EDGES MEMO #380

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December 13, 2021

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To: EDGES Group

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Subject: Simulations of calibration and tests of sensitivity to sources of error

A complete simulation of EDGES calibration is made by using a circuit model of the EDGES LNA to generate spectra for the ambient and hot loads, open and shorted cables along with the s11 for the LNA, ambient and hot loads, open and shorted cables. This is done in memo 334 to check the consistency of the EDGES noise wave analysis, which is based on the noise wave formulation of Meys 1978, with the EDGES S-parameter formulation with the "F" term in Rogers and Bowman 2012 and Monsalve, Rogers, Bowman and Mozden 2017. For a study of the sensitivity to noise and systematic errors a "simpler" calibration simulation is performed by deriving the spectra for each position of the 3 position switch which are then combined to a single uncalibrated spectrum with arbitrary gain and offset whose choice is found to have no effect on the final calibrated spectra as long as the same values are used for calibration and field data.

The simulation results for the case of spectra and s11 without noise are in Table 1 for which the Nature feature has been added to the sky noise of 300K at 150 MHz with -2.5 spectral index.

fstart	fstop	wfit	cfit	S	O	L	LNA	ant	center	amp	width	rms1	rms2
55	100	5	5	30	30	50.1	0	0	78	0.50	19	73	0
55	100	5	5	0	30	50.1	0	0	78	0.36	21	44	17
55	100	5	5	30	30	50.1	100ps	0	78	0.55	19	79	7
55	100	5	5	30	30	50.1	0	100ps	78	0.50	20	66	12
55	100	5	5	30	30	51.1	0	0	78	0.49	19	67	3
55	100	5	5	30	30	50.1	0.5dB	0	78	0.47	19	67	6
55	100	5	5	30	30	50.1	0	0.5dB	78	0.42	19	59	7
55	100	5	5	30	0	50.1	0	0	78	0.64	18	103	14

Table 1. Tests of the effects errors in VNA calibration SOL and offsets applied to LNA and antenna s11

The first entry is the case with no errors and no noise for which the simulation and processing use the same parameters and wfit = cfit = 5 is sufficient for 0 mK error in rms2 which is the rms residual after fitting the foreground with 5-physical terms and feature for which a perfect result was obtained. rms1 in mK is the residual after fitting without added terms for the feature. Figure 1 shows the results of the calibration with cross-checks. All the residuals are at the few mK level with 5 terms for wfit and cfit. An error in the offset of the calibration short of only 30 ps has a substantial effect on the feature and the calibration cross-check residuals which are shown in Figure 2. A 100ps or 0.5 dB error in the antenna s11 has a significant effect on the feature but doesn't effect the calibration as it is not involved in the

calibration. A 100ps or 0.5 dB error in the LNA s11 does effect the calibration and the 100ps in LNA s11 shown in Figure 3.

Ant noise	Cal noise	VNA noise	Center MHz	amp K	wid MHz	rms1 mK	rms2 mK
0	0	5e-4	78	0.77	19	133	73
0	30x4 sec	0	78	0.53	19	80	9
8 hours	0	0	78	0.59	19	121	87
8 days	0	0	78	0.52	19	78	18

Table 2. Effects of noise. The VNA noise is in fractional units. Spectral noise is in terms of the integration time.

The integration time for calibration noise is multiplied by 4 because hot, ambient, open and shorted cable spectra are needed for calibration. The VNA noise has significant effects at least at the level of 5e-4 and produces ripples as seen in the feature search seen in figure 4 and in the calibration spectra shown in figure 5. The effects of filtering the s11 with a polynomial filter are given in Table 3.

