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To: EDGES group

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Subject: Tests of the EDGES-3 electronics performance in the lab and remotely

EDGES-3 has all the electronics built into the antenna which makes it possible to conduct tests of its performance in the laboratory without additional instrumentation by taking s11 measurements of the ambient load, hot, open and shorted cable, along with their spectra plus SOL calibration s11. The VNA calibration L is used as the ambient load. A combination of simulated and measured data as in the evaluation of the impedance analyzer and VNA as used in some of the tests in memo 460 is useful the source of instrumental errors and bias.

In the laboratory an attenuator along with a filtered noise source connected to the input can be used as an "artificial antenna". A good test of the electronics can be made in the field using the hot load as an "artificial antenna" which should result in a flat spectrum in agreement with the measured temperature of the hot load.

Several tests of EDGES-3 using an "artificial antenna" are described in memos 303, 305, 361, 367, 369 and 460. In addition software simulations based on the theoretical analysis has been made in memos 303, 332, 380, 382, 394, 414. Simulations in memo 368 show the equations which help to identify the primary source of the sensitivity to s11 phase error and the simulations in memo 394 show the length of a cable needed for accurate noise wave calibration.

The "sim6" simulation code provides simulated spectra and s11 data for antenna, open and shorted cables, ambient and hot loads as well as the s11 for the lna and this data can be processed with edges3 processing code.

The simulated LNA s11 is fairly close to the measured LNA s11 of the EDGES-3. It can be changed to be closer to the circuit simulation result in figure 1 of memo 334. The default LNA s11 with tst = 0 is

ss11lna[j] = 0.005*(1.0+pow((freq-90)/40.0,2.0))*cexp(-2.0*PI*freq*1e6*2e-9*I)
and with tst = 1 is ss11lna[j] = 0.05*cexp(-2.0*PI*freq*1e6*2e-9*I)

	default	function
anoise	0	1 turns on noise in antenna spectra
vnoise	0	noise in vna in fractional units
cnoise	0	1 turns on noise in calibration spectra
intsec	0	spectra integration time in sec
fspac	0.1	Frequency spacing in MHz
tcal	1000	deg K
fstart	40	MHz
fstop	200	MHz
cablant	2.5	Antenna cable length in inches
cablehot	4.0	Hot cable length in inches
eoramp	0.5	2018 absorption depth in deg K
gha	999	gha < 999) t150 = 300+(gha-12)*700/12
cinch	120	open and shorted cable length in inches
adel	20	antenna delay in ns
c3pos	0	1 turns on 3-position switching correction
spi	-2.5	antenna spectrum spectral index
tst	0	change LNA s11 – see notes below
nloss	0	1 turns off loss corrections for ant and hot
rr	0	sets “srand” to change random noise

Table 1 sim6 software parameters

The antenna and hot cables use the parameters for UT-141C-SP and Molex WM10479-nd FEP are used for the open and shorted cables are used for the simulated data. Table 2 gives the results of tests used to test the integration time needed for calibration spectra and antenna spectra. The effect of vna s11 noise is assumed to be random for each cycle at the fractional level of the vnoise parameter. These results are for 50-190 MHz with 5 polynomial terms removed for 2018 absorption added to simulated sky noise spectrum. The results using the default parameters in table 1 with fspac = 1 are in the first entry in Table 2 below and plotted in Figure 1.

Freq MHz	SNR	amp K	wid MHz	rmsin mK	rms mK	anoise	cnoise	vnoise	intsec	test
78.0	595	0.50	18.9	109	2	0	0	0		Figure 1
79.0	27	0.51	18.3	123	49	1	1	3e-4	36000	Figure 2
78.0	248	0.49	18.9	108	5	0	1	0	3600	Cal needs 1hr
78.0	98	0.48	18.8	106	12	1	0	0	36000	Ant needs 10hr
79.0	29	0.50	18.3	121	45	0	0	3e-4		1 vna pass
78.0	147	0.45	18.7	99	11	0	0	3e-4		2 vna passes
78.0	40	0.64	20.5	145	42	0	0	0		lna 100 ps
78.0	35	0.68	20.9	154	49	0	0	0		lna 1 dB

Table 2 Results of sim6 with eoramp 0.5 K simulated data with edges3 calibration grid search

Tests of the effect of error in s11 measurements can be simulated using the delay and db corrections in edges3. The last two entries in table 2 show the effect of an offset in the lna s11 of 100 ps and 1 dB respectively.

