C56 (link1), from the bottom of the substrate step are to be measured with a micrometer. The maximum height must be within 2.63 mm.

Visual inspection: overall and components (SMD’s and Fan-in’s)

Pull test: 4 wire-bonds at 4 scratch pads (1 wire per 1 pad)

Maximum height of large capacitors: 2.63 mm

2.1.2 ASIC attachment with electrically conductive epoxy

In attachment of ASIC's onto hybrids, an electrically conductive epoxy, Eotite p-102, is used. The mixing ratio and the cure condition are given in SCT-BM-FDR-5.3 Section 7.2.1 and SCT-BM-FDR-5.5 Section 3 and Appendix 4.2:

Mixing ratio: 100:2 (% by weight)

Temperature (environment): 50 °C

Duration: 2 hr or more

Condition: hold the hybrids at the steps of the bridges or over the full length of the bus lines in order to prevent warping

Keep the mixing ratio exactly as the bond strength change rapidly as in the specification data sheet. The mixture can be stored in a freezer (-20 °C) for 100 ~ 120 hrs, according to the data sheet (Pot life after mixed).

KEK has tested two holdings: one at the steps and the other along and over the backend (over the bus lines). Both prevented increase of warping. There is no strong preference for which method to use.

2.1.3 Tests of Hybrids after ASIC Attachment

After attachment of ASIC's to the hybrids all wire bonds between hybrid and ASIC's are made. At this stage a visual inspection and an electrical test is made of the hybrid to ensure that all ASIC's perform properly and that all wire bonds are functional. This is done by performing a Characterisation Sequence (see section 3.3).

Visual inspection: overall and components (ASIC's, wire-bonds)

Electrical test: Characterisation sequence

2.1.4 Long Term Test of Hybrids with ASIC's

In addition to the full ASIC characterisation on the hybrids, a longer duration test is performed on assembled hybrids. The aim of this test is to catch infant mortality problems in the front-end ASIC's. The test is therefore performed at the first feasible stage, i.e. immediately after the ASIC's are mounted on to the hybrids. (It should be noted that experience to-date has shown no long-term failures of ASIC's).

The test consists of a long duration run at elevated temperature. The temperature and length of the run will be adjusted during production in the light of experience gained, e.g., 100 hybrids (i.e., 1,200 ASIC's), but initially a 100 hour test will be made with a temperature measured by the hybrid thermistors of 37 °C. The temperature of ASIC is expected to be about 50 °C. This temperature is a safe temperature to the glass transition temperature of the adhesive between the flex circuit and the bridges.

Temperature (measured by hybrid thermistors): 37 °C

Duration: 100 hrs

Condition: holding the hybrids at the steps or over the full length of the bus lines to prevent warping

During the test the hybrids are powered, clocked and configured and triggered at the nominal L1A trigger frequency of 100kHz. The currents drawn by, and the temperatures of, the hybrids are monitored every few minutes. Every few hours a test to establish correct functionality of the hybrid is performed, so that if problems do develop the time structure of the failures can be observed.

2.1.5 Final Tests of Hybrids

After the long term test, the ASIC's are bonded to the hybrid pitch adapter. A visual inspection for the damages in the long tem test and the wire-bonding is made. A final electrical Confirmation Sequence (see section 3.3) is performed to ensure that no inadvertent damage has been caused electrically.

Visual inspection: overall hybrids and components

Electrical test after the long term test: Characterisation sequence

2.2 Construction of the Sensor-Baseboard Sandwich

Before delivery to the assembly site, the individual components have already been subject to QA procedures as described in SCT-BM-FDR-5.1 for the Detectors (=Sensors) and in SCT-BM-FDR-5.2 for the Baseboards.

2.2.1 Visual Inspection

Before use, the four silicon detectors and the baseboard are all visually inspected to ensure that no damage has occurred in transit. The criteria for detector acceptance is the same as on their first delivery from the contractor. The baseboard is checked to ensure that it is free from any cracks or defects.

Following the gluing of the detectors to the baseboard, the assembly is checked visually.

2.2.2 Use of Sensors

The convention of the sensor numbers is the following. Sensors 1 and 2 are on the front (=upper) side and 3 and 4 the back (=lower) side. Sensors 1 and 3 are on the left when the module is held in the conventional orientation (i.e., hybrid on the right side and the pigtail on the bottom side). In a module, the four sensors are selected from the same kind: wafer orientation of <111> or <100>, wafer manufacturer's id, and pre-series or series sensors. Those sensors with no or less defective strips are to be used at Sensors 2 and 4 (i.e., the hybrid side) in order to maximise the strip area in case the wire-bonding to the defective strips must be removed between the sensors.

2.2.3 Sensor Leakage Currents

After the detectors are glued to the baseboard, the I-V curve is recorded for each detector individually up to a bias of 500V at room temperature. If any current (normalised to 20^{o}C) at 500V bias differs by more than 1μA from that last recorded in the database for the detector, the assembly is put to one side for further visual checks and current stability measurements (see section 3.2.1).

2.2.4 Metrology

The full set of metrology survey measurements (see section 3.1) is performed on the baseboard-detector assembly. If the results are outside specification the assembly is rejected.

2.3 Mounting the Hybrid

2.3.1 Electrical Check of Hybrid

On receipt at the module assembly site, the hybrid is checked for its continued correct electrical functionality before mounting on the module. This is done with the Confirmation Sequence as described in Section 3.3.

The glass fan-in on the hybrid is also checked visually for any damage.

2.3.2 Sensor Leakage Current Check

After the hybrid is mounted on the module, the detector bias is bonded, and the leakage current checked up to 500V bias. This is a diagnostic step, to establish whether any subsequent leakage current problems that may be observed have occurred before or after the detector strip bonding.

2.3.3 Wire-bonding of strips

A sensor has occasionally defective strips such as punch-through, etc. All strips, whether it has defect or not, are wire-bonded to ASIC's. This issue will be re-visited with the accumulation of experience of detrimental effect. When the wire-bonding fails to connect the strip to the ASIC, the failed strip numbers (1 to 1536) will be logged.

3 QA OF THE COMPLETED MODULE

The following QA steps are performed on fully assembled modules. The criteria for accepting a module as "good" are for initial use, and will evolve with experience.

3.1 Metrology

After completing the detector-baseboard assembly or the assembly of module, the object will be surveyed for mechanical precision. The precision is characterised by in-plane and out-of-plane parameters. For the in-plane survey, a well-defined set of fiducial marks on the sensors is used. For the out-of-plane survey, a matrix of points with equal spacing is measured. A 3D measuring machine is required for the out-of-plane survey.

In the out-of-plane survey, in addition to those of 5x5 matrix on four sensors, there is a survey of three areas which are mounting the modules kinematically and defining the module plane: two points in the cooling tab and the 3rd mounting point in the far-end tab.

In the module fabrication and survey, it is realised that the shape of the cooling tab is a critical parameter for the contact to the cooling block, specially the angle of the cooling tab to the module plane. The angle also provides information on how the 3rd mounting point deviates when the module is held at the cooling tab by the module-mounting robot. The angle of the cooling tab is subject to the hybrid mounting on the cooling tab of the sensor-baseboard assembly. The survey of the surfaces of the cooling and far-end tabs also provides information: thickness of the tabs, difference of the mid-heights of the sensor-baseboard-sensor and of the tabs. The difference then deduces the asymmetry of glue thickness between the sensors and the baseboard in the upper and lower sides.

