EDGES MEMO #422

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To: EDGES group

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Subject: Beam chromaticity of EDGES-3 on lunar regolith

The beam chromaticity of an antenna in orbit around the moon was studied in memo 279. In this case the effects of the reflections from the regolith were minimized by keeping the lunar surface far enough away from the antenna so that the lunar surface is in the minimum gain response of the dipole. A satellite orbit at a distance of 960 km from the lunar surface was chosen to obtain an acceptable beam chromaticity while being close enough to block the radio emissions from both the earth and the sun for a reasonable amount of observing time.

In this study the EDGES-3 antenna is on a thin metal ground plane to reduce the effects of the reflections from the rock below the regolith. The main purpose of the study is to determine how large a ground plane is needed to obtain an acceptable beam chromaticity. The results are obtained using FEKO with infinite layers below the ground plane. The parameters of the lunar surface used are the same as those used in memo 279.

Ground plane size m	Soil dielectric	Soil conductivity S/m	Rock dielectric	Rock conductivity S/m	Rock depth m	Average rms mK
4x4	Free space					1560
4x4	3.0	2e-4	8.5	2e-2	10	12000
16x16	3.0	2e-4	8.5	2e-2	10	1027
16x16	3.0	2e-5	8.5	2e-2	10	1379
16x16	3.0	2e-4	8.5	2e-2	6	1090
30x30	3.0	2e-4	8.5	2e-2	10	390
30x30	Free space					154
30x30	corrected	2e-4	8.5	2e-2	10	360
Cone 2m	3.0	2e-4	8.5	2e-2	10	27000
Cone 8m	3.0	2e-4	8.5	2e-2	10	16950
Cone 16m	3.0	2e-4	8.5	2e-2	10	16525

Table 1 Beam chromaticity vs ground plane size for EDGES-3 on the moon 55-100 MHz

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The sky coverage used for the simulations was that at the MRO using 24 1-hour blocks with 5-terms removed 55 – 100 MHz. The ground plane is a square metal sheet with the antenna in the center oriented along the diagonal. The 30x30 m took 3-days to run. The Haslam map scaled with a spectral index of -2.55 was used in the convolution of the beam to obtain the chromaticity.

Figure 1 shows the rms residuals with 5-terms removed for each GHA of the sky. Figure 2 shows that a grid search on the average of simulated data over all GHA gets a best fit absorption close to the EDGES 2018 result. However it turns out in a limited observing session it will not be possible get data over 24 hours of GHA and I find that 30x30m ground plane is not large enough to get a result and assuming that we need a factor of 3 decrease in the chromaticity to get to about 100 mK and I estimate that this will take a 60x60m or larger ground plane. The reason 24 hours helps is that beam effects tend to have opposite effects 180 degrees apart so that averaging data 12 hours apart tends to cancel out some of the chromaticity. Figure 3 shows that without averaging 24 hours of GHA over the sky the systematics from beam chromaticity are so large that a 21-cm absorption at the level of the EDGES result would not be detectable.

A small improvement in the effect of the chromaticity can be made by correcting the data with the free space beam is shown in the last entry of Table 1 labeled “corrected”.

Simulations were made of a cone over a circular ground planes with 2 8 and 16 m in diameters but these all have a very large beam chromaticity. Vertically polarized antennas on soil require an extremely large ground plane as discussed in memo 288 and are probably only a reasonable option on the large lake on the earth or in orbit around the moon as modeled in memo 279.

Some additional simulations were made for a 48x48m ground plane like that at the MRO and the results are given in Table 2 below:

Ground plane size	Soil dielectric	Soil conductivity S/m	Rock dielectric	Rock conductivity S/m	Rock depth m	Average rms mK
48x48	3.5	2e-4	8.5	2e-2	20	188
48x48	3.5	2e-4	8.5	2e-2	40	74
48x48	3.5	2e-5	8.5	2e-2	40	152

Table 2 Beam chromaticity of 48x48m ground plane for EDGES-3 on the moon 55-100 MHz

where the average rms is for 1 hour block over all GHA for the Sky coverage at the MRO. A 48x48m ground plane a soil depth of 40m along with soil conductivity of 2e-4 S/m or higher would be needed to achieve an acceptable beam chromaticity without needing a larger ground plane.

