ATLAS SCT/Pixel Grounding and Shielding Note

September 9, 1999, Ned Spencer, UCSC

The objective of a grounding and shielding configuration is to minimize the flow of externally induced currents in the small signal path of the SCT/Pixel detectors. For the SCT detector, the small signal path includes the detector strip, detector backplane, module backplane capacitor, module front analog ground bus, the small signal ground bus in the front chip, the first transistor in the amplifier channel, and the two chip bond wires for signal and ground. Generally, I call this path the small signal ground. This path is only a few centimeters in extent for the SCT and microscopic for the pixels. Figure 1 details the small signal path for the SCT.

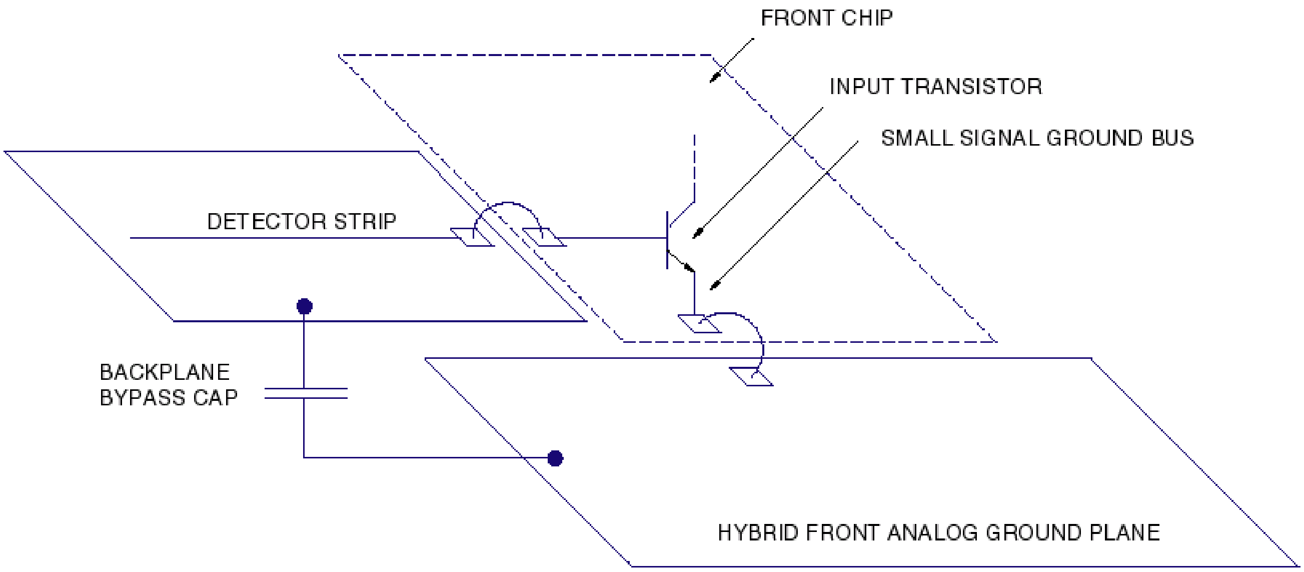


Figure 1. Small signal ground for SCT.

This proposal mostly connects existing mechanical and electrical conductive elements in a manner to provide this noise current minimization by design. A very unresolved area is the beam pipe shielding. An added element is a common-mode choke array at PP3, designed as part of the cable connector. In this document I will use “PP3” to inclusively refer to both PPB3 and PPF3; and likewise for PP1 and PP2.

The intent of this note is to further the grounding and shielding definition to eventually arrive at a common design. So view these proposals as inducements to productive discussion. The mechanical practicality of this proposal has not been fully developed.

We can divide the detector system grounding and shielding issues into five main areas:

(1) The shield

(2) The beam pipe relation to the shield

(3) Connections to the shield

(4) Conductors inside the shield

(5) Conductors outside the shield

The Module Array Shield

The main purpose of the shield is to provide a common referencing point for all conductors inside the shield: the shield provides a conductive path for all the metal connecting to its surface. All conductors going inside the shield should short to its surface or have capacitor bypassing that is equivalent. The aluminum foil heat shield (0.125 mm) is the main element of the shield. The foils around the forward, back, and barrel arrays can be treated as one shield, but if so, then the contact seams between sections should be as close to continuous as possible.

