EDGES MEMO #319

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January 6, 2020

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To: EDGES Group

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Subject: Simulations of the sensitivity of systematic errors in VNA S11 measurements to LNA parameters.

EDGES is limited by systematics rather than noise but the presence of LNA noise emitted from the input, and input miss-match still play a large role in the level of systematics. The need for a very good input match and low noise waves, especially low correlated noise has been recognized and studied in memos 16, 50, 62, 76, 77, 102, 105, 136, 164, 165, 218, 237.

In this memo the circuit model in memo 62 used for simulations has been augmented to include the 3 resistors of an attenuator and their associated noise.

Figures 1 and 2 show the LNA S11 and the noise waves respectively from a circuit model which includes a 3 dB attenuator on the input of the ATF-54143 with feedback.

Using simulated data generated using LNAs with different values of correlated and uncorrelated noise waves, LNA S11 and antennas S11 the sensitivities of VNA errors in magnitude and phase or delay have been estimated. Since the parameter space is very large the noise wave amplitudes and phase LNA and antenna s11 magnitudes are assumed to be constant in frequency. With these simplified assumptions the following sensitivities are obtained:

1] Very little sensitivity to uncorrelated noise if $T_{uncorrelated} < 300$ K

2] Sensitivity to antenna S11 delay

600 mK/120K $T_{correlated}$/33 ps /0.3 antenna S11 where the 600 mK is the rms residual to a 1-term fit of the sky noise spectrum.

$$T_{sky} = 300(f/150)^{-2.5}$$

where f = 50 to 200 MHz

The "/"s indicate that the rms fit is approximately proportional to the 120 K correlated noise wave, the 33 ps delay error in the antenna S11 and the S11 = 0.3 (-10.46 dB) so that doubling any of these quantities doubles the rms. Only the effects of error in the VNA measurement of antenna S11 are dependent on the correlated LNA noise and only significantly for $T_{correlated} > 60$ K.

3] Sensitivity to antenna S11 magnitude

500 mK/10^{-3}/0.3 antenna S11 where 10^{-3} is the change in antenna S11 magnitude in this case there is no sensitivity to LNA noise waves.

4] Sensitivity to LNA S11 delay

200 mK/33 ps /0.03 LNA S11

This shows the large sensitivity to LNA S11 so that doubling the LNA S11=0.03 (-30.4 dB) to 0.06 (-24.4 dB) increases the rms to 400 mK.

5] Sensitivity to error in measurement of LNA S11 magnitude is 500 mK/10^{-3}/0.3 antenna S11.

and is largely independent of noise waves and the magnitude of LNA S11.

The presence of a significant correlated noise wave makes the measurement of the delay of the antenna S11 more sensitive to errors in the VNA accuracy. A separate test shows that an error of 33 ps all S11 measurements, including those used in calibration results in a rms with 1-term removed of 960 mK for a correlated noise of 120 k and an antenna and LNA S11 of 0.3 and 0.03 respectively. Table 1 shows the sensitivity for different values of correlated noise and S11.

			Rms mK	
$T_{correlated\ K}$	Antenna S11	LNA S11	1-term	5-term
120	0.3	0.03	960	46
60	0.3	0.03	626	35
0	0.3	0.03	433	24
120	0.3	0.003	77	24
120	0.03	0.003	77	3
0	0.03	0.003	29	0.4

Table 1. Effect of VNA delay error of 33ps on all measurements including calibration. 1-term fit 50-200 MHz 5-term fit 50-120 MHz.

In the case of the LNA whose noise waves and S11 were simulated from the circuit model the sensitivities are given in Table 2.

	rms (mK)		
VNA measurement error	Case 1	Case 2	Case 3
Antenna S11 magnitude 33 ps	401	95	17
Antenna S11 magnitude 10^{-3}	475	332	39
LNA S11 delay 33 ps	261	76	9
LNA S11 magnitude 10^{-3}	481	361	37

Table 2. Simulations of VNA measurement errors (case 1) using circuit model and antenna S11=0.3.

