Noise Pickup and Filtering in the Chain of the AC Coupling Single-sided Silicon Microstrip Detectors and Frontend Electronics

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Abstract

The noise pickups and attenuations were simulated using the SPICE3 program for the detector and electronics chain of the ATLAS SCT Silicon microstrip detector module. Because of the use of the AC coupling single-sided detector, the filtering circuitry in the bias voltage supply lines should have an asymmetric setting in resistance. An effective way of reducing the pickup noise from the cooling pipe is also discussed.

I. INTRODUCTION

A Silicon microstrip detector system (SCT) is being developed for measuring charged particle passages in the ATLAS detector to be installed in the Large Hadron Collider (LHC) at CERN [1]. The system is made of thousands of detector-units, called “modules”. One module is consisted of four Silicon microstrip detectors, frontend electronics (FE) chips, and other components, as shown in Figure 1. The Silicon microstrip detector is a single-sided and AC coupling readout type: readout strips are only on one side of the detector and the signals induced in the strips are coupled to the metal strips with an insulator in between.

The FE chips are mounted on electrical circuit boards, called “hybrid”, near the middle of the module on the top and bottom sides. The electrical powers to the FE and to the detectors are supplied from the outer world through the “power and signal” cable extending from the top hybrid. The bottom hybrid is connected to the top hybrid via the interconnect on the far-end of the hybrids.

The detectors are glued on the baseboard in between. The baseboard is extended and contacted to the cooling pipe, by sandwiching an electrically insulating but thermally conducting material, Beryllia ceramics (BeO). Proper cooling of the Silicon microstrip detectors is a critical issue in designing the module. The leakage current induced by the radiation damage is so large that improper cooling will cause thermal runaway in the detector. A prime candidate for the baseboard material is Pyrolytic graphite, PG, which has a thermal conductivity of 1700 W/m/K, but is also electrically conductive [2].

Since the generated charge in the Silicon by a passing charged particle is very small, about 3 fC, any noise infiltration must be minimized into the inputs of the FE chips. One major component connected to the inputs is the Silicon microstrip detectors, and the electrical paths to the detectors are the power supply lines and from the cooling pipe through the baseboard. A simple electrical circuit model of the module was constructed and attenuation of the pickup noises were simulated with a circuit simulation program, SPICE3 [3].

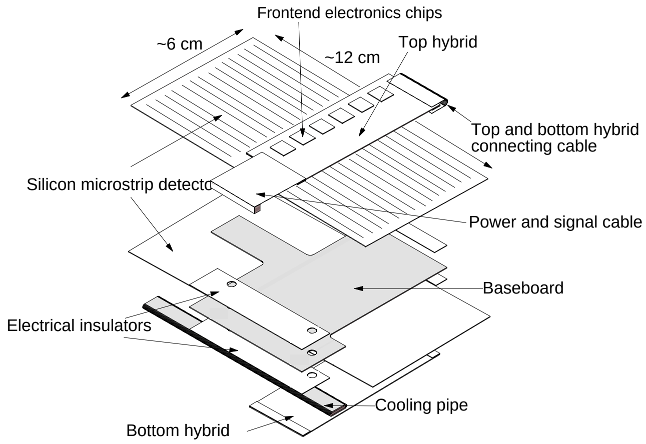

Figure 1: An expanded view of the Silicon microstrip detector module of the ATLAS SCT Barrel section.

II. SIMULATION MODEL

The Silicon microstrip detector of the module is made of 300 micron thick Silicon wafer with 768 readout strips implanted in a 80 µm pitch. Each strip is biased through a bias resistance and readout from a metal electrode which is AC-coupled to the strip. The backside of the detector is one simple pad and there is no resistance implemented in the pad.

A schematic diagram of the SPICE3 circuit simulation model is shown in Figure 2. Although one capacitance, Cd1 or Cd2, is representing the detector, five strips in a detector were explicitly modelled in the simulation model, together with the capacitances between the neighbouring channels (the interstrip capacitances), and the rest of the strips are combined into one equivalent capacitance in each side of the five strips.

