EDGES MEMO #347

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To: EDGES Group

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Subject: Effect of temperature difference between cable and load in an antenna simulator

An "antenna simulator" consisting of a cable connected to an attenuator which acts as a mismatched load has been used as a check of receiver calibration. In this case it has usually been assumed that the cable and load are at the same temperature so that no cable loss correction is needed. However if the temperature of the load is not the same as the cable a loss correction is needed using the measured S-parameters of the cable in the same way as in the hot load measurements during calibration. The hot load loss corrections are described in memo 113 and Monsalve et al. 2017. In addition to the effect of the temperature difference the effects of VNA error are included in the simulations.

Figure 1 shows a simulation of the use of an antenna simulator using the 10 foot Molex cable shown in memo 199 with an open ended 3dB attenuator to one connector and the other connector connected to the receiver input. The cable temperature is 297 K and the attenuator is 1 degree higher at 298 K. The rms amplitude of the ripples is only 2.1 mK but scales up in proportion to the temperature difference. The ripples and slope go away when a loss correction is made with the cable temperature of 297 K and attenuator temperature of 298 K. Table 1 shows the effects of changes using frequency range of 50-200 MHz.

Case - change	ripple rms mK	comments
Reference case – seen in Figure 1	2.1	10 ft Molex 3 dB atten 1 K diff.
Increase temperature difference to 10K	20.9	10 K difference
Increase attenuator to 6 dB	0.9	1 K difference
10 feet stainless 0.141 cable	5.8	1 K difference
0.001 dB error in antenna simulator S11	1.2	zero temperature difference
10 ps error in antenna simulator S11	69.9	zero temperature difference
0.001 dB error in VNA during calibration	1.3	zero temperature difference
10 ps error in VNA during calibration	99.5	zero temperature difference
1 ps error in VNA during calibration	10.0	zero temperature difference
0.001 dB error in antenna simulator S11	4.8	using noise source zero temp. diff.
0.001 dB error in VNA during calibration	9.9	using noise source zero temp. diff.
1 K difference plus 2e-5 VNA I/Q	3.1	crosstalk in addition to 1 K diff.
10 ps error in VNA cal. plus 6e-4 I/Q	113.7	Crosstalk and zero temp. diff.
0.01 dB S11 error in simulator plus 6e-4 I/Q	62.8	61.5 mK without 0.01 dB error

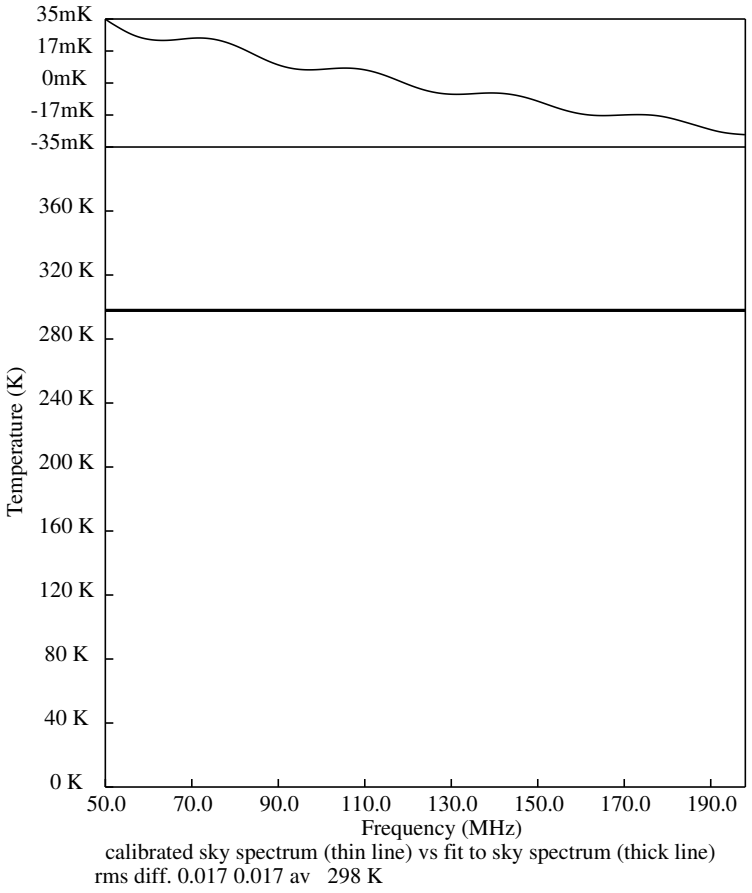
Table 1. Sensitivity of the rms residuals for 3 polynomial terms removed for changes listed in table

