Performance of the D0 Layer 0 Silicon Detector

Marvin Johnson
For the D0 Silicon Detector Group

Abstract

A new inner detector called layer 0 has been added to the existing silicon detector for the DZero colliding beams experiment. This detector has an all carbon fiber support structure that employs thin copper clad Kapton sheets embedded in the surface of the carbon fiber structure to improve the grounding of the structure and a readout system that fully isolates the local detector ground from the rest of the detector. Initial measurements show efficiencies greater than 80% and no common mode contribution to the signal noise.

Introduction

The original silicon detector for the D0 experiment had 4 layers of silicon. A new radiation hard inner layer was added to improve the resolution for displaced vertices and also provide increased redundancy for failures in the existing detector. Because the main barrel part of the existing detector could not be removed, this new detector had to be designed for in place insertion into the existing detector. This placed sever constraints on the design of the design. Table I shows the detailed specifications.

TABLE I

Over all Length	1660 mm
Minimum diameter	31.7 mm
Sensor pitch	71 or 81 micron
Length of Sensors	70 or 120 mm
Number of sensors in longitudinal direction	8
Number of sensors in azimuth direction	6
Sensor thickness	.3 mm

The overall length and small diameter required the use of very high modulus carbon fiber. It also made it very difficult to provide a dielectric break at the center. Since high modulus carbon fiber is quite conductive at high frequencies and there are readout electronics at each end, there would be a classic ground loop formed by the grounded electronics at each end, the carbon fiber support tube and the rest of the detector. In order to eliminate this ground loop, we developed a readout system that isolates the detector ground from the rest of the world. We achieved isolation greater than10 ohms at 10 MHz per end.

The small diameter of the detector did not allow the direct mounting of the readout chips on the sensors so we were forced to use a kapton cable (between 200 and 360 mm long) to bring the detector charge to the readout electronics. The capacitance of this cable (.35 pF/cm) essentially doubled the detector capacitance, which then doubles the intrinsic noise of the detector.

Mechanical Design

The support structures for the LØ (Figure 1) of the Run 2b silicon tracker in DØ were designed and fabricated at the University of Washington. The LØ support structure can be divided up into three major regions. The first region, occupying the central 760 mm of the structure, is the silicon sensor mounting outer shell with the precision sensor mounting surfaces. The second and third regions are the 450 mm long hexagonal hybrid mounting outer shells at each end of the structure. Cooling distribution manifold assemblies at each end also act as the support and connecting points for LØ. All of these components are connected together via a long dodecagonal inner shell.

The inner shell, the sensor mounting shell and the hybrid mounting shells are all made from unidirectional Mitsubishi Chemical K13C2U high modulus (900 GPa) carbon fiber pre-impregnated with RS-24 MOD resin supplied by YLA Inc. This pre-preg has a pre-cure fiber aerial weight of 66 g/m^2 and resin content of 39% by weight. The nominal thickness of the pre-preg is 63.5 μm. The inner shell spans the full length of the support structure (1660 mm) and has an inscribed diameter of 31.7 mm. It is made of three layers of pre-preg with a $0^\circ/90^\circ/0^\circ$ arrangement. In another words, fibers are along the long axis in the two outside layers and are in the azimuth direction in the middle layer. The nominal cured thickness is 195 μm. The sensor mounting and hybrid mounting outer shells are both made of 5 layers of the same pre-preg with a symmetrical fiber orientation of $+20^\circ/-20^\circ/0^\circ/-20^\circ/+20^\circ$. An outer layer of kapton with copper mesh and gold plated contacts is co-cured with the outer shells giving a combined cured thickness is 325 μm. The sensor mounting outer shell has a six-sided castellated shape that allows for mounting of the silicon sensors at two different radial locations. In the design of the shape of the inner and outer shells, spaces were reserved for cooling tubes. Fig. 1 shows the section views of the support structure in the sensor and hybrid region. As seen in Fig. 1, the cooling tubes are an integrated part of the support structure. The coolant (a mixture of 60% water and 40% ethylene glycol) flows through the cooling system at -3 psig to prevent leakage. Special thin wall (100 μm) triangular shaped cooling tubes that fit the space between the hexagonal outer shells and the inner shell are extruded from PEEK by TexLoc Inc. It is important to support the cooling tubes on all three flat surfaces to prevent them from collapsing. In the sensor region, a spacer made of Rohacell IG 51 closed cell rigid foam is used to bring the cooling tube in contact with the outer shell corners. In the hybrid region, the cooling tubes are directly bonded to the inner and outer shell. The six cooling tubes run the entire length of the structure and connect into the cooling distribution manifolds at each end. The coolant flows in the same direction through all six cooling tubes.

