Comparison of Methods for Reflection Calibration at the Receiver Input

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Since 2015 until now, we at ASU/CU have used the same method to calibrate the reflection coefficient of the antenna from measurements of the four positions of the switch inside the receiver. In addition to the antenna, the other three positions correspond to internal open, short, and match standards. They are generic devices, used as 'transference' standards. The absolute reflection standards correspond to Keysight open, short, and match 3.5 mm standards from the 85033E kit, measured at the receiver input in the lab.

Here we describe this method, and test it against different assumptions for the internal transference standards. We also describe an alternative method that produces almost the same results, with some practical differences related to the interpolation of the measurements in frequency.

For the tests we use lab measurements of the three Keysight standards and a 6-dB attenuator, done at the input of the Low-Band 1 receiver during the characterization of the switch in 2017-05. Also, we use the measurement of the antenna from day 2017-172.

1 Equations

When a device under test (DUT) with a reflection coefficient Γ is measured at the end of a network with S-parameters S_{11}, $S_{12}S_{21}$, and S_{22}, the measured reflection coefficient is represented by Γ'. The reflection coefficient of the DUT alone can be recovered using

$$\Gamma = \frac{\Gamma' - S_{11}}{S_{12}S_{21} + S_{22}(\Gamma' - S_{11})}. \tag{1}$$

The S-parameters of the network can be computed by measuring an open, short, and match connected at its port 2 (where port 1 is at the measurement plane), and then solving

$$\begin{bmatrix} S_{11} \\ S_{12}S_{21} - S_{11}S_{22} \\ S_{22} \end{bmatrix} = \begin{bmatrix} 1 & \Gamma_{\text{O}} & \Gamma_{\text{O}} \cdot \Gamma'_{\text{O}} \\ 1 & \Gamma_{\text{S}} & \Gamma_{\text{S}} \cdot \Gamma'_{\text{S}} \\ 1 & \Gamma_{\text{M}} & \Gamma_{\text{M}} \cdot \Gamma'_{\text{M}} \end{bmatrix}^{-1} \begin{bmatrix} \Gamma'_{\text{O}} \\ \Gamma'_{\text{S}} \\ \Gamma'_{\text{M}} \end{bmatrix}, \tag{2}$$

where Γ_{O}, Γ_{S}, and Γ_{M} are the reflections of the standards assumed as true, and Γ'_{O}, Γ'_{S}, and Γ'_{M} are their values as viewed at port 1 of the network.

2 Description of the Traditional Calibration Method

Our method works as follows:

1. We assume reflections $\Gamma_{\mathrm{O}}^{int} = 1$, $\Gamma_{\mathrm{S}}^{int} = -1$, $\Gamma_{\mathrm{M}}^{int} = 0$, respectively, for the internal open, short, and match connected to the 4-position switch.

2. In the lab we measure the reflection of each of the three internal standards.

3. In the lab we measure the reflection of the Keysight OSM standards connected at the receiver input, through the 4th (antenna) position of the switch.

4. In the lab, we calibrate at the switch the measurements of the Keysight devices from point 3). First, to compute the S-parameters between the switch and the VNA we use equation 2, and the assumptions (Γ) and measurements (Γ') of the internal standards from points 1) and 2) respectively. Then, the calibrated Keysight measurements (Γ) are obtained from the measurements (Γ') using equation 1 and the just computed S-parameters.

5. In the lab, using equation 2, we compute the S-parameters of the network that exists between the switch and the receiver input. For this we use the measurements of the Keysight standards calibrated in point 4) (Γ'), and the theoretical models for these standards (Γ). The resulting S-parameters are valid for the assumptions in 1). If different assumptions are used for the internal standards, the network S-parameters will be different.

6. In the field, we measure the reflection of the antenna and of the three internal standards.

7. We calibrate the antenna measurement first at the switch. To compute the S-parameters between the switch and the VNA we use equation 2, the measurements of the internal standards from point 6) (Γ'), and the assumptions for the internal standards from point 1) (Γ). Then, we apply equation 1 where the S-parameters are those just computed, Γ' is the antenna measured by the VNA, and Γ is the antenna measurement calibrated at the switch.

