EDGES MEMO #333

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Subject: Effect of I/Q crosstalk in VNA measurements

A study of systematic errors in VNAs was made in memos 135 and 156. The error source considered was non linearity. Most other error sources like a bias in S11 phase and offsets in the real and imaginary components of the S11 are removed in the calibration as along as the same errors are present in all 4 raw "input" measurements of calibration short, open and load (SOL) as well as in the device measurement.

Non linearity and crosstalk are not removed in the calibration process. Since EDGES requires an accuracy well beyond the accuracy specified by the manufacturer it is important that EDGES-3 use a VNA with the highest accuracy and be able to detect VNA inaccuracy and possibly make corrections.

Memo 332 looks at the detectability of error sources due to errors in the assumed values of the SOL calibration parts and the resistivity of the mechanical switches assuming that there are no errors in the VNA.

This memo looks at the effects and detectability of I/Q crosstalk in the VNA

Crosstalk is simulated using

$$\text{Tout} = (\text{real}(\text{Tin}) + c*\text{imag}(\text{Tin})) + i(\text{imag}(\text{Tin}) + c*\text{real}(\text{Tin})) \qquad (1)$$

where Tin is the original S11, Tout is the S11 with fractional crosstalk of c

A level of "ripples" have been found the antenna S11 2020 data from lowband with the antenna rotated by 45 degrees which go away when a correction of c = -6e-4 is applied is evidence for the presence of crosstalk at the level of 6e-4 in the VNA which replaced the VNA used in earlier EDGES measurements at the MRO.

Table 1 below shows the effects and detectability of crosstalk in the VNA

error	center MHz	SNR	amp K	width MHz	rms in mK	msfit mK	detectivity mK	case
0	78	4000	0.50	19.0	47	0	0	A
1e-4	78	116	0.53	19.0	50	3	112	B
8e-4	78	20	0.72	18.7	72	22	907	C
8e-4	78	20	0.71	18.7	71	22	907	D
8e-4	78	999	0.50	19.0	47	0	4	E
8e-4	82	16	0.15	14.7	31	11	907	F
8e-4	78	45	0.57	19.0	54	8	0	G
8e-4	77	27	0.69	22.3	60	14	0	H
8e-4	78	43	0.59	19.2	55	8	0	I
0	78	60	0.52	19.3	48	5	0	J

Table 1. Effects of VNA I/Q crosstalk on signature detection and the detectability of I/Q crosstalk in VNA

Table 1 shows the simulated effects of VNA I/Q crosstalk for EDGES-3 for which a common VNA is used for all VNA measurements. Cases A through E are simulations for which an absorption with the parameters of case A and tau=7 has been added to the sky noise spectrum. Case D is for no crosstalk when the VNA is measuring the LNA S11. Case E is when the crosstalk is only present when measuring the LNA S11 and has very little effect. In practice the crosstalk may be quite different when measuring the LNA because the output level has to be set at a low level but this crosstalk just degrades the S11 of the LNA and cannot be detected unless very large. Case F is case C without any added absorption to check the parameters of an absorption produced by uncorrected crosstalk.

The frequency range for the signature search is 60 to 100 MHz and 50 to 120 MHz for the detectability in the ripple of the residuals produced by VNA I/Q crosstalk in the residuals to the fit to the calibrated spectra of the open and shorted cables used in calibration.

Case G is when the crosstalk is only in the VNA measurements of the antenna, which the likely to be the case in EDGES-2. Cases H and I are the same as case G but when a 10-term and 12-term polynomial filter are applied to the calibrated antenna S11 respectively. It is noted that while the 12-term smoothing has a small but significant effect the 10-term smoothing has a large effect in the presence of the crosstalk. Case J shows the effect of the 12-term smoothing without crosstalk is smaller.

Figure 1 shows the spectra and s11 for the simulated observation and calibration case C. Note the ripples present in the residuals to the calibrated spectra on the open and shorted cables shown in a single plot. There are also ripples in the fits to the ambient and hot loads as a result of the VNA crosstalk. Figure 2 shows a fit to the antenna S11 using a 10 term polynomial from case H which shows the ripples not seen in the antenna S11 shown in Figure 1 because no polynomial smoothing fit has been applied in case C.