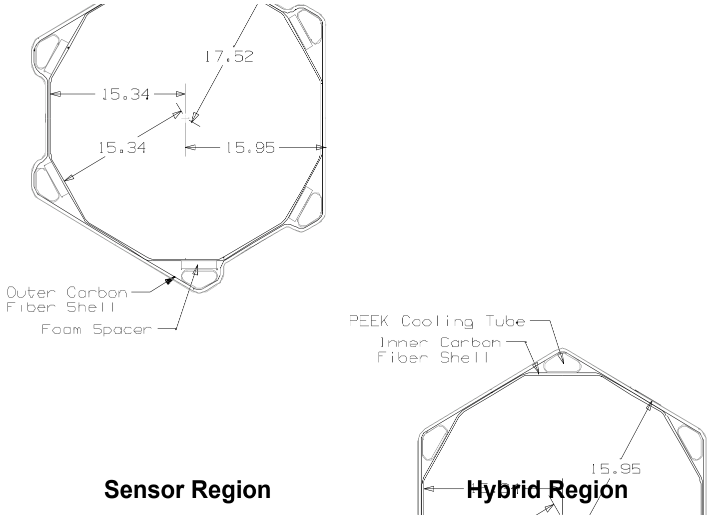

Figure 1. Cross-sections of the LØ structure in the sensor and hybrid regions

Fig. 2 shows the complete cooling manifold and an exploded view of the Unigraphics CAD model of the cooling manifold. As the cooling tubes need to move out radially in order to connect into the manifold, a small ramp made of Rohacell foam is used to space them out and a cover is bonded to the cooling tubes to protect them. Due to the intricate shape and size of the distribution manifold, it is made of five parts that are bonded together. The parts are all made from PEEK and consist of a front cover to connect to the cooling tubes, an inner ring that bonds to inner shell, an outer ring, three cooling nozzles that connect to the coolant supply, and a rear cover that the nozzles bond onto and also provides the three support points. These consist of precision machined conical inserts made from 7075 series aluminum with titanium #00-90 threaded studs that will receive 3 mm diameter sapphire balls. In order to determine the mechanical and thermal performance of the structures, detailed FEA analyses of LØ have been carried out and are described below.

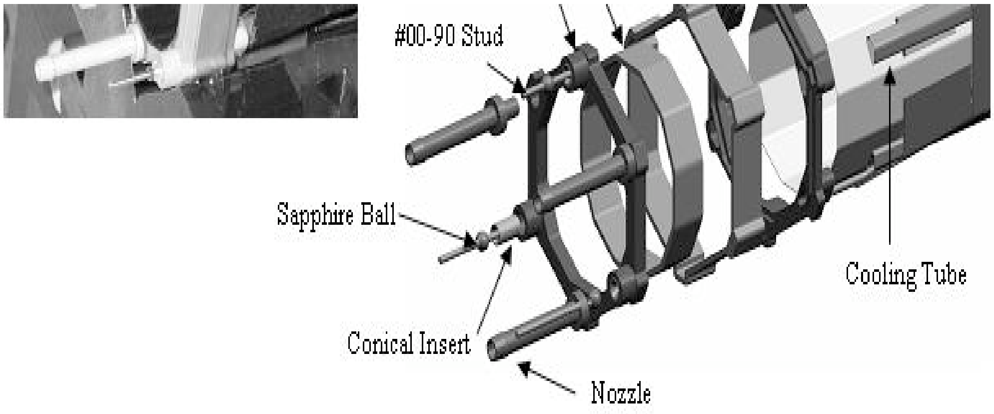

Figure 2. Cooling Manifold

Ground Circuit

A series of copper ground circuits printed on flexible Kapton® film (0.025mm thick) are applied to the outer layer of carbon fiber on the sensor mounting surfaces, and are bonded to the shell during the cure process, where the copper mesh is forced into good electrical contact with the conductive carbon fibers. These circuits are installed using the same techniques used for the plies of pre-preg with special care required to ensure that the Kapton/Cu-mesh conformed to the surface features of the castellated shell with no corner air gaps. A 0.7mm thick protective sheet of silicone is wrapped tightly around the finished lay-up to prevent the transfer of wrinkles from the vacuum bag to the part. Contact of the sensors with the ground circuit is made on the backside of the sensor by a conductive epoxy bond. For the B-layers that mount on the top of the constellations a flexible grounding strap is bonded to the ground circuit on the bottom of the castellation to make contact with the underside of the sensor, see figure 3

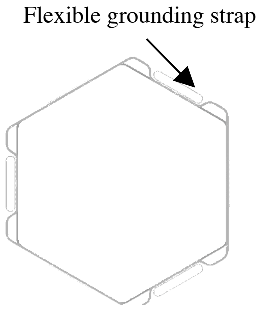

Figure 3. Detail of flexible grounding strap for the outer layer sensors.