Tests of the calibration accuracy can be made by substituting the hot load for the antenna. This can be used remotely to verify the spectrometer performance when the antenna input is connected to the sky and cannot be connected to a known an “artificial antenna”. In this case the rms fit to the spectra of the open and shorted cables labeled as “rmscab” is also used as a measure of error in table 3 and the sensitivity of error in the retrieval of the 2018 absorption which is added to the hot load spectra is modeled with 4 loglog terms.

Freq MHz	SNR	amp K	wid MHz	rmsin mK	rms mK	rmscab	anoise	cnoise	vnoise	intsec	
77.0	32	0.47	18.9	111	16	24	1	1	3e-4	36000	Figure 3
76.0	14	0.54	20.6	108	34	184	1	1	3e-4	36000	lna 100 ps
77.0	15	0.53	19.5	117	36	262	1	1	3e-4	36000	lna 1dB
76.4 fsp 0.1	48	0.54	20.3	120	35	263	1	1	3e-4	36000	lna 1dB

Table 3. Results of using hot load spectra and calibration to access performance remotely

The plots were made with a “fspac” of 1 MHz. The last test in Table 3 was made with a “fspac” of 100 kHz. This shows that while the SNR changes with the frequency spacing the rms residuals only makes small changes to “rmscab” and the residuals of the absorption test. The “rmscab” is obtained from the left hand plot in the second row of the figures. The complete set of plots with 100 kHz frequency spacing for last test in table are plotted in Figure 4.

Figure 5 shows an example of using the hot load as a test of the electronics and calibration by processing the laboratory test of the VNA performance shown in figure 4a of memo 460. The plot of the hot load spectrum is equal to the hot load temperature of 403 K is flat to within 200 mK and the 2018 absorption can be derived from a grid search when added to the hot load spectrum although the noise level is higher than in figure 4b of memo 460 because the integration time for the hot load was only 30 minutes.

In summary the simulation software provides a good check of the electronics and the parameters in the analysis code. In addition it allows a check of the integration time needed for calibration and sky data. The hot load can be used to check the calibration and performance at a remote deployment when the antenna connection is not accessible and sky noise spectrum is unknown.

