ATLAS Internal Note
INDET-NO_125
16 February 1996

A conceptual design for the module design and disc support structure for the ATLAS forward SCT tracker

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1 INTRODUCTION

The ATLAS inner tracker requires precision measurements over the range $|\eta| < 2.5$. In a recent internal review ATLAS adopted the concept of an integrated semiconducting tracker based on silicon and GaAs microstrip detectors. The original proposal (INDET-NO-69, Bowcock, Clark and Edwards) has been developed further and the current layout is shown in Fig. 1.

The demonstration of the viability of the silicon tracking in the forward region required conceptual designs for modules and support structures. These conceptual designs are presented below. The design of a "fan geometry" silicon module is discussed in section 2. Section 3 describes the support structure for a typical disc including three rings of semiconducting detectors while a possible solution for cooling the detector and electronics is presented in section 4. Finally an estimate of the material budget is presented in section 5 and the future programme of work is discussed in section 6.

2 MODULE DESIGN

Two possible designs for modules for use in the barrel detector, the "z" module and the "R-phi" module, are discussed in the Technical Proposal. The concept for a module suitable for the forward region discussed here has the electronics mounted at the end of the strips similar to existing LEP designs. This approach was adopted due to the different geometry of the detectors and support system as compared to the barrel but the design utilises the same electronic solutions and a similar hybrid and cooling solution. The basic detector unit is 12cm in length. At present, using 4" wafer technology, this is achieved by bonding two detectors together although the possibility of using 6" technology would allow the use of a single wafer.

2.1 "Fan geometry" wafer design

A "fan geometry" in which the read out strips measure the azimuthal co-ordinate ϕ directly has been adopted. This choice has been determined by the requirements of the second level trigger and the desire for simpler pattern recognition and alignment.

The current layout of a disc in the forward region involves one ring of silicon detectors covering the region $329 < r < 448.5$ mm and a second ring covering the region $437 < r < 560$mm with a ring of GaAs detectors at smaller radii down to $r = 260$mm as shown in fig. 2. Some of the discs have a more restricted radial coverage.

The choice of front end electronics is still an open question for the ATLAS SCT and the final solution will be adopted for both barrel and forward modules. The design described below is for a binary readout scheme but the design may be readily modified for an analogue or digital read out scheme. In the latter case the detectors would be designed with an intermediate strip and 112.5 μm read out pitch.

The "base line" technology for the ATLAS SCT is n+ strips in a n type substrate.

A design for a fan geometry detector is shown in fig. 3. The detector has 768 channels and all strips are AC coupled to the read out amplifiers. Each strip is biased by a polysilicon resistor and isolated from other strips by surrounding it with an individual p stop. For the inner (outer) ring the innermost wafer has a pitch varying from 69 μm to 81 μm (70 μm to 80 μm)and this is bonded to an outer wafer with pitch varying from 81 μm to 93 μm (80 μm to 89 μm). A prototype detector based on p strips in n type bulk designed on this basis for the MSGC / Silicon Review verified this design choice. A multi-strip guard structure is used to control the depletion region near the edges of the detector.

2.2 Detector construction

A complete module consists of a 12 cm long ϕ detector with a similar detector attached to it to provide a second co-ordinate rotated through 40 mrads to achieve a small angle stereo layer. The overall arrangement is shown in fig. 4 for a module on the inner ring. Due to the lack of radial space on the outside of the SCT tracker it is necessary for the electronics on the modules in the outer ring to be situated on the inside of the ring as shown in fig. 5. One design feature is that the individual detectors are constructed such that the non-active areas where the detectors are bonded together are offset for the stereo layer as compared to the ϕ layer. This design ensures that at least one of the two co-ordinates will be recorded in this region.

The engineering design aims at producing a stable structure with the minimum radiation length and good thermal properties. The issue of radiation damage to the silicon constrains the operating temperature of the silicon wafers to be of order -10°C and uniform to within 2 - 3 °C. The module is expected to dissipate up to 600 mW of power produced within the radiation damaged silicon detectors (W. Miller INDET-NO-102) in addition to the 4.6 W generated by the associated electronics (assuming 3 mW per channel). The cooling system is discussed in section 4. The stability of the module under changes of temperature of order 40°C (temperature at construction - working temperature) requires a symmetric construction when materials with different coefficients of expansion are involved.

