EDGES MEMO #332
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Subject: Simulations of the self-detectability of error sources in EDGES-3

1] Introduction

EDGES-3 is designed as a self-contained system with built-in automated self-calibration so that changes in the input S11 of the LNA and it's noise waves for example are corrected by the automated calibration. While all drifts in the electronics due to aging are corrected by calibration some changes like aging of the resistance of the Keysight internal calibration load can be detected by high residuals in the calibrated spectra from the open and shorted cables but may not be corrected without a lab measurement. These high quality SOL parts should be stable and not age since they are permanently attached and not being removed and re-connected. The calibration load resistance and the temperature coefficient of the resistance were accurately measured prior to the assembly and installation into the EDGES-3 front-end module. Other critical parts are the switches. The most critical being any changes in the contact resistance (see memo 238) to the internal SOL and especially the matched load. This memo uses simulations to estimate the effects of changes and their detectability and potential for correction without the need to return EDGES-3 to the lab.

2] Simulations

EDGES-3 simulation software has been improved by revision of the circuit model described in memo 319 to improve modeling of the LNA input S11 and the noise waves. To evaluate the effects of systematic errors in EDGES-3 simulated spectra and S11 data have been generated over a frequency range of 50 – 199 MHz using a sky model with spectral index -2.5 and strength of 300 K at 150 MHz. An absorption with the parameters of the result published in Nature has been added to the simulated sky noise spectra. This simulated data is then processed with the full available receiver bandwidth of 50 – 199 MHz to obtain the calibration and the simulated sky data analyzed over the frequency range of 60 – 100 MHz to determine the sensitivity to systematic errors. This sky data is calibrated and a grid search is made for the best fit absorption with fixed value of tau = 7 using a 5-term physical model for the foreground. Various sources of potential error are then introduced to see what happens to the best fit parameters for the absorption and test the level of detectability of the presence of the error in the rms residuals to the open and shorted cables used for the calibration. The results are shown below in Table 1 where rmsin is the rms fit to the foreground plus absorption and rmsfit is the rms fit when the best fit absorption is included. No noise is added so that the rmsin is zero when no sources of error are introduced and the nominal values of the absorption that was added to the sky is perfectly retrieved. For these simulations a frequency spacing of 1 MHz was used to match frequency spacing simulated LNA and beam data.

3] Comments on the results

error	center MHz	SNR	amp K	width MHz	rmsin mK	rmsfit mK	detectability mk	comments	case
no error	78	inf	0.50	19	47	0	0	Nature result as ref.	
+ 4% diel	78	11	0.33	19.9	35	17	750	change in internal cable	
- 10% diel	79	18	0.88	17.3	183	43	1887		
+ 0.3% diel	78	187	0.48	19	49	2	55	max teflon knee	
- 0.3% diel	78	221	0.51	19	49	1	55	min teflon knee	
- 0.5 ohm	78	14	0.37	19.8	36	15	490	error in load resistance	A
+1.0 ohm	79	18	0.72	17.6	92	30	1700		
- 0.1 ohm	78	85	0.47	19.1	44	3	160	error in load resistance	
+0.1 ohm	78	100	0.53	18.9	50	3	160	max error expected	
-30 ps load	78	752	0.50	19	47	0	40	error in load offset	
+30 ps	78	49	0.45	19.2	42	5	270	error in open and short	
-30 ps	78	58	0.55	18.8	53	6	270	error in op & sh offset	
0.1 ohm S	78	295	0.50	18.9	48	1	300	sw contact res on short	
0.1 ohm O	78	1554	0.50	19	47	0	7	sw contact res on open	
0.1 ohm L	78	100	0.53	18.9	51	3	160	sw contact res on load	B

Table 1 Simulations of the Sensitivity of EDGES-3 to systematic errors and detectability from the residuals to the calibrated spectra of the open and shorted cables used in calibration.

a] Internal cable stability

Even though the receiver front-end cables are short a change in dielectric due to temperature could be significant. The values of -10 to +4 % would introduce large enough to make a reasonable detection of the absorption unlikely but errors this large would result in very large residuals to the open and shorted cables. All the cables, except the one to the hot load, which has an expensive "custom" silicon dioxide cable, have a teflon dielectric which has a sudden shift in dielectric around 20C. But this shift is no more than +/-0.3% and this shift known as the "teflon knee" should not be encountered as EDGES-3 will be temperature controlled to 30C.

b] load resistance and other SOL errors

An error as large as -0.5 to 1 ohms would make the absorption detection problematic and even an error of 0.1 ohms has a fairly significant effect. Fortunately, the presence of an error this large would be seen in the calibrated spectra from the open and shorted cables. Errors in offset delay need to be well under 30 ps.

