EDGES MEMO #411

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

March 13, 2023

Telephone: 617-715-5533

To: EDGES group

From: Alan E.E. Rogers, John Barrett and Rigel Cappallo

Subject: Averaging of VNA s11 measurements to reduce error

Memo 93 discusses the need to maintain a constant temperature to obtain the highest VNA accuracy. In practice this is not easy as the VNA's electronics generates heat which changes the temperature in the temperature sensitive parts of the VNA and results in a temperature drift rate which depends on the mode of operation of the VNA. Consequently, the difference in temperature between the s1p data taken on the device and the s1p data on the calibration SOL needs to be minimized by reducing the time difference between the s1p data as much as possible. This can be achieved by minimizing the number of frequency scans made by the VNA for each s1p data file. This reduces the time between the s1p data on the device and the s1p data on the SOL calibration. The calibrated csv files can be averaged to reduce the noise.

For EDGES-3 at the MRO a new scheme is being tested:

The current scheme does:

400 VNA scans on each of amb hot ant open short S O L
and then 400 VNA scans on each of lna S O L

for a total of 12x400 = 4800 scans

Higher accuracy can be achieved in the presence of temperature changes as follows:

5 VNA scans on each x S O L for x=amb,hot,ant,open,short calculates the calibrated for each and repeats 40 times and then averages calibrated results

and then repeats lna calibration of 5 VNA scans on lna S O L 40 times to obtain the average

for a total of 40x4x6x5 = 4800 scans

This scheme ensures that the time difference of between the amb etc. and L is less than 3x5 = 15 scans = 45s for 3s per scan. A test on the EDGES-3 prototype was made. In this test s11 measurements were made using the warm up from 76F to 109F in one hour which corresponds to 0.3 degC/min.

The results for the fractional s11 error between the s11 at the start and the s11 for a one hour warm up are given in Table 1 for the open cable

Temperature difference	Time difference	Number scans per s1p measurement	Difference fraction
18 degC	1 hour	400	8.6e-3
with average of calibrations	1 hour	5	1.1e-4

Table 1. Fractional difference of s11 for open cable with time difference of 1 hour

The differences for the open and shorted cables are mostly in the form of ripples while the differences for the ambient, hot loads and the LNA are smooth while the antenna s11 difference has more structure.

After discussion another scheme was suggested:
In this scheme 5 scans are made on amb,hot,ant,open,short,SOL. Then in order to reduce the noise the procedure is repeated and the s1p data files are averaged and only the s1p files which are now the average of many 5 scan data from the VNA are saved for calibration processing later.

Following the repeated scans the lna power level is reduced and 5 scans on lna SOL are repeated and averaged.

This scheme reduces the time difference between the device data and the calibration SOL data.
For the average of 10 repeats of amb hot ant open S O L short and 10 repeats of lna S O L with the -30 dB level of the VNA needed to avoid saturating the LNA the total number of scans is 10x12x5 = 600 which takes about 1 hour. A single VNA measurement of 100 scans takes 5 minutes so a "warm up" of 2 hours, which is what has been used in the current EDGES-3 scripts would take 2400 scans.

The VNA at the MRO is Agilent N9923A: Serial: MY50371176 and the prototype is Keysight Technologies N9923A Serial: MY58331171 but the Agilent takes about half the time per scan as the Keysight with the same parameters. These time differences for the same model of VNA are probably due to different software from Agilent and Keysight.

In order to average s1p data from the VNA which is output in dB and phase in degrees it is necessary to convert to real and imaginary values of the s11 which are then averaged and the average in converted to the s1p format of dB and phase in degrees using a c-coded function s1pav. This function is called with 4 arguments:

arg1 = file name of s1p average
arg2 = file name of s1p to be added to average
arg3 = number of s1p files in final average
arg4 = 0 for first s1p file
arg4 = 1 for s1p file to be added to average

s1pav scales the first file by 1/number and then adds the file scaled by 1/number

ant	amb	hot	open	short	lna	first	second	# scans	# repeats
1.0e-4	7.5e-5	1.2e-4	2.9e-4	3.4e-4	3.8e-4	065_20	065_22	5	10
7.6e-4	9.9e-4	9.2e-4	1.3e-3	1.0e-3	8.5e-4	065_22	066_01	5	10
3.1e-4	4.4e-4	3.7e-4	3.5e-4	2.1e-4	1.8e-4	065_20	066_14	2	25
3.6e-4	5.2e-4	4.4e-4	4.9e-4	3.6e-4	3.6e-4	065_20	066_17	2	10
2.4e-4	3.2e-4	2.9e-4	4.5e-4	3.8e-4	3.7e-4	065_20	066_18	2	10
4.4e-4	6.7e-4	5.5e-4	5.5e-4	3.2e-4	4.9e-4	065_20	066_21	2	2
3.0e-4	6.2e-5	3.5e-4	1.0e-3	1.0e-3	1.2e-3	065_20	067_00	1	1
7.0e-4	8.1e-4	8.6e-4	8.6e-3	1.7e-3	1.4e-3	065_20	067_12	1	1
5.7e-4	8.2e-4	7.1e-4	7.4e-4	4.4e-4	9.0e-4	067_00	067_12	1	1