In order to put null voltage over the AC coupling capacitors, Cp1 or Cp2, the low bias voltage was connected to the bias resistance, Rb1 or Rb2, and the backside of the detector was connected to the high potential. This is to avoid putting stress on the AC coupling capacitors on the detector. The backside of the detector must be connected to the ground of the amplifier for completing the signal path, which is accomplished with one (or two) decoupling capacitance, Cb1 (and Cb2), per module.

The detector bias voltage was supplied from the outer world to the power supply leads, the Node 1 and 2, and passed through a filtering circuitry made of resistances, Rt1 to Rt4, and a capacitance, Ct1. A resistance, Rc, is put in the connection between the low-voltage bias line and the amplifier ground, which connection forces the potential of the detector strip to be equal to the potential of the amplifier, in order to evaluate the resistance effect. The resistances, Rg1 to Rg3, were also put in the ground and the bias connections between the top and the bottom hybrids for evaluation. The nominal values of the components are listed in Figure 2 which are obtained after iterations of the simulations. .

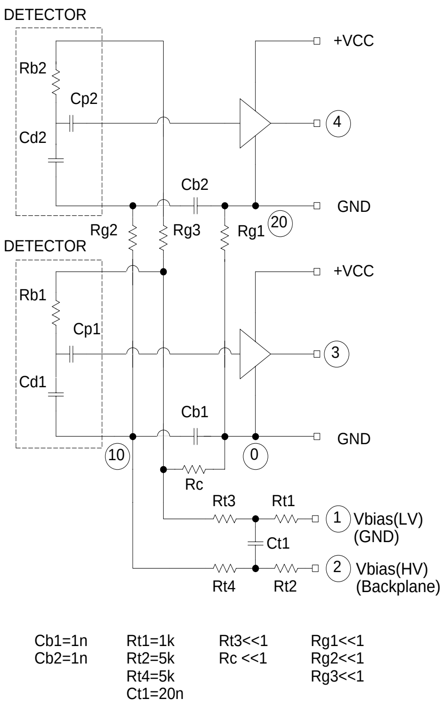

Figure 2: Simplified schematics of the detector-electronics chain modelled in the SPICE3 simulation. The nominal values of the components are also listed in the figure.

A simplified amplifier-shaper circuitry was connected to the readout strip (to the AC coupling capacitance). The shaper was modelled to have a Poisson shaping with a peaking time of 20 nsec. An amplifier response to a triangular input current of 10 nsec with a charge of 10 fC is shown in Figure 3. A crosstalk response is also shown in the figure for the adjacent channel. The crosstalk was caused by the interstrip capacitance. The major parameters of the Silicon microstrip detector and the FEE amplifier are summarized in Table 1.

III. Simulations and Results

A. Constraints on the components

In the simulations, we tried to determine the values of the components from the pickup-noise attenuation. There are, however, two constraints which set the value of the components.

1) Protection resistance:-- Sum of Rt2 and Rt4

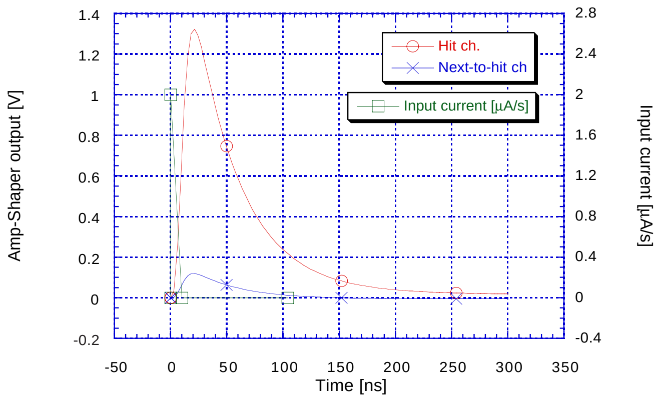

Figure 3: Response of the amplifier: Current in a strip (square), Amplifier output of the strip (circle), and Crosstalk output in the adjacent amplifier (cross)

