Kicking the Tires of the NIST Microwave Uncertainty Framework, Part 1

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***Abstract* — As with anything new, especially metrology tools, you want to know how good the new tool is. This is generally done through comparisons with existing systems. In this paper, such a comparison is described. The new NIST method of processing measurements and uncertainties, the Microwave Uncertainty Framework will be compared to the established NIST method for measuring one and two-port scattering-parameters. The setup of the comparison, results, and a discussion of the results will be covered. This paper, Part 1, will cover the comparison of the responses generated by the different methods. Part 2 will discuss the comparison of the uncertainties calculated with the different approaches.**

***Index Terms* — Microwave measurements, coaxial connectors, s-parameters, uncertainties**

I. INTRODUCTION

As with anything new you want to see how good it is. The colloquial expression for this is "kicking the tires" which has been defined as "checking the viability of an unknown system by a quick test" (derived from literally kicking the tires of an automobile). In the world of microwave metrology we have more formal approaches to testing the viability of a new analysis or measurement approach. The comparison of results and uncertainties from different techniques is one of the standard methods used to evaluate new approaches.

The NIST Microwave Uncertainty Framework (or Framework or MUF for short) is a recently developed tool for producing measurement results and uncertainties [1-5]. The ability of the MUF to produce accurate results must be verified and this will be done by comparing the MUF results against the existing technique used at NIST. The established technique used at NIST for s-parameter measurements is the multiline method for network analyzer calibration [6]. The multiline method is applied in a NIST software package titled "Multical." Data is taken from the Vector Network Analyzer (VNA) and analyzed using other NIST software packages.

II. KICKING THE TIRES – HOW DO YOU KICK A TIRE?

There are several steps involved in this comparison process. The VNA needed to be calibrated both with the multiline method and the method employed in the MUF (a version of the multiline calibration). Next, data was taken for a series of devices under test (DUTs). A set of six DUTs were measured, three one-ports (two matched terminations and an offset short) and three two-ports (a low-loss device, 20 dB and 50 dB attenuators). All of the devices, calibration standards and DUTs, had 3.5 mm connectors and the frequencies measured were from 0.2 to 33.0 GHz by 0.1 GHz steps. Finally, the corrected DUT results were compared.

The MUF process can be described as: take raw measurements of the calibration standards and the DUTs, the MUF will then generate the error correction coefficients based on the raw calibration standards' data, finally the correction coefficients are applied to the DUT raw data to get the final results. The established NIST technique is a bit different: take raw measurements of the calibration standards, use Multical to generate the correction coefficients, download these to the VNA, then take corrected measurements of the DUT.

The specifics of the actual process steps are as follows:

1) Uncertainty models were established in the MUF for the devices used in the VNA calibration
2) Raw measurements (no VNA correction applied) were taken of the devices used for the VNA calibration
3) The identical data was used in both Multical and the MUF to form the error correction matrices for the VNA
4) Starting with the VNA correction turned off, raw measurements were taken of one of the DUTs.
5) Without touching the DUT, the VNA correction from Multical was applied and corrected data of the DUT was taken using the NIST measurement software (a program called MeaslpX was used to take the corrected data from the VNA and another program called Calrep was used to analyze the data taken by MeaslpX)
6) All DUTs were measured by use of the process of 4) and 5)
7) The raw calibration standards data and the raw DUT data were processed through the MUF to arrive at the corrected response for each DUT
8) The corrected MUF responses were compared to the results from the Multical and NIST measurement software process

Throughout this comparison, we tried to keep the two measurement paths as similar as possible. Because of the differences in the two measurement paths, it was necessary to take both the uncorrected and corrected measurements of the DUTs. The uncertainty models used for the calibration standards will be detailed in Part II of this paper which will be published later. That being said, it is still necessary to have a basic understanding of the uncertainty models used for the Monte-Carlo analysis in the MUF. Figure 1 shows the basic model that was used for the airline standards in the MUF.