8. We complete the absolute antenna calibration by de-embedding the front-end network S-parameters, obtained in point 5), using again equation 1, where now Γ' is the antenna measurement calibrated at the switch, and Γ is the measurement calibrated at the receiver input.

3 Description of the Alternative Method

The alternative method is as follows:

1. In the lab we measure the reflection of each of the three internal standards.

2. In the lab we measure the reflection of the Keysight OSM standards connected at the receiver input, through the 4th (antenna) position of the switch.

3. In the lab, we calibrate the measurements of the internal standards from point 1) at the receiver input. We first compute the S-parameters between the receiver input and the VNA using equation 2, the measurements of the Keysight standards from point 2) (Γ'), as well as theoretical models for the Keysight standards used as their true value (Γ). Then, using equation 1 and the S-parameters just computed we obtain the calibrated reflection coefficients of the internal standards (Γ) from their measurement (Γ').

4. In the field, we measure the reflection of the antenna and of the three internal standards.

5. We calibrate the antenna measurement by first computing the S-parameters between the receiver input and the VNA using equation 2, the field measurements of the internal standards from point 4) (Γ'), and the calibrated measurements of the internal standards from point 3) (Γ). Then, using equation 1 and the S-parameters just computed, we obtain the antenna measurement calibrated at the receiver input (Γ) from the reflection measured by the VNA (Γ').

4 Tests

We conduct two main tests for this report.

1. Using our Traditional Method, we calibrate lab measurements of the Keysight standards and a 6-dB attenuator, as well as a field measurement of the antenna, at the receiver input, but assuming different values for $\Gamma_{\mathrm{O}}^{int}$, $\Gamma_{\mathrm{S}}^{int}$, $\Gamma_{\mathrm{M}}^{int}$. We choose the following 4 cases as assumptions for the internal standards:

   - case 1: $[1, -1, 0]$
   - case 2: $[0.8, -0.7, 0.2]$
   - case 3: $[0.7 - j0.3, -0.5 - j0.3, 0.3 + j0.3]$
   - case 4: $[0.5 + j0.5, -0.5 + j0.2, -0.3 - j0.3]$

   Then we look at the difference between the measurements calibrated with each of the 4 sets of assumptions.

2. We implement the Alternative Method and calibrate the same measurements of the standards, attenuator, and antenna, as in 1). Then, we compare the results to those obtained from the Traditional Method.

5 Results

The results are presented in the next figures. Specifically:

1. Figure 1 shows the S-parameters of the front-end network, between the switch and receiver input, for the 4 sets of assumptions for $\Gamma_{\mathrm{O}}^{int}$, $\Gamma_{\mathrm{S}}^{int}$, $\Gamma_{\mathrm{M}}^{int}$.

2. Figure 2 shows the calibrated test measurements for the 4 sets of assumptions. The Traditional Method is self-consistent in that the assumptions remain constant throughout the computations, i.e., in the computation of the front-end S-parameters and in the calibration of the DUT reflection. Therefore, the calibrated measurements for the 4 cases overlap almost perfectly.

3. Figure 3 shows the difference between cases 2, 3, and 4 for the reflections of the internal standards, relative to the nominal case 1. These differences are not exactly zero because, in each case, the different front-end S-parameters are interpolated down close to the noise level with different polynomials. Still, the differences are really small. Also notice that the assumptions for the internal standards tested in this report are frequency-independent for simplicity, but the Traditional Method is equally valid when the assumptions are frequency-dependent.

4. Figure 4 shows the calibrated reflections of the internal standards in the context of the Alternative Method.

5. Figure 5 shows the difference between the test measurements calibrated with the Traditional and Alternative methods. Again, the differences are attributed to the polynomial interpolation. In the Traditional Method, we interpolate the S-parameters of the front-end network, while in the Alternative Method, we interpolate the calibrated reflections of the internal standards.

