Progress Toward a Full Uncertainty Propagation Machinery for EDGES

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Description

This report describes the progress toward a full uncertainty propagation procedure for EDGES.

The procedure is based on a brute-force Monte Carlo, in which the calibration of the antenna temperature is done using calibration quantities modeled using parameter values drawn randomly from distributions derived from their covariance matrices. Figure 1 presents a block diagram of the process.

First, it is necessary to produce an Uncalibrated antenna temperature. This is done using:

- A sky-beam convolution using the GSM and a flat beam of the form $\cos^2\theta$. The quietest portion is chosen (LST ~ 7), and modeled as $\log(T_{ant}) = \sum_i a_i[\log(\nu/\nu_n)]^i$. See Figure 2.
- An antenna S11, with flat magnitude at -15 dB, and with a realistic phase. See Figure 3.
- The LNA S11 corresponding to a model fit to lab measurements.
- Scale, offset, and noise wave parameters (nwp) derived from lab measurements: spectra and S11 of Ambient Load, Hot Load, and Open Cable. The modeling of these quantities was done either in terms of polynomials or Fourier series.

The antenna temperature is then *recovered*, using:

- The perfectly known antenna S11.
- the LNA S11, whose model parameters are allowed to vary within their covariance.
- the Scale, Offset, and nwp, recomputed from models of lab measurements allowed to vary within their covariance.

Description

The sources of uncertainty are:

- Physical temperature of Ambient Load, Hot Load, and Open Cable. The 1σ uncertainty assigned is 0.3 K.
- Parameter covariance in the model fit to the spectra of the Ambient Load, Hot Load, and Open Cable. This uncertainty depends on the amount of integration of spectra. The results reported here correspond to the integrations conducted at ASU during the receiver calibration.
- Parameter covariance in the model fit to the Magnitude and Phase of the S11 of the LNA, Ambient Load, Hot Load, and Open Cable. Also, the S12 of the semi-rigid (SR) cable inside the Hot load. This uncertainty depends on the amount of integration of traces. The results reported here correspond to the measurements conducted at ASU during the receiver calibration.
- Uncertainty in S11 (and S12 for the SR cable of the Hot Load) of 0.01-dB (at -20 dB) and 0.1°, in both cases 1σ. The frequency shape of this uncertainty is modeled as a 5-term polynomial, for the magnitude and phase.

Results

Starting with Figure 4, the effect of each source of uncertainty is observed independently. The blue lines correspond to 1σ bounds obtained after running the MC 2000 times. The upper plots correspond to the uncertainty remaining after removing the *perfectly known* input antenna temperature, from the calibrated antenna temperature. The lower plots correspond to the uncertainty after removing the best-fit model of the form $\log(T_{ant}) = \sum_i a_i [\log(\nu/\nu_n)]^i$.

In particular, the S11 plots also have a label STAT or SYST, to distinguish between those two cases. The STAT case corresponds to the limitations of modeling the data itself, while SYST accounts for the suspected limitations in the measurement process.

Finally, Figure 30 presents the combined effects, after running the MC 50,000 times. The blue curves represent the effect of all the uncertainties being present simultaneously. The red curves represent the effect of only the systematic uncertainties, i.e., in the physical temperature of the Ambient Load, Hot Load, and Open Cable, and in all the S11 and S12 quantities. Clearly, the uncertainties regarded as systematic are limiting the precision of EDGES. Increasing the integration times used for measurements of spectra and S11 during receiver calibration would not provide significant benefits.

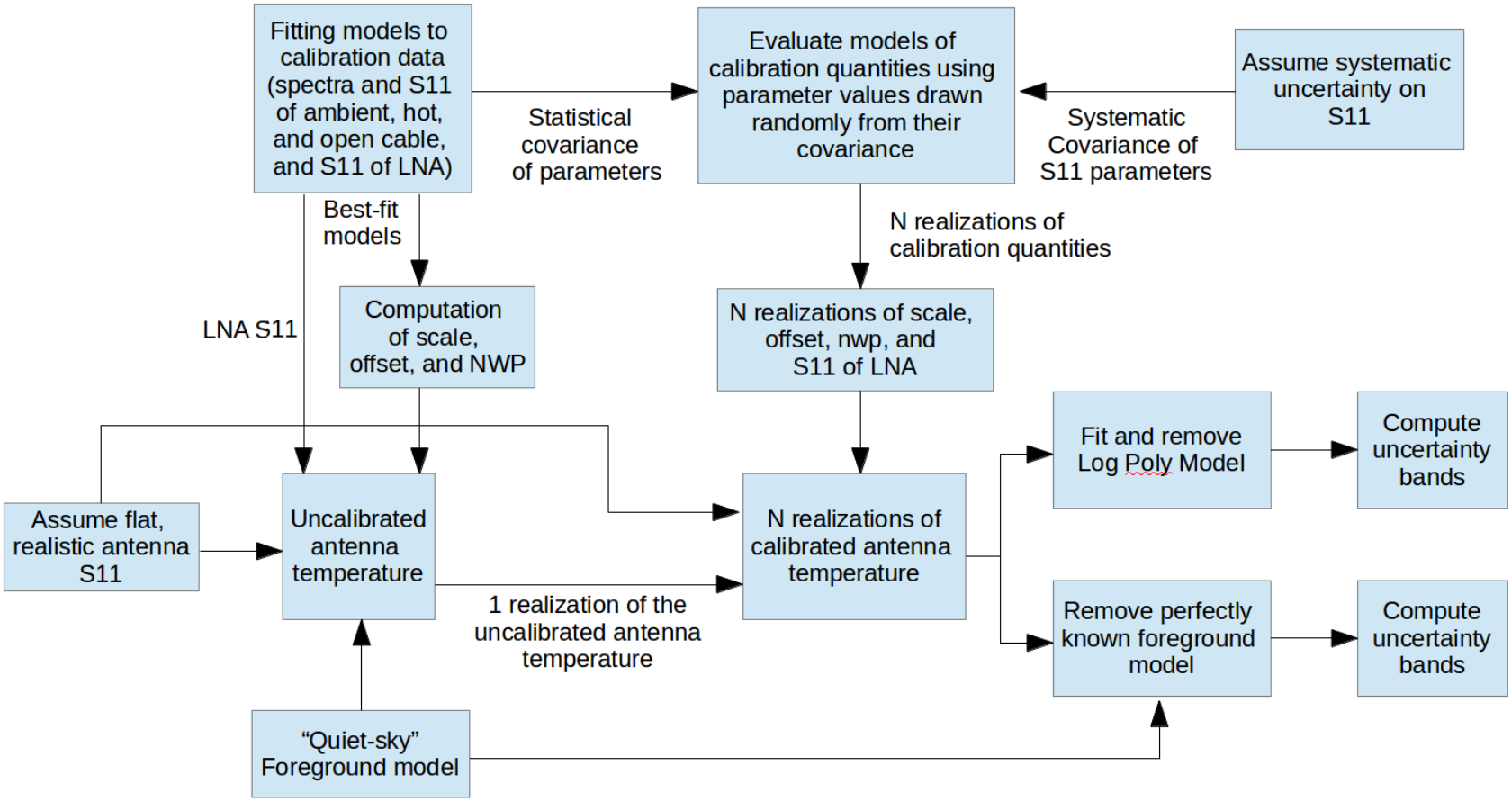
Fitting models to calibration data (spectra and S11 of ambient, hot, and open cable, and S11 of LNA)
Statistical covariance of parameters
Evaluate models of calibration quantities using parameter values drawn randomly from their covariance
Systematic Covariance of S11 parameters
Assume systematic uncertainty on S11
Best-fit models
N realizations of calibration quantities
LNA S11
Computation of scale, offset, and NWP
N realizations of scale, offset, nwp, and S11 of LNA
Assume flat, realistic antenna S11
Uncalibrated antenna temperature
1 realization of the uncalibrated antenna temperature
N realizations of calibrated antenna temperature
Fit and remove Log Poly Model
Compute uncertainty bands
Remove perfectly known foreground model
Compute uncertainty bands
"Quiet-sky" Foreground model

Figure : (1)

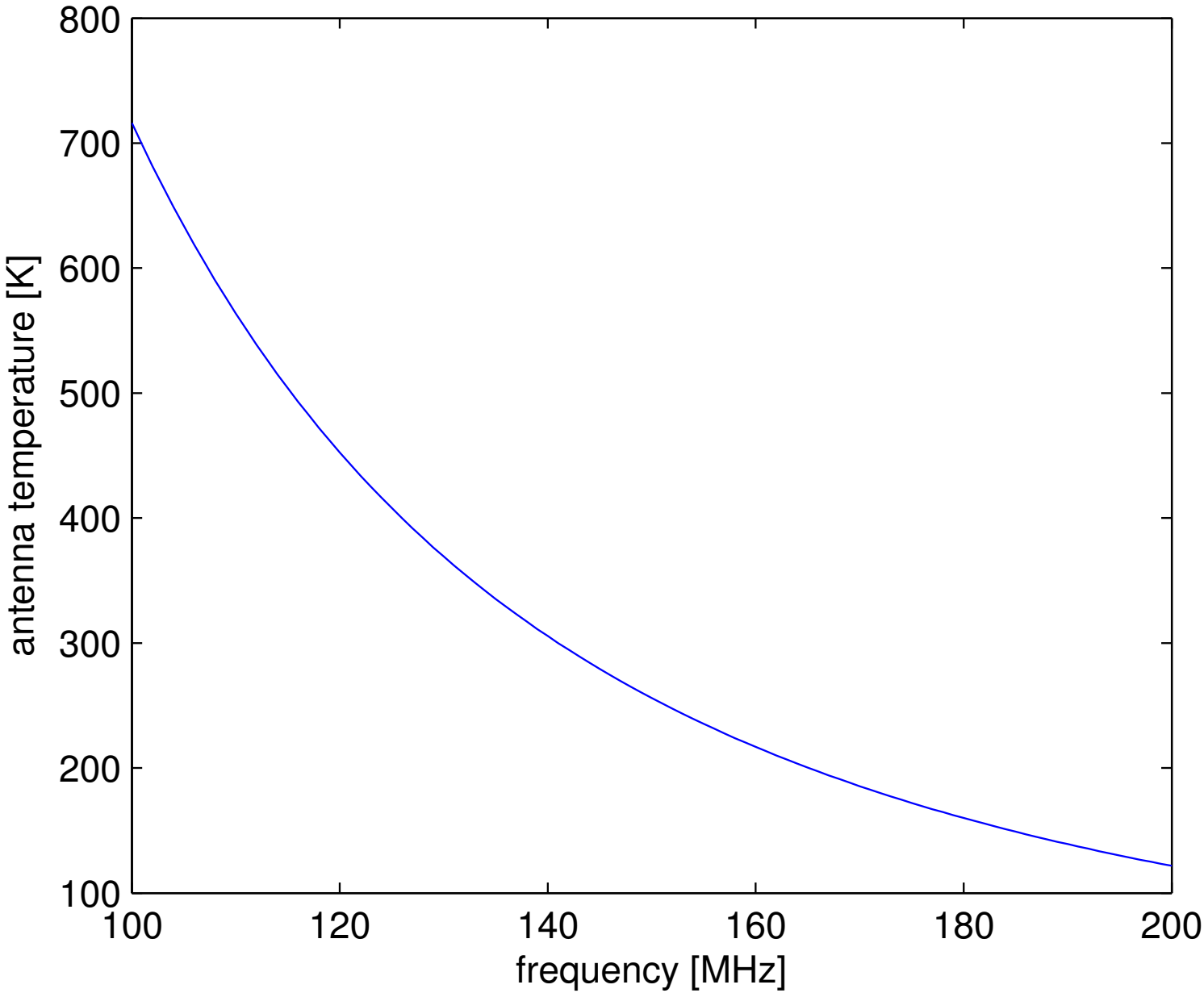
800
700
600
500
400
300
200
100
antenna temperature [K]
100
120
140
160
180
200
frequency [MHz]

Figure : (2)

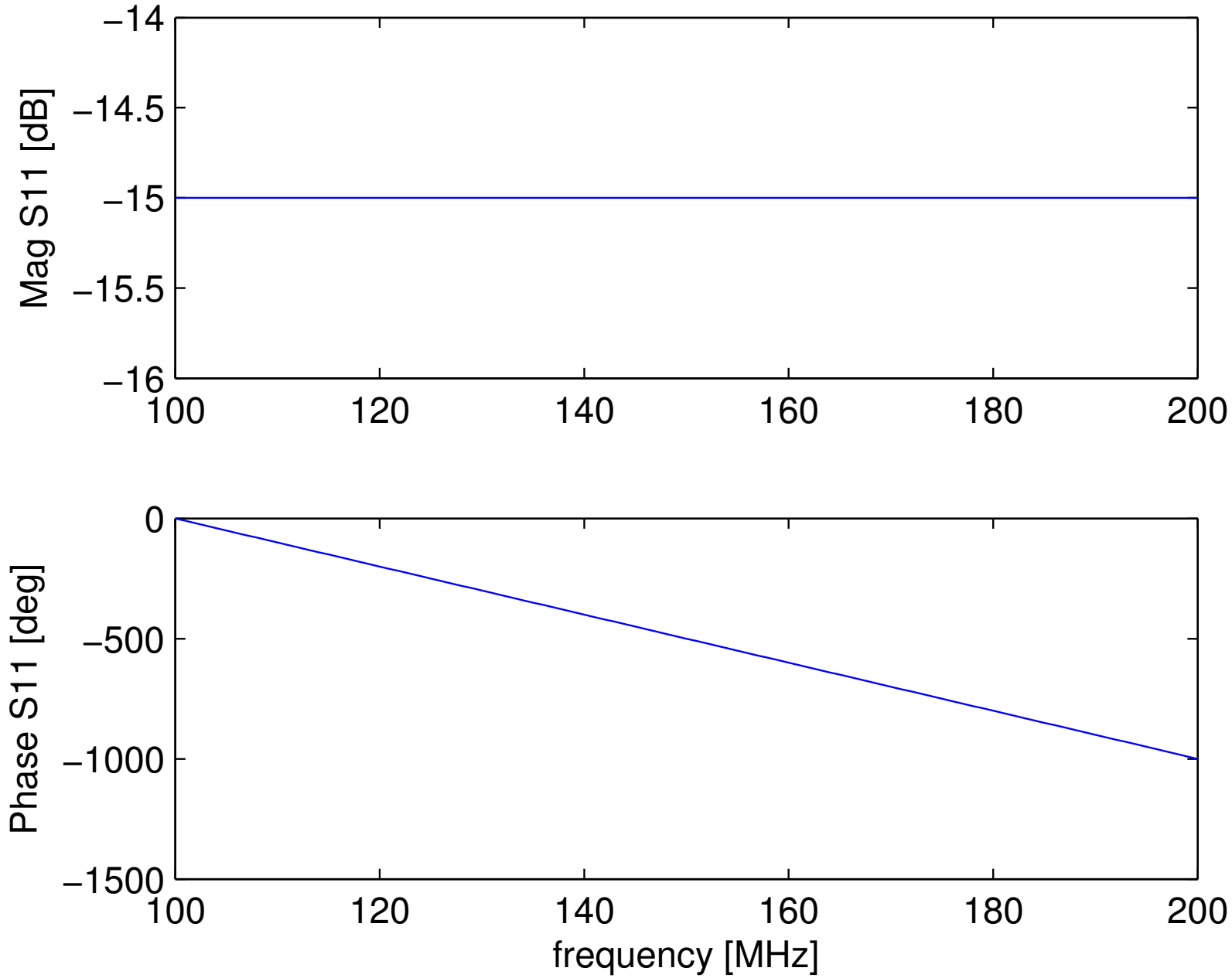
−14
−14.5
−15
−15.5
−16
Mag S11 [dB]
100
120
140
160
180
200
0
−500
−1000
−1500
Phase S11 [deg]
100
120
140
160
180
200
frequency [MHz]

