	ATLAS SCT Barrel Module FDR/2001				
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SCT Barrel Module FDR Document

SCT Barrel Module : Requirements and Specification of Barrel Modules

Abstract

This document details the requirements and specifications of the SCT barrel modules with reference to the chosen module design.

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1 SCOPE OF THE DOCUMENT

The document describes the requirements and specifications of the SCT barrel module, and how these relate to the final module design.

2 REQUIREMENTS OF THE BARREL MODULES

For the SCT barrel, the required tracking precision is obtained by modules with an intrinsic point resolution of 23 μm in the r-φ coordinate per single side measurement. The precision is obtained for the binary readout scheme (on-off readout) using silicon microstrip sensors with 80 μm readout pitch. A back-to-back sensor pair with a stereo rotation angle of 40 mrad gives a precision of 17 μm in the r-φ coordinate and 500 μm in the z coordinate from the correlations obtained through fitting. The mechanical tolerance for positioning sensors within the back-to-back pair must be ~ 5 μm lateral to the strip direction.

The severity and consequences of the high accumulated radiation levels for silicon detector operation, causing increased leakage current and type inversion, give rise to the need to operate the sensors at about -7 ^{o}C. The maximum expected fluence after 10 years of operation in the SCT is $2x10^{14}$ 1 MeV-neutron-equivalent/cm^2 (at the upper limit of uncertainty of 50% in the total cross section). The corresponding detector bias voltage required for high charge collection efficiency will be in the range 350-450 volts, depending upon SCT warm-up scenarios. This will result in a total leakage current of ~ 0.5 mA for a barrel detector operated at -7 ^{o}C at a bias voltage of 450 V. The leakage current is strongly dependent on temperature, roughly doubling every 7 ^{o}C. The detector heat generation is therefore a strong function of the temperature of the sensors in the module.

Thermal considerations, and especially concerns of thermal run-away, lead to a module design where the effective in-plane thermal conductivity must be increased beyond that of silicon. In practice this will be achieved by the use of high-thermal conductivity material in a baseboard which is laminated as part of the detector sandwich. The power consumption of the front-end ASICs is expected to be 6.0 W nominal and 8.1 W maximum. The thermal design of the module must allow for this.

The SCT will undergo temperature cycling over the range -20 ^{o}C to +25 ^{o}C in a controlled sequence, and it must be safe, in the event of cooling or local power fluctuations, up to temperatures of 100 ^{o}C. This requires the module design to have minimal CTE, and to be capable of elastic deformation. The precision of the tracking measurement depends on the modules having a stable profile after changes of the operating conditions.

The SCT modules are in the tracking volume and required to have as little mass as possible. With the use of carbon and organic materials, the goal for the amount of material is 1.2% X_o (radiation length) per module, averaged over the sensor area.

After considering the combined electrical, thermal and mechanical requirements, the optimised design of the barrel modules has a hybrid placed near the centre of the module, above the detectors, and connected to the strips near the middle of their total length.

3 SPECIFICATION OF THE MODULE DESIGN

In the barrel region, one module is made of four 63.96 mm x 63.56 mm (cut-edge to cut-edge) single-sided silicon microstrip sensors. Geometrical dimensions are shown in Figure 1 for the two sensors aligned to form a 128 mm long unit. Strips of the two sensors are wire-bonded to form 126 mm long strips. The pitch of the strips is 80 µm and there are 770 strips physically with the first and the last being connected to the strip bias potential for the electric field shaping and defining the strip boundary.