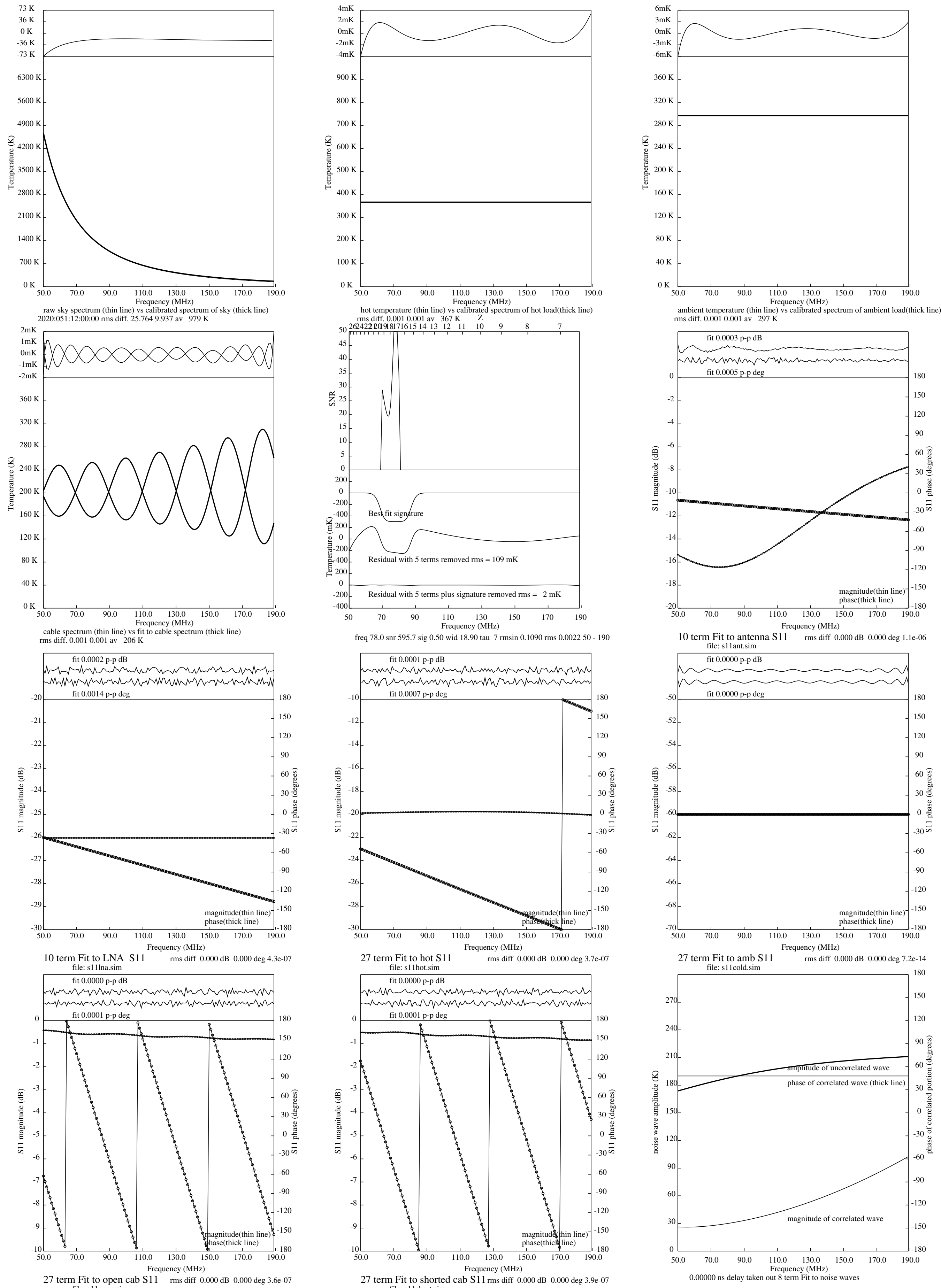

Figure 1. Plots of the simulations without noise or errors in the default parameters of table 1.

