Practical Application of the IEEE P370 standard draft for measurement of interconnects up to 50 GHz

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Abstract

The IEEE P370 standard committee was tasked with writing guidelines for the design of test fixtures for measurement of interconnects up to 50 GHz, defining techniques for fixture de-embedding, and developing techniques and tools for validating the measured or calculated S-parameter data. A preview of the unapproved draft standard draft (with target date for ballot vote in early 2019.) is described in Reference [1], which was also submitted to this conference. This paper discusses the practical aspects of these guidelines, reviews the "Plug and Play" validation kit hardware and S-parameter library files, and illustrates the use of one of the de-embedding techniques described in the standard. It also discusses the S-parameter quality metrics and the tools used for verifying S-parameter integrity, and illustrates their use by way of examples. Note that since the P370 standard is still an unapproved draft, any material included from it in this paper is subject to change.

In this paper, we show a few examples of the practical application of the draft IEEE P370 standard, to demonstrate the effectiveness of the draft standard for interconnect measurement.

Fixture Design Requirements

Fixture Design Requirements are covered in the companion paper of [1].

Fixture Electrical Requirements

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Calibration Methods

The P370 standard references two commonly-used calibration methods, Short-Open-Load-Thru (SOLT) and Thru-Reflect-Line (TRL). The calibration structures described in the draft standard are compatible with these methods.

De-embedding methods

The P370 standard describes two methods by which the DUT's S-parameters may be de-embedded from the measured data which include the fixtures: the traditional 2x thru method, and a new, "impedance-corrected" method. The former assumes that the two "left" and "right" fixtures that surround the DUT and the 2x thru reference all have identical impedance. However, this is sometimes not the case, which can introduce significant errors in the de-embedded results. Some examples of these problems are described in the Plug and Play Fixtures section later in this paper.

De-embedding Verification

There are a number of approaches that can be used to verify the accuracy of the results of a de-embedding process. Three methods are outlined in the P370 draft standard and Reference [1]:

1. Use of synthesized libraries
2. Use of Plug and Play test boards
3. Use of user-manufactured demonstration boards

Use of the Synthesized Library

With the first method, the user creates an S-parameter for the FIX-2x thru-FIX topology using modeling softare such as a 3D field solver or circuit simulator. He or she then chooses the corresponding elements from the S-parameter library provided by the P370 committee, simulates the two networks, and compares the results from the simulated structure to those of the corresponding de-embedded library element. The contents of the S-parameter library are described in [1].

A sample circuit was simulated using the open source Quite Universal Circuit Simulator (QUCS), which is available at http://qucs.sourceforge.net/, Simulation models were constructed of the 2x thru FIX-FIX and the composite FIX-DUT-FIX using elements from this library. Using the 2x thru simulated model, the DUT can be de-embedded from the composite structure using a candidate de-embedding tool, and the results of the original and de-embedded DUT TDR response can be compared. Examples of the simulated output are shown in Figures 1 and 2. Good agreement was found between the actual and de-embedded the frequency domain results.

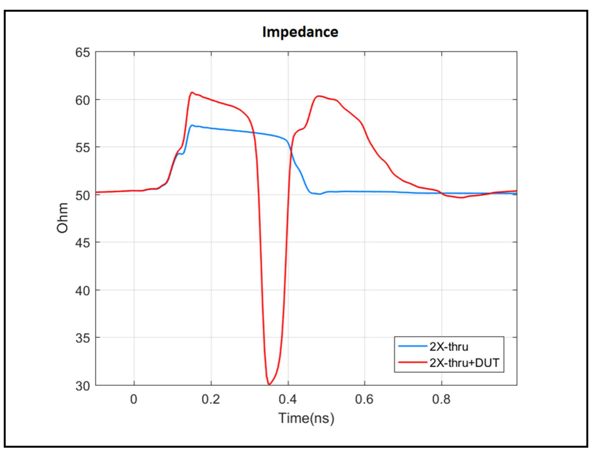

Figure 1. TDR response of the simulated circuit using elements from the S-parameter library