In assembling the modules on the barrel cylinders, the space available for the module insertion is very limited. The highest and critical component of the module is the big capacitors near the far-end tab. In order to ensure the module is within this module envelope, the heights of these capacitors and hybrids are measured.

The latest metrology analysis excel files[1] are:

surveyXY_idAction2.4.xls and surveyZ_idAction2.4.xls

[1] http://jsdhp1.kek.jp/~unno/SCTSGmod/production/surveyXY_idAction2.4.xls
http://jsdhp1.kek.jp/~unno/SCTSGmod/production/surveyZ_idAction2.4.xls

3.1.1 In-Plane Survey

(A) Sensors, hole and slot

The in-plane survey characterises the relative positions of the four sensors and the dowel hole/slot of the baseboard. Figure 1 shows a typical setup for the measurement. A module is placed on a frame and is held at three points. Sensors 1 and 2 are on the front (=upper) side and 3 and 4 the back (=lower) side. Sensors1 and 3 are on the left when the module is held in the conventional orientation (i.e., hybrid on the right side). The correlation of the front and the back sides is made by using a number of transparent fiducials on the frame or by using the edges of the front and the back sensors seen both from the front and the back sides simultaneously.

The x and y coordinates of a sensor are obtained from the measurements of the eight fiducial marks *A* (see SCT-BM-FDR-5.2 for their description). The reduced parameter set, however, does not rely, in the end, on which fiducial marks are used. For the front side, the centres of the dowel hole and slot are obtained from the measurements of the perimeter of the hole and the slot.

From the 34 (x,y) coordinates measured, the module coordinates and a reduced parameter set are obtained as shown in Figure 2. The coordinates origin is the geometrical centre of four sensors. The stereo angle is that between the axis of the front pair, C1C2, and the back pair, C3C4, where C1 to C4 are the geometrical centres of sensors1 to 4, respectively. The half-stereo angle defines the x coordinates, X_m, and then the y coordinates, Y_m. In this coordinates system, the reduced parameter set is listed in Table 1, with the design values and the tolerances specified.

(B) Hybrid and connector

The location of the connector on the flexible pigtail section of the hybrid is critical in mating the location of the dogleg cables on the barrel support cylinders. The location of the connector can be defined by the position of the pin#1 of the connector for the ideal case of flattened and straightened pigtail section. This ideal position is calculated from the measurement of the fiducial marks on the hybrid as shown in Figure 3. The coordinates and the tolerances of the fiducial marks and the deduced connector pin#1 are shown in Table 1. The relevant hybrid fiducial marks are of the front side, however, the same fiducial marks of the backside are also measured for monitoring the hybrid assembly precision.

Parameter	Design Value	Tolerance
Dowel hole, mhx [µm]	-6500.0	30.0
Dowel hole, mhy [µm]	-37000.0	30.0
Dowel slot, msx [µm]	38500.0	100.0
Dowel slot, msy [µm]	-37000.0	30.0
Mid-point of front pair, midxf [µm]	0.0	10.0
Mid-point of front pair, midyf [µm]	0.0	5.0
Separation of front pair, sepf [µm]	64090.0	10.0
Separation of back pair, sepb [µm]	64090.0	10.0
Sensor1 angle, a1 [mrad]	0.00	0.13
Sensor2 angle, a2 [mrad]	0.00	0.13
Sensor3 angle, a3 [mrad]	0.00	0.13
Sensor4 angle, a4 [mrad]	0.00	0.13
Half stereo angle, half-stereo [mrad]	-20.00	0.13
Mid-point of front hybrid fiducial pair, hymxf [µm]	7698.5	100.0
Mid-point of front hybrid fiducial pair, hymyf [µm]	-154.0	100.0
Angle of front hybrid fiducial pair, hymaf [mrad]	-20.00	3.145
Mid-point of back hybrid fiducial pair, hymxb[µm]	7698.5	100.0
Mid-point of back hybrid fiducial pair, hymyb [µm]	154.0	100.0
Angle of back hybrid fiducial pair, hymab [mrad]	20.00	3.145
Connector pin #1, conp1x [µm]	3611.8	320.13
Connector pin #1, conp1y [µm]	-69451.1	100.0

Table 1: Module in-plane geometry parameters and tolerances in the tolerance test