Electrical Design

The electrical design was dominated by the need to eliminate common mode noise. Because of the added capacitance of the analog cable and the use of 300 μ thick detectors, even a small amount of common mode noise could seriously affect the performance of the detector. In addition the analog cable can act as a good antenna for picking up common mode noise. Finally, there is a history of noise problems in detectors of this size.

The overall philosophy is two fold. First, we isolate the detector grounds from the rest of the world to prevent any ground loops through the body of the detector. Second, we provide connections with low resistance and inductance between the sensor and the SVX 4 chip so that there is little relative voltage between them at all frequencies in the pass band of the SVX 4.

Fig. 4 shows a simplified schematic of the detector readout electronics. Every circuit has two parts; the input path and the return path. The input path to the SVX 4 is from the reversed bias diode through the analog cable and into the preamp in the SVX 4.

There are no local ground traces on the analog cable and the cables are separated by a 200 μ polypropylene spacer that is needed to minimize cable-to-cable capacitance. Because there is no ground plane, detector pulses will couple into neighboring channels. However, the time constants for the adjacent channels are much smaller than the integration time for the SVX 4 so almost all the charge flows back into main channel before the end of the charge integration time.

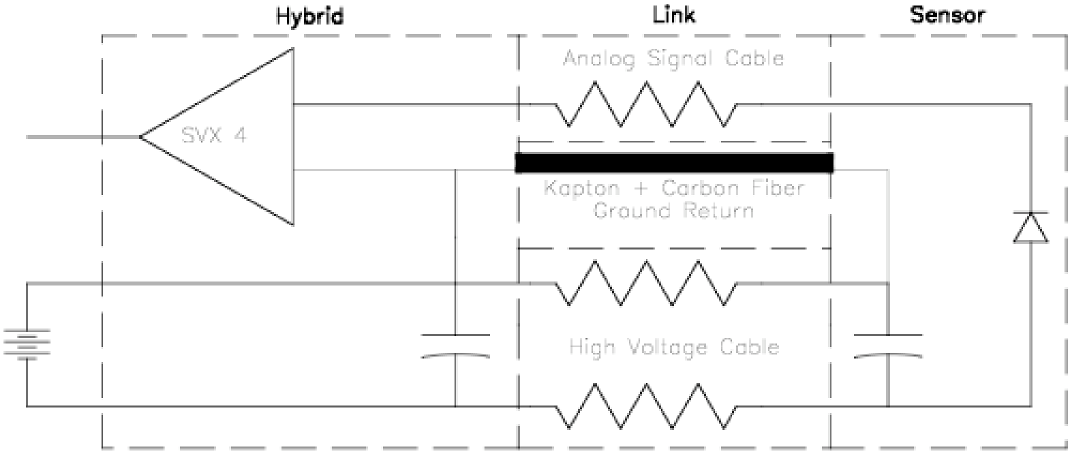

Fig. 4. Simplified schematic of the layer 0 electrical circuit. The hybrid refers to the BeO hybrid mounted on the carbon fiber substrate, the link is the combination of the analog cable and the carbon fiber support structure and the sensor includes the bias filter board..

The area between the signal line and the ground return must be kept as small as possible. Magnetic fields penetrating this area can cause common mode noise. Thus, the cables are stacked directly on the carbon fiber support but are separated by the polypropylene spacers.

The return circuit is as important as the input circuit and we paid special attention to this part. The return side of the silicon diode is actually at the bias voltage so the bias voltage must be well connected to the amplifier ground. In the layer 0 design this is done at both the hybrid and the sensor. The capacitor at the hybrid is not very important because the bias voltage trace on the analog cable has a DC resistance of about 20 ohms – too high for a good ground return. The bias return line on the analog cable also has a DC resistance of about 20 ohms so it is a poor connection to the sensor ground. We chose to use the carbon fiber structure of the detector itself as the ground return. Not only did this allow for much lower impedance, but it also forced the structure to be at the same voltage as the SVX 4 ground so that there would be little or no capacitive coupling into the analog cable.

