The Cryostat as an EM Shield

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Abstract
This note presents an analysis of the shielding power of a stainless steel cryostat as a function of the thickness of the shell. Results are presented for a range of wall thicknesses that should include both the microboone and LBNE cryostats. The last section has some comments about the ARUP preliminary design report.

Shielding Calculations
The first task in calculating shielding effectiveness is to understand what we want to shield against, i.e., is it plane waves (such as a radio station) or conducted signals (such as a ground loop) flowing on the cryostat shell. Radio stations are not likely to be a problem in either experiment but locally generated broad cast radiation could be present. Plane waves are essentially a far field phenomena so they typically require several meters of free space from the source before they are fully developed. For liquid argon detectors located in enclosures that are not much larger than the detector, it seems that plane waves are not very likely. Also, the thick thermal insulation will likely attenuate the radiation. Finally, most noise pickup is from conductive noise rather than from radiation. Therefore, I assume conductive noise.

The next task is calculate the shielding effectiveness of the cryostat wall. To do this, I calculate the transfer impedance which is defined as the voltage induced on the inner side of the shell from a current flowing on the outer surface of the shell. If the shield had 0 resistance, then no signal would penetrate the shield and the transfer impedance would be 0. All the current would flow on the outside of the shield. In effect, the outside of the shield would be completely disconnected from the inside as if there were 2 independent shells. As soon as the shield becomes resistive, there is the possibility of transferring a signal from outside to inside the shield. At 0 frequency (DC) the transfer impedance is just the resistance of the shell. Any current flowing in the shell generates the same voltage both inside and outside the shell. This is illustrated in fig. 1.

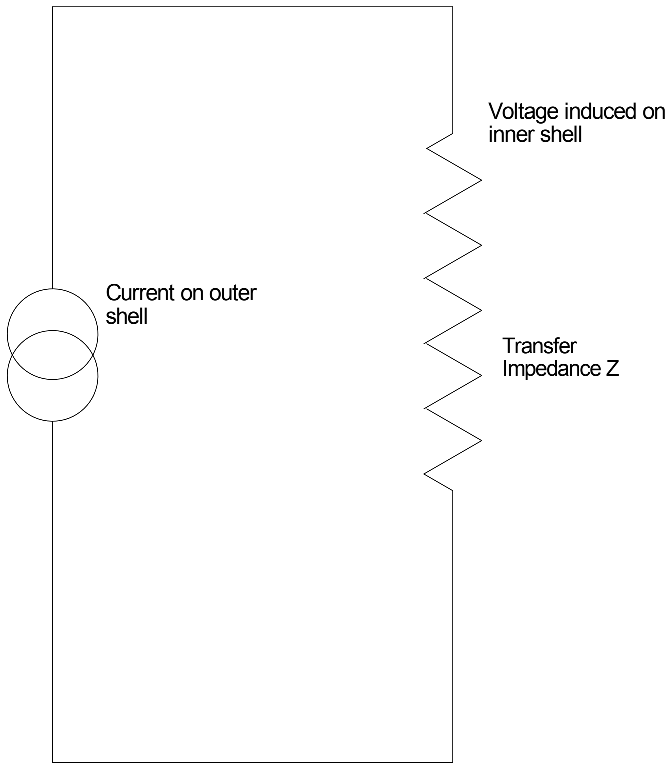

Fig. 1. Circuit diagram illustrating the idea of transfer impedance. Current flowing on the outer surface of a conducting cylinder induces a voltage on the inner surface if the transfer impedance is not zero.

As the frequency of the signal increases, eddy currents in the shell prevent full penetration of the signal to the interior so less less voltage is developed in the interior from the external current. An approximate solution for the transfer impedance for thin cylindrical tubes is given by the following[1].

$$Z_t = \frac{R\gamma t}{Sinh(\gamma t)} \tag{1}$$

where

$$\gamma = \left(\frac{i\omega\mu}{\rho}\right)^{0.5}.$$

Here t is the thickness of the cryostat shell, ω is the frequency in radians/sec, R is the resistance per unit length of the shield, μ is the permeability of free space and ρ is the resistivity of the shield. The limit of

$$\frac{x}{Sinh(x)}$$

as x->0 is 1 so the DC value is just R. The limit as x goes to infinity is 0 so at infinite frequency, there is no coupling between the inner and outer layers.

