EDGES MEMO #460

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To: EDGES group

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Subject: Tests of LBA TE3000 and TE3001 impedance analyzers for s11 measurements in EDGES-3

The potential of obtaining a high accuracy s11 measurements of the antenna, LNA,ambient and hot loads along with the s11 of the open and shorted cables used to calibrate the LNA noise waves from a TE3000/1 impedance analyzer is discussed in memo 433. Another advantage of the Trewmac TE3000/1 is a power consumption at about 7w compared with the 30w needed for the Keysight N9923A Fieldfox VNA described in memos 361, 363, 412, 414 and 423.

Initially it was thought that the TE3000 and TE3001 could not be run remotely because the power button needed to start start had to be pressed but this was eventually solved by a small wiring change so that it would power up when the DC power is applied. The key communication

```
outb (128 + 3, base + 3);
outb (0x01, base);
outb (0, base + 1);      // 115 8 data 1 stop noparity
outb (3, base + 3);
outb (7, base + 1);
outb (1, base + 2);
outb (3, base + 4);
```

The impedance is set by “Czo\r50.0\r” to 50 ohms and the serial format "Cformat\rpolS\r" and data is taken using measurement using the “F” command in a c-coded loop from 40 to 200 MHz in 1 MHz steps. Measurements of the amb hot ant open-cable S O L shorted-cable are made at a level of 80% of 230 mv p-p set by the "Coutput\r80\r" command and measurements of the lna S O L at the 20% level using the "Coutput\r20\r"command. Then in order to keep the time difference between the s11 devices and the calibration SOL the entire process is run and the data is averaged over 10 cycles which takes about 80 minutes. This is the same process that was found to be required for high accuracy of the VNA as described in memos 411 and 412. Another method of acquiring the data from the TE3000 is to use the “N” command to perform a linear sweep of from 40 to 200 MHz in 1 MHz steps. While this method has the advantage of using averaging with the "Caveraging\r%d\r" but returning the long serial string of characters from the scan required some special c-code loops with sleeps and difficulty below 50 MHz so the tests of both methods were limited to 50 to 190 MHz in 1 MHz steps.

For initial tests of the two methods EDGES calibration data was simulated and then processed using simulated spectra and s11 data. Figure 1 shows the results of simulated spectral and spectral data and Figure 2 shows the result of using simulated spectra and replacing the simulated s11 data with data from the TE3000 using the “F” command with only 1 cycle of averaging.

Tests of the repeatability of the entire 80 minute run are at the level of 2e-4 rms fractional reflection coefficient difference between runs. For the lna the rms difference between runs at 20% and 80% were about 1e-3 fractional difference indicating that 80% which isomqy184 mv p-p results in some saturation of the lna.

Having reached an acceptable level of repeatability the next test is a check of the level of systematics.

Tests of the accuracy were made using the s11 data from the TE3000 along with the simulated spectra to obtain the 21-cm absorption (Bowman et al 2018) which has been added to the simulated spectra which is then processed using the EDGES-3 c-code grid search with 5 terms removed to obtain the absorption 55 to 100 MHz.

These results are shown in Table 1.

case	freq MHz	sig K	SNR	width MHz	rmsin mK	rms mK
Trew2 “F” mode 1 cycle took 7 min	78.0	0.57	339	19.0	68	4
Trew4 “N” mode 1 cycle took 10 min	78.3	0.76	105	18.4	101	20
Trew2 repeat	78.1	0.57	306	18.9	69	5
Trew4 repeat	78.4	0.66	120	18.6	86	15
Trew2 2 cycles 14 min	78.2	0.65	149	18.7	83	12
Trew4 2 cycles 20 min	78.3	0.71	122	18.6	92	15
Trew2 4 cycles 30 min	78.1	0.61	207	18.8	75	8
Trew4 4 cycles 40 min	78.3	0.64	131	18.6	83	13
Trew2 10 cycles 72 min	78.1	0.62	188	18.8	77	8
Trew4 10 cycles 100 min	78.3	0.71	118	18.5	93	17

Table 1. Results of TE3000 s11 measurements using simulated spectra

The results of these tests show that while there is lower rms residual to the absorption rms using the “F” mode the biggest concern is the presence of the “ripples” in the fits to the open and short cables which are not present in the simulated data in Figure 1 and are also not present in the VNA data shown in figure 2 of memo 367 which shows the results of the s11 using the VNA for a test in the screen room at Haystack. This ripple is an indication that the TE3000 may have I/Q cross-talk or non linearity which produces ripple in the open and shorted cables in Figure 2. If present and consistent the I/Q cross-talk could be corrected as studied in memo 333.

