

# Impedance Characteristic Evaluation of SMD by Using the ENA with Inter-Continental Microwave (ICM) Test Fixture

Application Note 1463-5



Agilent Technologies

# Introduction

With the trend of wireless communications and digital equipment operating at higher frequencies, the need to evaluate RF components under higher and wider frequencies is becoming increasingly important. Generally, an RF impedance analyzer is used for impedance measurement up to 3 GHz; however, beyond this frequency range, a network analyzer is commonly used. The network analyzer is a convenient instrument for measuring impedance over a wide frequency range, but measurement accuracy is degraded in comparison with the RF impedance analyzer<sup>1</sup>. This application note describes impedance characteristic evaluation of SMD by using the ENA RF network analyzer with the ICM test fixture. In addition, we also explain the TRL calibration procedure using the ENA with ICM test fixture (TF-3001-S), special considerations for measuring surface-mount devices (SMD), and impedance characteristic evaluation using the impedance parameter display software.

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1. For information on the comparison between an impedance analyzer and a network analyzer, refer to reference application note 1369-2

# TRL Calibration Procedures

This section describes the TRL Calibration procedure using the ENA, ICM test fixture (TF-3001-S), and TRL calibration kit (TRL-3004B).

Figure 1 shows the ICM test fixture mainframe (TF-3000 Series) and the calibration kit (TRL-3004B).

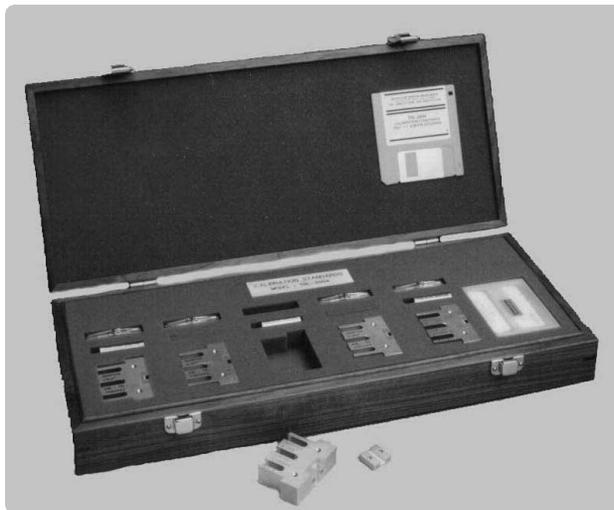
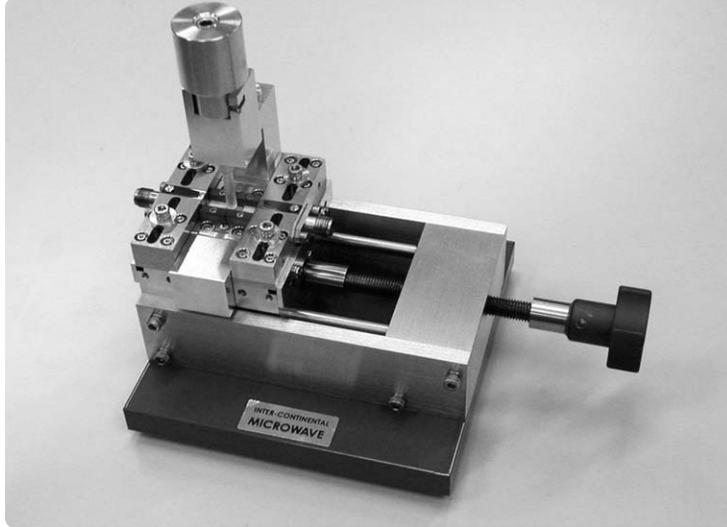


Figure 1. Test fixture mainframe (TF-3000 Series) and calibration kit (TRL-3004B)

## Step 1. Setting of the ENA

Before performing the TRL error correction, basic measurement parameters such as test frequency range, IFBW, power level, and measurement points should be set in advance. Please note that if you change measurement parameters such as test frequency range after performing error correction, the calibration data will be changed to compensation data, and this may degrade measurement accuracy. In the case of the ENA, once calibration data is changed to compensation data, status display “Cor”, which is located on the bottom-right corner of the screen, will be changed to “C?”.