The effects of crosstalk are approximately linear with the value of c. The value of 8e-4 is a little higher than a value of 6e-4 found to correct ripples in the VNA being used in 2020 observations at the MRO. A value of 8e-4 used in Table 1 higher than expected for a VNA.

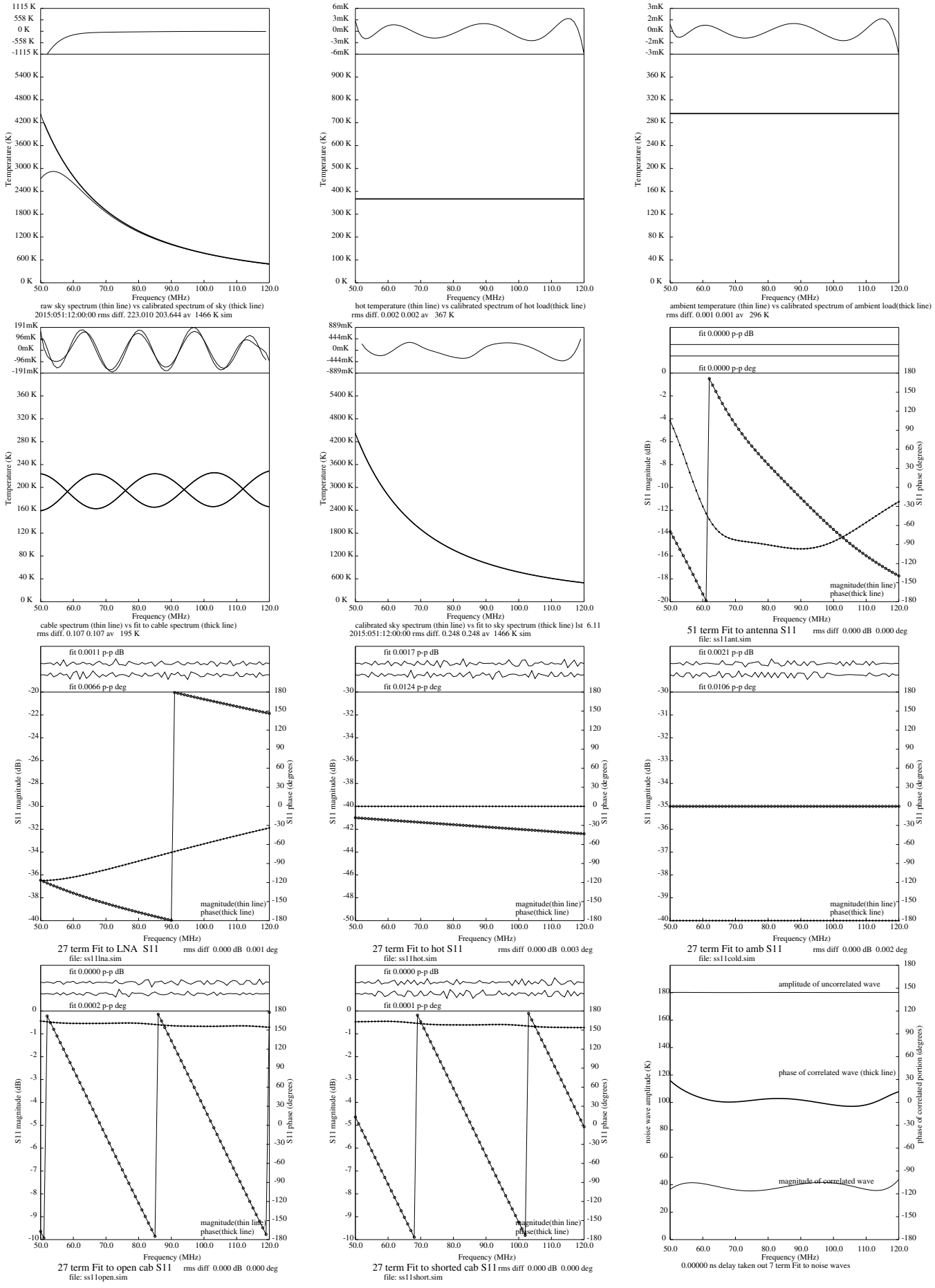

Figure 1. The spectra and S11 from a simulation using a VNA with a crosstalk of 8e-4 which is case C in Table 1.