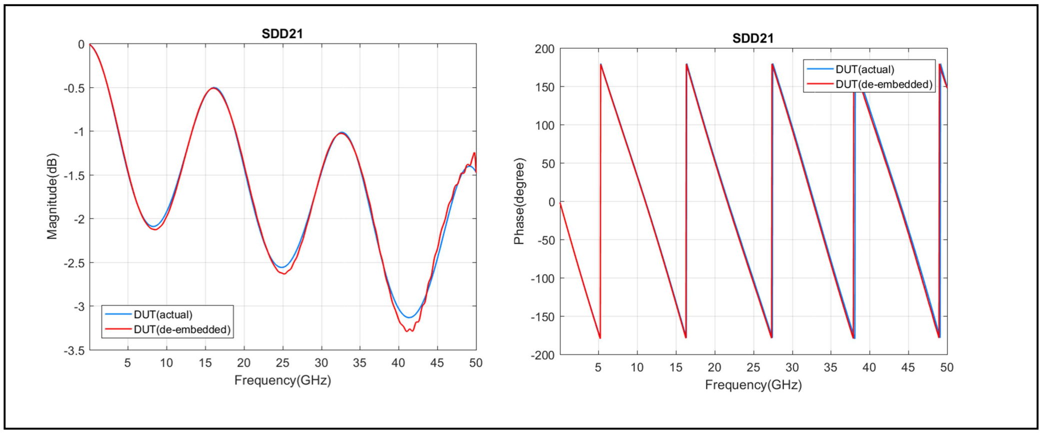

Figure 2. Thru response of the simulated circuit using elements from the S-parameter library

An example of the use of the second method, the use of the Plug and Play fixtures developed by the P370 committee, is included below. The third method, use of user-manufactured demonstration boards, is described in [1].

Plug and Play Fixtures

A number of plug-and-play fixtures, shown in 3, were fabricated. Adapters were inserted so that the DUT can be measured and compared directly with de-embedded results.

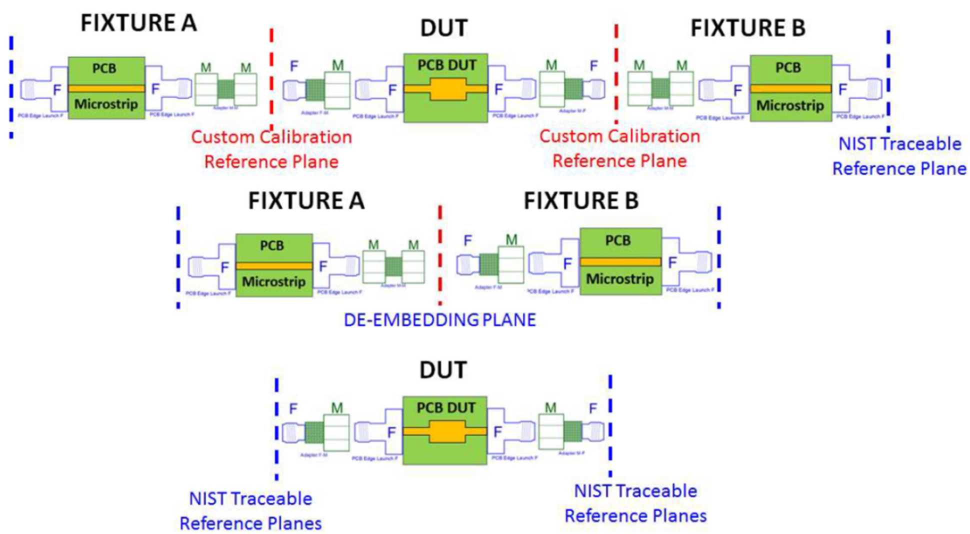

Figure 3. **Plug and Play board kit example**

The general procedure for using the Plug and Play kit to evaluate the de-embedding process and results is as follows:

1. Perform a Vector Network Analyzer (VNA) calibration up to the end of the coaxial test cables (NIST traceable reference plane in Figure 3).
2. Perform a VNA measurement for all the three configurations shown in Figure 3.
3. Use a de-embedding software tool to perform de-embedding, using the results of “FIX-DUT-FIX” and “FIX-FIX” (a.k.a 2x thru).

4. Compare the de-embedded results for the DUT against the directly measured DUT results.
5. A number of example cases are included below. The configurations of the various cases are listed in Table 1.

Case No.	Left Fixture	DUT	Right Fixture	2x Thru
1	A1	B1	A2	A1+A2
2	A1	B2	A2	A1+A2
3	A3	B1	A4	A3+A4
4	A3	B2	A4	A3+A4
5	A1	B1	A2	A5+A6
6	A1	B2	A2	A5+A6
A1,A2	Microstrip, 3cm, 50ohm			
A3,A4	Microstrip with vias, 3cm, 50 ohm			
A5,A6	Microstrip, 3cm, 45ohm			
B1	Microstrip, 6cm, 50ohm			
B2	Microstrip, 6cm, Beatty structure			

Table 1. **Plug and Play example configurations**

In Case 1, the fixtures (A1+A2) are identical and well behaved, and produce the data shown in Figure 4. The well behaved DUT, a 6 cm microstrip (B1), was de-embedded using the traditional 2x thru method, with results shown in Figures 5. The TDR waveform of Figure 6 is plotted at 50 ps rise time (20/80%).

