MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886
September 30, 2020

To: EDGES Group

From: Alan E.E. Rogers

Subject: Simulations of the effects of ground plane and antenna tilts

The effects of antenna and ground plane tilts were tested on the low2-45 data from 2020 day 55 to 160 in memo 336. The results of applying tilt and roll corrections made some improvement but the results were affected by the presence of large residuals at GHA = 21 hrs now thought to be due to reflections from rocks and brush southeast of low2-45 the details of which are discussed in memo 341.

If the antenna and ground are both tilted by the same amount and there are no reflections from other objects the beam would be pointed as if the antenna was located at a different longitude and latitude or equivalently for small tilts pointed with an offset in right ascension and declination. In practice the EDGES antennas and ground planes have small but different slopes. The ground plane tilts have been measured and the combinations of antenna and ground plane tilt are all under 1 degree but a tilt of the antenna relative to the ground plane changes the beam pattern in ways other than a tilt. Table 1 shows the results "tilting" and "rolling" an EDGES low-band antenna on an infinite PEC level ground plane with the antenna pointing north.

tilt(deg)	roll(deg)	RA offset(deg)	DEC offset(deg)	1-term rms(mK)	5-term rms(mK)
1	0	0	0.25	580.8	3.4
0	1	0	0	352.0	25.0
1	1	0	-0.1	688.8	25.2
0	-1	0	0	352.0	25.0
-1	0	0	0.0	521.8	4.0
0 30x30m	1	0	0.0	362.3	25.6

Table 1. Residuals to 1 and 5 physical terms at best fit beam offsets for tilt and roll of antenna over the level PEC ground for all entries except the last which is for the 30x30m ground plane over soil. Positive tilt is down from south to north and positive roll is down from east to west.

The results in Table 1 show that roll about the axis between the panels has a significant effect on the 5-term residuals while tilt has a larger effect than a roll on the 1-term fit while the tilt has a very small effect on the 5-term fit. Figure 1 shows the residuals for a 1 degree roll vs GHA for 52 to 95 MHz. A maximum of 64 mK is reached at GHA = 21 hours for GHA = 0 to 23 hours in one hour steps without averaging over 1 hour bins. The results are the same for positive and negative roll which is expected by symmetry and in addition the 5-term residuals are relatively insensitive to RA and DEC offsets.

The effect of the change in the beam seen in the 5-term fits is primarily a change in beam chromaticity and is larger at the high frequency end of the band. The results for midband and EDGES-3 are less significant. For EDGES-3 the average rms for 5-terms is reduced from 25.0 to 17.7 mK for 1 degree roll. In summary the effects of antenna tilt and roll relative to the ground plane mainly change the chromaticity and have only a small effect on pointing offset. The last entry is for the 30x30m ground over soil with dielectric 3.5 and conductivity 4e-2 S/m with 0 degree tilt and 1 degree roll with 30x30m ground as reference which shows that the sensitivity is almost the same as for the PEC ground.