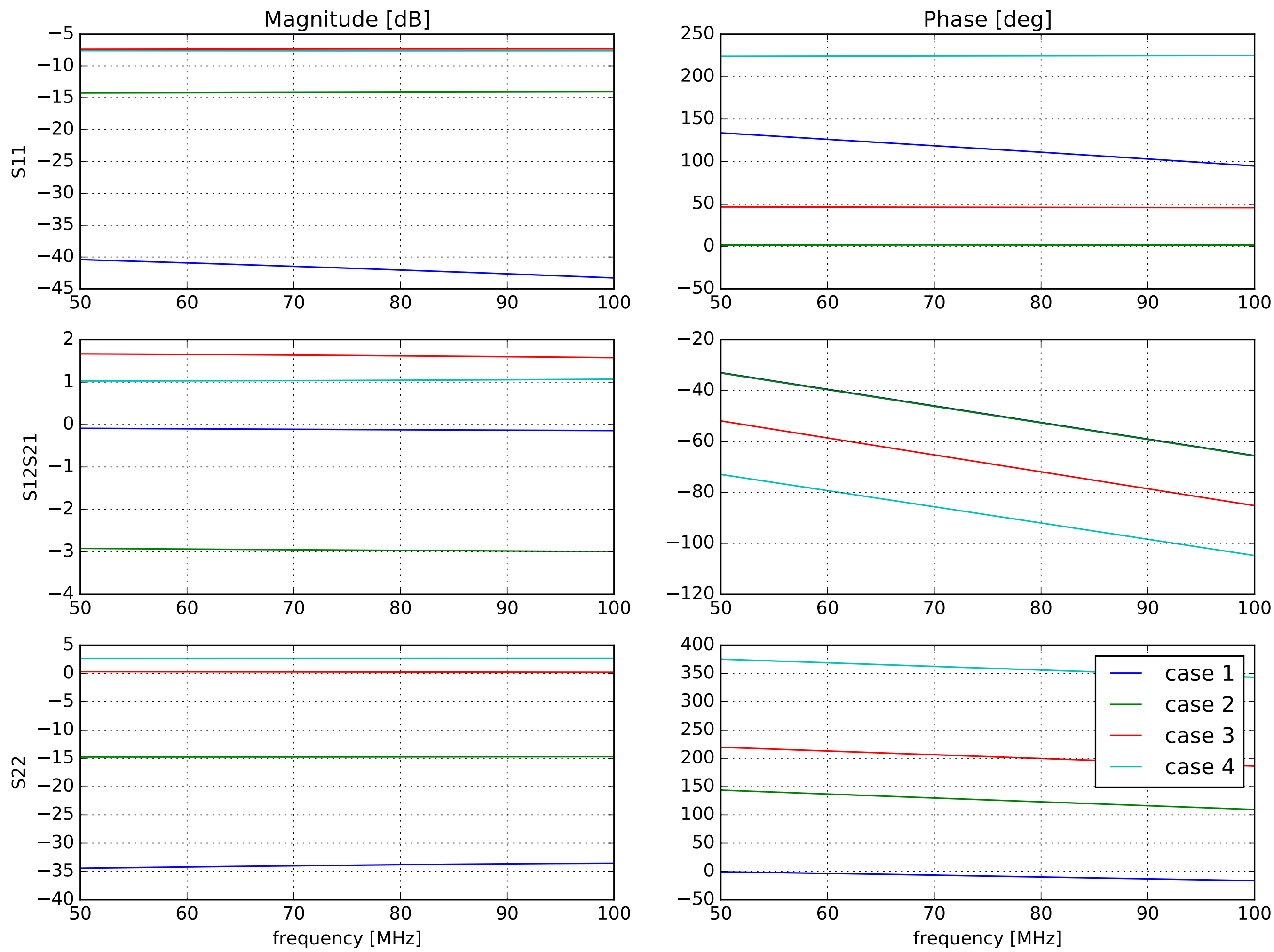

Figure 1: S-parameters for the front-end network computed using the Traditional Method, with 4 different sets of assumptions for the internal standards.