Figure : (3)

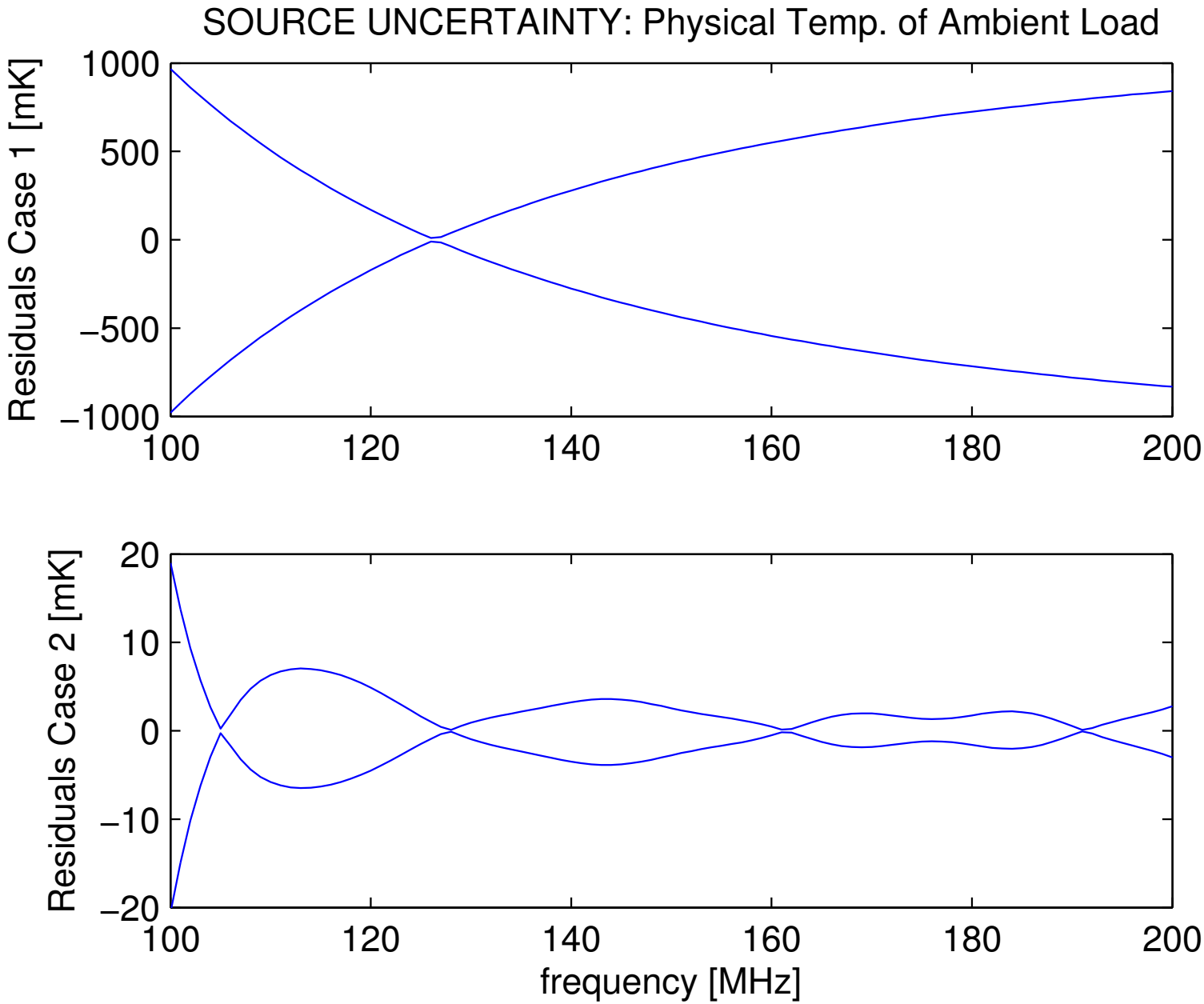
SOURCE UNCERTAINTY: Physical Temp. of Ambient Load
Residuals Case 1 [mK]
1000
500
0
−500
−1000
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (4)

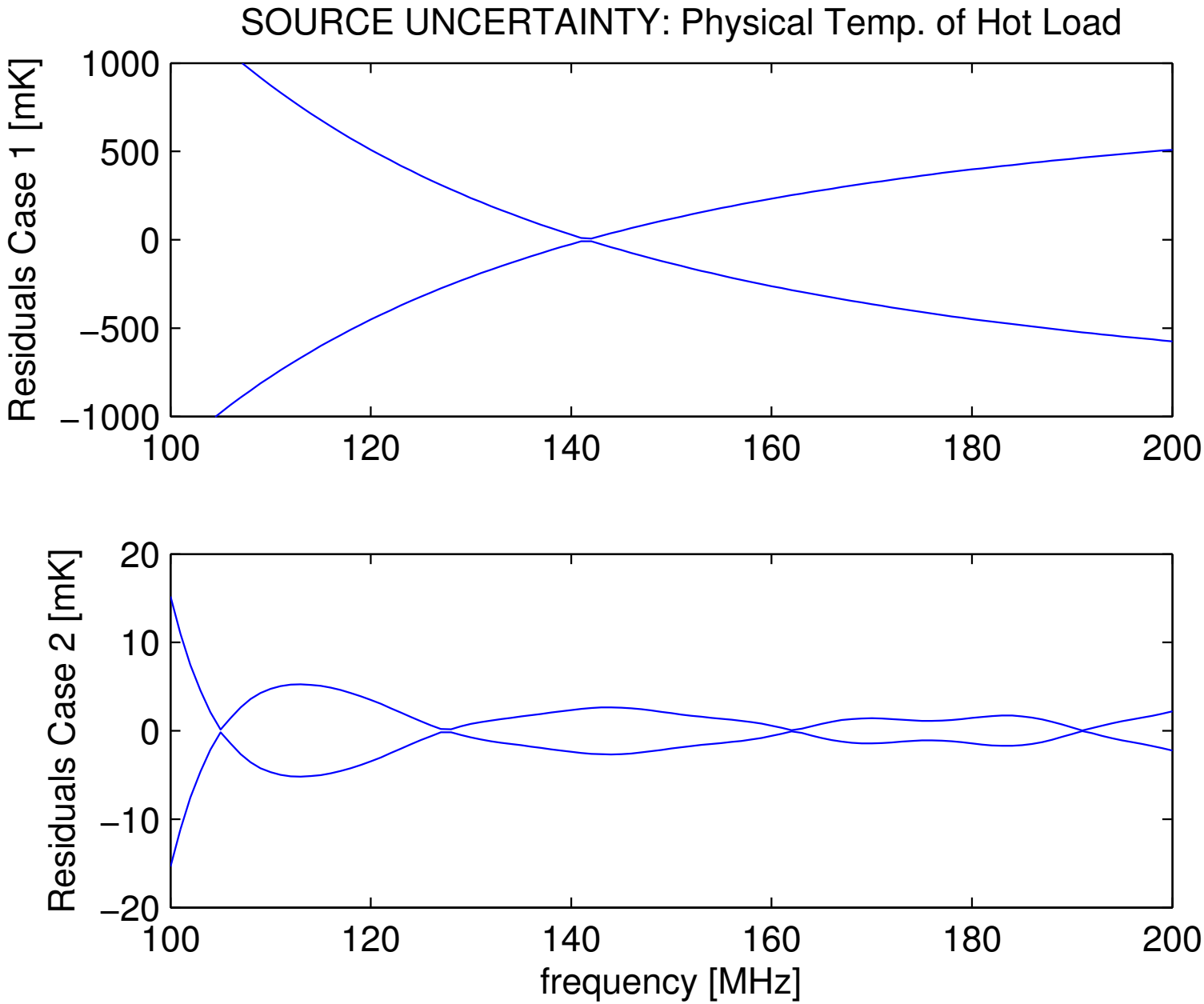
SOURCE UNCERTAINTY: Physical Temp. of Hot Load
Residuals Case 1 [mK]
1000
500
0
−500
−1000
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (5)

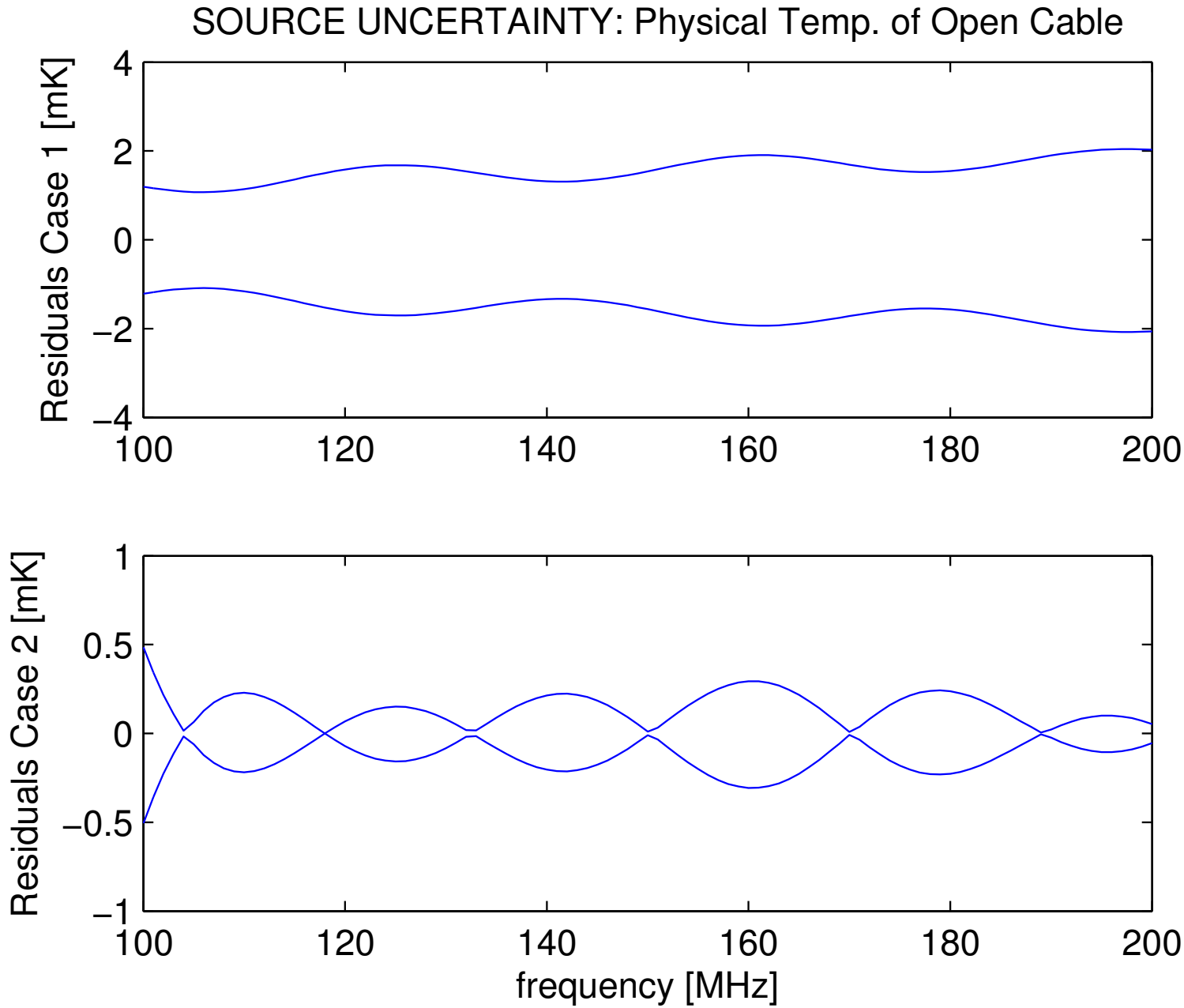
SOURCE UNCERTAINTY: Physical Temp. of Open Cable
Residuals Case 1 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
Residuals Case 2 [mK]
1
0.5
0
−0.5
−1
100
120
140
160
180
200
frequency [MHz]

Figure : (6)

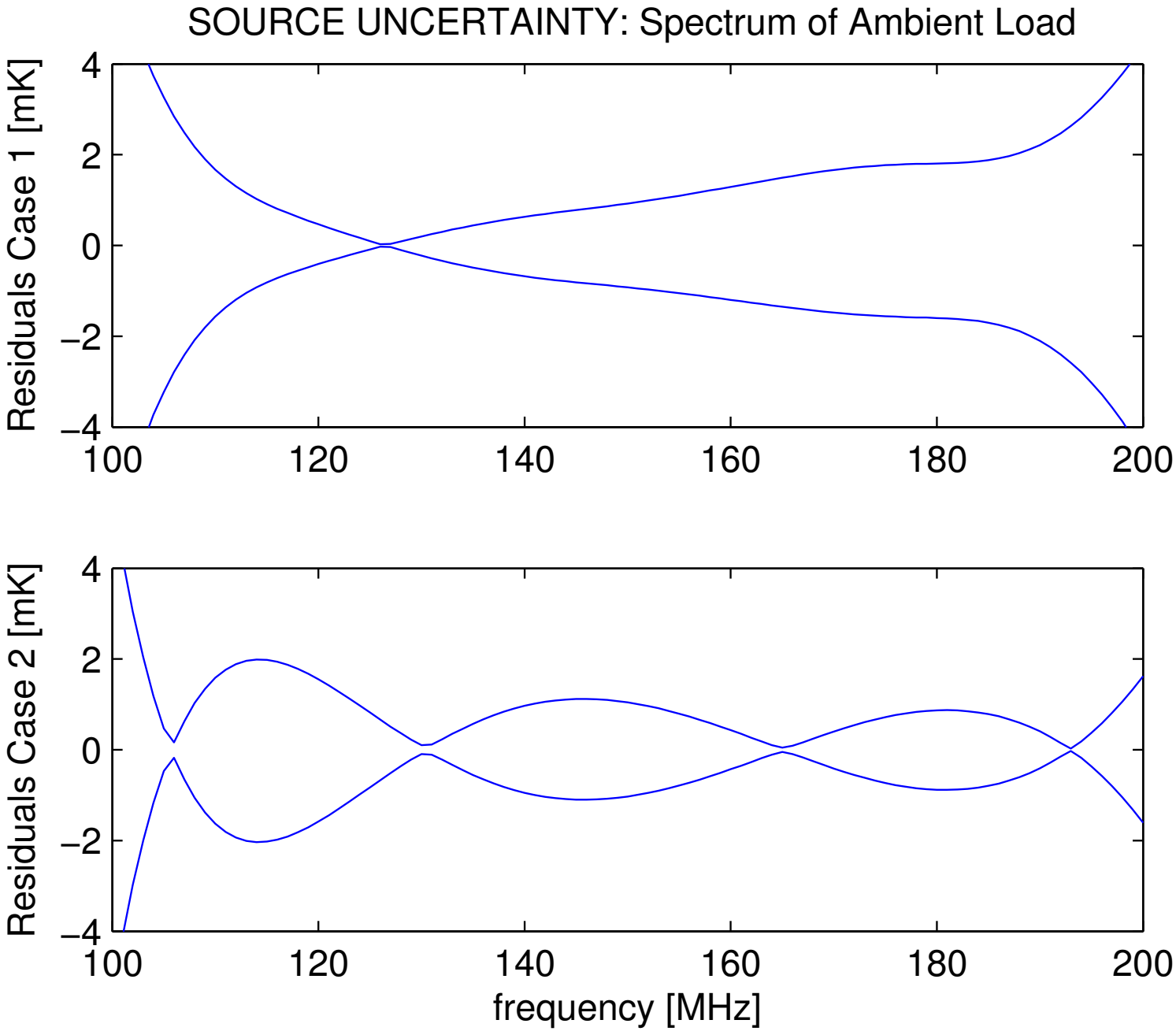
SOURCE UNCERTAINTY: Spectrum of Ambient Load
Residuals Case 1 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
Residuals Case 2 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
frequency [MHz]