The shield foils should be as continuous as possible with the connections between pieces, such as the outer barrel cylinder and the ends, done as seams and not as point contacts. The seams will tend to oxidize unpredictably, so some plating may be needed to maintain shield conductivity. The foil openings should be minimized, particularly where close to the beam pipe.

Figure 2 details the ground loop path without the shield used to shunt the power supply strays.

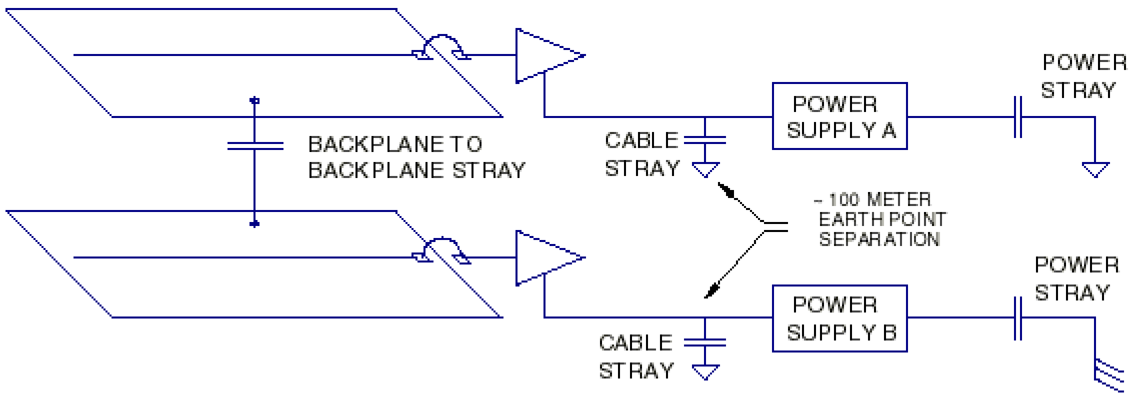


FIGURE 2: GROUND LOOP OF SEPARATED POWER CABLING INCLUDES DETECTOR SMALL SIGNAL GROUND

Figure 3 details the change in the ground loop by the introduction of the foil shield. This scheme illustrates the shunting of the problematic loop currents away from the small signal ground path and into the foil shield. The attenuation factor is the ratio of impedances through the detectors and the impedance of the path through the foil shield. Figure 2 indicates the risk of not using a shield: large loop currents could flow through the small signal ground.

The shield should be continuous around the beam pipe. Since this area of the heat shielding is not designed yet, I discuss the shielding considerations in the next section.