The antenna simulator using an ambient mismatched load of the end of a long cable provides a good check of the accuracy of VNA delay error but it not very sensitive to S11 amplitude errors. The sensitivity to S11 amplitude errors can be improved by using a noise source. The noise source simulation test in table 1 is made by replacing the attenuator with a noise source with a spectrum of 300 K at 150 MHz with spectral index -2.5 and same S11 as the open ended 3 dB attenuator. A test of including VNA crosstalk greater than about 2e-5 (see memo 333) has a significant effect on the results of these simulations. Figure 2 shows the residuals for 3-terms for the reference case and the reference case plus I/Q crosstalk of 2e-5. While the effect of I/Q crosstalk increases in proportion to the coefficient it is largely additive and independent of the other changes listed in Table 1. For example the level of 6e-4 only increases the effect of an error of 10 ps in the VNA during calibration from 99.5 to 113.7 mK but I/Q crosstalk does introduce residuals with a finer scale in frequency with a ripple period of half the period the ripple in the antenna S11. Finally, the last entry in table 1 shows that with 6e-4 I/Q crosstalk it will be difficult to detect amplitude error in VNA amplitude.

In summary these simulations show that the effects of a temperature difference are relatively small for a simulator with a mismatched load but while it has the sensitivity to detect small errors in VNA delay or phase it doesn't have the sensitivity to detect small errors in VNA amplitude especially if the VNA has significant I/Q crosstalk.

Reference:

Monsalve, R.A., Rogers, A.E.E., Bowman, J.D., and Mozden, T.J. (2017). Calibration of the EDGES high-band receiver to observe the global 21 cm from the Epoch of Reionization. *Astrophysical Journal* 835(1). doi:10.3847/1538-4357/835/1/49



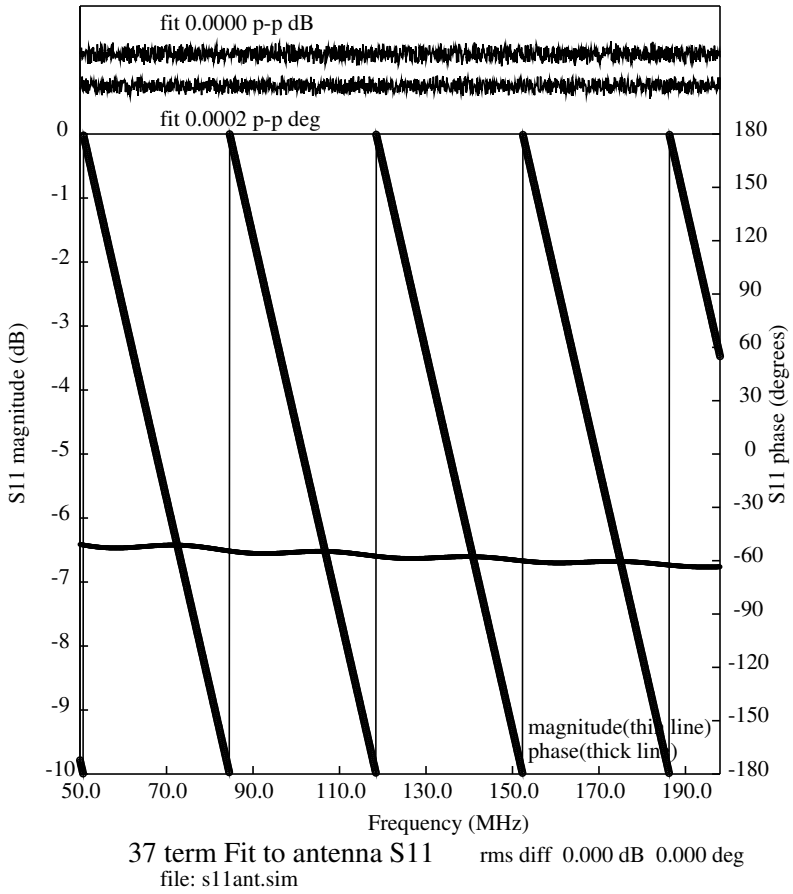


Figure 1. Simulation of the effects of the artificial antenna with 3 dB load at 298 with cable at 297 K.