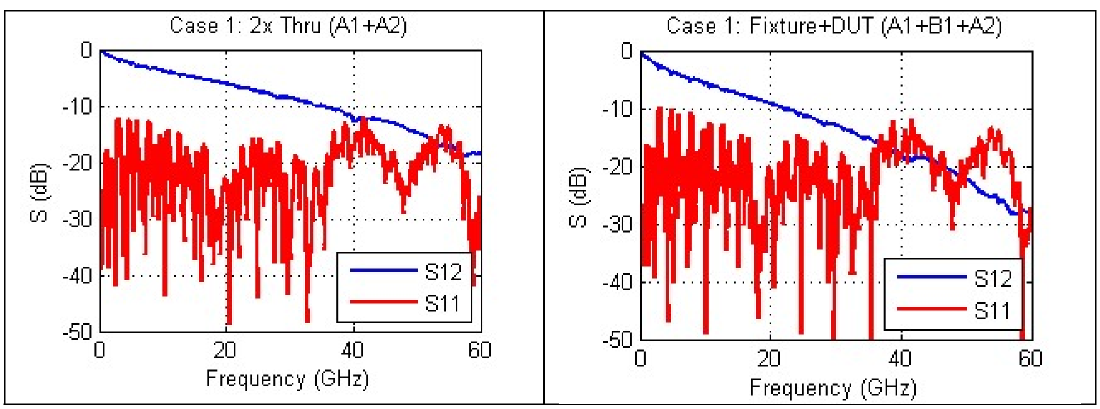

Figure 4. Case 1 insertion and return loss

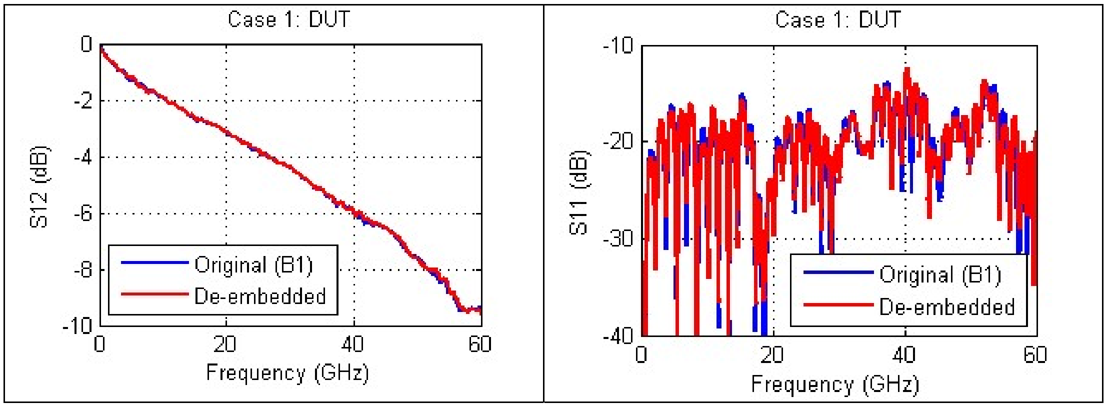

Figure 5. Case 1 DUT insertion and return loss

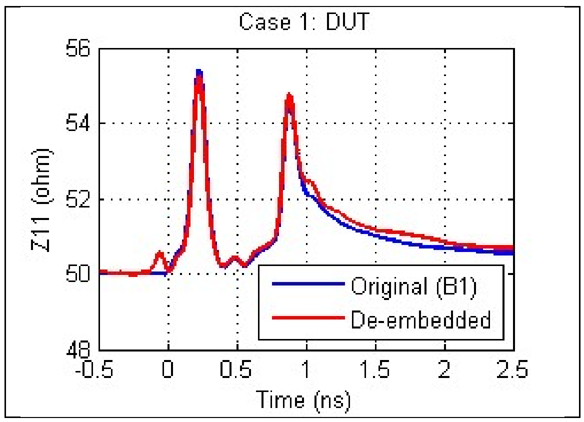

Figure 6. **Case 1 DUT impedance**

In case 3, the fixtures (A3+A4) are identical, and are ill-behaved. Vias exist in the paths of the fixtures as well as the 2x thru (B1), resulting in large reflections. The 2x thru's insertion loss (IL) and return loss (RL) cross each other at 13.2 and 33.7 GHz, as seen in Figure 7. Note that for good de-embedding results, RL should not exceed IL in general. After all, it is not possible to extract a DUT that is hidden behind a complete short or open. Under the special circumstance that the fixture and 2x thru are identical, as in this case, the DUT may still be extracted with good accuracy in the presence of strong reflections, as shown in Figures 8 and 9.