Fig 6 shows a side view of the module. The two detectors are glued back to back onto a 380 μm thick strip of beryllia which acts both as a mechanical support and as a channel for heat conduction. The read out chips are mounted on both sides of a beryllium oxide substrate with multi layer circuits on each side. To minimise material the technology for this multi layer circuit is likely to be thin film aluminium on kapton rather than the conventional double sided thick film gold on glass hybrid. Unfortunately this choice is not optimal from the thermal point of view since kapton is a relatively poor conductor of heat. The connection from hybrid to detector is accomplished using beryllia fan-ins. These fan-ins also play a major role in the heat conduction. At present it is envisaged that cooling connections will be made onto one side of the module on one fan-in and possibly also on the beryllia strip mounting the hybrids. Another solution under consideration makes use of two identical single sided modules (one rotated by the stereo angle) sandwiched either side of the cooling structure.

Fig. 7(a) shows a thermal model of the system while fig. 7(b) shows the temperature variation across the module as determined by a 2D finite element calculation.

The distortion of the module in cooling 30°C has been checked to be less than 1μm in z, whilst the overall contraction along its length is 35μm.

3 DETECTOR SUPPORT

The aim is to design a fully integrated system for all the precision detectors. In the forward region this involves supporting both silicon and GaAs detectors on the same structure with integrated services.

The basic support unit is a annular disc 10mm in thickness. A sandwich construction is adopted with outer surfaces formed from carbon fibre skins, each 0.3mm thick, and a filling of carbon fibre honeycomb. In order to keep the material budget to a minimum part of the material may be cut away. This step would require both finite element calculations and prototype work. The example shown in Fig. 2 shows two rings of silicon detectors plus a ring of GaAs detectors. The modules in each detector ring are arranged to provide an eight strip overlap in the ϕ co-ordinate. The individual rings are then arranged to give a 3mm overlap in the radial co-ordinate. Due to the lack of space at larger radii the hybrids on modules in the outer silicon ring are situated at the inner radius while the hybrids for all other modules are situated at the outer radius of the module.

Each module is attached to an aluminium silicon carbide metal matrix composite (MMC) block which is glued to the fan-in on the module. The block contains two precision dowels which gives an acurate location to the wheel, so the support block would need to be precision mounted to the module using a suitable assembly jig. The MMC blocks are part of the cooling structure and screwed onto the support disc. This MMC material was chosen because of its coefficient of expansion of 9.5×10^{-6} per degree C which is similar to the beryllia fan-in, thus placing the minimum amount of stress on the silicon. In addition it has a density similar to aluminium and good thermal properties and although very hard, can be machined. Precision dowel holes are drilled in the wheel allowing the modules to be positioned to an accuracy of 10μm. Alternate modules in a ring are offset perpendicular to the plane of the disc so as to allow the necessary overlapping in ϕ. The working environment for the silicon will be in an enclosure, flushed with dry nitrogen to prevent condensation, supplied at the equilibrium temperature of the enclosure. All the heat dissipated will be removed by the fluid cooling system .The disc has a very low coefficient of expansion of 0.5 x 10^{-6} per degree C whereas the silicon wafers have a coefficient of expansion of 3-7 x 10^{-6} per degree C. The attachment of the module to the disc must allow for the difference in expansion so as to avoid unnecessary stress on the module. This can be achieved by having a precision hole and slot to allow for the module contraction. The attachment of the cooling pipes presents a similar problem which will be discussed below.

4 COOLING

The currently favoured solution for removing the heat generated by both the detector and the electronics relies on the "binary ice" system. The total heat dissipated per module is expected to be of the order of 5.2 W. A typical wheel with 90 silicon modules will dissipate around 0.5 kW. The complete SCT forward detector consisting of 9 discs on each side of the interaction point will disspate in the region of 10 kW.