Table 1
Silicon microstrip detector and electronics parameters

Silicon microstrip detector (per amplifier)	Values
Capacitance to backplane of a channel, Cd1, Cd2	4 pF
Capacitance to one adjacent neighbour ch.	5 pF
Bias resistance, Rb1, Rb2	1 MΩ
Coupling capacitance, Cp1, Cp2	200 pF
Electronics	
Peaking time of the Poisson shaping	20 ns

In the case when large ionization is introduced in the Silicon bulk, e.g., a beam splash, the Silicon bulk is effectively short-circuitted, and a voltage of the bulk appears over the AC coupling capacitors, Cp1 or Cp2. In order to prevent full bias voltage to appear, a protection resistance is to be placed in the bias line to the backplane. The resistance, Rt2 and Rt4, works as the protection resistance in addition as the filtering resistance. If one third of a detector is short-circuitted, the effective resistance of the bias resistance in the readout side is about 6 kΩ, which sets the protection resistance to be greater than 6 kΩ so that the voltage is to be less than half of the full bias voltage. We set the sum of Rt2 and Rt4 to be 10 kΩ.

2) Blocking capacitance:-- Cb1 and Cb2

A large signal current will flow in the detector when a core of jet passes through the detector. The signal current flows through the blocking capacitance, Cb1 and Cb2, generating crosstalk over the strips through the backside of the detector. This crosstalk may shadow signals such as isolated leptons away from the core of jet.

The triangular current was injected in a strip and the crosstalk in a strip far away from the injected strip was simulated as a function of the blocking capacitance, Cb1 and Cb2. The attenuation, i.e., the crosstalk voltage divided by the signal voltage at the outputs of amplifiers, 20*log(Vcross/Vsignal), is shown in Figure 4. The crosstalk was attenuating at over 100 pF and decreased to -60 dB around 2 nF. The 60 dB attenuation is corresponding to a crosstalk level of 0.1 fC from about 30 particles.

A capacitance of 1 nF to 10 nF would be adequate for Cb1 and Cb2 to have small enough cross-talks.

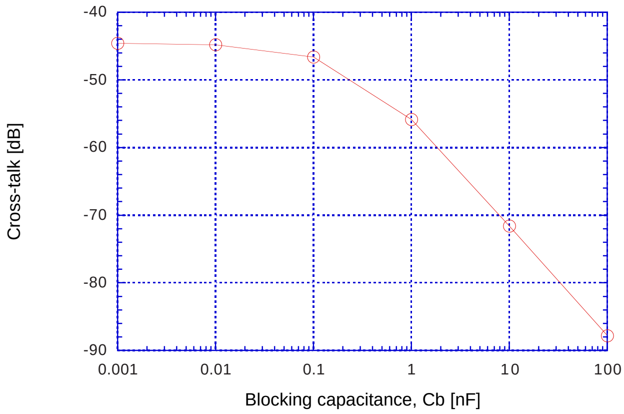

Figure 4: Attenuation of the crosstalk as a function of the blocking capacitance, Cb1 and Cb2

B. Common-mode pickup noise in the bias lines

The noises of interest are the pickup noises in loops. One of the major pickup loops is the one between the bias power supply lines and the ground of the amplifiers (Nodes (1 and 2) and 0 in Figure 2). The pickup noise was generated adding an external circuitry, Figure 5 (a). In order to simulate the worst case, the same triangular current of the signal was introduced in parallel to the resistance, Rh. The noise was coupled to the Nodes 1 and 2 through the capacitances, Ce's.

Attenuation of the pickup noise, referenced to the no filtering case, Rt1=Rt2=Rt3=Rt4=1 Ω, and no Ct1, is shown in Figure 6 as a function of the resistance, Rt3, parameterized with other filtering circuitry elements. Two clear trends are evident in the figure: (1) The smaller the resistance, Rt3, the larger the attenuation, (2) the larger the resistance, Rt4, the larger the attenuation. A 40 dB attenuation was obtained for Rt3=1 Ω and Rt4 = 5 kΩ, compared to the no filtering case (Rt1 = Rt2 = Rt3 = Rt4 = 1 Ω).