Tests of the TE3001 have been made using the “F” mode. It looks like the TE3001 gets a better result with the ripples on the s11 of the open and shorted cables more like those from the EDGES-3 test in memos 305 and 367. One concern is the TE3001 might saturate the LNA which begins to saturate at about -36 dBm as per memo 237 but tests have with different power show that using /home/edges/edges3/trew2t which has "Coutput\r10\r") which sets the output level to 10% of the 1v p-p output for the LNA is low enough to avoid any significant change up to 20%.

A full tests using an artificial antenna was made on the EDGES-3 used at Devon Island and then deployed at the WA is documented in memo 367. In this test to attenuation between the noise source which is filtered to have a spectrum similar to the sky noise, shown in figure 1 of memo 199 has been increased from 6 to 10 dB to obtain about 3000 K at 50 MHz. It is noted that the residuals to the S11 of open and shorted cable have about peak to peak ripple of 1K instead of 0.01 K peak to peak noise in figure 1 of memo 367. Figure 3a shows that the peak to peak ripple in the s11 of the open and shorted cables is reduced from 1 K peak to peak to about 0.3 K peak to peak using the TE3001 and in addition

Figure 3b shows the results of the grid search for the 21-cm absorption which was added to the noise spectrum gives a reasonable detection of the absorption with residuals only slightly higher than those obtained using the VNA shown in Figures 4a and 4b. From this it is clear that the performance of the TE3001 is better than the TE3000 but not quite as good as the VNA.

The results in figures 3a,b and 4a,b are for only 2 hours of antenna spectral data. A comparison of the grid search for the 21-cm absorption for 24 hours of antenna spectral data shown in Figure 5 shows relatively small difference between the use of the TE3001 and the VNA.

In summary while the TE3001 may not be quite as accurate as the VNA based on the presence of the ripple in the spectra of the open and shorted cables its low power, smaller size an probably lower sensitivity to temperature change could be an advantage and it potential warrant further tests.

