10OCT2017TMS
Rev 27NOV2017

This note attempts to summarize the result of several meetings held over the last couple of months. Meeting participants include Theresa Shaw, Linda Bagby, Paul Bauer, Steve Chappa, Arnab Ghosh, Veljko Radeka, Rick Van Berg, and Bo Yu.

Analysis of DUNE Grounding Plan

The DUNE grounding plan described in docdb 285 notes that a basic assumption has been made that "At the SURF 4850 Level where the Neutrino Detectors will be located, the electrical conductivity of the various rock masses is unknown but expected to have extremely poor and inconsistent conductive properties. To insure adequate sensitivity of the detectors special ground systems must be put in place that will isolate the detectors from all other electrical systems and equipment, and minimize the influence of inductive and capacitive coupling and ground loops….".

This note looks back at the DUNE grounding plan and suggests any additional requirements/mitigations. Before proceeding with the ground plan, it is advisable to test and make sure there is no significant amount of moisture which can affect isolation between the "Detector Ground" and the "Cavern Ground and Ufer Ground" references.

Suggested requirements/mitigations:

A. Use of high resistance, low water permeability concrete in the concrete pads that the detectors rest upon. *This **requires** that the concrete yield an electrical resistivity of 500 ohm-m or more after curing for 1 year.*[1]
B. Drainage control (sump pumps) to get rid of any "standing water".
C. It has been suggested that we may want to install a small model test in the cavern which can be used to verify the design. Such a test would require:
    a. the pouring of a small scale concrete pad (same concrete mix and thickness as in production pad) on the cavern floor,
    b. a block of steel sitting on the concrete pad to represent the detector,
    c. a saturable inductor would need to be installed between the block of steel and the Cavern/Ufer ground to create the Detector Ground reference. **NOTE:** This implies a nearby connection to Cavern/Ufer Ground.

    Megger tests could then be done to establish the resistivity at the location of the pad.

Questions:

Is small scale test needed? What can we learn from it which might change plan before "it is too late"?

1. Design and Control of Concrete Mixtures, Fourteenth Edition, by Steven H. Kosmatka, Beatrix Kerkhoff, and William C. Panarese - Chapter 17 http://www.ce.memphis.edu/1101/notes/concrete/PCA_manual/Chap17.pdf

Resistivity and Resistance Models

A simple model of the resistance seen between "Detector Ground" and the "Cavern Ground and Ufer Ground" references would be viewing the cryostat as an electrode with contact to Cavern/Ufer Ground through the concrete pad the detector rests upon.

Email from Bo Yu (10/31/2017)

The beam structure on the bottom of the cryostat is 0.4m wide at 1.6m centers along the length of the cryostat. Transversely, there are 6 beams along the full length, 9 beams at the ends (on 1.6m pitch). See picture below.

Here is a tally of the floor contact area:

beam type	**area**	**number**	**total**
long beam	26.4	6	158.4
short beam	2.2	6	13.2
transverse beam	7.6	39	296.4
overlap (double counted)	0.16	246	39.36
total contact surface			428.64

The total surface is about 430m^2.

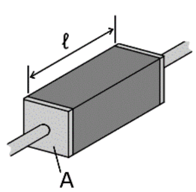
From McMaster Carr, ½" FRP plate cost $230/m^2, FR4 is about $400/m^2. The total material cost is 100-200k$.

Resistance of the Saturable Inductor:

DC resistance at 20 degrees C required to be 13 mOhms or less

Calculations:

$$\rho = R\frac{A}{\ell},$$



where

R is the electrical resistance of a uniform specimen of the material

ℓ is the length of the piece of material

A is the cross-sectional area of the specimen

Resistance of concrete pad under the metallic contact of the cryostat Frame:

Bottom of Cryostat is 430 m^2

Concrete Pad is 1 foot thick or 304.8 mm

Gravel layer is 8 inches thick or 203.2 mm (ignore for now)
Choose concrete resistivity of

a) **Conventional Concrete ~50 ohm-meter**
   R=ρl/A = 50 ohm-meter * 0.305 meter / (430 m^2) = **35 mOhms**

b) **High Performance Concrete ~500 ohm-meter**
   R=ρl/A = 500 ohm-meter * 0.305 meter / (430 m^2) = **355 mOhms**