## Step 2. Define the calibration kit

To ensure an accurate calibration, it is very important that the standard coefficient of the calibration kit (TRL-3004B) be entered in the ENA. The standard coefficient is provided with the calibration kit and each data item should be entered correctly. Table 1 shows examples of standard coefficient definitions.

**Table 1. Examples of standard coefficient definitions (TRL-3004B)**

Standard		Offset			Frequency (GHz)		Standard label
No.	Type	Delay ps	Z <sub>0</sub> Ω	Loss GΩ/s	Lower	Upper	
1	Short (Reflection)	-77	50	0	0	999	Short
2	Thru	0	50	0	0	999	Thru
3	Delay (Match)	1	50	0	0	0.501	Match
4	Delay (Line)	119	50	0	0.499	3.7	Line1
5	Delay (Line)	16	50	0	3.49	26.6	Line2

In this example, Short, Thru, Line1, and Line2 standards are used to perform TRL calibration. Follow these steps to define coefficients. Please note hardkeys are formatted as **[Cal]**, softkeys are formatted as **[Cal Kit]**.

### Procedure to create user specified calibration kit

1. Press **[Cal]** key.
2. Click **[Cal Kit]**, and then select a **[User]** that has not been registered.
3. Click **[Modify Kit] > [Label Kit [User]]**, then type a name you want. In this example, type **3004B**.

### Procedure to define Short (Reflect) and Thru

1. Click **[Define STDs]**.
2. Click **[1.No Name] > [Label]**, then type **Short**.
3. Select **[STD Type] > [Short]**.
4. Set **[Offset Delay]** to -0.077ns.
5. Click **[Return]** to return to the Define STD menu.
6. In the same way, repeat the procedure to enter the definition of Thru to **[2.No Name]**, then select **[Delay/Thru]** for STD Type.

### Procedure to define Line1/Line2

1. Click **[4.No Name] > [Label]**, Then type **Line1**.
2. Click **[STD Type] > [Delay/Thru]**.
3. Set **[Offset Delay]** to 0.119 ns.
4. Set **[Min Frequency]** to 0.499 GHz.
5. Set **[Max Frequency]** to 3.7 GHz.
6. Click **[Return]** to return to the Define STD menu.
7. Click **[5.No Name] > [Label]**, Then type **Line2**
8. Click **[STD Type] > [Delay/Thru]**.
9. Set **[Offset Delay]** to 16 ps.
10. Set **[Min Frequency]** to 3.49 GHz.
11. Set **[Max Frequency]** to 26.6 GHz.
12. Click **[Return]** to return to the Define Std menu.
13. Click **[Return]** to return to the Modify Cal Kit menu.

### Procedure to specify Short (Reflect) and Thru to subclass1

1. Click [Specify CLSs] > [Sub Class].
2. Click [Sub Class1].
3. Click [TRL Reflect] > [1.Short].
4. Click [TRL Thru] > [Set All] > [2.Thru] > [Return].

### Procedure to specify Line1/Line2 to subclass1/subclass2

1. Click [Specify CLSs] > [Sub Class].
2. Click [Sub Class1].
3. Click [TRL Line/Match] > [Set All] > [LINE1] > [Return].
4. Click [Sub Class2].
5. Click [TRL Line/Match] > [Set All] > [LINE2] > [Return].
6. Press [Cal] key and check that the name you specified is selected as Cal Kit.

In this example, TRL calibration uses two Line standards because the usable bandwidth of a single Line standard is limited by the TRL calibration 1:8 (frequency span:start frequency) guideline. The phase shift between Line and the Line must be between 20 deg and 160 deg. By assigning Line1/Line2 to subclass1/subclass2 respectively, you can calibrate the ENA for whole frequency range covered by two standards.

### Procedure to save and loading definition file of calibration kit

You can save the definition file of the calibration kit for each standard into a file on a storage device, and then recall it later to reproduce the definition.

1. Press [Cal] key.
2. Click [Cal Kit], and then select a calibration kit you want to save.
3. Click [Modify Cal Kit] > [Export Cal Kit...] to open the dialog box.
4. Specify a folder, enter a file name, and click Save.

## Step 3. Perform TRL error correction

The 2-port TRL calibration function lets you measure calibration data by connecting thru, reflection (open or short), line or match calibration standards among 2 desired test ports. This calibration provides the most accurate measurement for non-coaxial parts, using same error model as full 2-port calibration. To perform TRL calibration on firmware (fig 2), FW rev6.00 or later is required. For TRL calibration with FW rev5.02 or lower, we offer VBA macro to perform TRL calibration.