The radius only enters in the calculation of the cross sectional area of the shell which is needed for the DC resistance. As an example I chose a shell radius to be 1.98 m which is similar to the microboone radius. The material is taken to be 304 stainless steel. Fig. 2 shows the transfer impedance (eqn. 1)as a function of frequency for a shell wall thickness of 12 mm. I have normalized the plot to 1 at DC by dividing (1) by the DC resistance R so that one can see the frequency dependence more clearly. Fig. 3 shows the same function for a 1 mm thick wall and fig. 4 shows the results for a 25 mm thick wall. These results show that a 25 mm wall thickness has good shielding above a frequency around 5 KHz while the 1mm wall is not very good until 30 MHz or so.

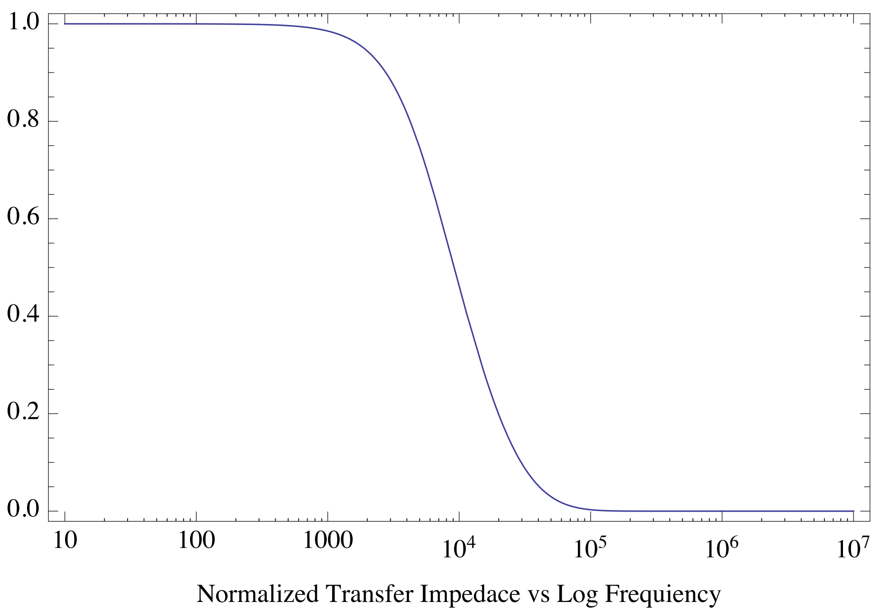

Fig. 2. Transfer impedance from (1) as a function of frequency for a 12 mm thick wall. Equation 1 has been normalized by dividing by R so that the DC value is 1.

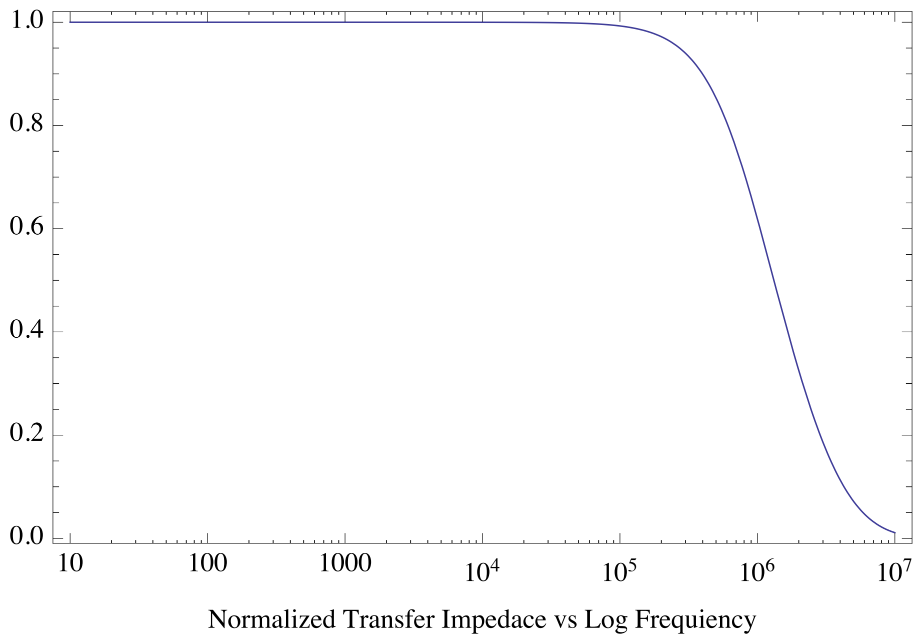

Fig. 3. This is the same as fig. 2 but for a 1 mm thick wall.