In summary for highest accuracy of the 21-cm absorption profiles the antenna should have the slope of the ground plane or the antenna tilt and roll relative to the ground plane should be included in the FEKO beam model. A pointing offset equal to the measured ground plane tilt should be used in the data analysis but the effect of using RA and DEC offsets in processing with 5 or more terms removed is very small. A simulation of a 1 degree shown in Figure 2 results in a maximum residual of only 34 mK at GHA=23hr for 1-hour bins 52-95 MHz 5 physical terms removed for -1 degree offset in RA.
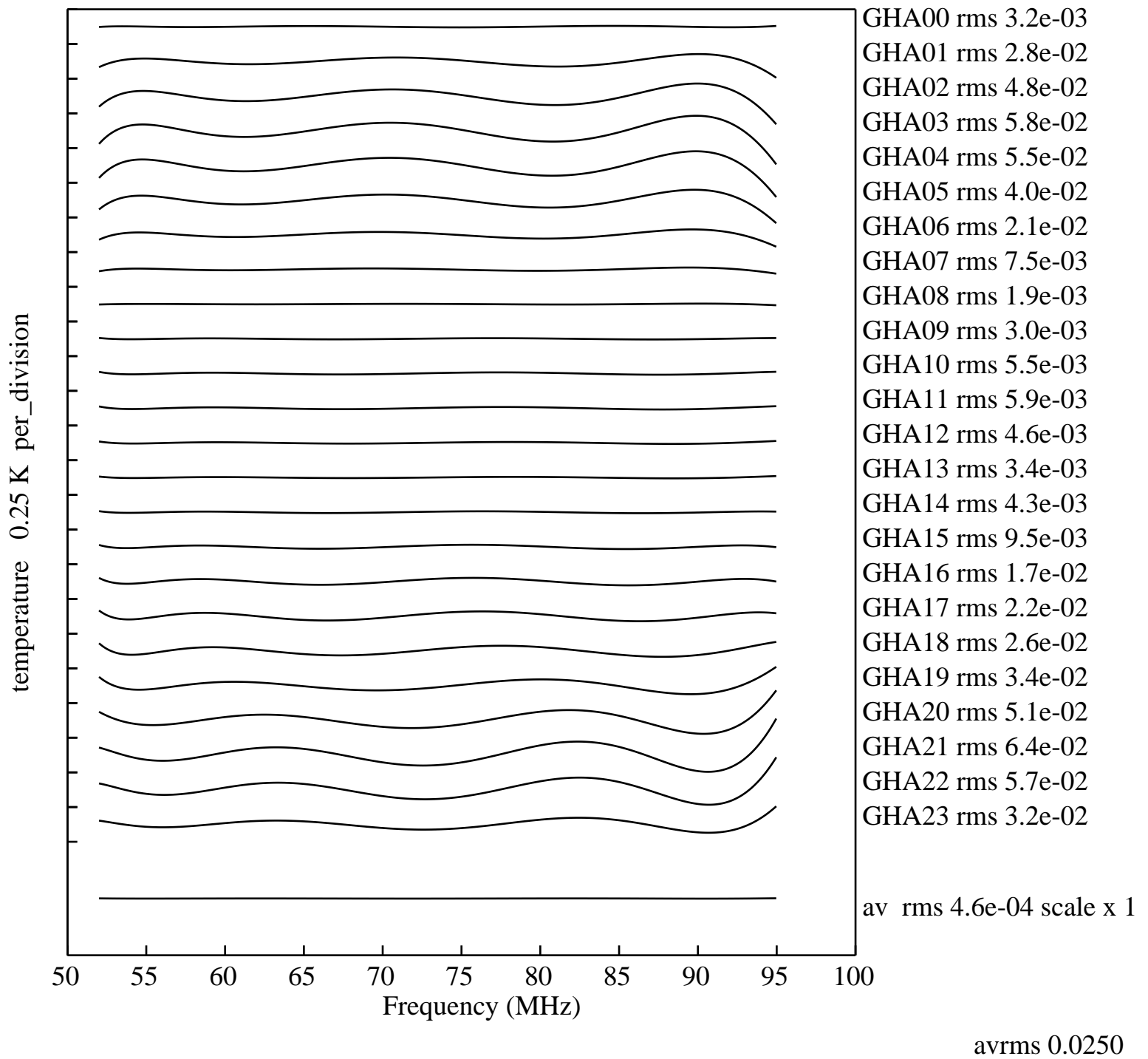
GHA00 rms 3.2e-03
GHA01 rms 2.8e-02
GHA02 rms 4.8e-02
GHA03 rms 5.8e-02
GHA04 rms 5.5e-02
GHA05 rms 4.0e-02
GHA06 rms 2.1e-02
GHA07 rms 7.5e-03
GHA08 rms 1.9e-03
GHA09 rms 3.0e-03
GHA10 rms 5.5e-03
GHA11 rms 5.9e-03
GHA12 rms 4.6e-03
GHA13 rms 3.4e-03
GHA14 rms 4.3e-03
GHA15 rms 9.5e-03
GHA16 rms 1.7e-02
GHA17 rms 2.2e-02
GHA18 rms 2.6e-02
GHA19 rms 3.4e-02
GHA20 rms 5.1e-02
GHA21 rms 6.4e-02
GHA22 rms 5.7e-02
GHA23 rms 3.2e-02

