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To: EDGES Group

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Subject: Sensitivity of spectral residuals with 3 parameters removed to systematics.

The ability to detect or exclude 21-cm signatures with widths greater than 20 MHz in the low band or 40 MHz in the high band is vastly improved if only 3 terms are removed. For example, the removal of 4 terms typically dilutes a Gaussian signature of FWHP of 20 MHz at 75 MHz by a factor of about 5 so that a 200 mK dip only shows a 40 mK "ripple" with 4 terms removed.

Figure 1 shows the low band data from 2016_258 to 2016_284 with 3-terms removed. The 3 terms are scale, spectral index, and curvature of spectral index. The beam correction was made using the "GF" beam for the ground plane with perforated sides (see memo 204) over soil with dielectric constant 3.5 and conductivity 2e-2 S/m. A correction of the balun loss was made and the ground loss was assumed to be zero. Figure 2 shows the SNR for a search for a Gaussian dip vs frequency. The residual spectrum for the highest SNR is shown along with the frequency, SNR, magnitude, FWHP width, rms before adding Gaussian term, and final rms of a 3-term fit plus Gaussian making a 4-term fit.

Figure 3 through 10 show how the search for a Gaussian dip changes with the following changes listed in Table 1.

Figure	Change
2	Reference case S11 from 2015_342
3	Beam correction with infinite ground plane
4	S11 from day 2015_289
5	No balun loss
6	+200 ps change to S11
8	-200 ps change to S11
9	-0.1 dB change to S11
10	No beam corrections

Table 1.

The effect of the ionosphere is significant and is not completely taken out with only the 3 parameters removed. Figure 11 shows the effect of removing an ionosphere equal to an opacity of 2×10^{-3} at 150 MHz. This lowers the magnitude of the dip from about 1K to 770 mK. With only 3-terms removed the ionosphere is the largest contribution to the uncertainty in the magnitude and width Gaussian dip. The value of opacity at 150 MHz is an estimate obtained from Figure 6 of Rogers et al. (Radio Science, 50, 130-137, 2015). The absorption of the nighttime ionosphere at 45 degrees elevation plotted in Figure 6 is based on the IRI-2007 for the TEC converted to absorption based on the collision frequencies from Aggarwal (1979) is about

0.003 dB which corresponds to an opacity of 0.7×10^{-3} . However, this value is quite uncertain and could well be as high as assumed value of 2×10^{-3} . One method of suppressing the effects of the ionosphere is to use Galaxy calibration using nighttime data of the Galaxy “Up” and “down”. Table 2 lists the results of simulations of a 200 mK dip of 20 MHz width centered at 80 MHz in the presence of and ionospheric absorption of 2×10^{-3} at 150 MHz.

Frequency range	#terms	Mode	Frequency	Amplitude	Width	rmsin	Rms
55-99	3	UpDn	78.9	0.21	20	32	1
55-99	3	Dn	77.0	0.85	29	113	7
65-99	3	UpDn	79.6	0.16	17	12	0
65-99	3	Dn	78.9	0.59	27	33	1
55-99	4	UpDn	79.3	0.15	17	11	1
55-99	4	Dn	79.7	0.19	20	17	0
65-99	4	UpDn	79.3	0.32	22.0	9	0
65-99	4	Dn	79.7	0.23	21	12	0

Table 2. Simulated effects of ionospheric opacity of 2×10^{-3} on detection of 200 mK Gaussian absorption with 20 MHz width at 80 MHz. rmsin is the rms in mK without adding Gaussian to basis functions. Rms is the final rms for fit with Gaussian.

The advantage of “Galaxy calibration” is that with only 3 terms the effects of the ionosphere and other systematics are largely canceled. It is noted that the largest effects of systematics are on the amplitude of the Gaussian.

Figure 12 shows the low band spectra from nighttime 2016_259 to 2016_295 with 3 terms removed for comparison with Figure 1 of memo 215. Figure 13 shows the effect of including daytime data for the Galaxy up which was excluded in Figure 12.

Figure 14 shows simulated data with 1K Gaussian dip at 80 MHz with 20 MHz FWHM. An ionosphere with opacity of 0.5% at 150 MHz and 1000 K electron temperature has been added to illustrate how it is canceled by the difference spectrum of Galaxy calibration while others including beam effects and losses are not.