All the systematics are reduced by a factor of 10 for an antenna with S11=0.03 so that in addition to having a LNA with good input match and low correlated noise it is important to have an antenna with a good match to avoid being limited by VNA accuracy. The rms values in case 1 are for the circuit model for case 2 and case 3 are for midband 60-120 MHz for a 1-term and 4-terms removed using sky model at GHA=12 hours at the MRO respectively. Figures 3 and 4 show the LNA S11 and noise waves from the 2018 calibration of receiver 1. Figure 5 shows the antenna S11.

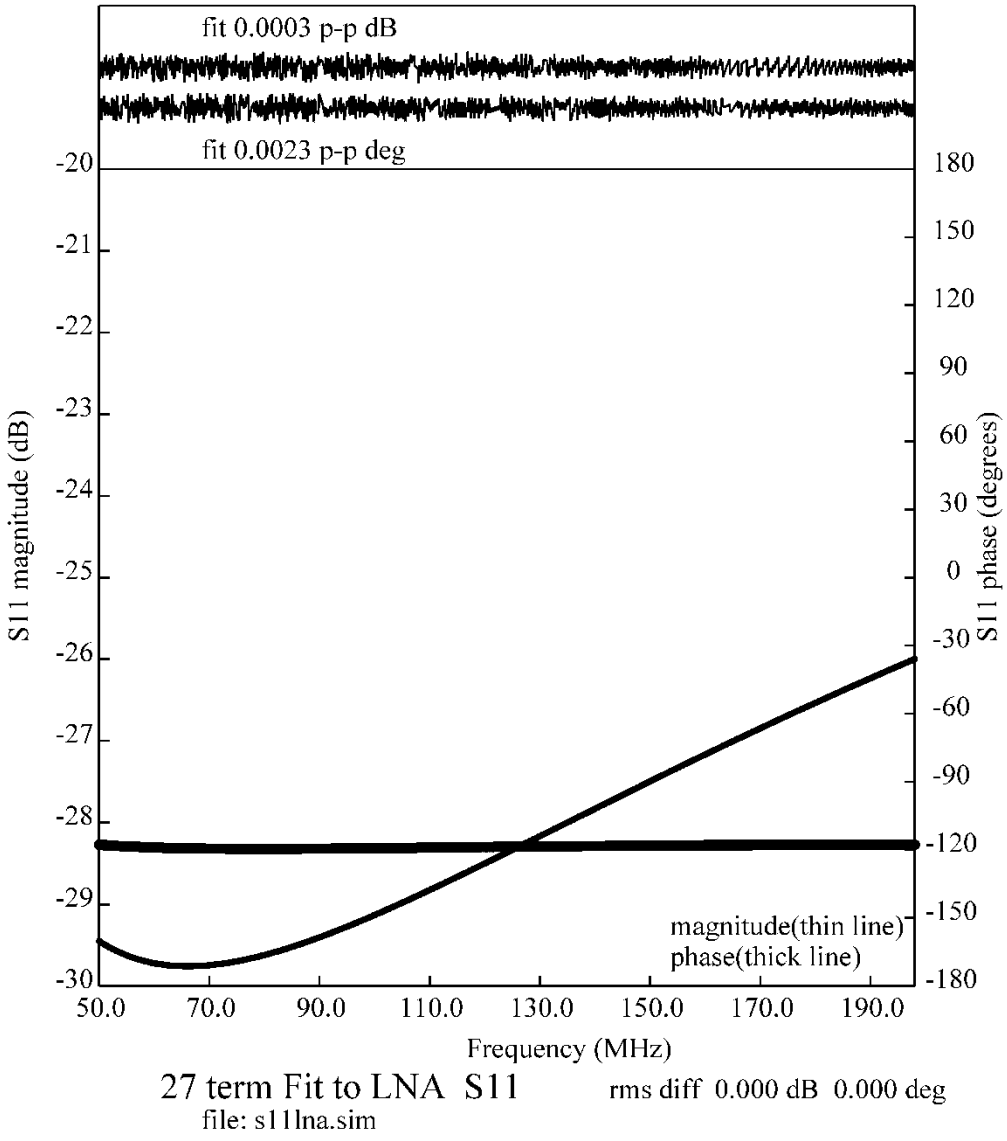

Figure 1. S11 of LNA with 3 dB attenuator from circuit model.