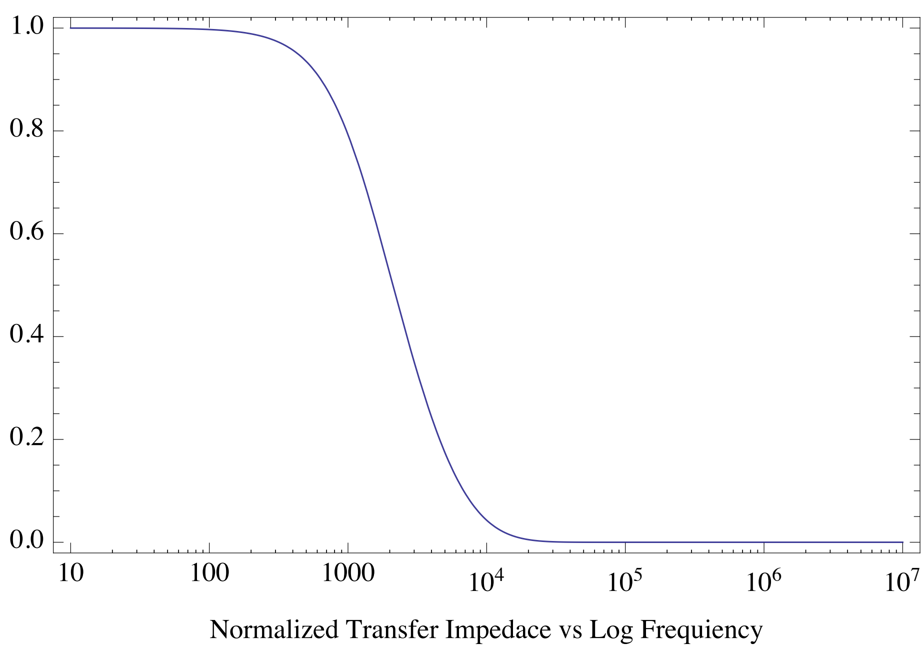

Fig. 4. This is the same as fig. 2 but for a 25 mm thick wall.

The resistivity of the material enters as the square root while the thickness is linear so thickness has a much bigger affect on the AC function than resistivity. However, the DC resistance is reduced linearly with decreasing resistivity so the overall affect of adding a 1 mm Al shield is quite large. Fig. 5 shows the transfer impedance for a 1mm steel plate and a 1 mm Al shield. The DC value for the steel plate has been normalized to one.

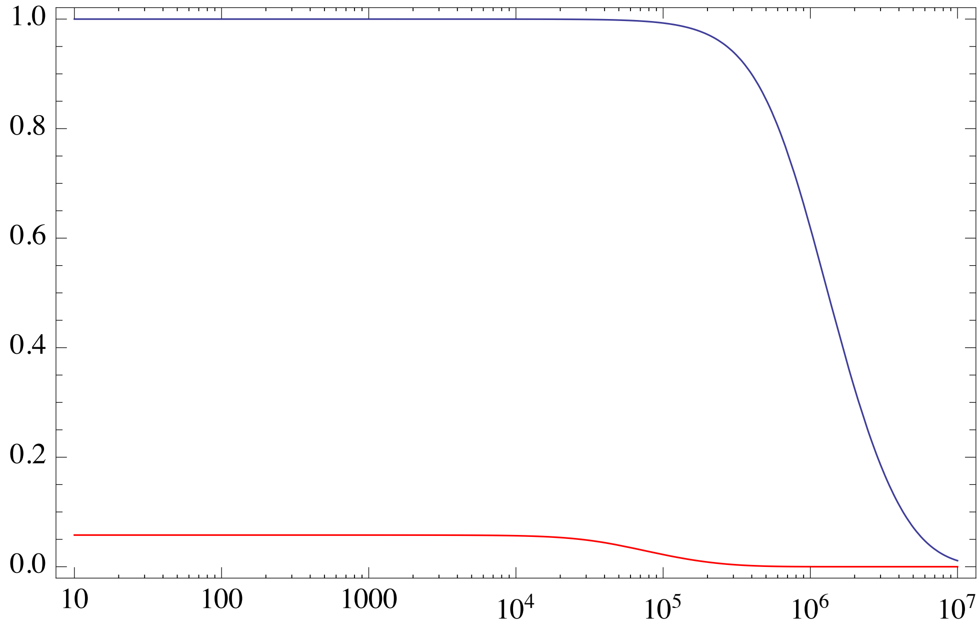

Fig. 5. Transfer impedance for a 1 mm thick steel plate (blue curve) and a 1 mm thick aluminum plate (red curve). The blue curve is the same as fig 3. The red curve has been multiplied by the ratio of the resistivity of aluminum to steel to reflect that the DC resistance of the aluminum is less than that of steel.

