EDGES MEMO #367

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

August 30, 2021

Telephone: 617-715-5533

To: EDGES Group

From: Alan E.E. Rogers

Subject: Repeatability and accuracy of EDGES-3 automated calibration

EDGES-3 automated calibration is based on the simplified method of defining the S11 reference plane at the 8 position switch as described in memo 303. In this scheme the SOL calibration standards are already at the reference plane. Small corrections are needed for the hot load loss and the loss of the short 1.5 inch input cable and its connectors between the 8 position switch and connection to the antenna. The latter can be included in the antenna loss. A correction of the calibrated s11 of the LNA input is needed to account for the different path the VNA takes for this measurement of the s11 of the LNA. However, this correction can be determined from a search of cable length, cable dielectric correction, and cable loss correction that minimizes the residuals to the calibration results for the open and/or shorted cables. The results of this correction for the prototype and new EDGES-3 are given in Table 1.

EDGES-3	Length inches	Dielectric correction %	Loss correction %
Prototype 7000	4.68	-2.9	-93.0
New 7002	4.46	-1.24	-91.5

Table 1. Best fit corrections for cable model fit LNA s11 measurement receiver at 30 C.

The difference between the two system is the result of slightly different cable S-parameters due to the use of minicircuits “handflex” interconnect 0.141” cables used to connect between the mechanical switches as shown in Figure 1 of memo 303. The best fit cable corrections are obtained over a wide frequency range of 50 to 190 MHz in order to obtain the highest sensitivity. The results for the preliminary results for prototype are shown along with the sensitivity to a number of potential sources of error are given in table 1 of memo 361.

A series of repeated s11 and spectrum measurements were made over a period of several days to access the repeatability of both systems while looking for differences between the systems. Several 2 hour sets of s11 measurements were taken each day along with only one spectral measurement set which was taken at the start of the day and lasting about 12 hours. Table 2 shows the repeatability using rms fit to sky spectrum with the reference calibration plus Nature feature processed with the test calibration. The rms1 is the rms before removing the feature and the rms2 is the rms following with parameter values the best fit feature. The first number in the Ref and test columns is the day number for the spectrum and the second number is the hour of the s11 dataset. Table 3 shows the repeatability for the EDGES-3 prototype.

The differences between the New EDGES-3 and the prototype are small as in most cases the values of rms2 are under 10 mK for the grid search fit to the Nature feature for fixed tau = 7 with 5 physical

terms removed over a frequency range 55 to 120 MHz. However the rms2 values only account for changes in calibration and LNA s11. A fixed antenna s11 from the FEKO electromagnetic simulation of the beam is used.

Ref.	test	Center MHz	SNR	amp K	width MHz	rms1 mK	rms2 mK
214	214-15	77.7	131	0.45	18.9	65	6.4
214	214	78.1	315	0.49	18.9	73	0.3
214	209	77.7	113	0.45	19.3	63	7.1
214	206	78.1	181	0.44	18.9	66	4.7
214	209-17	77.7	111	0.45	19.3	64	7.4
209	209-17	78.1	213	0.50	19.0	74	4.5

Table 2. Repeatability tests for the new EDGES-3 system

Ref.	test	center MHz	SNR	amp K	width MHz	rms1 mK	rms2 mK
223	223	78.1	348	0.49	18.9	73	2.7
223	191	77.7	169	0.49	19.1	70	5.4
223	191-17	78.5	69	0.54	18.8	85	15.7
223	223-224-15	78.9	52	0.55	18.8	90	21.9
191-17	223-224-15	78.1	140	0.52	19.1	77	7.0
191-17	191-224-15	77.7	186	0.52	19.3	73	5.1
191-17	225-224-15	78.1	96	0.53	19.2	78	10.4
225-224-15	225-224-15	77.4	64	0.49	19.3	67	13.4

Table 3. Repeatability tests for prototype. The last entry is for a change in loss correction for LNA s11 -93.0 to -90.0 given in table 1.

