EDGES MEMO #388

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Telephone: 617-715-5533

To: EDGES Group

From: Alan E.E. Rogers

Subject: Ground plane designs for deployment of EDGES-3 in the tundra

Wire grid designs were proposed in memo 298 and studied by Ethan Blair in memo 308 and a wire grid was used in the test deployment of EDGES-3 in Oregon which is described in memo 310. Mesh and wire grid ground planes were compared in memo 378 and the wire grid was further optimized in memo 384. In this memo the wire grid is studied for a deployment of EDGES-3 in a location close to the Dalton highway north of the Brooks range about 50 miles south of Prudhoe Bay in Alaska. In order to avoid the snow this deployment would be made in August when the top layer of the soil is unfrozen down about 50 cm to the frozen permafrost below. This upper layer which is known as the "active layer" is a challenge for EDGES because reflections from the permafrost can degrade the beam chromaticity and produce frequency structure in the loss. If the layers are uniform and the ground plane is right on the active topsoil the attenuation in the active layer may be sufficient to limit the strength of the reflection. The attenuation is high because the high moisture content of the active layer raises the conductivity to about 2e-2 S/m. However it may not be possible to place the ground plane directly on the tundra in which case the ground plane may have to be on gravel which may not go all the way down to the permafrost in which case the effects of 3-layers layers need to be studied. In summary deployment of a ground plane in a region with layers below the ground plane presents an added challenge which requires careful study, modeling and checking with Ground Penetrating Radar (GPR).

Profiles of the dielectric constant and conductivity of the active layer were obtained by Kazem Bakian-Dogaheh *et al* (2022 *Environ. Res. Lett.* **17** 025011) in August 2018 at SGW-1 69.4778 -148.5647 which is on the tundra about 7 km from a potential site for EDGES-3 at 69.5426 -148.5938. An approximation of the results are in table 1 below

site	layer	dielectric	conductivity S/m	Depth m
SGW-1 Dogaheh et al. August 2018	active	20	2e-2	0.5
North slope survey Karen L. Hodel 1986	permafrost	7	1e-4	650
EDGES-3 69.5426 -148.5938 - estimated	gravel	10	5e-3	0.5 TBD
Esther Babcock's data taken at Nuiqsut	permafrost		3e-4	
" taken at Deadhorse	moist gravel	11-14	< 1e-2	
" taken at Kuparuk	dry gravel	7.5	< 1e-3	
Esther's estimate of the "active layer" of	thawed soil		~ 3e-3	0.3

Table 1. Layer parameters used in FEKO simulations of ground below wire grid

The estimates of the permafrost dielectric and conductivity come from Wong, J., J. R. Rossiter, G. R. Olhoeft, and D. W. Strangway. "Permafrost: electrical properties of the active layer measured in situ." *Canadian Journal of Earth Sciences* 14, no. 4 (1977): 582-586. These measurements were made at 100 MHz at Tuktoyaktuk, NWT. Measurements from Esther Babcock of Logic Geophysics & Analytics LLC were made in the summer of 2017 using GPR 100 to 1000 MHz.

Case eps S/m	loss %	loss rms mK	avrms mK	center MHz	amp K	width	rms1 mK	rms2
1 perm 20 2e-2	2.2	45	113	77.4	0.58	18.3	69	16
2 gravel 10 5e-3	1.8	21	106	77.4	0.63	19.2	66	11
3 perm 20 2e-2	2.2	45	89	77.7	0.57	21.4	47	22
4 gravel 10 5e-3	1.8	21	82	78.1	0.47	19.2	46	3
5 gravel 10 5e-3	2.0	194	156	77.4	0.57	18.0	70	23

Table 2. Simulations of data with Nature feature added to sky and processed without beam correction

