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To: EDGES Group

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Subject: General trends in antenna design for constant beam.

The goal of obtaining an EDGES antenna with minimum frequency dependence of the beam was first discussed in Memo #7. It was noted in memo #71 that the rms residuals when the Galaxy is "down" were at the level of 80 mK following the removal of 4 terms but could be dropped to 1 mK by lowering the antenna by a factor of 2. An optimization of the "fourpoint" dipole was carried out and the results given in memo 69. An estimate of the effect of the change of beam with frequency of about 10 mK at 6 hours LST is given in memo 70. A more complete examination of the beam effects was given in memo 118 at which time it was realized that the frequency dependence of the beam is a major limitation especially if observations during the LST range when the Galactic center transits are used to aid in calibration as described in memos 48 and 145. A further examination of the effects of the frequency dependence of the EDGES beam is given in memo 151 and compared with the "blade" antenna as an alternate design to replace the Fourpoint. Some variations of the blade were tested and are listed in table 1. In general a horizontal planar structure is better than a structure with vertical component unless the antenna is over an absorbing ground screen. For example a biconical antenna, which is normally conserved a good choice for a wideband S11 and constant beam, is not a good choice when over a reflecting ground screen. A conical antenna over a reflecting ground has a constant beam and good S11 over a wide bandwidth but has a maximum gain at the horizon which increases the RFI, ground noise pickup and amplifies the frequency dependent effects of the refraction by the ionosphere at the horizon.

	General trend		
Variation examined	Beam	S11	Comments
Tilt the panel up	D	N	Also degrades horizon response
Tilt the panel down	D	N	Also degrades horizon response
Make panels into bowtie	I	D	
Make panels with triangular tips	D	D	
Lower antenna	I	D	0.52 m best for high band
Increase the length to width ratio	I	D	Best ratio ~1.6
Decrease the length to width ratio	D	I	

Table 1 General trends of the effects of the shape of the blade antenna. D= degraded, I = improved N = no effect.

So far the combination of the lowest residuals to a low order polynomial fit to the beam convolved with the sky noise and an acceptably lower S11 or less -15 dB over a 1.8:1 frequency range is achieved by the “blade” antenna with full length to width ratio of about 1.6:1 described in memo 154. However, at this time not every horizontal planar structure has been tried. By symmetry any such structure can be defined in the first quadrant and simply mirrored about X and Y into the other quadrants. Changing the rectangle of the current best version towards the shape of a bowtie has the greatest promise. In this case the antenna impedance is which results in a poor S11. This might be corrected using a higher impedance balun to act as a transformer.

Measure of comparison for EoR detection

For comparison of antennas a measure of comparison is the rms residual and average magnitude EoR bias to a weighted least squares fit from 100 to 190 MHz to a 5 term polynomial of the $(f/150)^{-2.5+i}$ $i = 0$ to 4, and a Gaussian centered at 150 MHz of 30 MHz full width at half power.

Antenna	rms (mK)	EoR_bias (mK)
Dipole	0.1 (0.5)	0.9 (3.7)
Blade	0.9 (2.2)	16 (30)
Fourpoint	2.1 (5.4)	18 (42)

Table 2. Rms residual and EoR bias to 5 term polynomial fit

The results above are for an average over a LST range more than 8 hours away transit of the Galactic center. The number in ( ) are for an estimate of the EoR using Galaxy “updown” method.

$$EoR(f) = \left(Sd(f)Su(150) - Su(f)Sd(150)\right) / \left(Su(150) - Sd(150)\right)$$

Where $Su(f)$ is the convolution of the antenna beam with the sky 12 hours from $Sd(f)$.

For a 6-term polynomial plus an EoR Gaussian of 30 MHz width.

Antenna	rms (mK)	EoR_bias (mK)
Dipole	0.08 (0.4)	0.4 (1.9)
Blade	0.3 (1.1)	0.3 (2.5)
Fourpoint	1.8 (4.5)	2.9 (14)

Table 3. Rms residual and EoR bias to 6 term polynomial fit.

The results in Table 3 show the advantage of the blade over the Fourpoint more clearly however the square root of the covariance for the EoR determination is increased from 3.3 to 8.5 in going from a 5 term polynomial to a 6 term polynomial so that about 60 days of data at 8 hours per day would be required to reduce the noise in order to reach a 10 sigma detection of 20 mK assuming no additional systematic error. The Galaxy “updown” method requires twice the integration due to increased noise. Increasing the EoR width to 40 MHz increases the square root of covariance to 6.1 and 25.3 respectively. Tables 2 and 3 were derived using the Haslam map with constant spectral index of -2.5. The numbers increase by about 20% when a map with variations in spectral index is used.