EDGES MEMO #186

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To: EDGES Group
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Subject: Contribution of the ground plane to antenna beam chromaticity

A critical factor in the measurement of the global 21-cm signature is the frequency dependence of the antenna beam also known as the "beam chromaticity." This has been studied and is reported in memos 5, 7, 71, 118, 140, 141, 142, 150, 151, 153, 155, 163, 170, 184 and 185. While the effect of the ground plane on the antenna loss has been well studied the added beam chromaticity due to a finite ground plane has only recently been studied largely driven by attempts to understand the low frequency end of the low band. A more general study of the ground plane effects on beam chromaticity using the GF/Sommerfeld method in FEKO show the following:

1] The beam chromaticity increases with ground plane size, reaches a peak at about 5m × 5m for low band (50-100 MHz) and then decreases by about a factor of 2 at 10m × 10m. Beyond this the chromaticity decreases by a factor of about 4 for each doubling of the ground plane size.
2] The chromaticity decreases by a factor of about 4 if the relative permittivity of the Earth increases from 3.5 to 13.0.
3] The chromaticity which results from a finite sized ground plane is not strongly dependent on antenna type (i.e. blade vs Fourpoint or dipole.)
4] For a square ground plane the level of chromaticity is not changed significantly by the orientation of the ground plane relative to the antenna.

These general dependencies are derived from the test results given in table 1. The residuals are to a fit of 5 physical functions which represent scale, spectral index, spectral curvature, ionospheric emission and absorption.

Ground plane size	ε_r	Galaxy Up mK	Galaxy Dn mK	Antenna
Infinite	-	355	70	Blade
20m × 20m	3.5	480	45	Blade
10m × 10m	13.0	460	27	Blade
10m × 10m	3.5	1330	138	Blade
10m × 10m	1.0	1771	291	Blade
10m × 10m	4.5	941	96	Blade
10m × 10m	3.5	1193	176	Rotated
5m × 5m	3.5	2850	300	Blade
2.5m × 2.5m	3.5	878	141	Blade
10m × 10m	3.5	1610	200	Dipole
Infinite	-	130	5	Dipole
None	3.5	123	20	Blade

Table 1. rms residuals of beam chromaticity 5-physical terms 51-95 MHz.

The low dielectric constant of the dry sandy soil (ref 1.) at the MRO is the key factor in the significant additional chromaticity of the ground plane. The added chromaticity could be made insignificant by increasing the size of the ground planes to 20m × 20m and 10m × 10m for the low and high band antennas. This size equals 5 × 5 wavelengths at the center of each band. For comparison the 5-term residuals for estimates of other sources of error are given in table 2 for low band.

Galaxy Up mK	Galaxy Dn mK	Source
63	15	Balun loss
11	3.6	Antenna S11 error
62	10	Foreground
36	12	calibration

Table 2. Other error sources with 5-term residuals for 51-95 MHz.

The S11 error is obtained from the difference between antenna measurements on day 2015_342 with those on day 2015_289 so it is only a measurement of repeatability and hence it may be optimistic. The estimate for the foreground is the difference between computing the beam correction for an infinite ground plane using the Haslam sky model with constant spectral index and a sky model which includes spectra index and spectral curvature as well as a correction for the North Polar Spur (NPS) given in memo #160.

The estimated calibration error is fairly conservatively estimated using an offset in LNA S11 of 30ps and 0.5 dB. In addition to the significant chromaticity of the current low band ground plane the chromaticity of the loss is also a concern because of the high foreground temperatures.

References:

1. Sutinjo, A. T., Colegate, T. M., Wayth, R. B., Hall, P. J., de Lera Acedo, E., Booler, T., Faulkner, A. J., Feng, L., Hurley-Walker, N., Juswardy, B., Padhi, S. K., Razavi-Ghods, N., Sokolowski, M., Tingay, S. J., & Bij de Vaate, J. G. "Characterization of a Low-Frequency Radio Astronomy Prototype Array in Western Australia," ITAP, 63, 5433-5442, (2015). Doi: 10.1109/TAP.2015.2487504.