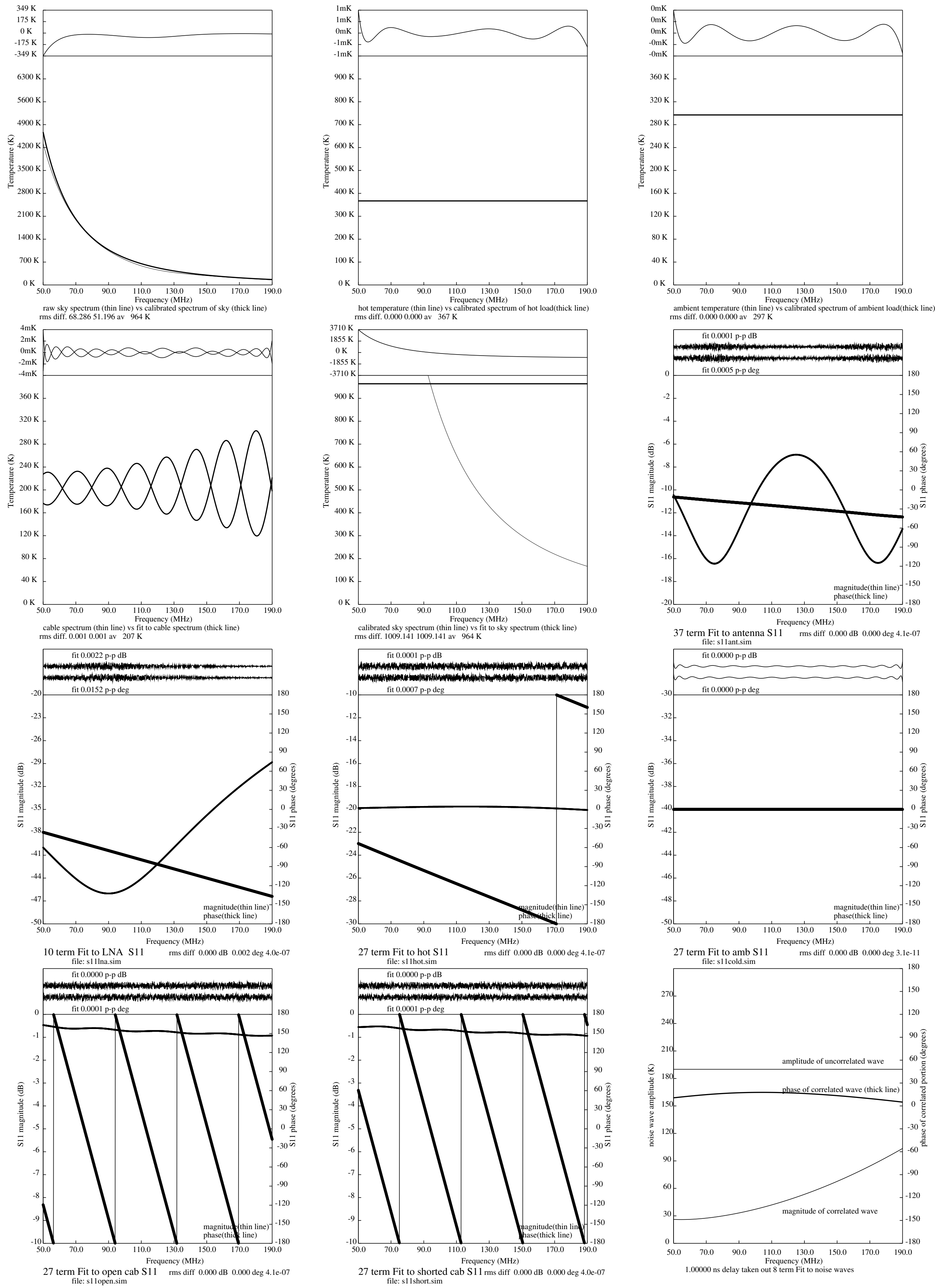


Figure 1. Simulated spectra and s11 data with 21-cm absorption added to antenna spectrum