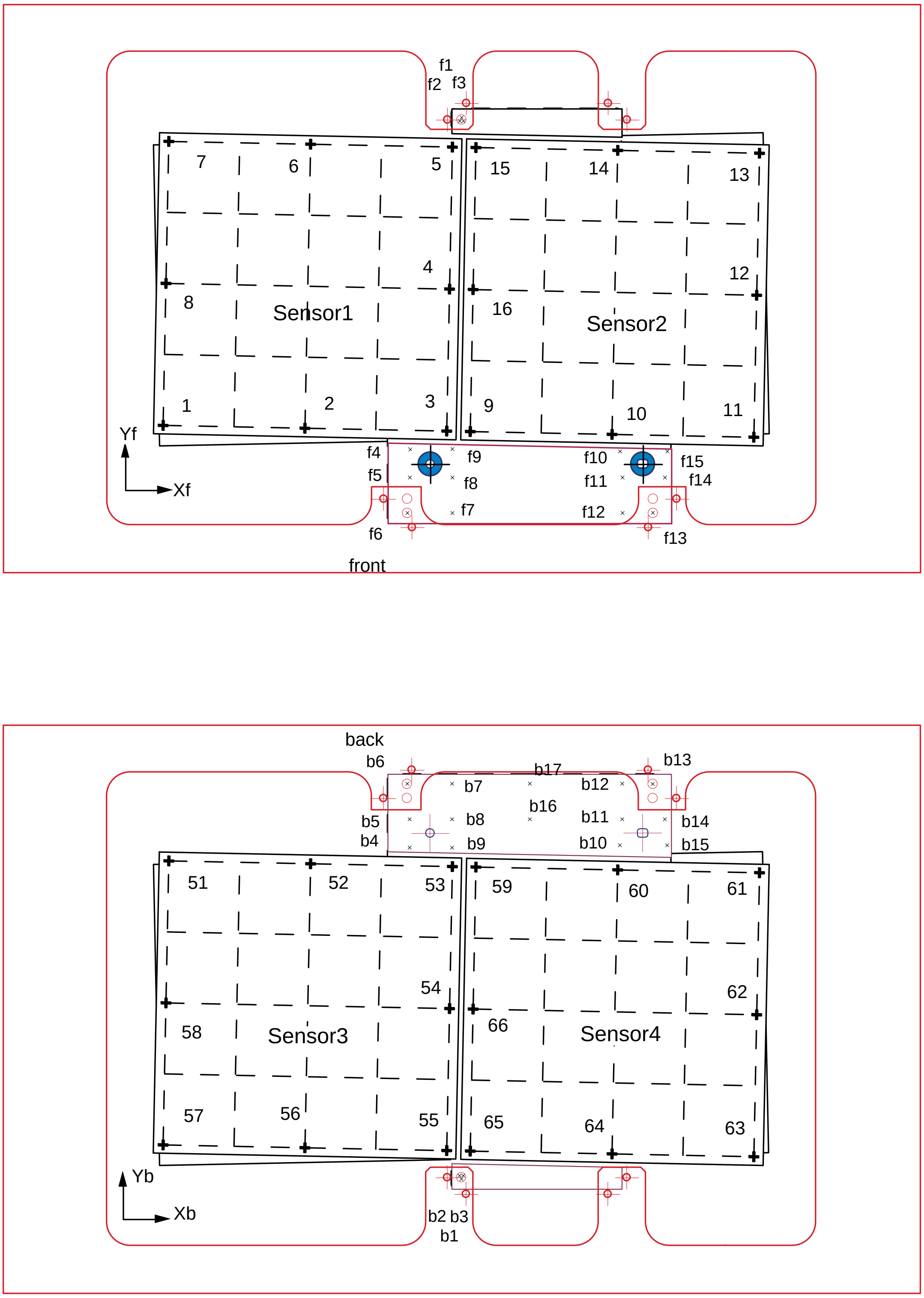

Figure 1: An example of survey frame and the survey points on a barrel module. Sensors 1 and 2 are on the front (=upper) side and 3 and 4 the back (=lower) side. Sensors1 and 3 are on the left when the module is held in the conventional orientation (i.e., hybrid on the right side). The mark "+" represents the fiducial mark A on the sensors. Points 1-18, 41-44, and 51-66 are for the in-plane survey. For the out-of-plane survey, points on a 5x5 matrix are measured for a sensor. A survey frame has "peepholes" at the 3rd mounting point in the far-end tab and at the tab-corners in the cooling tab. The arm opposite to the 3rd mounting point of the survey frame is made retracted in height so that the module is held kinematically at three points, two points in the arms of the cooling tab and the 3rd mounting point in the arm of the far-end tab.

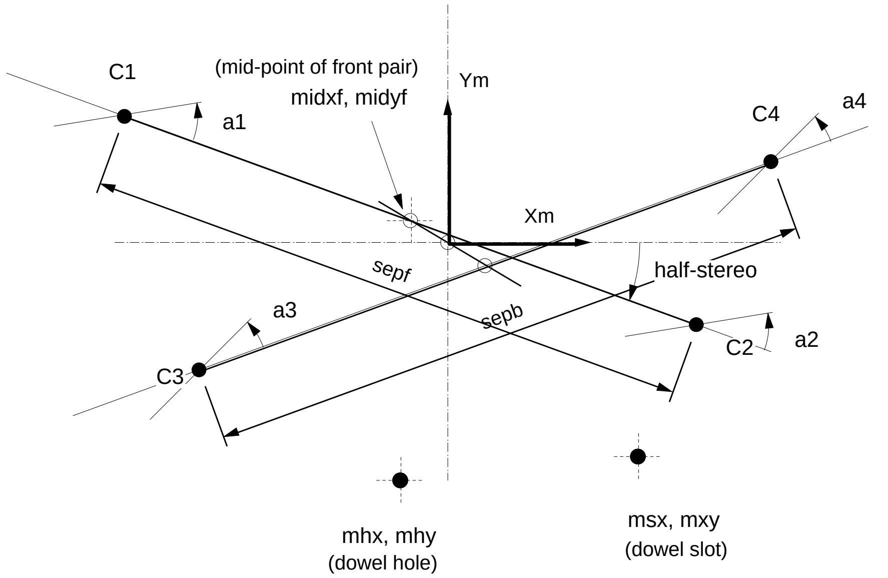

Figure 2: Definition of the parameters which describe the geometry of a module. The black circles C1 to C4 are the measured centres of the four sensors. The dashed line through each centre gives the measured orientation of each sensor. Open circles are the centre points of lines. The module is described in the database by 13 numbers: the coordinates pairs of the dowel hole, slot, and centre of front/back pair: (mhx, mhy), (msx, msy) and (midxf, midyf), the sensor separations: sepf, sepb, sensor angles: a1, a2, a3, a4, and the half-stereo angle. The stereo angle is measured from the X_m *axis and sensor angles from the stereo axis, with anti-clockwise rotation being positive.*

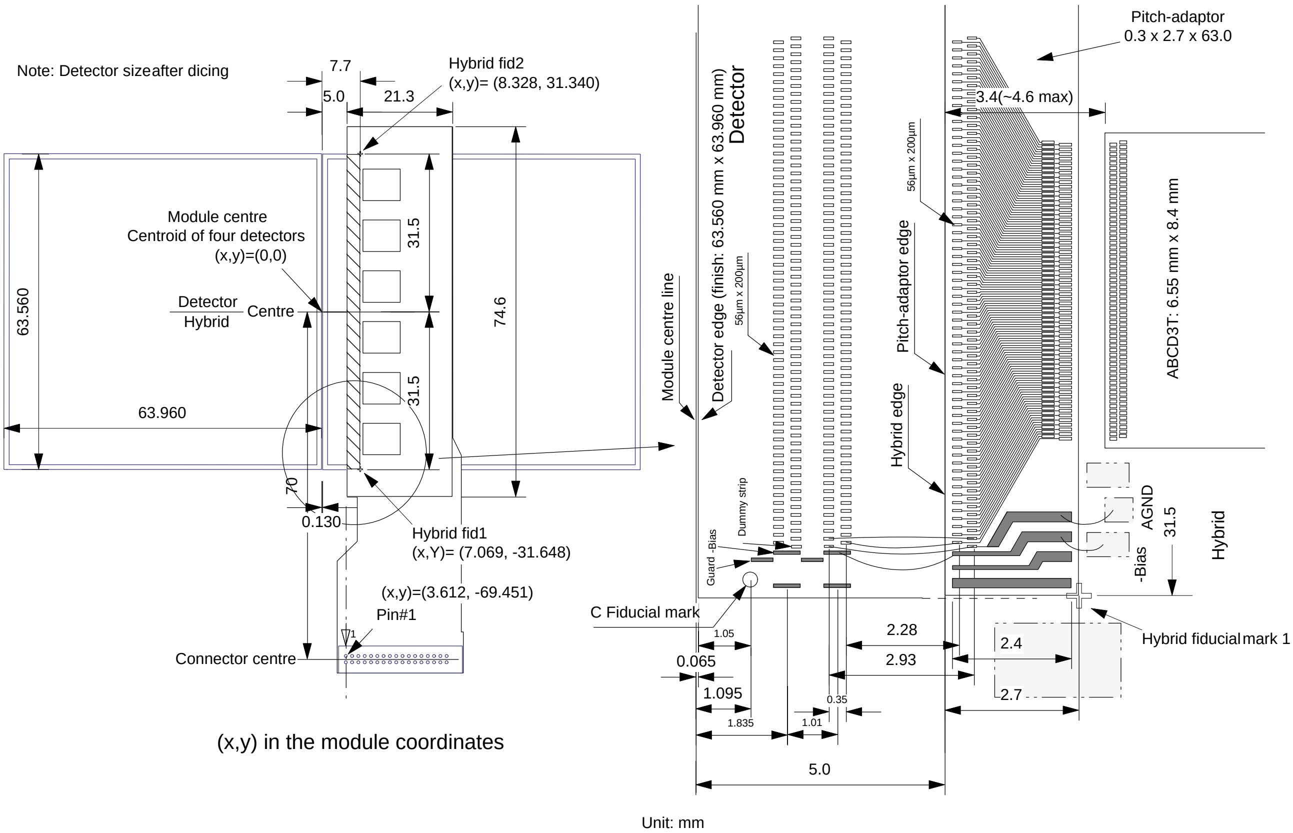

Figure 3: Fiducial marks of the hybrid in the front-side hybrid. The coordinates (x, y) is the one in the module coordinates, i.e., the upper side is half-stereo (-20 mrad) rotated. The marks are also used to align the pitch adapter.