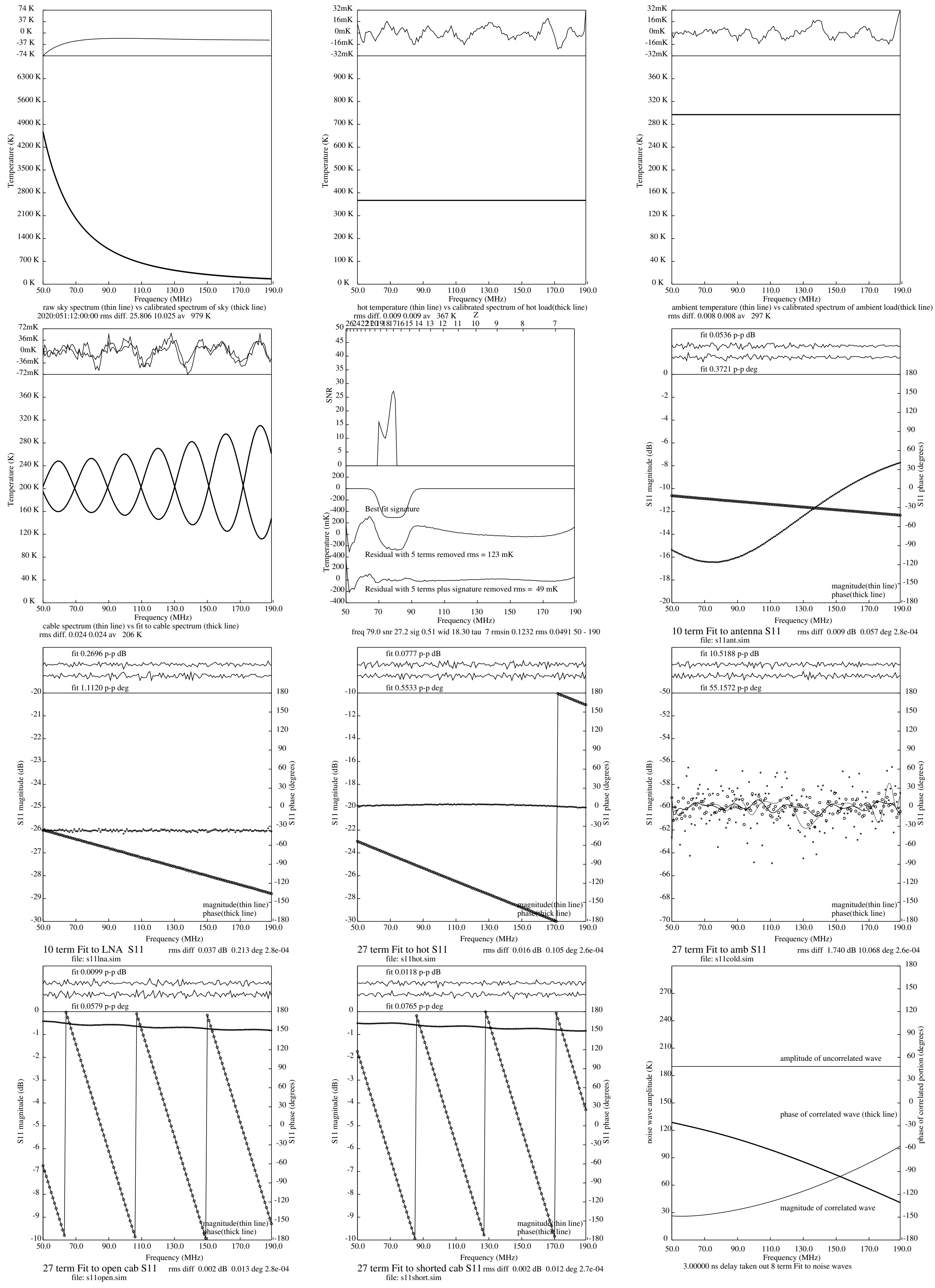

Figure 2. Plots of the simulations with noise as in the second entry of table 2.