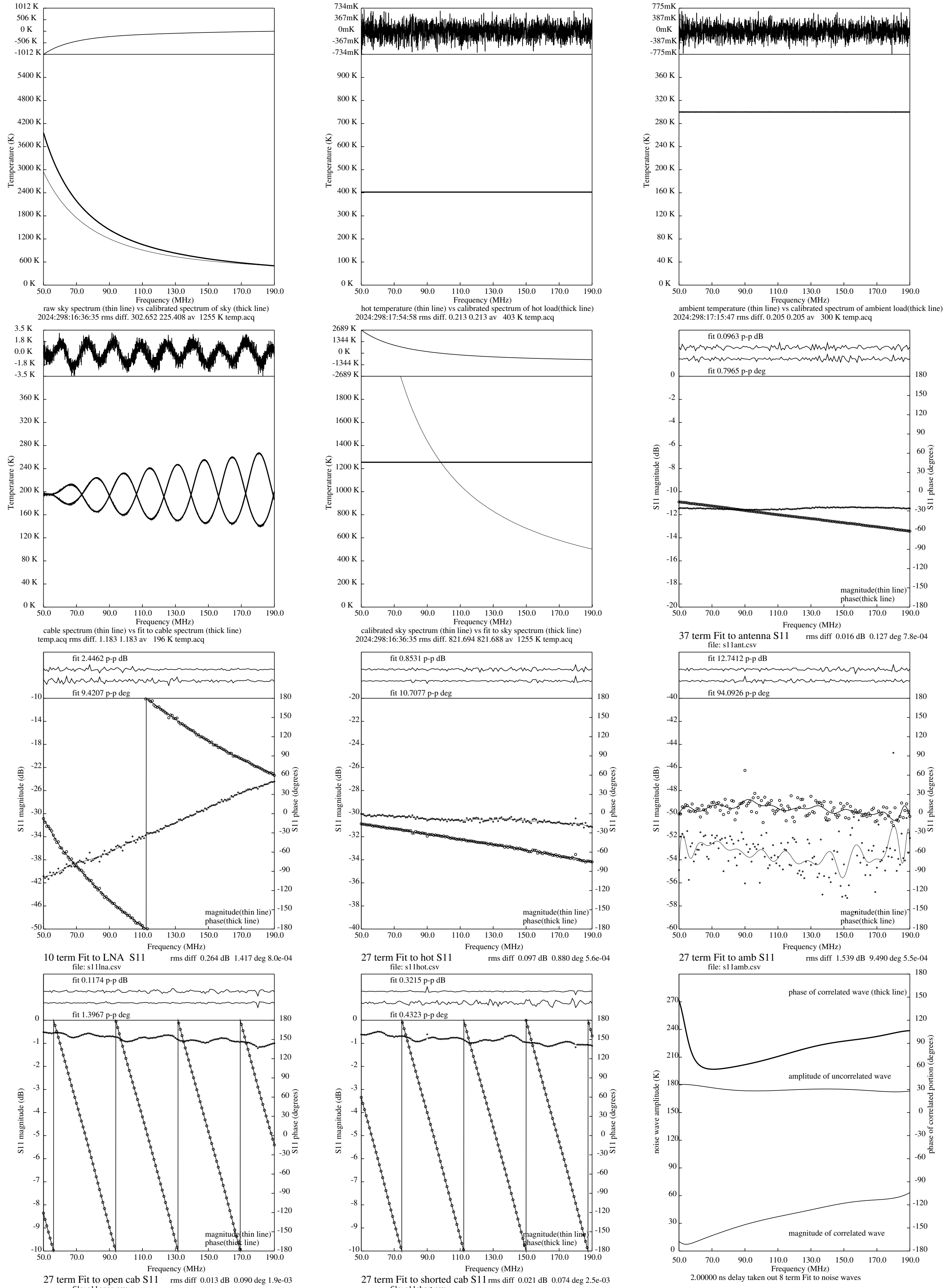


Figure 2. Spectra and s11 data from TE3000 “F” mode s11

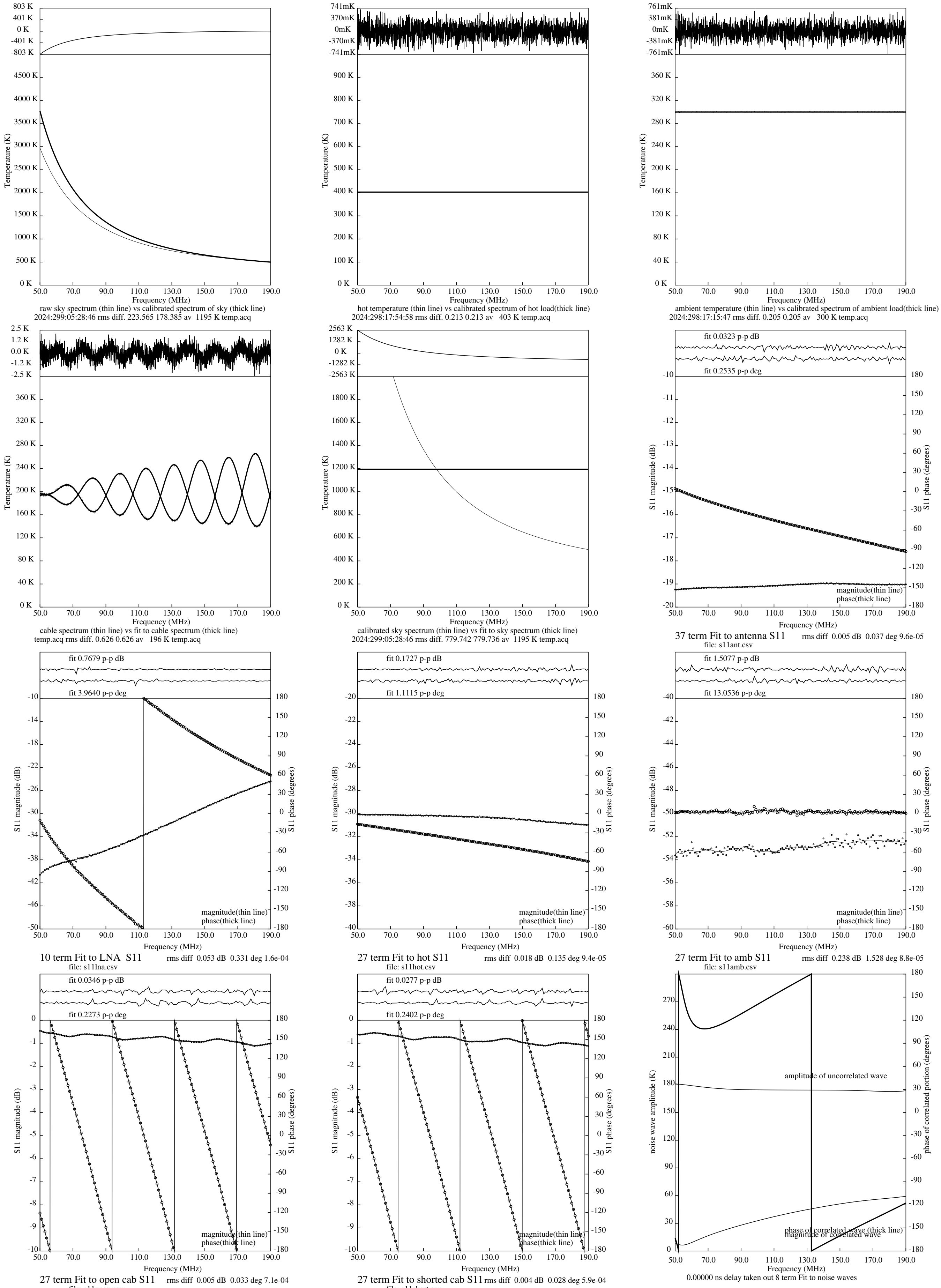


Figure 3a. Spectra with s11 