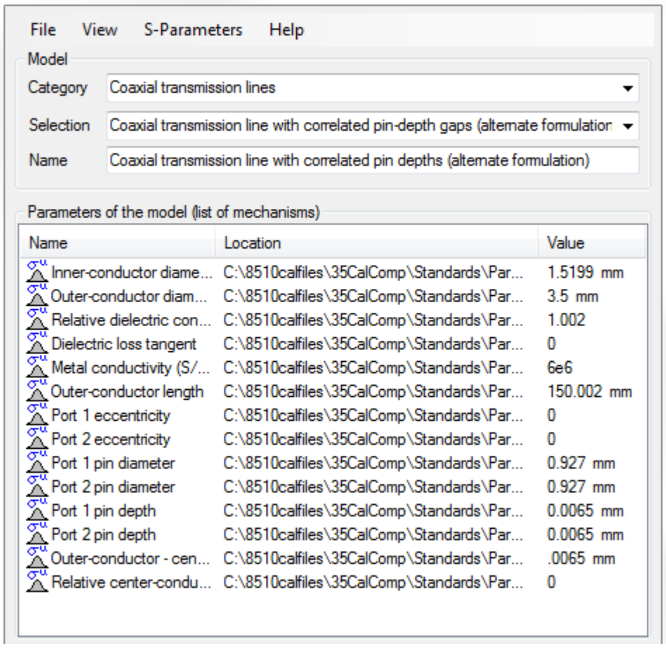
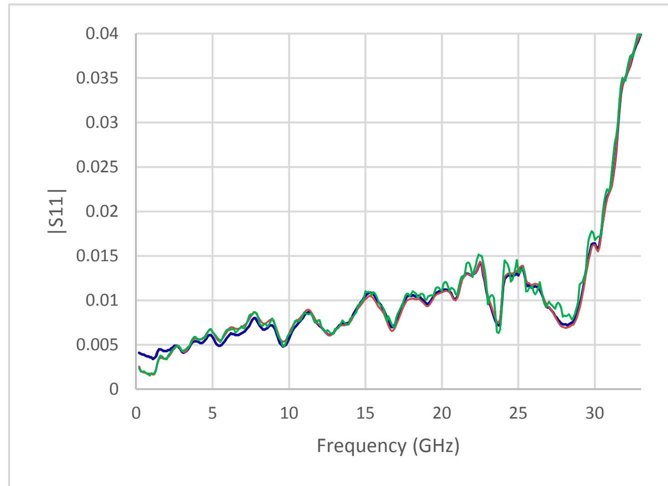


Figure 1. Airline uncertainty model used in the MUF

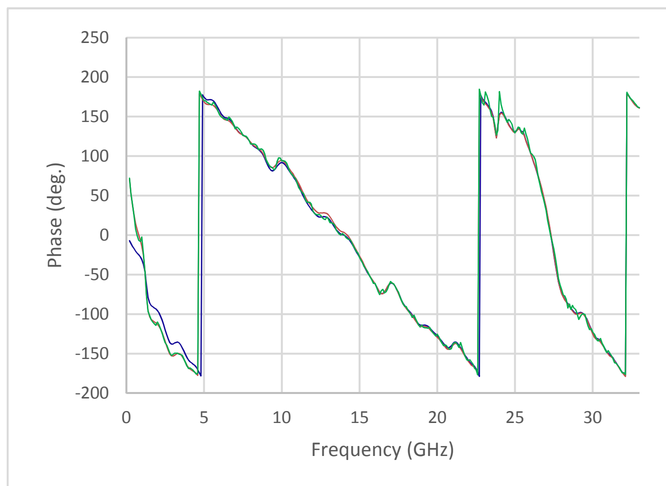
III. I'VE KICKED THE TIRES - HERE'S HOW THEY FELT

In all, three sets of data are being compared. One from our established technique (notated as Calrep) and two sets from the MUF. One of these sets is the Nominal Value result which is produced when only the base data is used and is not perturbed by any uncertainty components (notated as MUF SA (for Sensitivity Analysis)). The other MUF result is the result from the Monte-Carlo process (MUF MC) that includes a statistical bias introduced in the results (in other words, this is the average value calculated from the results of all of the Monte-Carlo passes) [7].

Figure 2 shows the S_{11} response results from one of the DUTs, a matched termination. There are several items that are noteworthy on the chart. Except at frequencies below approximately 2.5 GHz, there is good agreement between the results from the established technique (Calrep) and the two MUF results (MUF SA and MUF MC). The two MUF responses agree with each other as one would expect. The MUF Monte-Carlo response shows more "raggedness" which is also expected because of the statistical nature on which it is based (100 Monte-Carlo simulations were used). The differences between the various results can be seen in figure 7.



(a)



(b)

Figure 2. S_{11} magnitude (a) and phase (b) results for a matched termination. Blue line is the Calrep response, Red is the MUF SA response and Green is the MUF Monte-Carlo response (note the orange and green plots lie virtually on top of each other).

Figure 3 shows the S21 magnitude results for a 50 dB attenuator. Here there is good agreement between all three responses. The statistical variations in the Monte-Carlo result are about the same magnitude as the dynamic range variations.