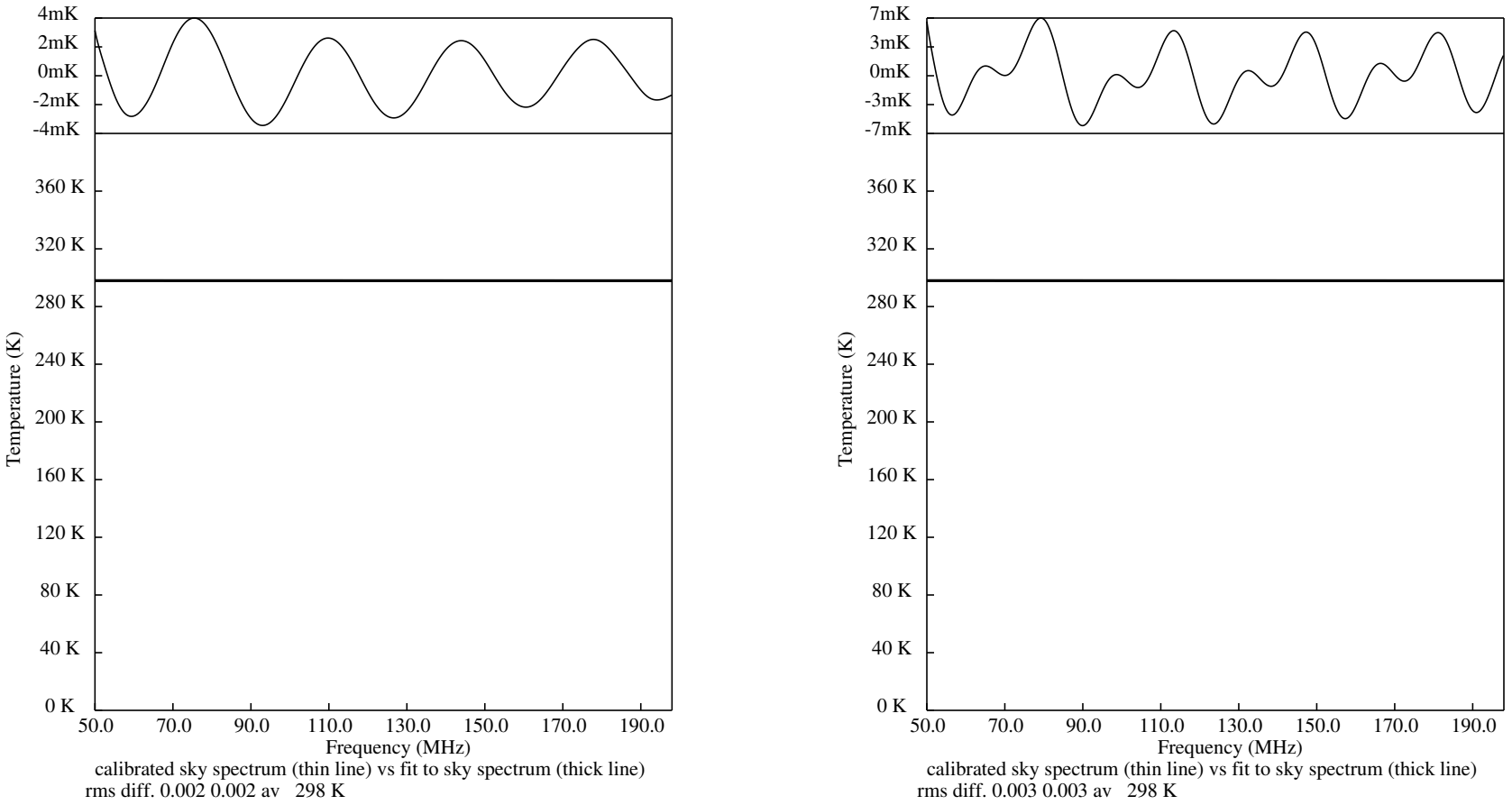


Figure 2. Reference case on the left and reference case plus 2e-5 VNA I/Q crosstalk on the right. In both 3-terms have been removed.