The changes with the controlled temperature of the receiver front end are shown in Table 4 for both the prototype and the new EDGES-3

	center	SNR	amp	width	rms1	rms2
New change of s11 set 30 to 25 C	79.3	32	0.61	19.0	106	40
Prototype change of s11 set 30 to 25 C	79.3	36	0.54	18.7	75	32
New change of s11 and spec 30 to 25C	78.5	59	0.44	18.9	69	15
Prototype change of s11 and spec 30 to 25C	78.5	80	0.46	18.7	73	12
Repeat New with another spec at 25 C	78.5	59	0.45	18.9	71	15
Repeat prototype with another spec at 25 C	78.5	86	0.47	18.7	75	11

Table 4. Effects of a change in controlled temperature of receiver front end

The calibrated spectra for 2.5 hours integration were run on the artificial antenna simulator described in memo 199 without the added cable. In this case the spectrum is 15,400 K at 50 MHz which is about 20% stronger than the highest observed sky noise with EDGES-2 at GHA = 0 hours. The results of fitting for an absorption with tau = 7 are given in table 5. With 5 physical terms removed there is no indication of a significant level of instrumental systematics to limit the measurements of "Galaxy-up" data.

EDGES-3	Integration hours	Feature added	range	center	SNR	amp	width	rms1	rms2
New	2.5	no	50-120	77.3	2	0.29	14.9	372	368
Prototype	2.5	no	50-120	78.9	1	0.26	18.6	464	463
New	48	no	55-120	76.6	3	0.16	13.1	107	103
New	48	yes	55-120	77.7	12	0.57	17.3	139	103

Table 5. Tests using artificial antenna simulator for frequency range 5-terms removed.

Figures 1 and 2 show the calibration results along with the spectra on the antenna simulator, ambient and hot loads as well as the open and shorted cables. Also shown are the S11 measurements and the best fit LNA noise waves.

A test effect of the out of band noise was made on the prototype by removing the power from the noise source. This made a change in the LNA s11 of about 0.2 dB and 1 degree of phase because the removal of the power changes the match on the output of the 14 dB amplifier which follows the LNA. This significant change is the result of the loss of power to the amplifier in the noise source. When new spectra without the out of band noise are taken along with a S11 measurements and recalibration the overall effect on the calibrated spectra of the artificial antenna simulator is within the level of repeatability.

Longer integrations than the 2.5 hours used in figures 1 and 2 have been run using the new EDGES-3 with the antenna input connected to an artificial antenna noise source. With 48 hours integration the rms residual with 5-terms removed 55 - 120 MHz using the artificial antenna noise source of memo 199 is 100 mK. The signal strength is about 6,000 K signal at 75 MHz as shown in the "calibrated sky spectrum" in Figure 1 which is comparable with the sky noise at transit of the galactic center. The results of a grid search for an absorption feature with tau = 7 is shown in Figure 3 and in Figure 4 with the 0.5 K absorption feature reported in the Nature paper with 78 MHz center frequency and width of 19 MHz added to the spectrum of the artificial noise source.

In summary the differences between the new EDGES-3 and the prototype are at a low enough level that the residuals to a 5-term fit from 55 – 120 MHz should be under 20 mK for the Nature feature, assuming it is real, and assuming the systematics are from errors in calibration and and antenna s11. The systematics due to beam chromaticity and uncertainty in ground plane loss corrections are expected to be similar to those of EDGES-2. The current plan is to provide a 48x48m ground plane on level ground for EDGES-3 but the limits set by the current uneven 30x30m ground plane could be reduced by running EDGES-2 on the new proposed 48x48m ground plane.