Table 3 shows the effect of systematics using the rms of the difference spectrum as the figure of merit. The high sensitivity to the beam chromaticity with only 3 terms removed is greatly reduced by removing 4 terms so that the improved sensitivity for the detection of broad signatures is offset by the high sensitivity to errors in beam correction.

	3 terms	4 terms
Test	Rms mK	Rms mK
Ionospheric opacity of 5×10^{-3} at 150 MHz	7	5
No balun or ground loss	12	12
No beam correction	1600	54
Finite vs infinite ground plane	37	11
Rotation of antenna by 10 degrees	63	25
cmb correction to Haslam map	85	3
Table 3. Simulations of systematics.		

In summary this memo shows the effects of removing only 3 physical parameters in order to detect broad signatures but given the increased sensitivity to systematics the results shown are extremely tentative. Also while the Galaxy calibration method shows great promise for detecting broad signatures it is essential to use only nighttime data to avoid the sensitivity to the ionosphere. Currently there is limited low band nighttime data with Galaxy up and it will be 6 months before more “Galaxy Up” nighttime data is acquired.

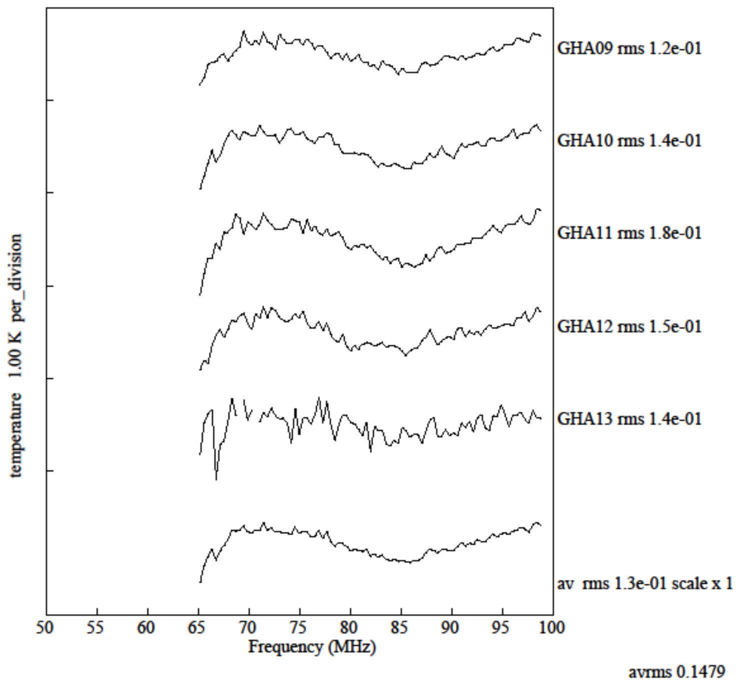

Figure 1. Residuals to nighttime spectra from 2016_258 is 2016_284 with 3-terms removed.