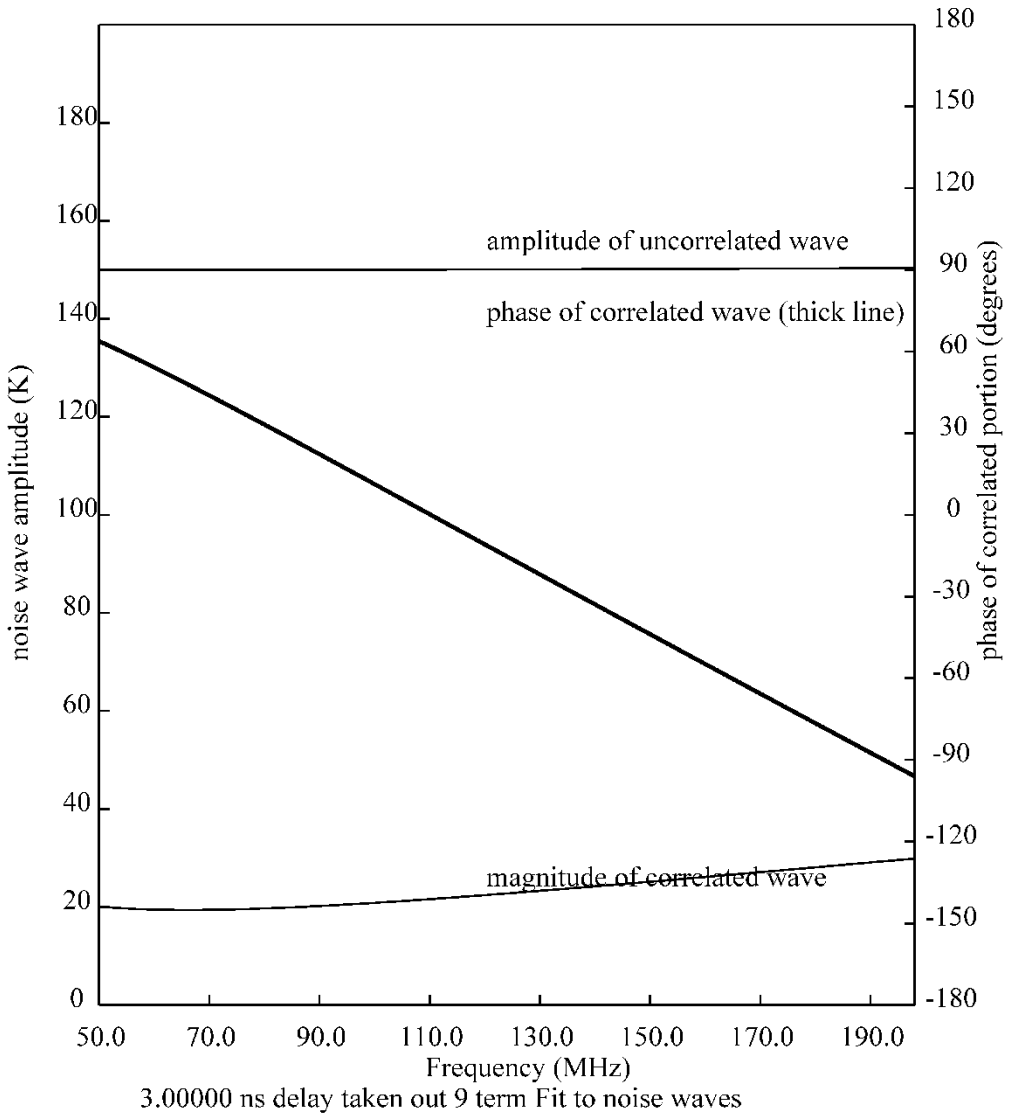

Figure 2. Noise waves from circuit model.