Ant filter # terms	LNA filter # terms	center	amp	wid	rms1 mK	rms2 mK
none	10	78.3	0.77	19.1	133	73
none	27	78.5	0.73	18.6	141	87
10	27	78.4	0.63	18.4	105	36
10	10	78.3	0.67	18.9	100	16
6	10	77.1	0.30	18.9	57	38

Table 3. Effects of polynomial fitting filters on s11 measurements

Table 3 shows the results of filtering the s11. Filtering the s11 of the s11 of the open, shorted cables and the hot and ambient loads is only needed with 27 or more terms if interpolation is needed to accommodate a different frequency spacing for the spectral and the s11 data. A 10-term polynomial is useful in filtering the LNA and antenna s11 as long as it doesn't remove real structure in the s11 which can be observed in the residual plot. For example a 6 term polynomial is an insufficient number of terms to model the real structure as illustrated in Figure 6 for the last entry in table 3.

cfit	wfit	VNA noise	center	amp	wid	rms1	rms2	rms open	rms short
6	6	5e-4	78.4	0.56	20.3	104	76	117	127
7	7	5e-4	75.0	1.72	29.9	151	94	244	251
7	7	2e-4	78.4	0.48	20.4	77	49	76	78

Table 4. Effect of increasing cfit and wfit with high VNA noise

For some EDGES systems more cfit and wfit terms may be needed to account for more frequency structure in the noise waves. However, note that in the second of the simulation the VNA noise will need to be reduced in order to obtain a reasonable calibration. This problem can be recognized by the large cross-check residuals in the open and shorted cables shown in the last 2 columns of table 4.