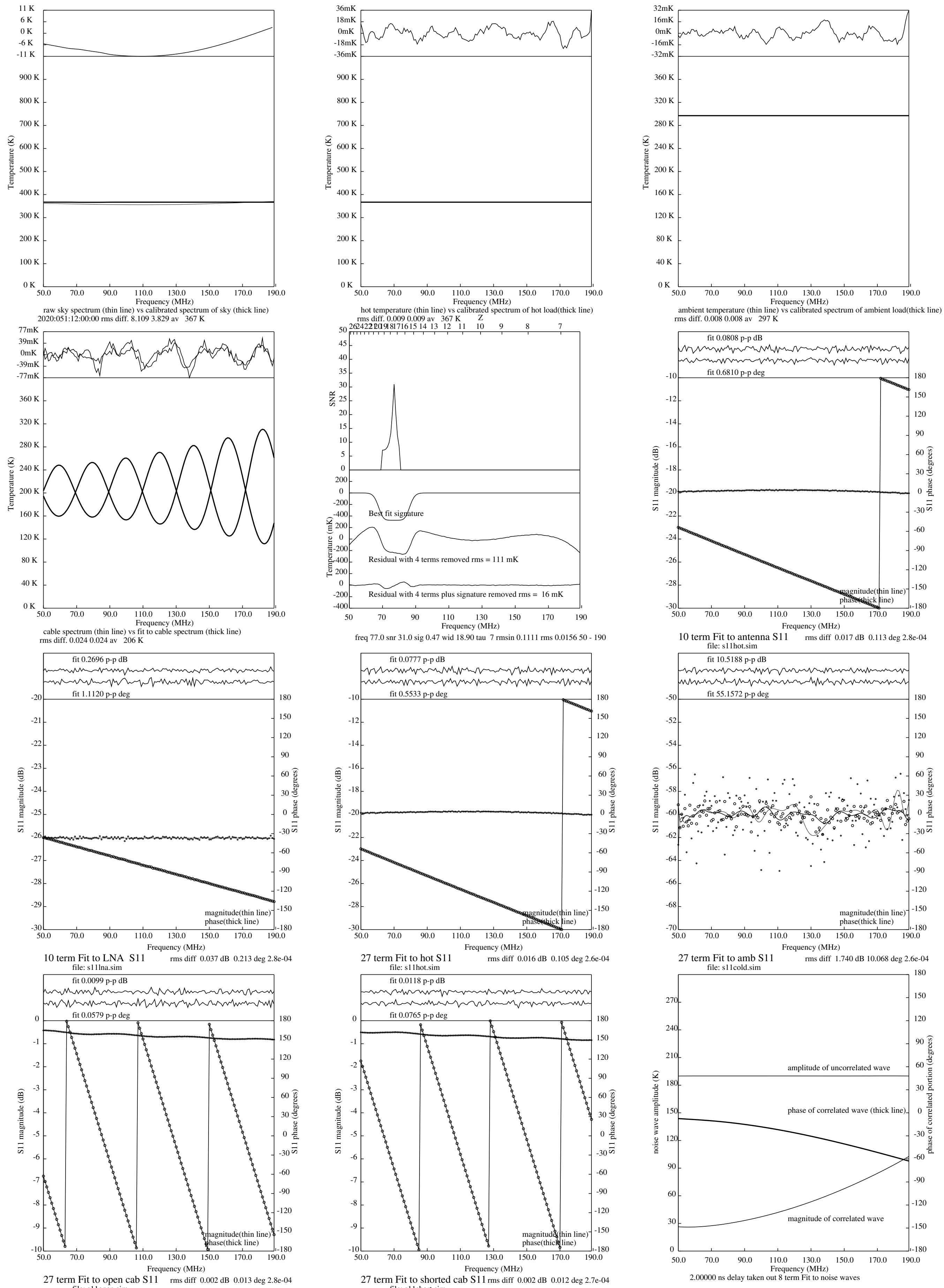

Figure 3. Plots of the simulations with noise as in the first entry of table 3.

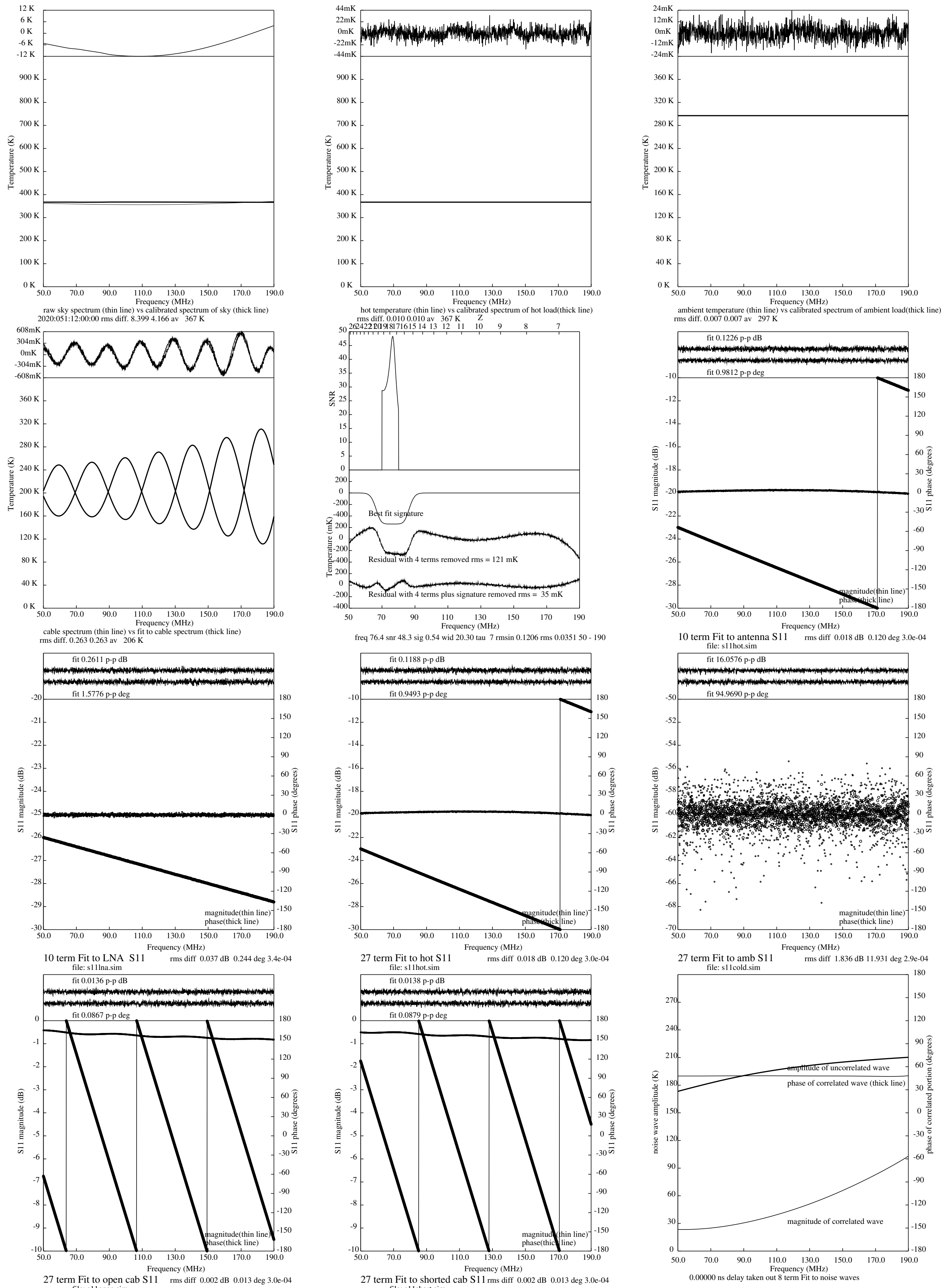

Figure 4. Plots with 100 kHz spacing and 1 dB offset in the LNA s11 for last entry on table 3