Figure : (7)

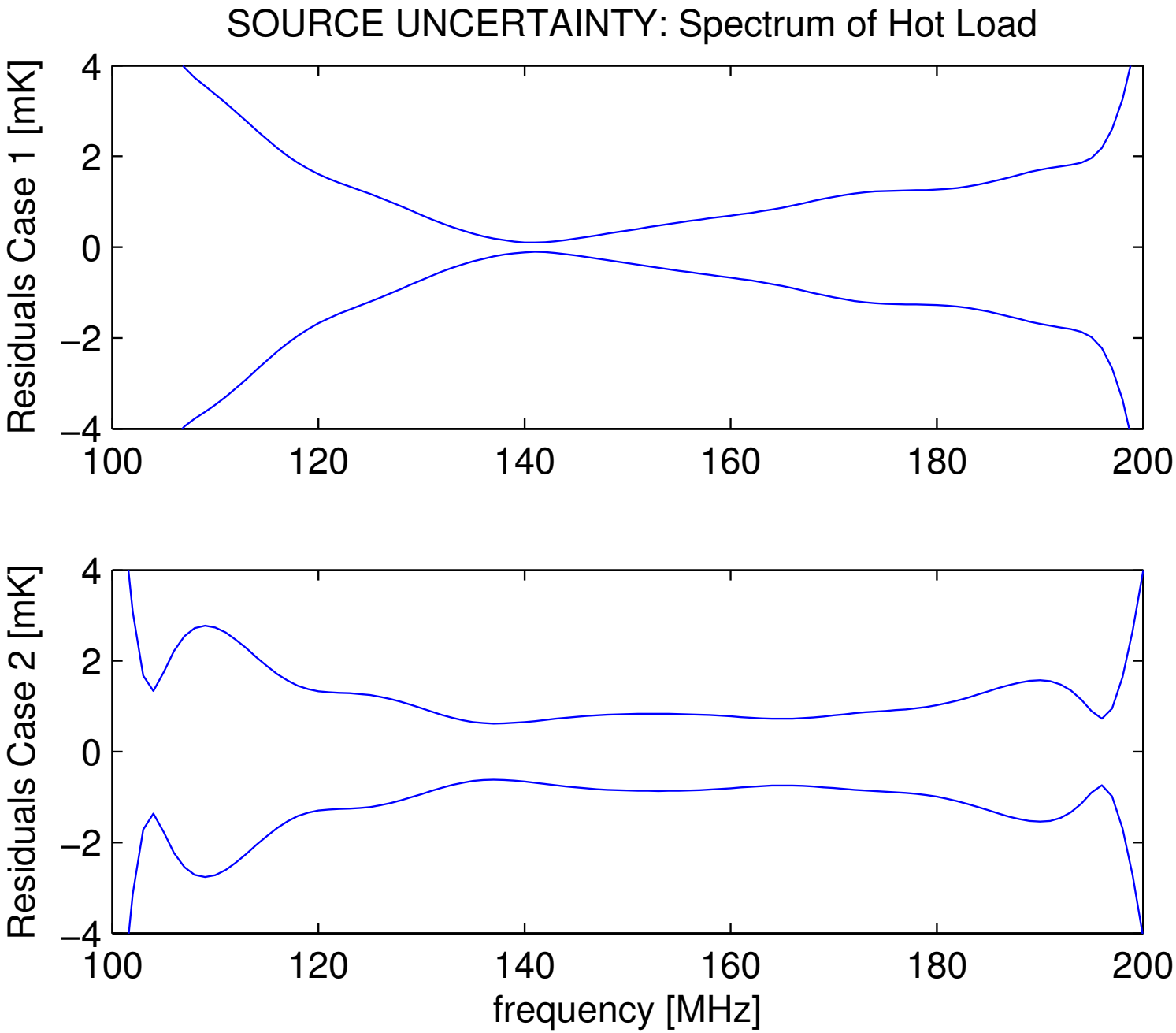
SOURCE UNCERTAINTY: Spectrum of Hot Load
Residuals Case 1 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
Residuals Case 2 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
frequency [MHz]

Figure : (8)

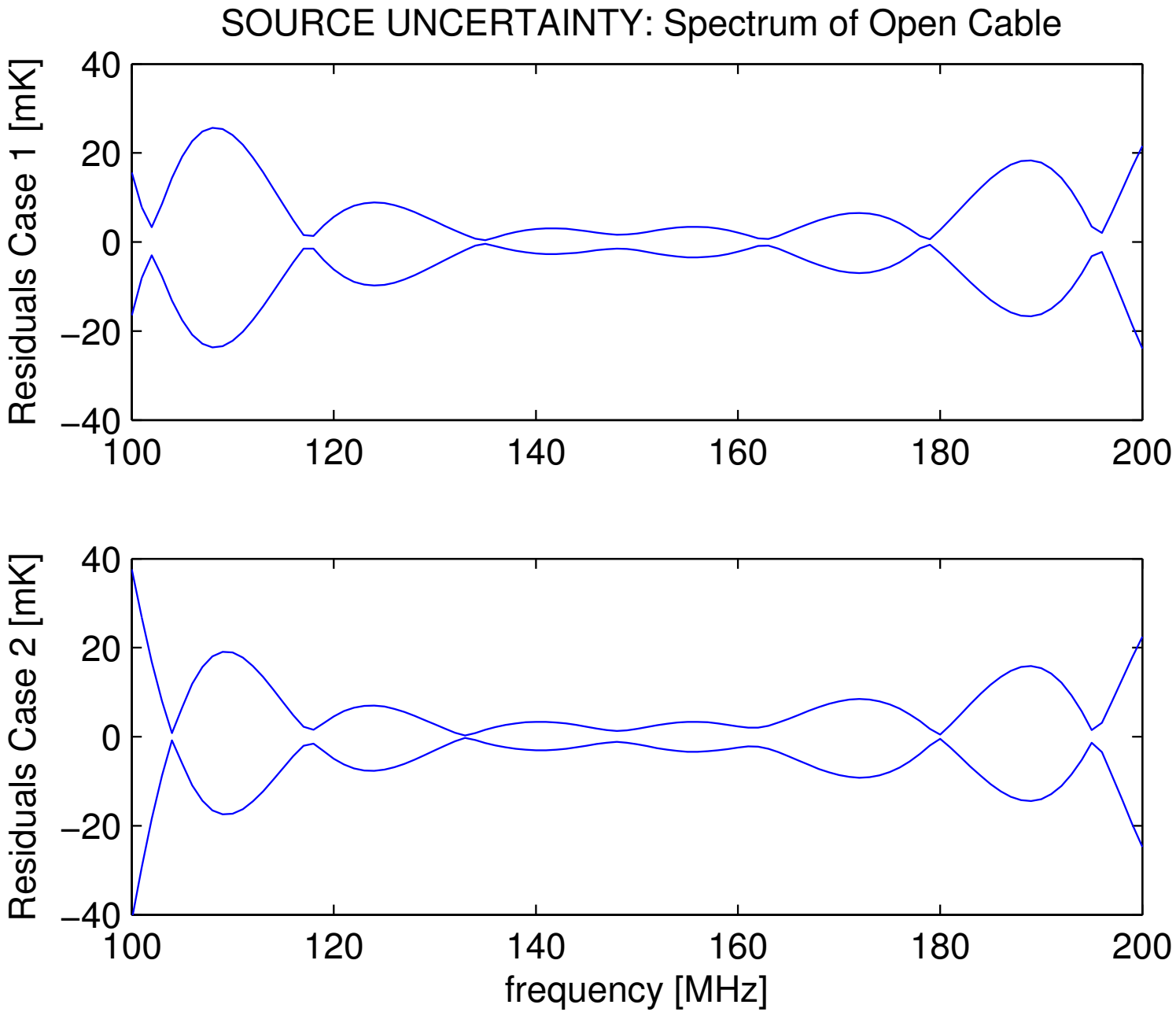
SOURCE UNCERTAINTY: Spectrum of Open Cable
Residuals Case 1 [mK]
40
20
0
−20
−40
100
120
140
160
180
200
Residuals Case 2 [mK]
40
20
0
−20
−40
100
120
140
160
180
200
frequency [MHz]

Figure : (9)

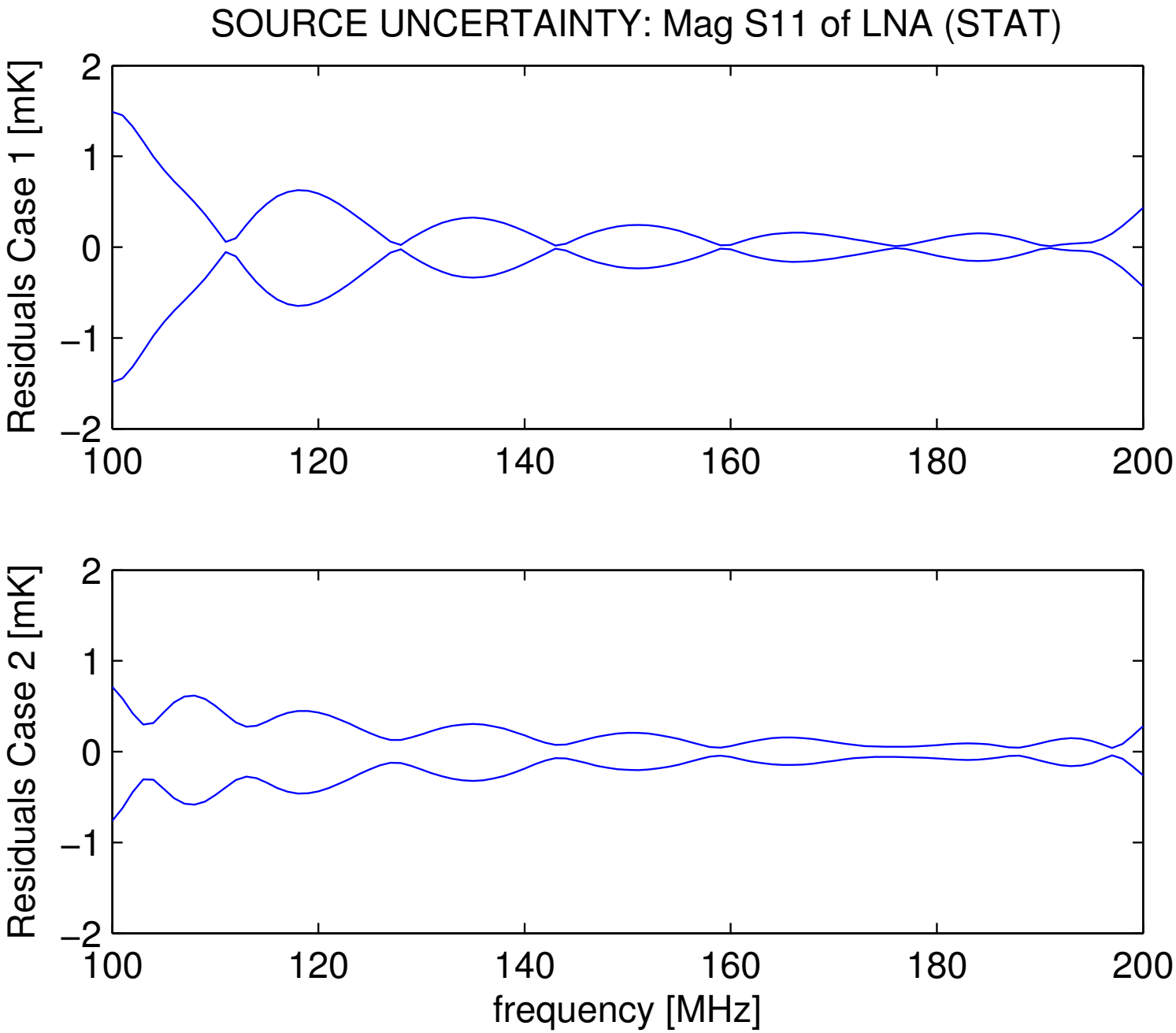
SOURCE UNCERTAINTY: Mag S11 of LNA (STAT)
Residuals Case 1 [mK]
2
1
0
−1
−2
100
120
140
160
180
200
Residuals Case 2 [mK]
2
1
0
−1
−2
100
120
140
160
180
200
frequency [MHz]

Figure : (10)

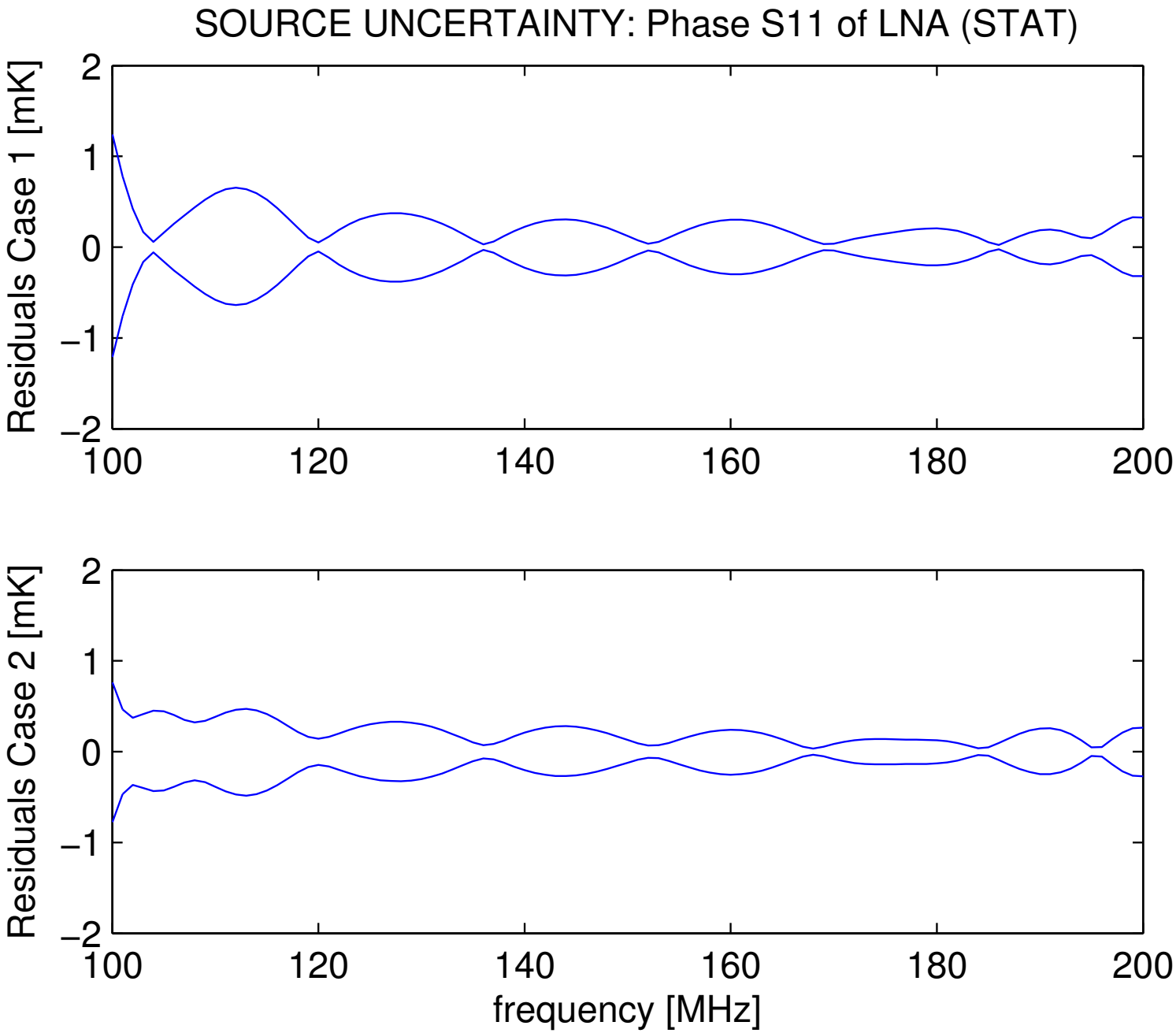
SOURCE UNCERTAINTY: Phase S11 of LNA (STAT)
Residuals Case 1 [mK]
2
1
0
−1
−2
100
120
140
160
180
200
Residuals Case 2 [mK]
2
1
0
−1
−2
100
120
140
160
180
200
frequency [MHz]

