EDGES MEMO #206

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July 9, 2016

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To: EDGES Group
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Subject: Effect of ground plane model parameters

A good test of the accuracy of the receiver calibration, loss estimates, antenna S11 and beam model is to examine the calibrated spectra with beam correction as a function of Galactic Center hour angle (GHA). The "Galaxy up" and "Galaxy down" in which the spectra from around GHA = 0 and GHA = 10 hours are used has been discussed in memos 48, 55, 145, 171, 172 and 202. In this memo the parameter space of soil dielectic and conductivity is explored further using the average rms of the spectra from each hour of GHA as a metric rather than the rms of the spectrum averaged over GHA.

The average rms for 3 cases at low band are given in Table 1. The first case is a 5-term polynomial fit from 65 to 99 MHz and the second case is a 4-term fit of scale, spectral index, spectral curvature and ionospheric absorption from 72 to 95 MHz. The third case is for 52-97 MHz with 5-terms removed.

| dielectric | conductivity | 65 – 99 MHz | 72 – 95 MHz | 52 – 97 MHz |
|---|---|---|---|---|
| constant | S/m | av. rms mK | av. rms mK | av. rms mK |
| 2.0 | 2e-3 | 95 | 64 | |
| 2.0 | 1e-2 | 78 | 46 | |
| 2.0 | 2e-2 | 67 | 50 | 235 |
| 2.0 | 3e-2 | 70 | 62 | |
| 2.0 | 5e-2 | 83 | 76 | |
| 1.1 | 2e-2 | 64 | 55 | |
| 1.5 | 2e-2 | 64 | 51 | |
| 1.7 | 2e-2 | 65 | 51 | |
| 2.5 | 2e-2 | 76 | 51 | |
| 3.5 | 2e-2 | 75 | 54 | 211 |

Table 1. Average rms over 24 hr range of GHA in steps of 2 hrs for low band. The last column is for average rms to 5 term physical function

| dielectric constant | conductivity S/m | average rms mK |
|---|---|---|
| 3.5 | 2e-2 | 70 |
| 2.0 | 2e-2 | 75 |

Table 1b. Residuals to 5-term physical function for high band 104 to 194 MHz

The lowest average of residuals over 24 hrs are obtained for a dielectric constant around 2.0 to 3.5 and conductivity 1e-2 to 2e-2 S/m. While the conductivity seems reasonable the dielectric constant is lower than that measured by Sutinjo (see memos 195 and 201). This can be explained, at least in part, by the lack of contact of the ground screen with the soil. Simulations using the “GF card” in EZNEC and FEKO show approximate equivalence of the effect of an air gap and a lower value of dielectic constant for the soil as shown in Table 2.

| mesh height above soil cm | dielectric constant |
|---|---|
| 0 | 1.7 |
| 0.5 | 2.2 |
| 1.0 | 3.0 |
| 2.0 | 4.5 |

Table 2. Equivalent mesh height and dielectric

In addition to the dependence of the beam model on the soil dielectric and conductivity the beam is affected by tilts in the ground plane, non-uniform contact with the soil and non-uniformity of the soil. Figures 1a and 2a show the residuals with 5 physical terms removed for low and high band respectively as a function of GHA is one hour steps. In each case the beam model for the blade antenna and its ground plane with soil dielectric 2.0 and conductivity 2e-2 has been used for beam correction. The scales are set at 2.0 and 0.4 K per division respectively to approximately compensate for the sky noise ratio between bands. The data for low band is from 2015_286 to 2016_143 and from 2015_205 to 2016_179 for high band.

The following filtering tests were performed and seen to make little difference in the general trends and “signature” of the residuals at each GHA:

1] nighttime only

2] first vs second half of data

3] moon below the horizon

4] alternate days

Of these tests only the first vs the second half of the data made a significant difference above the noise. The results are given in table 3.

| band | rms of average of average mK | | average rms mK | |
|---|---|---|---|---|
| band | 1st half | 2nd half | 1st half | 2nd half |
| low | 143 | 93 | 248 | 244 |
| high | 55 | 98 | 23 | 86 |

Table 3. rms of average and average rms for first and second half of data

The change between the first and second half is more significant for the high band. In either case the change is probably seasonal. When a given GHA occurs in a different season the ground conditions and the temperature gradients in the receiver are different. Another factor is condensation on the antenna affecting the antenna S11 as discussed in memo 178. This has a larger effect on the high band antenna due to the smaller gap between panels relative to the condensation drop size.

Both low and high band have significant signatures in the residuals to the 5-term fits which change on the time scale of about one hour and are repeatable with GHA. While the signatures are different between the low and high band they are similar in nature. Figures 1b and 2b show simulations in which the data is simulated with one beam model and corrected with the beam model used to correct the data. For the low band the data is simulated with a model which includes approximations to the measured slopes in the ground plane which are not on perfectly level ground while the beam is corrected using a perfectly flat ground plane. In both cases the soil was assumed to have a dielectic of 2.0 and a conductivity of 2e-2 S/m. For the high band the data was simulated using a flat ground plane on the high band “plus” shape with soil dielectric 3.5 and conductance 2e-2 and corrected using a dielectric of 2.5 and conductance of 2e-2.