3.1.2 Out-of-Plane Survey

The z-coordinates of a matrix of 5x5 points are measured on the surface of each sensor in the front (=upper) and back (=lower) sides, as shown in Figure 1, by using a 3D machine. The precision of the z measurement would be enough to be a few microns, which can be fulfilled with a 3D machine with an optical focusing. The z-measurements of the sensor's corner areas which are offset due to the stereo rotation and visible in the measurements of the upper and the lower sides enable the correlation of the z-measurements of the front and the back sides by assuming the sensor thickness of 285 µm.

In addition, the three surface areas around the dowel hole, dowel slot, and the 3rd mounting point are measured on the surfaces of the cooling and the far-end tabs. The three z coordinates of the lower side of the facings define the lower facing plane, *loFacingFrame*, as mounted on the bracket on the barrel cylinder. The plane displaced to the middle of the upper and the lower sensor surfaces define the module plane, *moduleFrame*. The names in *Italics* are the ones used in the analysis excel files.

The out-of-plane tolerances are constrained by two factors. One is the requirement for keeping the separation between the surfaces of adjacent two modules to be at least 1 mm (see SCT-BM-FDR-4, section 4). This requirement sets the maximum deviation of sensor surfaces from the nominal ones to be < 200 µm. The other is the requirement for the deviation in z-flatness. This requirement comes from the correlation of the z to the r-phi measurements because of the tilt angle of the modules on the support cylinder. This requirement sets the deviation in z-flatness to be < 50 µm.

(A) Surface of sensors

The surfaces of the sensors are to be measured at a matrix of 5x5 points in each sensor, as shown in Figure 1. The coordinates of the points are defined by the fiducial marks "A", 1 to 16 in the front (=upper) and 51 to 66 in the back (=lower) side. Those points where the hybrid is are measured but the z-coordinates are interpolated from the neighbouring points: in the columns of 9-15 and 10-14 in the front (=upper), and, 59-66 and 60-64 in the back (=lower) side.

These surface measurements allow the calculation of the maximum deviation and the deviation in z-flatness of each point in the upper and the lower sides. In a reconstruction of particle tracks, the maximum use of these 100 points is to use all data in every modules. The data of 100 points times 2112 barrel modules requires no parameterisation of the deviations nor the tolerance to the z-flatness, other than the maximum deviation in ensuring the physical clearance between the adjacent surfaces. This point-by-point referencing, however, cannot be regarded as a practical solution in a reconstruction program. The opposite case of "no referencing" requires the module surface to be flat within the value, < 50 µm. From the experience of the module fabrication, this is neither a practical solution since there is an intrinsic bowing in the sensors and in the baseboards which are larger than 50 µm.

The barrel community adopted the "minimum (or optimal) use" of the 100 z-data points with a procedure carried out in the following three steps.

(1) Parameterisation of the *midplanes* of the left and the right sensors: The averaged plane of the surfaces of upper and lower sensors defines the *midplane*. This *midplane* is fitted separately in the left- and the right-side sensors to the plane equation, $z = ax + by + c$. These (a, b, c) parameters per side express non-planarity of the module, basically driven by the baseboard.

(2) *Module thickness*: By averaging the deviations from the fitted *midplanes* at the points where the sensors are glued on the baseboard, the distance between the surfaces of upper and lower sensors defines the *module thickness*.

(3) *Common profile*: Averaging over modules of the deviations from the fitted *midplanes* and the half *module thickness* at the 100 points defines the *common profile* of the sensor surfaces. The 100 points of the *common profile* express the shape of sensors in the modules which use the sensors of the same kind, such as vendor, wafer orientation of <111> or <100>.

After the above parameterisation, the residuals are regarded as the errors in z-flatness. The maximum residual is called *optimalMaxZerror* and the r.m.s. of the residuals *optimalRMSZerror*. As long as these errors are within the requirement, the module can be said fulfilling the specification. In reconstruction of tracks, the surface of sensors of modules can be obtained with one set of 100 points of *common profile* and each of *module thickness* and the plane parameters (*a*, *b*, *c*)'s of 2112 barrel modules.

Furthermore, the concavity of the module is defined in the x and y directions: in the x direction from the z coordinates of the mid-planes of the rows (1-7, 11-13) and (3-5, 9-15); in the y direction the mid-planes of the rows (1-11, 7-13) and (8-12).

(B) Surface of tabs

The surfaces of the far-end and the cooling tabs are measured for 17 (lower) and 15 (upper) points, b1 to b17 in the lower and f1 to f15 in the upper side, as shown in Figure 1. These points on the surface of the tabs are taken at the same or similar (x, y) locations so that the thickness of the tabs can be derived. The upper side has two points less where the pigtail of the hybrid hides the surface. An expanded view of the far-end and the cooling tab areas of the lower side is shown in Figure 2 and Figure 3, respectively.

The 3rd mounting point is measured three times with a slight shift of the locations: b1 to b3, through a "peephole (2 mm diameter)" in the survey frame, in order to increase the accuracy. The hole and slot areas are to be measured at four points each: b4, b5, b8 and b9, and b10, b11, b14, and b15. These points are 2 mm away from the hole/slot washers so that the fillet of adhesive around the washers does not affect the measurement. The average of (b4, b5, b8, b9) defines the z-coordinates of the hole, Z1; the average of (b10, b11, b14, b15) the z-coordinates of the slot, Z2; and the average of (b1, b2, b3) the z-coordinates of the 3rd mounting point, Z3. The 3 z-coordinates of the surface of the lower facing of these Z1, Z2, and Z3 define the *loFacingFrame* and then *moduleFrame*, the module plane.

The points b4-b6, b7-b9, b10-b12, and b13-b15 are to be used to derive the angle of the cooling tab to the module plane. The points b5, b6, b16, b17, b13, and b14 are to be used to derive the concavity of the cooling tab. The tab-corner points, b6 and b13, are to be measured through "peepholes (2 mm diameter)" in the survey frame.

The z-coordinates of the upper and the lower facings define the thickness of the tabs and their centre z-coordinates. The thickness of the tabs, together with the thickness of the sensor-baseboard-sensor in the baseboard area, allows a derivation of the thickness of the adhesives between the baseboard and the sensors. The difference of the z-coordinates of the centre of the tabs and the centre of the sensor-baseboard derives the asymmetry of the adhesives in the upper and the lower sides of the baseboard. The survey of tabs allows derivation of many quality parameters of the module fabrication.