Figure : (11)

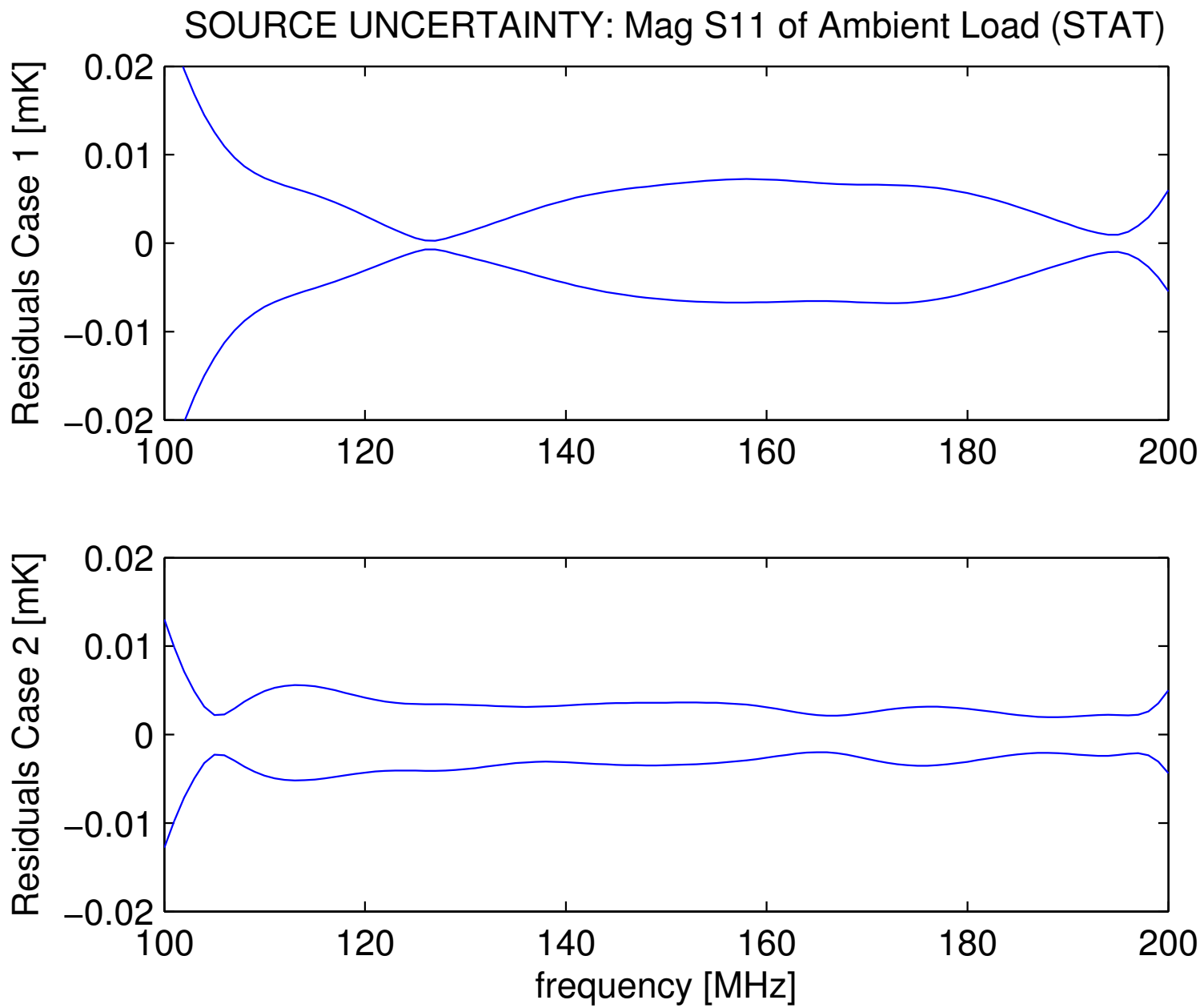
SOURCE UNCERTAINTY: Mag S11 of Ambient Load (STAT)
Residuals Case 1 [mK]
0.02
0.01
0
−0.01
−0.02
100
120
140
160
180
200
Residuals Case 2 [mK]
0.02
0.01
0
−0.01
−0.02
100
120
140
160
180
200
frequency [MHz]

Figure : (12)

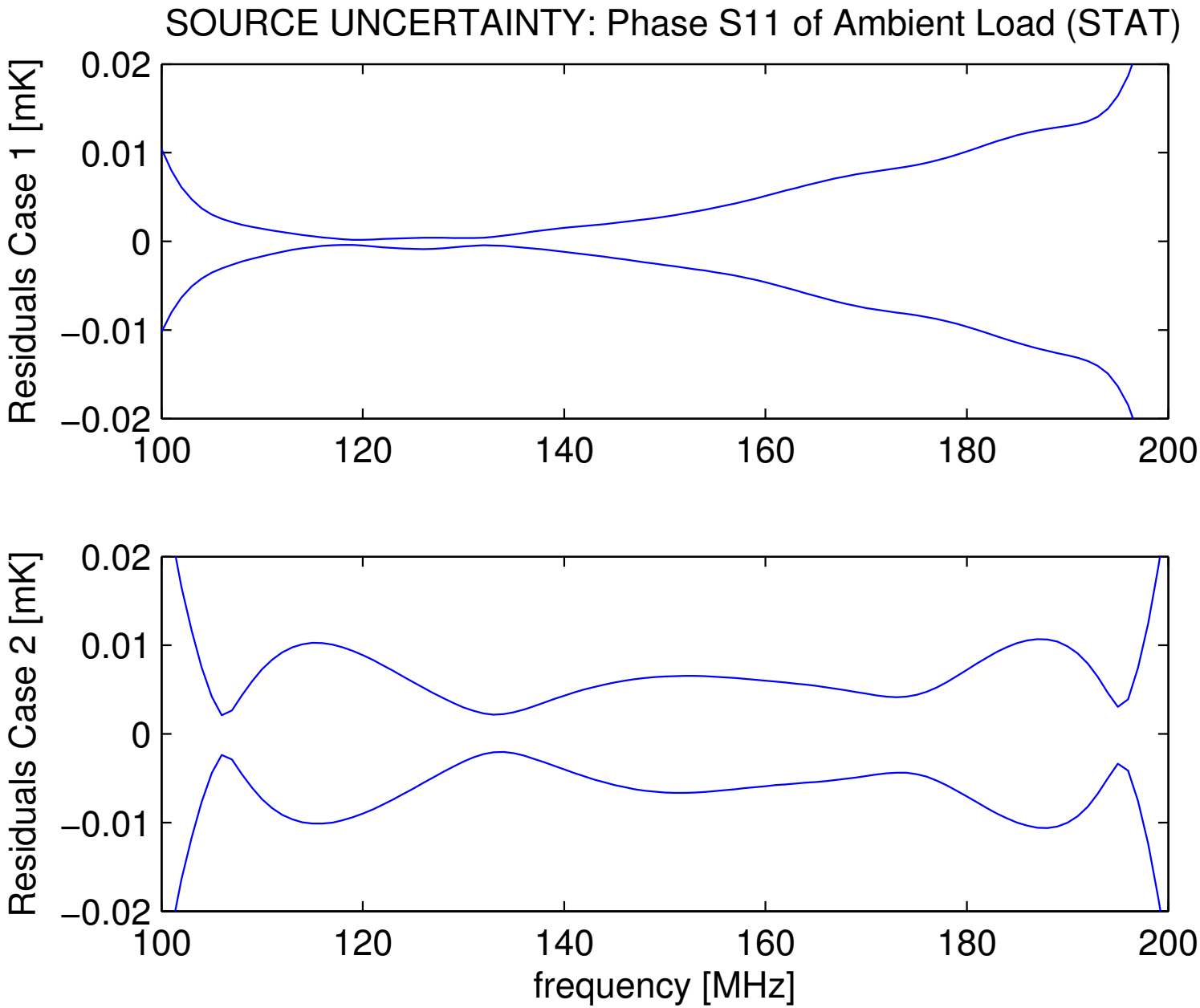
SOURCE UNCERTAINTY: Phase S11 of Ambient Load (STAT)
Residuals Case 1 [mK]
0.02
0.01
0
−0.01
−0.02
100
120
140
160
180
200
Residuals Case 2 [mK]
0.02
0.01
0
−0.01
−0.02
100
120
140
160
180
200
frequency [MHz]

Figure : (13)

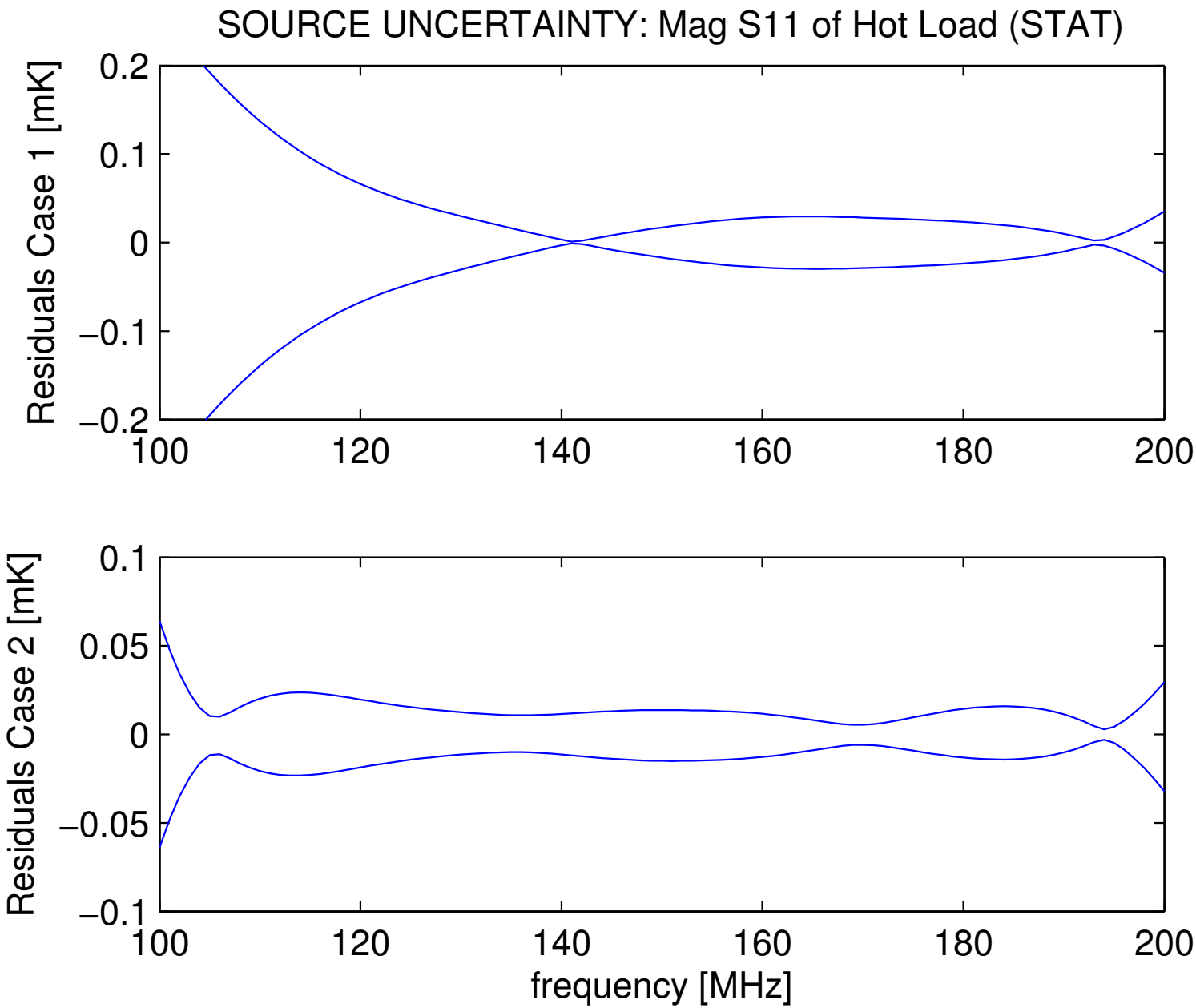
SOURCE UNCERTAINTY: Mag S11 of Hot Load (STAT)
Residuals Case 1 [mK]
0.2
0.1
0
−0.1
−0.2
100
120
140
160
180
200
Residuals Case 2 [mK]
0.1
0.05
0
−0.05
−0.1
100
120
140
160
180
200
frequency [MHz]

Figure : (14)

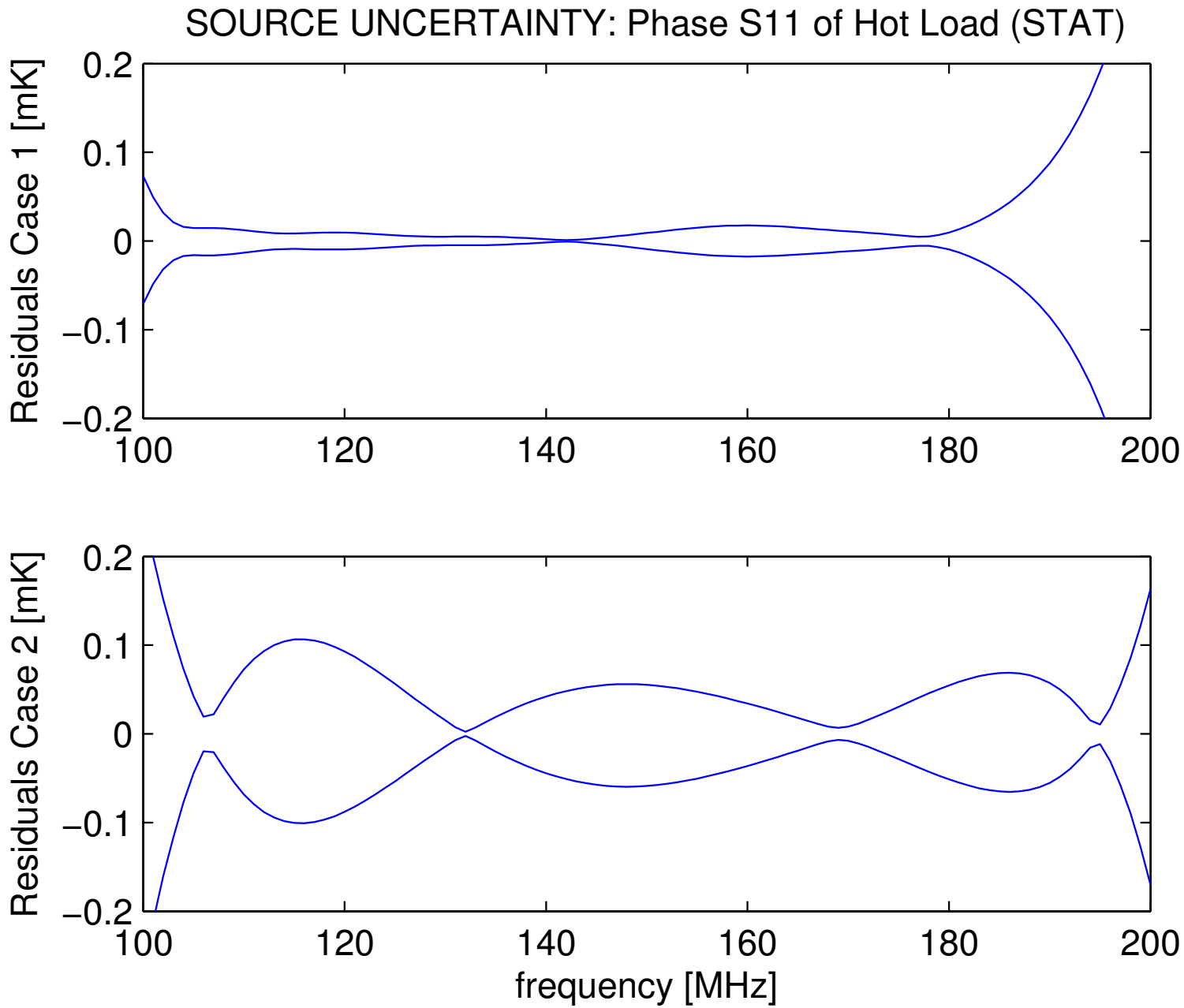
SOURCE UNCERTAINTY: Phase S11 of Hot Load (STAT)
Residuals Case 1 [mK]
0.2
0.1
0
−0.1
−0.2
100
120
140
160
180
200
Residuals Case 2 [mK]
0.2
0.1
0
−0.1
−0.2
100
120
140
160
180
200
frequency [MHz]