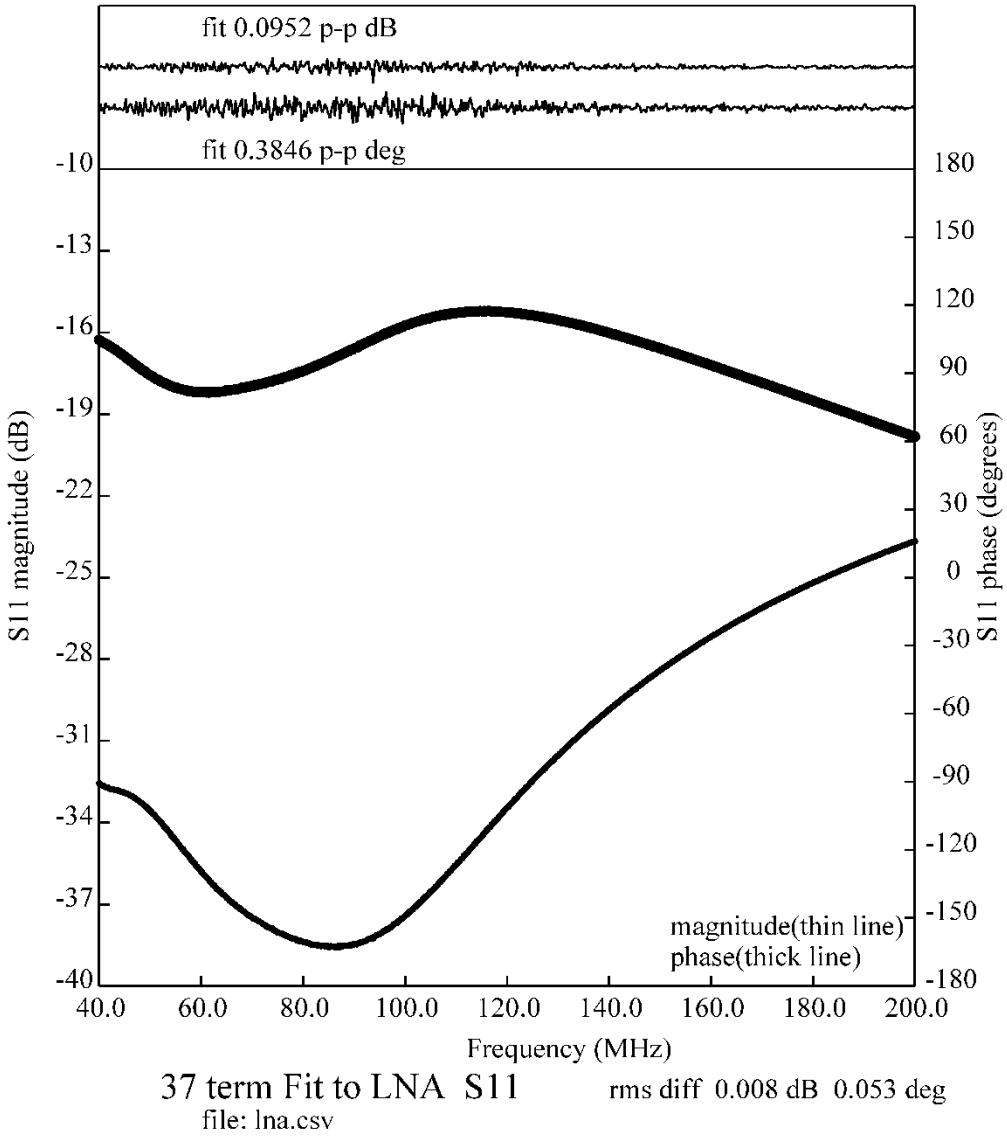

Figure 3. S11 of midband LNA in receiver 1.

