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To: EDGES Group

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Subject: Simulations of the effects of scattering on the shape and frequency dependence of the beam

The residuals to EDGES data show features at certain Galactic Hour Angles (GHA) that are different for different antenna configurations. For example, in the top two plots in Figure 4 of memo 335 the residuals of low2 and low2-45 with 5-terms removed are compared and show few similarities. Memos 336, 337 and 338 look at a range of systematic errors and conclude that a tilted and uneven ground plane is contributing to the residuals. Memos 339 through 345 continue to look at other structures including brush and trees close to the edges of the ground plane. Memo 340 points out that scatter from structures effectively acts like an "adding" interferometer. In this memo the effects of the scatter on the beam are examined in more detail.

Simulations of a lowband blade antenna on an infinite PEC ground plane on which 3 cubic structures 0.7x0.7x1.7m with dielectric 5.0 and conductivity 3e-1 S/m are placed on the ground plane 20m from the antenna. Table 1 shows the average residual obtained for 24 1 hour blocks over all GHA. An antenna azimuth 90 degrees at the MRO with infinite PEC instead of the 30x30m shown in Figure 2 was used.

case	rms using 4 terms	rms using 5 terms	rms using 6 terms
Full scale antenna without dielectric	349	48	4
Full scale antenna with dielectric	351	52	14
Half scale antenna without dielectric	3	1	0.5
Half scale antenna with dielectric	18	14	11
Full scale ant. with diel. and beamcor.	20	15	12

Table 1. Average rms of 1 hour blocks in mK using LINLOG terms 60 – 100 MHz

Table 1 shows that the large scale frequency structure in the antenna for the lowband antenna is mostly the result of the antenna itself while the small scale frequency structure, which is limiting the accuracy of the absorption measurement, is due to scattering and has a similar amplitude in the full scale antenna and the half scale antenna which is electrically small over the 60 – 100 MHz frequency range. This is confirmed by the last entry which shows that the full scale antenna gives rms values close to the electrically small antenna when the beam correction using the beam without the scattering dielectric is applied.

Figure 1 shows the rms residuals vs GHA for the last two entries of Table 1 for 5-terms removed which shows that while the electrically small antenna has a frequency independent beam on an infinite PEC ground plane the beam becomes highly frequency dependent in the presence of the scattering material shown in Figure 2.

Figure 3 shows the difference of the lowband beam patterns with scattering material and without scattering material. The difference for 68 MHz is on the left and 78 MHz is on the right. Note how the "fringe" spacing is closer at 78 MHz compared with 68 MHz. The term "fringe" is used because the scatter effectively makes the single antenna into an interferometer with unknown response since it will be difficult to incorporate all the scattering objects into FEKO with any certainty. Further while drone measurements should be explored note that the spatial and frequency dependence due to the scatter is at a level of 0.02 dB of antenna gain over an isotropic antenna.

case	rms using 4 terms	rms using 5 terms	rms using 6 terms
Without dielectric	53	6	1
With dielectric	60	17	13

Table 2. rms residuals in mK for "fullscale" lowband antenna simulated with 45 and 408 MHz map using beam correction with Haslam 408 MHz map.

Table 2 shows rms residuals of spectra simulated using a map which combines the 45 MHz map of Guzman and the 408 MHz Haslam maps to obtain a map with spectral index from the 2 maps and then applying a beam correction using only the Haslam map. This shows that when the scattering is included low residuals cannot be obtained because the scatter introduces effects that are very sensitive to the accuracy of the maps on a fine frequency and angular scale. The scatter results in an antenna with fine structure in both angle and frequency as illustrated in Figure 3 which limits the accuracy that can be achieved using calibrated and beam corrected data.

case	rms using 4 terms	rms using 5 terms	rms using 6 terms
Full scale ant. with beam correction	20	15	12

Table 3. rms residuals in mK for lowband blade on 30x30m ground plane and dielectric cubes with beam correction using beam from simulation without scatterers.

The results when the 30x30m ground plane is included are almost the same as last entry of Table 1 for which an infinite PEC ground was used. This was done using the "reflection ground" method to avoid the limited accuracy in the MoM calculations of the Sommerfeld integrals used when using the Green's function for a soil ground under the ground plane discussed in memo 277. A dielectric of 3.5 and conductivity of 2e-2 S/m was used for the soil.