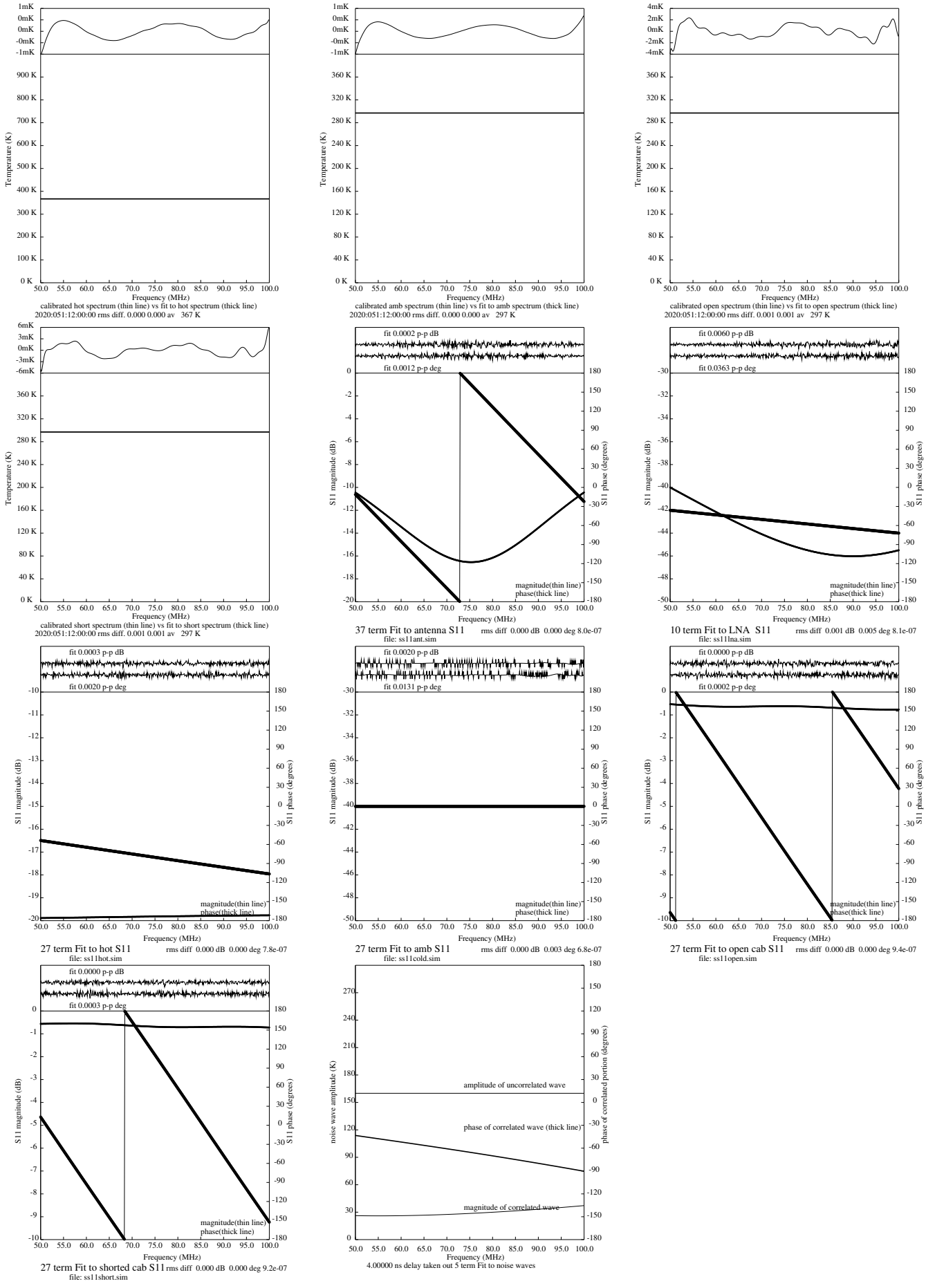


Figure 1. Calibration spectra with cfit and wfit of 5 polynomial terms with details in the first entry of table 1.