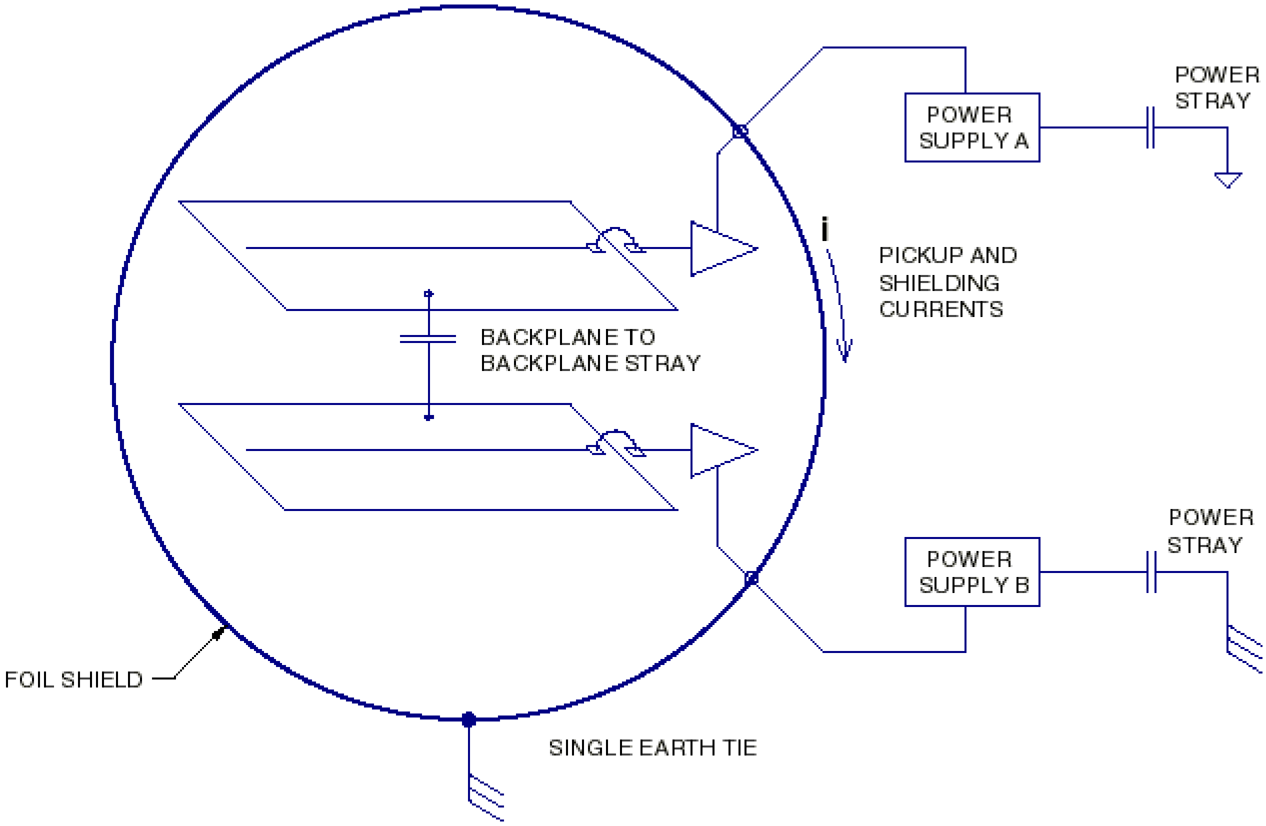


FIGURE 3: GROUND LOOP OF SEPARATED POWER ENTRY.

Beam Pipe Shielding

There are many configurations being considered for the beam pipe, the heat shield, and the detector array shielding. I will list five of the many choices that will develop the grounding and shielding considerations:

(1) Single wall beam pipe exposed to detector array, unreferenced to array

(2) Single wall beam pipe exposed to detector array, referenced to array

(3) Double wall beam pipe exposed to detector array, outer wall referenced to array

(4) Double wall beam pipe exposed to detector array, outer wall unreferenced to array

(5) Heat shield foil completely around beam pipe connected as shield

In the first approach, Case 1, the single wall beam pipe would be inside the foil shield with no shielding, and the shield would not be tied to the beam pipe: the single ground tie would be independent of the beam pipe earth referencing. If the relative AC potentials and currents on the beam pipe prove to be large, then the detectors could have pickup, since they are attempting to reference to a different ground than the beam pipe. This does not appear to be a workable path, because estimating pickup accurately is too difficult.

The second approach would reference the whole detector to the beam pipe. The shield would tie hard to the beam pipe as its single earth tie. Electrically, this is a workable procedure. This probably cannot be done for many reasons. One shielding issue is that the TRT would have to deal with the beam pipe fields, rather than use SCT as a shield from the beam pipe.

In the third approach, Case (3), the outer beam pipe could be used as part of the module array shield. If there are large AC currents on the inner pipe, the least pickup will occur if the outer pipe is allowed to drive the whole shield, rather than attempt to isolate the foil shield from it. The outer pipe would need two isolators, one at each end of the module array shield near the pipe entry point. The shield foil should connect in a continuous fashion to the pipe, since the pipe might have substantial current density.

Case (4) looks similar to Case (1) with less uncertainty. It is still too difficult to estimate beam pickup accurately.