data from TE3001 “F” mode s11

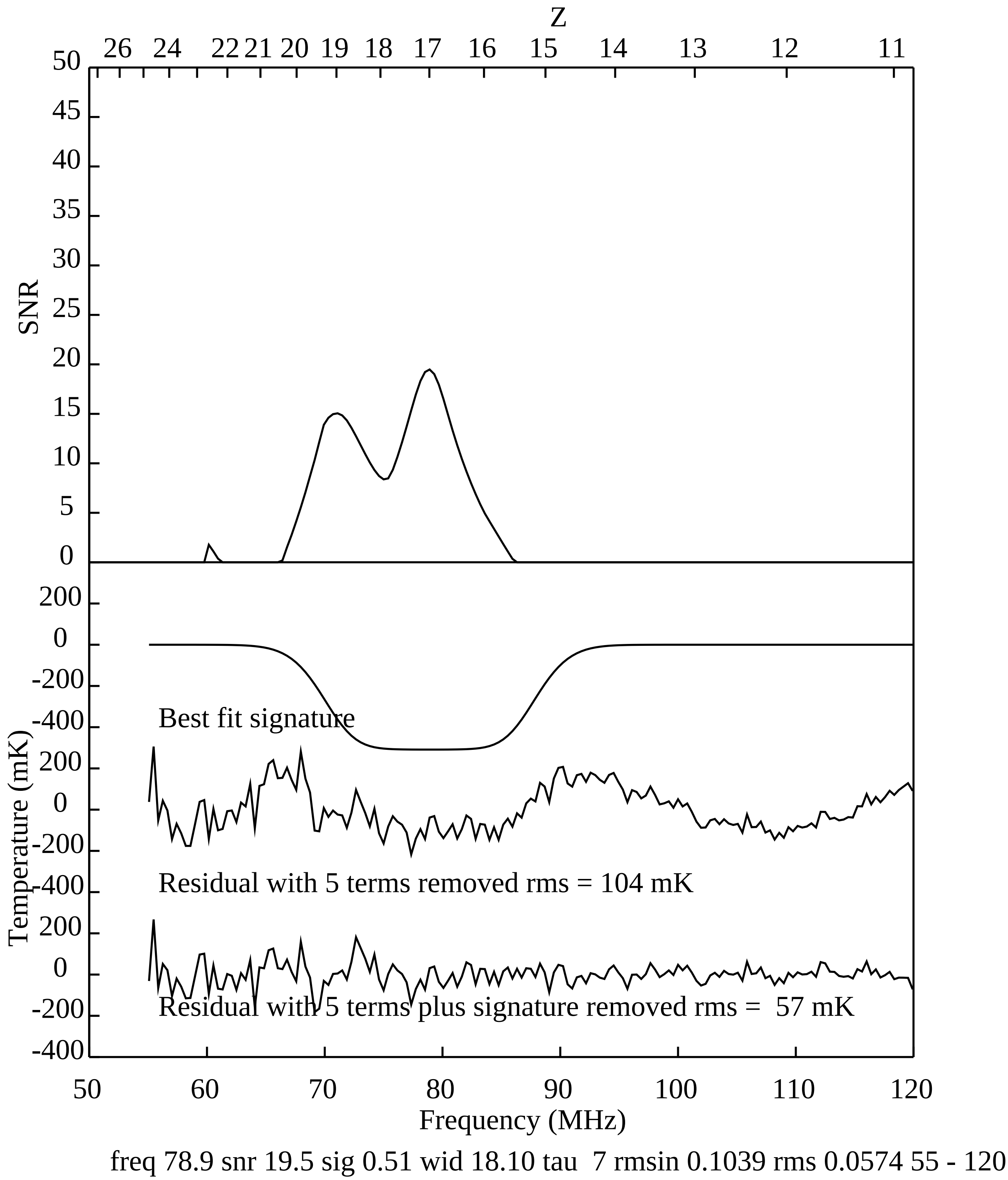


Figure 3b. 5-term search using TE3001 for 2018 absorption added to artificial antenna spectrum