It is noted that the ripples with period of about 2.9 MHz are seen in the low band data from GHA = 19 and 20 hrs. These are consistent with a reflection from the electronics hut which is 50m away from the low band antenna. Figure 1c shows a FEKO simulation which includes the hut. These were not seen in the simulation of the hut in memo 194 because the beam from FEKO had been sampled at 5 MHz intervals, interpolated and smoothed. The new simulation clearly shows the ripples when the beam model with 2 MHz spacing is used without smoothing. Figure 1d shows a simulation in which the hut was rotated by 45 degrees. The 2.9 MHz ripples change and get weaker as expected but the other structure hardly changes strongly suggesting that this structure is an artifact of the modeling. In another test the model is run with the antenna, hut and ground plane are in free space. The ripples get stronger by a factor of about 20, as expected, while the other broader structures do not get stronger. This is further evidence that the hut should only produce the ripples and that the somewhat broader structures are artifacts possibly due to numerical errors. In another test the hut was moved from 50m to 70m from the antenna. The ripples decreased in amplitude by more than a factor of 4 so they are hard to see while the broader structures remained about the same. This test is definitive evidence that the broader structures are largely due to modeling errors. Figure 1e and 1f show the difference of the model with 50m separation and that with 70m separation.

The sensitivity to changes in ground plane and other beam related parameters is given in Table 4 for 3 cases. The first is 52 to 95 MHz with 5 physical terms removed. The second and third are 67 to 99 MHz with 4 physical terms removed. In the first and second cases the rms is the average the rms values obtained for each GHA from 0 to 23 hrs. In the third case it is the average of the rms values obtained for GHA = 10, 11, 12, 13 and 14 hrs. The results show a decrease of more than a factor of two except for the hut which has fine structure in frequency. The added tilts to the ground plane were modeled by changing the separation to the ground plane since the FEKO model for the soil is a plane infinite lossy dielectric. The effect of a tilt in the antenna was model by simply tilting the antenna panels by 1 degree.

| change | 52-97 MHz | 67-99 MHz | 67-99 MHz GHA 10-14 hrs |
|---|---|---|---|
| $\varepsilon$ = 2.0 to $\varepsilon$ = 3.5 | 121 | 67 | 23 |
| $\sigma$ = 2e-2 to $\sigma$ = 2e-3 | 201 | 160 | 42 |
| $\sigma$ = 2e-2 to $\sigma$ = 1e-2 | 55 | 10 | 5 |
| add tilts to ground plane | 107 | 49 | 14 |
| add tilt to antenna | 35 | 18 | 4 |
| add hut | 50 | 50 | 44 |
| add cmb correction | 27 | 10 | 5 |
| change to infinite ground plane | 550 | 240 | 86 |

Table 4. Simulation of sensitivity to change in ground plane model in mK

## General Conclusions

The beam effects are large within 6 hours of the transit of the Galactic center for both the low and high band. The signature changes on a time scale of about 1 hour. The magnitude of these large signatures are about 5 to 6 times larger in the low band than in the high band as expected for being in proportion to the sky brightness temperature.

The effect of reflections from the hut are clearly visible in the low band in the form of a ripple with a period of about 3 MHz at GHA = 19 and 20 hrs. The simulated beam effects due to the hut in the range GHA = 10 to 14 hrs are at the 30 mK level which is significant and reason for concern. While the “ripples” are expected the other structure in the simulations of the hut may be artifacts of the EM modeling. The residuals of the differences in the simulated beam effects for a range of soil dielectric from 2.0 to 3.5 and conductivity from 1e-2 to 2e-2 are at the 30 mK and 6 mK level for the low and high band respectively and these decrease by a factor of about 2 when the range is limited to 62 to 97 MHz and 124 to 194 MHz.