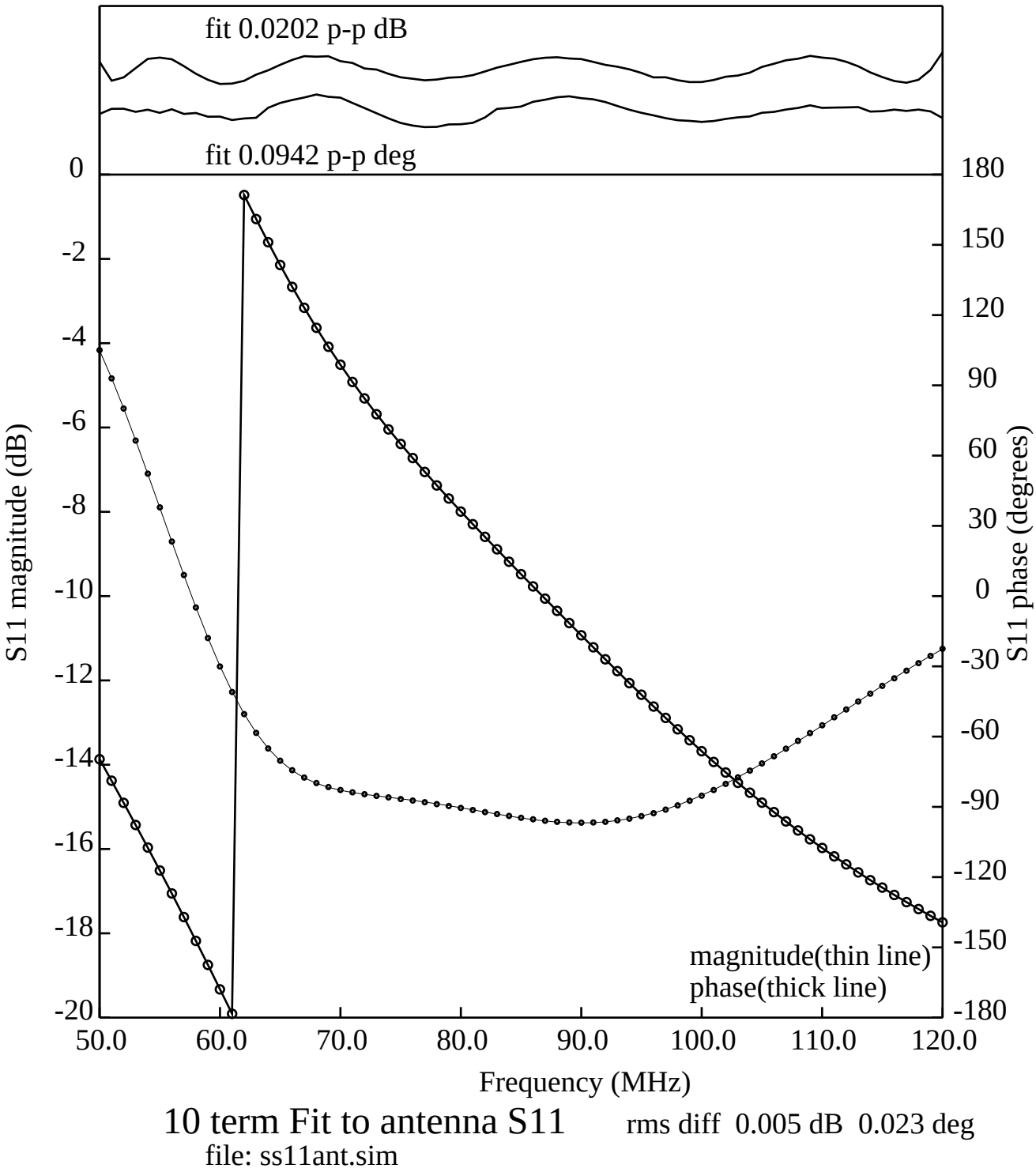

Figure 2. The antenna S11 with 10-term polynomial to smooth the ripples produced by the 8e-4 crosstalk in the VNA.