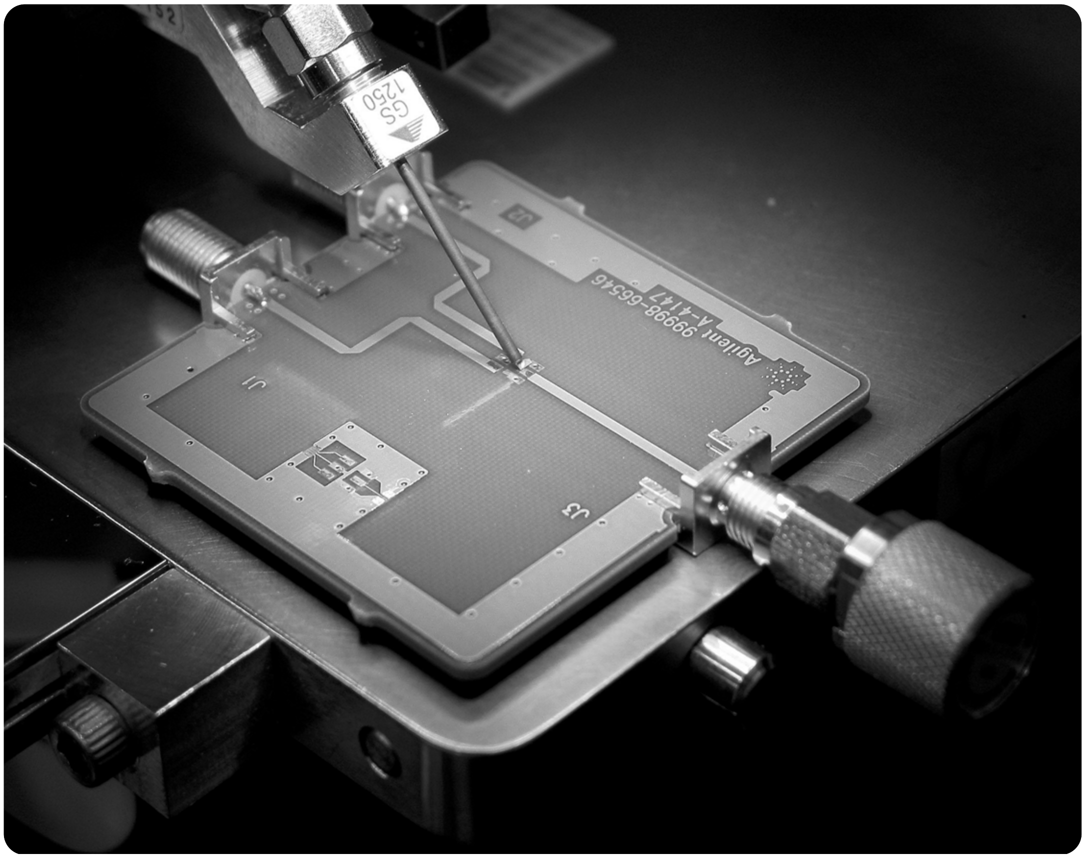
Agilent
In-Fixture Characterization Using the ENA Series RF Network Analyzer with Cascade Microtech Probing System

Product Note E5070/71-4



Agilent Technologies

Introduction

Many different techniques have been developed for eliminating the influence of test fixtures from measurement results. These can be classified into two fundamental approaches. One is performing calibration at the tips of a test fixture's electrodes and the other is de-embedding characterized test fixture models. The first method requires customized calibration standards for each test fixture, which are very expensive and inflexible.

On the other hand, de-embedding uses a model of the test fixture to mathematically remove unwanted test fixture effects from the overall measurement results. Usually, de-embedding data can be obtained from the simulation results of the test fixture model, which is modeled with simulation tools such as the Agilent Advanced Design System (ADS); however, accurate test fixture modeling is difficult and time-consuming. Therefore, engineers have been seeking an easy and accurate in-fixture characterization method.