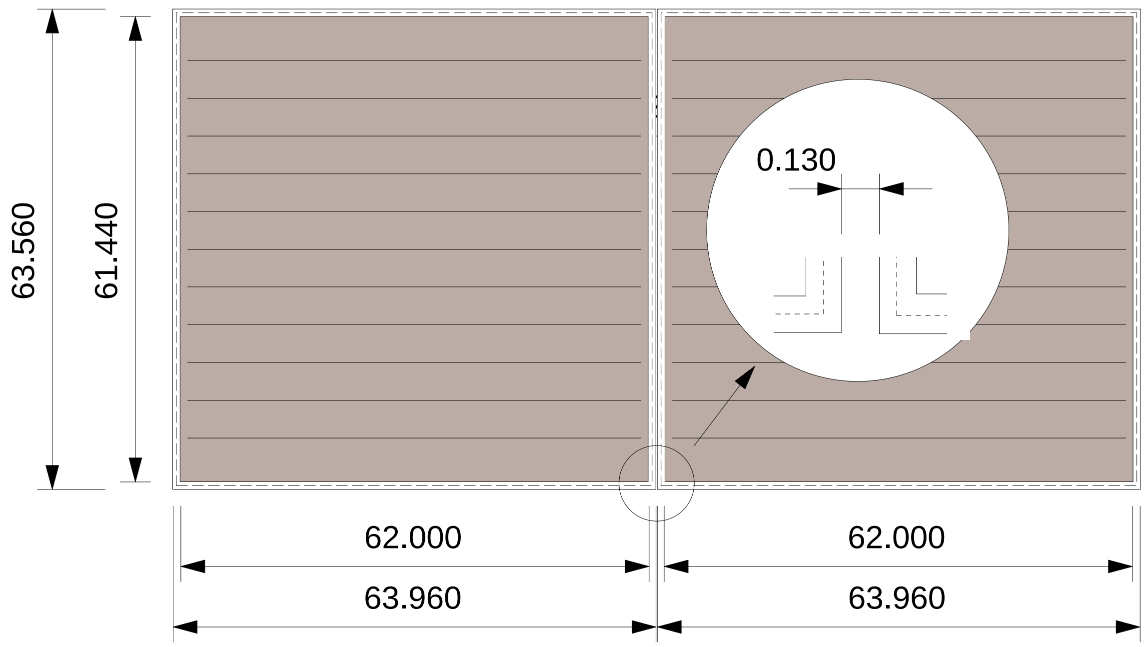

Figure 1 A pair of the barrel microstrip sensors forming a 128 mm strip unit. The active (readout) areas of the sensors are shaded and the gap between the sensors is shown in the inset.

Figure 2 shows a 3D view of the barrel module and the key features of the design. In order to form a double-sided readout module, a pair of 128 mm long units are back-to-back aligned and glued with a stereo angle of 40 mrad. Figure 3 shows an expanded view of all the components. The measuring planes, each formed of a pair of wafers, are glued to a central VHCPG baseboard of thermal conductivity up to 1700 W/m/K. As shown in the figure, the baseboard extends outwards, with BeO facings fused to the VHCPG surfaces, on both lateral sides of the module. These exposed facings are the places at which the readout hybrids are attached, and the larger facing contacts the cooling pipe. The contact BeO facing includes dowel holes to locate the module on the support structure accurately. The hybrids form mechanical bridges across the silicon, in a design that reduces the thermal coupling between the front end chips and the silicon by avoiding contact with the silicon surface. This also has the advantage of avoiding gluing to the active surface, which would carry the potential for damage and also the uncertainties associated with long term ageing and radiation effects.

The module parameters are summarised in Table 1.