In summary simulations show that the antenna, ground plane and the surroundings form an antenna with a beam which has structure in angle and frequency which limits the accuracy of the extraction of the 21-cm absorption.

A solution consistent with simulations suggested in memo 344 is to use a flat horizontal ground plane larger than about 48x48m with objects up to about 100m from the antenna removed if EM simulations show they will result in significant scatter to degrade residuals. The simulations show that better knowledge of the sky will not lower the residuals if significant scatter is present so the scatter needs to be reduced.

If a vertically polarized antenna or an antenna with a vertically polarized component is used an even larger area of ground plane and its surroundings free of scattering objects are needed as discussed in memos 317 and 323.

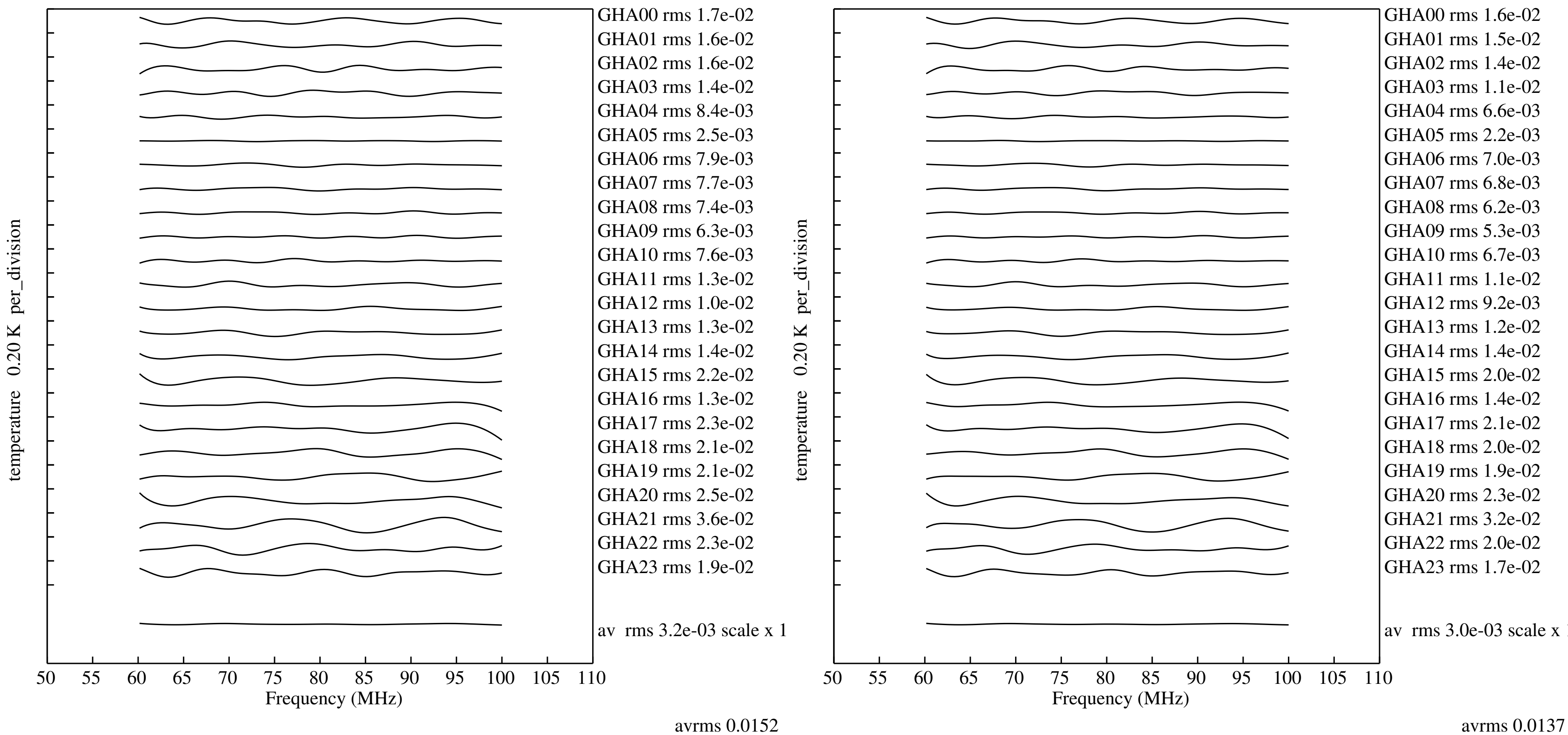

Figure 1. rms residuals vs GHA with 5-terms removed for lowband blade antenna on PEC ground plane with dielectric scattering material using beam correction without scattering material. The plot on the left is for the full scale antenna compared with rms residuals for a half scale blade antenna on the right.

