EDGES MEMO #169

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Subject: Limits of EoR signature detection imposed by systematics

Using the weighted difference between nighttime with Galaxy “down’ and the Galaxy “up” reduces the systematic errors due to imperfect calibration and antenna S11 measurements but it does not help reduce the errors due to frequency dependence of the beam. The method also fails to remove errors in the estimate of the emission which results from the antenna, balun loss and other losses in the signal path to the reference plane.

In this memo we evaluate the effects of frequency dependence of the beam, antenna and balun loss uncertainty and VNA bias on the detectability of a Gaussian EoR signature of 20 MHz full half power width centered at 150 MHz based data from days 2015-108 through 2015-119. This range of data is chosen because it is free of the resonance at 175 MHz and is without rain.

In order to evaluate the sensitivity to systematic error the following procedure is used

1] The calibrated spectra for an average of up to 8 hours per day as long as the Sun is 5 degrees below the horizon are obtained for GHA – 9 hr (Galaxy down) and for GHA – 1 hr (Galaxy up).

2] The spectral difference Sdiff is computed using equation 2 of memo #145.

3] The best fit of the 5 function given in memo #167 plus a 20 MHz EoR signature are removed from Sdiff

4] The strength of the EoR signature and its SNR are calculated.

5] The fitting algorithm is checked by adding an EoR signature of 1 K and the measured signature is seen to increase by 1K.

6] A “Test” perturbations are then made to key instrumental parameters.

		100-190 MHz			110-185 MHz				
Test	dn	Up	4	5	4	5	EoR mK	SNR	delta
Std.	207	485	24	23	19	16	94	8	0
A	195	594	295	55	146	24	199	16	105
B	206	518	45	24	28	16	78	7	-16
C	345	853	47	36	36	20	153	13	59
D 0.2	270	534	38	26	23	20	161	15	67
D -0.2	170	500	56	35	37	19	29	2	-65
E 20ps	274	507	38	34	33	22	185	17	91
E -20ps	296	690	23	23	16	15	2	0	-92

Table 1 Effects of test perturbations.

dn	rms residual in mK to 4 term poly fit to Galaxy down
Up	rms residual in mK to 4 term poly fit to Galaxy up
4	rms residual in mK to 4 term fit to Sdiff 100-190 MHz
5	rms residual in mK to 5 term fit to Sdiff 100-190 MHz
4	rms residual in mK to 4 term fit to Sdiff 110-185 MHz
5	rms residual in mK to 5 term fit to Sdiff 110-185 MHz
EoR	EoR signature from 5 function + EoR
SNR	SNR based on weighted least squares covariance matrix and rms of residuals to fit.

Table 2. Description of columns.

Std	Processing using best knowledge of EDGES system
A	Without correction for beam from FEKO simulation
B	Beam correction without sky map spectral index adjustment for Galactic plane
C	Assuming zero loss for antenna plus balun
D	Added 0.2 and -0.2 dB to antenna S11
E	Added 20 and -20 ps to antenna S11

Table 3. Description of tests

Conclusions

Based on the change of EoR signature solution the most significant systematics are bias in the phase of the antenna S11 and a lack of knowledge of the frequency dependence of the antenna beam. Less significant are a bias in the S11 magnitude and correction for the antenna and balun loss. The bias in the VNA measurement is expected to be well under 0.05 dB and 0.1 degrees (2 ps at 150 MHz) but changes in the antenna are likely to be the major source of S11 error. The current Fourpoint antenna has significant beam variation with frequency and is sensitive to a change of S11 when it rains or moisture condenses on the quartz dielectric spacers between the panels. It is also “tuned” with additional quartz capacitors at the “top plate” connection and on the balun. These help obtain a broad S11 bandwidth but also lead to greater environmental sensitivity. A simpler and potentially better antenna for EDGES known as the “blade” antenna described in memo 154. The blade antenna has less variation of the beam with frequency, a smoother S11 with smaller delay and is expected to be more stable.

Some comments on sensitivity to S11 phase:

In the high band most of the sensitivity to phase comes from the reflected LNA noise waves due to a change in the ϕ in equation (8) of Rogers and Bowman 2012. In the low band the sky noise is much higher and a change in the phase of $\Gamma_a \Gamma_\ell$ in equation (4) dominates. The minimum change of phase delay, $\Delta\Gamma$, of any antenna is approximately given by

$$\Delta\tau \approx \tau_a d$$

Where τ_a is the antenna delay (~18 ns for the high band Fourpoint and 14 ns for the high band blade) and d is the fractional dimension or refractivity change. For example 20 K change in temperature with a 20 ppm/K coefficient of expansion and a 100% change in humidity at 38 C result in 400 ppm and 250 ppm in d corresponding to about 6 and 3 ps for the high band blade antenna respectively. Some day to day variation in the spectra over the longer period to day148 which are correlated with rain. For example rain on days 123, 136 and 137 make substantial changes but this is also a hint of smaller changes which are associated with high humidity. For example changes on day 112 may be associated with condensation on the antenna on nights with high humidity. If condensation is occurring it could be the result of excessive panel cooling due to the presence of the Goldstone #6 paint. Tests will be made on the blade prototype. The high band EDGES system could be improved by using a cryogenically cooled LNA or other methods for reducing the correlated noise waves to below the current value of about 20 K. A lower antenna S11 would also help but both the Fourpoint and the blade are limited to about -15 dB.