This asymmetry in the resistances of Rt3 and Rt4 is understood as the result of asymmetry in the bias resistance. There is the bias resistance, Rb, in the line from the Node 1 to the input of amplifier, but no resistance in the line from the Node 2 to the ground of the amplifier, excluding the filter resistances. The transient pulse to the input of the amplifier must be compensated by a similar pulse in the ground not to generate output. A few kΩ resistance in the line from the Node 1 to the ground will compensate the impedance in the line from the Node 1 to the input of the amplifiers, which is mainly the 768 bias resistances, Rb's, in parallel.

C. Differential-mode pickup noise in the bias lines

Another noise pickup is through the loop between the two bias supply lines, the Node 1 and 2. The noise was generated with an external circuitry in Figure 5 (b). The attenuation of the noise is shown in Figure 7 as a function of the filtering resistance, Rt1, and parameterized with Rt2 (and Rt4). The result shows, (1) the larger the resistance in Rt1, the larger the attenuation, and (2) the larger the Rt2 the larger the attenuation. This

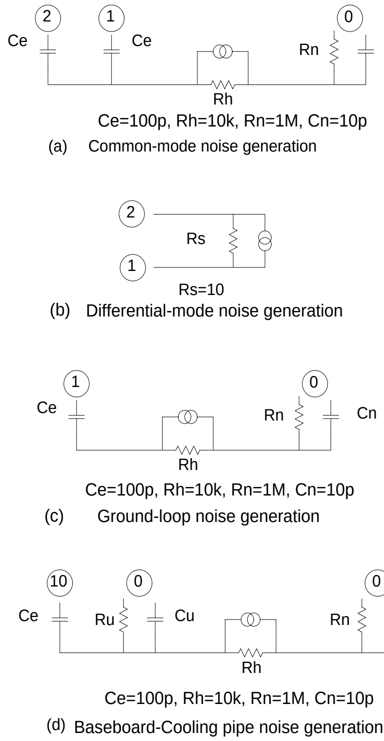

Figure 5: Implementation of pickup noise generation in the SPICE3 simulations: (a) Common-mode pickup on the bias power lines with the noise between the power supply leads, Nodes 1 and 2, and the amplifier ground, Node 0, (b) Differential-mode pickup in the bias lines, between Nodes 1 and 2, (c) Pickup on the ground-side bias line, between Node 1 and 0, and (d) Pickup on the cooling pipe, between the detector backside, Node 10, and Node 0, with an extra coupling to the Node 0 through Ru and Cu.

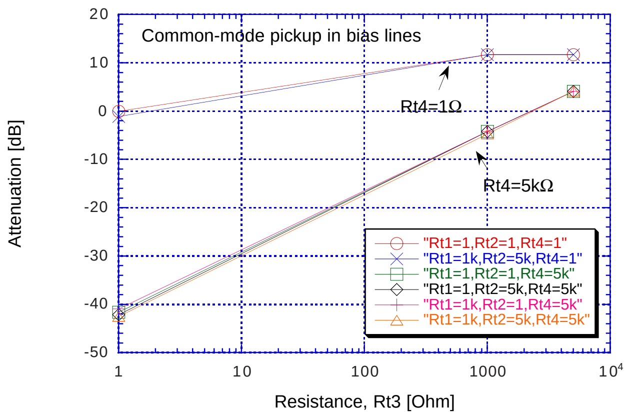

Figure 6: Attenuation of the common-mode noise in the bias power supply lines as parameterized with the filtering circuitry elements. The upper cluster of lines are the circle and cross, and the lower cluster of lines, the square, rhombus, plus, and triangle.

attenuation is due to the filtering with the resistance Rt2 and the shunt capacitance, Ct1.

The attenuation as a function of the shunt capacitance, Ct1, is shown in Figure 8. The attenuation is 100 dB with Rt1 = 1 kΩ, Rt2 = 5 kΩ, Rt3 = 1 Ω, Rt4 = 5 kΩ, and Ct1 = 20 nF. The change of the attenuation by the change of capacitance from 2 nF to 20 nF is much larger than the change from 20 nF to 200 nF, which justifies the choice of the capacitance of 20 nF.