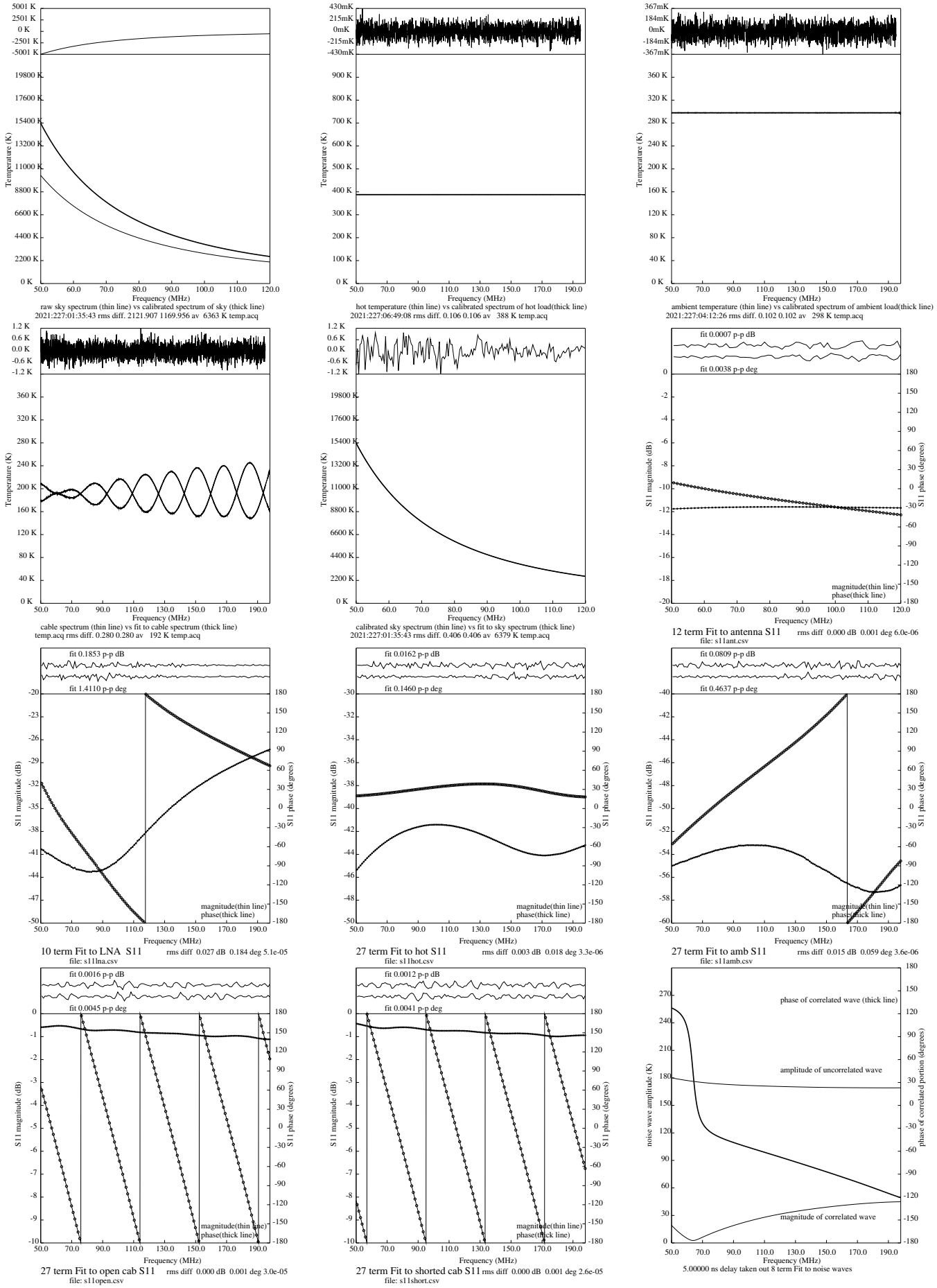

Figure 1. Spectra of antenna simulator, loads, s11 and noise waves for new EDGES-3.