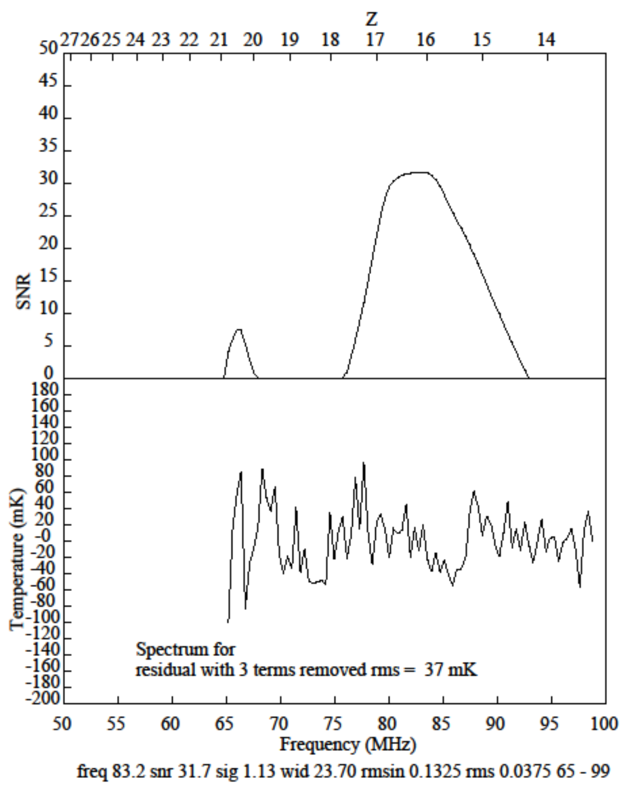

Figure 2. Search for highest SNR fit to Gaussian dip.

