The MicroBooNE Cryostat Wall as EMI Shield—Additional Information

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Abstract

Marvin Johnson has just published a very useful note on the frequency dependence of the shielding effect of a stainless 304 cryostat tank wall, in Microboone and for the LBNE membrane tank.
His graphs show the normalized transmission impedance for a 1/2inch and a 1 mm thick wall, among others. In each case there is a clear transition form a high impedance (the DC value) at low frequencies to a much better and lower impedance at high frequency. The transition occurs at about 1600 Hz for the 12 mm thick SS 304 wall, and at about 160 kHz for the 1 mm SS 304 wall.
In this note I try to estimate the noise charge induced on a detector wire for either condition. For a very strong external electromagnetic field I find a high noise rate for the thin wall (1mm thick) cryostat, supporting Marvin's conclusion that an additional shield is needed if the noise frequencies fall within the interesting frequency range of the TPC. Pipe connections can (barely) be isolated using ferrite cores; dielectric breaks may be needed.

DC Resistance of the tank shell

I could not find the cold resistivity for SS 304, but it will be just a little lower than the room temperature resistivity, which is widely quoted as 720 nano-Ohm-m. I use this (more conservative) number in my analysis.
We assume the worst case of a noise current flowing in the cryostat in the horizontal direction, transverse to the tank axis. This geometry generates the strongest noise field to couple into the sense wires.
The DC resistance would be the parallel path over the top and under the belly of the tank. It is expressed in Ohm for 1 m of tank length (actually, Ohm * m, to be precise).
For the 12mm tank wall and the 1.98 m radius used by Marvin, we get 2.24 mili-Ohm for 1 m tank length,
and for the 1 mm wall we get 0.19 mili-Ohm for 1 m length.

Estimate of the Wire Noise

In order to estimate the noise pickup into one of the TPC wires we need to make assumptions. From the results it will be easy to scale to different assumptions if desired.
We make the following assumptions:

First Scenario:

We assume a certain current flow per meter of tank length.
The current flows horizontally into the tank wall (worst case orientation).
--the noise current (from lack of electrical tank insulation) is 1 mA / m of tank length
--the characteristic time Tau for the TPC' s sensitivity is 10 microseconds
We are in the low frequency (i.e. high sensitivity) section of the transfer impedance.
With these assumptions we find the voltage difference across the tank diameter by Ohm's law.

It is 0.19 micro-V for the 12 mm wall, and 2.24 micro-V for the 1 mm wall.
The wire capacitance is approximately 20 pF /m, for a total of about 80 pF per wire.
The current into the wire is estimated at the typical frequency (1/Tau) and integrated for the duration Tau. These are crude assumptions, but should be close enough.
We find a noise charge to be 600 electrons for the 12 mm wall, and 7,000 electrons for the 1 mm wall.
These are significant, and not acceptable.

Second Scenario:

The tank is exposed to a horizontal electromagnetic noise field, normal to the tank axis.
We assume (arbitrarily) a rather strong noise field, of 1 V/m.
This is not unreasonable, since we wish to be immune to intermittent high noise conditions.
We find a wire noise of 130 electrons for the 12 mm wall, and 1500 electrons for the 1 mm wall.
These noise numbers are not acceptable.

Third Scenario:

A pipe carries a noise current (we assume 10 mA) toward the tank.
We use a commercially available ferrite core (10 each of leadertech inc.'s model CS28B4000) and assume a grounding path of 0.1 ohms outside the ferrite core.
We find a noise of 30 electrons for the 12 mm wall, and 350 electrons for the 1 mm wall.
These rates could become acceptable if larger and better ferrite- and iron cores could achieve a 10X improvement. The grounding resistance can also clearly be improved.

Comments:

The analysis was using conservative assumptions at all points.
The current direction , as an example, maximizes the noise pickup.
Currents flowing in the tank vertically would cause no noise.
I do not know if the amount of noise current or the strength of the noise field is realistic; it would be useful to have more information or measurements.

Remedies

Remedies fall into two categories:

- Lower the frequency at which the transfer impedance becomes very small
- Lower the noise current in the cryostat wall.

In any case we would like to reduce the noise by a factor of 100 or so.
Marvin has shown that a roughly 12 mm wall will lower the noise impedance for frequencies above 1600 Hz, which appears to be safe.
If one wishes to reduce the noise current in the wall, one has two options:
--add a highly conductive layer. Marvin shows that a 1 mm thick Aluminum layer will lower the cutoff frequency, but apparently not quite enough (need more study).

-- add an insulated conductive layer. The layer might be a thin conductive aluminum layer on the outside of the foam insulation. The layer would short—circuit the current around the tank.
This is a very effective remedy.
We find, for example, that an aluminum foil layer of just 0.1 mm thickness on the outside of the foam insulation will reduce the noise from the 1 V/m electromagnetic noise field from 100 electrons to 0.0001 electrons.
Similarly an aluminum wire mesh of 1/16” diameter wires at 0.437 spacing (McMaster # 9227T142; $ 4.25 per sf) would reduce the noise even more, to half of the above aluminum foil value. The mesh would be used under the outer mastic coating, where it can replace the planned fiberglass mesh.
I have not calculated the LBNE membrane cryostat case.
It is not clear what noise fields can exist hundreds of feet below the surface.
Local noise source can, of course, exist.
One can imagine covering the cave side of the insulation modules with thin aluminum foil, and interconnecting the modules using wide aluminum tape, or relying on the secondary confinement membrane (if it has a conductive aluminum layer). Care must be taken to make complete connections, e.g. around all edges.