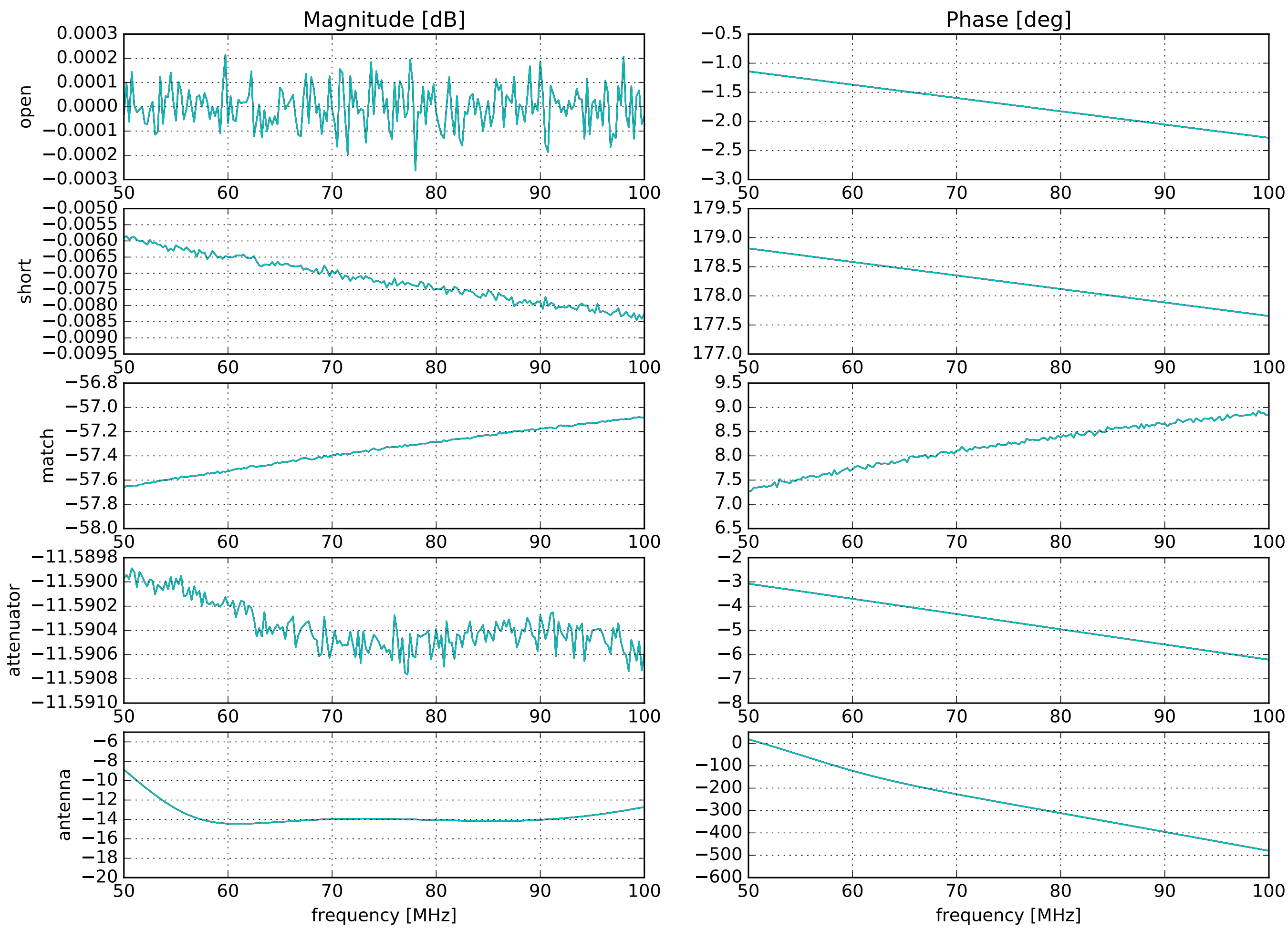

Figure 2: Calibrated test measurements using the 4 sets of assumptions and, thus, S-parameters shown in Figure 1. The overlap is almost perfect.