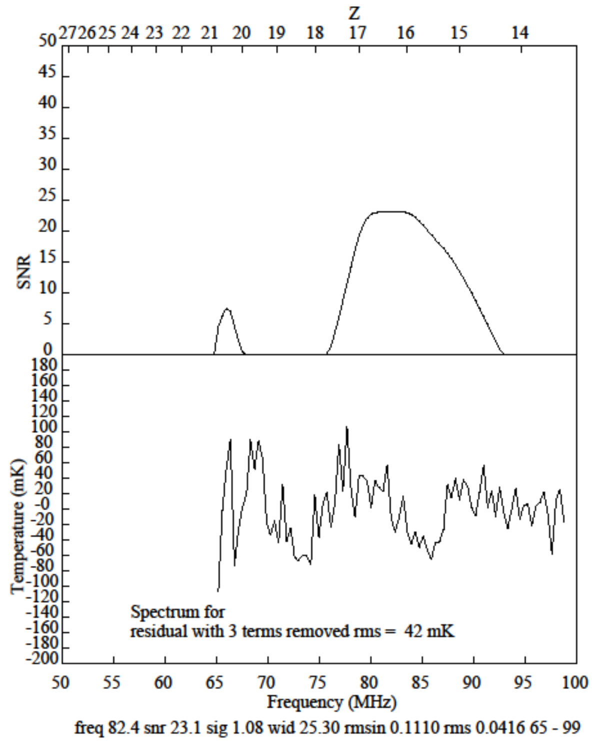

Figure 3. Change to infinite ground plane

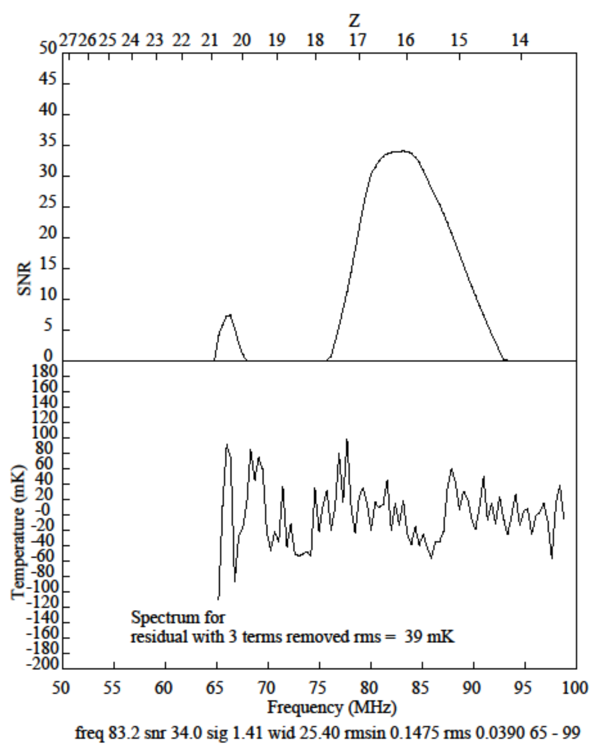

Figure 4. S11 from 2015_289

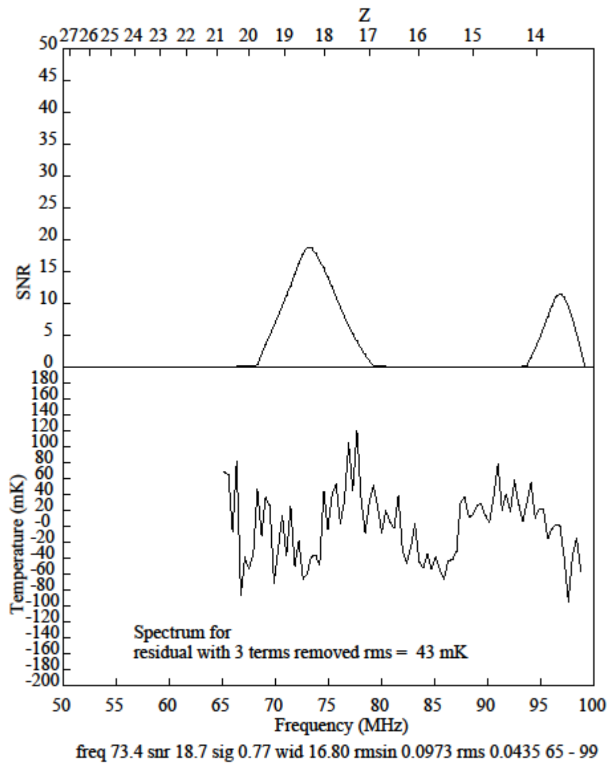

Figure 5. No balun loss

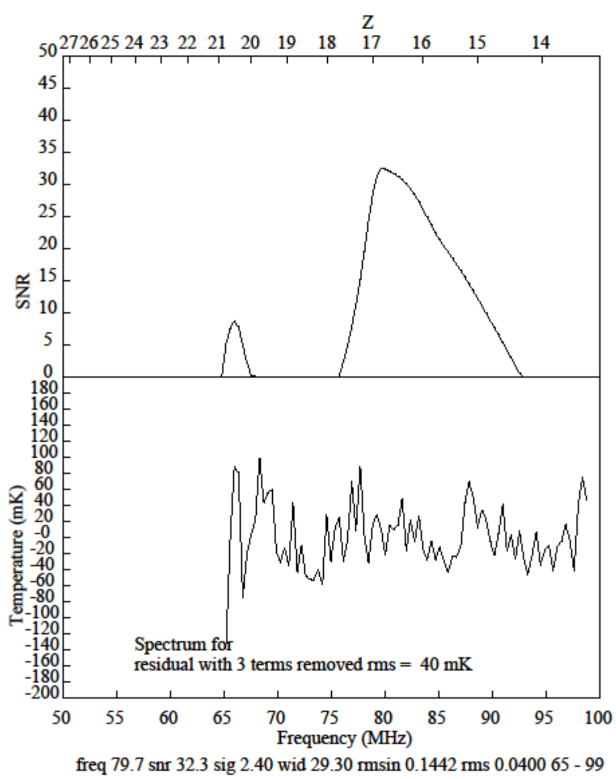

Figure 6. 200 ps added to antenna S11

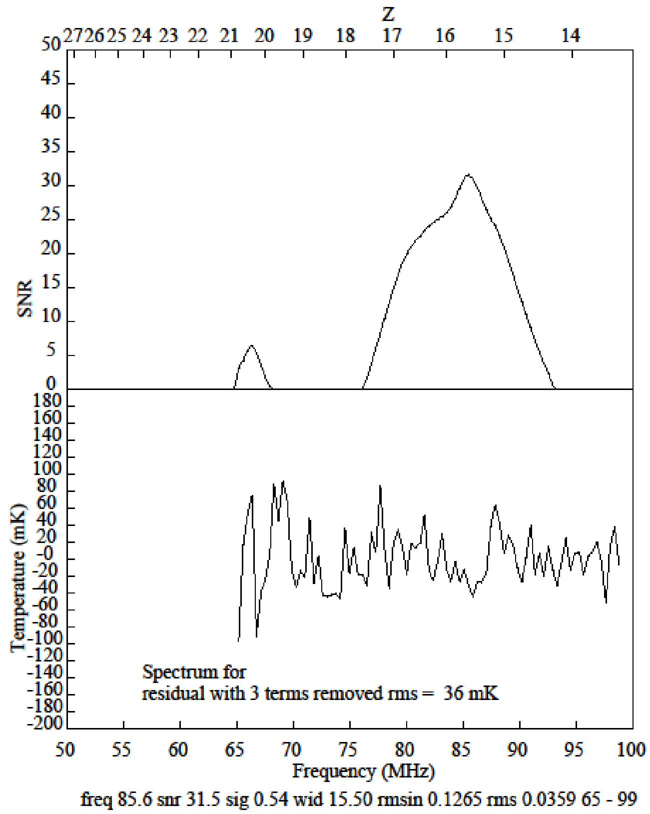

Figure 7. 200 ps subtracted from antenna S11.