(C) Surfaces of hybrids and large capacitors

In mounting the modules on the support cylinders, it is realised that the module envelope, specially the thickest part, i.e., the hybrid areas, is critical in the insertion of a module between the brackets and the opto-hybrid-cables. The most critical one is the three large capacitors of the hybrid at the far-end tab (C72, C53, C54 in the upper side, C73, C55, C56 in the lower side in the document SCT-BM-FDR-5.3). The open surfaces of these three capacitors as marked in Figure 4 are measured. The z measurements in the upper and the lower sides enable to reduce their heights from the surface of the facing of the tab and the distance of the surfaces, the total thickness. The maximum total thickness of the large capacitors is in the tolerance test.

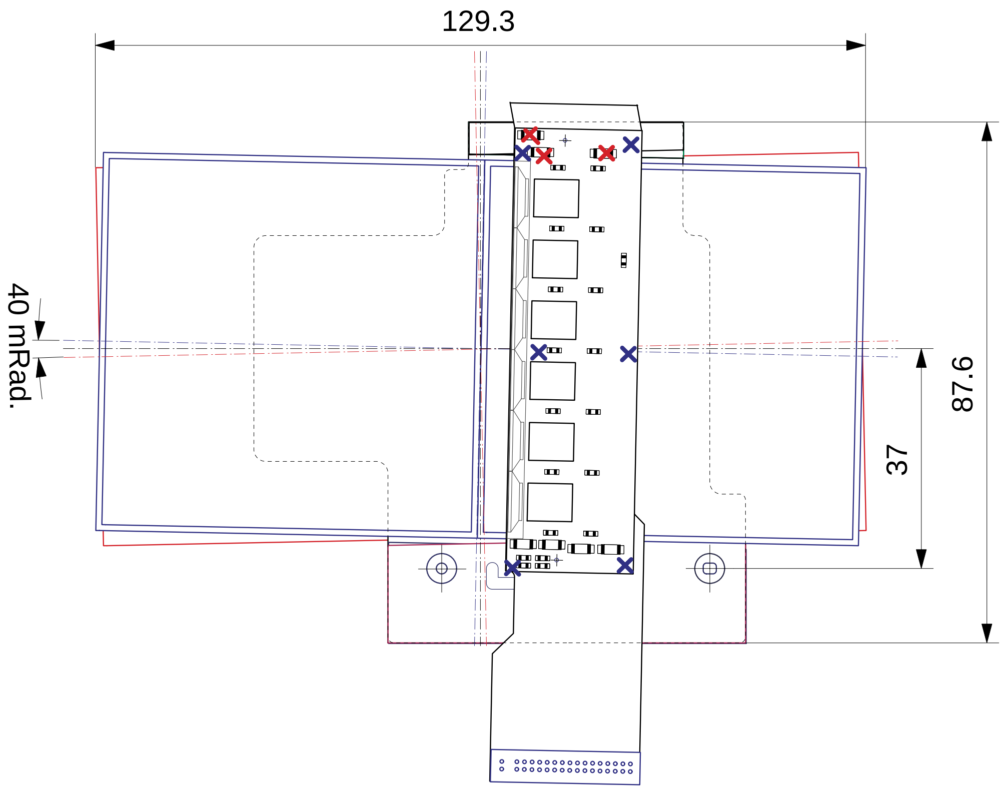

Figure 4 Survey of surfaces of hybrid and of large capacitors in the far-end. The surface of the hybrid is measured in open space at six locations: two in the near-end, two in the middle, and two in the far-end.

In addition, the open surfaces of the are measured at six points, two in the near end, two in the middle, and two in the far end, in the upper side and lower side. The heights of surfaces from the facings at the near and the far ends are a monitor of the hybrid mounting process. The difference of the height of the middle to the average of the near and the far end is a bow of the hybrid.

(D) Survey frame

A concept of a survey frame is drawn in Figure 1. The frame is constructed from two equivalent halves with the upper and the lower pieces held together with screws in the frame peripheral once a module is placed inside. The frame has "peepholes" where the module-holding arms are required: at the 3rd mounting point in the far-end tab and at the tab-corners in the cooling tab.

This survey frame is being used not only for the out-of-plane survey but also for the in-plane survey where the perimeters of the hole and slot are to be measured. Because of the in-plane survey, the use a screw in the dowel hole and slot is prohibited and because of the peepholes an equivalent to clamp the tabs in the area is not desirable. An alternative to the screw or the clamp is to use vacuum, through the holes.

By using the correlation method internal to the module, e.g., using the edges of sensors visible from the upper and the lower sides, the module can be free when it is flipped. The vacuum is switched from the lower side to the upper side when the module is flipped for the measurement of the upper side to the lower side, respectively. The strength of the vacuum is to hold the module such that it does not move while a side is being measured.

There are pins around the corners of the tabs in the frame to hold the module while the vacuum is off. The pins are planted in the lower frame and the upper one has female holes to mate the pins. There are two arms in the far-end tab in the frame. The height of the opposite arm to the

3rd mounting is made recessed so that the module is held kinematically at the three points, two points in the arms of the cooling tab and the 3rd mounting point in the arm of the far-end tab.

(E) Coordinates of the survey points

The x-y coordinates of the survey points in the module coordinates are summarised in Table 2. The points 1 to 50 are of the sensors, 51-53 of the 3rd mounting point in the far-end tab, and 54-67 in the cooling tab. The centre of the coordinates is the origin of the module, i.e., the centre of the four sensors.

(F) Derived parameters and tolerances

The module parameters derived from the measurements of the surfaces of sensors, tabs, and hybrids are summarised in Table 3. The nominal values of the parameters are listed in the table, together with tolerances. In the analysis file (spreadsheet), surveyZ_idAction2.4.xls, a set of selected parameters is used to judge the PASS of the QA in the "Tolerance sheet", as shown in Table 4. Finally, a "Datasheet" sheet is prepared in the analysis file, and an example of the datasheet is shown in Table 5.