I also simulated an antenna of half the size of EDGES-3 which is "electrically small" on a 4x4m ground plane and got an average rms of 9.6 K compared with 12 K in Table 1 for the full size antenna for a 10m regolith.

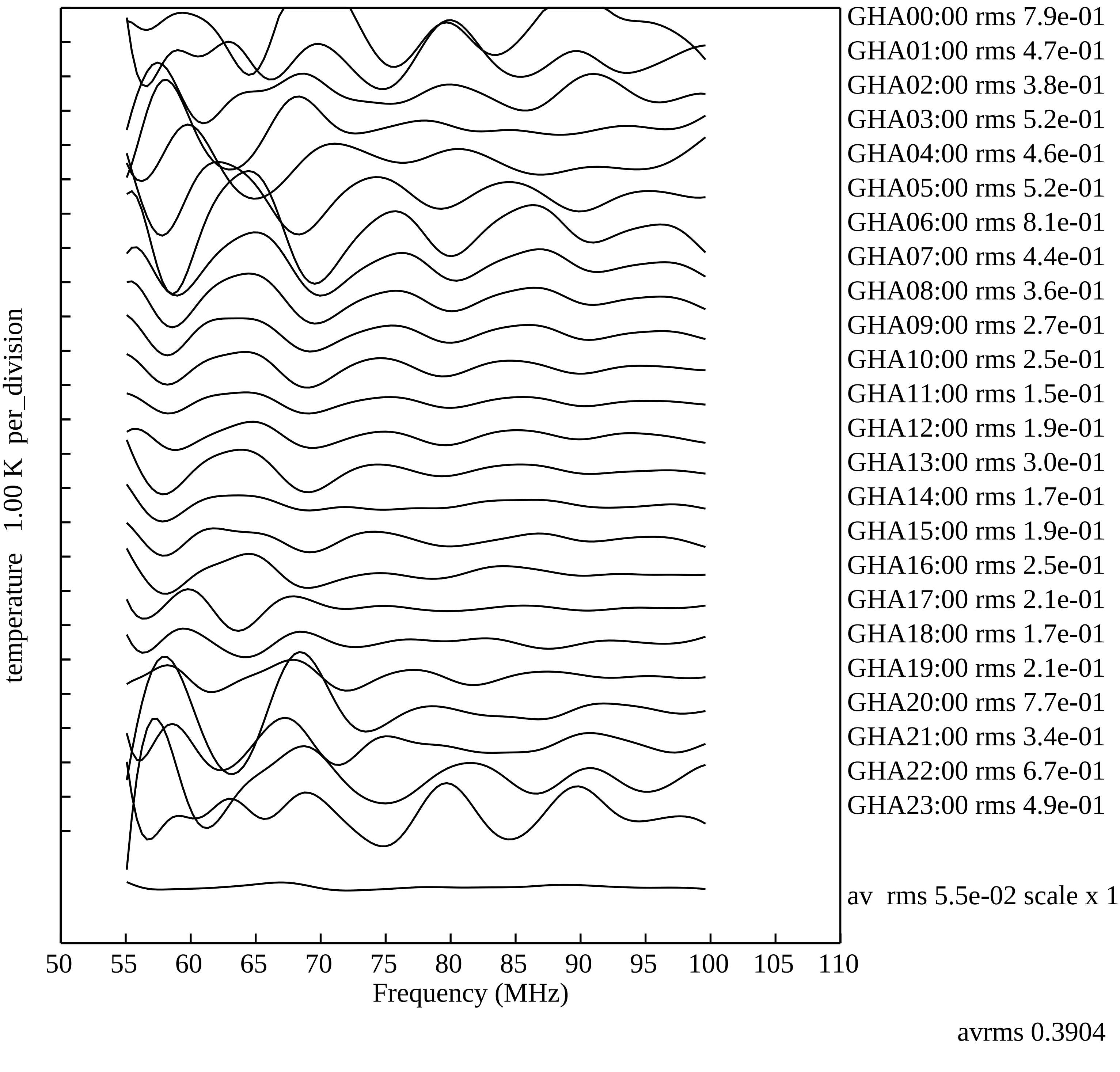

Figure 1. Residuals vs GHA for 30x30m ground plane with 5-polynomial terms removed