Table 2 Fractional differences between calibrated s11 measurements made on EDGES-3 prototype

Table 2 shows the difference between s11 derived from 5 scans repeated 10 times. The second row was the difference following a 2 hour warm-up prior to 2023_065_20 and the other rows are for data taken

during warm up. The “ant” is an open ended 6 dB attenuator. The difference for the open cable in the first entry in table 4 is shown in Figure 1. Figure 2 shows the differences in S11 for EDGES-3 data from the MRO taken at 2022_319_14 and 2022_329_07 for comparison.

A test was made on the EDGES-3 at the MRO repeating 2 scans per VNA s1p 25 times. This result is shown in Figure 3. The fractional accuracy was reduced by a factor of about 10 compared with the plots antenna, ambient load, hot load, open and shorted cables and LNA in Figure 2.

In summary compared with the current 400 scans, whose results are in in Table 1, the number of scans needs to be brought down to 5 or lower to bring the effect of a temperature change rate of 0.3degC/min down below 1e-3. Table 2 shows that more than a single scan is needed to lower the VNA noise below 1e-3. The best overall performance is about 3e-4 with 25 repeats of 2 scans per VNA s1p measurement.

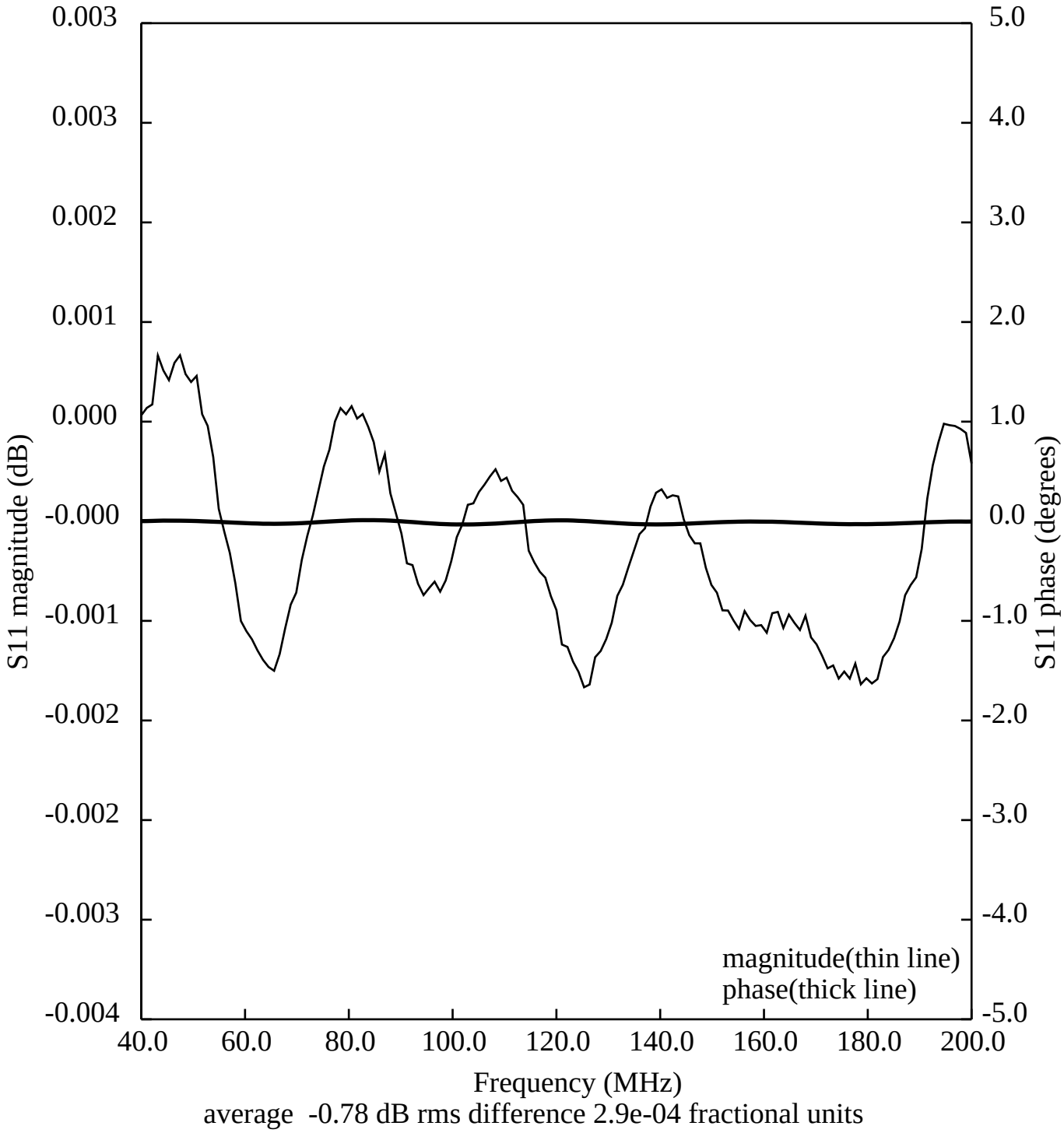

Figure 1. Plot of S11 difference for the open cable result in the first entry of Table 2

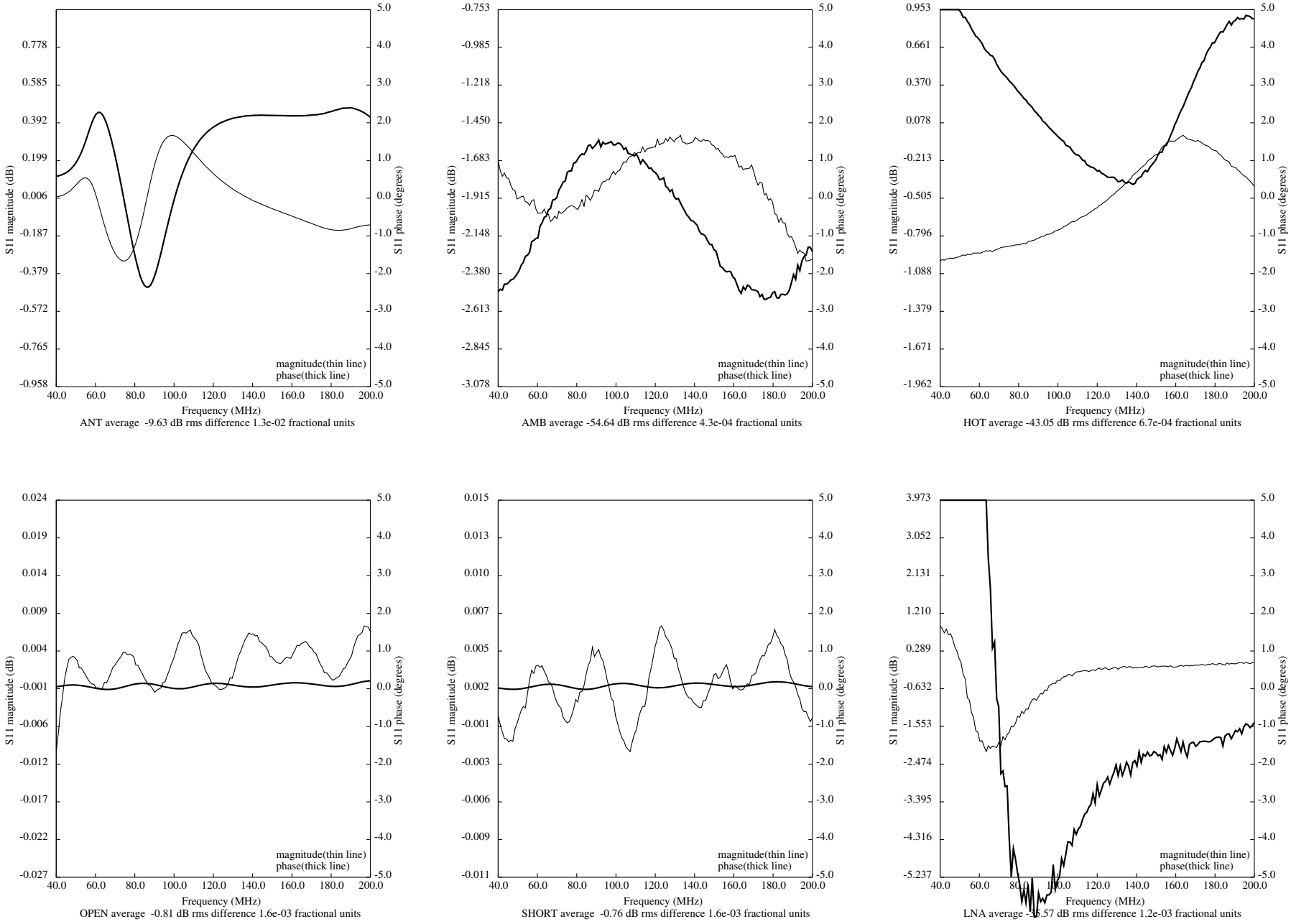

Figure 2. Plots of the difference between calibrated S11 data from 2022_319_14 and 2022_329_07.