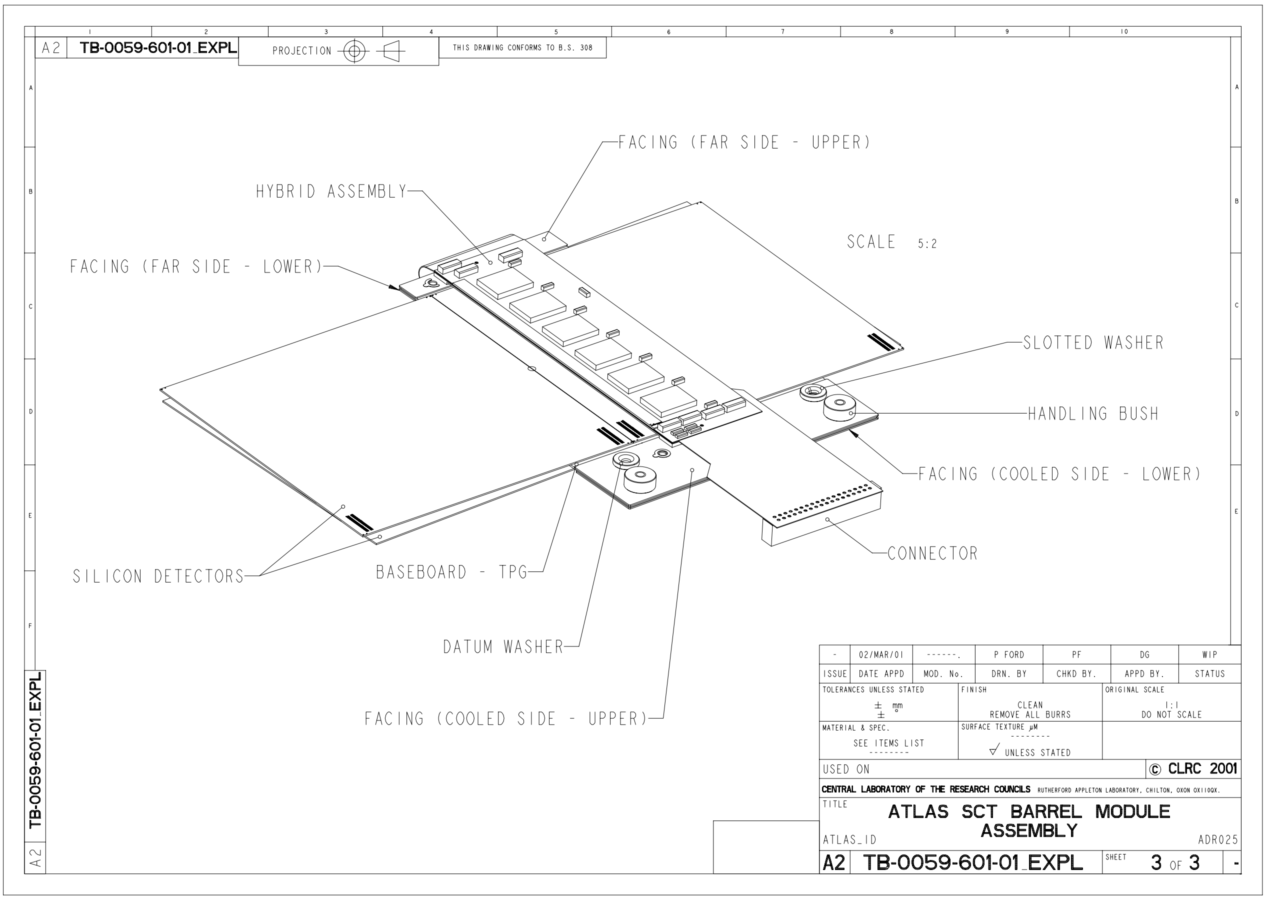

Figure 2 Layout drawing of barrel module

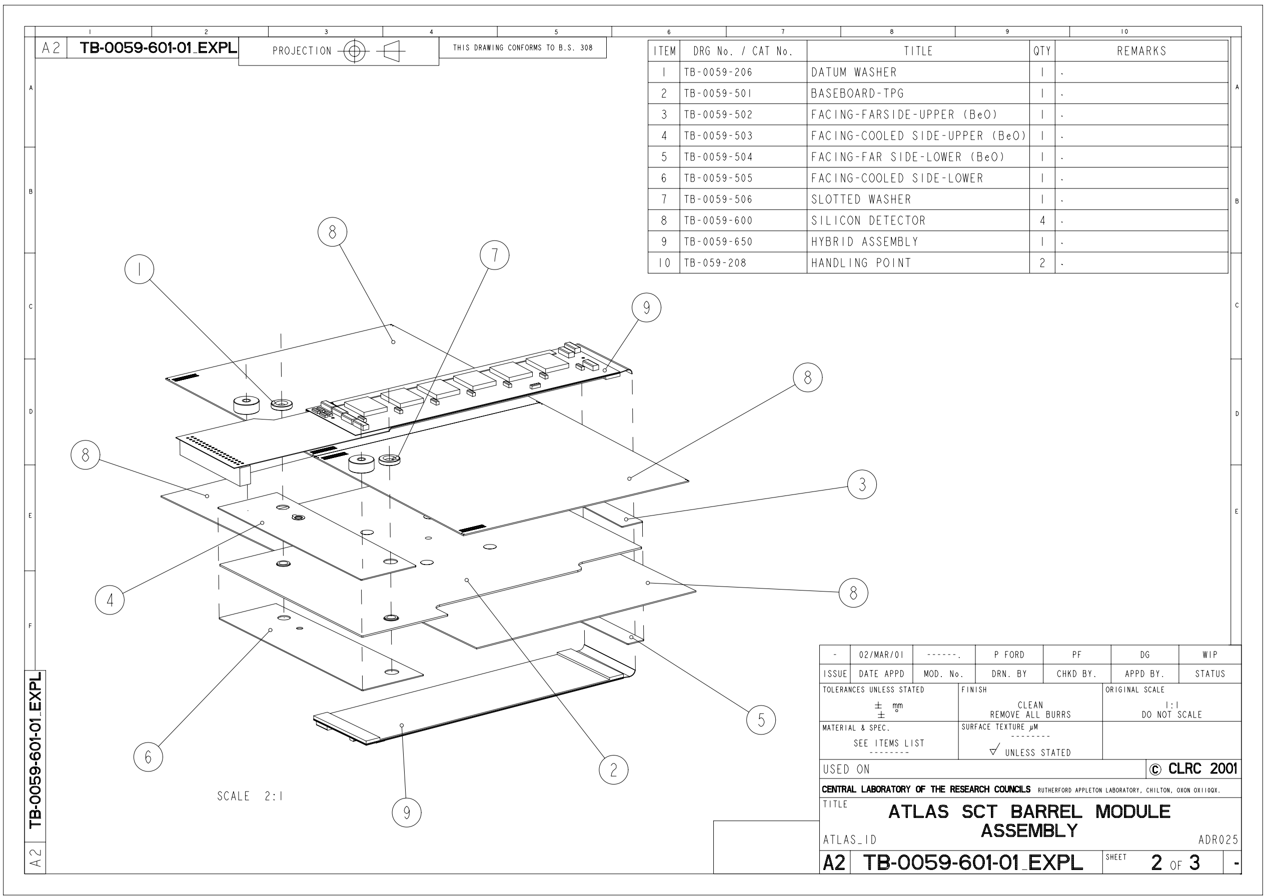

Figure 3 Exploded view of barrel module

Silicon outer dimension	63.56 mm x 128.05 mm (cut-edge)
Construction	Four 63.56 mm x 63.96 mm p-in-n single sided sensors to form back-to-back glued sensors
Mechanical tolerance	back-to-back: <5 µm (in-plane lateral), <10 µm (in-plane longitudinal), <50 µm (out-of-plane, deviation from the average profile) Fixation point: <30 µm (in-plane lateral), <30 µm (in-plane longitudinal)
Strip length	126.09 mm (2.090 mm dead in the middle)
Strip directions	±20 mrad (0, ±40 mrad on support structure)
Number of readout strips	768 per side, 1536 total
Strip pitch	80 µm
Hybrid	two single-sided hybrids bridged over the detector
Hybrid power consumption	6.0 W nominal, 8.1 W maximum
Maximum detector bias voltage	460 V (on the detector), up to 500 V in the module
Operating temperature of detector	-7 ^{o}C (average)
Uniformity of silicon temperature	<5 ^{o}C
Detector power consumption	1 W total at -7 ^{o}C, Heat flux (285 µm): 120 µW/mm^2 at 0^{o}C
Thermal runaway	Heat flux: >240 µW/mm^2 at 0 ^{o}C
Radiation length	<1.2% X_o

Table 1: Barrel module parameters

4 MODULE ENVELOPE AND ELECTRICAL STAY-CLEAR REQUIREMENTS

Figure 4 shows the barrel module envelope. The thicknesses of the modules are 1.15 mm in the sensor area, 0.92 mm in the BeO facing area, 3.28 mm in the blank hybrid area, 6.28 mm in the highest component area, 4.48 mm in the ASIC area, and 5.08 mm in the highest wire-bond area. Since wire-bonds have height variations, at least a 1 mm stay clear distance is required in elevation, and so the module stay-clear thickness in the highest wire-bond area is 7.08 mm.

The wrap-around part of the interconnect cable extends to reach a distance of between 40.0 mm from the module centre (for a perfect round shape at the wrap-around) and 41.22 mm maximum (for a perfect wedge shape at the wrap-around). The hybrid placement error of order 50 µm is then to be added to these number.

The error in the pigtail connector position comes from the error in the hybrid placement, the connector pin-hole play, and the soldering error, which are of order of 100 µm, 100 µm, and 200 µm, respectively, and thus of order 500 µm in total. The pigtail cable, which is flexible, connects to the less flexible opto-harness. The flexible pigtail cable is therefore made sufficiently long so that its route can adjusted to achieve the correct mating between the two connectors.