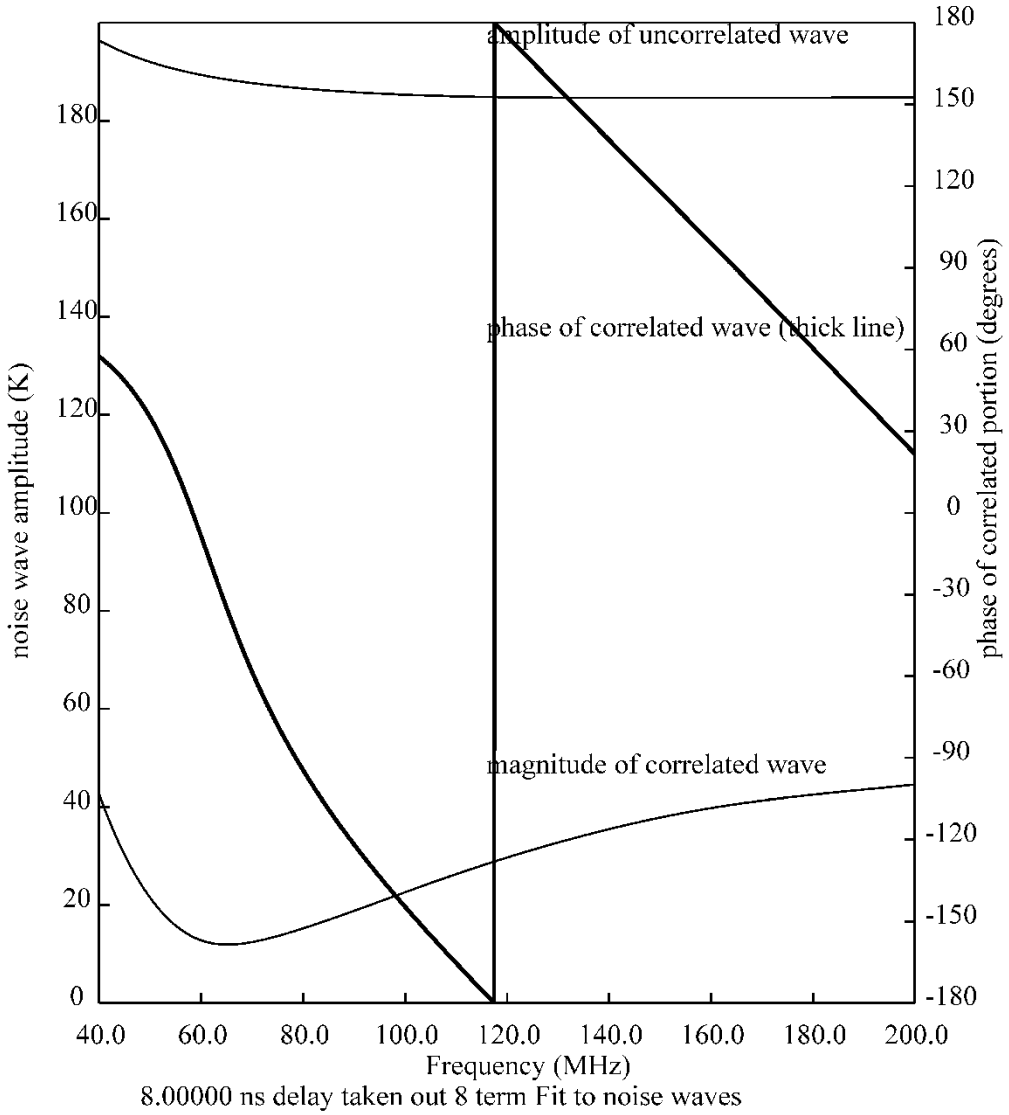

Figure 4. Noise waves from midband LNA.