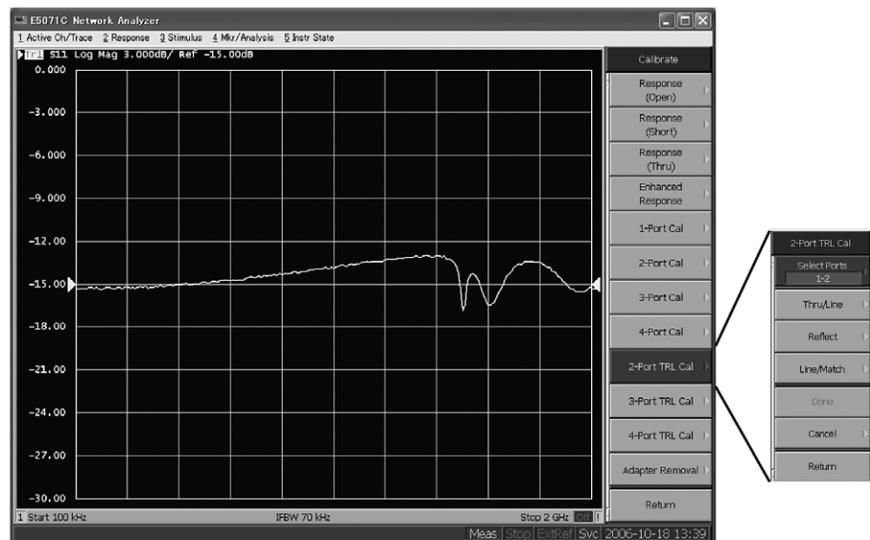


Figure 2. Performing TRL calibration on FW

#### **Procedure to select calibration method and port to be calibrated**

1. Press **[Cal]** key.
2. Click **[Calibrate] > [2-Port TRL Cal]**.
3. Click **[Select Ports]**, and then select the test ports for which you want to execute TRL 2-port calibration. (In the following procedure, test ports you selected here are expressed as test ports x and y.)

#### **Procedure to take Thru calibration measurement**

1. Make thru connection between ports x and y.
2. Click **[Thru/Line]**.
3. Click **[x-y Thru/Line]** to execute a Thru/Line measurement.
4. Click **[Return]**.

#### **Procedure to take Reflection calibration measurement**

1. Connect short standard to port x.
2. Click **[Reflect]**.
3. Click **[Port x Reflect]** to execute a reflection calibration for test port x.
4. In the same way, repeat the procedure to execute calibration for test port y.
5. Click **[Return]**.

#### **Procedure to take Reflection calibration measurement**

1. Make Line1 connection between ports x and y.
2. Click **[Line/Match]**.
3. Click **[x-y Line/Match] > [Line/Match 1[Line1]]** to execute Line calibration using calibration standard of Line1. Using **[x-y Line/Match]**, both forward and reverse direction measurement is taken at the same time. This is equivalent to measuring both **[x-y Fwd (Syx)]** and **[x-y Rvs (Sxy)]**.
4. Make a Line2 connection between ports x and y.
5. Click **[Line/Match]**.
6. Click **[x-y Line/Match] > [Line/Match 2[Line2]]** to execute Line calibration using calibration standard of Line2.
7. Click **[Return]**.

When frequency ranges specified overlap such as this example (Line1:0.499GHz-3.7GHz, Line2:3.49GHz-26.6GHz), the standard last executed is applied for the overlapping portion (3.49GHz - 3.7GHz).

#### **Procedure to finish the calibration**

Click **[Done]** to finish TRL 2-port calibration. At this point, the calibration coefficient is calculated and saved. The error correction function is automatically turned on.

## Step 4. Verification of TRL calibration

Before performing actual measurements, it is important to verify the calibration. This section explains how to verify the calibration performance by using the Line standard. After each calibration, set the measurement display as shown in Figure 3 and measure the S-parameters of the Line. Basically, the Line can be seen as an ideal transmission line, so it does not have transmission loss and the port impedance is very close to 50  $\Omega$ . If the TRL calibration is performed correctly, the S-parameter measurement result of the Line can be obtained as shown in Figure 3.