Case (5) places a complete foil shield around the beam pipe, integral to the end pieces of the heat shield with attention paid to conductive seam connections. Electrically, this is the simplest configuration, since a complete shield with its own single point tie provides the most pickup rejection. Case (3) and Case (5) are very similar, and show the best possibility of low beam pickup. These two configurations do not necessarily meet the mechanical, cooling, installation, or material cross-section requirements.

Commoning of Conductors

The shielding foil should have electrical isolation from the metallic mechanical supports that are outside the shield.

All conductors that enter into the volume enclosed by the foil shield should short to the foil. The tendency of aluminum electrical connections to oxidize needs design attention.

Cooling pipes need an isolator as close as possible to the respective foil entry point. A conductive tube with multiple passages through the foil should short to the foil at only one of its entries: in this manner shielding currents on the foil will not be shunted onto the cooling tube. The tube travels very close to the detectors, with large capacitance to detector backplanes, so noise currents on the tubes require minimization.

The module power supplies will be at very different locations, with many different entries to the foil. If possible, all power supply 0 volt conductors (4 by my count) should short to the foil close to their entry point:

(1) Power tape shielding elements

(2) Analog ground: AGND

(3) Digital ground: DGND

(4) Detector Bias return

At PP1, a PC board for the connectors can be used to common these conductors together. Module cables that enter the foil as a bunched group can have a shared commoning node at PP1. The ground shield from a PP1 board to the main shield foil needs to tubular: The TRT system needs shield isolation from the SCT conductors. The PP1 tubular shields should tie to the main foil as a seam or use multiple point connections.

There is no particular need for capacitive bypassing at PP1: the power tape design maintains adequate AC coupling between power pairs.

Single Point Earth Tie of Foil Shield

The foil shield should be the location of the single point earth tie for the SCT/Pixel array. The foil is the least troublesome object for large pickup currents to flow, and it is the commoning point for the system. For beam pipe Case 3, the outer beam pipe is the thickest conductor with the probable largest AC currents, so the single tie should be at the pipe next to one of the isolators.

Power Tape Shielding PP1 to PP2

The power tape bundles from PP1 to PP2 should have a shielding wrap around each bundle. The shields should connect to AGND at PP1 as detailed above. If a shield is connected to AGND at more than one place, then it becomes an AGND current carrier. The best capacitive shielding for the TRT is obtained by tying the shield only at PP1.

Conductors Inside the Shield

The power tape for a module has a single point commoning tie: a module and power tape inside the foil is isolated from other conductors. This forces shielding currents to flow on the foil and not flow through the modules. The power tapes have no shielding inside the foil.

Mechanical supports inside the foil shield, like the cooling tubes, should tie to the foil at one point. Multiple point ties to the foil would bring the shielding currents inside the detector array.

Stray capacitance between a cooling tube and a SCT detector backplane can be as great as 100 pF. This is the largest contributor to the ground loop indicated in Figures 2 and 3. Since a cooling tube serves modules with power tapes entering the shield at very different points, the strays create a shunt path for the shield currents that include the detector backplanes. The ground loop would include a cooling tube, its modules from different power supply groups and their backplanes, and the portion of the shield between the two power supply entry points as shown in Figure 3. A module shunt shield between the cooling tube and the backplane is needed.

The shunt shield is created by an additional conductive layer in the module mounting block between the cooling tube and the detector. This layer should have a low AC impedance tie only to the power tape AGND entry point at the module connector. Most of the currents in this ground loop now flow through the power tape only, leaving the backplane more isolated from stray currents. The stray capacitance from the tube to backplane should be reduced to 1 pF or less.

Conductors Outside the Shield: Ferrite Common-mode Chokes

The power supplies are in very different locations at the ends of ~110 meter cables. This forms a ground loop with the path including the two or more cable bundles running to different supply locations, the aggregate capacitive strays to earth of the cables, the strays of the floating supplies, the foil shield, and the detector backplanes. This loop is shown schematically in Figures 2 and 3. The detector backplanes are in the loop because the foil is thin and the cooling pipes create a secondary shield shunt through the backplanes as detailed above.

