MDT Faraday enclosure measurements
29 June, 1999

J. Huth, E. Hazen, J. Oliver, C. Posch, W. Riegler, J. Shank

Enclosure requirements

The signal processing within the front end ASD chip has been carefully designed under the assumption that the noise is dominated by that of the MDT termination resistor along with an additional component from the preamp itself. The discriminator threshold is set, typically, at five sigma above noise. Insufficient shielding could easily result in pickup that exceeds this noise level and would, in turn, seriously compromise chamber performance. The enclosure requirement, therefore, is that under expected operating conditions, the noise be dominated by the inherent thermal noise. The pickup must be kept well below this level.

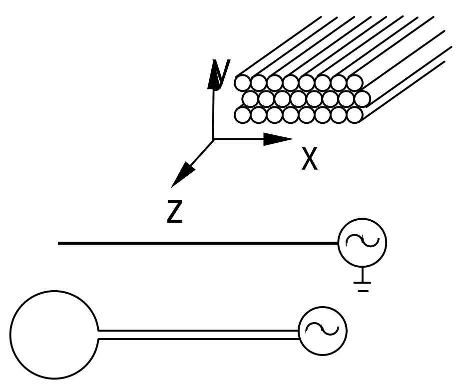
It is impossible to know with any degree of accuracy, what the ATLAS operating environment will be. However, we can take measurements by stimulating the faraday enclosure with known signal sources and compare these with the types of sources one is familiar with, such as CMOS voltage swings, LVDS voltages and currents etc. These can be used as the basis for a reasonable faraday enclosure design.

Test setup

Testing was done with two signal types.

a) **Line antenna , 1 meter length** to produce near field electric excitation with very little magnetic component (*high impedance wave*)
b) **Loop antenna, 25 cm diameter** to produce near field magnetic excitation with very low electric field (*low impedance wave*)

All testing was done at a frequency of 30 MHz. While additional information could be obtained by sweeping over a range of frequencies, 30 MHz was chosen since it is in the range in which the ASD pickup tends to be maximum. It is also near to the LHC clock frequency of 40 MHz at which one expects to see maximum radiated emi since virtually all front end systems are clocked at this frequency or multiples thereof.



Using the basic setup shown, all testing was done in x, y, and z directions as a function of the distance to the faraday enclosure. A key feature of the faraday enclosure is the bottom plate. In particular, the sealing of the bottom plate to the end-plugs is an essential feature. The faraday bottom plate has two screw holes locations for attachment to the end plugs. One location is for the ground pin which is used as a fastener while the other is for a second screw. The shielding effectiveness of the faraday enclosure can be measured by examining the four following conditions;

a) Faraday enclosure cover open. (**box open**)
b) Faraday enclosure cover closed. Bottom plate is attached to the end-plugs with ground pin only and no secondary screw. (**1 screw**)
c) Faraday cover closed. Bottom plate attached with ground pin and second screw. (**2 screws**)
d) Cover closed and additional aluminum skin around entire chamber. (**skin**)

In each of the cases above, the measurements were performed by observing the analog output of the ASD on an HP4195A spectrum analyzer as well as observations on a scope. The data are plotted on a dB scale noting that 20 dB corresponds to a factor of 10 in voltage or 100 in power.

The scale of measured data is set by the somewhat arbitrary definition below.

a) 0dB is defined as the intrinsic thermal noise of the preamp and termination resistor which has been measured and subtracted from the data. This is convenient in that it tells us immediately whether the noise pickup is visible above the intrinsic thermal noise.

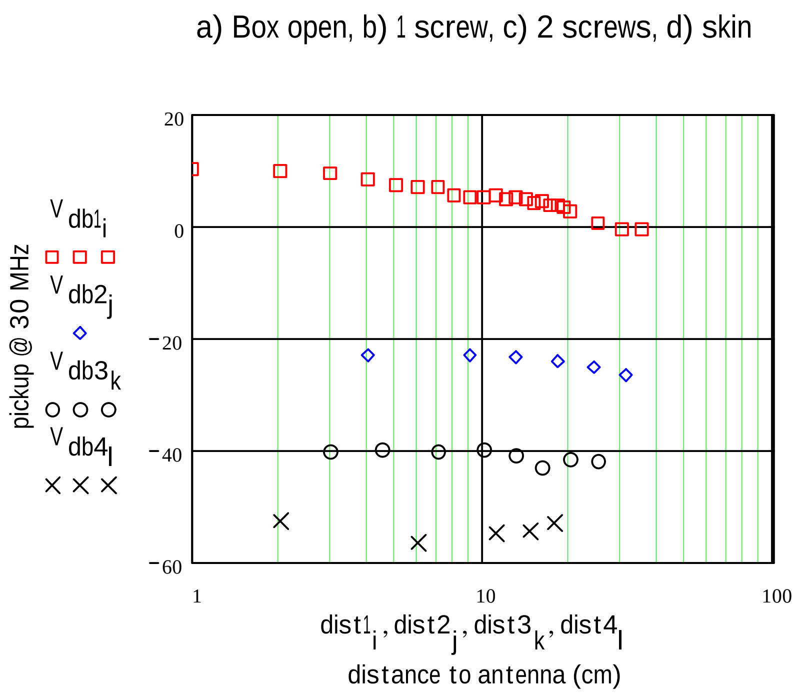
b) The data for line antenna measurements are all normalized to a *200 mv pk-pk* antenna voltage. As a comparison, a single ended 5V CMOS signal swing would be 25 times higher or +28 dB