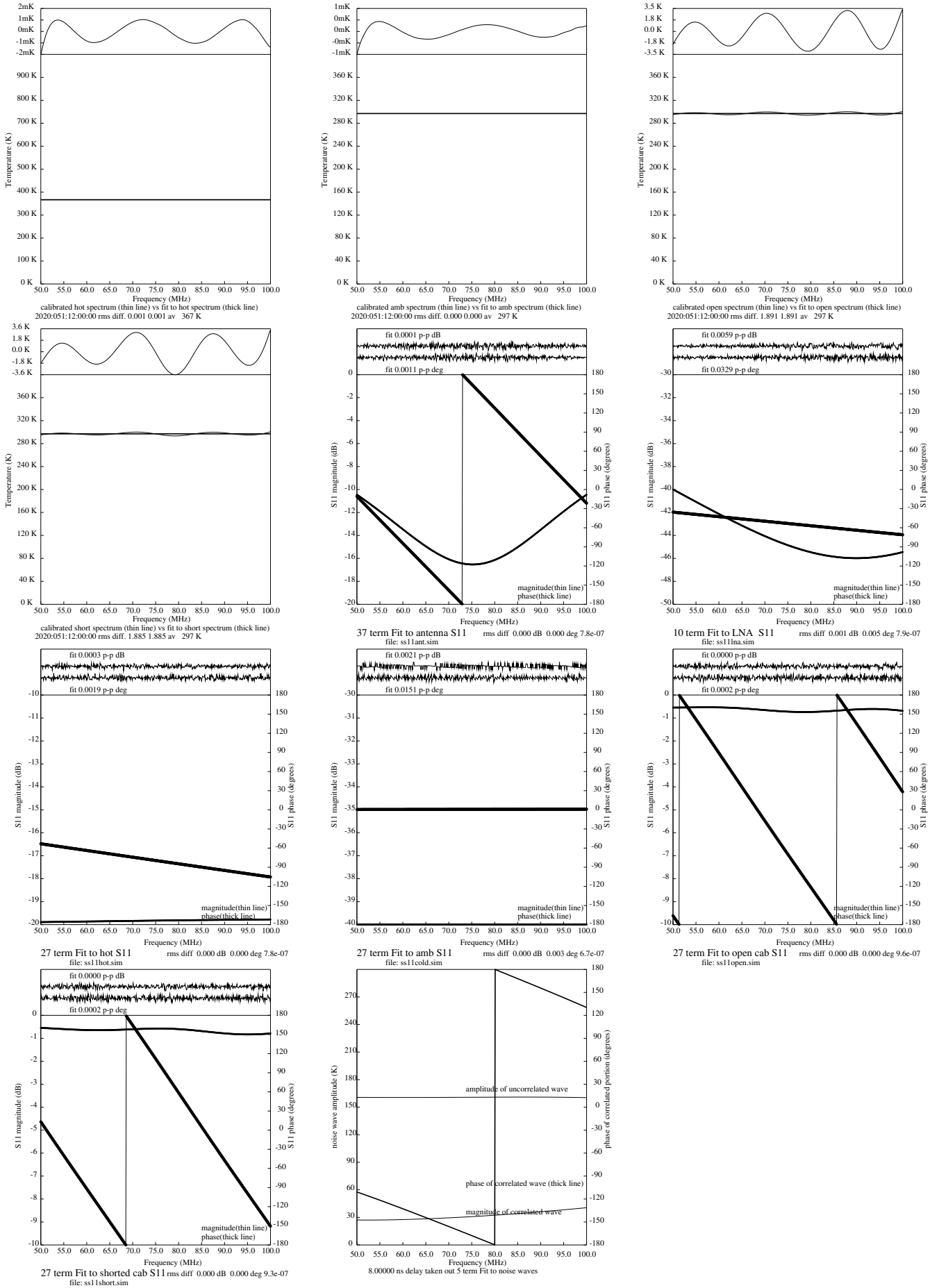


Figure 2. Calibration spectra for s11 data is simulated using 30 ps for the SOL and processed with a an offset of 0 ps for the calibration Short.