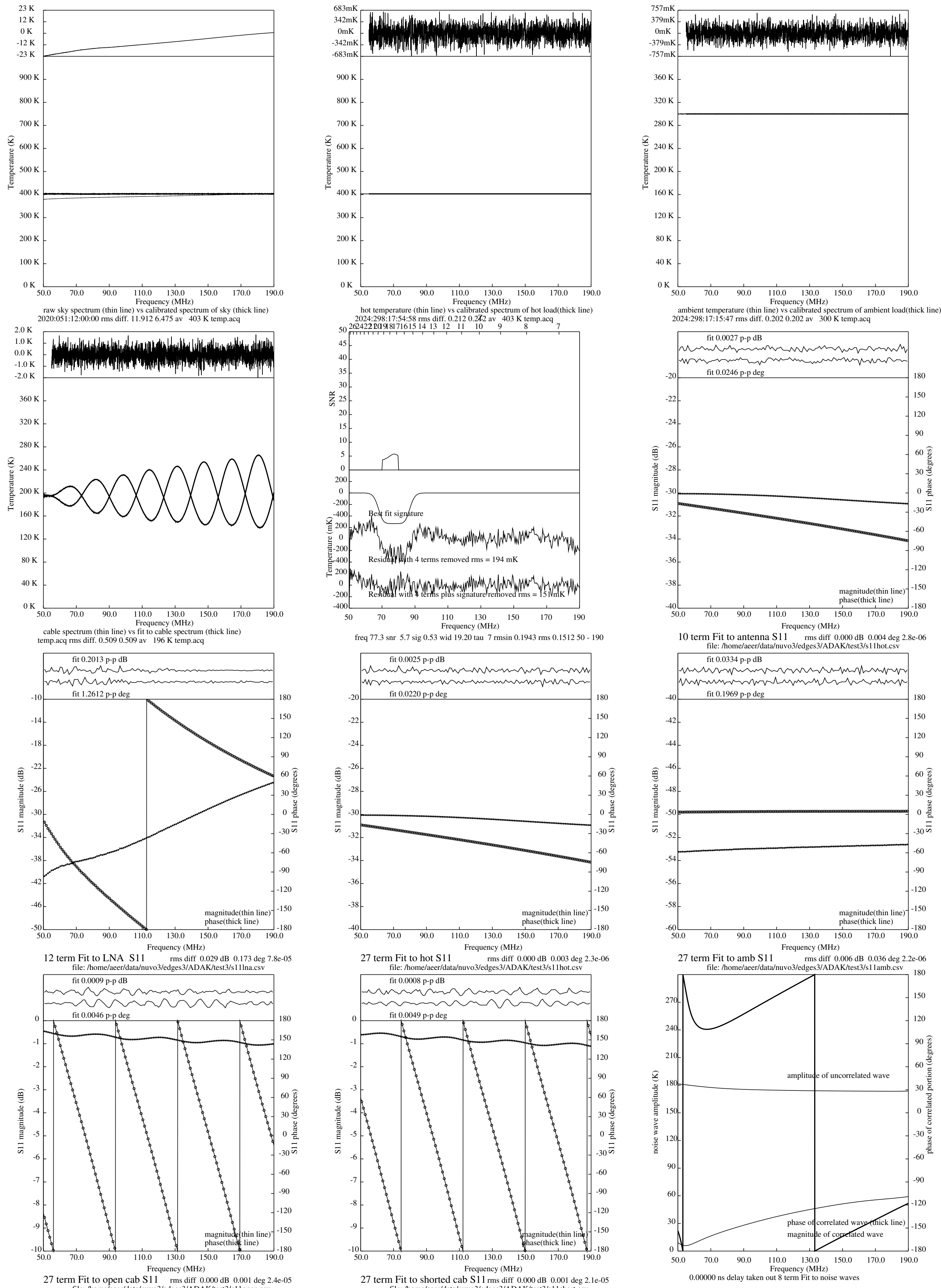

Figure 5. Plots of the EDGES-3 laboratory test of the EDGES-3 using VNA in memo 460