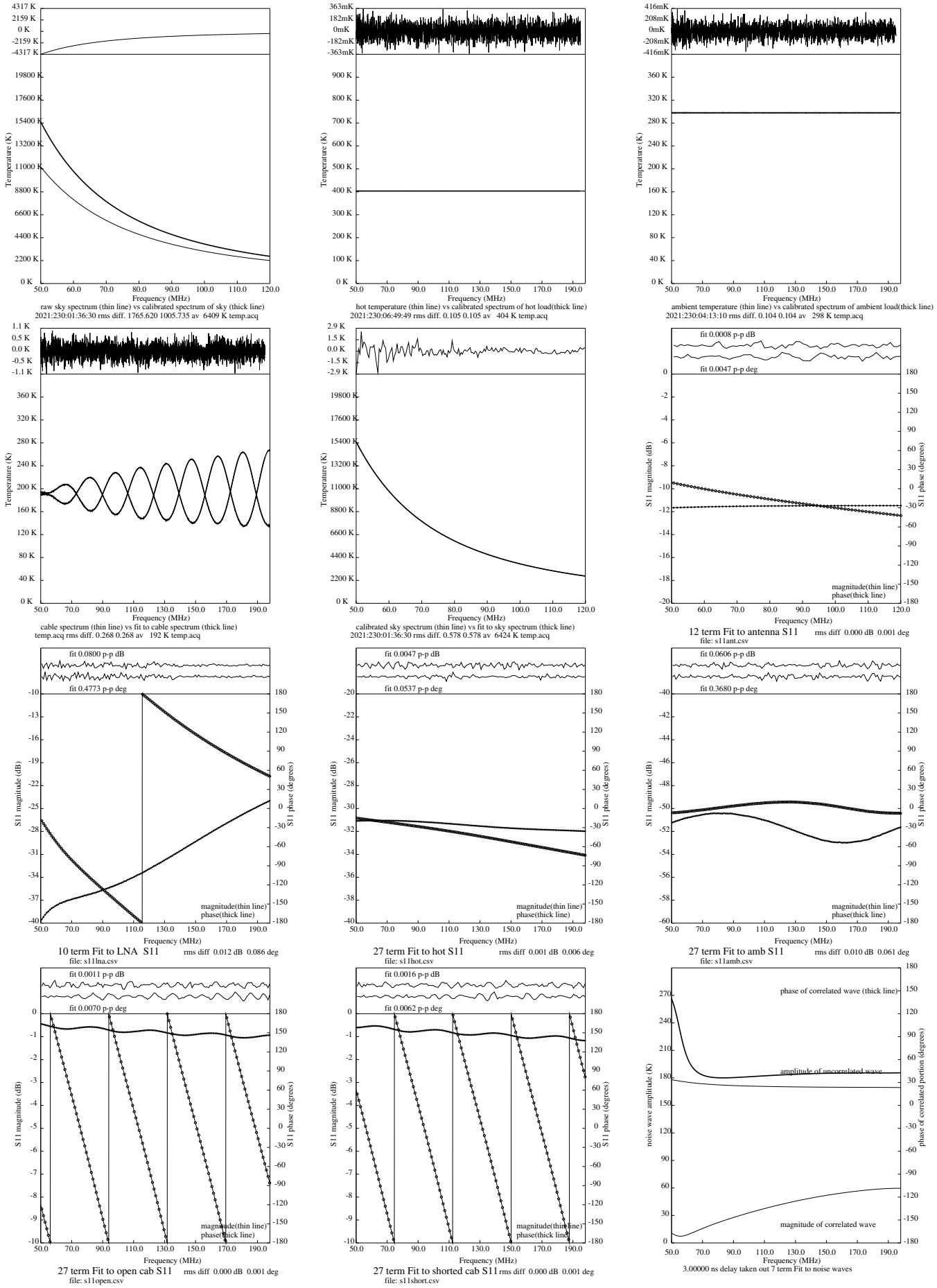

Figure 2. Spectra of antenna simulator, loads, s11 and noise waves for prototype.