Ferrite common-mode chokes on all the power cables can break this ground loop. A choke introduces a series impedance, on the common-mode current on a differential conductor pair that is wrapped on the choke. The differential signal on a pair is unaffected. For ferrites to function, they need shielding from the DC magnetic fields. At UCSC we have designed a PP3 common-mode ferrite choke with cable connector and magnetic shield. The mechanical design was done by Max Wilder. A shielding factor of 1000 is needed for a possible maximum ambient field of 1 kilogauss. The magnetic shielding has two layers separated by isolators. Each layer is a length of standard low-carbon steel tube with 0.25” thick steel discs plugging each end.

The estimate of the steel shielding effectiveness in its magnetic saturation region uses the techniques in “Magnetic Shielding of an Accelerator Beam using Passive Ferromagnetic Material”, IEEE Transactions on Magnetics, 32-4, 1996, page 2663. For a soft iron cylinder of interior diameter 40 mm with 10 mm wall, the attenuation factor at 1 kilogauss is over 100. The UCSC design is not prototyped, so the shielding efficiency has not been shown. The area of uncertainty is the leakage through the board cross-section where it passes through the discs. If prototyping indicates insufficient shielding, there are a variety of simple modifications to decrease the board cross-section at the discs.

Figures 4, 5, and 6 detail the ferrite filter design, paying particular attention to the mechanical aspects of the magnetic shielding. Our purpose in detailing the design at this level is to allow a feasibility and cost estimate for using ferrites in a strong magnetic field. We show it is possible to shield using standard steel stock, straightforward machining, and a minimum of close tolerance fitting joints. The estimated weight of the steel is 900 grams for one module cable.

The ferrite filter components used are from Pulse Electronics, and are packaged in a reliable surface-mount package. The chokes will introduce a kohm or so series impedance down to 100 kiloHerz for common-mode signals on their conductors. Strays that create ground loops are effectively cut off from small signal interaction for the system beyond PP3. These design areas can have loosened specifications by using the filters:

(1) Cable tray isolation and grounding.

(2) Cable shielding outside PP3.

(3) Conductor twisted pair requirement outside PP3.

(4) Power supply strays.

(5) Pickup from other systems of all types onto the power supplies and cabling.

(6) Safety grounds type and construction outside PP3.

(7) Power supply locations.

(8) Relationship of earthing points in different buildings and caverns.

SUMMARY

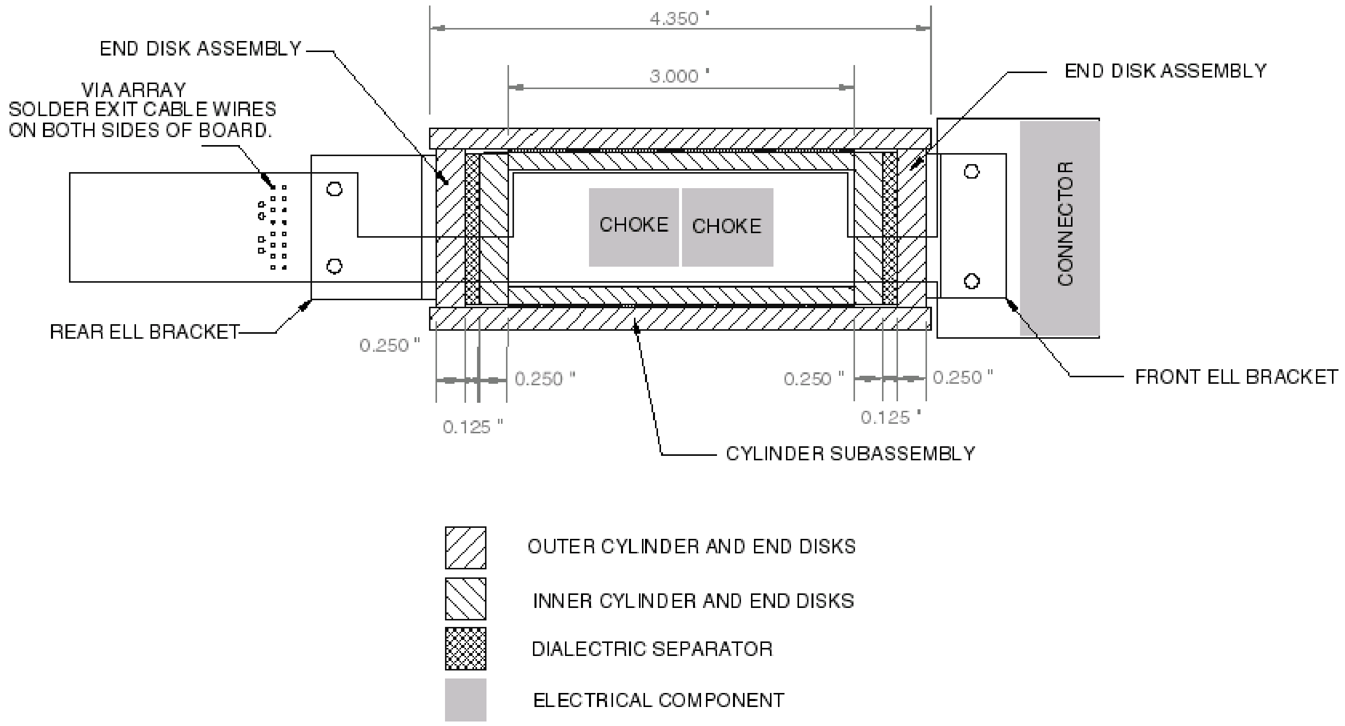
(1) The foil shield can be used to shunt possible system ground loops away from the small signal area.