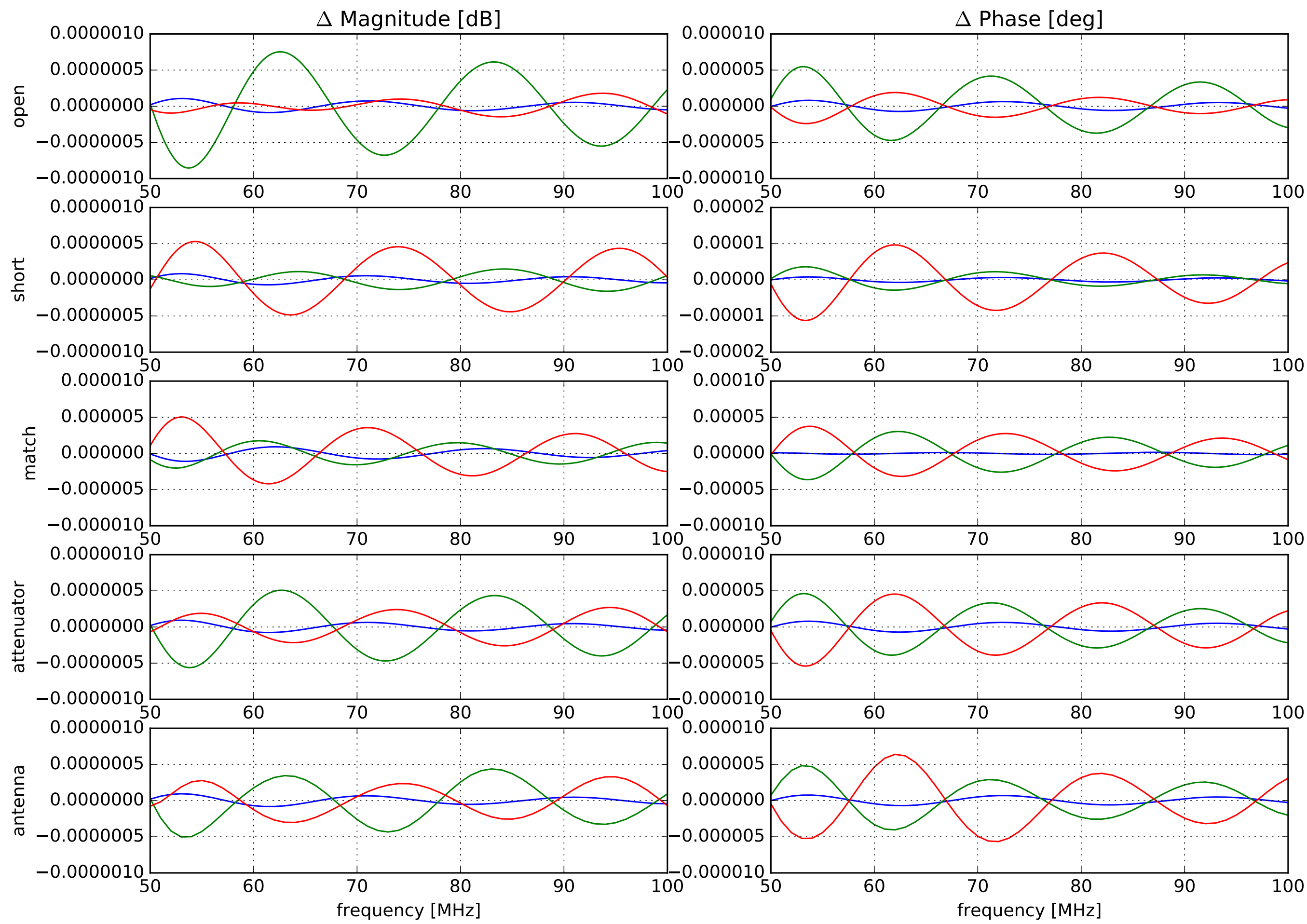

Figure 3: Difference between sets of assumptions 2, 3, and 4 (blue, green, and red, respectively) for the internal standards, and the nominal set 1. The very small differences are due to the polynomial interpolation of the different S-parameters (Figure 1).