Figure 4 shows the results from the offset short DUT. Here, 100 Monte-Carlo simulations were used and there is reasonable agreement between the two MUF results. Figure 5 shows the absolute value of the differences between the Calrep and the MUF results with the Calrep uncertainty also shown for the offset short. At the higher frequencies there is good agreement between the Calrep and the MUF results; however, at the bottom end, about 5 GHz and below, there are discrepancies in the results. Note that there was very good phase agreement between all three approaches (less than 0.3 degrees).

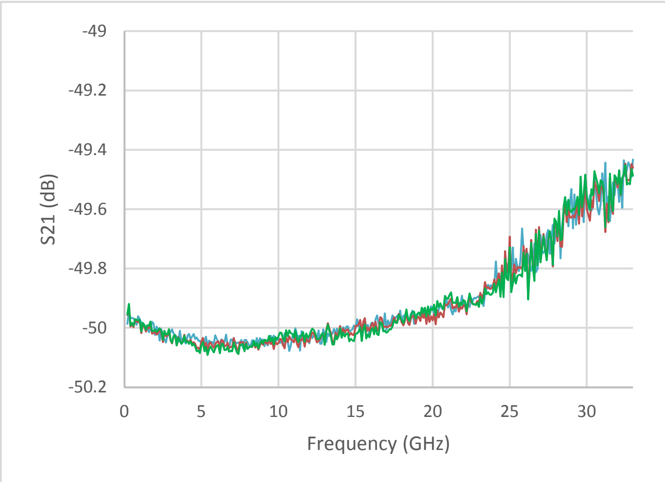


Figure 3. S_{21} magnitude results for a 50 dB attenuator. Blue line is the Calrep response, Red is the MUF SA response and Green is the MUF MC response.

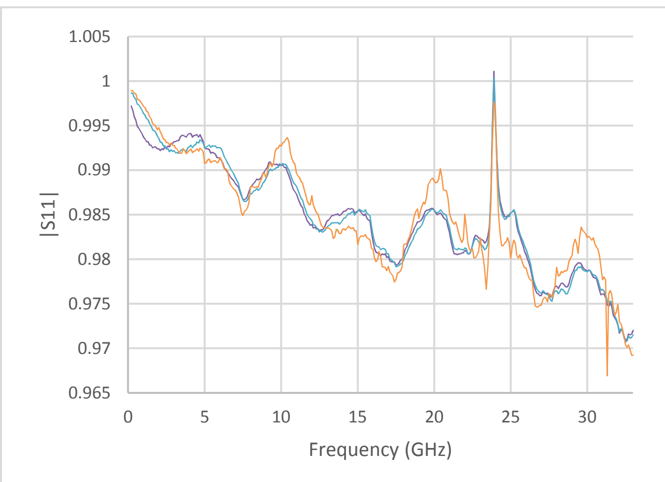


Figure 4. S_{11} magnitude results for an offset short. Blue line is the Calrep response, Orange is the MUF SA response and Green is the MUF MC response.

There are several common treads found from the results. In general, there is good agreement between the different methods used for obtaining the results. Discrepancies are seen at the low frequencies (5 GHz and below), although these differences are fairly small (on the order of 0.002 for S_{11} and on the order of 0.04 dB for S_{21}). This low frequency problem is seen in both reflection and transmission responses, but not seen in all of the DUT responses. The Monte-Carlo response shows more variation than the other responses due mostly to the statistical nature of its derivation.

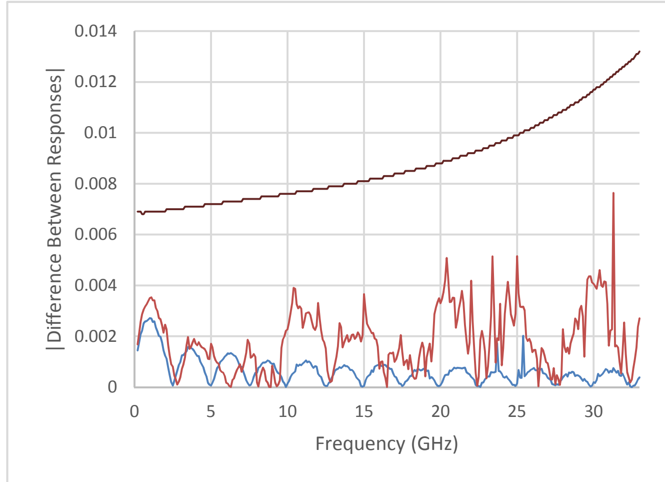


Figure 5. Absolute value of differences in responses for the offset short. Blue is |Calrep – MUF SA| and red is |Calrep – MUF MC|. The brown line represents the typical uncertainty associated with the Calrep measurement.