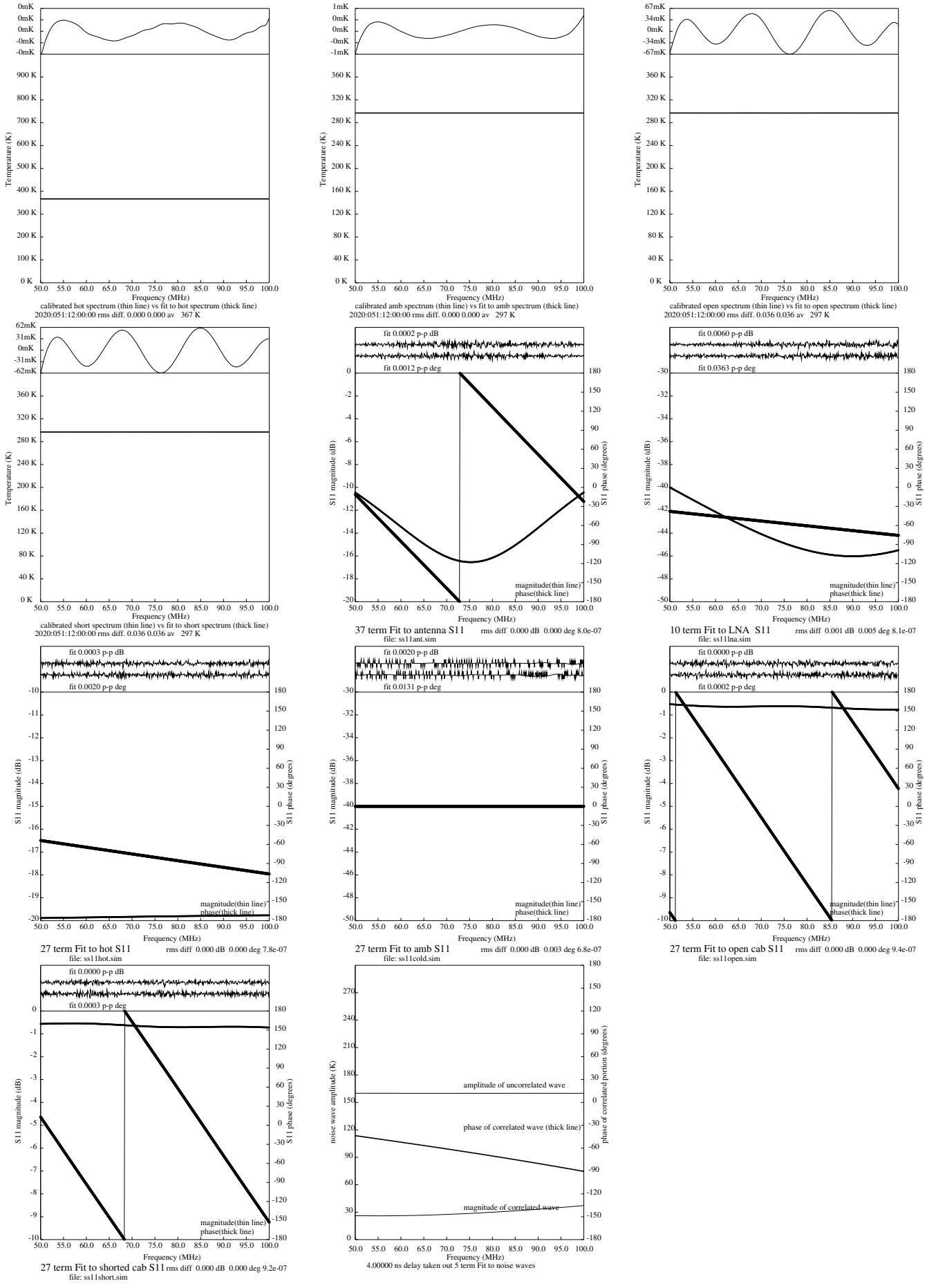
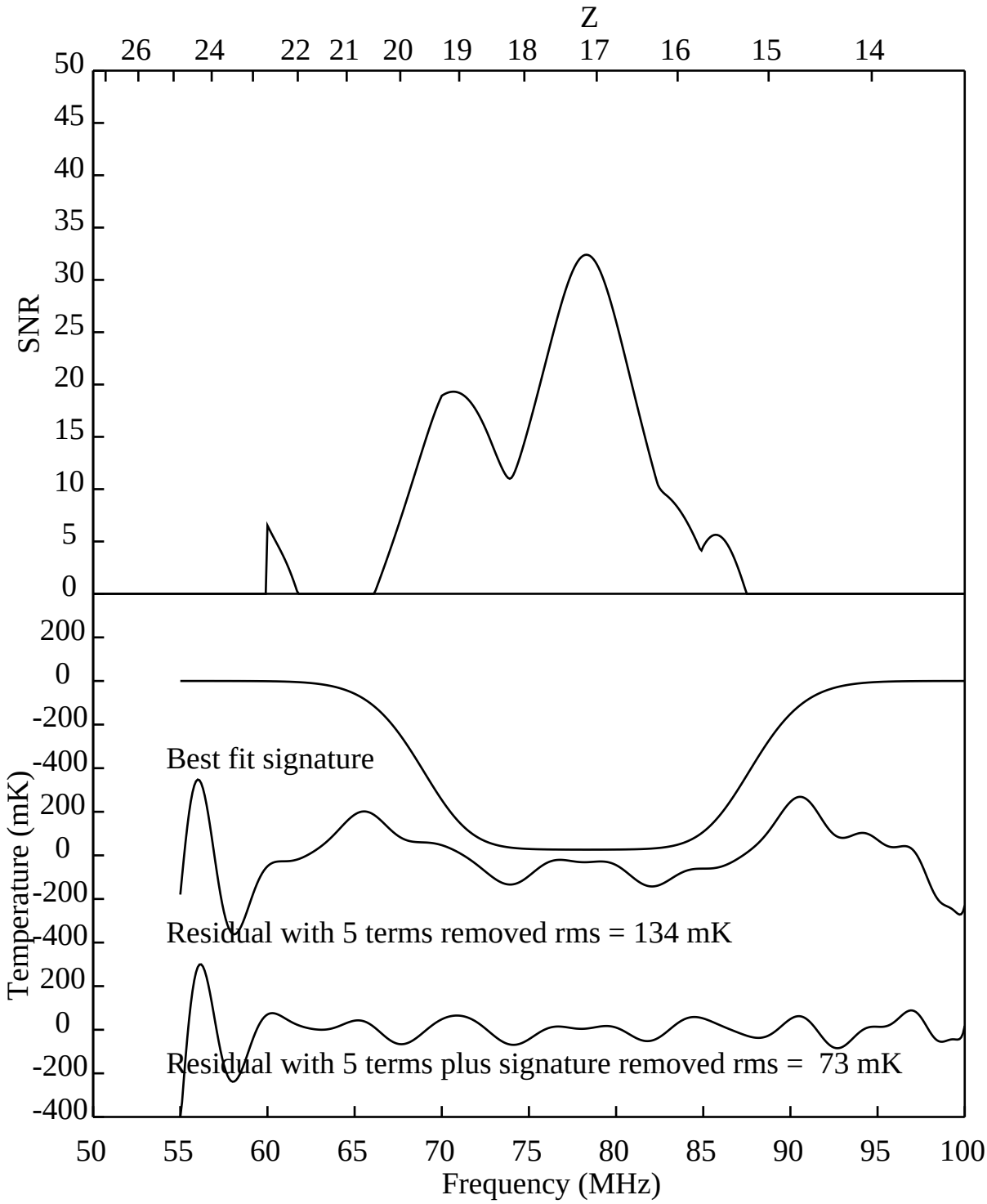


Figure 3. Calibration spectra for s11 data is simulated using an LNA s11 offset of 100 ps.



freq 78.3 snr 32.4 sig 0.77 wid 19.10 tau 7 rmsin 0.1337 rms 0.0733 55 - 100

Figure 4. The effect of 5e-4 noise in s11 has in the spectra of the feature search.