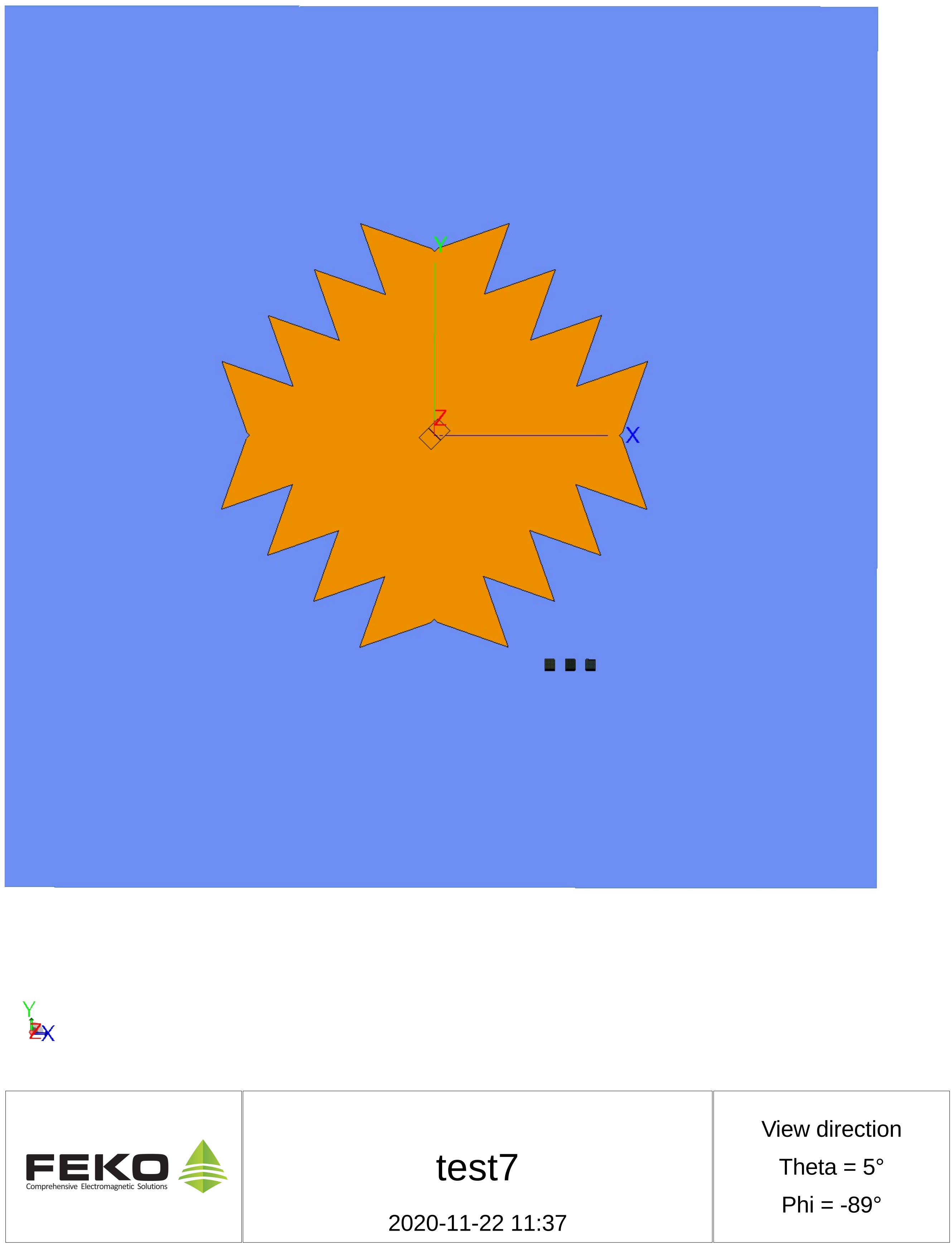

Figure 2. Location of scattering material relative to the lowband antenna from FEKO. The 30x30m ground plane is also shown but was replaced with a PEC ground plane for the simulations in Table 1.