(2) A shunt shield on the SVT cooling tube connection will attenuate possible ground loops.

(3) The foil shield will work best when following a connection protocol to it for conductors both inside and outside the shield.

(4) A supply cable ferrite choke at PP3 is possible, and it greatly reduce the area and complexity of the system grounding and shielding.

SCT/PIXEL PP3 FILTER ASSEMBLY



PP3 PC BOARD DETAIL DRAWING

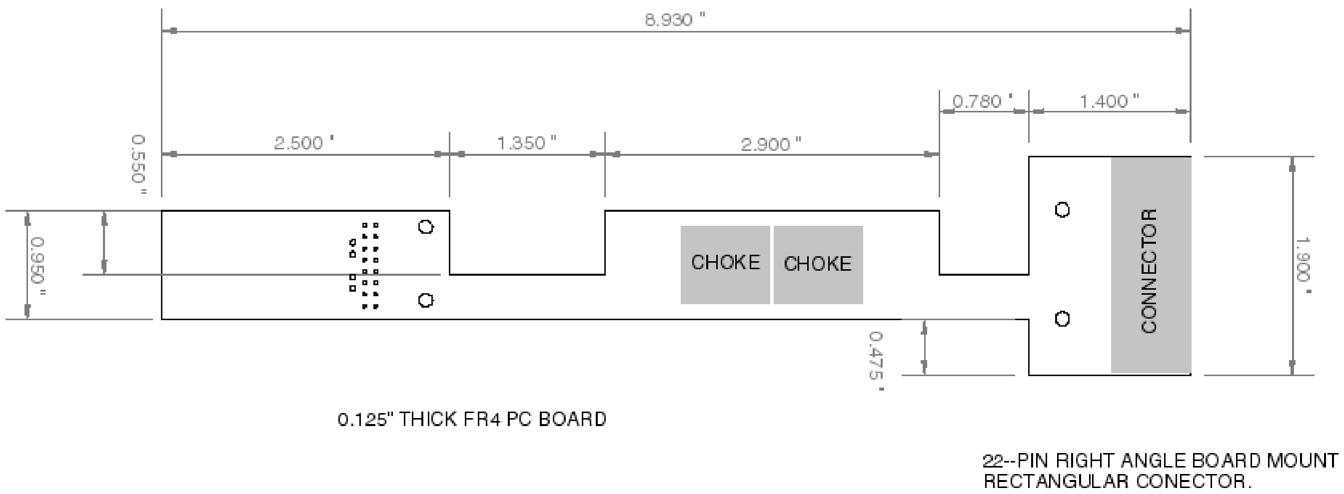


Figure 4.