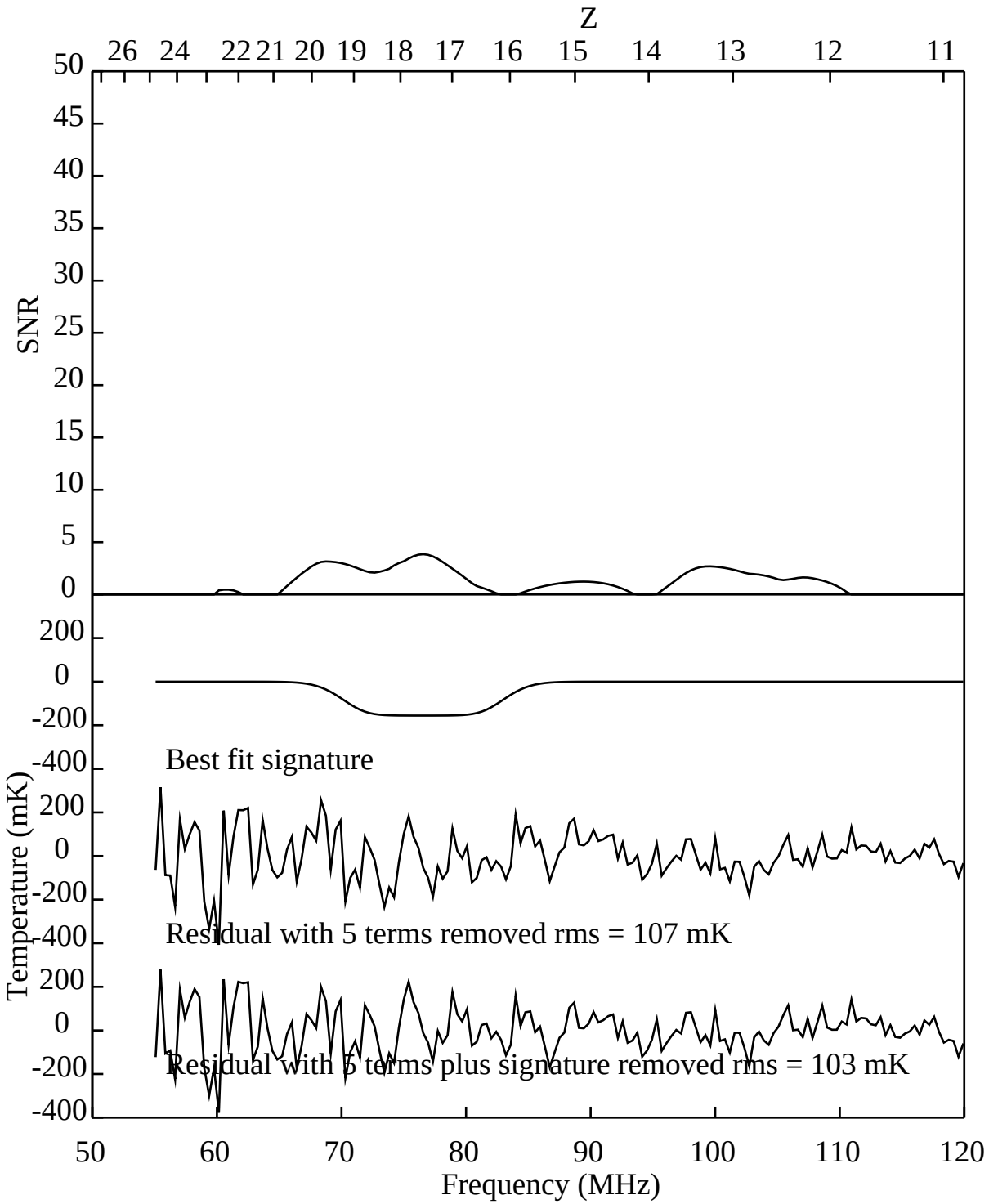

Figure 3. Feature search of 48 hour integration on the artificial antenna simulator.