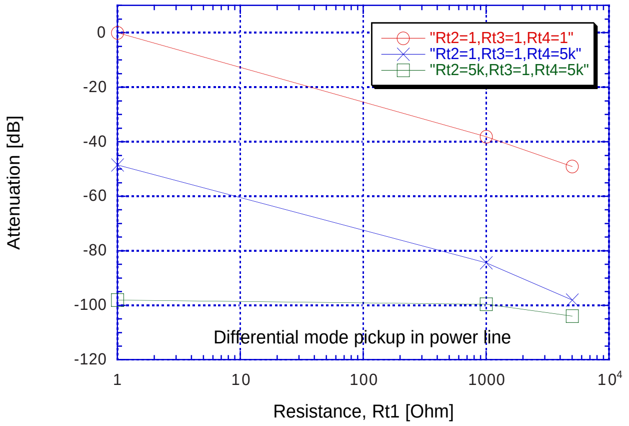

Figure 7: Attenuation of the differential-mode pickup noise in the bias power lines. The shunt capacitance, Ct1, was 20 nF.

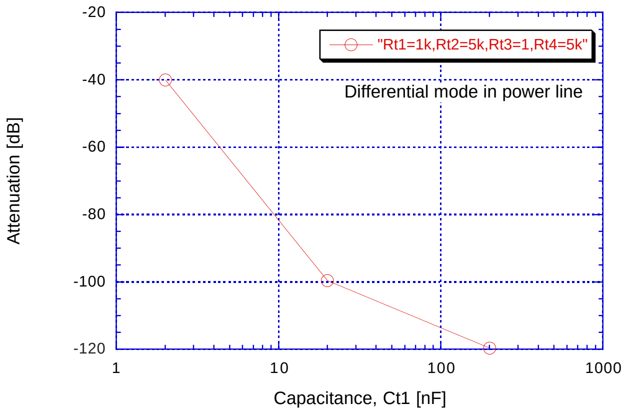

Figure 8: Attenuation of the differential-mode pickup noise in the power supply lines as a function of the shunt capacitance, Ct1.

D. Pickup noise in the ground-loop of the bias line (ground level) and amplifier ground

Another pickup loop is the ground-loop of the bias line (ground level), Node1, and the amplifier ground, Node 0. The pickup noise was generated with the circuitry, Figure 5 (c), similar with the Figure 5 (a) but the noise was only coupled to Node 1. The attenuation is shown in Figure 9 as a function of the shunt resistance, Rc. The result clearly indicates Rc to have the minimum resistance, not to generate voltage to the input of amplifier. The filtering resistance, Rt1, had effect, although small, to reduce the pickup by going from null (i.e., 1 Ω) to 1k Ω.

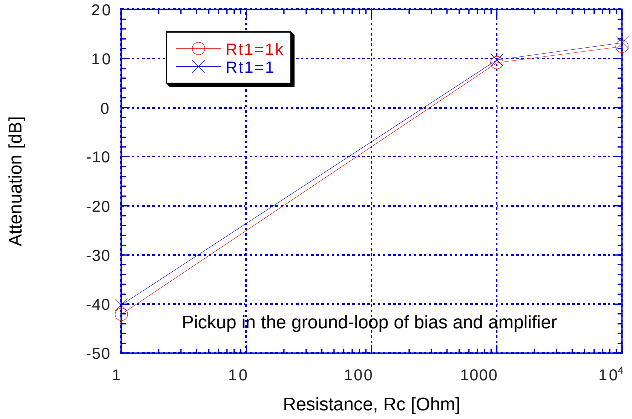

Figure 9: Attenuation of the pickup noise in the ground-loop of the bias line and the amplifier as a function of the shunt resistance, Rc.

E. Noise pickup through the cooling pipe

In the design of the Silicon microstrip detector module for the ATLAS SCT application, cooling is a critical element in order to cool the electronics and, specially, the detector, to avoid the thermal runaway in the detector induced by the radiation damage. The detectors are cooled through a thermally conductive baseboard which edge is extending over the cooling pipe to have a good heat transfer from the detectors to the cooling pipe. A prime candidate of the baseboard, PG, is not only thermally but also electrically conductive. Although the cooling pipe and the baseboard is electrically insulated in DC, they are coupled in AC with a capacitance of about 100 pF, and the electrical noises in the cooling pipe will be infiltrating into the detector backplane and to the amplifiers. The noise pickup was introduced between the backplane, Node 10, and the amplifier ground, Node 0, with the circuitry, Figure 5 (d), which coupled the noise to the backplane with a capacitance, Ce. A resistance, Ru, or a capacitance, Cu, was also introduced to shunt the noise to the amplifier ground.