This product note explains a new approach to in-fixture characterization using the Agilent ENA Series RF network analyzer with Cascade Microtech's probing system. This solution can drastically reduce your characterization time, especially for multiport test fixtures. By using this new approach, you can easily obtain fixture characteristics data without modeling complex multiport test fixtures. This product note also compares the new in-fixture characterization method with the de-embedding technique using ADS.

1. System configuration

The recommended system configuration of an in-fixture characterization system using the ENA Series along with the Cascade Microtech Probe Station is shown in figure 1.

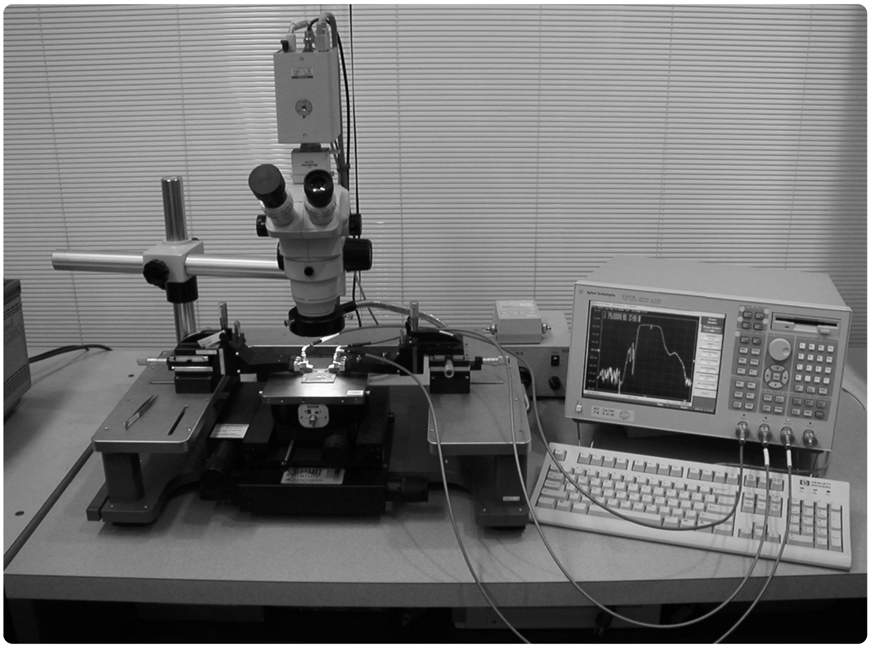


Figure 1. In-fixture characterization system configuration: Agilent ENA Series RF network analyzer and Cascade Microtech Summit 9100 RF Probe Station

This solution enables you to characterize test fixtures up to 8.5 GHz. Furthermore, an Air Coplanar Probe (ACP) Series (refer to figure 2) or Fixed-Pitch Compliant (FPC) Series probe (refer to figure 3) provides a reliable connection from the ENA Series to the test fixture's electrodes over a wide bandwidth. Both probes are available with a pitch range of 150 to 1,250 microns, so you can choose probes that are suitable for a variety of test fixture electrodes.

Accurate in-fixture characterization requires accurate one-port calibration at the tip of the probe. As shown in figures 4 and 5, Cascade Microtech provides high-precision calibration standards on Impedance Standard Substrates (ISS) and ENA Wafer Cal for highly accurate calibration. ENA Wafer Cal* is a software program that runs on the ENA Series. This software guides the user through the setup of the CalKit and calibration steps, thus reducing one of the greatest sources of error in calibration. Consequently, this program improves calibration accuracy and repeatability.