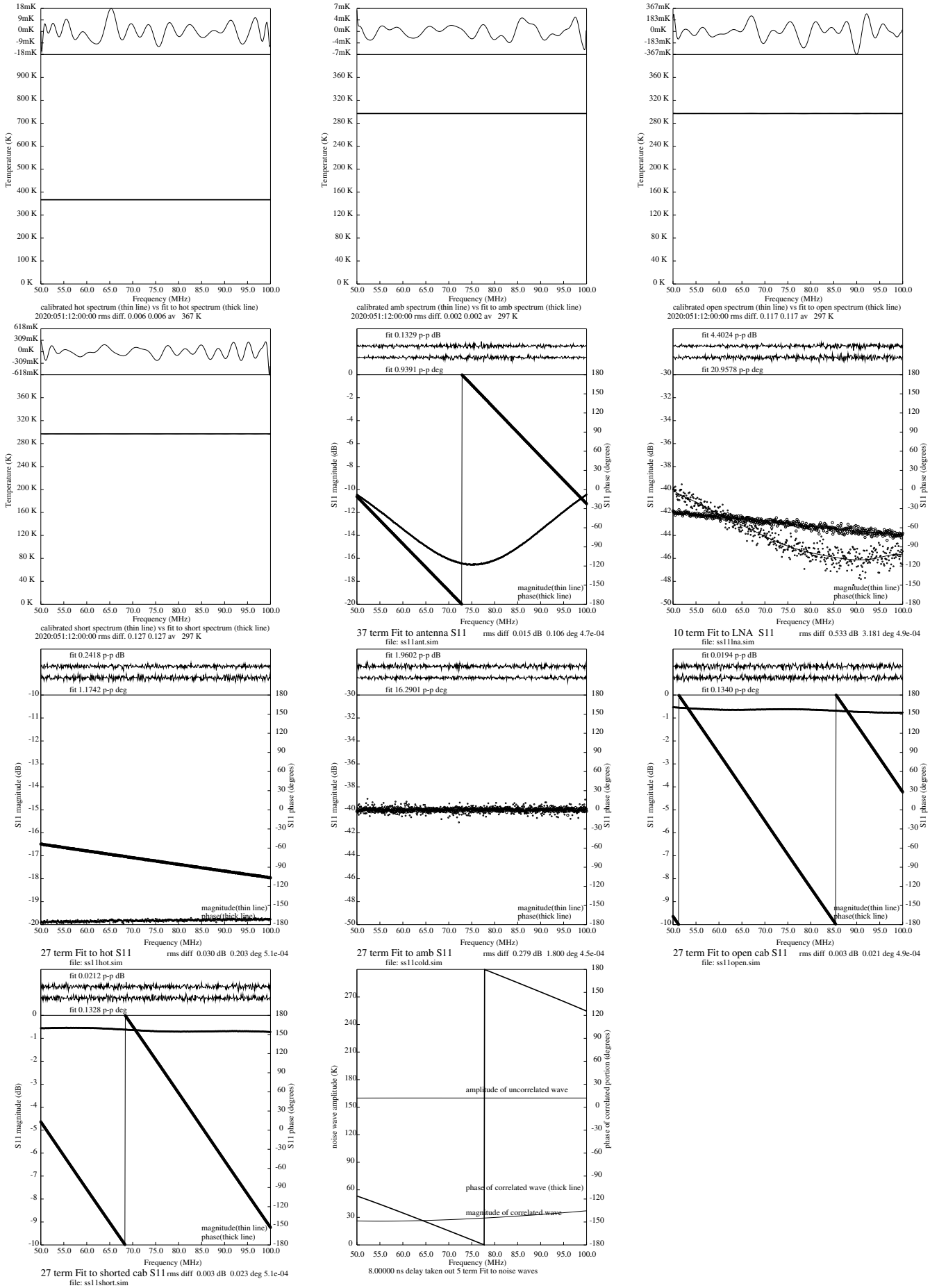


Figure 5. The effects VNA noise of 5e-4 in the s11 on the calibration spectra. While the added noise is Gaussian random noise the effects on the spectra look far from being Gaussian.