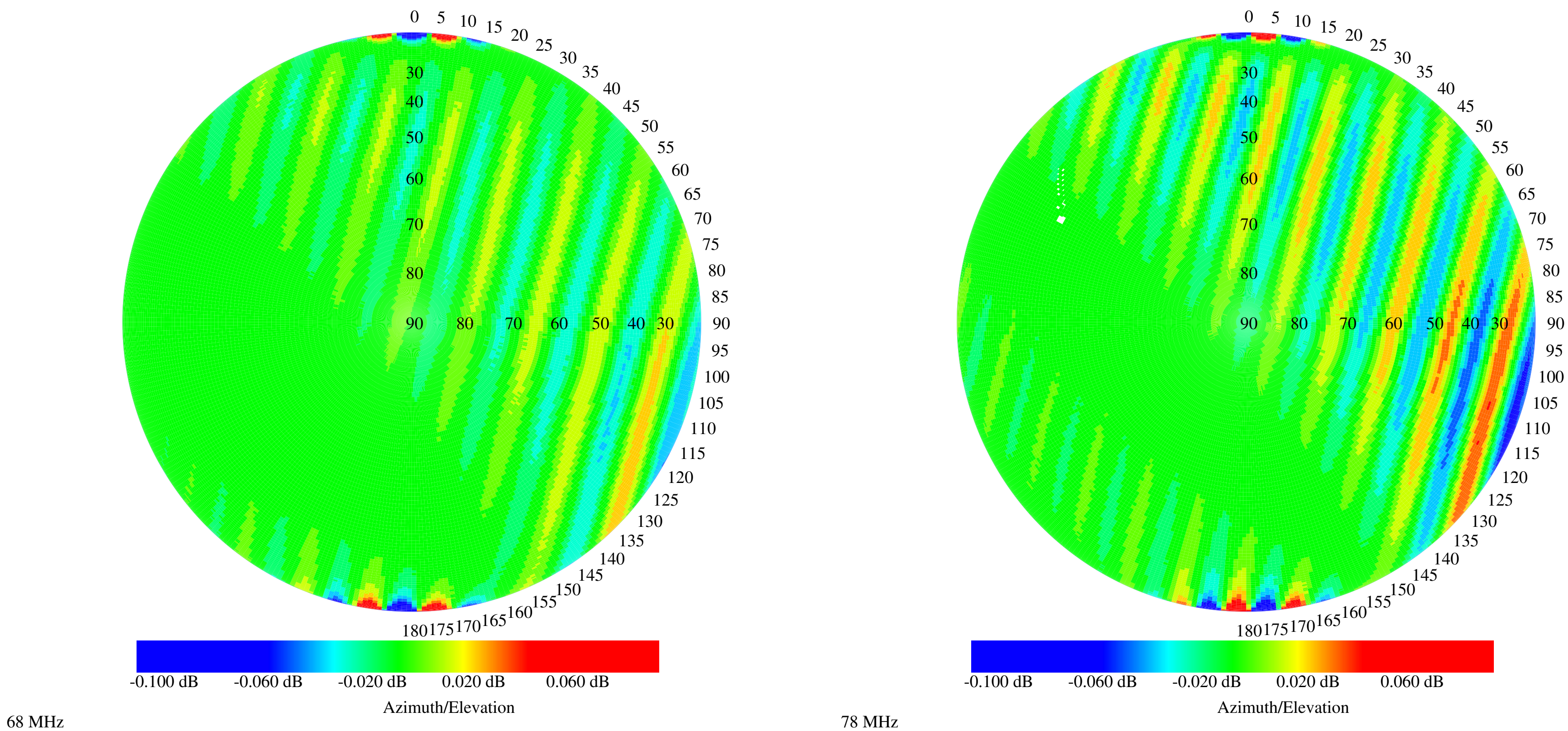

Figure 3. The difference of the lowband beam patterns with scattering material and without scattering material. The difference for 68 MHz is on the left and 78 MHz is on the right. Note how the fringe spacing is closer at 78 MHz compared with the spacing at 68 MHz due to the changing phase of delay in the scattered signal.