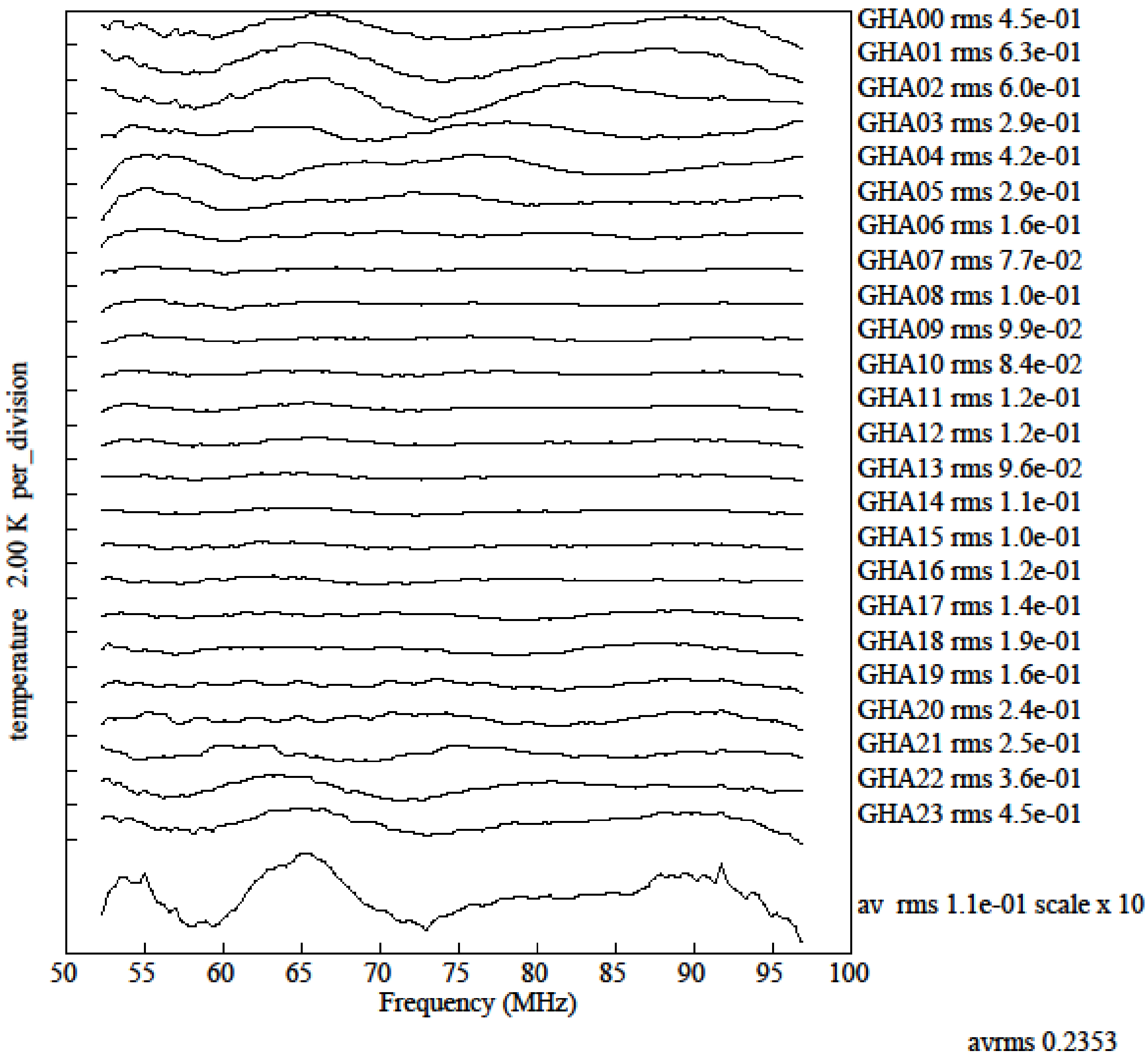


Figure 1a. Residuals to 5-term physical functions with beam correction using ε=2.0 σ=2e-2