Figure : (15)

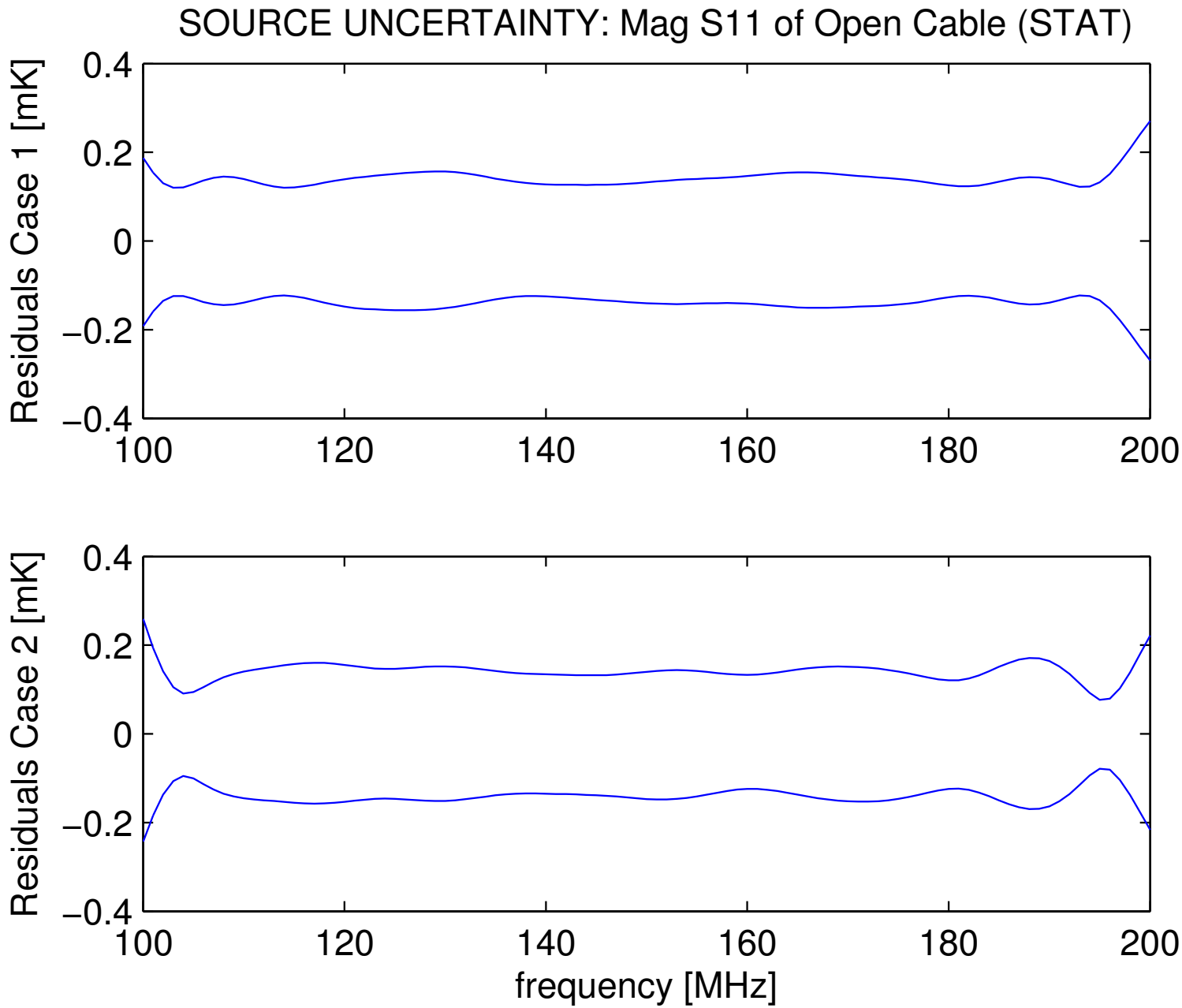
SOURCE UNCERTAINTY: Mag S11 of Open Cable (STAT)
Residuals Case 1 [mK]
0.4
0.2
0
−0.2
−0.4
100
120
140
160
180
200
Residuals Case 2 [mK]
0.4
0.2
0
−0.2
−0.4
100
120
140
160
180
200
frequency [MHz]

Figure : (16)

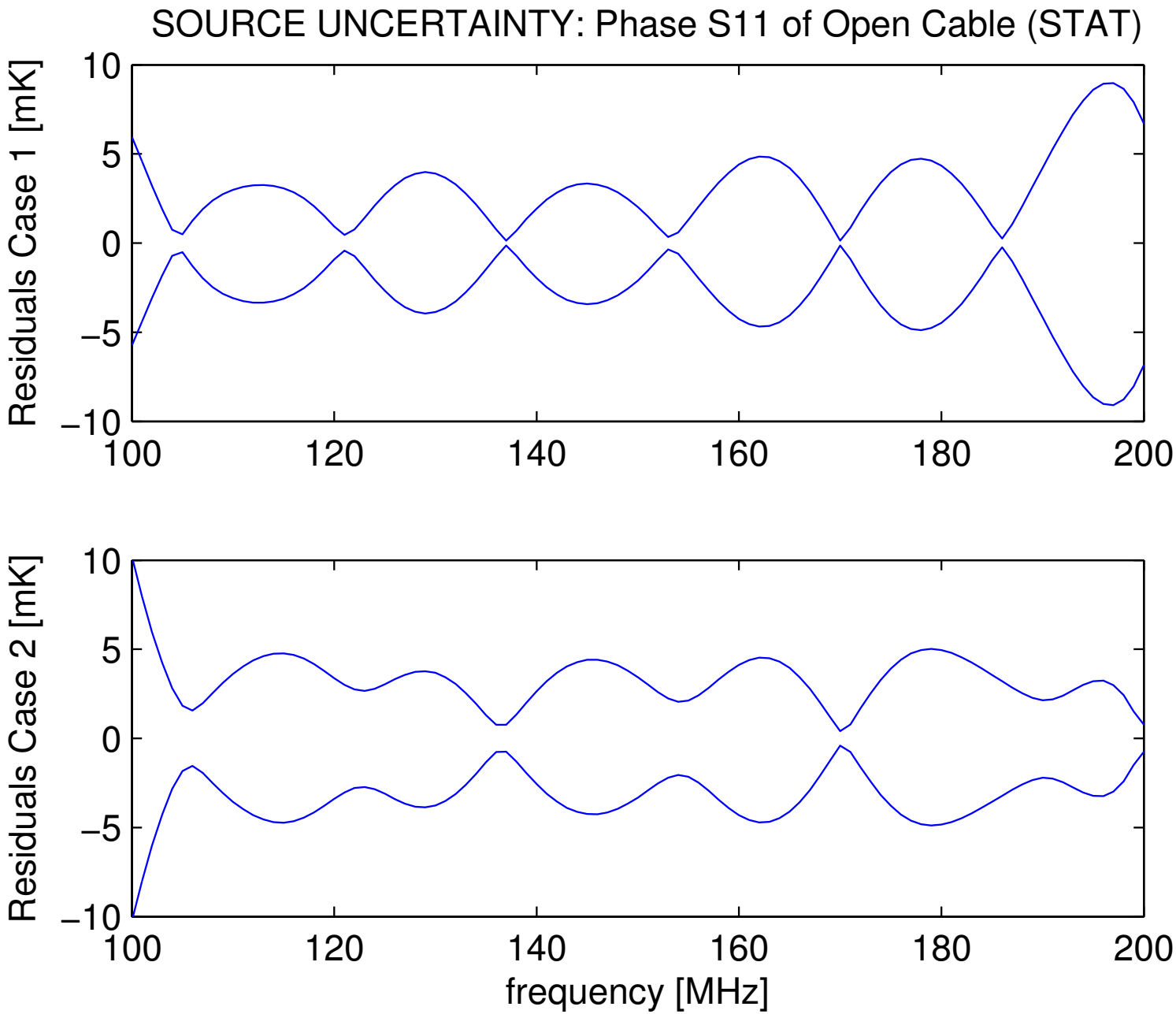
SOURCE UNCERTAINTY: Phase S11 of Open Cable (STAT)
Residuals Case 1 [mK]
10
5
0
−5
−10
100
120
140
160
180
200
Residuals Case 2 [mK]
10
5
0
−5
−10
100
120
140
160
180
200
frequency [MHz]

Figure : (17)

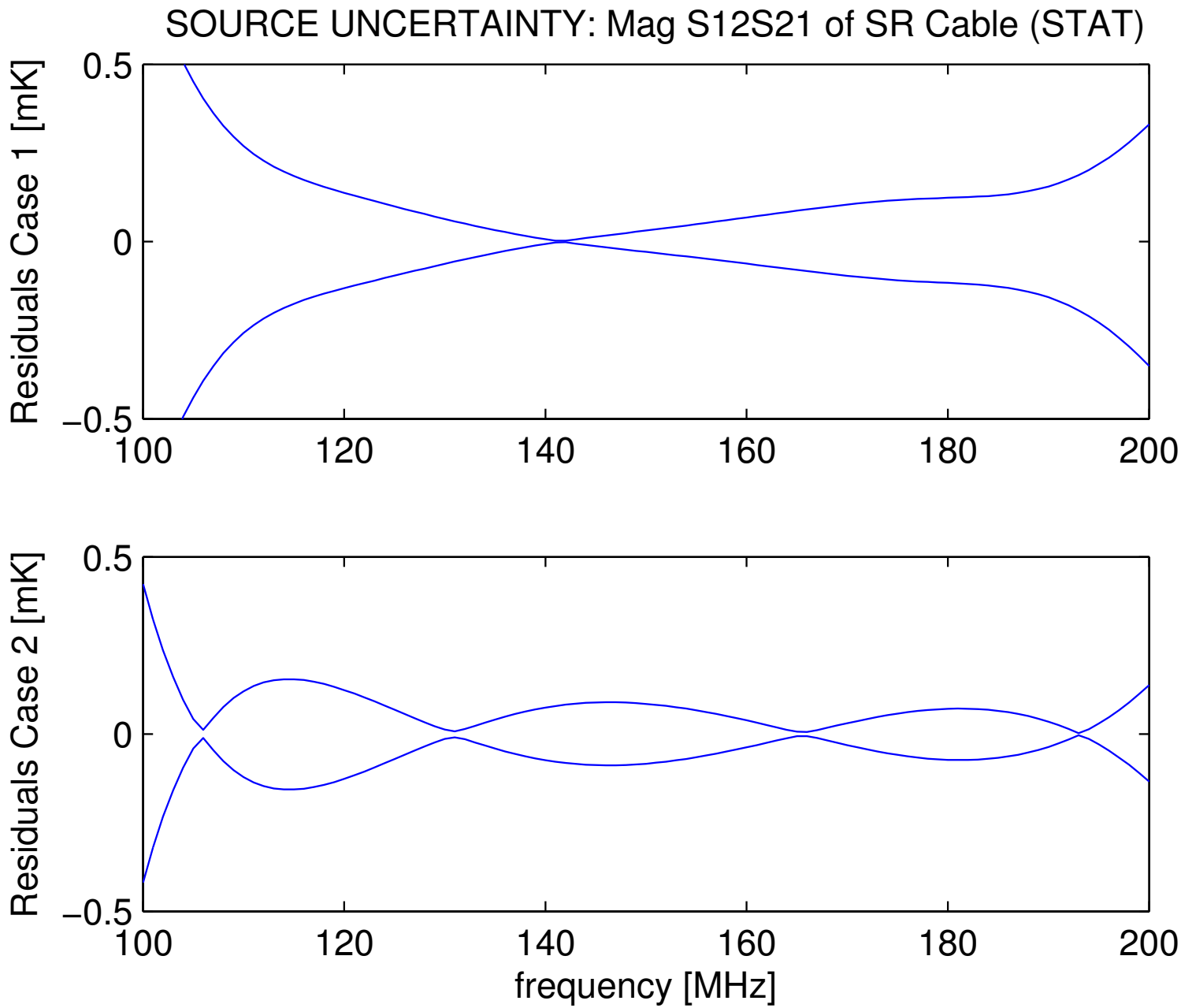
SOURCE UNCERTAINTY: Mag S12S21 of SR Cable (STAT)
Residuals Case 1 [mK]
0.5
0
−0.5
100
120
140
160
180
200
Residuals Case 2 [mK]
0.5
0
−0.5
100
120
140
160
180
200
frequency [MHz]

Figure : (18)