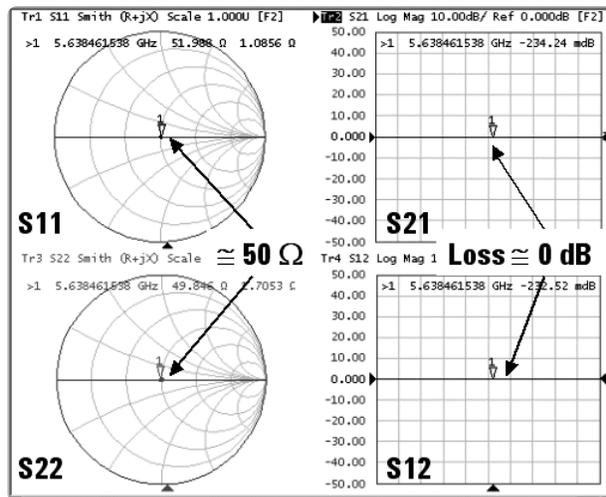


Figure 3. S-parameter measurement result of the Line

If the measurement result shown in Figure 3 cannot be obtained, then most likely the calibration kit will not be defined correctly and the TRL calibration will not be performed properly.

# Measurement Procedure of SMD

This section describes impedance measurements of SMD by using the ENA and ICM test fixture with the impedance parameter display software.

## Impedance parameter display software

The ENA is supplied with impedance parameter display software (Figure 4). This software calculates impedance parameters such as  $|Z|$ ,  $C_p$ ,  $L_s$ ,  $Q$ ,  $R$ , and  $X$  from S-parameter measurement results and displays them on the ENA's screen up to three traces at a time.

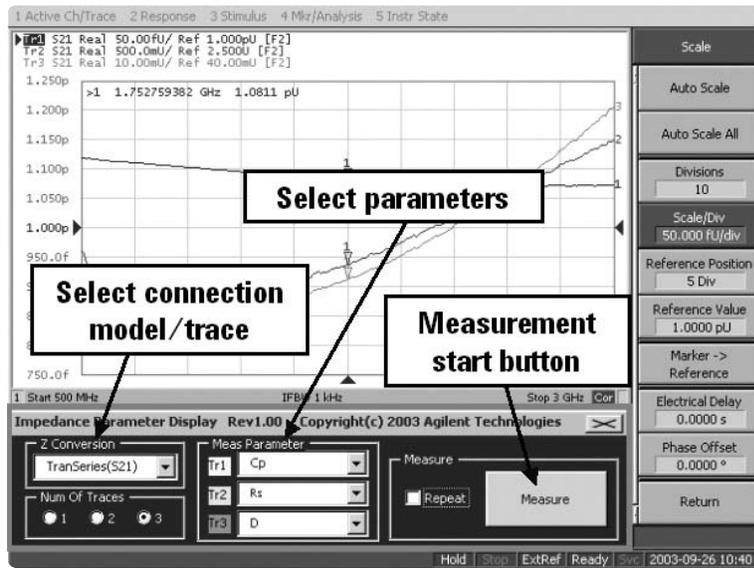


Figure 4. Impedance parameter display software

In addition, as shown in Figure 5, this software works with three different connection models: Series-Thru (TranSeries S21), Shunt-Thru (TranShunt S21), and Shunt-to-GND (Refl S11).