The main problem to be solved is how to make a good thermal connection between the module and the cooling pipe given that there will be relative movement up to 0.4mm between an aluminium cooling pipe and the module as the temperature changes. One idea shown in fig. 7 is to construct a sliding joint based on using thermal grease. The cooling pipe for one ring will be sub divided into 4 sections. The design shown shows the cooling pipe passing through a grease filled cavity in the MMC support block. Ideally this would allow some relative movement between the pipe and block while still maintaining a good thermal contact. There are several worries with such a design such as the longevity of the grease and the effect of radiation. Prototype work is essential and other ideas are being considered.

5 THE MATERIAL BUDGET

The material budget has been estimated in a similar manner to that for the barrel modules. A rectangular area of 60 mm x 120 mm has been assumed as a normalising standard corresponding to the active area of a barrel module. Other components have their thickness scaled by the ratio of their areas to 7200 mm^2. These contributions are then added thus producing a radiation length for the full detector and disc support averaged over the detector area for normally incident particles. The contributions to the overall radiation length have been compiled with the collaboration of Richard Apsimon (CLRC) and are shown in Table 1. It should be noted that the contribution from the support disc assumes that no material has been removed.

6 CONCLUSIONS

A conceptual engineering design for construction of the forward semiconducting tracker has been described. Further finite element analysis, thermal modelling and prototype evaluation will lead to a refinement of the design. The development of low mass multi layer aluminium / kapton hybrid is currently being pursued to evaluate the viability of this new technology The outstanding problem for which a totally satisfactory solution has yet to be found is the design of the thermal contact between the module and the cooling pipe.

Acknowledgements to R Apsimon (CLRC), G J R Tappern (CLRC) and E Perrin (Universite de Geneve) for many useful discussions and suggestions.

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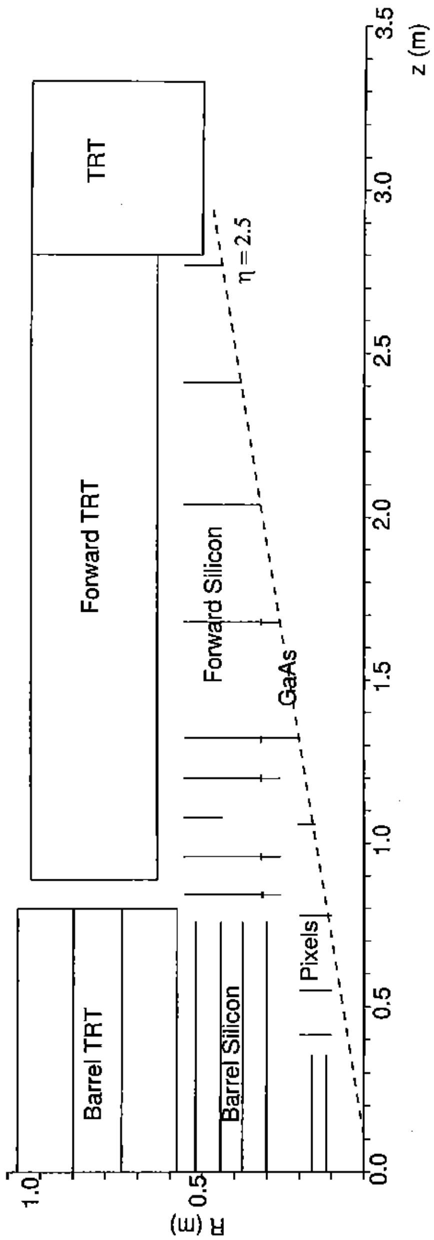

TRT
Forward TRT
Forward Silicon
GaAs
$\eta = 2.5$
Pixels
Barrel TRT
Barrel Silicon
z (m)
R (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Figure 1