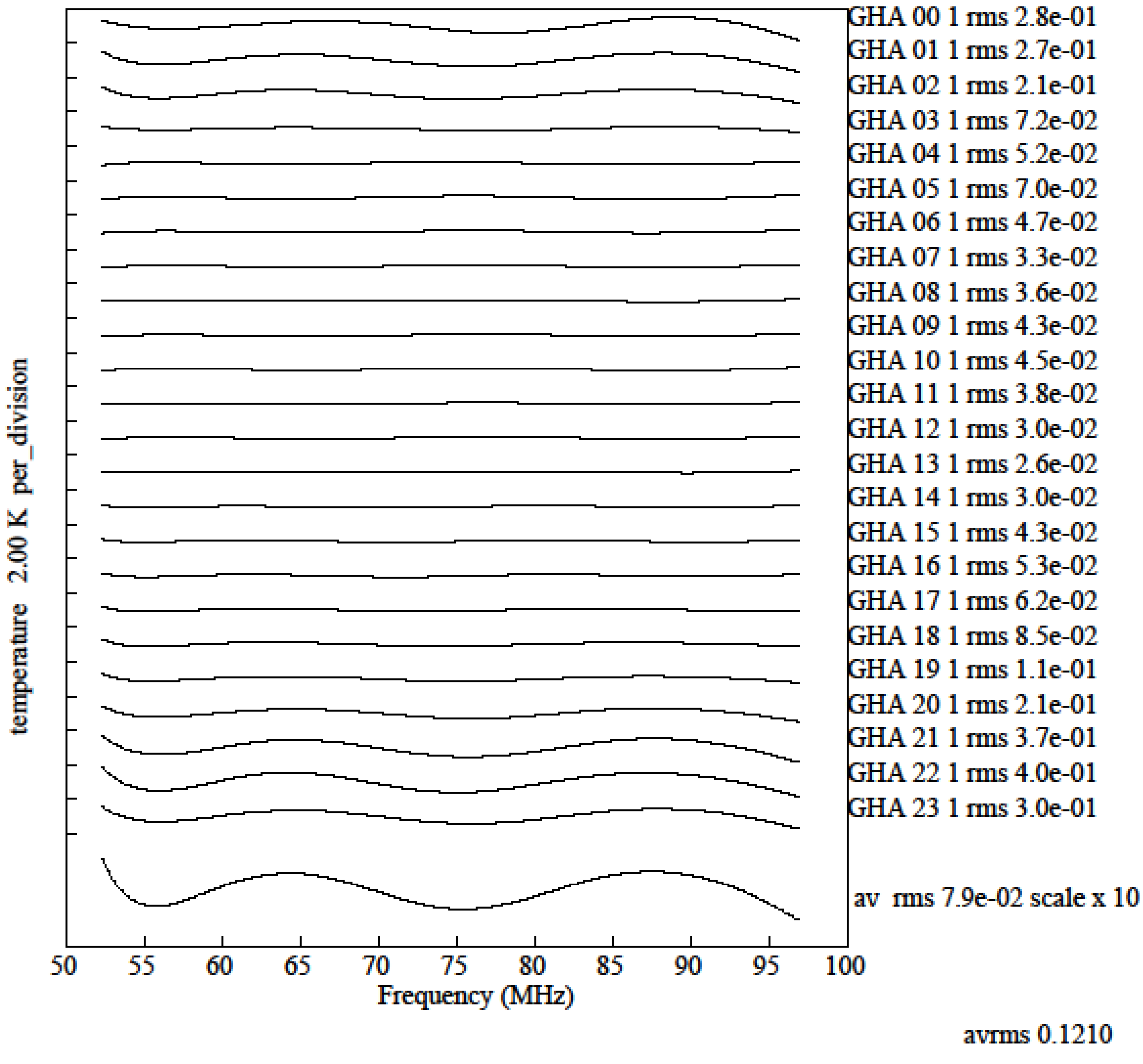


Figure 1b. Simulation difference between ε = 3.5 and ε = 2.0

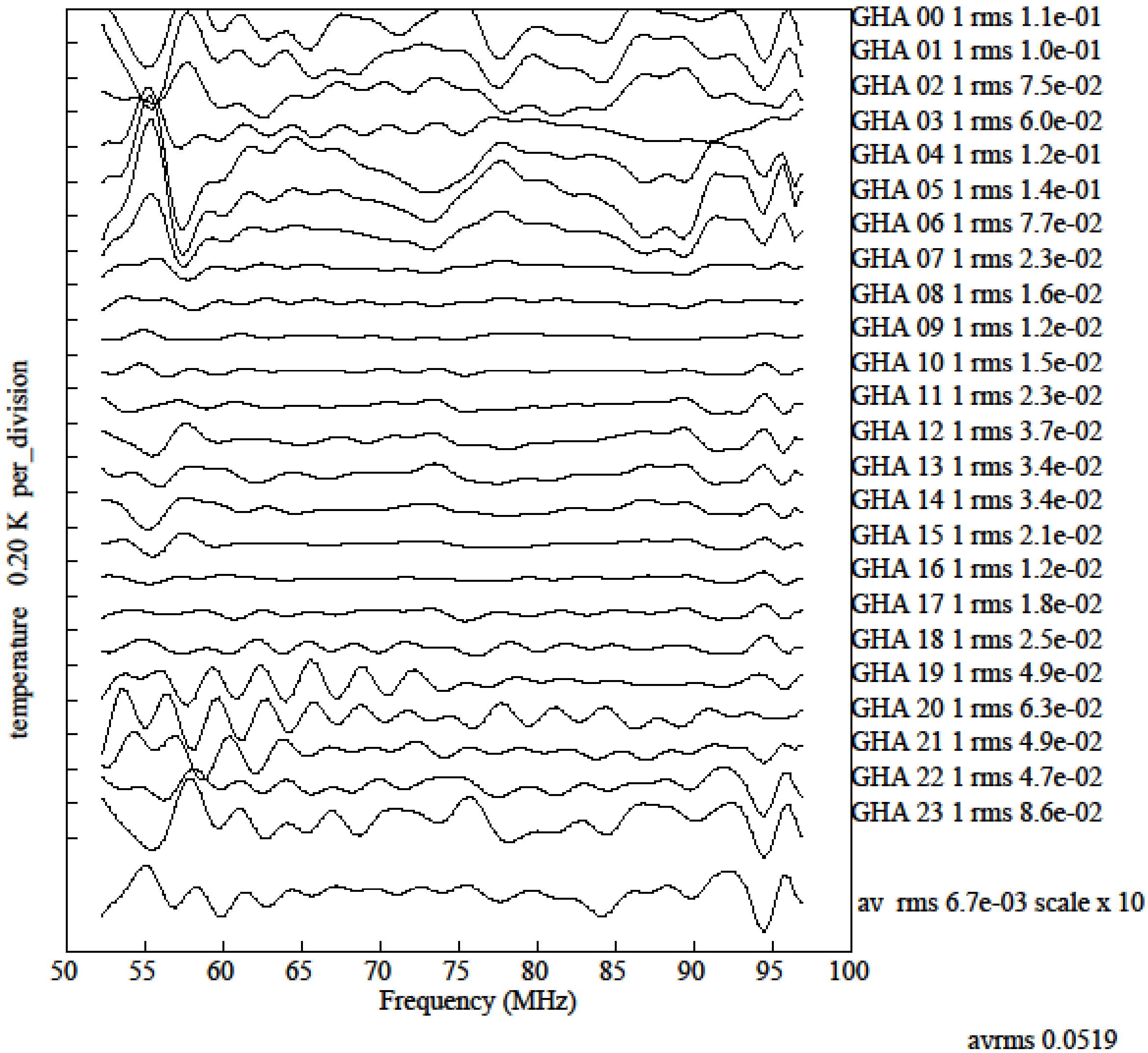