c) The data for loop antenna are all normalized to a *4 ma pk-pk* current level. By comparison, a loop formed by untwisting and forming the wires in an LVDS twisted pair cable into a 25 cm loop, would be 2 ma pk-pk or –6dB relative to our measurements.

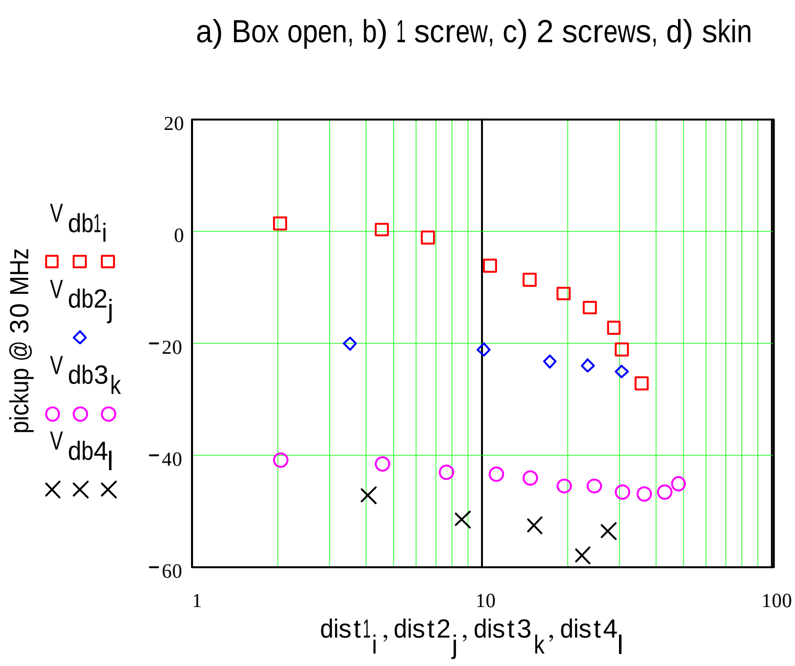
Results

Measurement results are shown in the plots a) through f) below. In each plot, the data corresponds to the conditions a) box open, b) closed with 1 screw in bottom plate, c) closed with 2 screws in bottom plate, and d) chamber completely enclosed by outer aluminum skin. In each case the data corresponding to condition a) is at the top and descends to condition d) at the bottom.

a) Line antenna in x direction (horizontal) as a function of distance in z direction.