The attenuation, referenced to the DC coupling of the cooling pipe and the baseboard, is shown in Figure 10 as a function of the coupling capacitance, Ce. In order to attenuate the noise, the coupling capacitance must be small, e.g., 0.01 pF for the 40 dB attenuation, which capacitance seems impossible to have considering the coupling capacitance of 100 pF in the present design.

A larger attenuation was seen when the shunt resistance, Ru, or the shunt capacitance, Cu, was introduced. A 40 dB attenuation was obtained with Ru = 1 Ω for the coupling capacitance of 100 pF. A shunt capacitance, Cu, of 20 nF had the similar attenuation as the shunt resistance, Ru, of 1 Ω, in the frequency domain of interest.

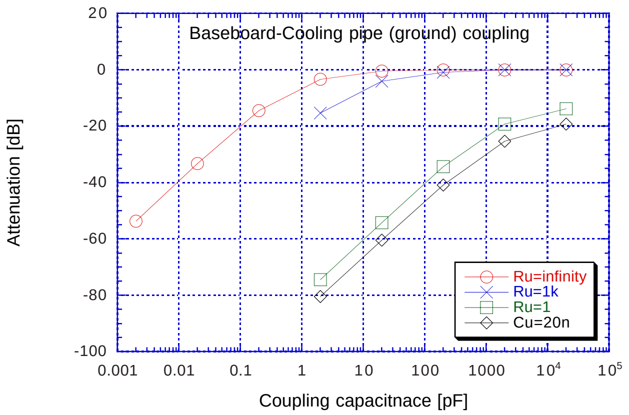

Figure 10: Attenuation of the noise in the cooling pipe as a function of the coupling capacitance between the cooling pine and the baseboard, parameterized with the shunt resistance, Ru, or the shunt capacitance, Cu.

F. Noise pickup in the loops of the top and bottom hybrids

The two hybrids, top and bottom, are connected via three lines, the amplifier ground and the two detector bias lines (the backplane and the strips) in which the three resistances, Rg1, Rg2, and Rg3, were introduced, respectively. The noise pickup in the lines were simulated by adding the current generation source in parallel to the resistances. The noise outputs were small for the noise generation in the Rg2 and Rg3 because of the filtering in the bias resistance and the detector capacitance. The effect of the resistance, Rg1, was linear: 20 dB attenuation for the resistance decreasing from 1 Ω to 0.1 Ω. All these resistances, Rg1, Rg2, and Rg3, must be as small as possible.

IV. Conclusion

The noise pick-ups and attenuations were simulated using the SPICE3 program for the detector and frontend electronics chain of the ATLAS SCT Silicon microstrip module configuration. The simulation was focused on the noise infiltration to the input of the amplifier through the Silicon microstrip detectors, via various noise pickup types, such as common-, differential-, and ground-loop modes. A resulting choice of the resistance and capacitance values for the chain is summarized in Figure 2 after the iterations of the simulations.

From the simulations, two important consequences were observed: Firstly, because of the use of the AC coupled single-sided detector, the filtering circuitry in the bias voltage supply lines should have an asymmetric resistance setting to compensate the bias resistance only in the strip side. Secondly, an effective way of reducing the pickup noise from the cooling pipe is to short-circuit the cooling pipe to the amplifier ground resistively or capacitively.

V. Acknowledgment

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VI. References

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[2] Pyrolytic graphite data sheet, Advanced Ceramics Corporation, P. O. Box 94924, Cleveland, Ohio 44101, U.S.A.

[3] SPICE3 software can be obtained from software@eecs.berkeley.edu or EECS/ERL Industrial Support Office, Attn: Spice Technical Question, 205 Cory Hall, U.C. Berkeley, Berkeley, CA 94720