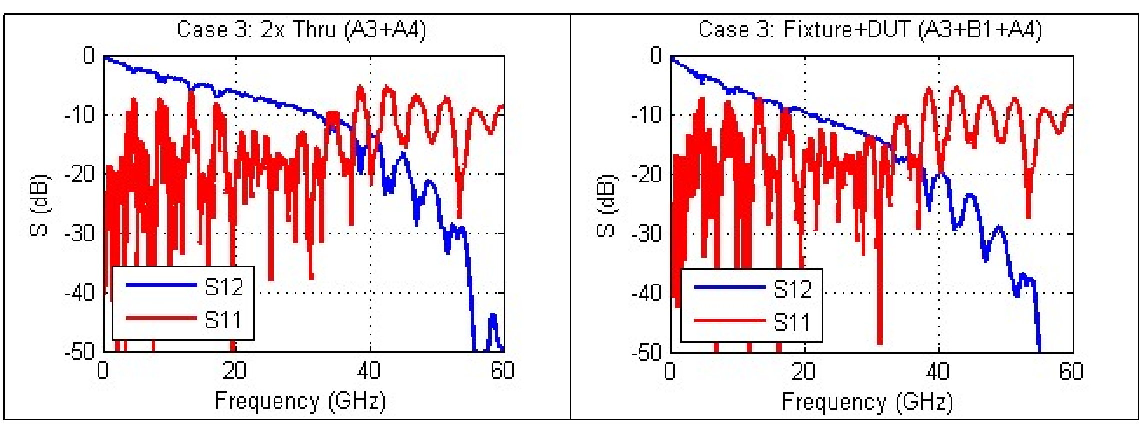

Figure 7. Case 3 insertion and return loss

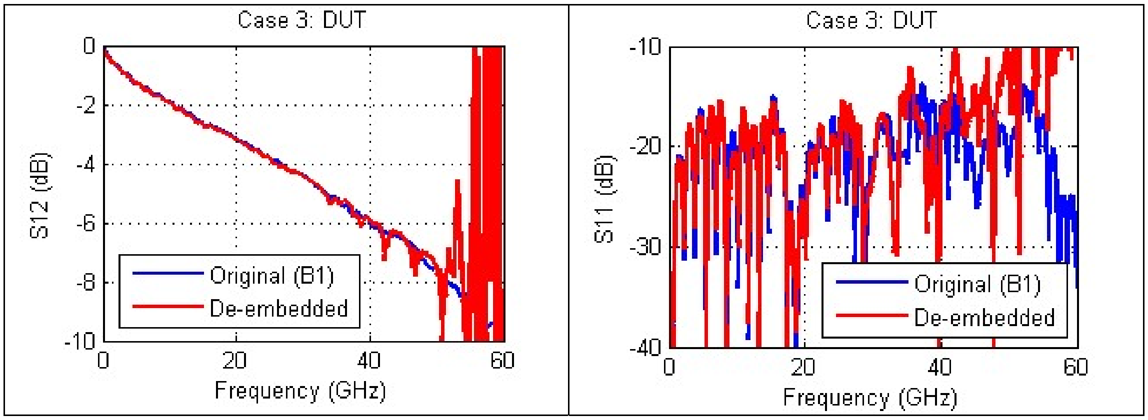

Figure 8. Case 3 DUT insertion and return loss

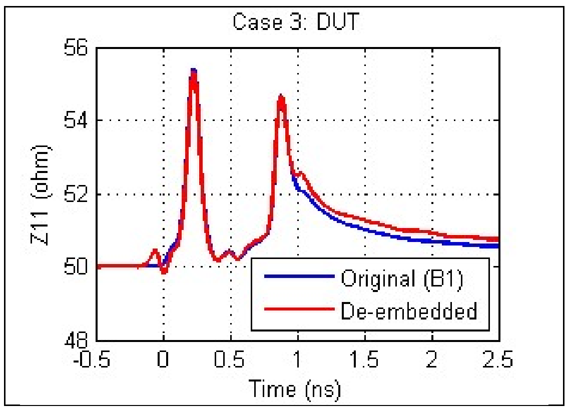

Figure 9. Case 3 DUT impedance

In case 5, fixtures (A1+A2) are 50 Ohm microstrips and the 2x thru (A5+A6) is a 45 Ohm microstrip. The DUT, a 6 cm 50 Ohm microstrip (B1), is to be extracted. This setup was made to mimic the most practical applications where the fixtures and 2x thru do not have identical impedance at every location. The results, shown in Figures 10 to 12, demonstrate that the traditional 2x thru method (Dmbd-1) gives significant error in all IL, RL and TDR, while the impedance-corrected 2x thru method (Dmbd-2) is still able to extract the DUT with very high accuracy. The traditional 2x thru method splits the 2x thru directly for de-embedding, so the impedance difference between the fixtures and the 2x thru appear as non-causal error in the de-embedded DUT results. This non-causal error gives rise to artificial ripples in the DUT's IL and RL, and produces a response before time zero (and after the DUT) in the TDR waveform. The impedance-corrected 2x thru method, on the other hand, is free of causality error because it modifies the de-embedding S-parameters by matching the fixture's impedance.

Therefore, for the cases with noticeable impedance variation between the fixture and the 2X-thru structures, use of an impedance-corrected 2x-thru method is necessary to obtain good results.