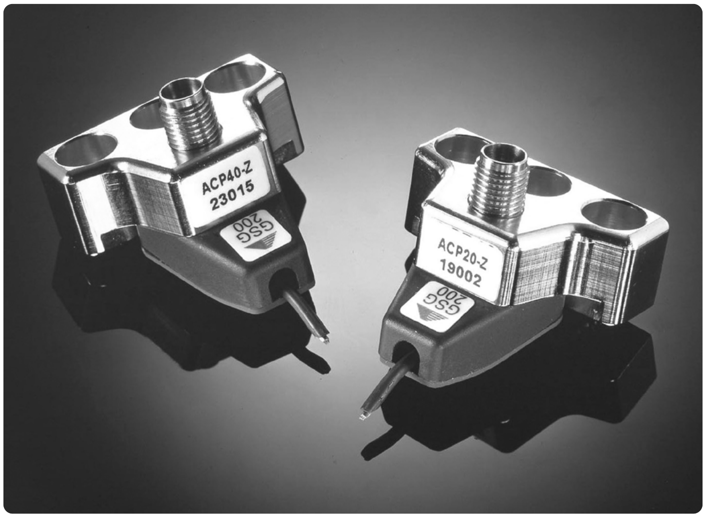


Figure 2. ACP Series probe

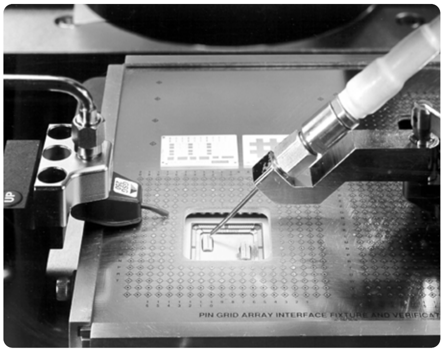


Figure 3. FPC Series probe

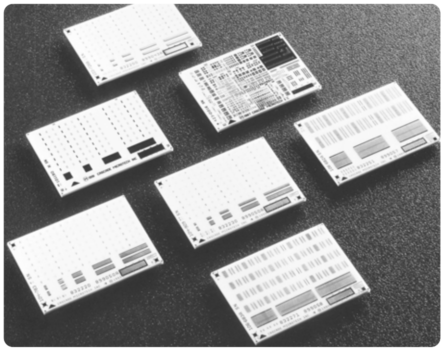
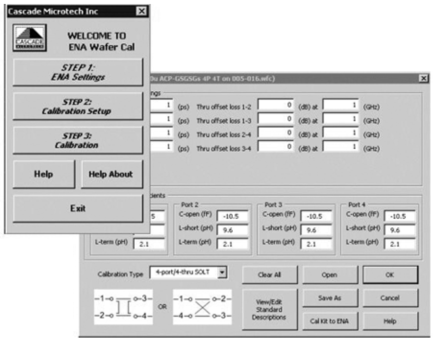


Figure 4. Impedance Standard Substrate (ISS)



Cascade Microtech Inc

WELCOME TO
ENA Wafer Cal

…u ACP-GSGSGs 4P 4T on 005-016.wfc)

1 (ps) Thru offset loss 1-2 0 (dB) at 1 (GHz)
1 (ps) Thru offset loss 1-3 0 (dB) at 1 (GHz)
1 (ps) Thru offset loss 2-4 0 (dB) at 1 (GHz)
1 (ps) Thru offset loss 3-4 0 (dB) at 1 (GHz)

	Port 2	Port 3	Port 4
	C-open (fF) -10.5	C-open (fF) -10.5	C-open (fF) -10.5
	L-short (pH) 9.6	L-short (pH) 9.6	L-short (pH) 9.6
L-term (pH) 2.1	L-term (pH) 2.1	L-term (pH) 2.1	L-term (pH) 2.1

Calibration Type 4-port/4-thru SOLT

Figure 5. ENA Wafer Cal software program for the ENA Series

---

* ENA Wafer Cal requires the "B" version of the ENA Series, which has Windows® 2000 built into the instrument.

2. How to characterize the test fixture

In this section, a new approach to in-fixture characterization and an actual procedure are explained.

2.1 What is fixture de-embedding?

Fixture de-embedding uses a model of the test fixture to mathematically remove the fixture characteristics from the overall measurement results. The ENA Series provides fixture de-embedding* capability as part of the fixture simulator function. Therefore, once fixture characteristics are obtained, unwanted test fixture effects can be removed mathematically without using an external PC or simulation tools.