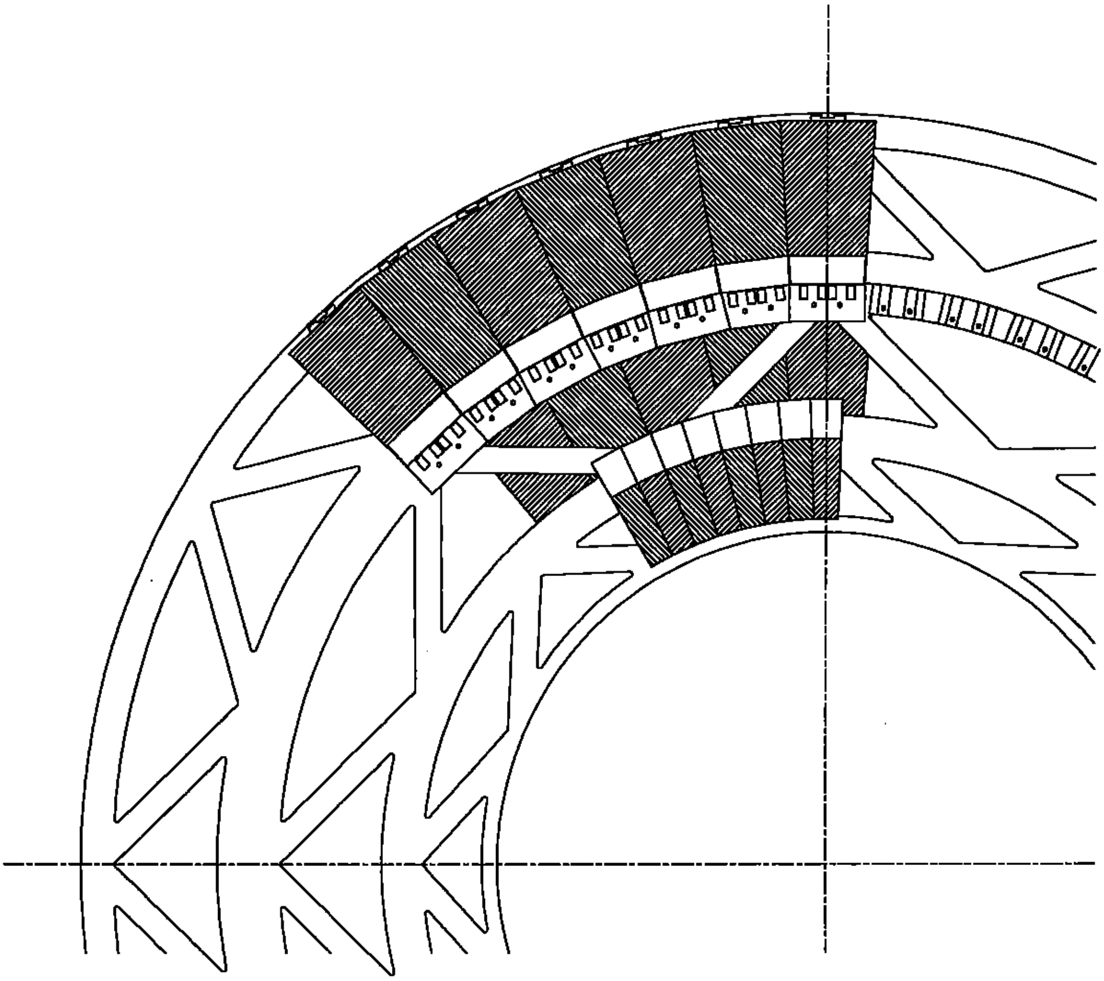


Fig 2

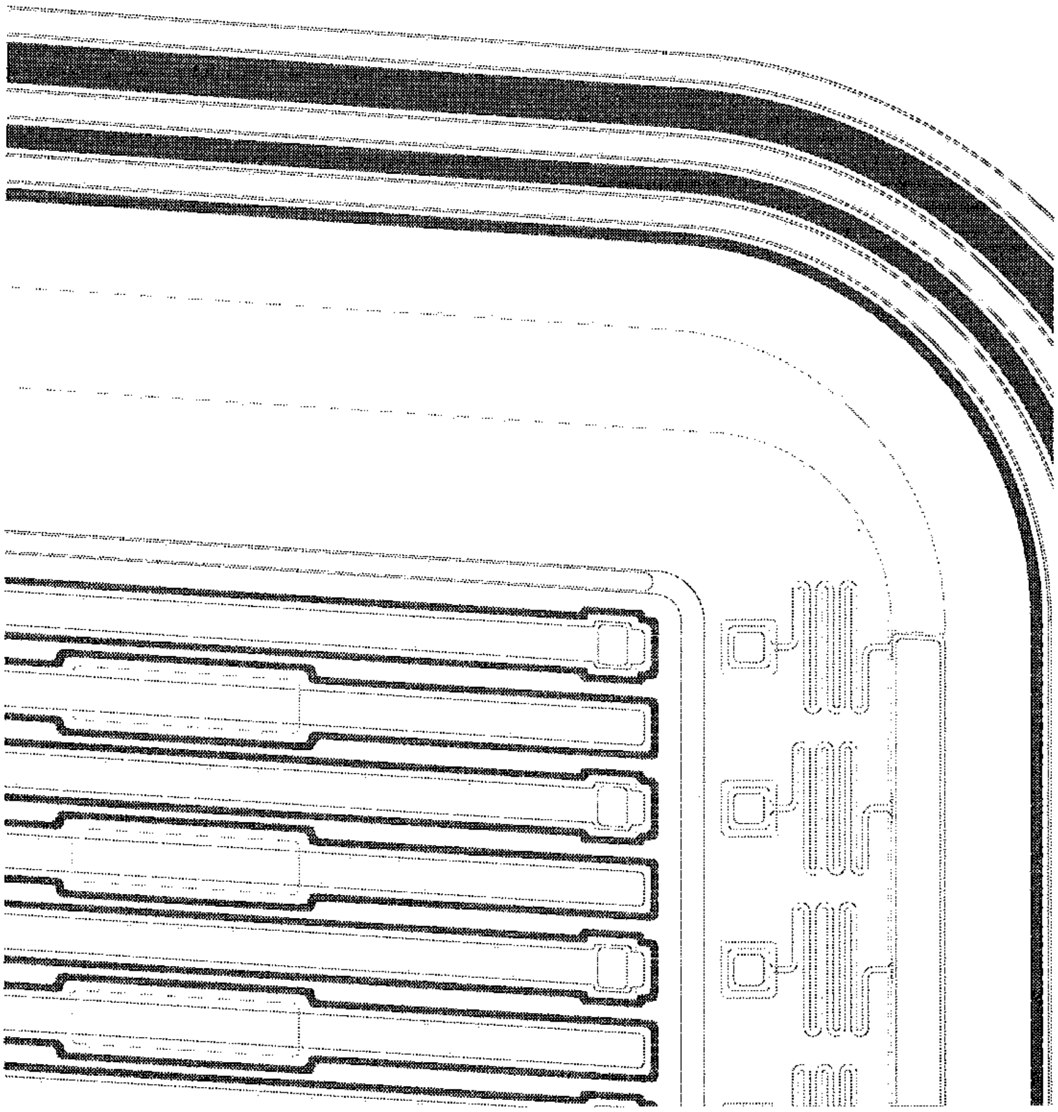
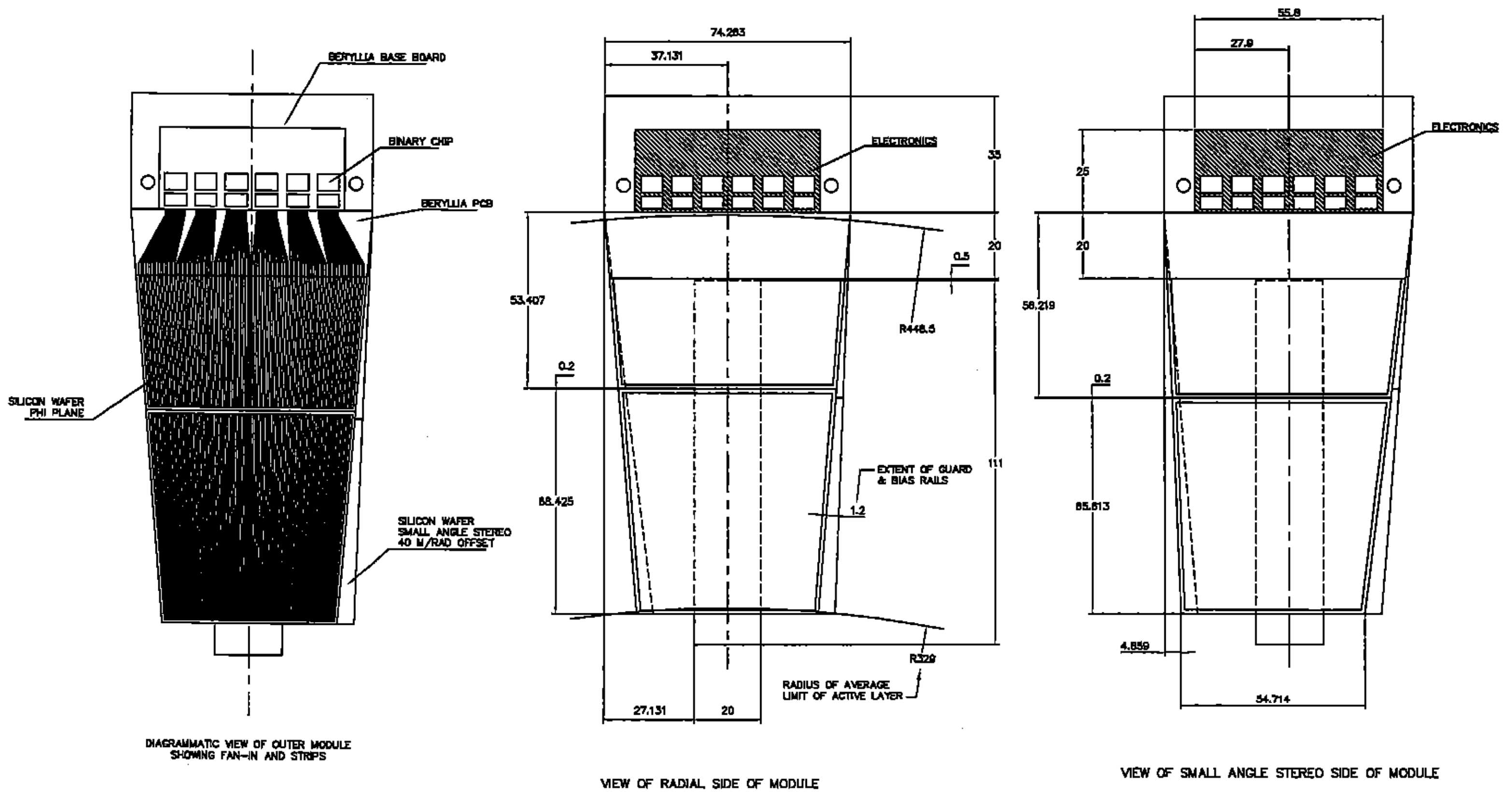