IV. What Have I Really Learned From Kicking the Tires

There are several points of discussion coming from the results of the "kick". First, there is generally good agreement between the results from our established technique and the results from the MUF.

Increasing the number of Monte-Carlo iterations from 100 to 1000 does not greatly influence the difference between the Monte-Carlo responses and the unperturbed Nominal Solution from the sensitivity analysis. This can be seen in figure 6 which shows the difference between the nominal unperturbed solution and the Monte-Carlo 100 iteration and 1000 iteration solutions. There is a periodicity to the difference that needs to be investigated further (maybe a Part III?)

As pointed out earlier, there is a difference in the responses at frequencies less than approximately 5 GHz. The difference is between the established technique and both of the MUF results (SA and MC). This is best seen in figure 2a. To investigate this issue, we have taken several steps. The first was to process the exact same DUT raw file through the Multical software and through the MUF (this differs with how we took the Calrep data which was obtained as corrected data through the use of another NIST software package). The results of this can be seen in figure 7. There is essentially no difference between the Calrep results and the results obtained by processing the files through the Multical software. There is the

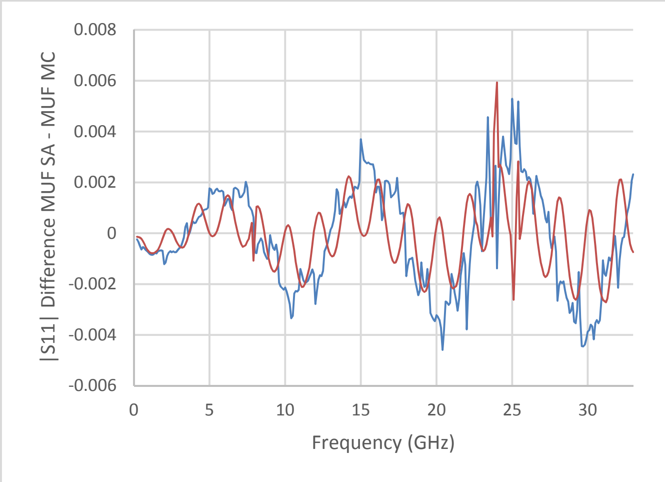


Figure 6. Differences in the Monte-Carlo $|S_{11}|$ responses for the offset short. Blue is (MUF Nominal Solution – MUF Monte-Carlo 100 iterations) and red is (MUF Nominal Solution – MUF MC 1000 iterations).

difference, as seen before, with the MUF results. This indicates that there is a difference in how Multical and the MUF are applying the multi-line calibration technique. The best guess as to a cause for this is the different way that Multical handles moving from an 8 to 12-term solution versus how the MUF uses the 8 and 12-term solutions. Investigation into this is ongoing.

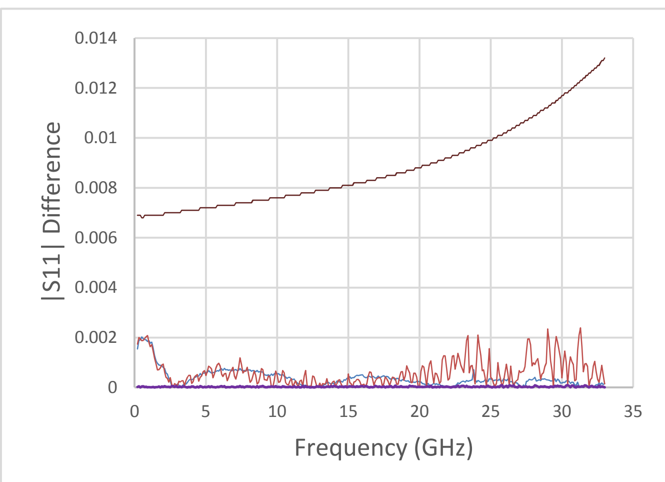


Figure 7. $|S_{11}|$ Differences for the matched termination. Blue is |Calrep - MUF SA|, red is |Calrep – MUF MC|, brown is the Calrep uncertainty (k=2), and purple is |Calrep – Multical| (which is essentially zero).

V. My toe is sore from kicking – what else have I learned

The response results from the NIST Microwave Uncertainty Framework show good agreement with our established method with a few caveats. We are still investigating differences in responses at low frequencies and periodicity issues related to the Monte-Carlo responses.

Stay tuned for Part II or "My Tires Have Air, How Certain am I that they Will Roll?"

References

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