Figure 1c. Simulation difference with and without hut. Note scale change

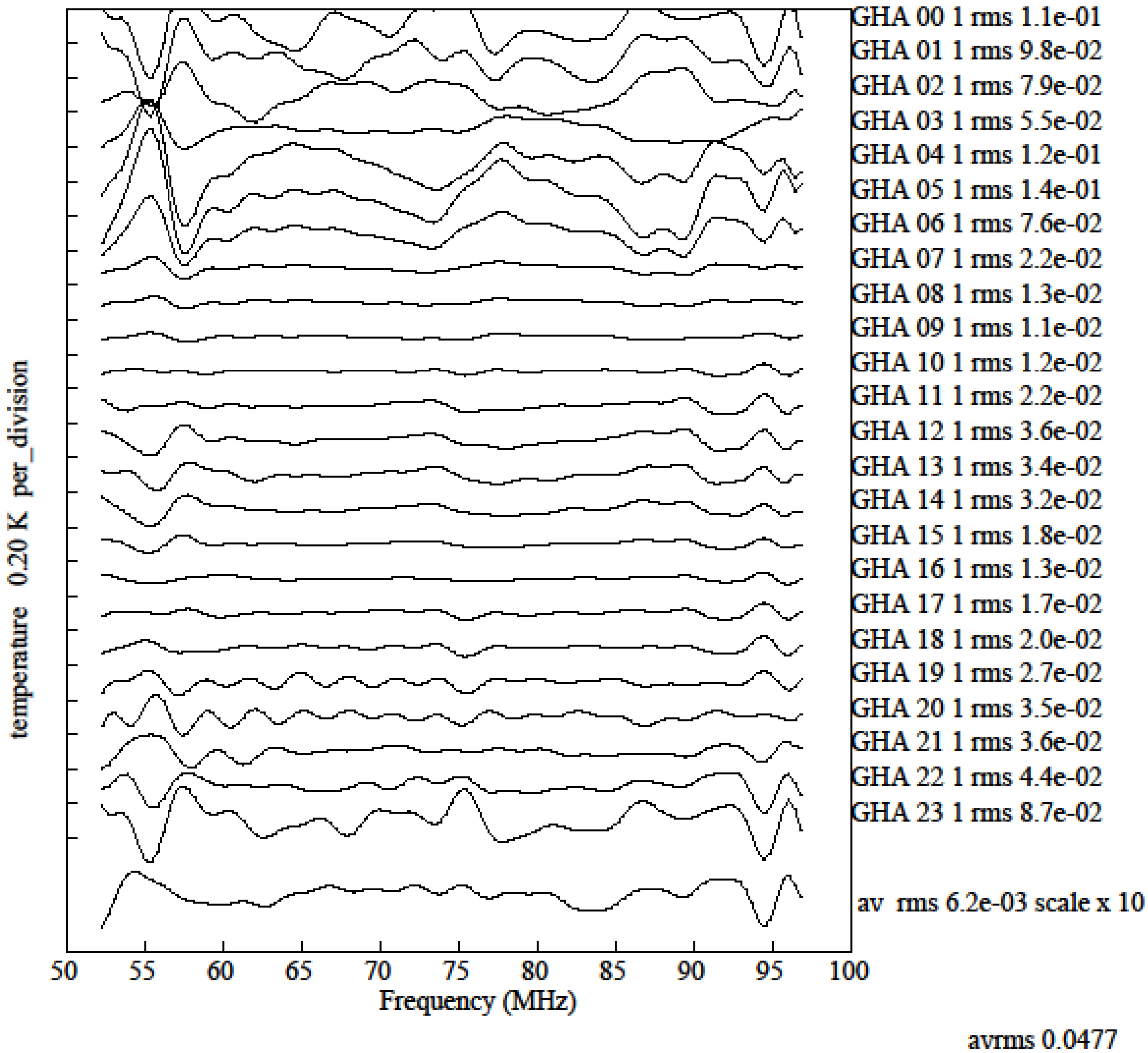


Figure 1d. Simulation difference with hut rotated 45deg and without hut.