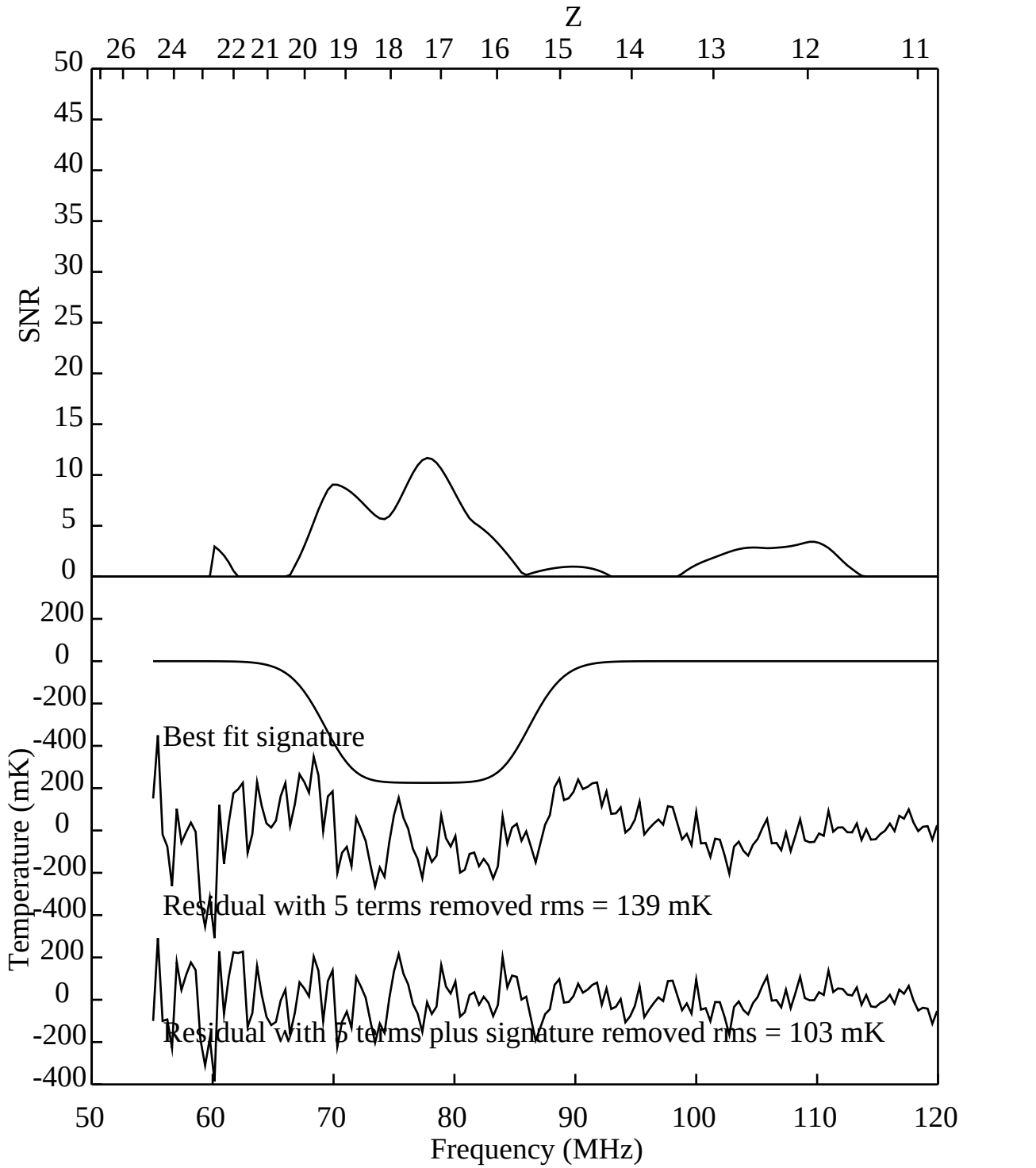

Figure 4. Feature search with Nature result added to spectrum from simulator.