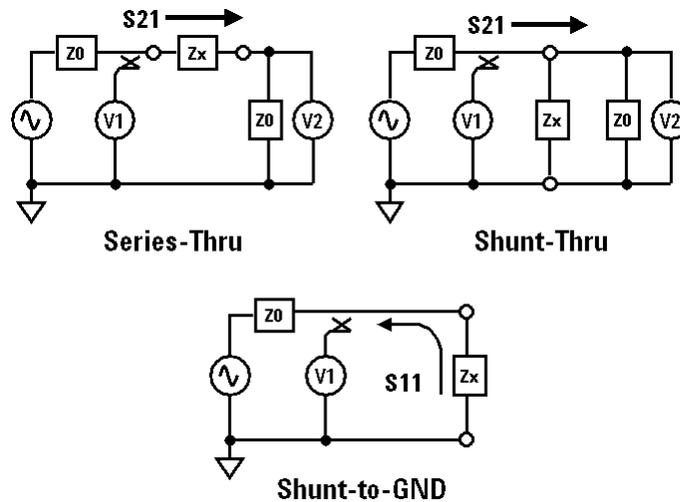


Figure 5. Connection models

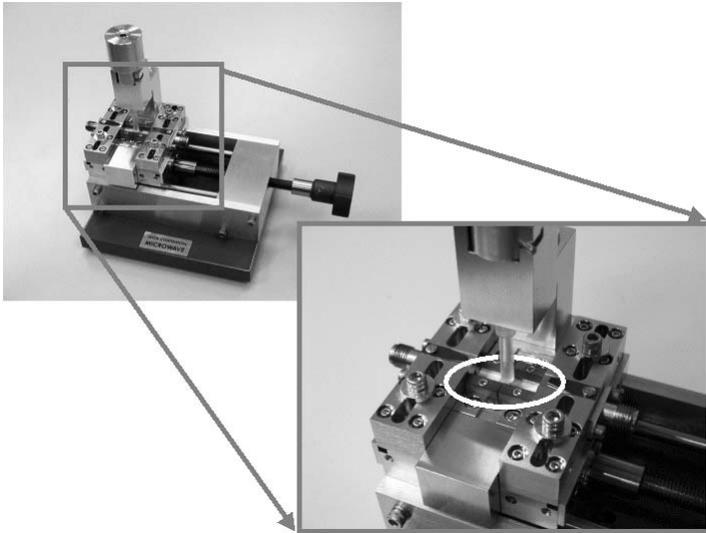
In general, the Series-Thru connection model is suitable for high-impedance measurement, while the Shunt-Thru connection model is suitable for low impedance measurement. The Shunt-to-GND connection model is better suited for impedance measurement close to  $50 \Omega$ .

## Evaluation procedure of SMD

The SMD capacitor (1 pF, size 1005 mm/0402 inch) is measured by using the Series-Thru connection model.

The TF-3000 Series provides three kinds of mid-section adapters: Series-Thru, Shunt-Thru, and Shunt-to-GND (refer to Figure 4). Also, the TF-3000 Series can be adapted for various kinds of DUT sizes by changing the specialized midsection adapter. Furthermore, changing the midsection does not require re-calibration, so this feature drastically reduces additional engineering work.

Before measuring the SMD, the positioning of the test fixture needs to be adjusted. The midsection of the TF-3000 Series holds the SMD with a push rod (white circle in Figure 6 inset). If this positioning is not adjusted properly, the contact between the device and the fixture's electrode becomes unstable, which may cause scattered measurement results.



**Figure 6. Midsection adapter**

In this evaluation, the 1005 mm/0402 inch shorting device provided by Agilent (P/N: 16191-29005) is used to confirm the contact condition between the device and the test fixture's electrode.

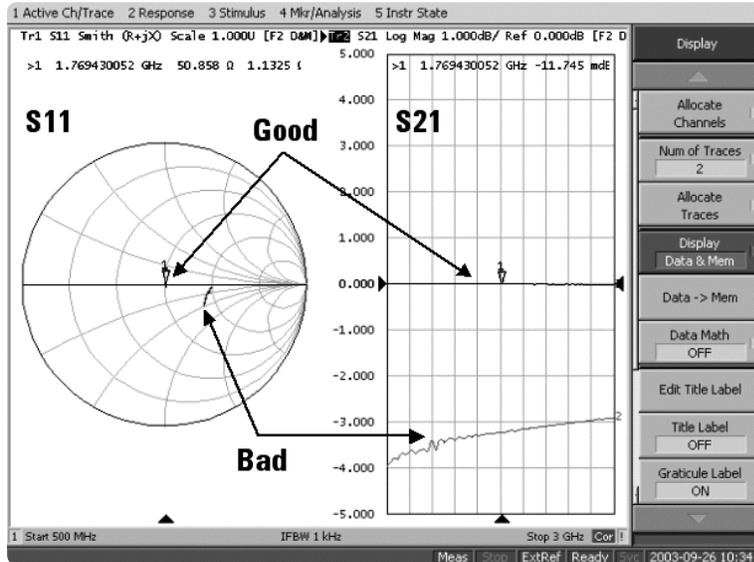


Figure 7. Confirmation of device contact condition

Figure 7 shows examples of both good (dark color) and bad (light color) contact conditions. Here, a shorting device is measured with the Series-Thru connection model, so almost the same results as a transmission line measurement can be obtained. If the device contact is poor, transmission loss becomes large and impedance is away from 50  $\Omega$ .