av rms 4.6e-04 scale x 1

avrms 0.0250

Figure 1. 5-term residuals for simulation of an EDGES-2 low1 antenna on an infinite PEC ground plane with -1 degree rotation ("roll") of the antenna about the axis of the E-field between panels using FEKO model without rotation as the reference.
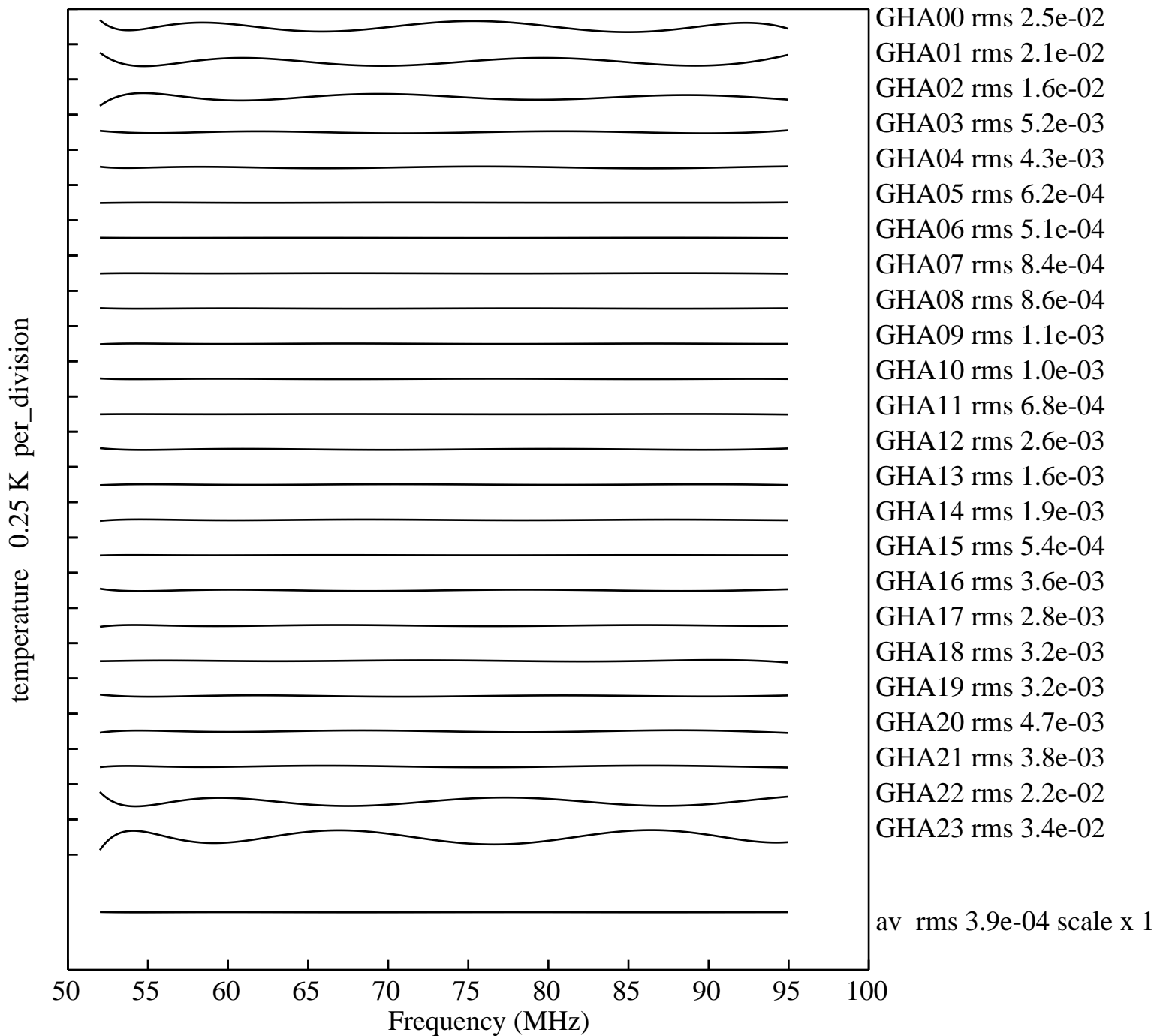
Figure 2. 5-term residuals for simulation of an EDGES-2 low1 antenna on 30x30 m ground plane for 24 1-hour bins of GHA using FEKO beam model used in lowband1 2016_250 - 2017_095 and -1 degree offset in RA.