	Lower		Upper	
point	x	y	x	y
1	-63.151	32.820	-64.413	-30.268
2	-47.279	32.502	-48.541	-30.585
3	-31.408	32.185	-32.670	-30.903
4	-15.536	31.867	-16.798	-31.220
5	0.336	31.550	-0.926	-31.538
6	-63.467	17.048	-64.098	-14.496
7	-47.595	16.730	-48.226	-14.814
8	-31.723	16.413	-32.354	-15.131
9	-15.851	16.095	-16.482	-15.448
10	0.021	15.778	-0.610	-15.766
11	-63.782	1.276	-63.782	1.276
12	-47.910	0.958	-47.910	0.958
13	-32.039	0.641	-32.039	0.641
14	-16.167	0.323	-16.167	0.323
15	-0.295	0.006	-0.295	0.006
16	-64.098	-14.496	-63.467	17.048
17	-48.226	-14.814	-47.595	16.730
18	-32.354	-15.131	-31.723	16.413
19	-16.482	-15.448	-15.851	16.095
20	-0.610	-15.766	0.021	15.778
21	-64.413	-30.268	-63.151	32.820
22	-48.541	-30.585	-47.279	32.502
23	-32.670	-30.903	-31.408	32.185
24	-16.798	-31.220	-15.536	31.867
25	-0.926	-31.538	0.336	31.550
26	0.926	31.538	-0.336	-31.550
27	16.798	31.220	15.536	-31.867
28	32.670	30.903	31.408	-32.185
29	48.541	30.585	47.279	-32.502
30	64.413	30.268	63.151	-32.820
31	0.610	15.766	-0.021	-15.778
32	16.482	15.448	15.851	-16.095
33	32.354	15.131	31.723	-16.413
34	48.226	14.814	47.595	-16.730
35	64.098	14.496	63.467	-17.048
36	0.295	-0.006	0.295	-0.006
37	16.167	-0.323	16.167	-0.323
38	32.039	-0.641	32.039	-0.641
39	47.910	-0.958	47.910	-0.958
40	63.782	-1.276	63.782	-1.276
41	-0.021	-15.778	0.610	15.766
42	15.851	-16.095	16.482	15.448
43	31.723	-16.413	32.354	15.131
44	47.595	-16.730	48.226	14.814
45	63.467	-17.048	64.098	14.496
46	-0.336	-31.550	0.926	31.538
47	15.536	-31.867	16.798	31.220
48	31.408	-32.185	32.670	30.903
49	47.279	-32.502	48.541	30.585
50	63.151	-32.820	64.413	30.268
51	0	-36	0	36
52	-0.4	-35.3	-0.4	35.3
53	0.4	-35.3	0.4	35.3
54	-11	34	-11	-34
55	-11	40	-11	-40
56	-11.5	47.5	-11.5	-47.5
57	-2	47.5	-2	-47.5
58	-2	40	-2	-40
59	-2	34	-2	-34
60	33.5	34.5	33.5	-34.5
61	34	40	34	-40
62	34	47.5	34	-47.5
63	40.5	47.5	40.5	-47.5
64	43	40	43	-40
65	43.5	34.5	43.5	-34.5
66	14.5	40		
67	14.5	47.5		
68	7.28	32.30	5.38	-34.18
69	25.58	34.12	24.21	-32.01
70	8.64	-0.12	8.55	-0.23
71	24.78	-0.48	23.02	-0.52
72	5.85	-32.52	7.22	34.45
73	24.14	-32.41	25.03	34.02
74	6.86	-36.24	8.39	35.97
75	8.66	-33.56	10.02	33.15
76	19.14	-33.65	20.56	32.93

Table 2: Out-of-plane survey points in the lower and the upper side. The points 1-50 are of the sensors, 51-53 the 3rd mounting point, 54-67 the cooling tab, 68-73 the hybrid, and 74-76 the large capacitors.

Parameters	Nominal	Tolerance	Description
maxZlower [mm]	0	abs()<0.2	lower sensor maximum deviation from ModulePlane
maxZupper [mm]	0	abs()<0.2	upper sensor maximum deviation from ModulePlane
midplaneHeight [mm]	0.45		z in LoFacingFrame (z=0)
moduleThickness [mm]	1.15	diff<0.1	
optimalMaxZerrorLower [mm]	0	abs()<0.05	lower sensor maximum deviation from CommonModuleProfile
optimalMaxZerrorUpper [mm]	0	abs()<0.05	upper sensor maximum deviation from CommonModuleProfile
optimalRmsZerrorLower [mm]	0	abs()<0.025	lower sensor RMS deviation from CommonModuleProfile
optimalRmsZerrorUpper [mm]	0	abs()<0.025	upper sensor RMS deviation from CommonModuleProfile
moduleConcavity x [mm]	0		bow of the midPlane along the module
y	0		bow of the midPlane across the module
sensorSkew x [mm]	0		difference of z along the module at two ends
y	0		difference of z across the module at two ends
coolingTabThickness [mm]	0.92		cooling-side tab thickness including baseboard and adhesive
farTabThickness [mm]	0.92		far-side tab thickness including baseboard and adhesive
halfTabThickness [mm]	0.460		mean half-tab thickness of cooling- and far-side
tabSkew y [mm]	0		non-zero if coolingTabThickness and farTabThickness are different
adhesiveThicknessTotal [mm]	0.160		total adhesive thickness, I.e., twice the thickness per side
adhesiveAsymmetry [mm]	0		difference of the adhesive thickness of two sides
loCoolingFacing a [mrad]	0	abs()<0.5	lower cooling facing angle along the module, 30 um over 60 mm
b [mrad]	0	abs()<3	lower cooling facing angle across the module, 30 um over 10 mm
loCoolingFacingConcavity [mm]	0	abs()<0.03	lower cooling facing concavity along x, 30 um over dowel hole/slot
hyb1NearH [mm]	1.18	0.19	height of the near-side surface of the upper hybrid from the upper facing
hyb1FarH[mm]	1.18	0.19	height of the far-side surface of the upper hybrid from the upper facing
hyb2NearH [mm]	1.18	0.19	height of the near-side surface of the lower hybrid from the lower facing
hyb2FarH [mm]	1.18	0.19	height of the far-side surface of the lower hybrid from the lower facing
hyb1Concavity [mm]	0	0.075	concavity of the upper hybrid (+ : away from sensors)
hyb2Concavity [mm]	0	0.075	concavity of the lower hybrid (+ : away from sensors)
hyb1CapMaxH [mm]	2.43	0.30	maximum height of the large capacitors, C73, C53, C54, of the upper hybrid from the upper facing
hyb2CapMaxH [mm]	2.43	0.30	maximum height of the large capacitors, C74, C55, C56, of the lower hybrid from the lower facing
hybridMaxThickness [mm]	3.28	0.44	maximum thickness of the module at surface of the hybrid
capMaxThickness [mm]	5.78	0.66	maximum thickness of the module at surface of the large capacitors

Table 3: Module out-of-plane geometry parameters

Parameters	Design Value	Tolerance
maxZlower [mm]	0.000	- 0.200
maxZupper [mm:	0.000	+0.200
diffModuleThickness [mm]	0.000	+0.100
optimalMaxZerrorLower [mm]	0.000	+0.050
optimalMaxZerrorUpper [mm]	0.000	+0.050
optimalRMSZerrorLower [mm]	0.000	+0.025
optimalRMSZerrorUpper [mm:	0.000	+0.025
loCoolingFacing a [mrad]	0.000	±0.500
loCoolingFacing b [mrad]	0.000	±3.000
loCoolingFacingConcavity [mm]	0.000	±0.030
capMaxThickness [mm]	5.780	+6.440

Table 4: Module out-of-plane geometry parameters and tolerances in the tolerance test. The sign of the Tolerance shows the upper(+) and/or lower(-) limit.

atlasPartsId	20220170200042
eventDescription	SURVEY_Z-INITIAL
date [dd/mm/yyy]	09/05/2002
location [instituteCode(DB)]	KEK
personInitial	YU
problem [YES/NO]	NO
pass [YES/NO]	YES
comments	
temperature [C]	25.7
measurementJigID	MT2
maxZlower [mm]	-0.024
maxZupper [mm]	0.015
midplaneEq	z=ax+by+c
Left a	-0.000341235
b	-0.000107838
c	0.474182974
Right a	-0.000673743
b	1.07372E-05
c	0.474422594
midplaneHeight [mm]	0.474
moduleThickness [mm]	1.150
optimalMaxZerrorLower [mm]	0.028
optimalMaxZerrorUpper [mm]	0.020
optimalRmsZerrorLower [mm]	0.007
optimalRmsZerrorUpper [mm]	0.007
moduleConcavity x [mm]	0.011
y	-0.001
sensorSkew x [mm]	-0.063
y	-0.003
coolingTabThickness [mm]	0.935
farTabThickness [mm]	0.934
halfTabThickness [mm]	0.467
tabSkew y [mm]	0.001
adhesiveThicknessTotal [mm]	0.145
adhesiveAsymmetry [mm]	-0.007
loCoolingFacing a [mrad]	-0.120
b [mrad]	-1.401
loCoolingFacingConcavity [mm]	0.007
hyb1NearH [mm]	1.071
hyb1FarH[mm]	1.066
hyb2NearH [mm]	1.077
hyb2FarH [mm]	1.072
hyb1Concavity [mm]	-0.009
hyb2Concavity [mm]	-0.003
hyb1CapMaxH [mm]	2.305
hyb2CapMaxH [mm]	2.309
hybridMaxThickness [mm]	3.092
capMaxThickness [mm]	5.549
optimalFrameRawDATA	
names to follow...	data to follow ...