c] The most worrisome of all the potential error sources is the development of a significant contact resistance to the internal load. Measurements of various switches in memo 238 show contact resistances up to 0.03 ohms and Dowkey switches are expected to stay under 0.05 ohms even after millions of operations. In EDGES-3 the effects of contact resistance is small if it is the same for all positions. Tests reported in memo 303 of the 8-position switch show repeatability at the 1 ps and 0.001 dB level. 0.1 ohms is 0.034 dB.

error	center MHz	SNR	amp	width MHz	rmsin mK	rmsfit mK	case	comments
-0.5ohm load	81	13	0.32	29.9	22	9	D	simulation without add ref. absorption
0.1 ohm	80	13	0.03	15.4	5	3	E	load sw contact without added ref.
w/o loss	78	1514	0.50	19.0	47	0.3	F	no correction for 1.5” input cable
no beam cor	78	41	0.44	19.2	42	6	G	no beam correction GHA=12 48x48
0.1 ohm	78	19	0.76	19.2	95	35	H	case B in table 1 with 60-120 MHz
0.1 ohm ant	78	66	0.55	18.8	52	5	I	switch contact resistance to antenna

Table 2. Cases D and E are Table 1 cases A and B without added absorption.

The results of cases D and E in table 2 show that the errors don’t result in an absorption close to the reference case confirming that the errors don’t create a false absorption with parameters close to the reference case. Cases F, G and I, which have no “detectability” in the open and shorted cable results are shown for comparison. The input cable loss, which can only be measured in the lab, is small and at GHA=12 hrs the beam correction with the large 48x48 ground plane is not large and is shown for comparison. Of most concern is the potential for error due to switch contact resistance which fortunately can be detected if present, but not fixed in EDGES-3 without returning EDGES-3 receiver front-end to the lab for replacement of the switch or bad cable.

Figures 1 and 2 show the results of the signature search for a 0.1 ohm contact resistance in the switch to the calibration matched load, cases B and H respectively, for a frequency span of 60 – 100 MHz and 60 – 120 MHz.

Summary

EDGES-3 built-in calibration should provide a very low level of instrumental systematics and an ability to detect instrumental problems like poor and/or intermittent mechanical switch contact resistance.