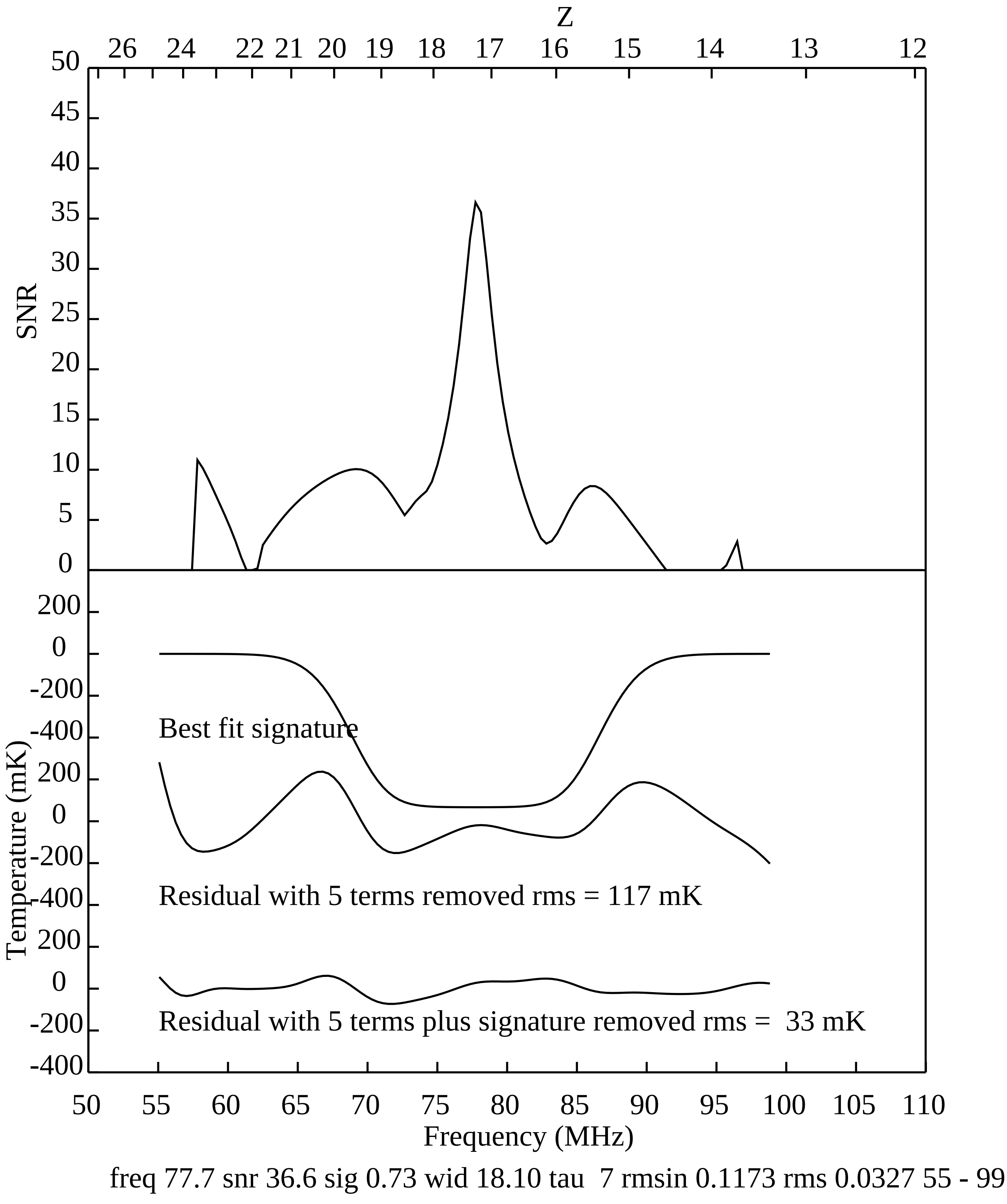

Figure 2. Grid search with EDGES 2018 absorption added to Haslam map