Table 5: An example of the datasheet from the surveyZ_idAction2.4.xls analysis file

3.2 Leakage Current Tests

3.2.1 I-V Scan to 500V

With the ASIC's unpowered, the detector I-V curve of the completed module is recorded up to 500V bias at room temperature. For a good module, the total leakage current of the module will differ from the sum of those for the four individual detectors by no more than 4vormalised (normalised at 20 °C). Outside this limit, the module will be visually inspected for any signs of damage to the detectors, and subjected to long-term current tests at a range of bias voltages.

If the current behaviour is the microdischarge, i.e., normal up to a certain voltage and then shooting up, the module is subject to the high-voltage (350 V) long-term (24 hr) testing at room temperature with the ASIC's unpowered. If the current decays to the typical current of normal sensors within 24 hrs and stable more than 3 hrs, the module is passed the test.

When the I-V scan is stand-alone, i.e., no electrical tests being followed, the temperature of the module can be at room temperature (25 ± 3 °C). In the series module production, the I-V scan is in a sequence of the module characterisation where the module is cooled for ASIC powering. Accordingly, the most likely temperature of the module in this sequence is, although warm, at the cooled environment somewhere like +15 °C. In order to allow the temperature range, it is important to log the temperature (of the hybrid thermistors). Comparison of currents will be made by normalising at 20 °C according to the formula,

I(20[C]) = I(T[C]) * ((293/(273+T[C])^2 * exp(-7019*(1/293-1/(273+T[C]))

Temperature (measured by hybrid thermistors): about +15 to +30 °C

Bias voltage: 0 to 500 V

Condition: ASIC's unpowered, log the temperature

In case of microdischarge: high voltage long-term test

Bias voltage: 350 V

Temperature: about +15 to +30 °C

Condition: ASIC's unpowered, log the temperature, 24 hrs

3.2.2 Long Term Leakage Current Stability

All modules will be tested for long-term leakage current stability over a 24 hour period, in parallel with the long-term electrical test, in an environmental chamber containing dry air (nitrogen). The ASIC's are powered, clocked and triggered, and the detector bias is maintained at 200V. The current is monitored every 15 minutes over the period. The cooling and environment temperature is adjusted so that it is around 0°C measured by the hybrid thermistors.

The maximum increase in leakage current over the period should be less than 4µA for a good module, after an initial settling time of 5 minutes.

This test can be performed in parallel with the long-term electrical test on modules, section 3.5 below.

Temperature (measured by hybrid thermistors): 0 ± 3 °C

Bias voltage: 200 V

Condition: in an environmental chamber, dry air (nitrogen), measured in parallel with the long-term electrical test (i.e., ASIC's powered, clocked, with confirmation sequence in every few hours)

3.3 Electrical Tests

An extensive suite of both hardware and software[2] has been developed to facilitate module testing. The readout system is based around the VME modules CLOAC, MuSTARD and SLOG. The prototype low voltage and high voltage modules, SCTLV and SCTHV, are also part of the system.

Two largely automated series of tests[3] have been devised to simplify the testing procedure, as outlined in Table 5. The *Characterisation Sequence* aims to perform the full characterisation of a hybrid or module whereas the shorter *Confirmation Sequence* provides a reduced set of information. The *Confirmation Sequence* ensures that the digital part of the ASIC's is functioning, none of the critical wire-bonds have been damaged and that the basic analogue performance of a module has not deteriorated. It is anticipated that the *Confirmation Sequence* would be repeated at regular intervals during the long-term tests and each time that a hybrid or module is shipped between institutes.

	Characterisation	**Confirmation**
Power On Tests / Verification of Response to Hard Reset	√	
Clock and Command Reception Test	√	√
Bypass Functionality Test	√	√
Pipeline Efficiency Test	√	
Strobe Delay Scan	√	√
Three Point Estimation of Gain, Noise and Offset	√	√
TrimRange Scan	√	
Determination of the Response Curve	√	
Noise Occupancy Scan	√	
Timewalk Scan	√	

Table 5: The Characterisation and Confirmation Sequences

In general, the analogue performance of a module/hybrid is measured with respect to the internal calibration circuitry of the ABCD3T chip. Hence it is necessary to make a correction for the variation of the calibration capacitance between batches of ASIC wafers.

There follows a brief description of the individual tests to be performed as part of the electrical QA procedure. The description contains the method in general terms, the purpose of the tests and in quantitative terms the criteria for PASS/FAIL cuts. A summary of the results of each test will be recorded in the SCT database.

A module is classed as "good" if at least 99% of its readout strips will operate efficiently with low noise occupancy at 1fC threshold.

[2] http://sct.home.cern.ch/sct/sctdaq.html

[3] The tests are described fully in http://hepwww.rl.ac.uk/atlas-sct/documents/Electrical_Tests.htm

3.3.1 Temperature of Electrical Test

The electrical tests are performed in room temperature. A module is stored in a module box and connected to the DAQ system. In order to keep the ASIC's in room temperature, the module box has to be cooled in an environment chamber or with attaching a cooling element to the module box. The temperature of the environment chamber or the cooling element is about +15 °C to keep the temperature of the hybrid thermistor around 27 °C.

Temperature (measured by hybrid thermistors): 27 ± 3 °C

Condition: cool the module box, in an environmental chamber, dry air (nitrogen)

3.3.2 Power on Tests / Verification of Response to Hard Reset

The module/hybrid is clocked and the power is switched on. The operator must verify that each data-link responds with CLK/2 and that, after the chips have been configured, the clock feed-through signal stops. The analogue and digital currents are then recorded. Finally Hard Reset is issued to bring back the CLK/2 signal.

This test verifies that the Clock, Command and Hard Reset signals are received correctly, that the chips can be configured and that the current consumption is reasonable. The test will identify modules/hybrids with severe failures. Every module must pass this test without error.

This is the only test that would normally require operator intervention.

3.3.3 Clock and Command Reception / Addressing Error Test

The chips are configured to return the contents of the Mask Register and a burst of triggers is issued for each of the Primary and Redundant Clock and Command options. Prior to each event, a different bit pattern is loaded in the Mask Register such that consecutive events are not the same.

By comparing the received data with expectation it is verified that both the Primary and Redundant Clock and Command signals are received correctly and that the top address bit of each chip changes as the Clock/Command source is varied, as specified in the module design. This test will identify modules/hybrids with faulty command reception or addressing errors. Modules/hybrids with such defects would be considered to have failed pending further investigation and possible rework.