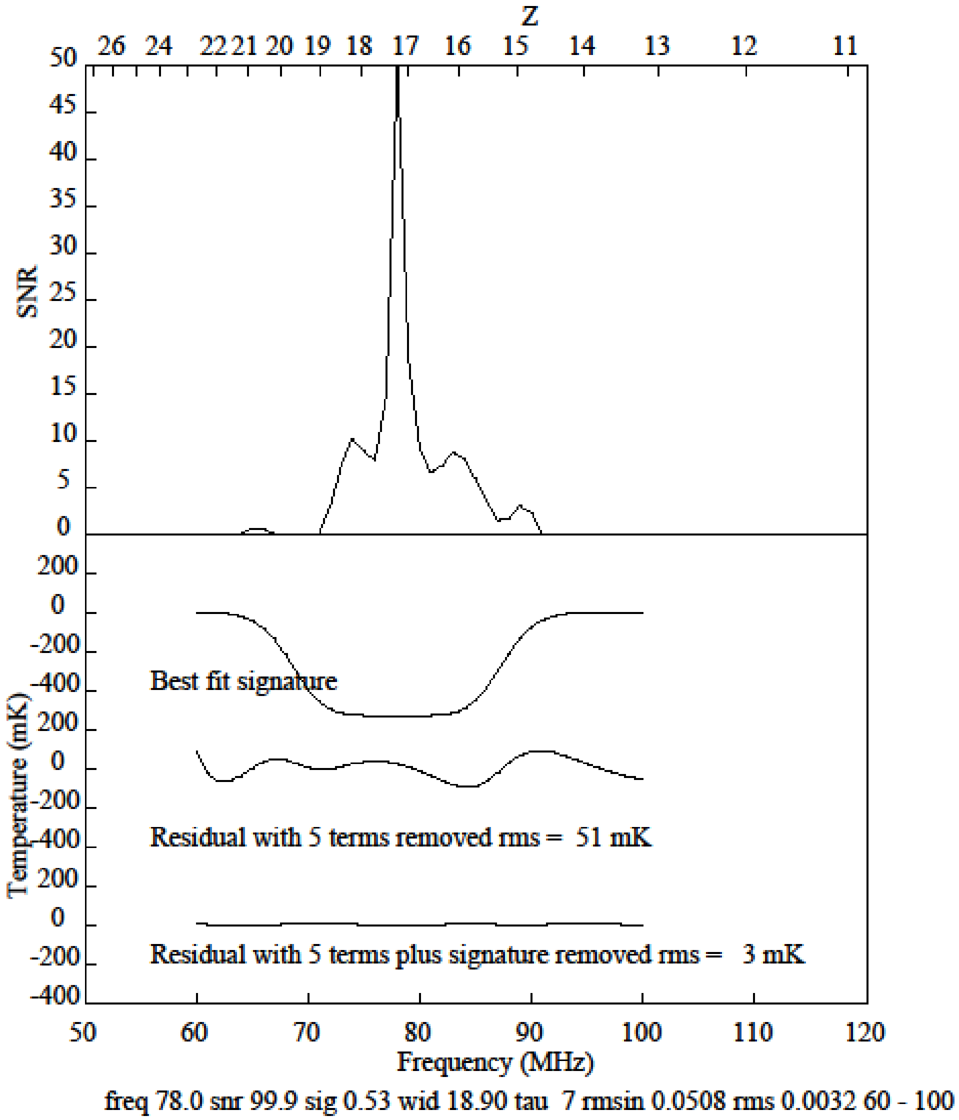
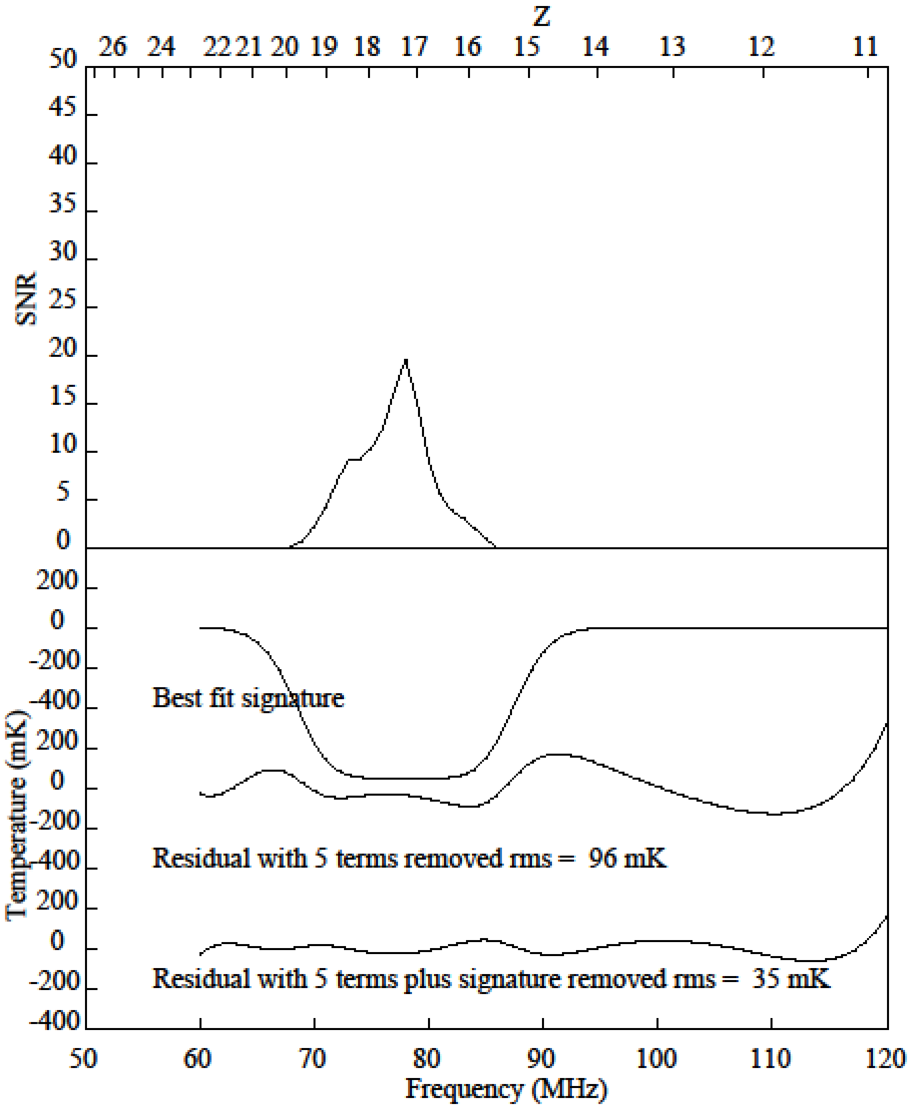


Figure 1. Simulation results of the presence of 0.1 ohm contact resistance to the matched load.



freq 78.0 snr 19.5 sig 0.76 wid 19.20 tau 7 rmsin 0.0956 rms 0.0355 60 - 120

Figure 2. Simulation results for a wider frequency range of 0.1 contact resistance to the matched load.