The cut edge of the sensor is conductive and at the backplane bias high voltage; conducting debris between the cut edge and ground could cause high voltage shorts. An electrical stay clear distance of at least 1 mm has been defined. This assures a high voltage breakdown of 3 kV to ground at sea level in air[1]. The distance between the centres of the modules is specified to be 2.8 mm in height in the overlap region of adjacent modules on the barrel cylinder, which leaves a nominal stay clear distance of 1.65 mm between the cut edge and the opposing sensor surface. Of this, 400 µm is allocated to accommodate thickness tolerances and non-planarity of overlapping modules (see SCT-BM-FDR-3. Section 2.2). A maximum deviation of 200 µm of the module surface from the nominal can thus be accommodated.

5 MODULE THERMAL PERFORMANCE

A thermal FEA simulation has been carried out for the barrel module design (see Figure 5). Figure 6 and Figure 7 shows the maximum (T_{si} max) temperature of the silicon sensors in the module as a function of the bulk heat generation normalized at 0 ^{o}C, for hybrid power consumption of both 6.0 W and 8.1 W and three coolant temperatures. The simulation shows that the thermal runaway of the silicon detector occurs at 220 µW/mm^2 for the maximum 8.1 W chip power at -14 ^{o}C coolant temperature. The bulk heat generation after 10 years of operation at LHC is estimated to be 120 µW/mm^2 in the worst case. The 6W power at –17^{o}C has a factor 3 in the thermal runaway safety margin, and for 8.1W, -14^{o}C gives nearly the required factor of 2, and –20^{o}C more than a factor of 3.

Thus the barrel module design is expected to provide the necessary thermal environment for normal operation of the silicon detectors and the ASICs, and to be safe against thermal runaway.

[1] Spark gap voltages, based on results of the American Institute of Electrical Engineers, Air at 760 mmHg, 25 oC