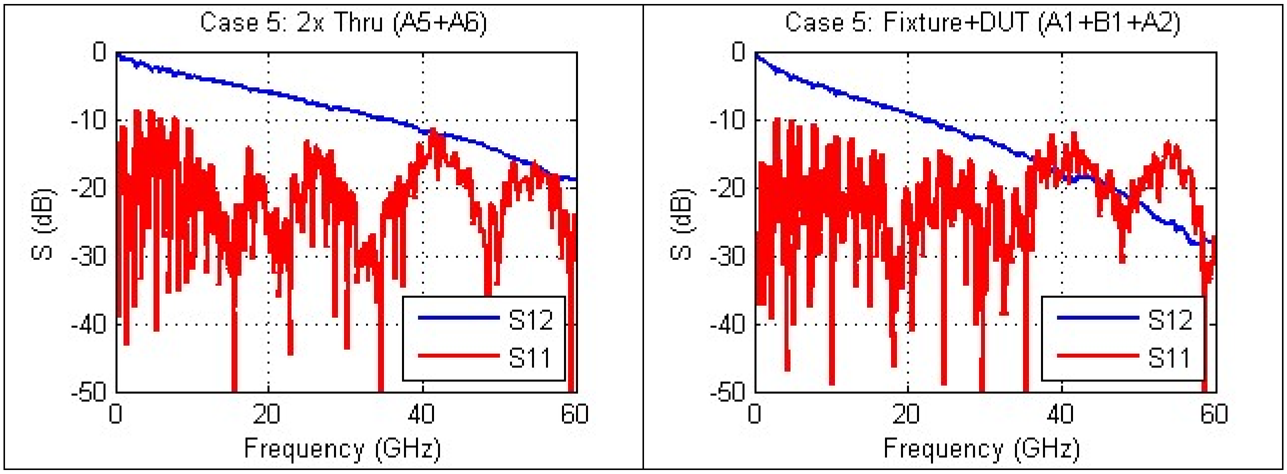

Figure 10. Case 5 insertion and return loss

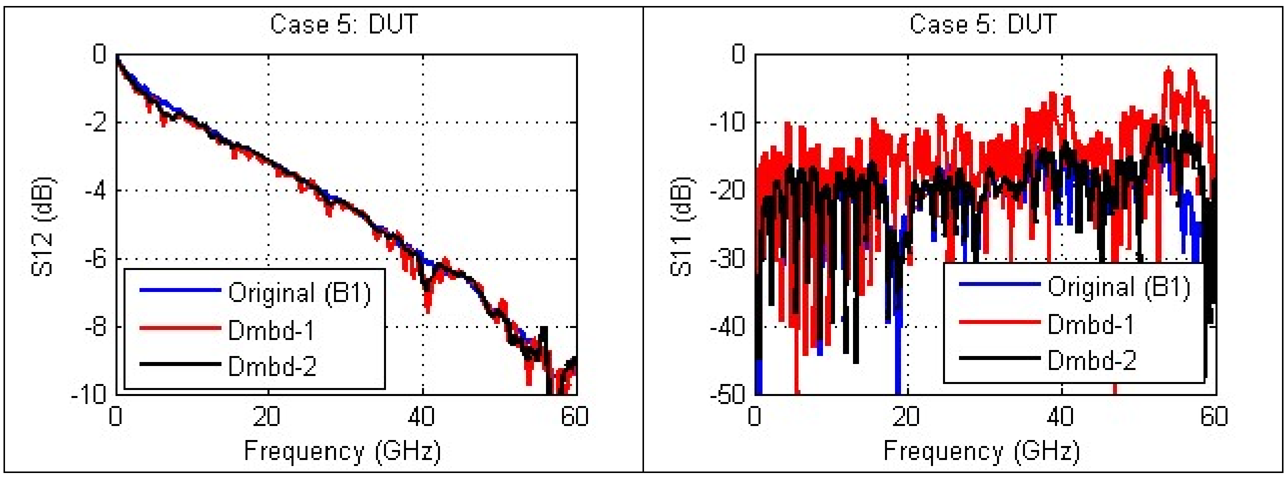

Figure 11. Case 5 DUT insertion and return loss

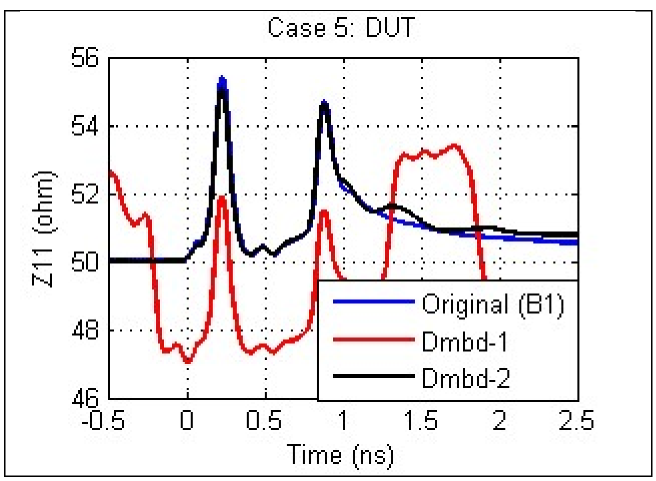

Figure 12. Case 5 DUT impedance

S-parameter Quality Tools and Metrics

Given the large amount of data typically contained in S-parameters, it is often difficult to ascertain the quality of the data without some quantitative evaluation. Manual comparison of plot traces is insufficient for quality assessment. Similar tools may already exist or will exist in the future, which P370 committee also provides a free tool for all users to assess their own tool Using DUT 5 as an example, application of the P370 quality tool to an S-parameter