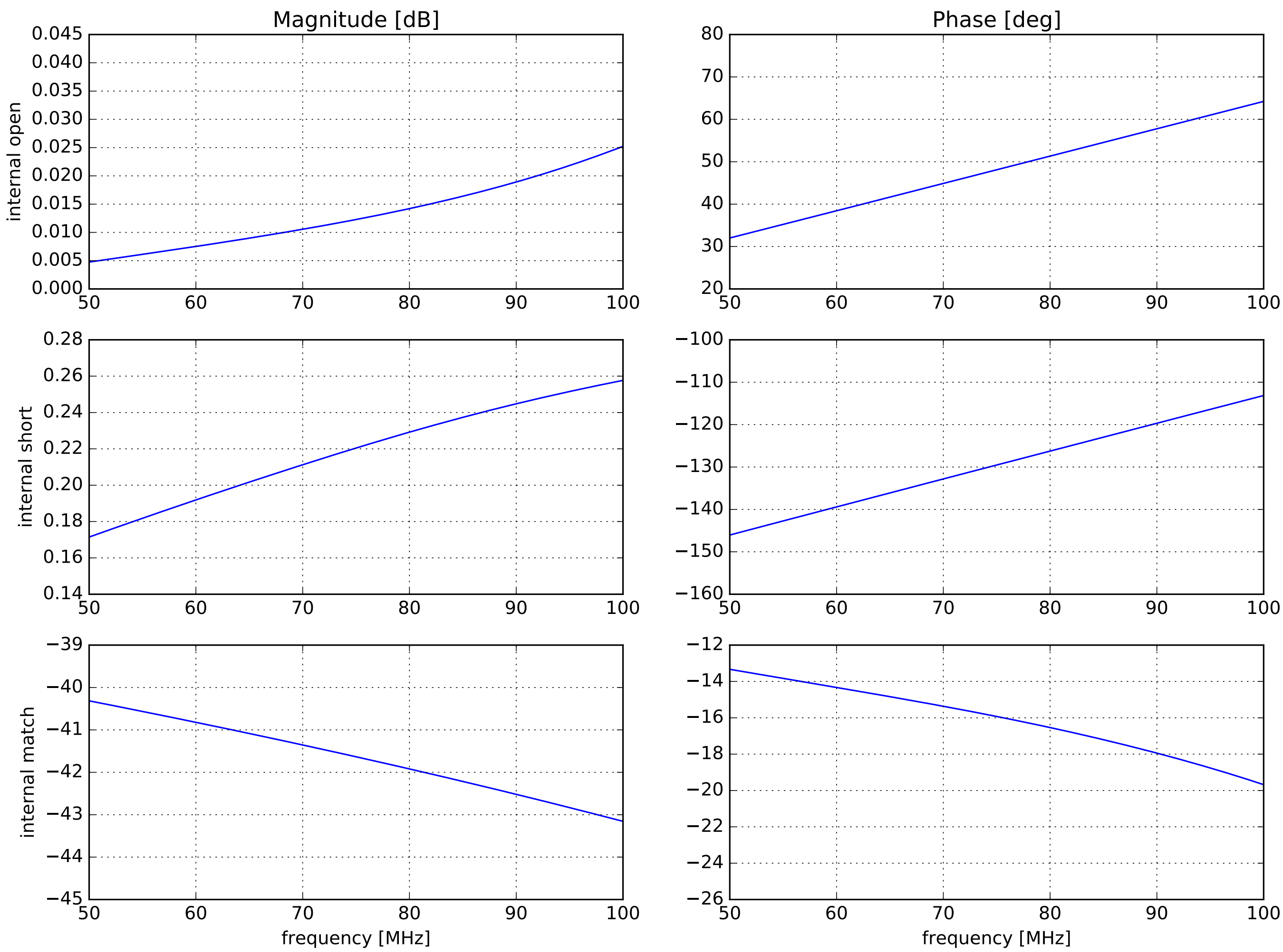

Figure 4: Reflection coefficients of internal standards after calibration with the external Keysight absolute standards and using the Alternative Method.