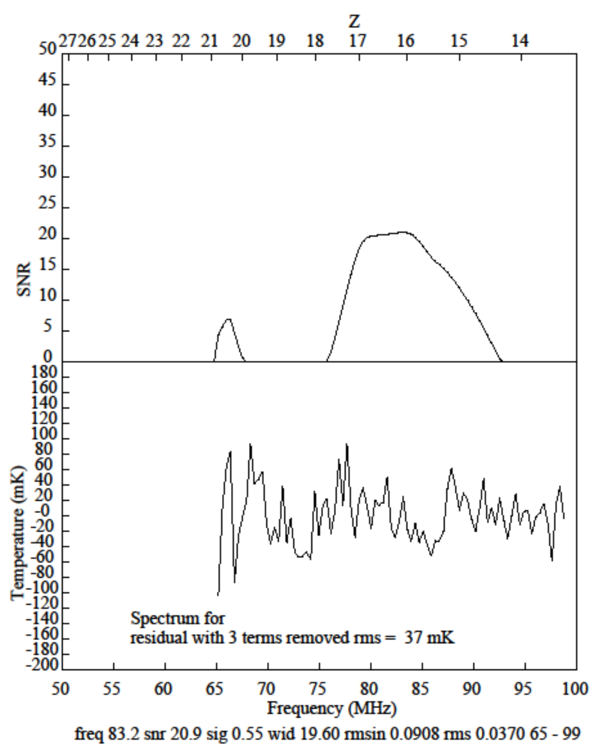

Figure 8. 0.1 dB subtracted from antenna S11.

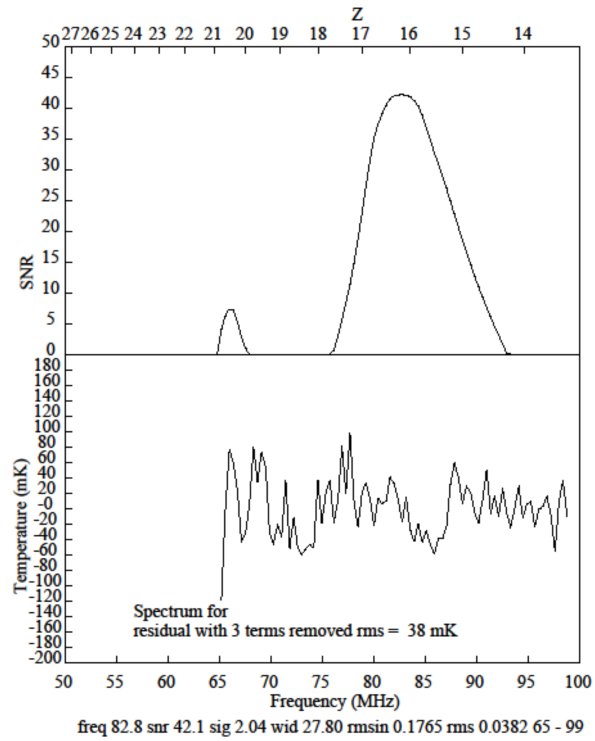

Figure 9. 0.1 dB added to antenna S11.