It is fairly well known that thin sheets of stainless steel provide both poor grounds and poor shielding. These results just quantify that knowledge.

It seems clear that if the shell thickness is only a mm or so, some additional shielding should be provided. This shielding is best placed inside the cryostat shell so that it can serve as a system ground as well as provide shielding from external currents. An aluminum shell of 5 mm thick should provide both a good local ground and good shielding down to 5 KHz (fig. 6).

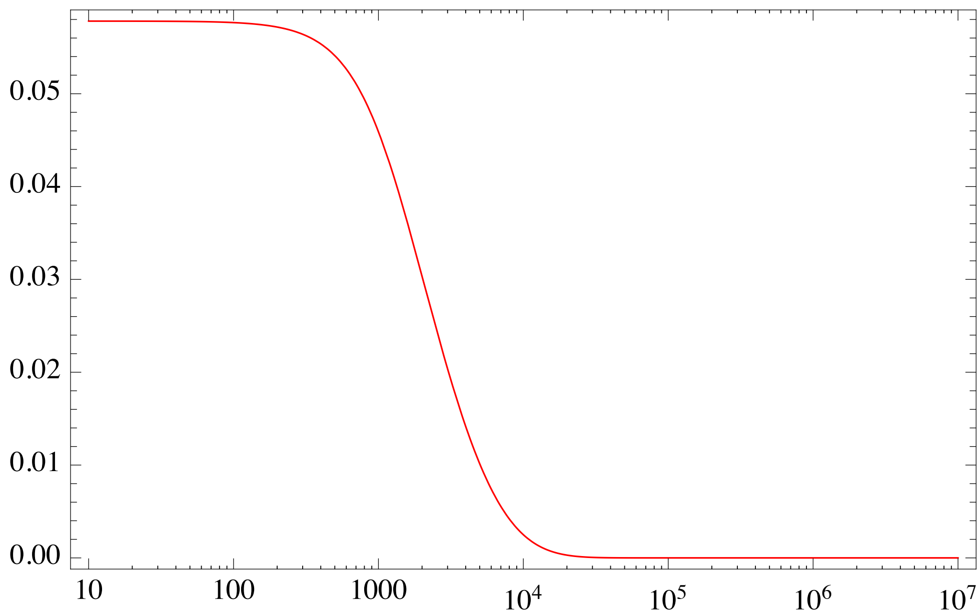

Fig. 6. Transfer function for a 5 mm thick aluminum shield.

Comments on the ARUP design

These comments are restricted to grounding and shielding issues. The design has chosen a membrane cryostat but the wall thickness does not seem to be specified. If it is 1 mm or so, I do not believe that it will provide adequate shielding for ground currents on the shell. Some additional shielding will almost certainly be needed.

The design also includes an electric heating elements in the walls and floor of the concrete support structure. The size of the heater is not specified but the cryogenic heat load calculation in table 2 gives about 25 KW. This is probably close to the required heater size. An SCR controlled heater this large and this close to the cryostat is most likely not acceptable. A simple AC resistance heater that is switched on and off at the zero crossing point of the AC cycle is probably acceptable. The design will need to be carefully monitored. Otherwise, linear or switch mode power supplies will be required which will be quite expensive.

Even with an internal aluminum shield, there is no large mass to sink unwanted noise currents. That is, one needs a conducting body with enough capacitance so that sending unwanted signals to the body does not alter its potential much at all, i.e., it is a ground. One possibility is to use the concrete reinforcing structure as a Ufer ground.

Ufer grounds are named after an engineer in WW II who developed a method of using the metal reinforcing rods in concrete to provide a ground to protect ammunition dumps against static discharges. It has since been used for a wide variety of structures. I am trying this concept for the NOVA far detector building. If this is successful, it will be a low cost method of adding a good ground structure to the detector.

References

[1] Anatoly Tsaliovich, *Cable Shielding for Electromagnetic Compatibility,* International Thomson Publishing, Florence, KY, pp. 150-157