2.2 A new approach to in-fixture characterization

Figure 6 shows the three systematic errors involved in measuring a one-port device. E_{df} is the forward directivity error term resulting from signal leakage through the directional coupler on the port. E_{rf} is the forward reflection tracking error term resulting from the path differences between the test and reference paths. E_{sf} is the forward source match error term resulting from the ENA's test port impedance not being perfectly matched to the source impedance. This set of error terms is used as the error adapter coefficient of a one-port measurement system.

A vector network analyzer's calibration process can be considered a type of de-embedding of the error adapter coefficients from the measurement results. Our new in-fixture characterization technique is based on this concept. In this approach, S_{11} measurements are made of the three calibration standards (open, short, load), and the three S_{11} definitions of the standards are used to calculate the error adapter coefficients between the measurement port and the device under test (DUT). These calculated error adapter coefficients can be used as the de-embedding data. Accordingly, this process removes unwanted test fixture effects.

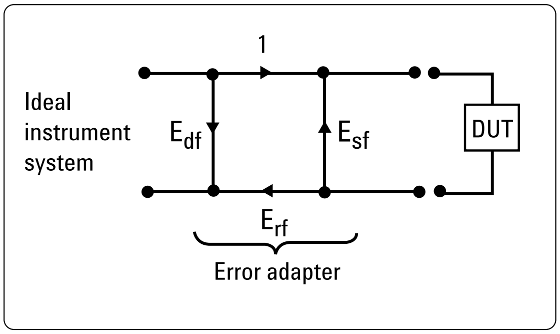


Figure 6. Signal flow diagram of one-port error adapter model

---

* For more details on fixture de-embedding, refer to Application Note 1364-1,"*De-embedding and Embedding S-Parameter Networks Using a Vector Network Analyzer.*"

2.3 In-fixture characterization procedure

The products listed in table 1 and a test board, shown in figure 7, are used in the following evaluation.

This test board is designed for balanced SAW filter evaluation. It is a three-port device that has a single-ended input port and a balanced output port. The center frequency is 942.5 MHz, and the insertion loss is 3.5 dB maximum in the passband.

Table 1

Product	Model number	Remarks
ENA Series RF network analyzer	E5071B Option E5071B-414	300 kHz to 8.5 GHz 4-port test set
Cascade Microtech RF Probe Station		Summit 9101
FPC Series Probe	FPC-GS-1250	1,250 mm pitch
Impedance Standard Substrate (ISS)	106-683	Wide-pitch GS/SG
ENA Wafer Cal software	125-950	Requires ENA Series B (E5070B/E5071B)

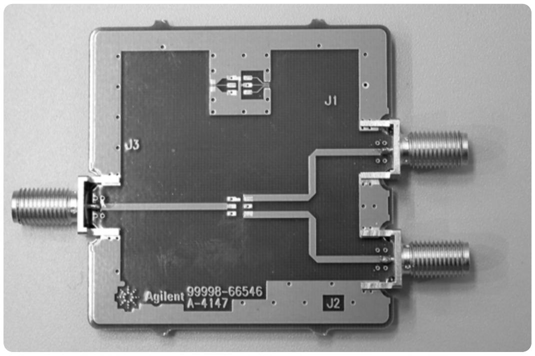


Figure 7. Test board

Procedure

The actual in-fixture characterization procedure is conducted as follows.

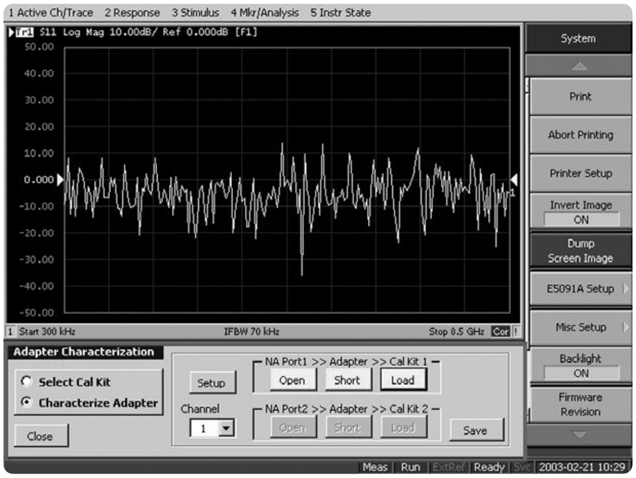
Step 1: Perform one-port calibration with the ENA using the ACP or FPC probe with the ISS* and ENA Water Cal.