For comparison, look at adding a thin layer of G10 insulator (like at ProtoDUNE):
Resistance of 0.1mm G10 insulator
http://advancedmaterialscience.com/assets/nema-g10.pdf
6 x 10^6 megohm-cm

R=ρl/A = 6 x 10^{10} ohm-meter * 10^{-4} meter / (430 m^2) = **13.95 Kohms**

Also, for comparison look at approximate resistance of 1 meter of rock which is under concrete pad:

Resistivity of rock ~50,000 ohm-cm (guess)

R=ρl/A = 500 ohm-meter * 1 meter / (65.896 meter * 18.996 meter) = **0.4 ohms**

Plate Capacitor Capacitance Calculator
C= K*Eo*A/D, where Eo= 8.854x10-12 F/m
where:
K is the dielectric constant of the material, 4.5 for concrete
A is the overlapping surface area of the plates,
d is the distance between the plates, and
C is capacitance

Capacitance for concrete under steel beams

K ~4.5 for concrete

C= 4.5 * 8.854x10-12 Farads/meter * (430 m^2) / 0.305 m = 0.056 µF

Capacitive Reactance is $|X_c|$ = 1/2πfC; is 284 ohms @ 10KHz and 1.42 ohms at 2MHz

Capacitance for 0.1mm G10 under beams

K ~4.2 for G10

C= 4.2 * 8.854x10-12 Farads/meter * (430 m^2) / 0.0001 m = 159.9 µF

Capacitive Reactance is $|X_c|$ = 1/2πfC; is 99.5 mOhms @ 10KHz and 0.5 mOhms at 2MHz

Total Capacitance

Treat concrete and G10 as series capacitors, total capacitance is 0.056 µF

Capacitive Reactance is $|X_c|$ = 1/2πfC; is 284 ohms @ 10KHz and 1.42 ohms at 2MHz

Conclusions

1) For the Impedance Monitor to work well with our saturable inductor, the overall DC resistance through the saturable inductor (12 mOhms) should be much less than the DC resistance through the concrete pad to the “Cavern and Ufer Grounds”. This is true only when we
   a. **require the use of high resistivity concrete of 500 ohm-meter or greater**; higher resistivity concrete has the additional benefit of additional water resistance.
   b. **or, have a thin layer of high resistivity dielectric between the cryostat and concrete or earth ground to yield at least 10 ohms – this is favored solution.**

2) To eliminate coupling of stray low frequency noise currents onto the detector and detector electronics, we should **strongly consider adding a thin (0.1mm) layer of G10 under any of the support beams making contact to the concrete pad**. Calculations show that this would increase the resistance between the “building” and “detector” ground from roughly 355 mOhms to 13.95 Kohms.

   Some background for 2)
   We are concerned about stray low frequency currents from any services which are on the Cavern and Ufer grounds. This has been addressed in the current grounding plan by providing a low impedance ground return near the bottom of the cavern “septum” where we expect the cryo pumps/equipment to be located. We have also provided a low impedance path for Cavern and Ufer ground utilities at the crown area of the caverns which should serve as a low impedance path for any equipment located on the mezzanine and other services such as the lights and monorail. Finally, we reduce the overall capacitive coupling between Cavern and Ufer Grounds and the Detector ground by removing conductive rebar and other conductive material from the concrete pad. These are all mitigations to stray “building” currents, however, will not be as effective as having the detector sit atop a thin G10 layer or some other thin high resistivity dielectric.

   We would also like to point out the uncertainty of how much moisture/water will be at the base of the cryostat. **It is important to keep the base of the cryostat as dry as possible.**

Small Scale Test

It is our belief that any “small scale test” requires almost all the infractructure, other than the cryostat, to be in place. Once the floor and walls of the cavern are finished, one could do a test in which the detector is represented by a block of steel and placed near to the septum wall. A high resistivity test could then be done to establish the resistance in that local area between the steel block and the Cavern and Ufer grounds. It should be noted that this will give us a resistance that is representative of the immediate area of the test. It has been stated by experts at SURF that rock striations can vary results as well as moisture content.

Email from Tom Hamernik – November 20, 2017

… Epoxy has excellent dielectric properties (including volume resistivity values of 10^12 ohm-cm and greater, a high dielectric strength) and high compressive strength, as well. It is commonly used in civil construction and available for a number of applications, including as a grout and as a floor coating. …

Idea is that we could use epoxy grout and maybe coat beam bottoms or concrete with epoxy.