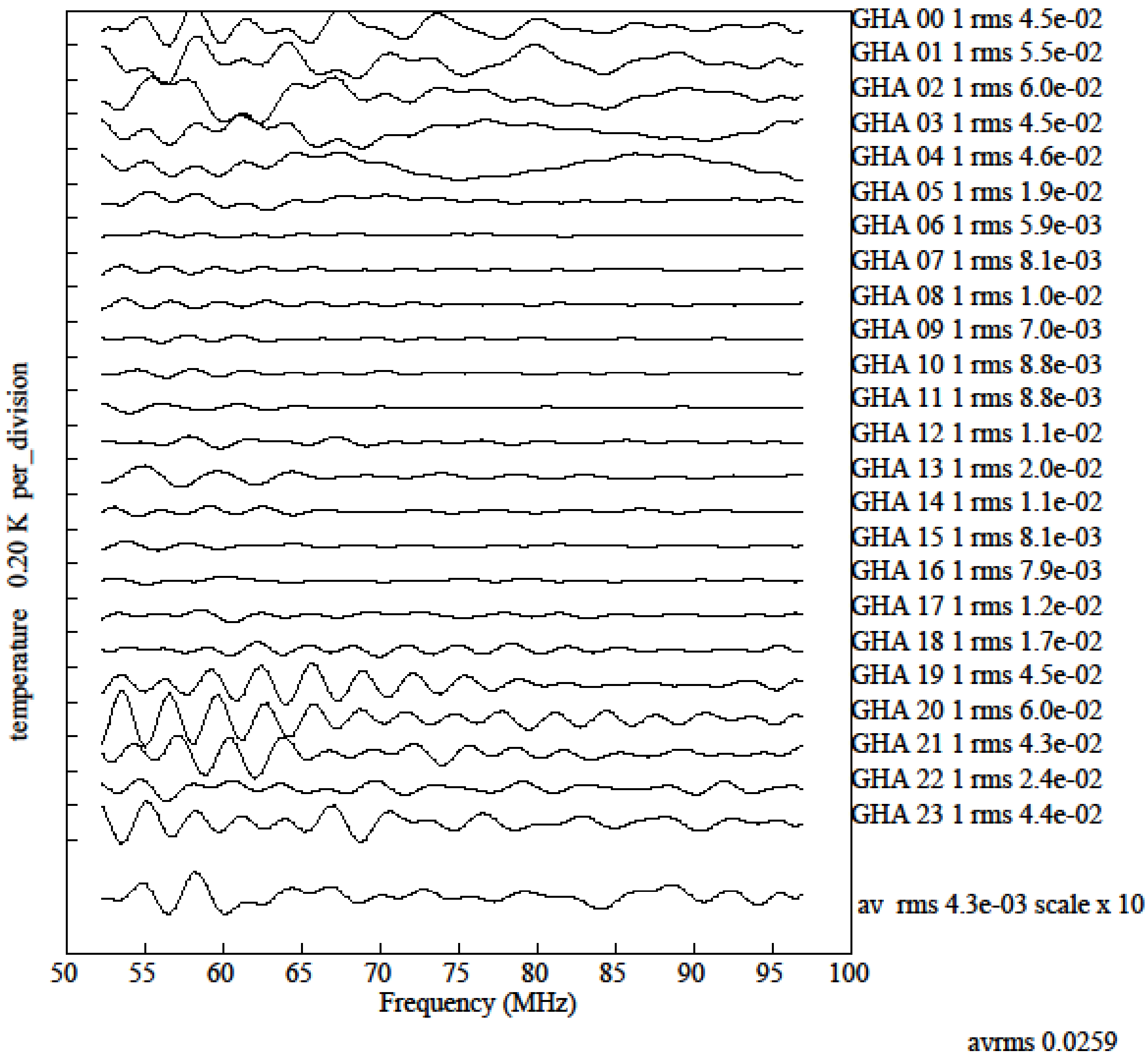


Figure 1e. Simulation difference with hut at 50m and hut at 70m.