Step 2: Run the adapter characterization program (figure 8), which is provided as a VBA macro. This is a very useful tool for fixture characterization. This software program calculates two-port S-parameters by using S_{11} measurement results with each of the three standards (open, short, and load) connected to the coaxial port of the test board, as shown in figure 9. Also, CalKit values of major coaxial calibration kits are registered in the instrument beforehand, so you do not need to enter CalKit values into the ENA Series.

Step 3: Finally, obtain two-port S-parameters from the three S_{11} parameters and save them as a .s2p Touchstone file.

Step 4: Repeat steps 1 to 3 for each test port.

Step 5: Apply de-embedding data to each test port as shown in figure 10, thereby removing unwanted test board effects.



S11 Log Mag 10.00dB/ Ref 0.000dB [F1]

Start 300 kHz IFBW 70 kHz Stop 8.5 GHz

Invert Image ON

Backlight ON

○ Select Cal Kit

● Characterize Adapter

Channel 1

2003-02-21 10:29

Figure 8. Adapter characterization program

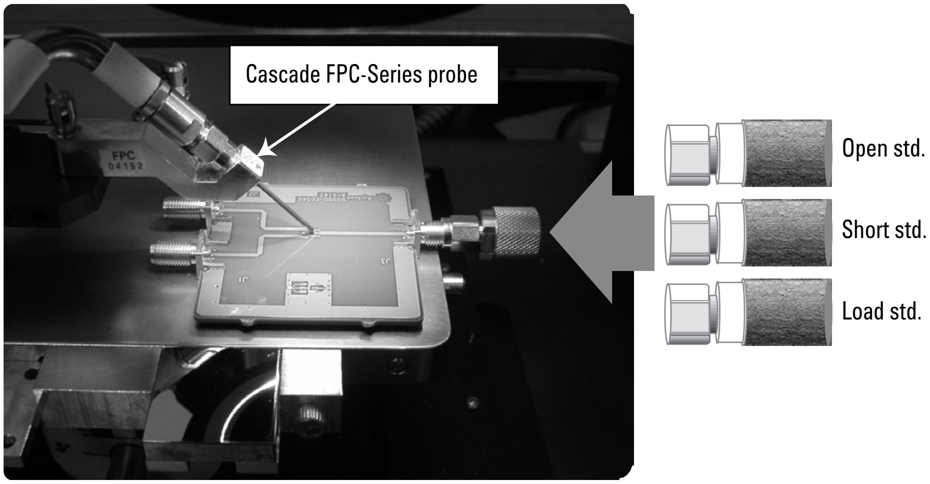


Figure 9. Characterizing the test board using Cascade Microtech’s FPC Series probe

---

* For more details on calibration using Cascade Microtech’s probe with the ISS, refer to Product Note E5070/71-3, “*On-wafer Multiport Calibration using the ENA Series RF Network Analyzer with Cascade Microtech Probing System*.”

3 In-fixture characterization using ADS

A software simulator can be used to characterize a test fixture. Agilent ADS is an integrated design platform including system, circuit, and electromagnetic simulation as well as synthesis and physical design. This section describes how to use ADS to characterize a test fixture.

3.1 Modeling a test board

As shown in figure 10, the test board is modeled using ADS. First, the coaxial connector on the test board is modeled as a small length of coaxial line. Second, a coaxial-to-microstrip transmission line is modeled as a lumped series inductor and a shunt capacitor that is optimized to correlate with the test board's actual coaxial measurement results.

This optimization uses the S_{11} measurement data of the test board when the DUT's electrodes are shorted by using a short plate or solder. Third, a microstrip thru-line is placed after the series inductor and shunt capacitor model. This microstrip line requires an accurate value for dielectric constant and loss tangent for the substrate material of the test board. Uncertainty in these values, which are usually provided by the component's manufacturer, will directly affect the accuracy of the model.