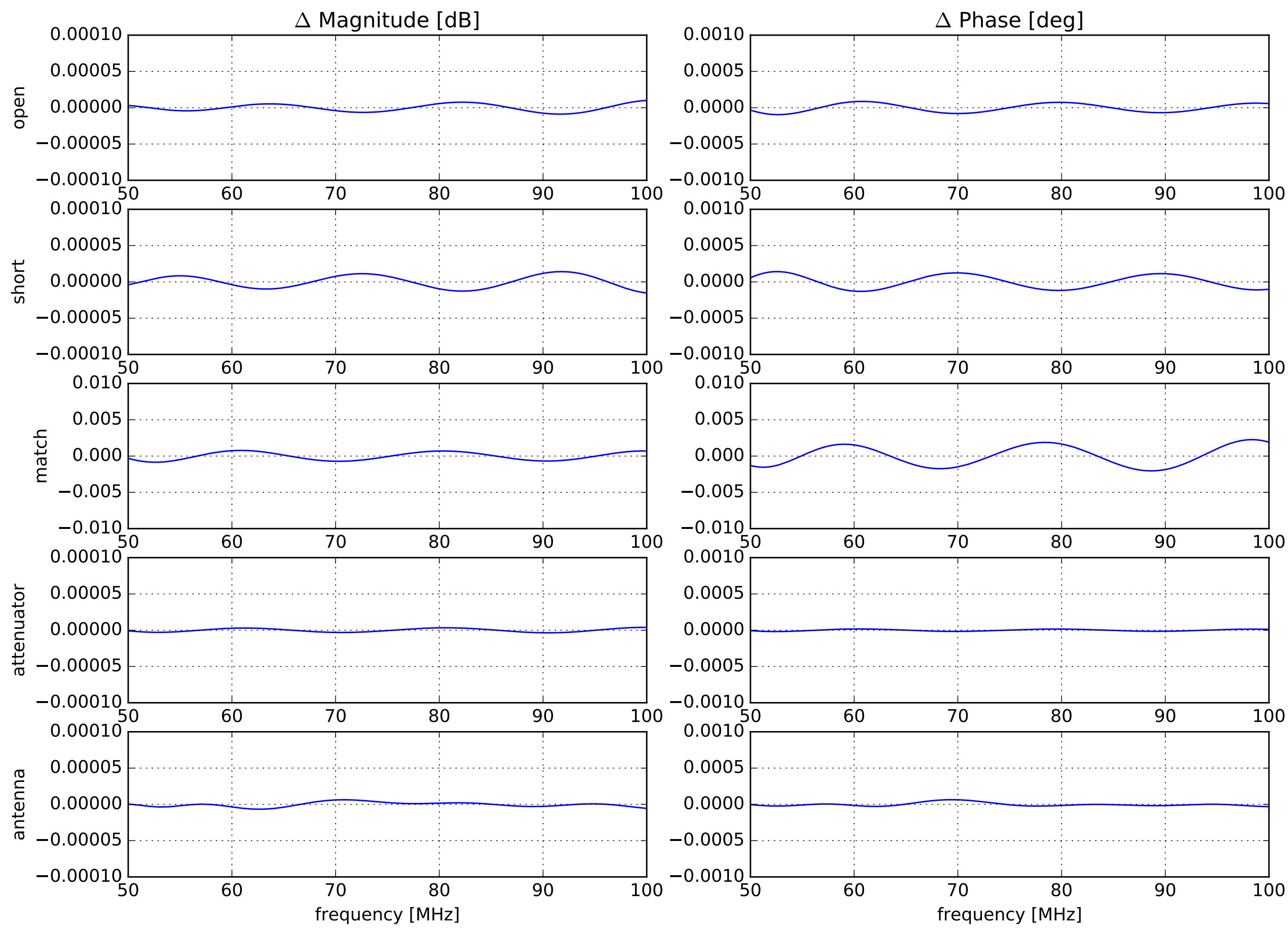

Figure 5: Difference between the test reflection coefficients calibrated using the Traditional and Alternative Methods. In the Traditional Method, here we used the nominal assumptions for the internal standard reflections $(1, -1, 0)$. Again, the small difference is the product of the different polynomial modeling in both methods.