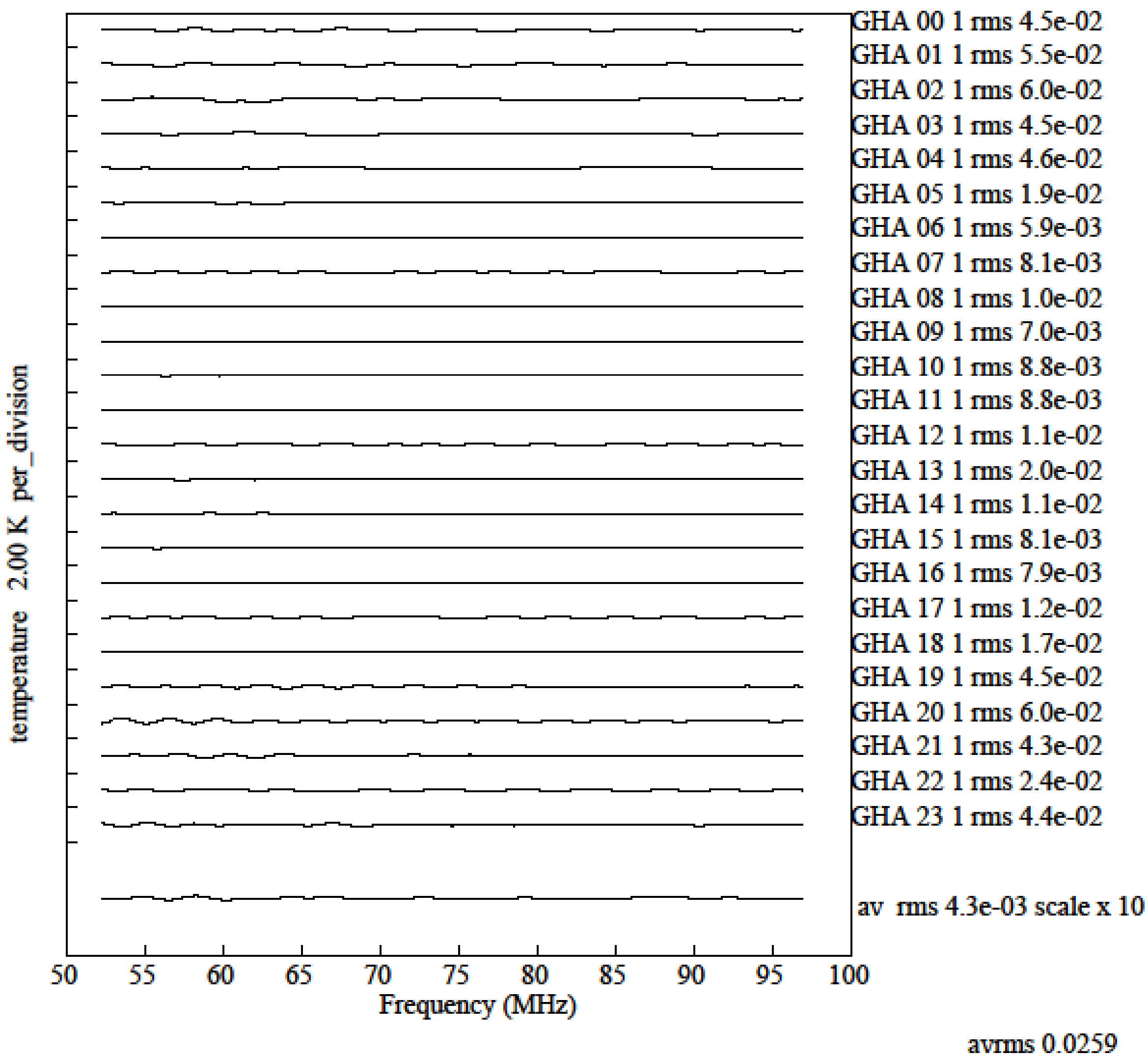


Figure 1f. Same as figure 1e with scale changed for comparison with the data shown in figure 1a.