3.3.4 Bypass Functionality Test

A trigger burst is recorded with the module/hybrid programmed to each of a number of different configurations, sufficient to exercise all data/token passing links between the chips. In each case the chips are configured to return the contents of the Mask Register such that the expected data is accurately known. The test is repeated across a range of digital supply voltages.

This test determines the minimum value of the digital supply voltage needed for each of the data/token passing links to work. Any link that did not work at the designated supply voltage, and which could not be identified as being due to a missing wirebond and subsequently repaired, would cause a module/hybrid to be rejected.

3.3.5 Pipeline Efficiency Test

For this test, a Soft Reset command is sent to reset the pipeline followed a certain number of clock periods later by a Pulse Input Register command and L1A trigger. In this way, a known pattern is injected into a given location in the pipeline. By varying the distance between the Soft Reset and Pulse Input Register commands it can be verified that each of the eleven blocks within the pipeline is free of defects.

Zero occupancy for a particular number of clock periods between the Soft Reset and Pulse Input Register commands would indicate a dead cell in the corresponding block of the pipeline.

Zero occupancy for all values would indicate a dead channel. Modules/hybrids with a large number of dead Pipeline cells or dead channels will be rejected.

3.3.6 Strobe Delay Scan

This scan is performed to determine the correct Strobe Delay setting, corresponding to the timing of the charge injection pulse, to be used during the Analogue Tests.

3.3.7 Three Point Estimation of Gain, Noise and Offset

Threshold scans are taken for three injected charges to facilitate a quick measurement of gain, noise and the discriminator offset. Pathological channels are categorised as FAULTY if the defect would result in the channel having a reduced but non-zero detection efficiency in ATLAS, or as LOST if the defect would result in the channel having zero efficiency:

Lost: Dead, Stuck, Unbonded or Noisy channels

Faulty: Inefficient, Low Gain or Partially Bonded channels

Modules/hybrids having any chips with abnormal gain or high noise will be rejected, for potential re-work, as will those with large numbers of pathological channels.

3.3.8 Trim Range Scan

For each of the four possible TrimRange settings, a series of Threshold scans are performed for a subset of the sixteen possible TrimDAC settings, all with 1fC injected charge. For each TrimRange setting a straight line is fitted to the data for each channel to characterise the TrimDAC response and to determine the TrimDAC slope. The number of trimmable channels and the spread of the resultant trimmed thresholds are also recorded. The optimised TrimDAC settings and a list of channels to be masked are produced for use in the subsequent analogue tests.

The chips used to build modules will have been selected such that all channels may be trimmed using the smallest TrimRange. Modules which do not meet this specification on at least 99% of channels will be rejected, for potential rework, as will those where a particular TrimRange has a slope other than that expected.

3.3.9 Response Curve

Threshold scans are performed for a series of input charges and, for each channel, an appropriate function is fitted to the resulting response curve. From this the Gain, Noise and discriminator Offset are extracted.

The parameters from the fit are stored since they describe the correspondence between the Threshold, in mV, and input charge, in fC. The categorisation of pathological channels is repeated as described for the Three Point Gain. Modules/hybrids with a large number of pathological channels will be rejected.

3.3.10 Noise Occupancy Scan

A high statistics Threshold scan is performed at the nominal ATLAS trigger rate of 100kHz, without any injected charge, to determine the Noise Occupancy of each channel as a function of Threshold. The analogue and digital current consumption as a function of Threshold is recorded.

Channels with high Noise Occupancy will be added to the list of masked channels.

3.3.11 Timewalk Scan

This test performs a series of Strobe Delay scans with the Threshold set to 1 fC, varying the input charge from 1.25 to 10 fC. In each case a fit is made to the rising edge of the pulse to determine the Strobe Delay value needed to obtain 50% occupancy.

The Timewalk is defined as the time variation in the crossing of a threshold of 1fC over a signal range of 1.25 to 10.0fC. This parameter is calculated and recorded.

3.4 Thermal cycling

For every module a thermal cycle from -25° to +40°C will be carried out ten times, in an inert atmosphere. The module(s) will be placed inside an environmental test chamber and purged with nitrogen for sufficient time to prevent dewing when cold (e.g., 3 volume changes within the chamber). During the test, each module will be unpowered. The test cycle will start and end at room temperature and the first temperature excursion will be to +50°C. The ramp up/down times will be approximately 30 minutes (2-3°C/minute) and the soak time about 30 minutes at each temperature. The total test time will therefore be about 20 hours. This test could also be extended to carry out long-term electrical tests at the operating temperature.

Temperature (measured by hybrid thermistors): -25 °C to +40 °C

Number of cycles: 10

Condition: ASIC unpowered, in an environmental chamber, inert gas atmosphere

3.5 Cold long-term electrical test

In addition to detailed electrical testing and characterisation, a longer duration test will be performed on assembled modules at the ATLAS operating temperature. This test verifies that modules will function electrically at reduced temperatures.

The test consists of an extended (24 hour) run, with the ASIC's being clocked and triggered. The temperature is adjusted so that the temperature of the hybrid thermistors is around 0 °C. The currents drawn by and the temperatures of the hybrids are monitored every 15 min. Every few hours a *Confirmation Sequence* is performed. At the end of the test, a *Characterisation Sequence* is performed while the modules are kept cold.

Temperature (measured by hybrid thermistors): 0 ± 3 °C

Duration time: 24 hrs

Condition: ASIC's clocked and triggered, in an environment chamber, inert gas atmosphere

This test may be performed in parallel with the long-term leakage test (section 3.2.2).

4 SAMPLING QA ON COMPLETED MODULES

The fraction of modules to be used initially for the sub-sample tests is indicated in each of the following sections.

4.1 Irradiation Tests

A very small sample of the completed barrel modules (approximately 10 per annum during the construction period) will be fully and uniformly irradiated in the SCT facility at the CERN PS to a fluence of 3×10^{14} pcm^{-2} 24 GeV/c protons. They will be annealed for 7 days at 25°C following the irradiation and then checked for mechanical integrity and for noise performance, for full ASIC functionality and for detector leakage current when run cold at the SCT operating temperature. Several of these modules will also be tested in the beam for signal:noise and efficiency performance.

4.2 Readout Performance with Particles

4.2.1 Beam Tests

A small number (approximately 20 per annum during the construction period) of the barrel modules will be fully tested in the H8 beam at CERN, with a magnetic field and with varying angles of incidence of the particles to check their continued performance characteristics. Modules will also be tested in the beam at KEK.

4.2.2 Source Tests

It is anticipated that a fraction of the modules will, at least initially, be read out in the laboratory when exposed to a Ru^{106} beta source. This will allow signal:noise values to be confirmed for the different batches of delivered ASIC's.

4.2.3 Laser Tests

A subset of the produced modules may also be submitted to scanning Laser tests. A focused LASER of wavelength e.g. 1050 nm is mounted on a x-y stage and scanned over the module. This test provides very precise position information, hence the correct functionality of all channels can be verified.

5 SUMMARY

The QA procedures for the Barrel SCT module are designed to ensure the quality and performance for each individual module produced. They should cover all aspects of the module, such as mechanical tolerances, electrical performance and long-term stability. These goals should be achieved uniformly during the production cycle, regardless of production site, for all batches of constituent components and for the assembled modules.