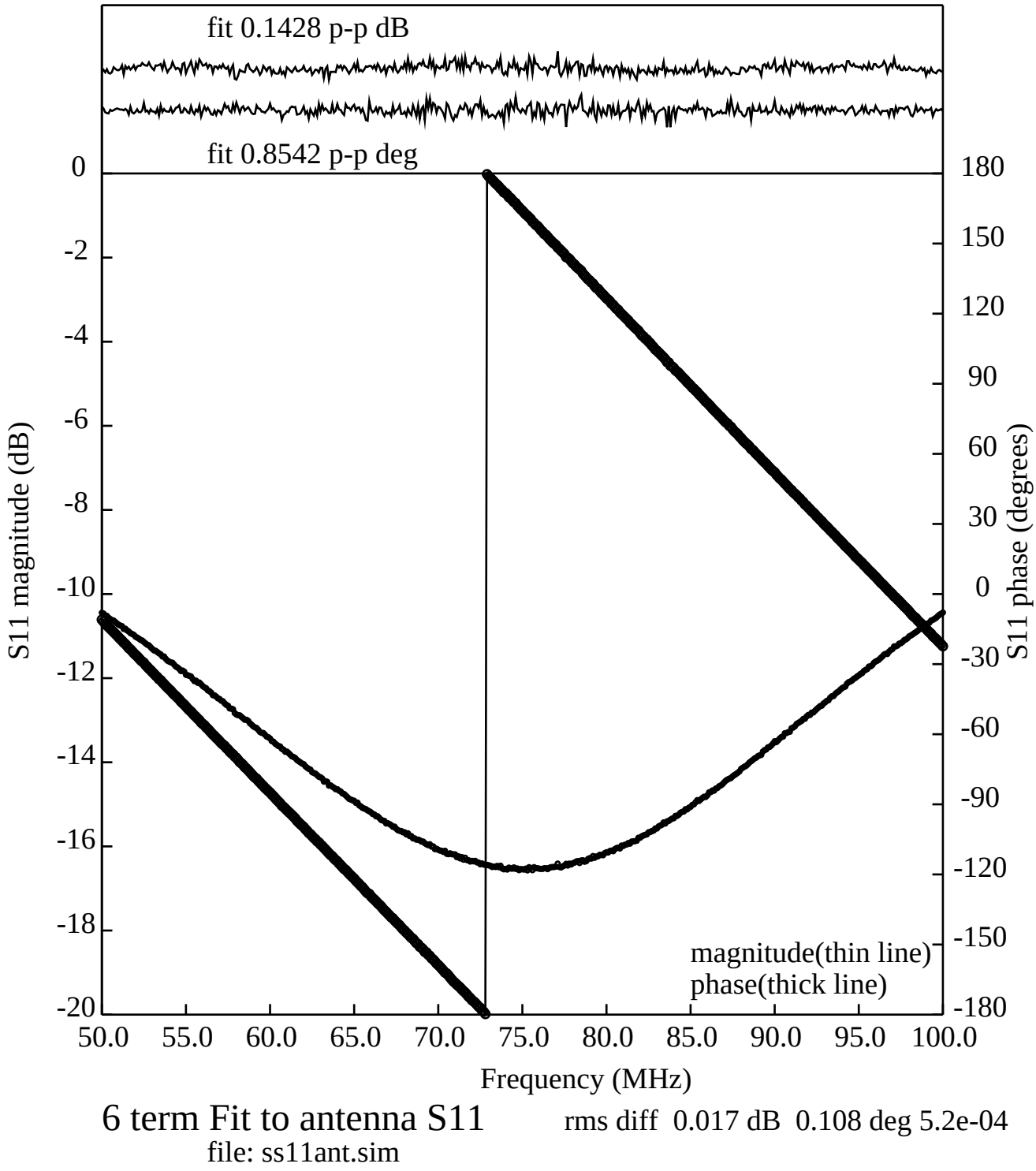


Figure 6. Plot of the 6-term fit to the antenna s11 used in the last entry of table 3.

