The Grounding Study for Run 2B SMT Layer 0

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Abstract

This note describes the Layer 0 grounding study using a prototype module installed on the Layer 0 support structure. We found the importance of low inductance ground connection to the hybrid. Achieving such a low inductance connection turned out to be one of the most critical issues to establish the signal to noise ratio better than 10 which is our design goal. The newly proposed grounding scheme, especially around the hybrid support area, is also discussed.

1 Introduction

The innermost layer of the Run 2B silicon tracker (referred to as Layer 0 or L0) [1] is crucial for achieving better vertex resolution, and thus b-jet tagging efficiency. Compared to the Run 2A detector, the impact parameter resolution will be improved by a factor of 1.5 because of the L0's proximity to the interaction point. As a consequence, the single b-jet tagging efficiency will improve by 19%. In order to accomplish such tracking resolution and b tagging efficiency, our design goal is to keep the S/N ratio of L0 higher than 10 after accumulating 15 fb^{-1} of data.

While L0 is very attractive in terms of physics, the development of L0 is technically very challenging because of its radiation hard environment, and the tight space constraints. The space constraints and heat dissipation require us to use an analog cable to transmit the signal from the sensor to the SVX4 chip mounted ($\sim$ 46 cm at maximum) apart from the sensor. This results in increased noise due to the extra capacitive load and possible pick-up effects by the long analog cable. The test result for the prototype L0 module inside the Faraday cage indicates the size of noise is between 1800 and 1900 electrons. This is consistent with the expectation by the measured noise performance of SVX4 and the capacitive load by the sensor and the analog cable. It is predicted that the noize level of 1800 electrons become 2100 electrons [1] after the irradiation corresponding to 15 fb^{-1} of data. Because a minimum ionizing particle creates 22000 electrons by traveling through the sensor, the S/N ratio is just above 10 which is our design goal. Therefore, it is obvious that we must avoid any additional noise. Special attention must be paid for the grounding scheme to minimize the possible noise coupling either capacitively or electromagnetically.

This memo describes the studies of grounding scheme for L0. First we describe the test setup, and then the test results. Based on the test result-s, the proposal for the grounding scheme and mechanical requirement are discussed in the end.

2 Test Setup

The L0 prototype module in this test consists of three parts; the ELMA L0 sensor, the Dyconex analog cable, and the hybrid for L1[1] with four SVX4 chip mounted. The hybrid sits on the additional ceramic substrate to connect the hybrid and the analog cable. The detail of each component can be found in the TDR [1].

The whole L0 module was placed on the copper-clad G10 with 70 μm thick Kapton tape for insulation. The surface, i.e. the copper, of the copper-clad G10 is tied together to the ground of readout system (the Purple Card), and HV power supply. The whole assembly was put inside the dark box made of plastic. With this configuration, we first measured the noise (the result is described in the next section) to compare it after installing the module onto the L0 support structure.

After the above measurements, the sensor was placed on the A-sector of the L0 support structure. The p-side of the sensor was additionally grounded to the carbon fiber support structure through the biasing R-C filter on the sensor, and then the Kapton flex with copper embedded. This Kapton flex was cocured on the carbon fiber support so that it is an integral part of the support structure. As discussed in [2], carbon fiber is really a good conductor for high frequency AC such as 10MHz. Even at DC, the resistance is measured to be around 10 Ω for the 47 cm long inner support cylinder. In

[1]The L0 hybrid is not available yet.

this way, the whole L0 support structure was supposed to be grounded. The hybrid with the ceramic underneath was glued on top of the carbon fiber extension from the support structure. The photograph of the L0 module on the support structure plus its extension is displayed in Fig. 1. Note that the

Figure 1: Top: Photograph showing the sensor part installed on the L0 support structure. Bottom: Photograph showing the hybrid part installed on the carbon fiber extention.

carbon fiber extension was not electrically well connected to the L0 support structure. The assembly above was secured inside the Faraday cage made of aluminum. The Faraday cage was placed on the copper-clad G10. Again the copper-clad G10 was well tied together to the ground of the readout system and HV power supply. The electrical connection between the copper-clad G10 and the Faraday cage was quite good, as the resistance was measured to be less than 1 Ω.