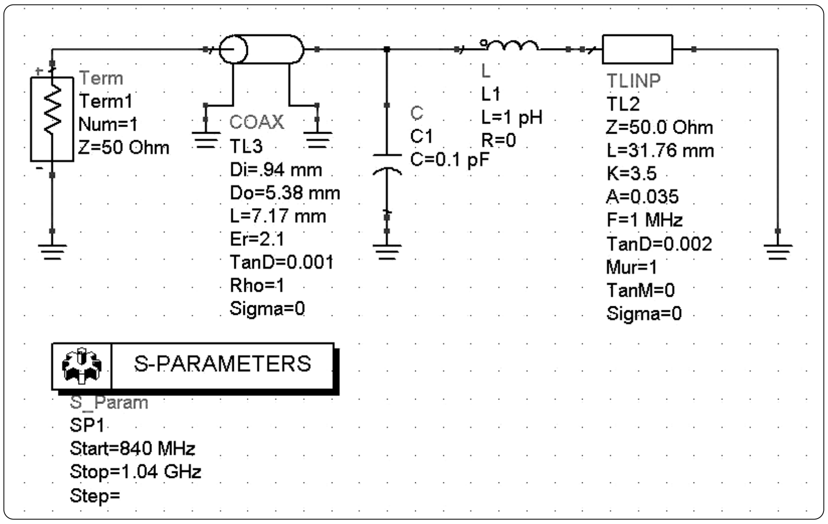


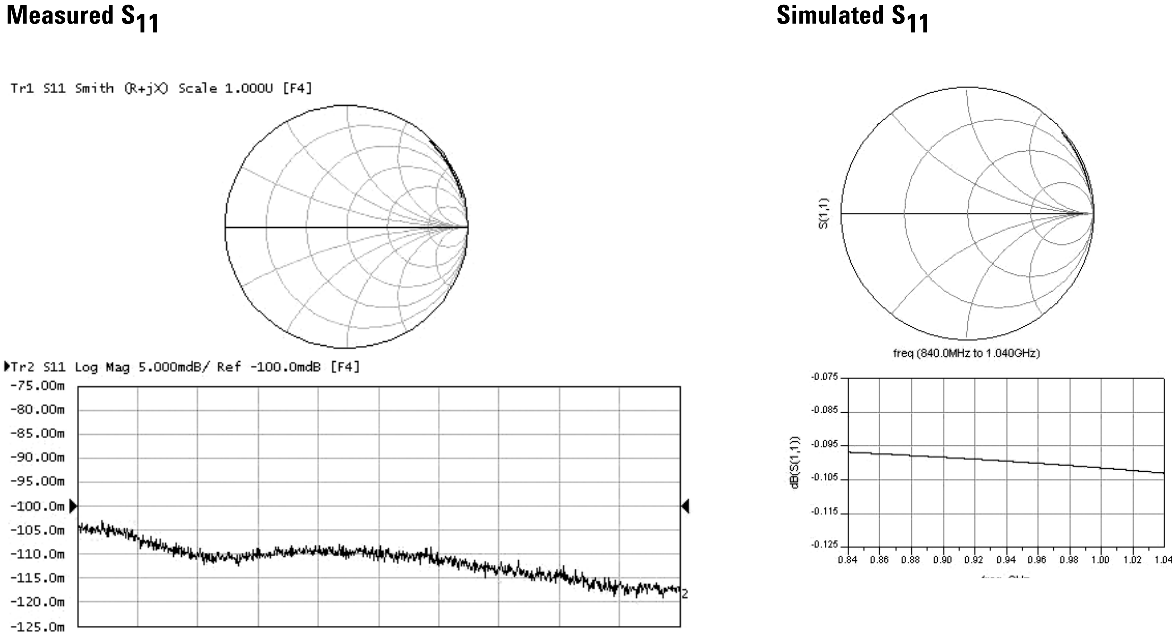
Figure 10. Simulated model of test board using ADS

3.2 Optimizing a test board model

The model values for inductance and capacitance are optimized using ADS until a good fit is obtained. Figure 11 shows the measured and simulated results for the S_{11} value of the test board. Simulated S-parameters should be optimized and compared to the measured S-parameters to verify their accuracy.