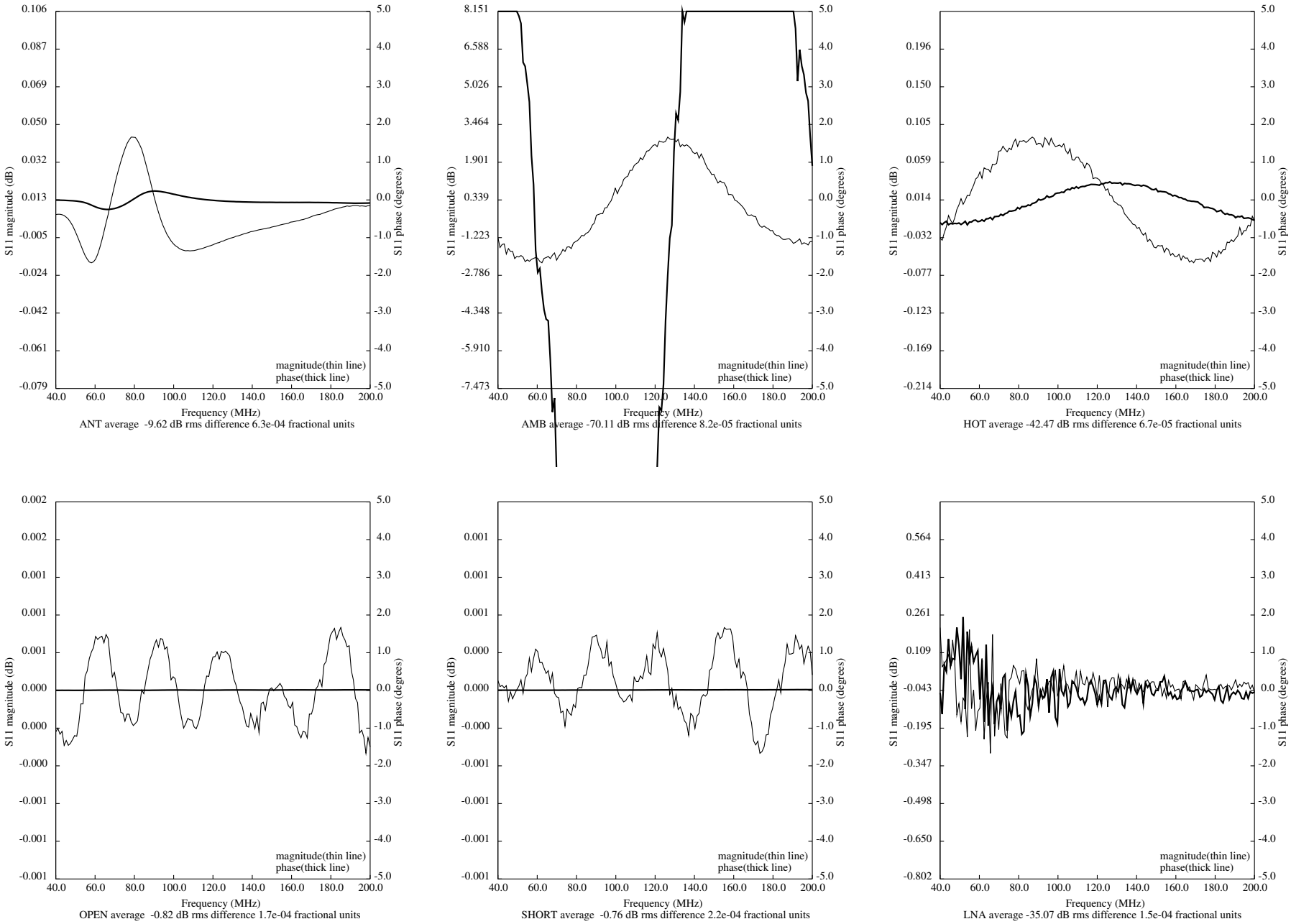

Figure 3. Plots of the difference from averaging method on data from 2023_068_21 and 2023_068_18