resulting from a suboptimal de-embedding algorithm produced results shown in Figure 13a. The value of CQM in this case is 81 mV for a 10 Gbps data rate, a rather poor result. Note that the value is dependent upon the data rate, which determines the maximum frequency of interest. The corresponding value at 40 Gbps is 167 mV. The S-parameter extracted using the recommended 2x impedance corrected de-embedding algorithm, on the other hand, produced the results in Figure 13b, with a CQM value of 7 mV, a dramatically improved value.

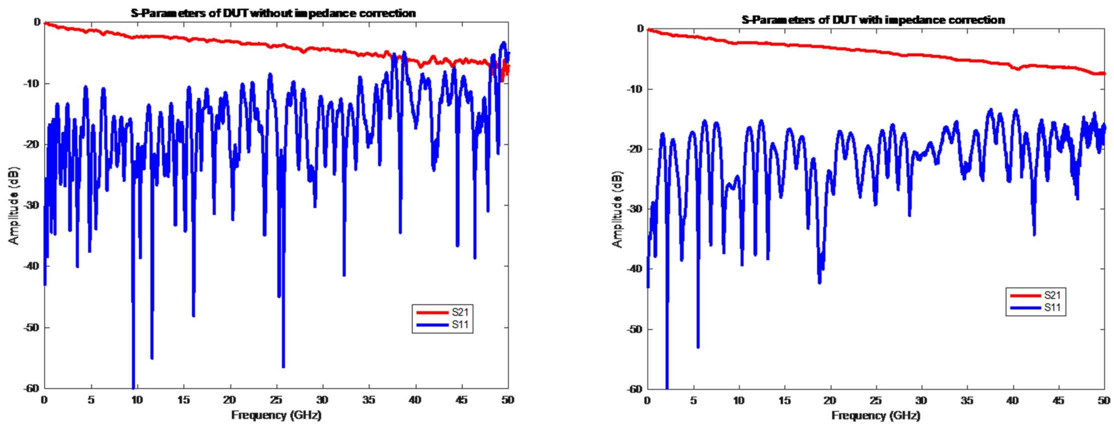

Figure 13. S-parameter plots for “bad” and “good” S-parameters

Figure 14 shows the s21 pulse response, indicating severely non-causal delay behavior for the suboptimal de-embedding case.

