EDGES MEMO #142

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Telephone: 781-981-5400
Fax: 781-981-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: Low order fits to the effect of antenna beam change

The recent deployment of EDGES with the LNA box above the ground plane has prompted a more detailed study of the effects of the frequency dependence of the antenna beam. In memo 7 the frequency dependence of a dipole was shown to require a 7 term polynomial to reduce the effect on the residuals to below 1 mK. While EDGES-1 used a polynomial basis function EDGES-2 hopes to reduce the number of parameters in the weighted least squares fit to functions which are more closely related to the sources of systematic error. In addition it may be possible to model these sources of error well enough to be able to limit the number of parameters to 5 or less. Hence a re-examination of the effects of the frequency dependence of the antenna beam is useful.

Table 1 shows the results of simulation run for frequency range 110 to 190 MHz for various antennas at 10 hours before transit of the Galactic center at Boolardy WA. FEKO patterns were used for the Fourpoint and Fat dipole and analytic expressions for the isotropic and ½ wave dipole. The basis functions were scale (of spectral index, beta = -2.5), delta spectral index, ionosphere absorption ionosphere emission, a constant, and spectral curvature (gamma) introduced in that order. The spatial variation was obtained from the Haslam 408 MHz map scaled to the frequency with a constant spectral index of -2.5. The case of spatial plus frequency variation was taken as the Haslam map scaled with a spectral index which depends on Galactic latitude and longitude using the expression given in memo 7. The residuals at 5 terms, except for the case of the Fourpoint with box are small enough to allow EoR detection of a 20 mK Gaussian of width less than 10 MHz assuming no other significant sources of error. Introducing another basis function to bring the systematic rms below 1 mK might allow detection of a 20 mK Gaussian with width up to 15 MHz but the detectability degrades very fast for widths of more than 15 MHz unless the rms residuals due to the systematic errors can be reduced to about 1 mK for 5 or less terms needed for the systematics. Averaging over hour angles with the Galaxy center below the horizon helps but modeling of the beam has a greater potential. An indication of the potential is the comparison of antenna pattern corrections made using different EM modeling software and difference assumptions of spatial distribution of spectral index. Simulations show that if the true beam correction can be fit to within a few mK with a polynomial of no more than 5 terms there is little advantage as the beam correction will be “soaked-up” in the basis functions needed to account for the foreground. If there is real frequency structure in the beam correction which cannot be fit within about 1 mK with a 5 term polynomial then it has to be accurately modeled with EM simulation to within a few mK to avoid being a fundamental limit to the detection of a 20 mK EoR signature with more than 20 MHz width.

In summary the smoothness of the corrected beam, foreground and corrected instrument needs to be at the level of about 3 mK or lower after fitting with no more than 5 basis functions. Various tests made with different basis functions show that there is little difference made by a particular choice of $(\log f)^n f^{-2.5}$, $f^n f^{-2.5}$ or the scale, spectral index, ionosphere absolution ionosphere emission plus constant used simulations of Table 1. It is also found that it makes little difference whether a fit is made to the spectrum or the log of the calibrated spectrum. In all cases the calibrated spectrum, with beam correction modeling if required, needs to be well fit at the level of a few mK with no more than 5 functions to reach a level of EoR detectability for width greater than about 20 MHz.

		rms residual to fit vs # of terms mK					
Antenna	Sky	1	2	3	4	5	6
Isotropic	Spatial variations	0	0	0	0	0	0
Isotropic	Spatial + frequency variations	1000	200	42	3	0	0
Fourpoint	Spatial variations	1400	400	150	33	4	1
Fourpoint	Spatial + frequency variations	350	220	110	29	4	1
½ wave dipole	Spatial variations	930	210	57	7	1	0
½ wave dipole	Spatial + frequency variations	2000	450	110	11	1	0
Fat dipole	Spatial variations	3000	650	170	22	2	1
Fat dipole	Spatial + frequency variations	4000	910	230	27	2	1
Fourpoint with box	Spatial variations	900	350	200	100	75	74
Fourpoint with box	Spatial + frequency variations	220	180	150	80	56	55

Table 1. Residuals of corrections for frequency dependence of beam to lower order basis function fit as a function of the number of terms.