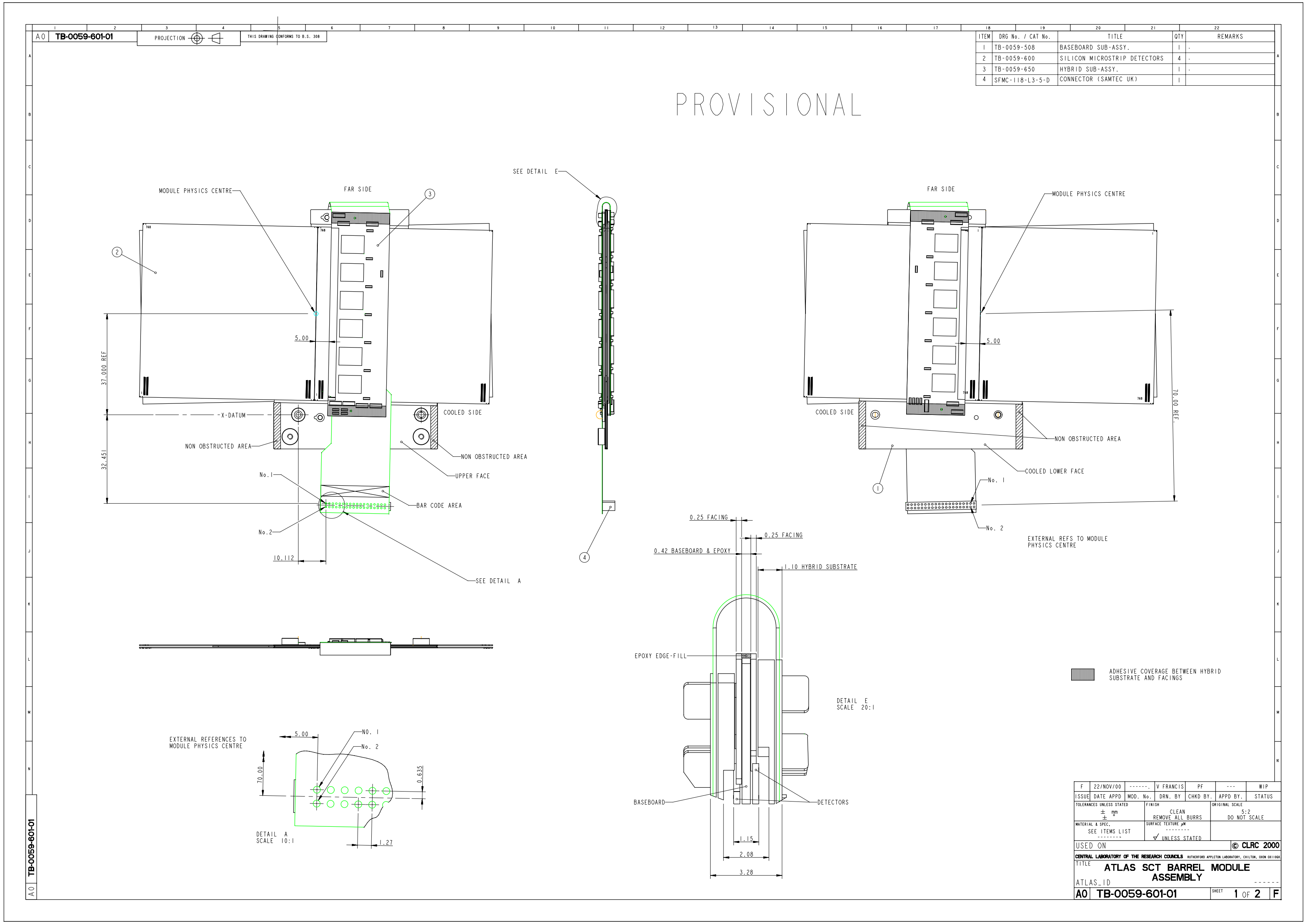

Figure 4   Barrel module envelope

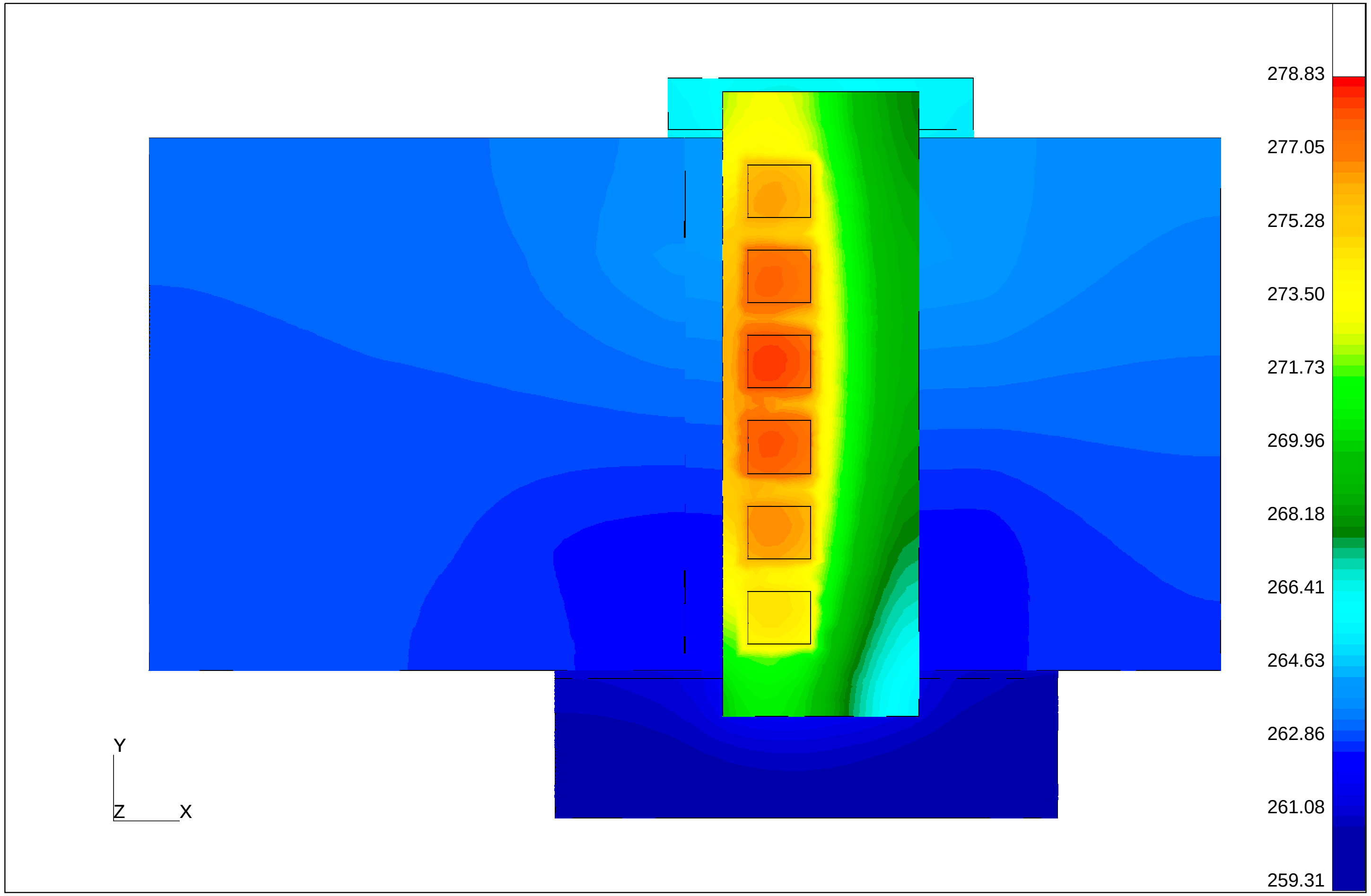

Figure 5   Thermo profile of the module with nominal heat generation in the silicon sensors and a hybrid power of 6.0 W

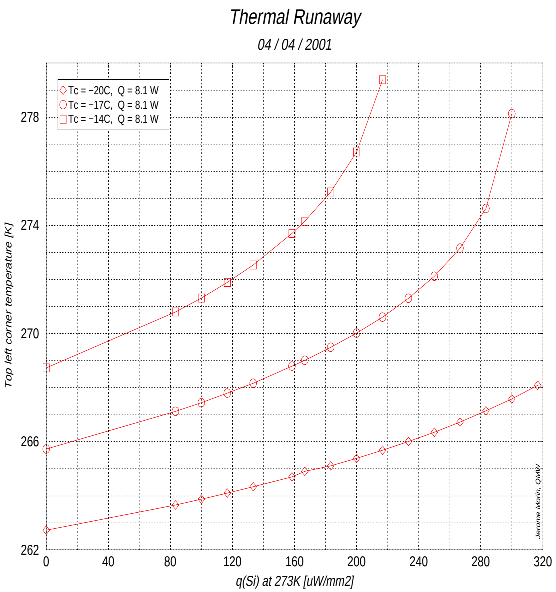

Figure 7: Temperature of the hottest point in the sensors as a function of heat flux, with various coolant temperatures, for the hybrid power at 8.1 W

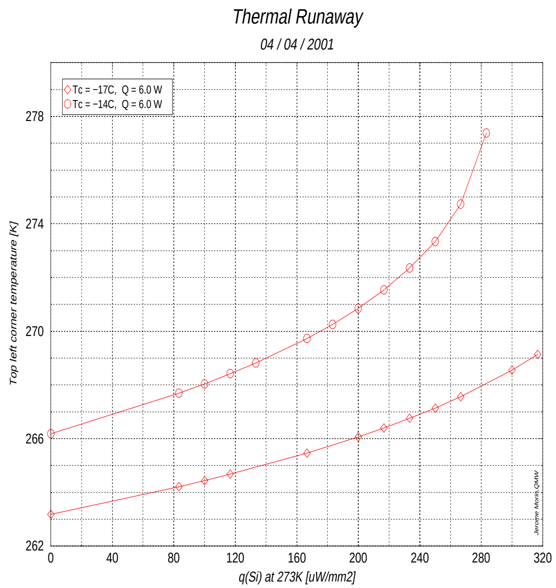

Figure 6 Temperature of the hottest point in the sensors as a function of heat flux, with various coolant temperatures, for the hybrid power at 6.0 W

6 RADIATION LENGTH OF THE MODULE

Table 2. summarises the estimated radiation length and weight of the module components. The weight of each item has been measured and the results match to within a few percent of the estimated value. The matching in weight ensures the validity of the estimation of the radiation length of the module in the table. The overall weight of the module is 25 gm and the radiation length averaged over the silicon sensor area is 1.17 $\%X_o$, which satisfies the specified <1.2 $\%X_o$.

Component	**Radiation length [% X_o]**	**Weight [gm]**
(a) Silicon sensors and adhesive	0.612	10.9
(b) Baseboard and BeO facings	0.194	6.7
(c) ASICs and adhesive	0.063	1.0
(d) Cu/Polyimide hybrid	0.221	4.7
(e) Passive components	0.076	1.6
Summed material	**1.17**	**24.9**

Table 2: Radiation length and weight of the module