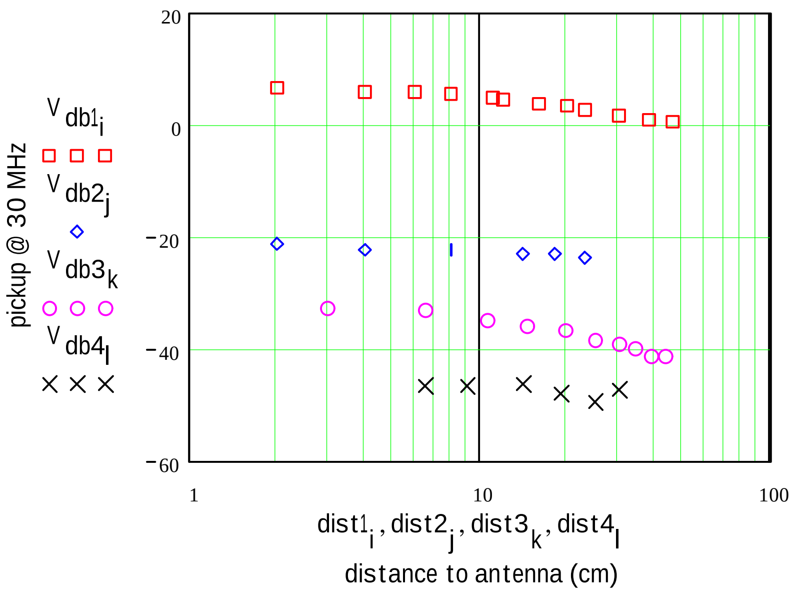


b) Line antenna in y direction (vertical) as a function of distance



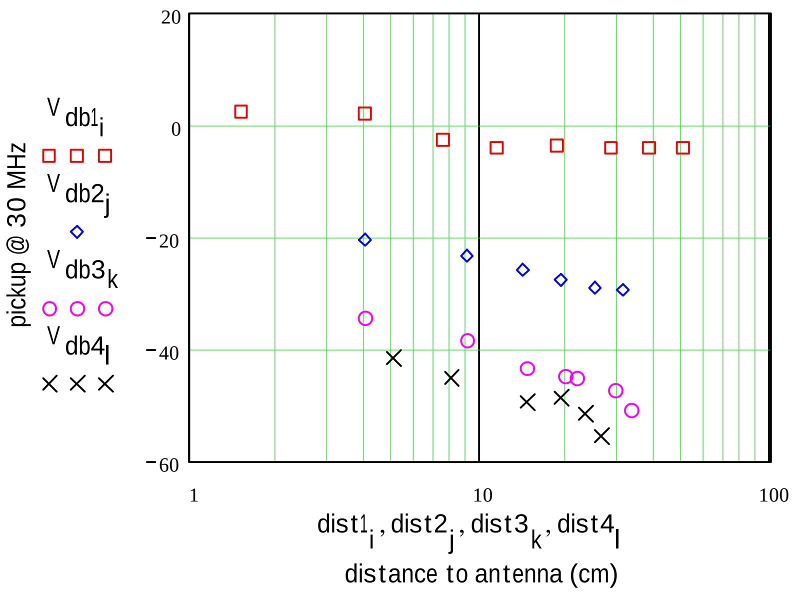
c) Line antenna in z direction (parallel to tubes)

a) Box open, b) 1 screw, c) 2 screws, d) skin



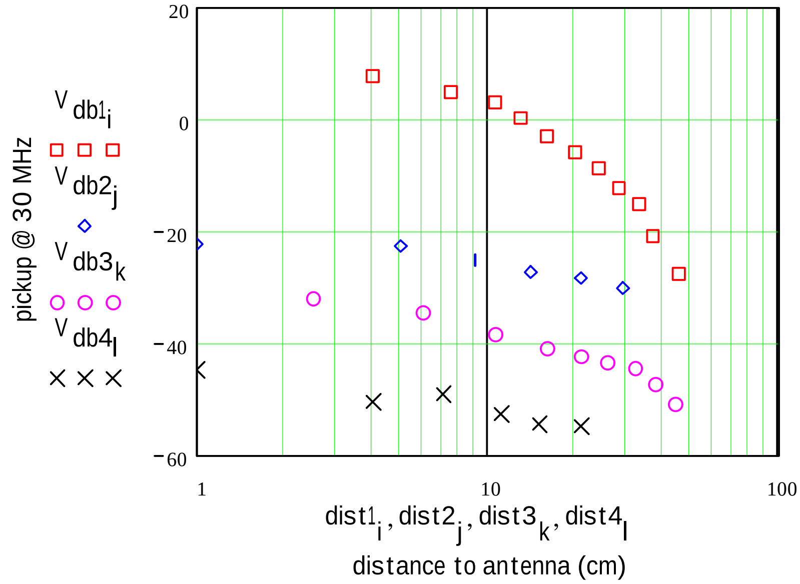
d) Loop antenna in x direction (normal to plane of loop)

a) Box open, b) 1 screw, c) 2 screws, d) skin



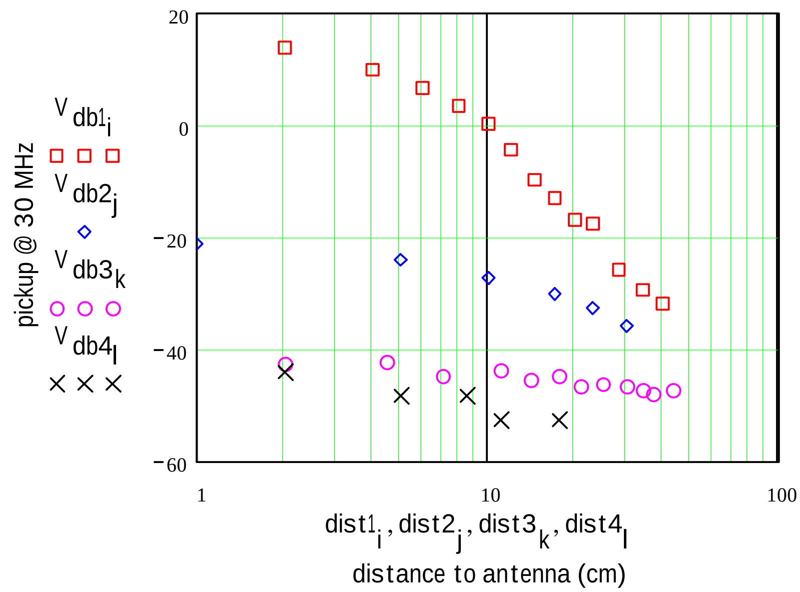
e) Loop antenna in y direction (loop in horizontal plane)