As discussed in [1], carbon fiber is quite conductive at high frequencies but it is not conductive enough to provide a low impedance path. We increased the conductivity of the carbon fiber by placing a sheet of copper clad Kapton (25 μ thick Kapton coated with a 5 μ thick layer of copper) on the surface of the carbon fiber structure. The Kapton is etched in a mesh pattern (234 μ trace width , 1.45 mm pitch, 30% copper coverage) to reduce the amount of added material. The mesh size is very small so for frequencies that the SVX 4 can respond to it appears as a solid sheet of copper.

The connections shown in fig. 4 from the hybrid to the kapton sheet and from the kapton sheet to the filter board on the sensor are quite important. They must be low inductance and have a very small loop area. The hybrid Beryllium Oxide hybrid is 380 microns thick and has a gold plated stripe on both sides. This stripe is connected to the hybrid ground plane by vias through the BeO. The Kapton mesh on the carbon fiber support structure has a corresponding gold plated section. The hybrid is the glued to this support structure with silver epoxy. This creates a connection with very low inductance and almost no loop area. The outer layer hybrids are connected to the ground plane by copper clad kapton tabs.

The small bias voltage card sits on top of the sensor so its connection to the support structure is more complicated. We also used copper clad kapton tabs to make this connection (fig. 5).

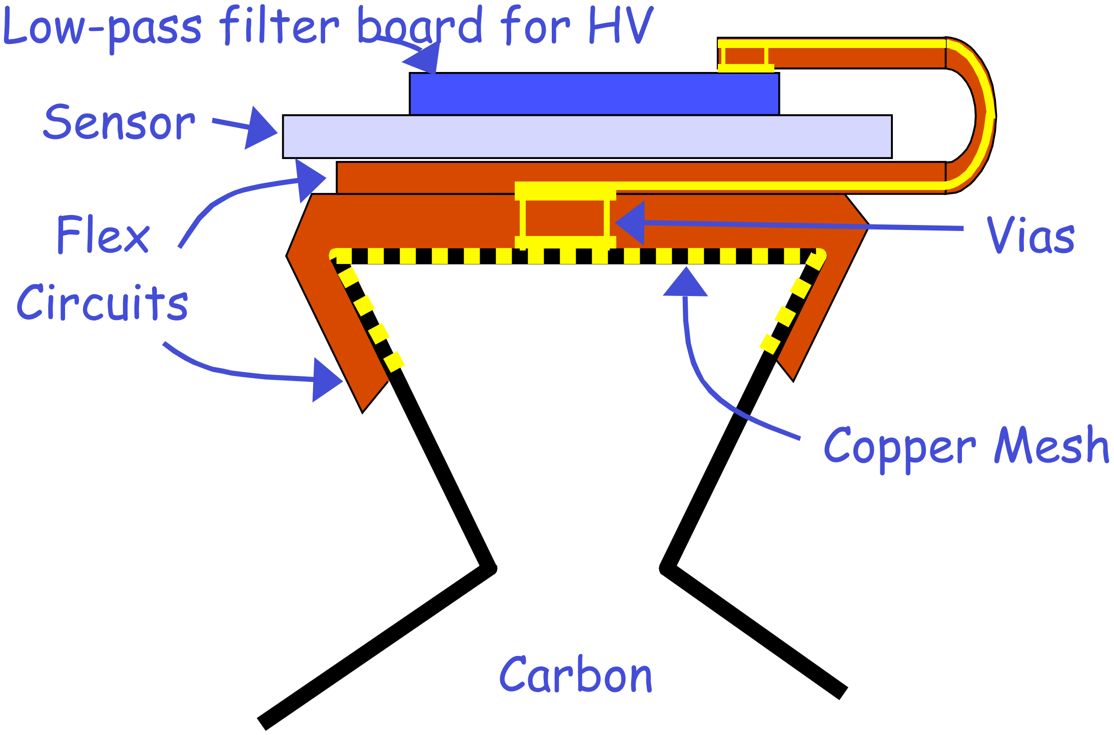

Fig. 5. Sketch of copper tab connection between the ground plane and the bias voltage board.

The ground loop through the body of the detector is eliminated by creating an isolated ground on the detector side of the electronics. We do not need large voltage isolation so we chose a fairly simple method. We converted all single ended signals to differential ones and sent the signals across the ground barrier to a differential receiver. The power supplies use local regulators that were chosen on the basis of their AC isolation specifications. On an individual basis these ideas worked quite well. But there are about 500 parallel connections at each end so the overall ground isolation is around 10 ohms which is adequate for this device.