Table 2 shows FEKO simulations using 24 1 hour blocks 5 physical terms 55-95 MHz 30x15m wire grid 282 pegs #18 wire gauge from Table 6 of memo 384 at azimuth 340 degrees. Nature feature is added with 0.5 K absorption centered at 78 MHz with width 19 MHz and tau = 7. The first entry is for the wire grid directly on the tundra with the permafrost 0.5 m below. The second entry is for the wire grid on a 0.5m layer of gravel which sits on the permafrost below. Both of these are modeled with 2-layers with the parameters in table 1. In cases 1 and 2 the data is simulated with beam from FEKO and is processed without beam or loss correction to be sure that a good result can be obtained without knowledge of the layers. Cases 3 and 4 include the effects of the loss in the simulated data. Case 5 is for gravel on the active layer for which the frequency structure of the loss is so high that the added feature cannot be detected when the effects of the loss are added to the simulated data in case 6.

Case eps20 S/m	loss %	loss rms mK	avrms mK	center MHz	amp K	width	rms1 mK	rms2
6 gravel 1e-2	2.2	123	143	78.9	1.64	27.2	109	41
7 gravel 2e-2	2.0	36	88	78.1	0.47	18.0	57	17
8 gravel 5e-2	2.0	8	71	78.1	0.54	18.8	57	4

Table 3. Simulations of gravel with dielectric 20 of depth 0.5m over an layer active layer with dielectric 20 and 2e-2 S/m conductivity for the values of conductivity indicated.

The simulations in table 3 which include the effects of frequency structure in the loss show that a gravel conductivity of 2e-2 is needed to obtain a reliable verification of the Nature absorption parameters without correction of the loss and beam chromaticity. Accurate beam and loss correction may be difficult to accomplish with a ground plane on the type of layered ground present in the arctic even with GPR data given the changes with moisture and non-uniformity of the layers. If gravel of sufficient conductivity is not available a proposed solution is to ensure a high conductivity under the ground plane by treating the gravel with calcium chloride out to several meters beyond the edges of the ground plane. The conductivity of an aqueous solution of calcium chloride or sodium chloride is about 1 S/m at a volume concentration of 1%. Another possible solution is to cover the gravel with electrically conductive silicone sheeting which has a conductivity of 24 S/m and comes in thickness 1.6 to 6.4 mm. The cost of 1.6 mm is about $200/sqm or about 90 k$ for 30x15m.

Case	loss %	loss rms	avrms	center MHz	amp K	width	rms1 mK	rms2
9 Infinite 1.6mm 24 S/m	4.2	11	44	78.1	0.47	19.7	43	7
10 10x5m 20x10m 3.125	1.8	10	130	77.7	0.63	19.4	61	11
11 10x5m 20x10m 6.25	2.4	7	132	78.1	0.62	19.6	58	11

Table 4. Simulations of added conductivity underground plane

In case 9 which is case 6 with an added layer 1.6 mm thick layer with 24 S/m below the ground to the layers using the GF method. Since this is an infinite layer it is an overestimate of the achievable improvement. Case 10 is a 10x5m 3.125 cm wire grid with 20x10m layer of electrically conductive silicone sheeting 24 S/m 1.6 mm thick on the ground under the wire grid. Case 11 is the same as case 10 but with 6.25 cm wire spacing.

Simulations show that while the conductive silicone sheeting needs to extend out to twice the size of the wire grid the sheeting only needs to extend under the wire grid for about 2m from the edges in order to achieve capacitive coupling. A direct connection between the wire grid and the conductive sheeting is not practical as slot resonances can easily be produced and this is a potential issue with close capacitive coupling.