Due to the non-linear effects in the coaxial-to-microstrip transmission line, this simplified lumped element model of the transition may only be valid over a small frequency range. If broadband operation is required, a model must be improved to incorporate the non-linear behavior of the measured S-parameters as a function of frequency.

Please note that this optimized model is only a one-port model; consequently, to meet the requirements of the ENA's de-embedding function, it needs to be converted to a two-port model to extract two-port S-parameters as a Touchstone format file (.s2p).


Measured S_{11}

Simulated S_{11}

Figure 11. Comparison of S_{11} for simulated and measured test boards

4 Actual device evaluation using de-embedding techniques

This section describes a balanced SAW filter evaluation result obtained using the de-embedding technique.

4.1 Balanced SAW filter evaluation

A balanced SAW filter is evaluated by using the test board with de-embedding data. Figure 12 shows the balanced SAW filter evaluation result, which compares de-embedding using Cascade Microtech's probe to the ADS de-embedding method. The measurement result obtained with the port extension method is also shown along with these results to gauge the validity of both de-embedding methods.

The overall filter shapes of the three traces look almost the same, but the measurement values in the passband are somewhat different (refer to figure 13).

Unfortunately, no specified balanced SAW filter data exists, so it is difficult to say which value is closer to the true value of the device. However, if the Cascade Microtech de-embedding data is compared to the ADS de-embedding data, the maximum difference in the measurement value is less than 0.1 dB. The shapes of the passband filters' curves are also similar to each other, so it can be assumed that the Cascade Microtech and ADS de-embedding results have a good correlation.

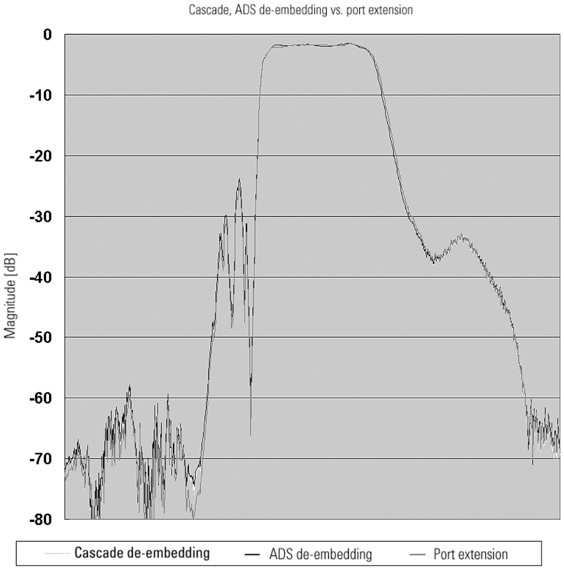


Figure 12. Comparison of balanced SAW filter measurement results

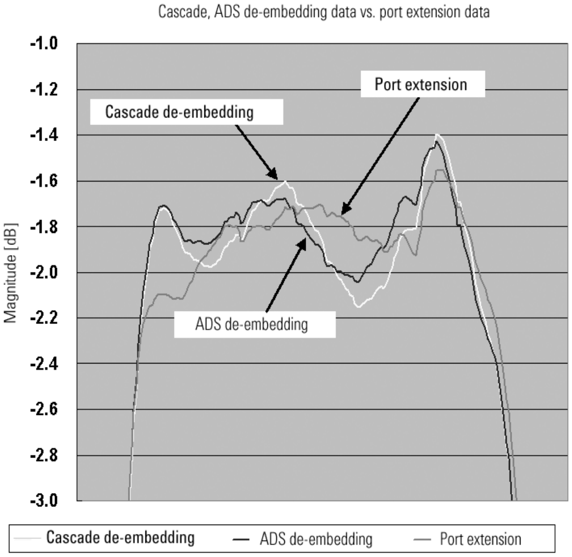


Figure 13. Comparison of balanced SAW filter's passband measurement results

On the other hand, the port extension result is clearly different from the others. In particular, the left shoulder of the passband measurement value has a difference of 0.4 dB or more from either de-embedding result.