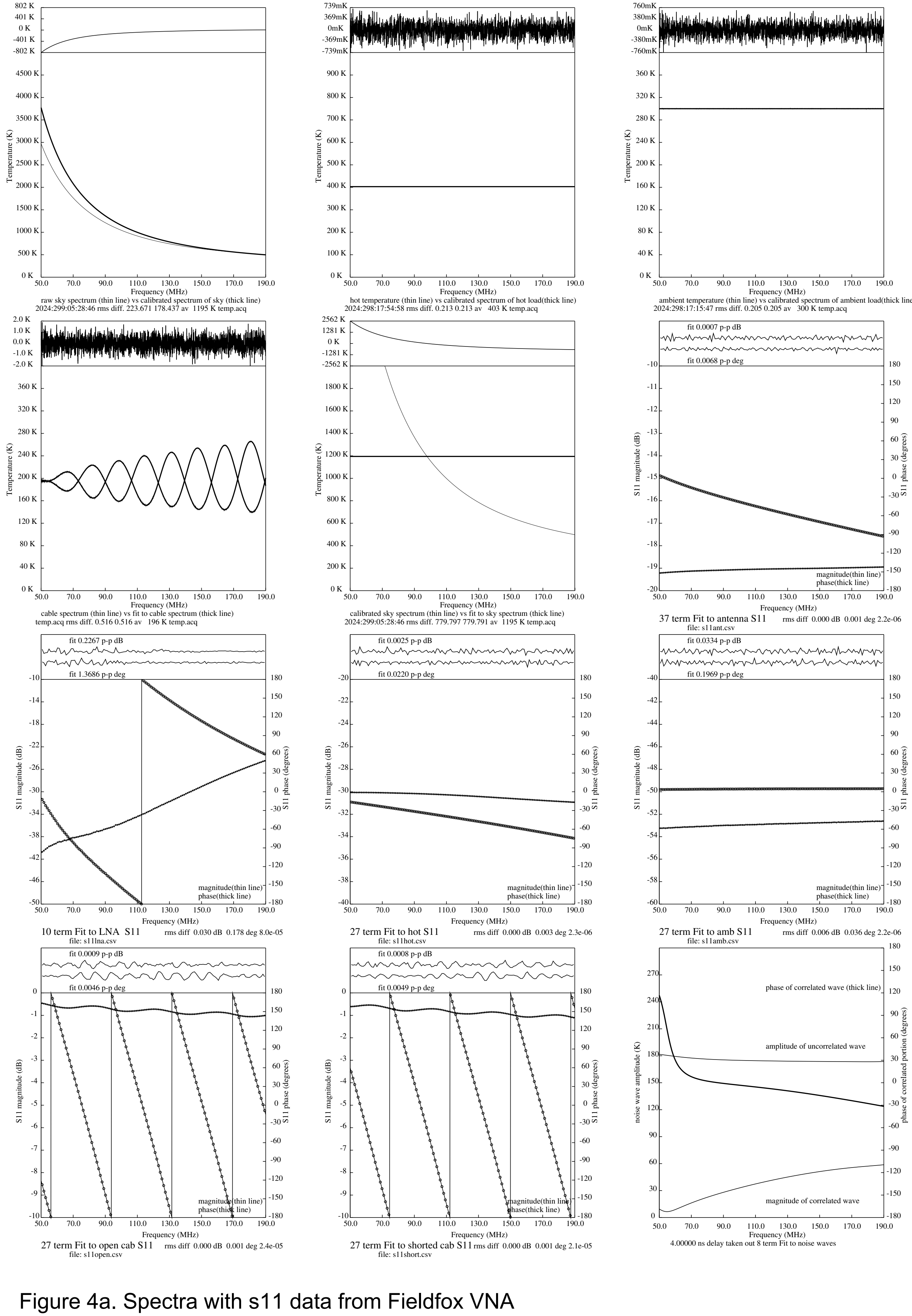


Figure 4a. Spectra with s11 data from Fieldfox VNA

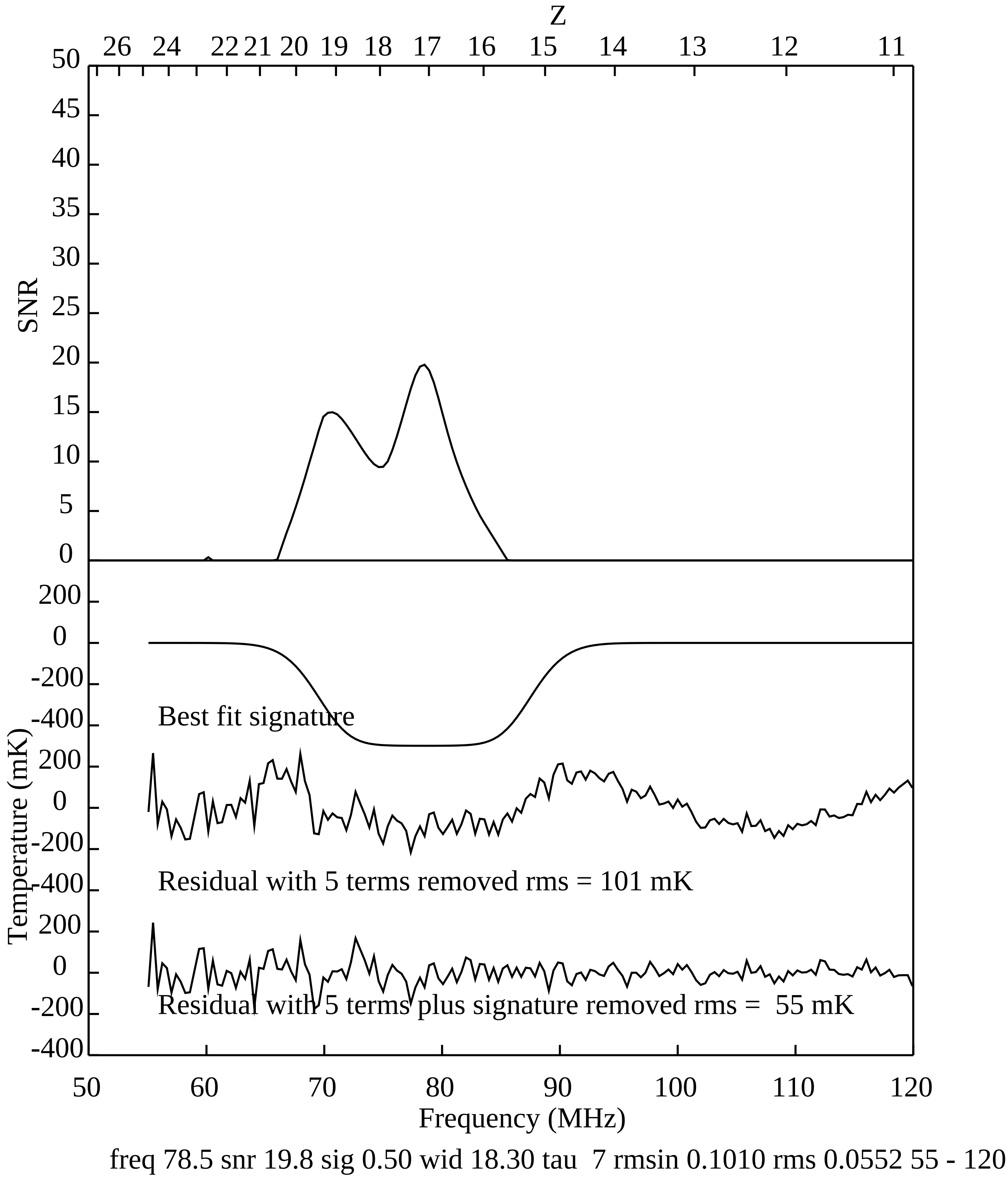
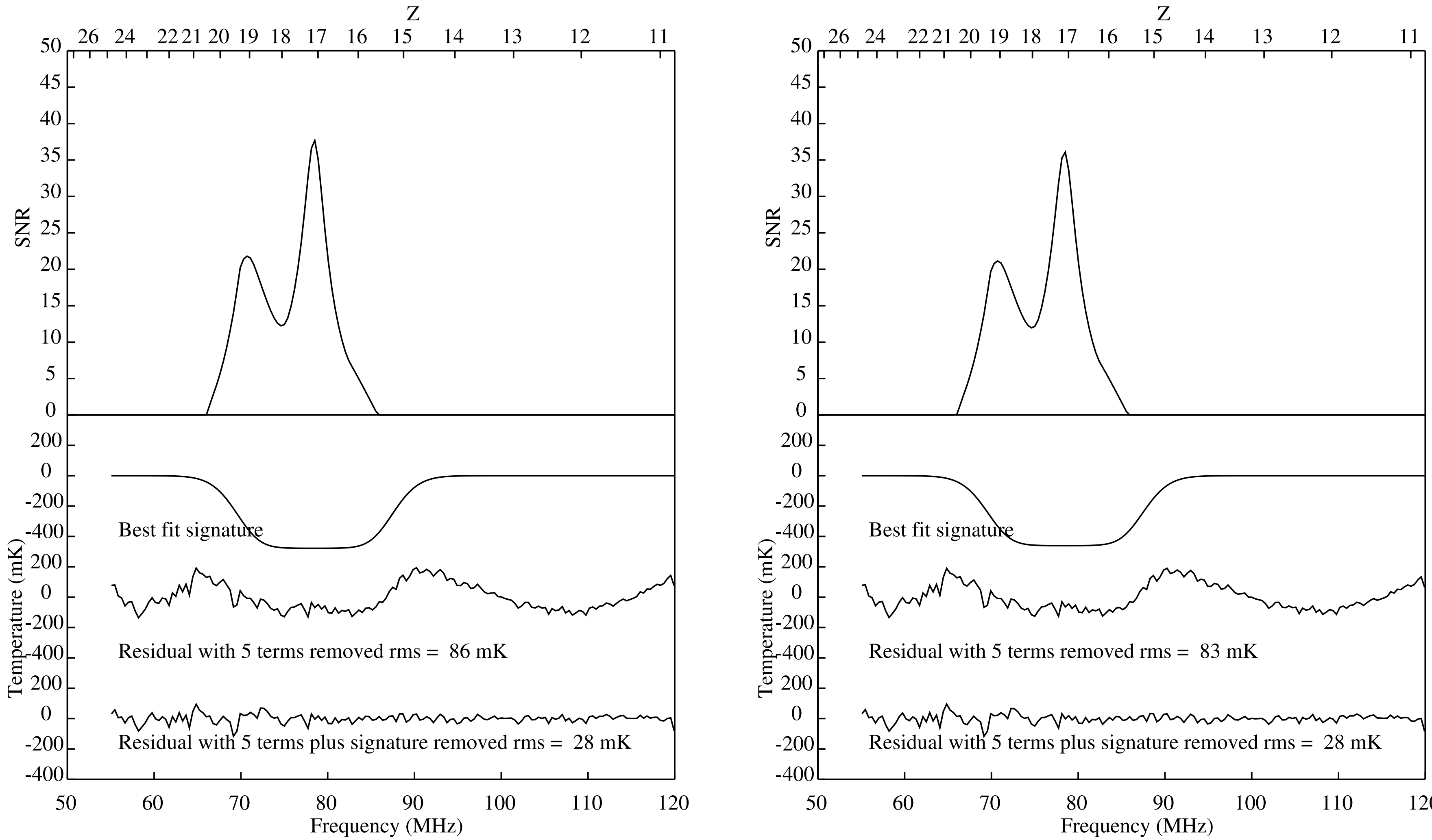


Figure 4b. 5-term search using VNA for 2018 absorption added to artificial antenna spectrum



freq 78.5 snr 37.7 sig 0.48 wid 18.20 tau 7 rmsin 0.0862 rms 0.0280 55 - 120

freq 78.5 snr 36.1 sig 0.46 wid 18.20 tau 7 rmsin 0.0835 rms 0.0281 55 - 120

Figure 5. 5-term search using TE3001 on left and VNA on the right for 24 hrs of antenna spectral data