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Subject: Tests of the sensitivity of low band to systematics

To test the sensitivity of low band to balun loss, ground loss, S11 bias, calibration and other processing parameters data was simulated with one set of parameters and processed with another. Residuals to a 5-term polynomial fit from 51 to 97 MHz and a 4-term physical parameter fit from 61 to 97 MHz used to measure the significance of the changed parameters. Residuals for the maximum (normally close to GHA=0) and the minimum (normally close to GHA=$12^h$) are given in Table 1.

| | 5-term 51-97 | | 4-term 61-97 | | |
|---|---|---|---|---|---|
| Parameter change | max mK | min mK | max mK | min mK | Note |
| No balun loss | 680 | 240 | 270 | 76 | |
| No ground loss | 9 | 6 | 39 | 10 | |
| Ant. S11 + 30ps | 51 | 19 | 6 | 6 | |
| Ant. S11 +0.1 dB | 550 | 190 | 77 | 21 | |
| Ant. S11 342-289 | 32 | 11 | 13 | 4 | 1 |
| Calibration wfit 5-3 | 33 | 33 | 23 | 23 | 2 |
| Calibration wfit 5-4 | 9 | 9 | 8 | 8 | |
| Calibration nfit3 11-7 | 14 | 5 | 5 | 2 | 7 |
| LNA S11 +30 ps | 44 | 15 | 4 | 0 | |
| LNA S11 +0.1 dB | 53 | 18 | 14 | 5 | |
| Ant. S11 nfit4 9-10 | 18 | 6 | 14 | 5 | 3 |
| Ant. S11 nfit4 9-8 | 70 | 23 | 44 | 15 | |
| Beam infinite to plus | 63 | 11 | 124 | 7 | 4 |
| Beam infinite to 10×10 m | 1100 | 110 | 1520 | 160 | 5 |
| Beam infinite to circ | 62 | 11 | 24 | 7 | 6 |

Table 1. Sensitivity of low band to parameter changes

Note: 1. Change of antenna S11 measurement from 2015_342 to 2015_289.

2. 5-term poly to 3-term poly fit to noise waves.

3. 9-term poly to 10-term poly fit to antenna S11.

4. “Plus” is 5×20×20 m ground plane.
5. Current 10×10 m ground plane.
6. Circular ground plane of 50.4 m diameter which is same area as “Plus”.
7. 11-term polynomial fit to LNA S11 to 7-term polynomial.

From Table 1 it is clear that the largest source of error at low band is the beam correction for the 10×10 m ground plane. While the balun correction is also large it should only be in error by no more than 10 percent whereas the beam correction is very uncertain as it depends on the condition of the soil.

While the ultimate solution is a much larger ground plane Table 2 shows the sensitivity of the beam correction to the ground characteristics, ground plane size, and Foreground. A circular or “Plus” shaped ground plane is better than a square ground plane of the same area.

| | 5-term 51-97 | | 4-term 61-97 | | |
|---|---|---|---|---|---|
| Parameter change | max mK | min mK | max mK | min mK | Notes |
| *gf* 2.45- *gf* 2.35 | 1088 | 55 | 406 | 21 | |
| $\Delta\ \varepsilon = 0.5$ | 490 | 41 | 336 | 25 | 1 |
| $\sigma = 0.1 \rightarrow 0.01$ | 435 | 52 | 688 | 76 | 2 |
| Correct for Galaxy | 140 | 36 | 81 | 21 | 3 |
| Beam fit 22-9 | 470 | 29 | 286 | 12 | 4 |
| Azimuth $-6 \rightarrow 0$ | 143 | 13 | 120 | 14 | 5 |
| Full model with balun | 96 | 8 | 73 | 2 | 6 |
| HEALPix | 57 | 5 | 43 | 3 | 7 |
| *gf* 2.45 – no beam | 1770 | 130 | 856 | 21 | |
| Plus – no beam | 48 | 13 | 789 | 75 | 8 |
| Infinite – no beam | 35 | 9 | 815 | 50 | |

Table 2 Sensitivity to beam correction parameters.

Notes:
1. Difference in soil dielectric 3.5 to 4.0.
2. Difference in soil conductivity 0.1 to 0.01.
3. Spectral index -2.5 for $|glat| < 10$ to -2.57 elsewhere.
4. Beam fit with 22 term Fourier series to 9 term polynomial.
5. Change in antenna azimuth of 6 degrees.
6. FEKO model with and without balun and shield.
7. Change to updated Haslam map using “HEALPix.”
8. “Plus” is 5×20×20 m ground plane.

Detectability of EoR signature

In the low band redshifted hydrogen is expected to be in absorption. Consider an absorption of Gaussian shape centered at 85 MHz with half power full width of 15 MHz and peak absorption of 100 mK. Table 3 shows the weighted least squares solution amplitude and SNR for this signature which has been added in the simulation where the standard deviation is obtained from the rms of the post fit residual. The deviation from 100 mK shows the bias. For example a value of zero would correspond to a non-detection owing to a 100 mK bias in the contribution of systematics. A value of -100 mK would correspond to a bias of 200 mK. A value in the range of 70 to 125 mK along with an SNR>6 indicates the potential for a significant detection. In all cases 10 mK noise has also been added.

| Systematic | EoR amp mK | SNR |
|---|---|---|
| 10 ps bias in ant. S11 | 95 | 7.05 |
| 0.02 dB bias in ant. S11 | 126 | 9.14 |
| Ant. S11 342-289 | 93 | 6.94 |
| Ant. S11 smooth 9-10 | 63 | 4.5 |
| No beam corr with infinite ground plane | 115 | 8.6 |
| No beam corr with large ground plane | 158 | 9.8 |

Table 3. Simulated EoR solution with selected systematics. In all cases a 5-term polynomial plus an EoR Gaussian with 15 MHz width centered at 85 MHz are used as functions in weighted least squares.

Table 4 shows the change of SNR for change number of terms in the polynomial, width of the EoR signature and width of the data window.

| | SNR | Comments |
|---|---|---|
| # terms 1, 2, 3, 4, 5, 6 | 52, 33, 28, 21, 9, 4 | For 15 MHz width |
| EoR width 10, 15, 20 MHz | 15, 8, 4 | For 5-term poly |
| Data width 65-97, 61-97, 61-99 | 6, 8, 9 | For 15 MHz width |
| Data width 65-97, 61-97, 61-99 | 3, 4, 4.5 | For 20 MHz width |
| Data width 51-99 | 6 | For 20 MHz width |

Table 4. SNR with 10 mK noise and no systematics. A 5-term polynomial is removed in all cases after the first. 100 mK EoR signature is added in each case.

Summary

1] Beam effects dominate low band.
2] A 5×30×30 m ground plane should reduce beam effects to levels comparable with the estimated systematics from S11 and calibration errors.
3] 5-terms are needed to reduce systematics to level of 10 mK over 61-97 MHz needed for the potential detection of a 100 mK absorption signature of up to 15 MHz width.