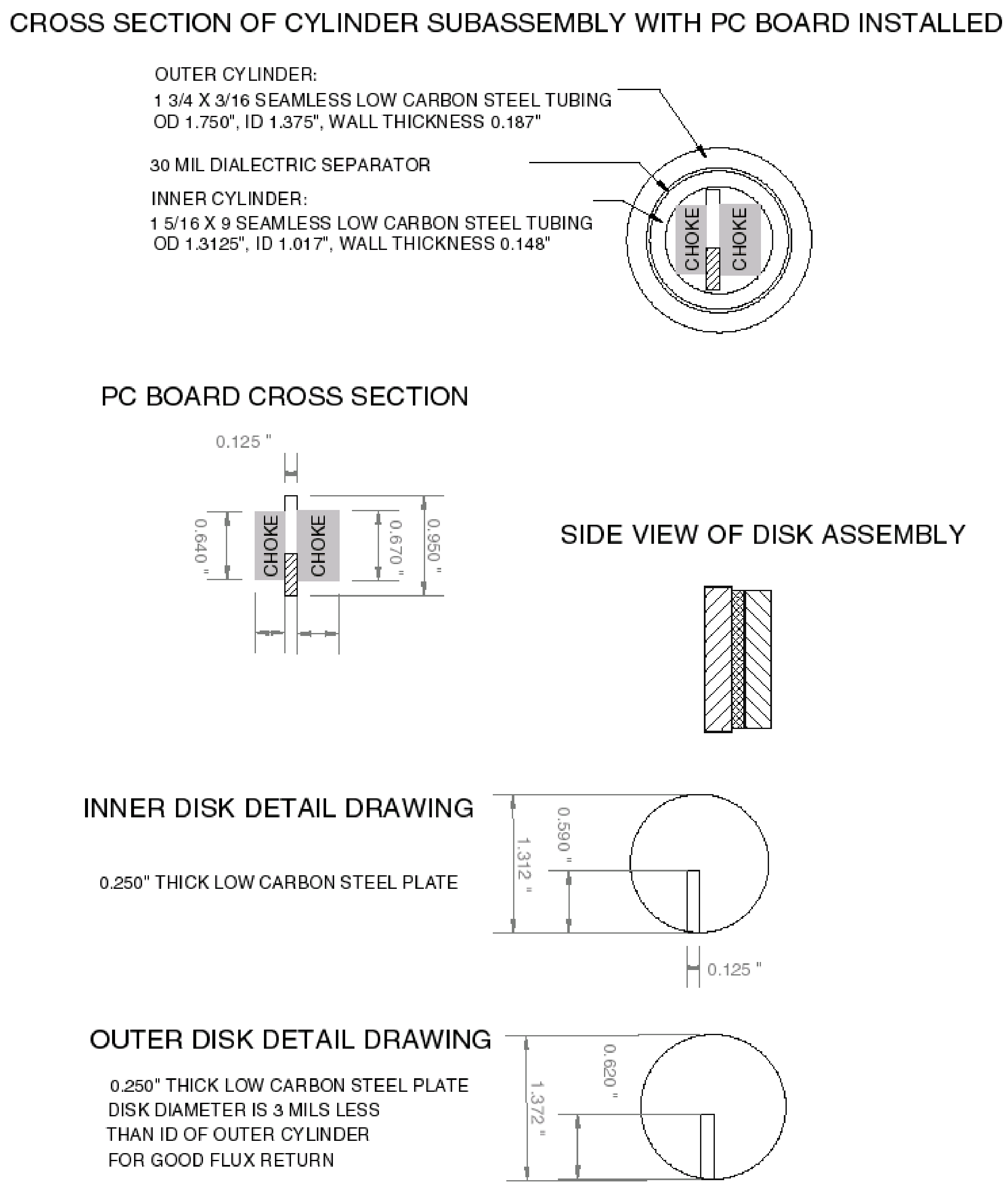


Figure 5. Cross-sections and steel disk details