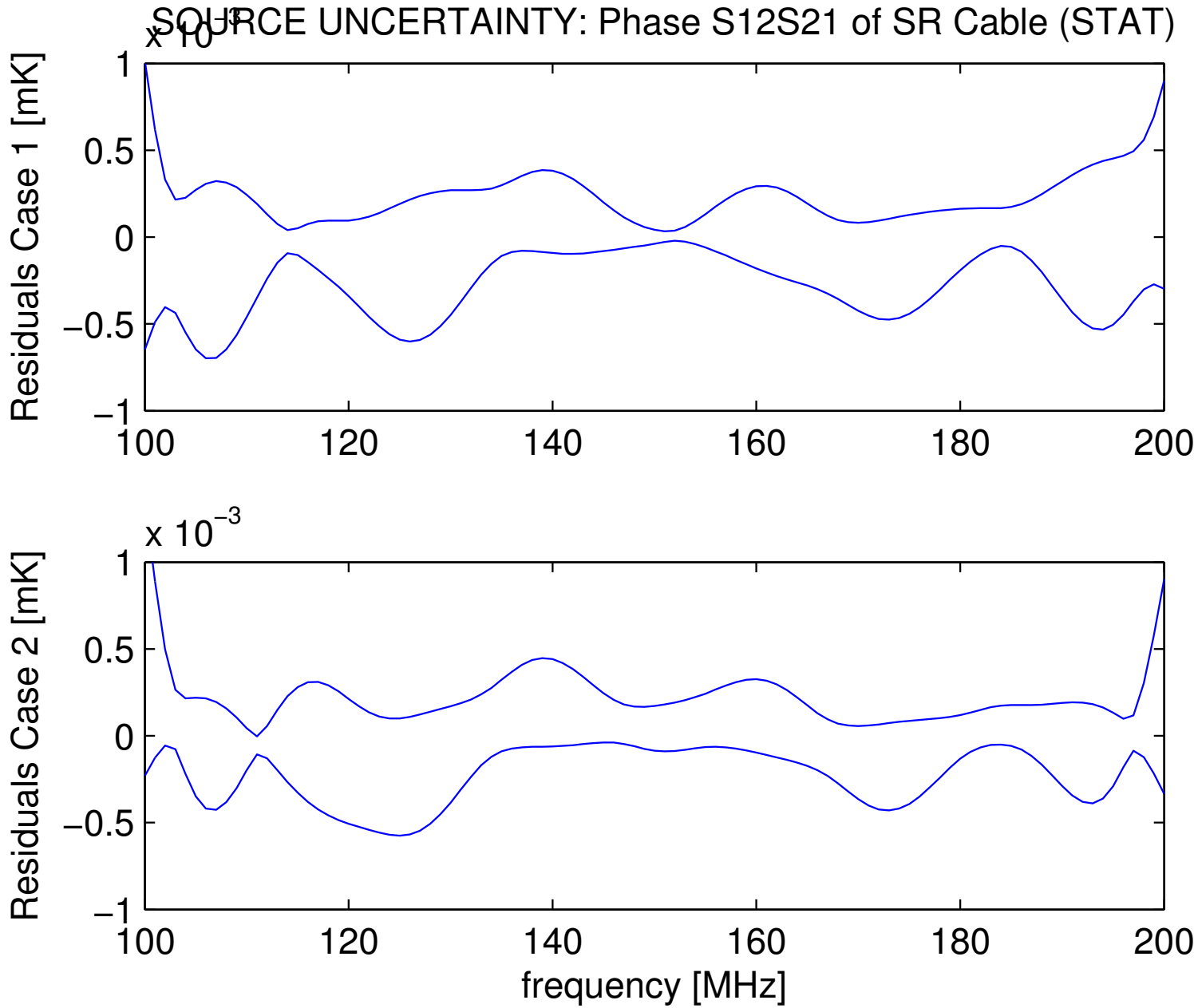
SOURCE UNCERTAINTY: Phase S12S21 of SR Cable (STAT)
x 10^-3
Residuals Case 1 [mK]
1
0.5
0
−0.5
−1
100
120
140
160
180
200
x 10^-3
Residuals Case 2 [mK]
1
0.5
0
−0.5
−1
100
120
140
160
180
200
frequency [MHz]

Figure : (19)

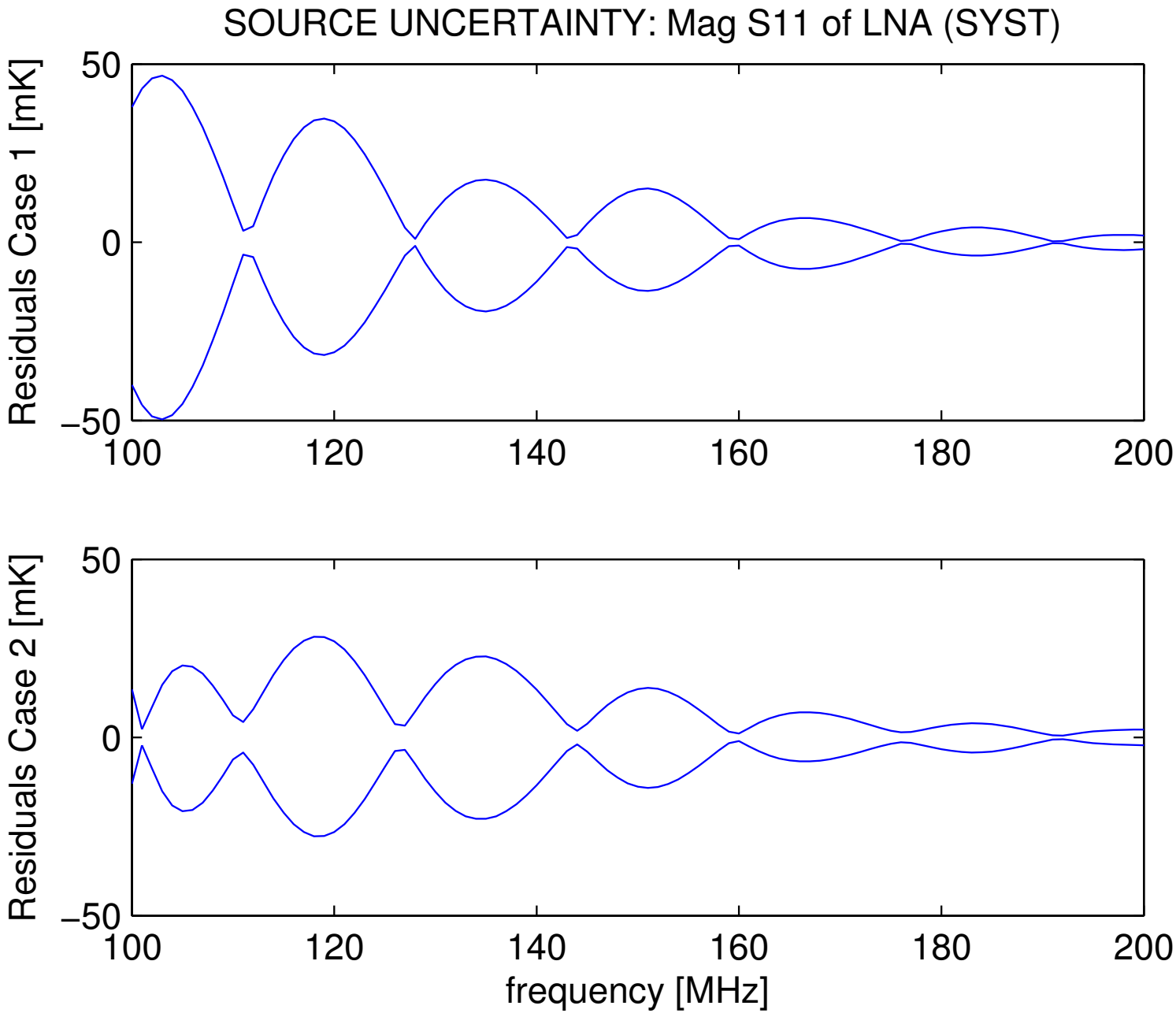
SOURCE UNCERTAINTY: Mag S11 of LNA (SYST)
Residuals Case 1 [mK]
50
0
−50
100
120
140
160
180
200
Residuals Case 2 [mK]
50
0
−50
100
120
140
160
180
200
frequency [MHz]

Figure : (20)

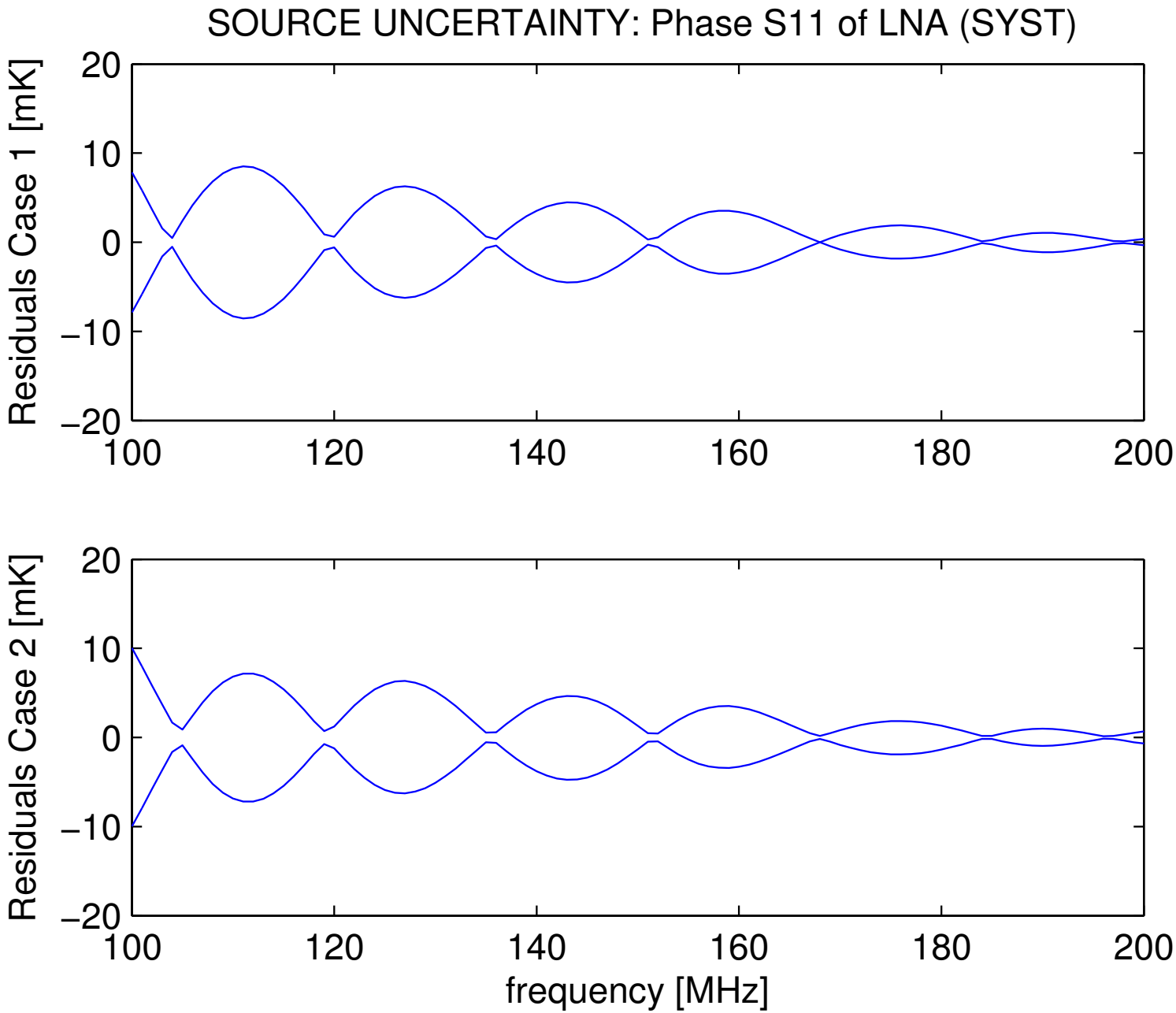
SOURCE UNCERTAINTY: Phase S11 of LNA (SYST)
Residuals Case 1 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (21)

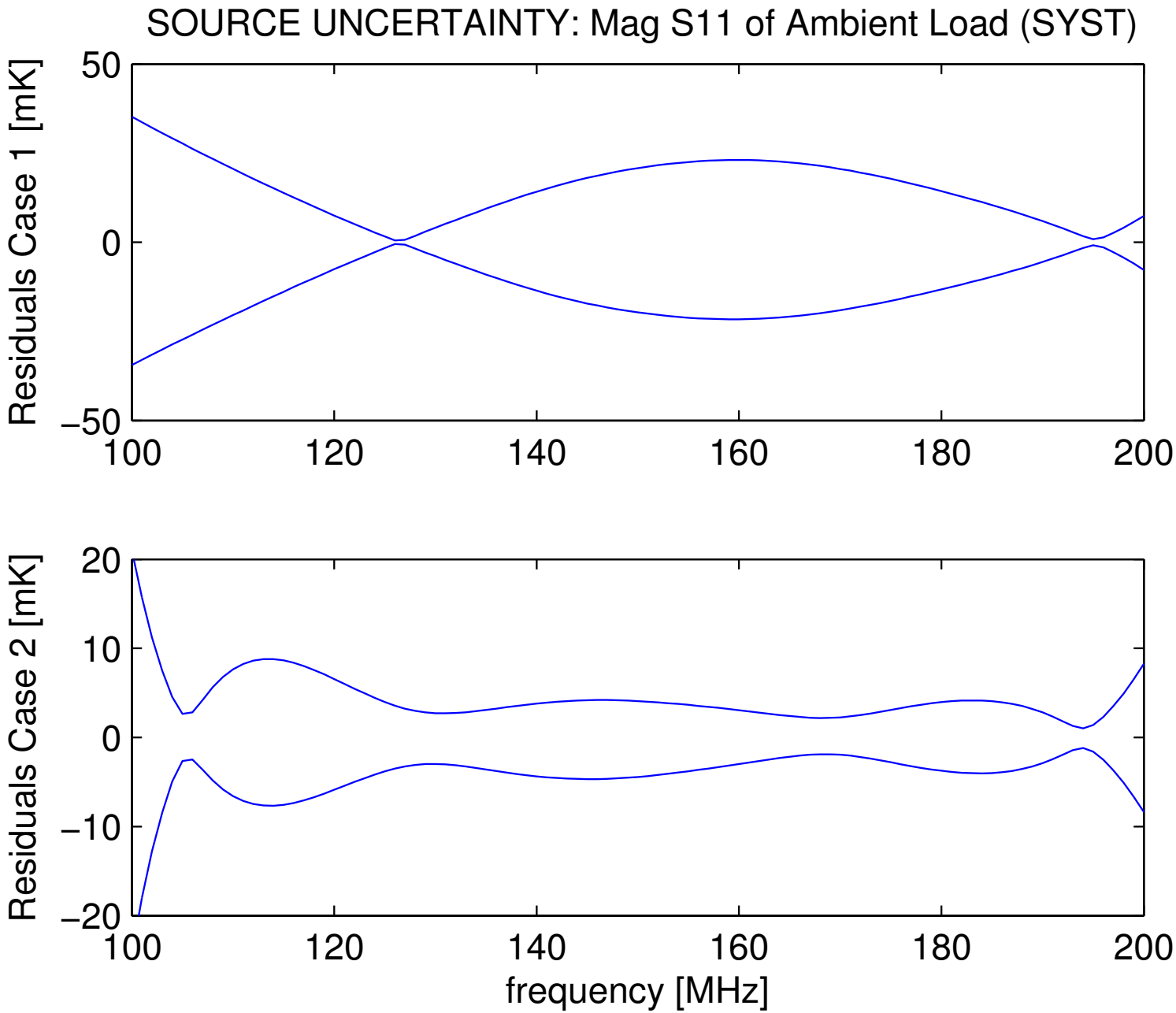
SOURCE UNCERTAINTY: Mag S11 of Ambient Load (SYST)
Residuals Case 1 [mK]
50
0
−50
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (22)