a) Box open, b) 1 screw, c) 2 screws, d) skin



f) Loop antenna in z direction

a) Box open, b) 1 screw, c) 2 screws, d) skin



Discussion

Plots (a,b,c) show that, with the box open at least, pickup of electric field excitation is worst with the line antenna horizontal. It is also true but not shown here, that the open-box data fit very well to a 1/r function. This suggests that the mechanism for this pickup is direct capacitive coupling into the long horizontal traces on the hedgehog card which are parallel to the antenna in this direction. Rotating the antenna by 90 degrees as in plot (b), reduces the coupling. The fact that the box open data of plot (a) is above the 0dB level indicates that the pickup dominates over the thermal noise, a fact which is easily seen by observing the traces on a scope.

Plots (c,d,e) show the magnetic coupling results. In the box open configuration, B field in z direction (into the open box) is the highest coupling.

As stated previously, the box closed condition was observed with both **one screw** and **two screws** in the bottom plate. The value of the second bottom plate screw is clearly seen in the plots which show that, depending on direction, 10 dB to 20 dB increase in shielding effectiveness is seen. With one screw in place, the test antennae result in pickup which is only 20 dB (ie 10%) below thermal noise. The importance of the second screw is in no way a surprise. Without it, the bottom plate is poorly sealed to the end-plugs and results in the observed leakage.

With the entire MDT chamber enclosed by an aluminum skin, generally an additional 10 dB below the two-screw condition was obtained. While such a shield is the ultimate weapon for pickup immunity, an additional 10 dB probably does not justify the cost.

The line and loop antennae we have used are clearly idealizations. Signal cables throughout the ATLAS detector have been mandated to be LVDS (Low Voltage Differential Signals) and not single ended. Cable is required to be twisted pair and possibly shielded as well. The emi from such cables will be considerably less than that of the loop and line antennae. There will, however, be tens of thousands of them. There will also inevitably be emi sources not covered by the LVDS mandate. These can come from a wide variety of sources which are difficult to control. For this reason, we should adopt the best possible enclosure procedure consistent with reasonable costs. In almost all cases, the faraday enclosure with two screws in the bottom plate provides a shielding effectiveness of 40 dB which is equivalent to 1% of the voltage level observed with the cover open.

We should also note that the bottom plate with two screws is only one possible solution and there are others. The use a commercial rf gasket under the bottom plate to prevent leakage is also a possibility. The faraday outer skin solution, not surprisingly, is shown to be the most effective.

Finally note that all of these observations are consistent with good shielding practices as discussed in a number of useful references [1-4].

Conclusions and recommendations

There are two ways to ensure adequate “shielding effectiveness” of the faraday enclosure; a) **adequate sealing of the bottom plate** or b) a complete aluminum **skin** around each super-layer.

a) Sealed bottom plate
Sealing the bottom plate to prevent rf leakage can be done by using two screws to clamp the plate to the endplugs. In this case, maintaining good tube length tolerance of 100 to 150 microns makes this job significantly easier. Use of rf gasket or rf caulking materials on the endplug aluminum rings is a potential option, but not yet measured. Many commercial products are available for this purpose.

b) Faraday skin
If feasible, the entire Superlayer may be wrapped in a complete outer skin of aluminum of thickness at least 200 microns. Doing so relaxes, but does not eliminate, the requirement of sealing the bottom plate. To be effective, the outer skin would need to be hermetic or near hermetic. Some number of reasonably sized holes would probably be acceptable. The skin should cover each superlayer individually and not be penetrated by uncontrolled cabling such as DCS sensors of various types.

References:
[1] “Noise Reduction Techniques in Electronic Systems” H.W. Ott, Wiley
[2] “Grounding and Shielding Techniques in Instrumentation” R. Morrison, Wiley
[3] “Shielding and Grounding in Large Detectors” V. Radeka , not yet published
[4] “Engineering Design and Shielding Product Selection Guide” Instrument Specialties catalog