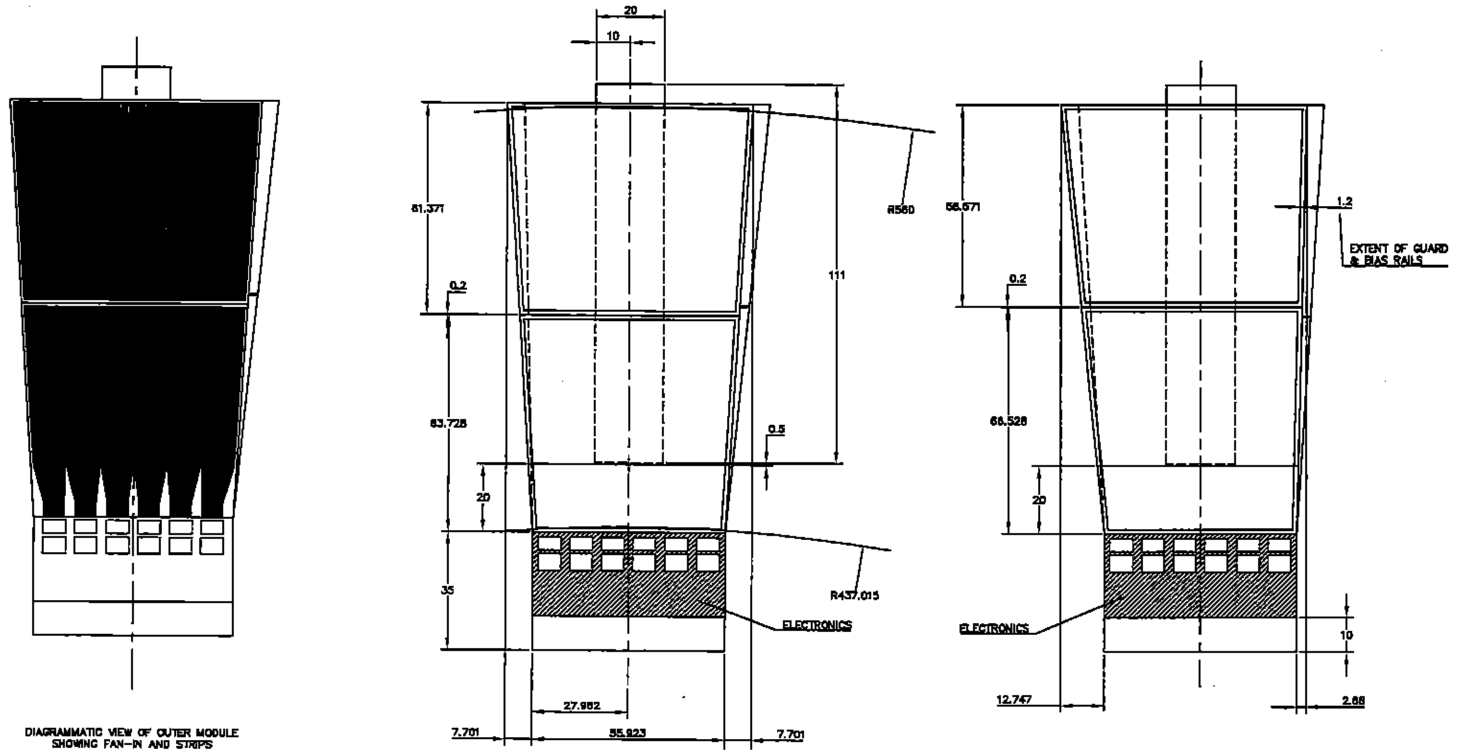


Fig 3.



Inner Module
40 per Ring

Fig 4



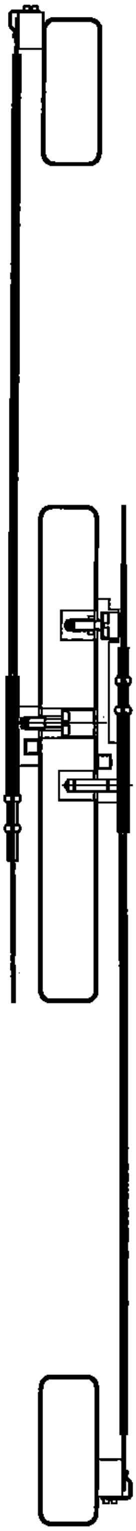
DIAGRAMMATIC VIEW OF OUTER MODULE
SHOWING FAN-IN AND STRIPS

VIEW OF RADIAL SIDE OF OUTER MODULE

VIEW OF SMALL ANGLE STEREO SIDE OF OUTER MODULE

Outer Module
52 per Ring

Fig 5



Section thru Wheel
Showing Inner and Outer
Module Mounting and Cooling

Fig 8