Case diel S/m	loss %	loss rms	avrms	center MHz	amp K	width	rms1 mK	rms2
12 10x5m 5 1e-3	1.9	17	150	78.5	0.59	19.3	61	21
13 10x5m 5 1e-4	1.9	22	155	78.5	0.62	19.6	61	23
14 30x15m 5 1e-3	1.5	20	160	78.1	0.63	18.3	72	13
15 30x15m 5 1e-4	1.5	26	168	78.1	0.64	18.2	74	14
16 30x15m 5 1e-5	1.5	26	168	78.1	0.63	18.2	73	14
17 30x15m 35 1e-1	2.5	39	74	78.1	0.61	18.3	71	19
18 30x30m 35 1e-1	0.3	79	103	77.7	0.75	17.4	102	35
19 30x30m 5 1e-5	0.4	26	108	78.5	0.60	19.8	56	16
20 30x30m 10 1e-3	0.4	15	70	78.1	0.56	19.3	55	11

Table 5. Comparison of 10x5m wire grid (6.25cm wire spacing) extended to 30x15m with conductive sheeting, cases 12 and 13, with 30x15m wire grids, cases 14, 15, 16 and 17, and 30x30m mesh with perforated edges as at the MRO in cases 18, 19 and 20.

Table 5 shows that using conductive sheeting to extend the ground plane size of 10x5m by a factor of 3 to 30x15m results in very similar overall performance to the performance of the 30x15m wire grid without conductive sheeting.

For better performance higher conducting sheeting might improve performance. Using the plane wave propagation formula

$$\alpha = real\sqrt{(i\omega\mu(\sigma + i\omega\epsilon))}$$

with α = attenuation constant
i = sqrt(-1)
ω = frequency in radians/s
μ = permeability in units of 1.25663706e-6
σ = conductivity in S/m
ε = permitivity in units of 8.85418782e-12

Using this analytic formula 24 S/m produces an attenuation of about 3 dB at 100 MHz for a thickness of 1.6mm. However the performance of the 30x15m wire grid without absorber is about the same as the 10x5m wire grid with absorber. The advantage of an absorber would arise if the space for a ground plane is very limited.

The use of electrically conductive sheeting to improve the antenna beam is described in “Electro-Textile Ground Planes for Multipath and Interference Mitigation in GNSS Antennas Covering 1.1 to 1.6 GHz” by B. Rama Rao and E. N. Rosario of MITRE corporation. Figure 8 in this paper shows an EDO antenna on a conductive ground plane with edges of resistive textile. The 7” conductive square is increased to a 14” square. Scaled to from 1.6 GHz down to 50 MHz 14” becomes about 11m. The concept of resistive edge loading goes back to Rose Waikuen Wang. "Reduction of the edge diffraction of a circular ground plane by using resistive edge loading." PhD dissertation, University of Michigan, 1985.

Estimates of the electrical conductivity of concrete covers a range of about 0.03 to 0.8 S/m with dielectric constant from 5 to 10 from chapter on “Measurement of RF Propagation into Concrete Structures over the Frequency Range 100 MHz to 3GHz” by Clayborne D. Taylor, Samuel J. Gutierrez, Steven L. Langdon, Kenneth L. Murphy, William A. Walton in “Wireless Personal Communications” by Jeffrey H. Reed, Theodore S. Rappaport and Brian D. Woerner 1997. However there are many variables in concrete which raise the concern that if a concrete pad is considered for an EDGES antenna it should be checked using ground penetrating radar (GPR). It may be necessary to lay electrically conductive sheeting for a significant distance TBD beyond the edges of the ground plane to prevent beam and loss chromaticity if the layer under the ground wires or mesh has insufficient conductivity to suppress reflections from a layer below. For example runways typically have a rebar rods about 10 inches below the surface.

In summary the best solution for deployment in the arctic would be to either deploy on the active layer or on gravel whose conductivity has been enhanced using calcium chloride. In the ideal case the gravel would go down to the permafrost which may be the case at the TAPS access road 129 APL/AMS-1 off the Dalton highway at 69.5426 -148.5938. For a deployment on concrete like that at an old unused runway a large welded mesh ground plane might be needed to provide enough isolation from reflections from underlying highly conductive material like rebar which may be present about 0.5m below the surface.