3 Test Results

First we describe the test result before the L0 module was installed on the prototype L0 support structure. This result serves as a reference to see the effect added by the support structure. Then we present the test results performed after the installation.

3.1 Before Installation

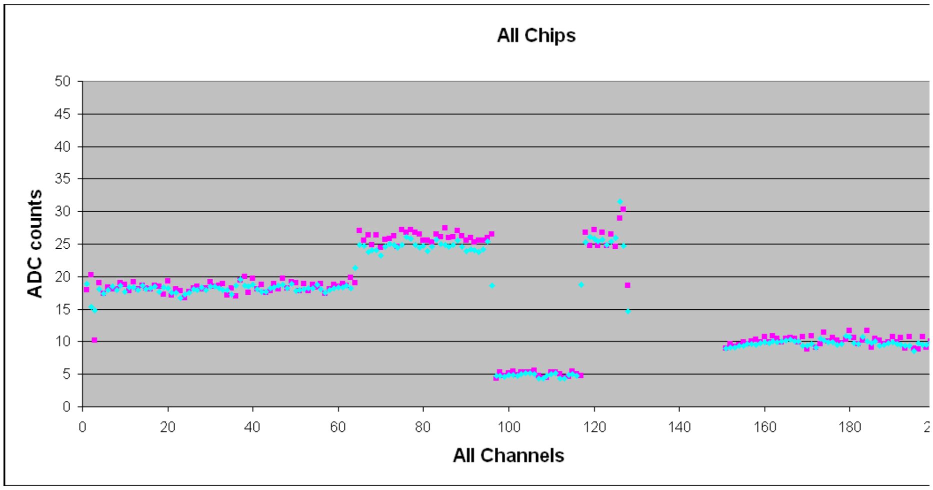

Figure 2: Total (red squares) and differential (light blue circles) noise for the L0 module before installing onto the support structure. The unit is in $\times 10$ ADC counts.

Figure 2 shows the total noise and differential noise for each readout channel. The first half of the chip is connected to the analog cable only, and the latter half to both the analog cable and the sensor. The noise of a few channels in another bare chip is also shown as a reference. In this way, the noise increase due to the capacitive load is visualized. The bandwidth setting of the SVX4 was fixed to four in our testing[2]. The resulting risetime is fast enough not to change the gain (<10%) even though the capacitive load changes within our interesting region[3]. Therefore we simply quote the ADC count as a unit representing the size of noise for the following comparisons with different grounding scheme or test setup configurations.

[2]The 10-90% risetime is measured to be 35 ns and 65 ns for 10 pF and 33 pF capacitive load, respectively. On the other hand, the integration time of the preamp is 132 ns.

[3]We had calibrated the SVX4 chip as 700 electrons per ADC count for the SVX4 parameter settings used for our tests

3.2 After Installation

As shown in Fig. 2, the total noise before the installation was 2.7 ADC counts for the channels having both the sensor and the analog cable. After installing the module onto the L0 support structure as described in Section 2, the noise level went up to more than 50 ADC counts, indicating the necessity of additional grounding. We tested the following three different grounding scheme.

- A Additional ground connection at the hybrid. One end of a thin wire is soldered to the ground of the bypass capacitor on the hybrid. The other end is taped to the Faraday cage by copper tape. We refer this scheme as Hybrid Ground.

- B As described in Section 2, the sensor is grounded to the L0 support structure. We put the connection between the support structure and the Faraday cage by copper tape. One end is taped to the chassis of the Faraday cage, and the other end to the gold pads on the Kapton flex embedded onto the support structure. We refer this scheme as Sensor Ground.

- C Both the Hybrid Ground and Sensor Ground are established.

Each grounding scheme gives the noise level of $\sim$4.8 (A), $\sim$70 (B), and $\sim$10 (C) ADC counts, respectively. The noise distribution in (C) is shown in Fig. 3. Because the ground trace on the analog cable has a resistance of about 20 Ω, the actual signal return is the chassis of the Faraday cage in the scheme of (B) and (C), as displayed in the top of Fig. 4. The Sensor Ground has the largest and the Hybrid Ground has the smallest ground loop. Therefore, the observations above imply that the noise level is affected by the size of ground loop.