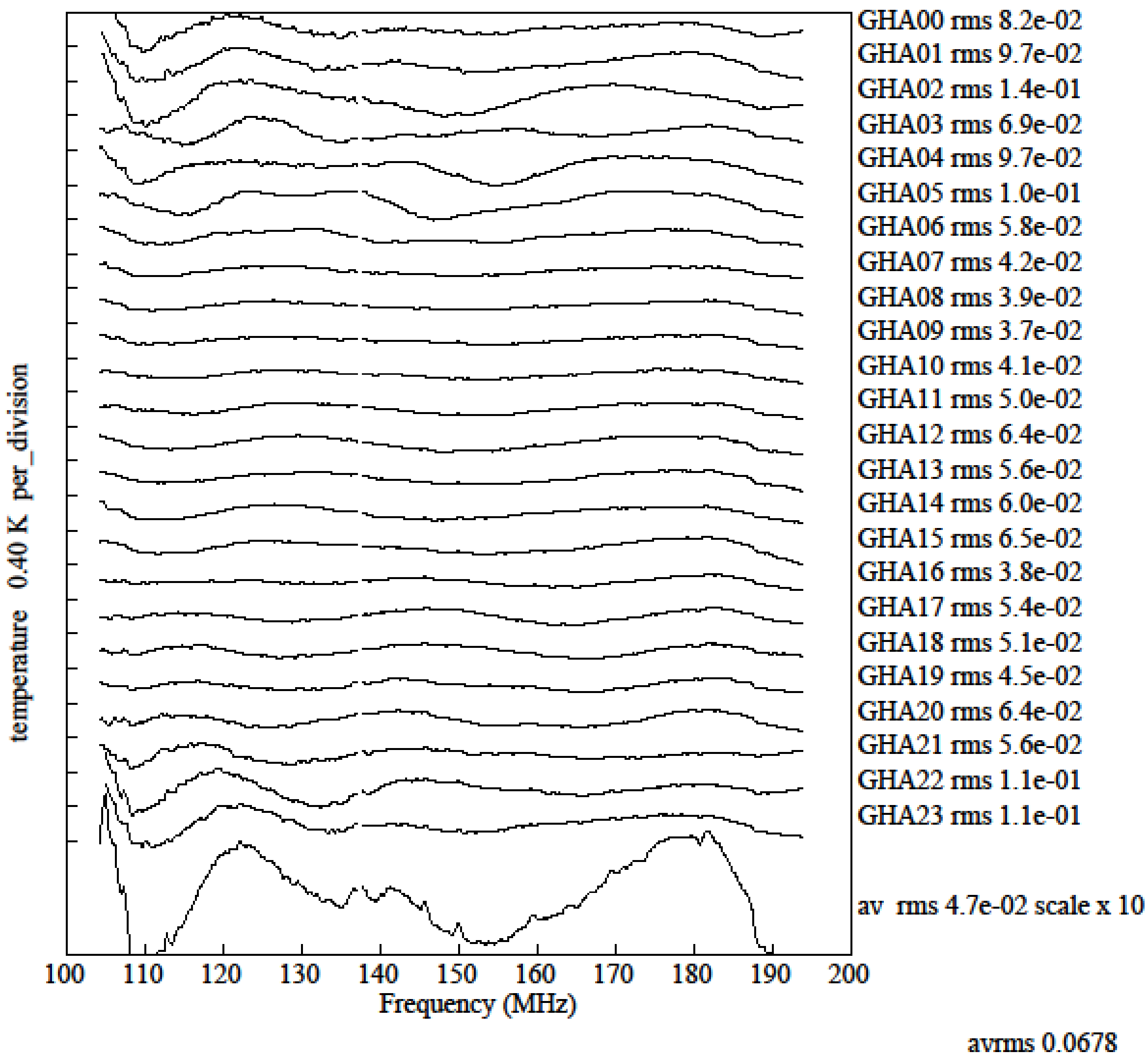


Figure 2a. Residuals with 5 physical terms removed. Beam correction with ε=2.5 σ=2e-2

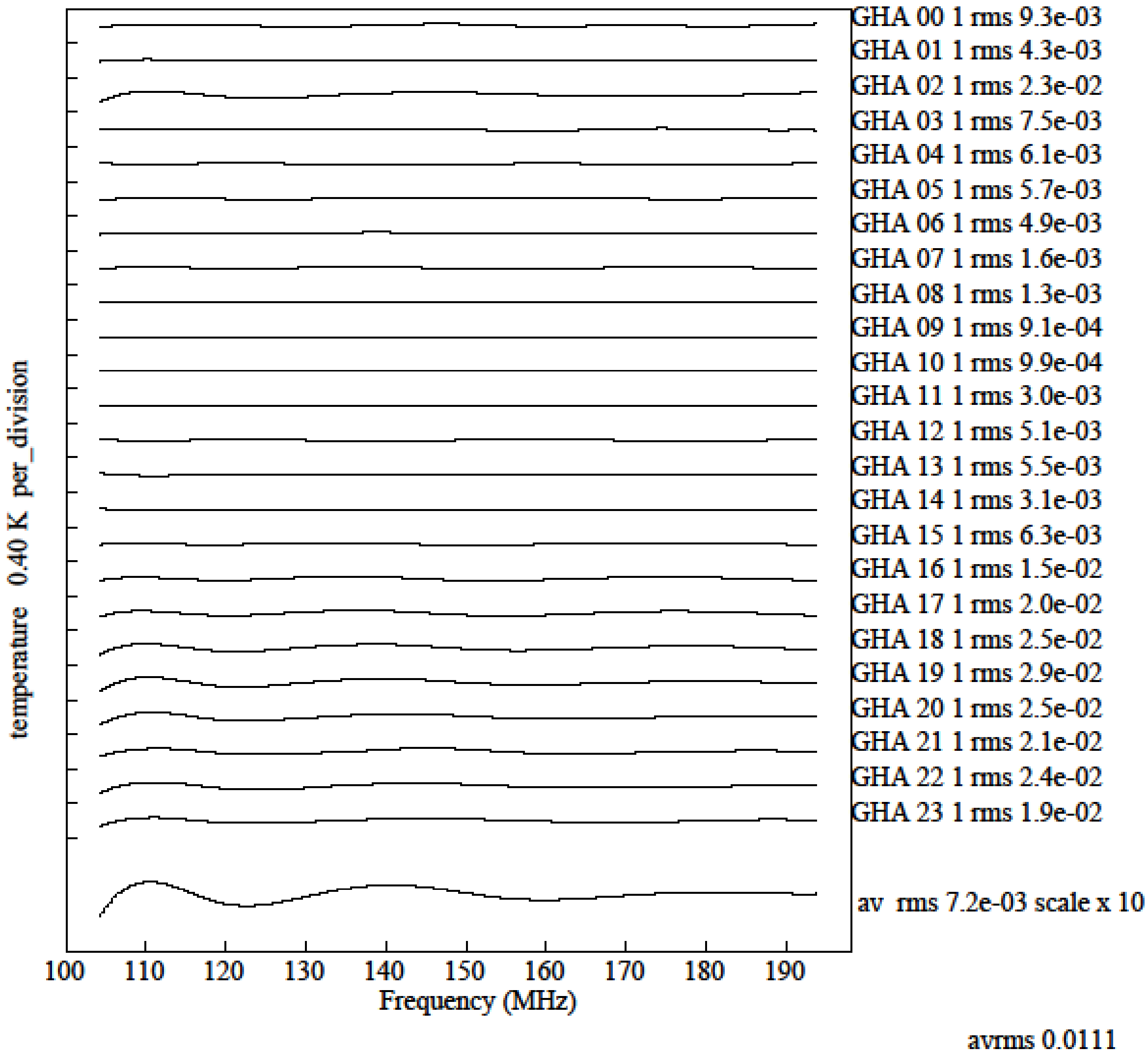


Figure 2b. Simulation difference between ε=3.5 and ε=2.0