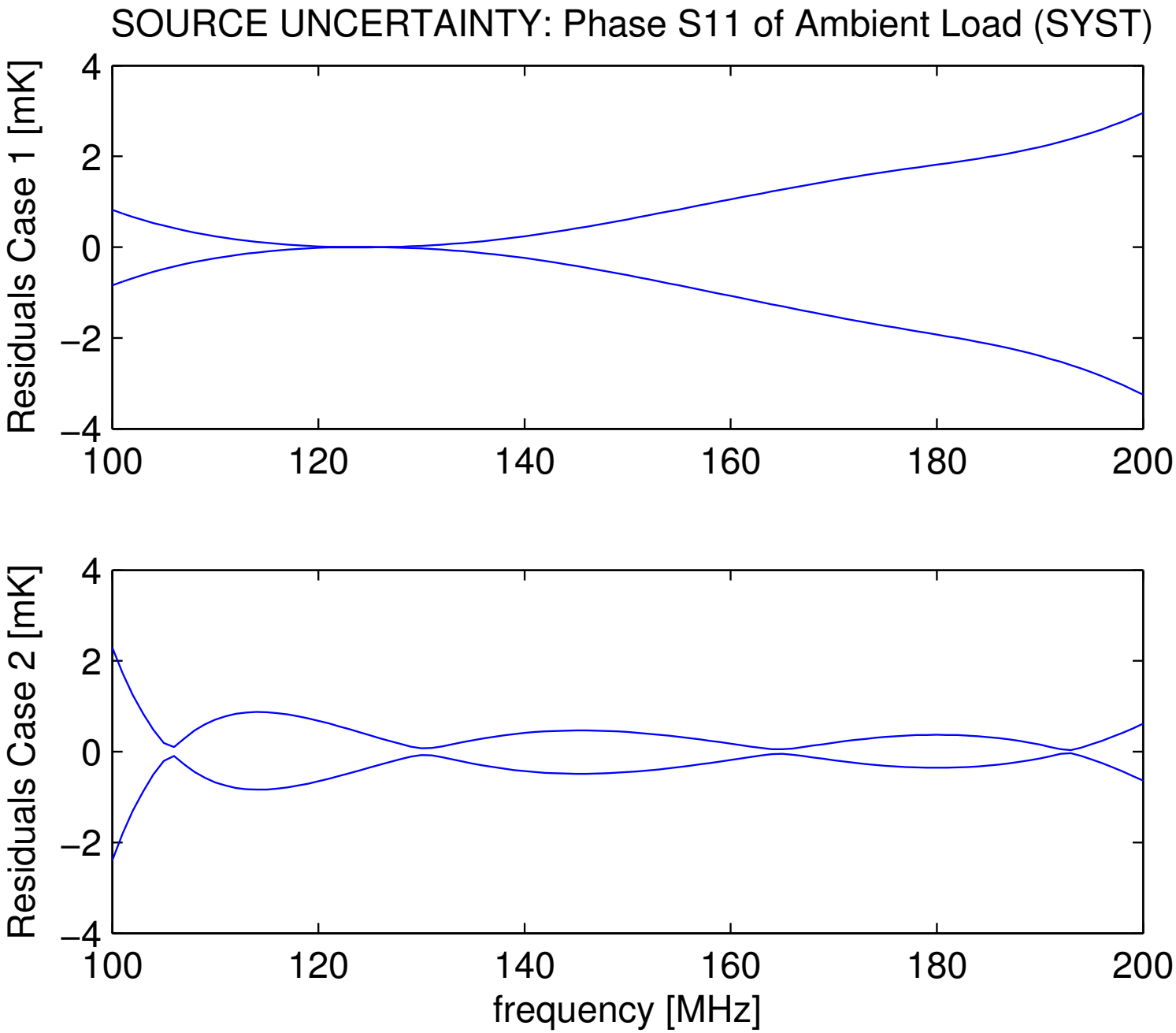
SOURCE UNCERTAINTY: Phase S11 of Ambient Load (SYST)
Residuals Case 1 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
Residuals Case 2 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
frequency [MHz]

Figure : (23)

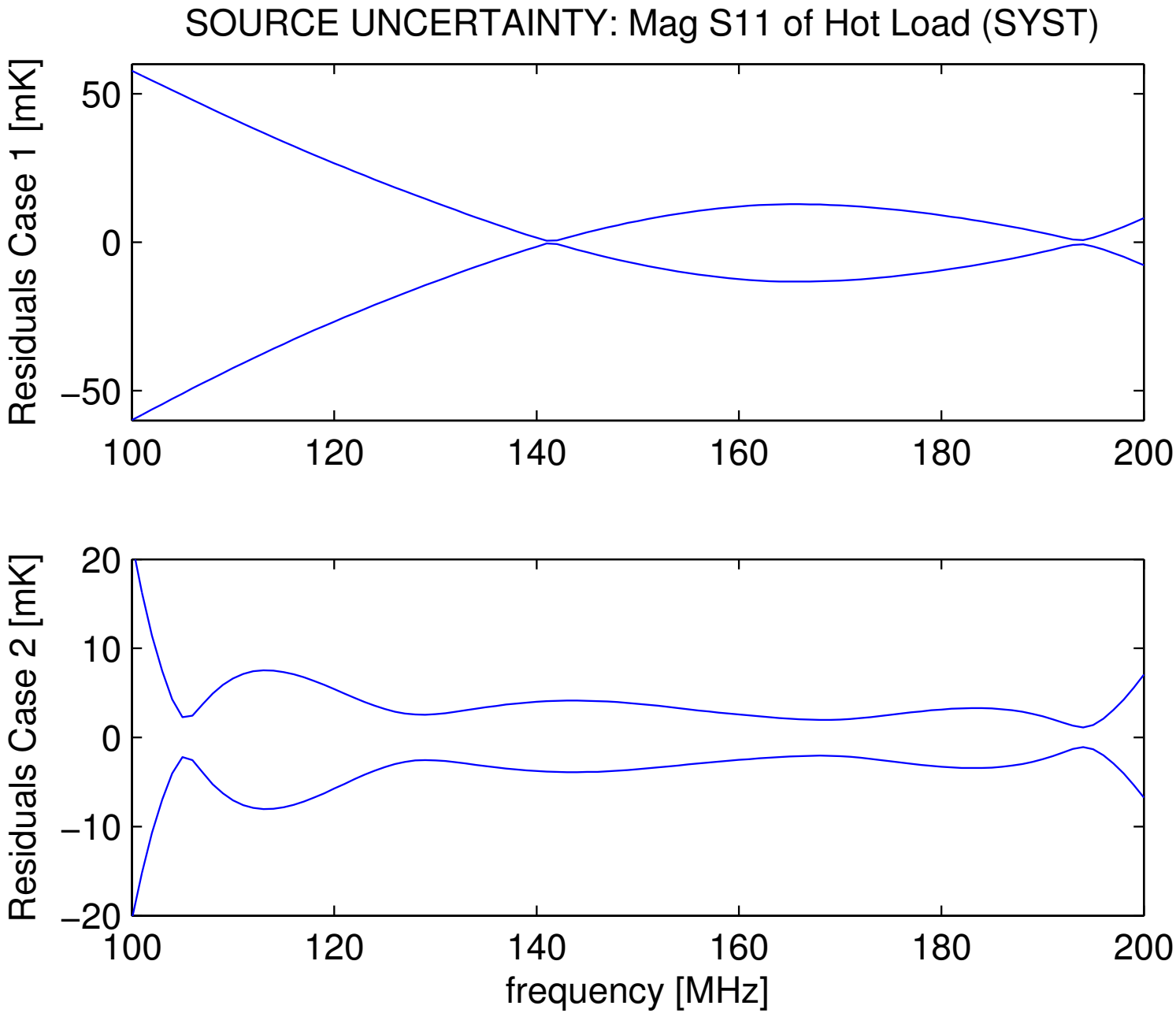
SOURCE UNCERTAINTY: Mag S11 of Hot Load (SYST)
Residuals Case 1 [mK]
50
0
−50
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (24)

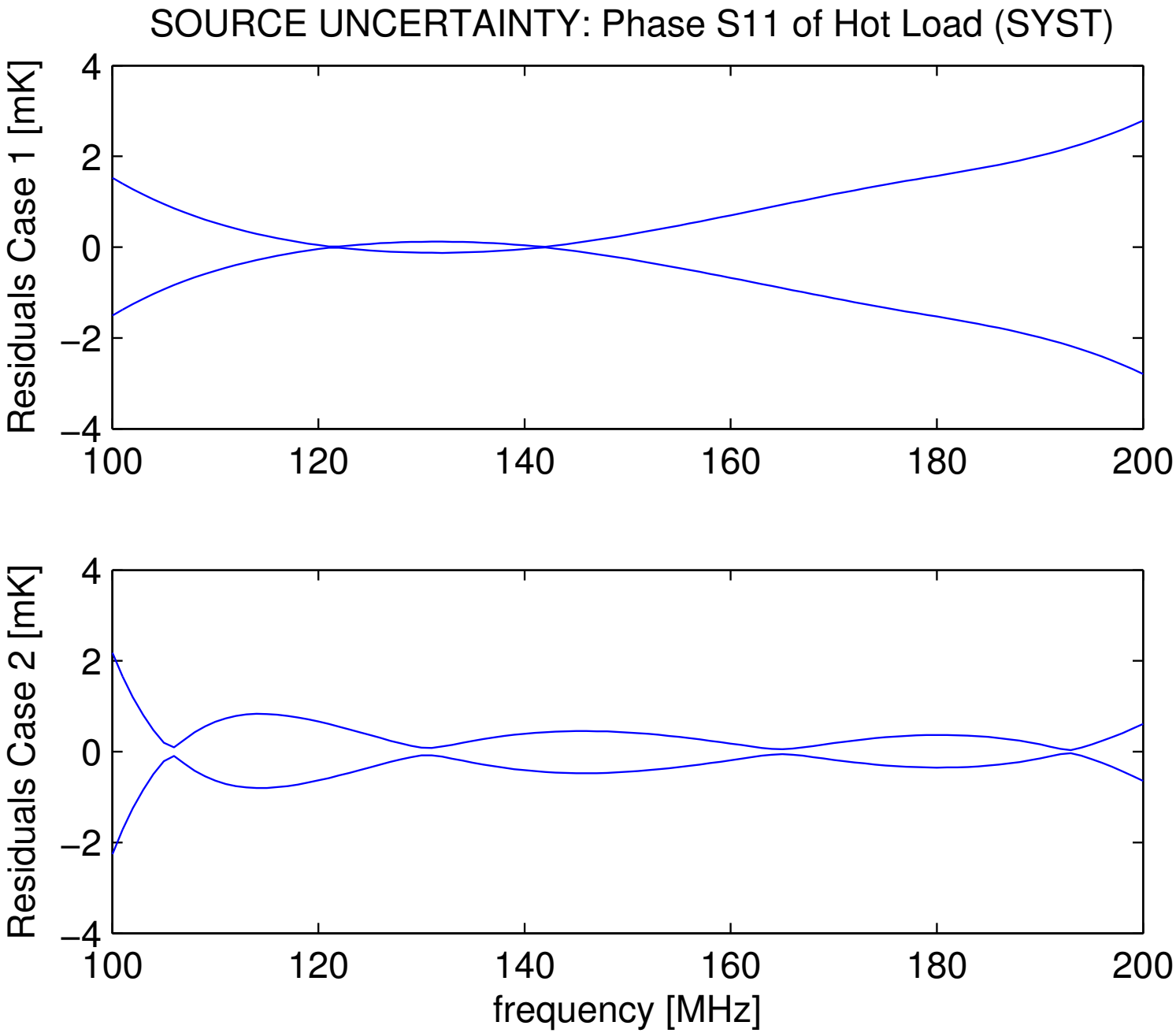
SOURCE UNCERTAINTY: Phase S11 of Hot Load (SYST)
Residuals Case 1 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
Residuals Case 2 [mK]
4
2
0
−2
−4
100
120
140
160
180
200
frequency [MHz]

Figure : (25)

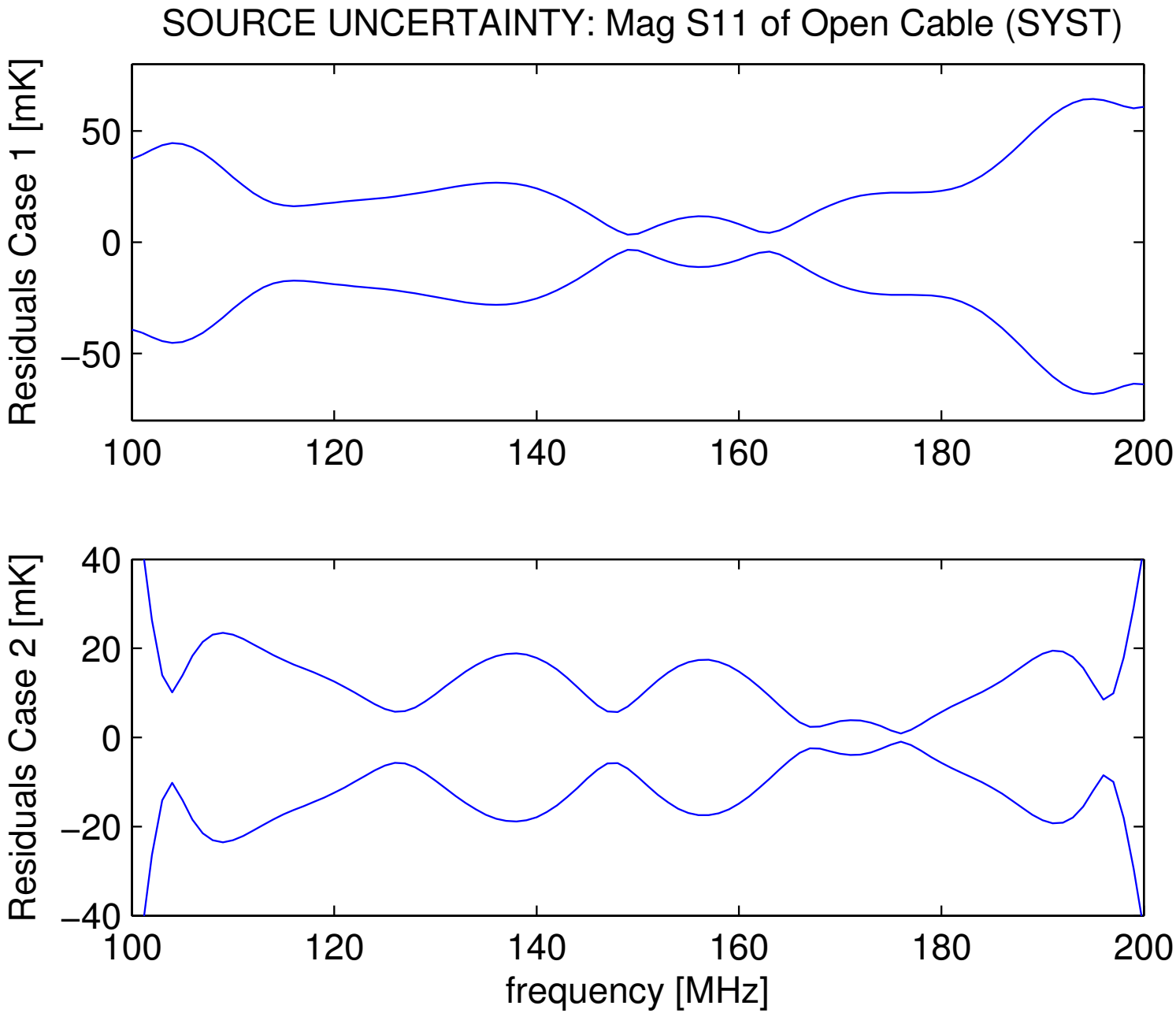
SOURCE UNCERTAINTY: Mag S11 of Open Cable (SYST)
Residuals Case 1 [mK]
50
0
−50
100
120
140
160
180
200
Residuals Case 2 [mK]
40
20
0
−20
−40
100
120
140
160
180
200
frequency [MHz]

Figure : (26)