In order to minimize the area of ground loop or short out the loop, we placed the Kapton flex circuit under the analog cable and on top of the extension for supporting the hybrid. The one end is attached to the gold pad on the Kapton flex cocured onto the L0 support structure. The other end is connected to a copper tape, and then the thin wire is used to bridge the copper tape and the hybrid, where the wire is soldered at the both end. This situation is shown in the bottom of Fig. 4. The resulting noise distribution in (C) is shown in Fig. 5. The noise level changed from the original value of 10 ADC counts to $\sim$3.8 ADC counts.

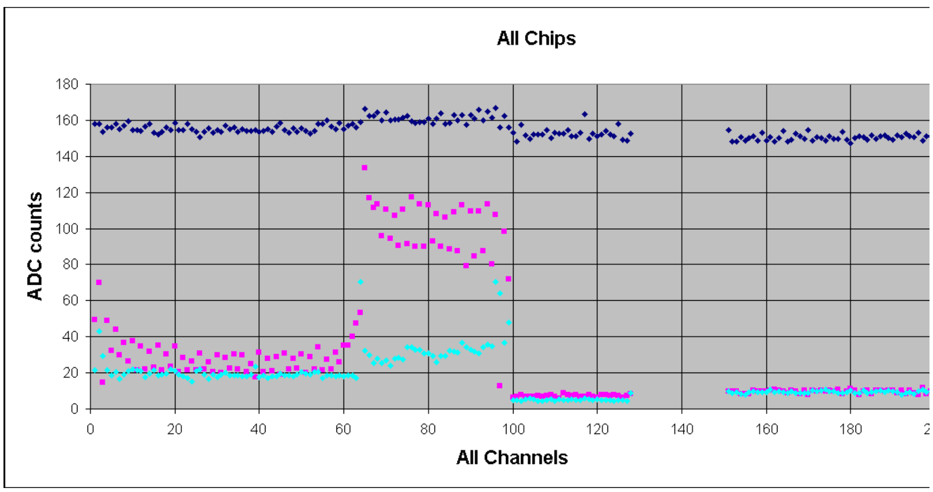

Figure 3: Noise distribution after installing the L0 module onto the support structure. The grounding scheme is (C), both the Hybrid Ground and Sensor Ground. The total noise is represented by red squares, the differential noise by light blue circles, and the pedestal by the black diamonds. The unit is in ADC counts for pedestal and $\times 10$ ADC counts for noise.