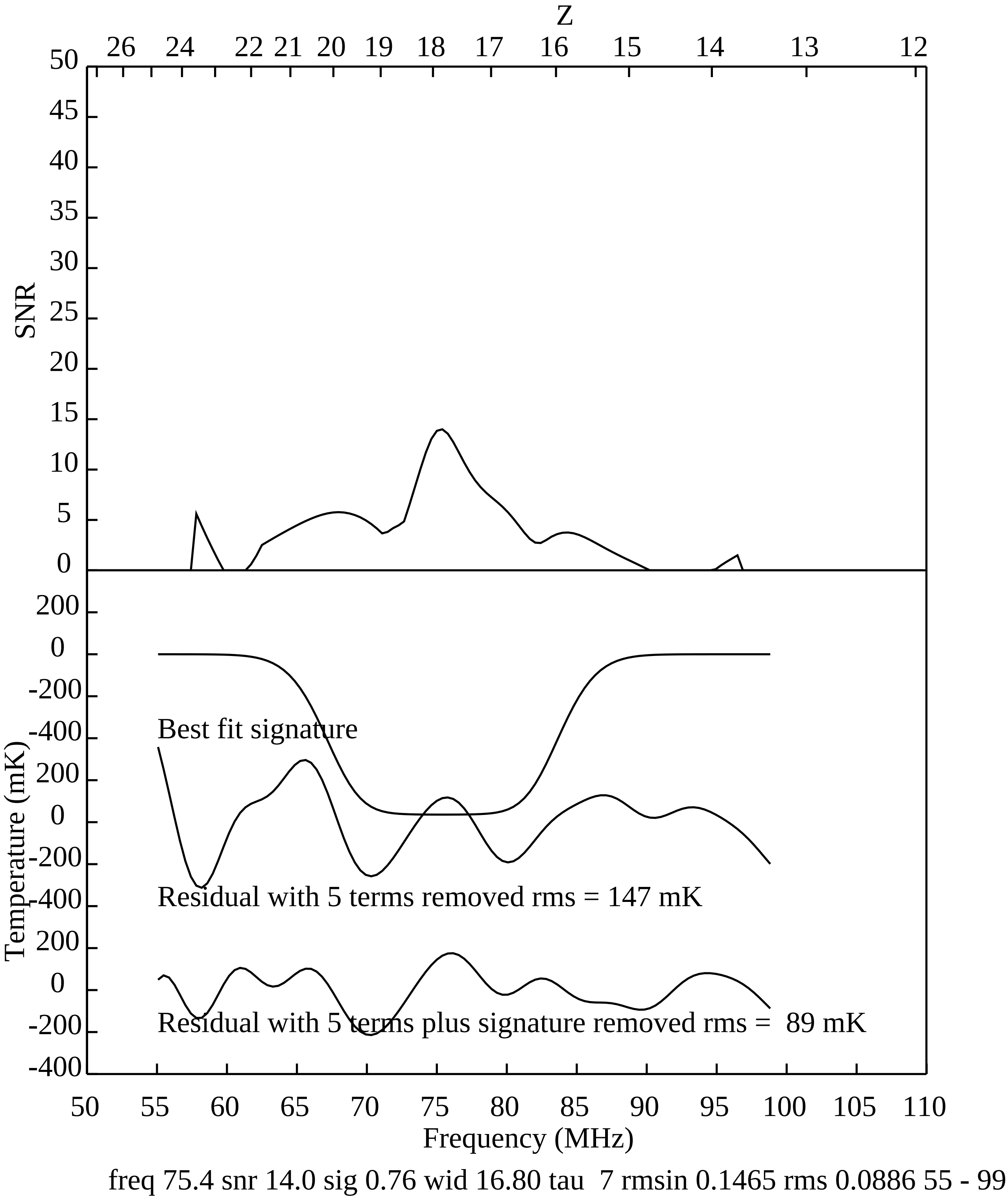

Figure 3. Same as figure 2 but with GHA over a range of 3 to 20 hrs.