The power supplies need a DC reference point so that the power supply voltages have the same 0 point on both ends. This is provided through the high voltage bias system. The bias voltage return line has a 10K ohm resistor to external ground that provides both ground isolation and the proper DC reference point.

Performance

Fig. 6 shows the pedestal, total noise and intrinsic noise for the intrinsic noise for the layer 0 detector in normal running mode. The average pedestal is plotted in blue. We compute the sigma of the pedestal for a larger number of events (plotted in yellow in fig 8.). We then define the differential noise in a given channel as 1/2 of the standard deviation between the output of a given channel and its downstream neighbor. Ten times this value is plotted in red in fig. 8. Any positive correlation between channels (common mode noise) would show up as a positive displacement of the differential noise with respect to the total noise and none is observed.

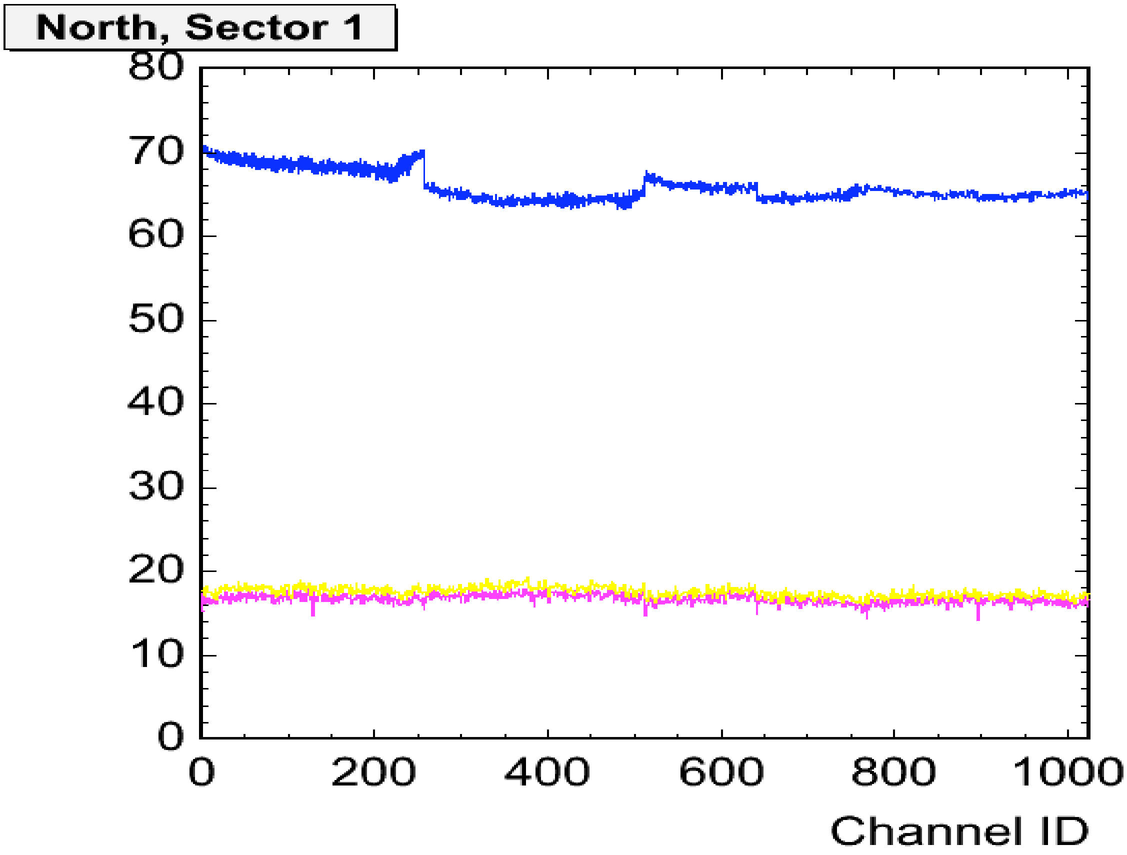

Fig. 6. Pedestal and noise signal for 1 sector of layer 0. The blue trace is the average pedestal. The yellow trace is 10 times the sigma for that channel and the purple trace is 10 times the differential noise (see text).

References

[1] W. Cooper et al.,Nucl. Instrum. Meth. A **550,** 127 (2005)