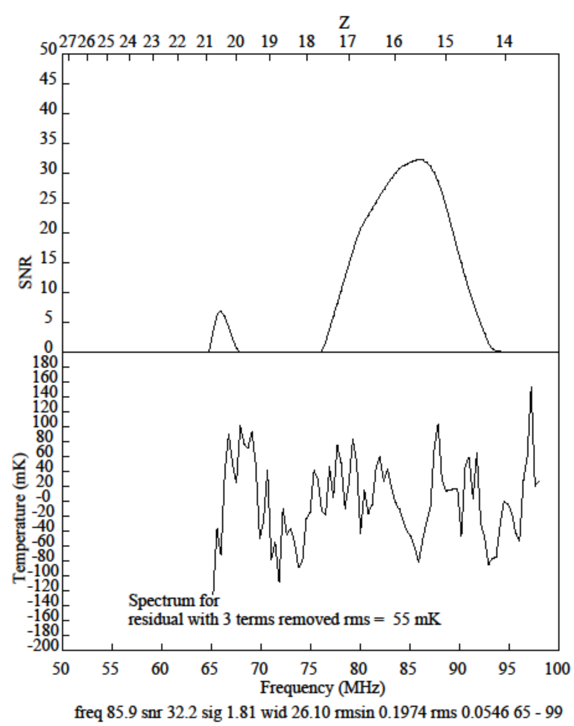

Figure 10. No beam correction.

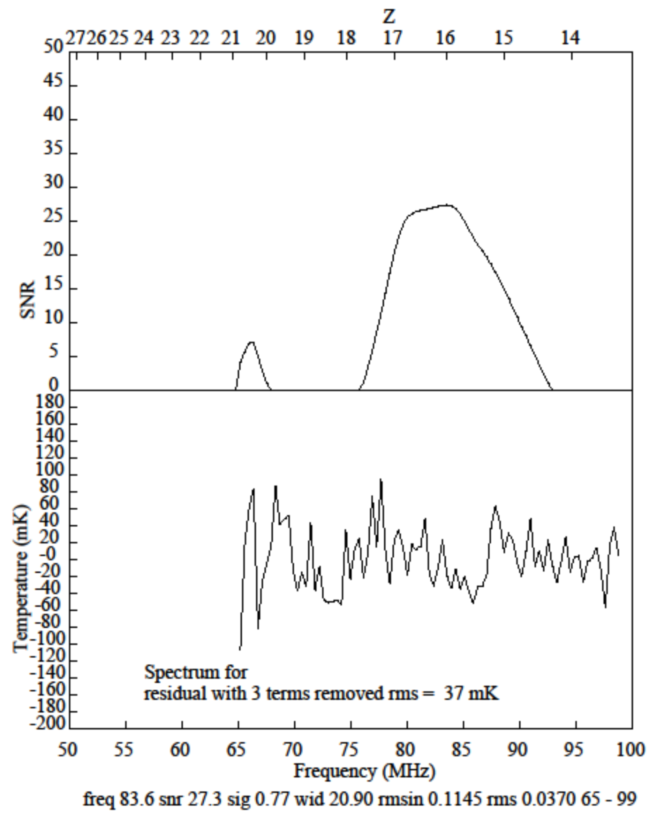

Figure 11. Effect of removing ionosphere.

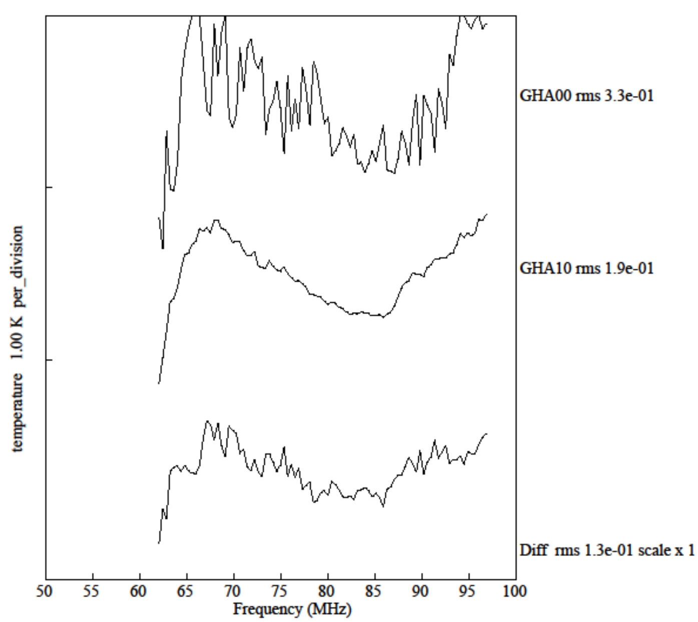

Figure 12. Difference spectrum for 2015_259 to 2016_295 with 3 physical terms removed.