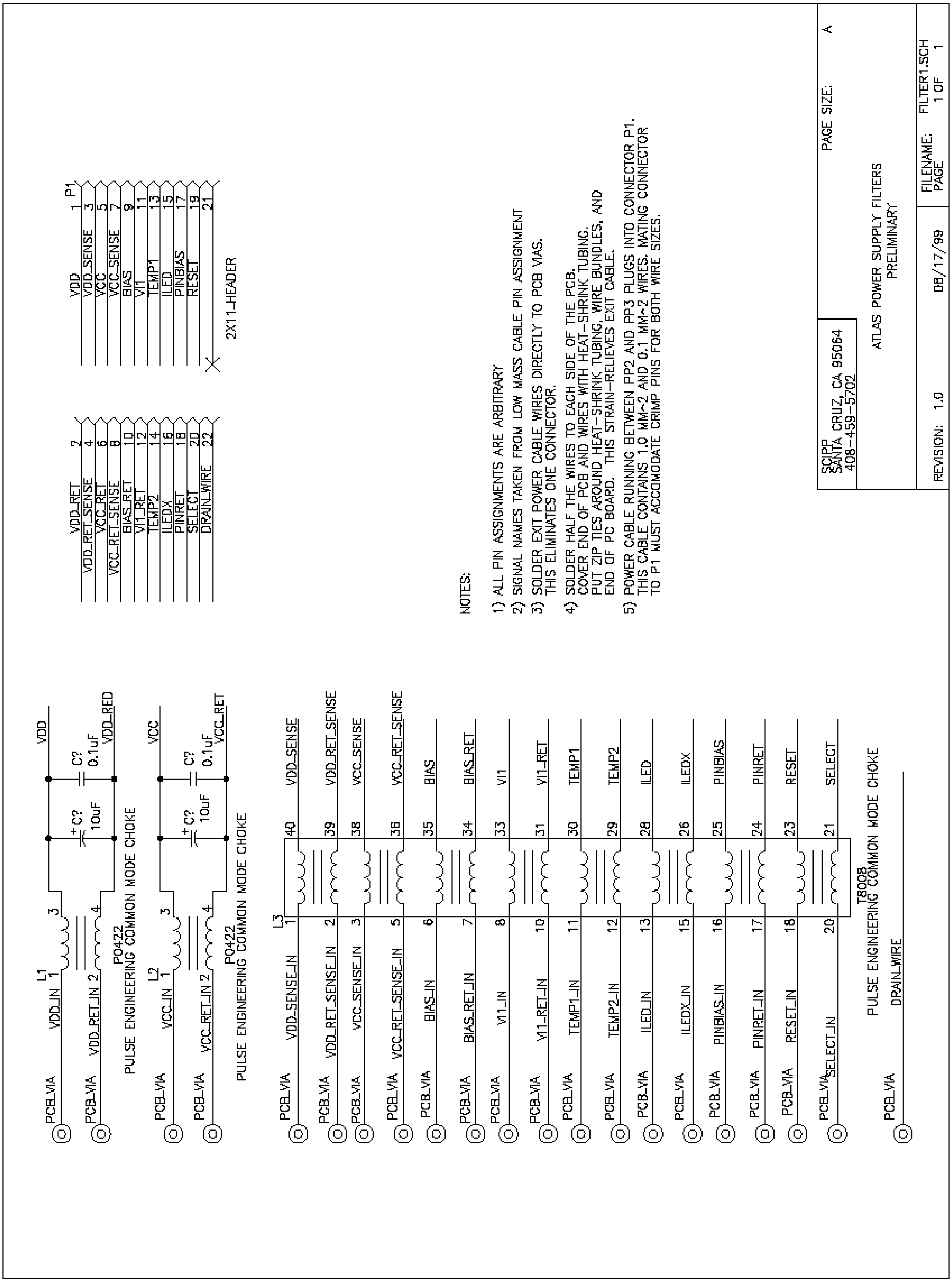


Figure 6. Schematic of PP3 common-mode choke assembly.