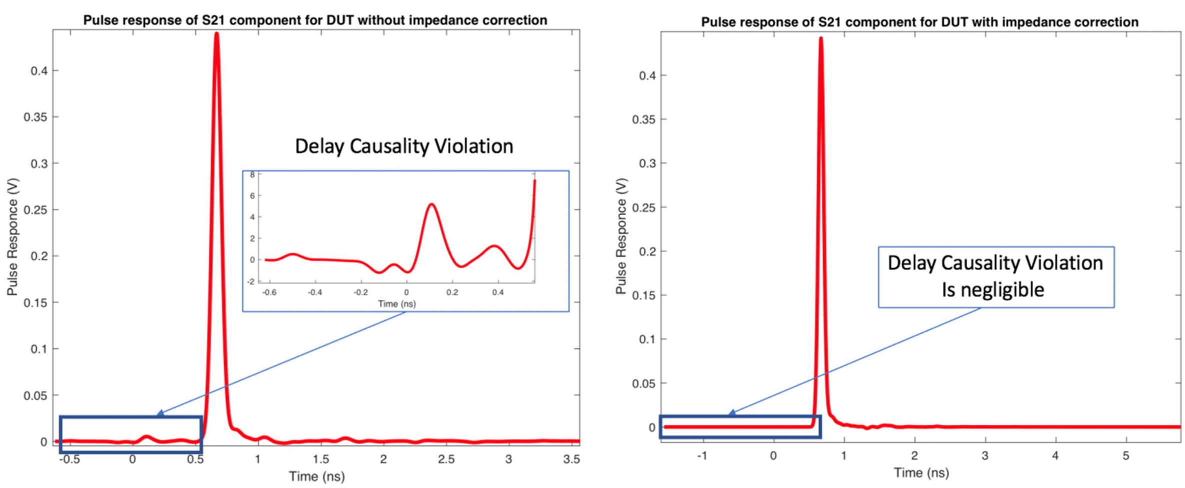

Figure 14. s21 Pulse response plots for bad” and “good” S-parameters

Table 2 summarizes the values of the three P370 quality metrics for these S-parameters. Both S-parameters are passive, indicated by the zero value for PQM. Severe non-causal behavior is found, as indicated by the 81 mV CQM value for the non-impedance corrected case. The non impedance-corrected data are only slightly non-reciprocal.

Parameter	Non-corrected	Impedance corrected	Comment
PQM	0	0	
CQM	81 mV	7 mV	Non-corrected severely non-causal
RQM	-1.15 mV	0	

Table 2. Quality metric summary for DUT 5

Comparison of S-parameters

Quantitative comparison of S-parameters can be extremely useful in the validation of the data, and is more accurate than a simple qualitative ("eyeball") comparison of plots of specific parameters; e. g., s21. A sample plot for one parameter (s11) for simulated and de-embedded results is shown in Figure 15. Figures 16 and 17 show the similarity metrics for two individual S-parameters from the same data. These would have to be reviewed for each individual S-parameter of concern; e. g., s11, s21, etc. Note that the port numbering in this example is not the conventional, so s31 is the insertion loss.