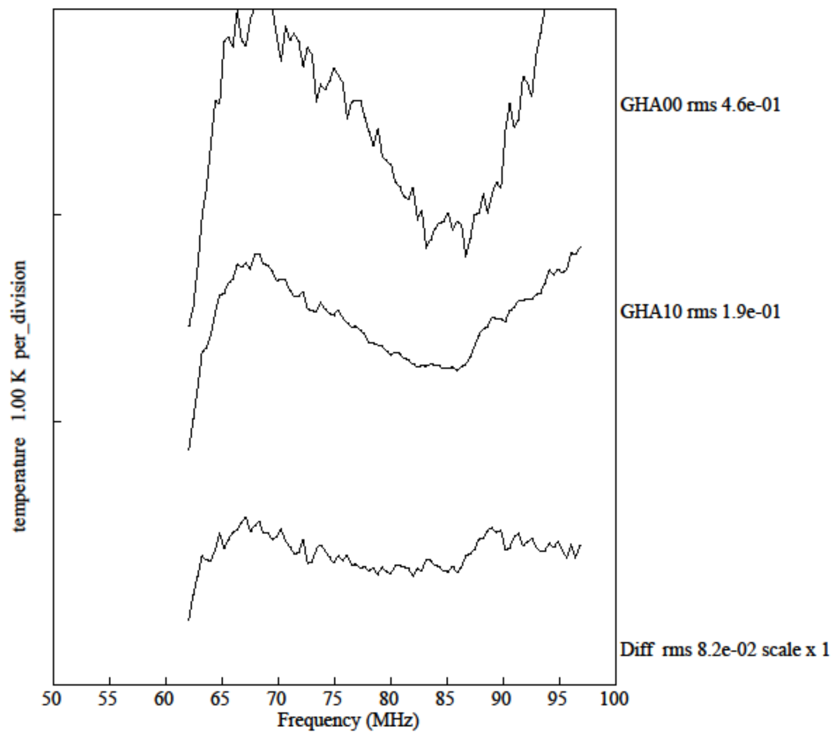

Figure 13. The effect of adding daytime data for GHA=0.

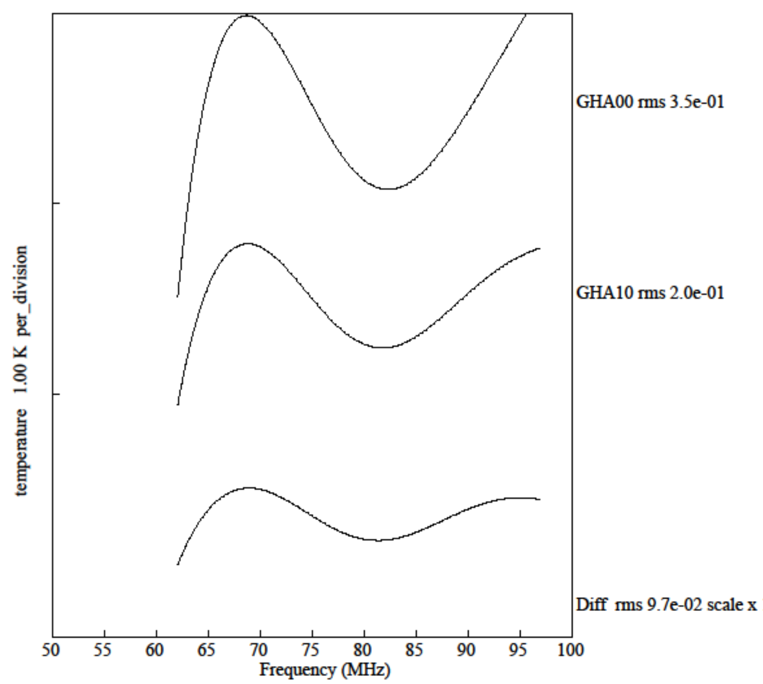

Figure 14. Simulation of 1K Gaussian dip at 80 MHz with 20 MHz FWHM in the presence of ionospheric opacity of 0.5% at 150 MHz.