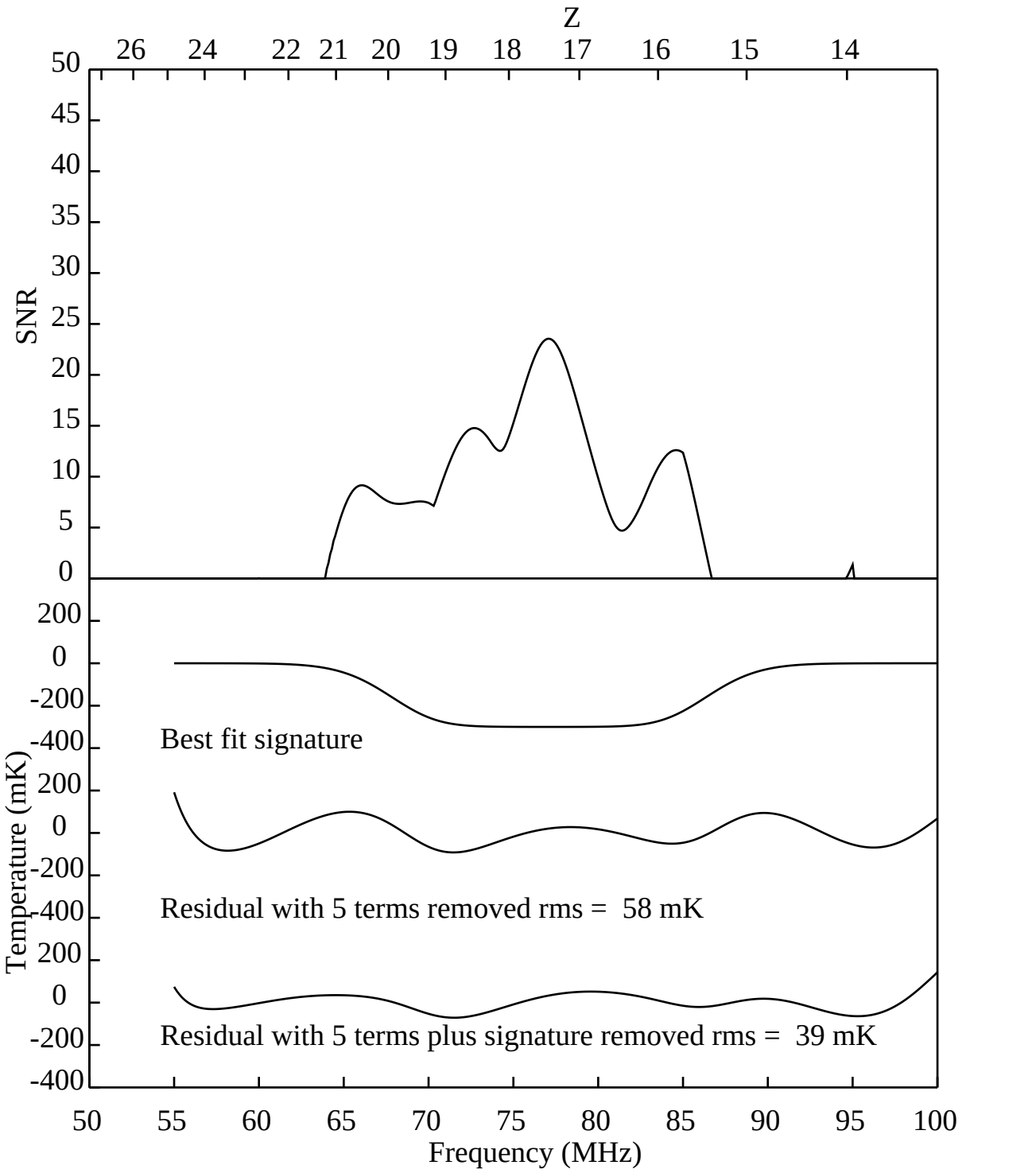


Figure 7. Plot of feature search showing the ripples introduced from using only 6-terms in the fit of the antenna s11 shown in Figure 6.