The difference in measurement values between the Cascade Microtech and ADS de-embedding can be reduced if the test board model is optimized by taking into account the non-linear effects such as stimulus signal reflection and coupling that can occur in the test board. However, such precise non-linear test fixture modeling is very difficult and time-consuming.

Table 2 summarizes the advantages and disadvantages of both the Cascade Microtech and ADS de-embedding methods.

Summary

This product note describes a new approach of in-fixture characterization using the ENA Series RF network analyzer together with the Cascade Microtech Probing System. By using this new de-embedding technique, you can easily characterize a test fixture, even if it has multiple test ports. The guidelines in this product note should make it easier for you to characterize test fixtures and give you more confidence in your device evaluation results.

Table 2. Comparison of Cascade Microtech's Probe and ADS de-embedding methods

De-embedding method	Cascade Microtech's Probe	ADS
Advantage	Easy to extract accurate de-embedding data without test fixture modeling	Lower-cost solution than Cascade de-embedding method
Disadvantage	More expensive than ADS de-embedding method	Need to learn ADS modeling procedure Accurate test fixture modeling is time-consuming

References

1. Agilent ENA Series 2-, 3- and 4-port RF Network Analyzers, Product Brochure (P/N 5988-3765EN)

2. Agilent De-embedding and Embedding S-Parameter Networks Using a Vector Network Analyzer, Application Note 1364-1 (P/N 5980-2784EN)

3. On-wafer Multiport Calibration using the ENA Series RF Network Analyzer with Cascade Microtech Probing System, Product Note E5070/71-3 (P/N 5988-5886EN)

4. Introduction to the Fixture Simulator Function of the ENA Series RF Network Analyzers, Product Note E5070/71-1 (P/N 5988-4923EN)

For Cascade Microtech Products, contact Cascade Microtech, Inc.

Cascade Microtech, Inc.
2430 NW 206th Avenue
Beaverton, Oregon 97006, USA
Tel: (503) 601-1000
Fax: (503) 601-1002
E-mail: sales@cmicro.com
URL: http://www.cascademicrotech.com

Agilent Technologies' Test and Measurement Support, Services, and Assistance

Agilent Technologies aims to maximize the value you receive, while minimizing your risk and problems. We strive to ensure that you get the test and measurement capabilities you paid for and obtain the support you need. Our extensive support resources and services can help you choose the right Agilent products for your applications and apply them successfully. Every instrument and system we sell has a global warranty. Support is available for at least five years beyond the production life of the product. Two concepts underlie Agilent's overall support policy: "Our Promise" and "Your Advantage."

Our Promise

Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

Your Advantage

Your Advantage means that Agilent offers a wide range of additional expert test and measurement services, which you can purchase according to your unique technical and business needs. Solve problems efficiently and gain a competitive edge by contracting with us for calibration, extra-cost upgrades, out-of-warranty repairs, and on-site education and training, as well as design, system integration, project management, and other professional engineering services. Experienced Agilent engineers and technicians worldwide can help you maximize your productivity, optimize the return on investment of your Agilent instruments and systems, and obtain dependable measurement accuracy for the life of those products.

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

Get the latest information on the products and applications you select.

By internet, phone, or fax, get assistance with all your test & measurement needs

Online assistance:
www.agilent.com/find/assist

Phone or Fax
United States:
(tel) 800 452 4844

Canada:
(tel) 877 894 4414
(fax) 905 282 6495

China:
(tel) 800 810 0189
(fax) 800 820 2816

Europe:
(tel) (31 20) 547 2323
(fax) (31 20) 547 2390

Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Korea:
(tel) (82 2) 2004 5004
(fax) (82 2) 2004 5115

Latin America:
(tel) (305) 269 7500
(fax) (305) 269 7599

Taiwan:
(tel) 0800 047 866
(fax) 0800 286 331

Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 6836 0252
Email: tm_asia@agilent.com

Printed in USA, October 13, 2003
5988-6522EN

Agilent Technologies