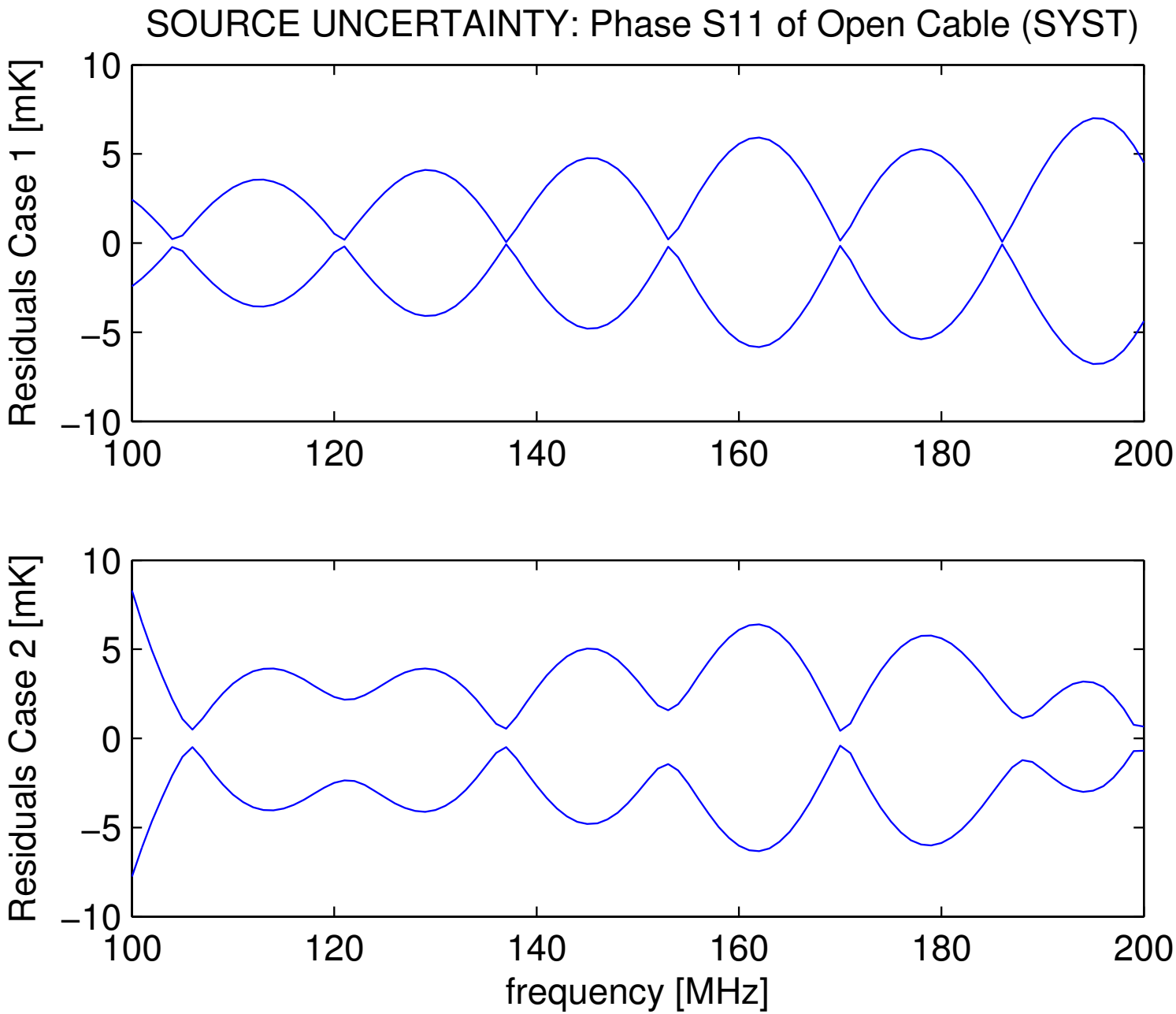
SOURCE UNCERTAINTY: Phase S11 of Open Cable (SYST)
Residuals Case 1 [mK]
10
5
0
−5
−10
100
120
140
160
180
200
Residuals Case 2 [mK]
10
5
0
−5
−10
100
120
140
160
180
200
frequency [MHz]

Figure : (27)

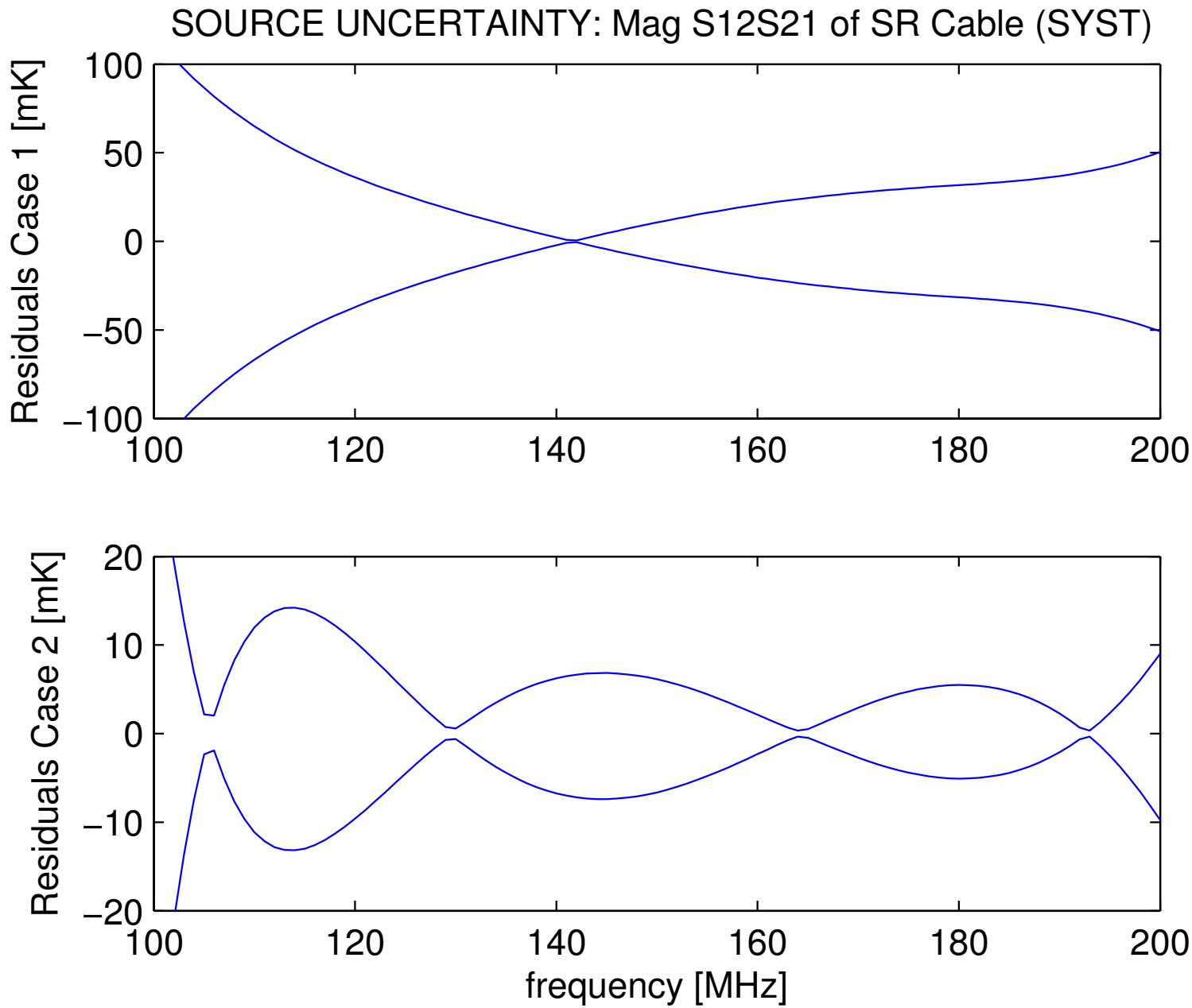
SOURCE UNCERTAINTY: Mag S12S21 of SR Cable (SYST)
Residuals Case 1 [mK]
100
50
0
−50
−100
100
120
140
160
180
200
Residuals Case 2 [mK]
20
10
0
−10
−20
100
120
140
160
180
200
frequency [MHz]

Figure : (28)

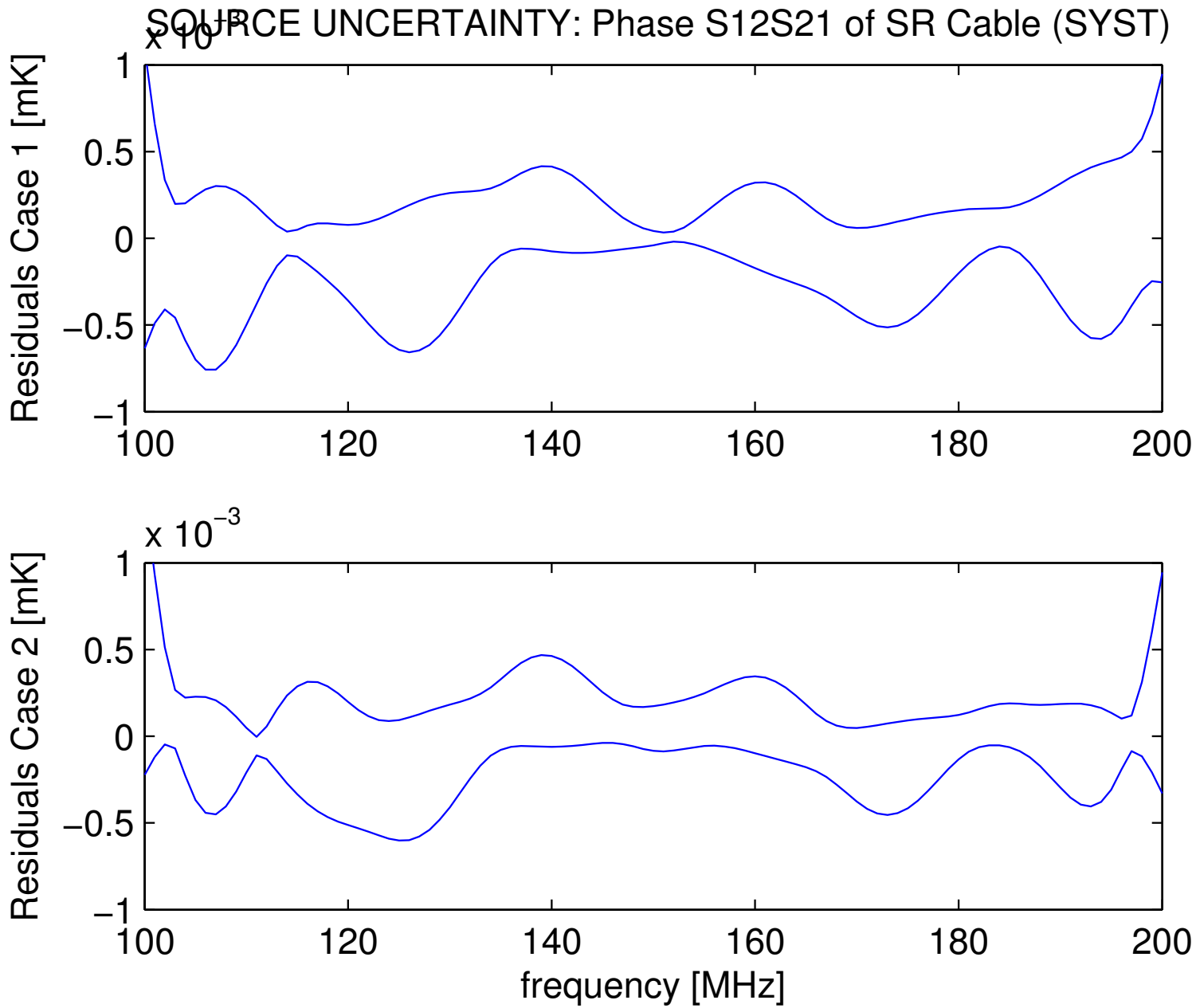
SOURCE UNCERTAINTY: Phase S12S21 of SR Cable (SYST)
x 10^-3
Residuals Case 1 [mK]
1
0.5
0
−0.5
−1
100
120
140
160
180
200
x 10^-3
Residuals Case 2 [mK]
1
0.5
0
−0.5
−1
100
120
140
160
180
200
frequency [MHz]

Figure : (29)

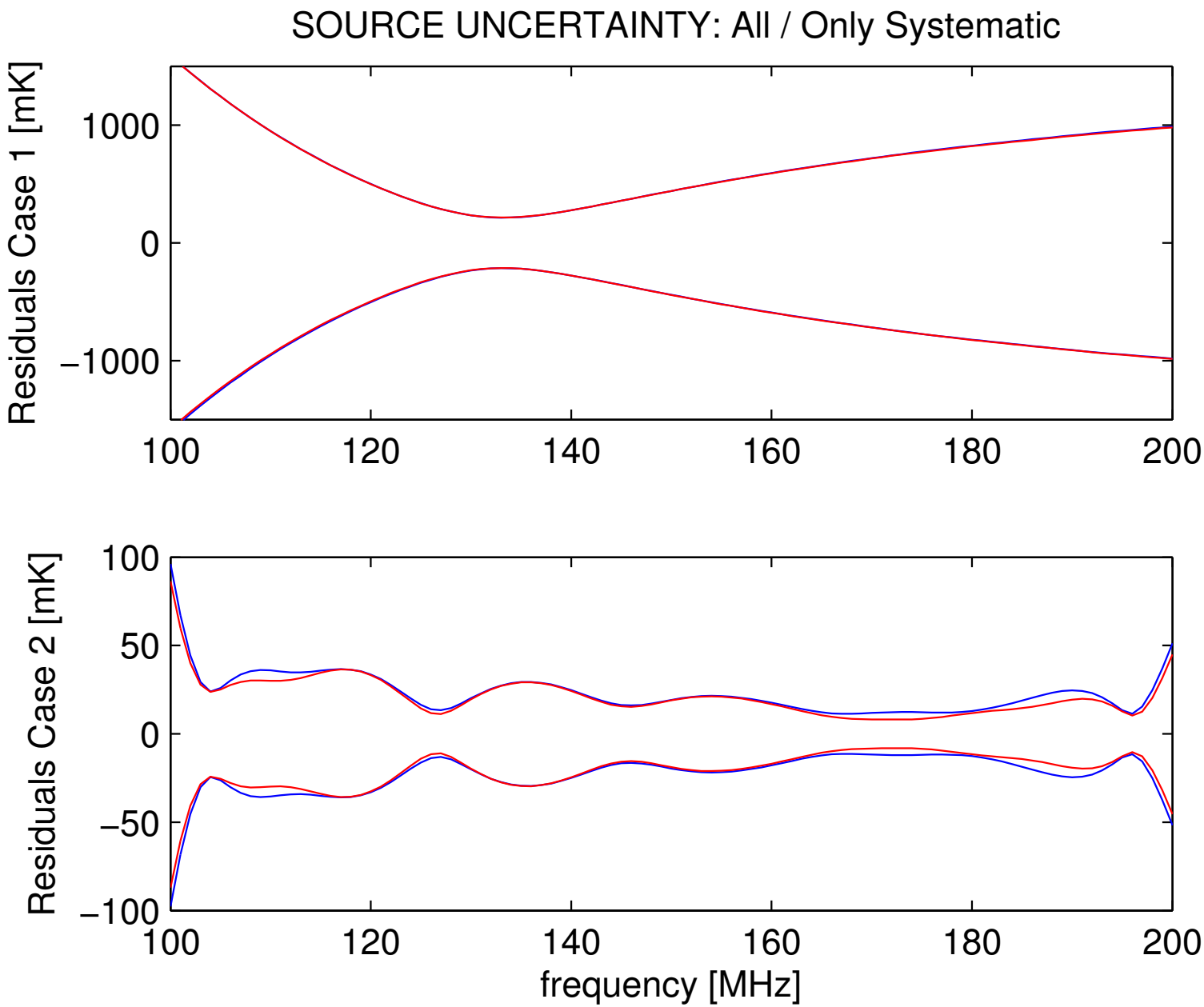
SOURCE UNCERTAINTY: All / Only Systematic
Residuals Case 1 [mK]
1000
0
−1000
100
120
140
160
180
200
Residuals Case 2 [mK]
100
50
0
−50
−100
100
120
140
160
180
200
frequency [MHz]

Figure : (30)