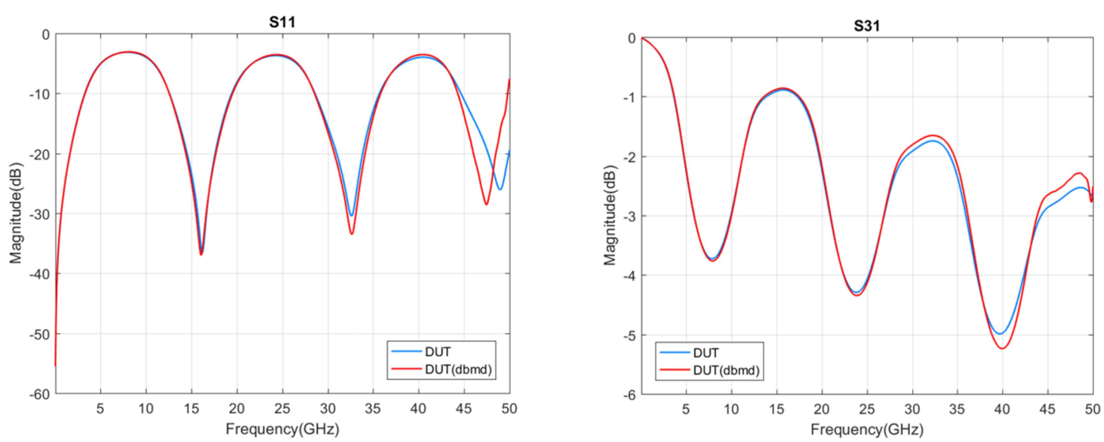

Figure 15. Measured and de-embedded s11 and s31 data comparison

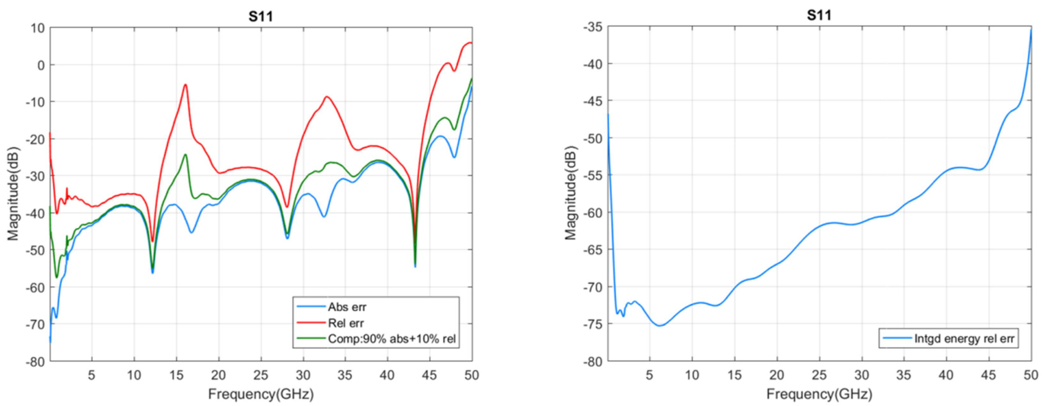

Figure 16. Sample s11 error plots and metrics

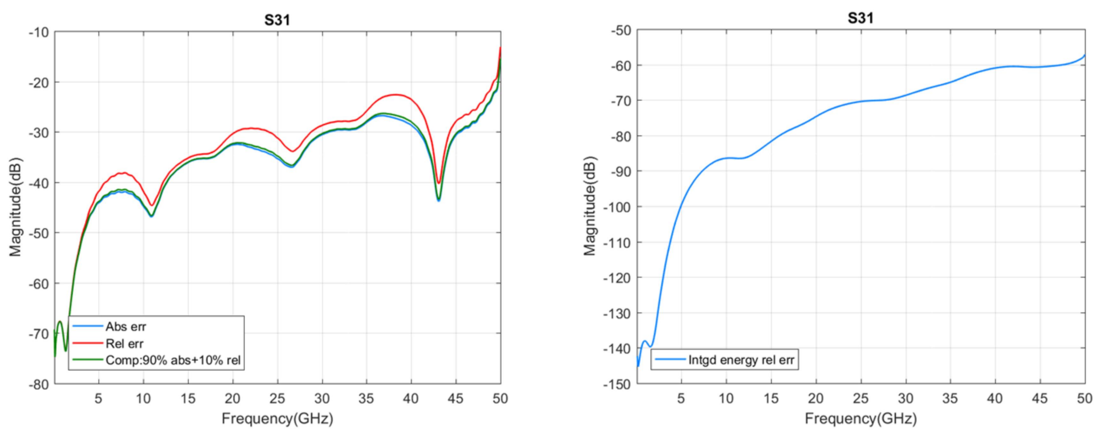

Figure 17. Sample s31 error plots and metrics

Conclusion

The IEEE P370 standard provides guidance on fixture designs, best practices, a data library for use in verifying de-embedding tools, and sample tools for evaluating and comparing S-parameter data. Designing fixtures and measuring devices for use up to 50 GHz is non-trivial, and it is hoped that this paper has given some insight into the potential use of the standard when it is published.

Acknowledgements

The authors would like to thank the members of the IEEE P370 committee, for their contributions to the standard and this paper.

References

1. Diepenbrock, J., et. al., "IEEE P370: A fixture design and data quality metric standard for interconnects up to 50 GHz," also submitted to this conference.