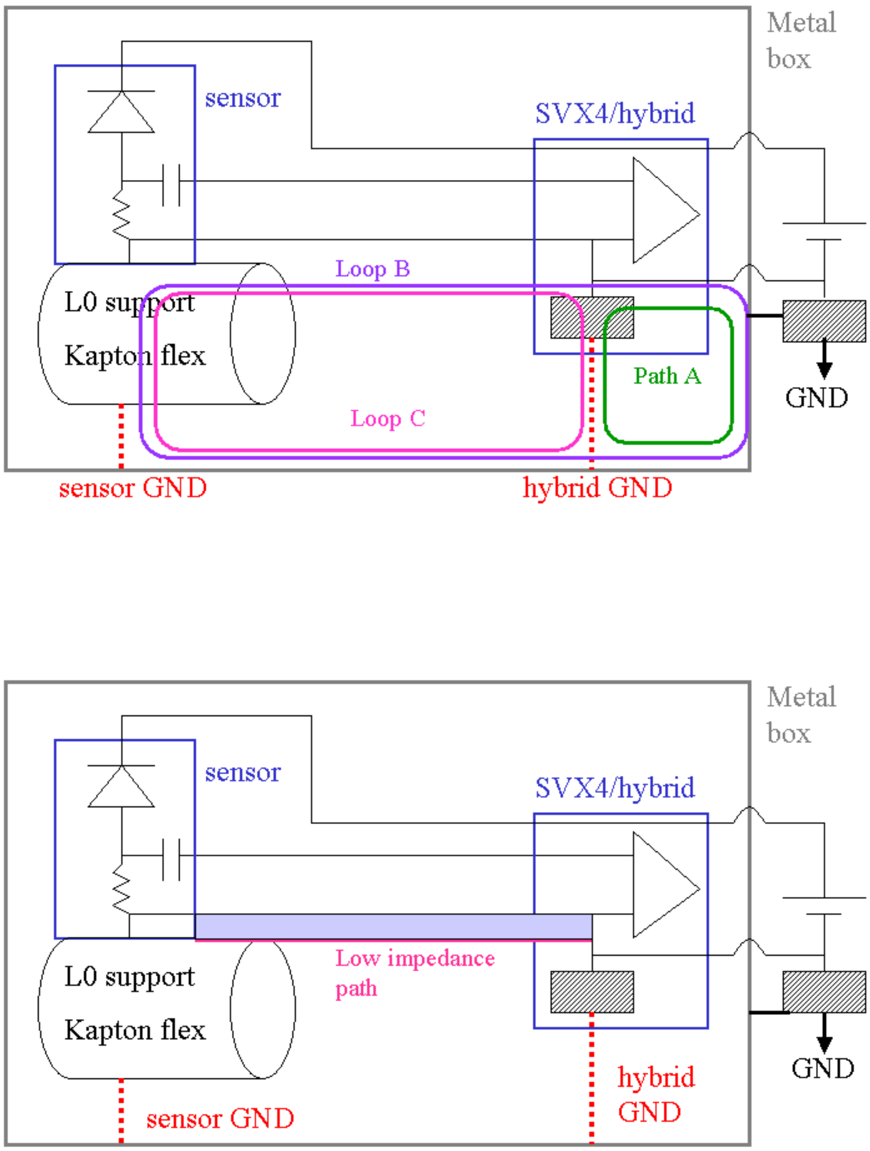

Figure 4: The circuit diagram equivalent to the test setup.

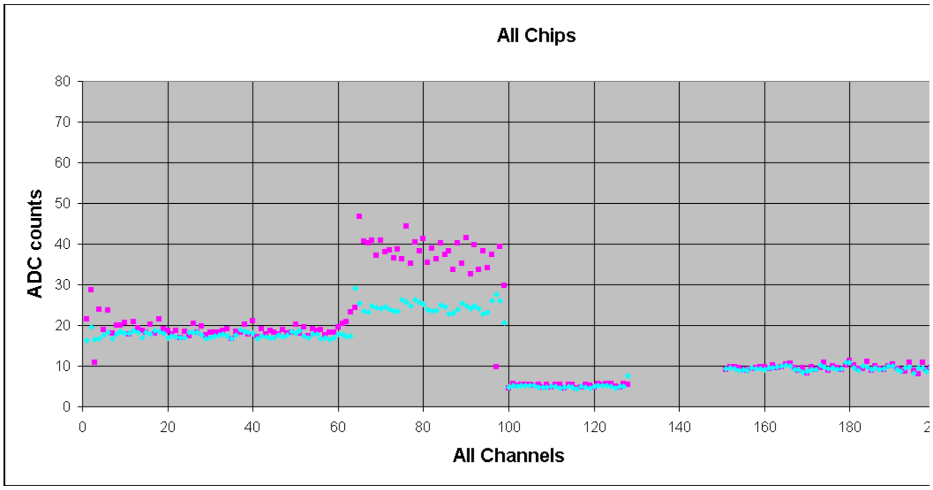

Figure 5: Noise distribution after putting extra grounding connection by the Kapton flex between the support structure and the hybrid. The grounding scheme is (C). The total noise is represented by red squares, and differential noise by light blue circles. The unit is in $\times 10$ ADC counts.

High impedance ground connection can cause a potential difference between the reference point of hybrid (or actually the preamp in SVX4) and the input, resulting in noise. One can imagine the potential unbalance as a generator. Therefore, low impedance ground connection is crucial to reduce noise. To achieve the low impedance connection, one must pay attention not only to the resistance but also to the inductance. Or actually for high frequency AC such as 10MHz, the inductance is more relevant than the resistance to determine the impedance. In other words, low impedance connection becomes equivalent to low inductance connection for our SVX4 operation frequency. The impact of low inductance ground connection is shown in Fig. 6 which displays the total noise as a function of the number of wires used for the grounding scheme (C) without the extra ground connection under the analog cable. The wire length is about 4 cm each. Because the resistance of each wire is quite small, much less than 1 Ω, this dependence is attributed as a dependence on the inductance. The improvement of noise by the low inductance connection is also found by changing the length of wires in the Hybrid Ground or (C). In the Hybrid Ground scheme, for example, shortening the wire length from 4 cm to $\sim$1.5 cm suppresses the noise by $\sim$10%. As