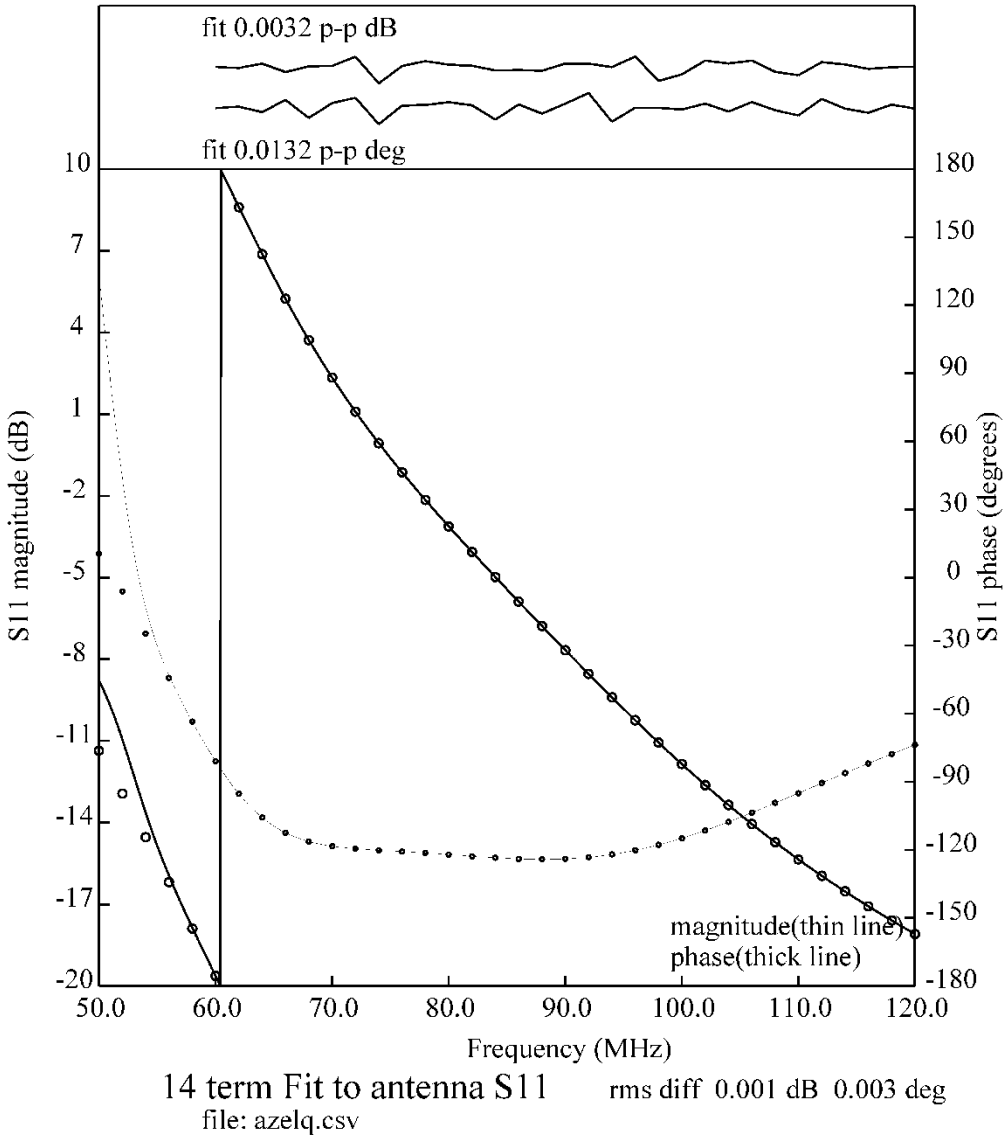

Figure 5. S11 of midband antenna in 2018.