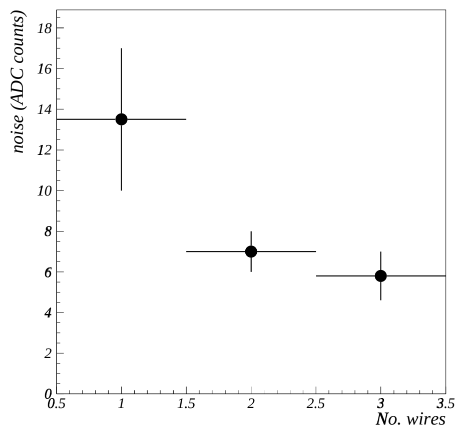

Figure 6: Noise in terms of ADC counts as a function of number of wires connecting the hybrid ground and the Faraday cage.

a result of having the extra ground connection and replacing the wire to two short ones, the noise of Hybrid Ground was reduced from 4.8 to less than 3 ADC counts.

To summarize the test results, there are two key issues to suppress the noise in L0; 1) groundloop must be shortened out or minimized, and 2) low impedance ground connection is crucial to remove any potential difference working as a generator. For the operation frequency of SVX4, low inductance connection is needed to achieve the low impedance connection.

4 Proposal of Grounding Scheme

4.1 General Concept

In principle the single point grounding scheme is better than the multi-point ground to achieve low noise system. However there is a difficulty to establish the single point grounding scheme because of the tight space constraints for the L0. For example, the support structure of the outer layer of L0 can easily couple to the L0 capacitively, resulting in the breakdown of the single point grounding scheme, and the possible noise increase or even pedestal shift in the local region. This is the situation we must avoid because we have a crutch to suppress the common mode noise by the real time pedestal subtraction by the SVX4, but the localized noise cannot be suppressed. Taking into account these factors, we decided to adopt the multi-point grounding, i.e. both the hybrid and the sensor will be tied to the ground, and all the conductors must be grounded.

As discussed in [2], the carbon fiber is very conductive for the high frequency AC such as 10MHz (or even for DC). The impedance measurements show no distinctions among the carbon fiber, some stainless steels, and aluminum. Based on this fact, the carbon fiber support structure will be used as the grounding plane. Since the outer layer of the L0 (referred to as L1) also uses the carbon fiber as the support structure, we plan to tie the both L0 and L1 structure together. This configuration gives another advantage that the grounded L1 support structure works as a shielding for L0 or Faraday cage.

4.2 The Local Grounding Scheme

The application of low inductance connection of the sensor is rather straightforward. The Kapton flex with copper mesh is embedded on the surface of the L0 support structure. Another Kapton flex under the sensor provides a route of grounding path from the HV filter card to the L0 support. The gold plated connection pads on the Kapton flex are glued each other by silver epoxy.

To minimize the inductance due to the area between the analog cable and grounding plane, a uniform continuous ground plane between the sensor and hybrid is needed. Since the L0 support and the hybrid support are separate pieces, use of the inner cylinder with another Kapton flex embedded has been proposed as a ground plane.

The remaining is the grounding scheme of the hybrid, which is most tricky because there is a space (>15 mm for B-sector) between the hybrid and the well grounded inner cylinder. Besides, there are many parts with complicated geometry, such as a cooling tube, which are also made of carbon fiber and thus must be grounded. Based on the rule of low inductance connection, the shortest path from the hybrid to the inner cylinder has to be investigated. At the same time, wide strip rather than the wire should be used to minimize the inductance. The concrete designing work is under the progress.

5 Conclusion

We found that the low inductance grounding scheme with minimum ground loop is essential to achieve the low noise for L0. This implies the importance of use of short and wide electrical connection, and a careful design of detector to short out ground loop both in locally and generally. People are well aware of these rules, but sometimes forget to apply or do not realize the existence of higher inductance route. Based on the observation of the test results, we proposed the conceptual scheme of the grounding for L0.

Acknowledgment

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References

[1] D0 Run 2B Silicon Detector Technical Design Report.

[2] B. Quinn, Vertex 2002.