In the next step, the SMD capacitor is measured. As shown in Figure 8, when the capacitor is measured with the Series-Thru connection model, impedance of the capacitor becomes high in the low-frequency range and the transmission signal is attenuated. As a result, the Smith chart indicates the open condition. On the other hand, in the high-frequency range, impedance of the capacitor becomes low and the transmission signal is not attenuated. Consequently, the port impedance value comes near 50  $\Omega$  and the measurement trace moves to the center of the Smith chart.

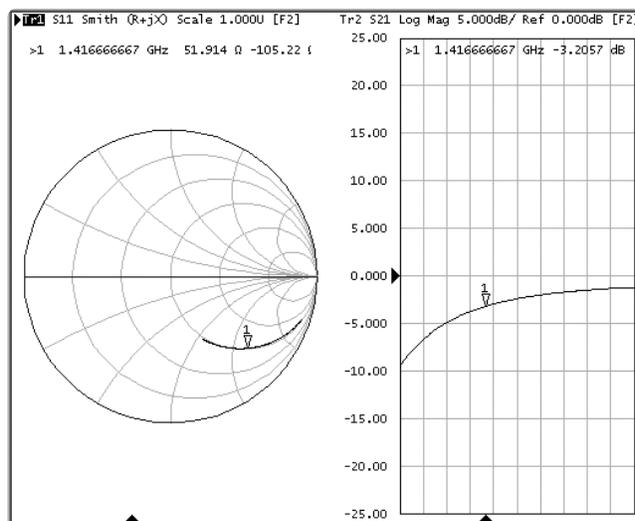


Figure 8. SMD capacitor measurement (1pF, size 1005 mm/0402 inch)

This process is very important for confirming whether the measurement of the device can be done precisely while giving consideration to the behavior of the device; furthermore, it is a key step in performing accurate measurements.

After confirming the measurement result, impedance parameters can be extracted by using the impedance parameter display software.

## Measurement using the impedance parameter display software

Launch the impedance parameter display software and select the Series-Thru connection model from the [Z Conversion] menu. Then choose the measurement parameters from the [Meas Parameter] menu. The impedance measurement can be performed by pushing the “Measure” button in the [Measure] menu. If repeatable measurement is required, enable the “Repeat” check box at the right side of the “Measure” button. Figure 9 shows the measurement results for an SMD capacitor using the impedance parameter display software.

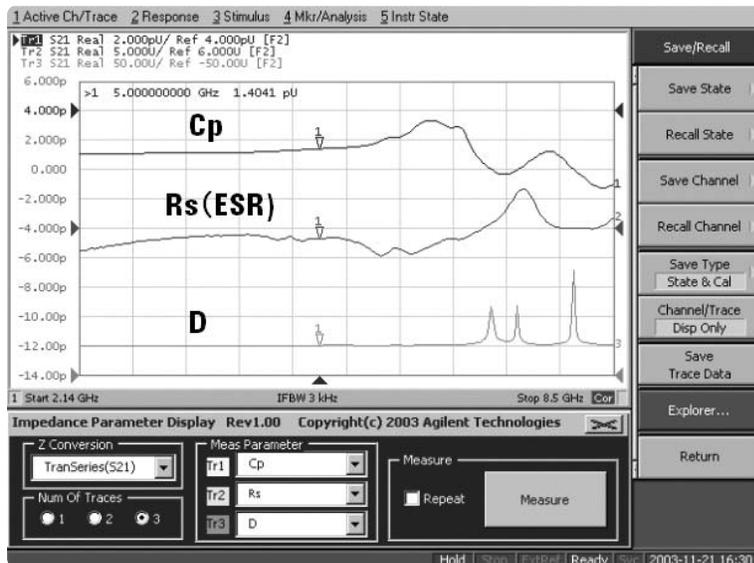


Figure 9. Measurement results of SMD capacitor using impedance parameter display software

In this example, common parameters of capacitor evaluation, such as Cp, ESR, and D, are measured up to 8.5 GHz. The measurement result for the device varies with the connection model of the test fixture, depending on whether it's Series-Thru, Shunt-Thru, or Shunt-to-GND. Therefore, it is important to define not only the instrument used but also the test fixture's connection model when comparing the measurement values of devices.

## Conclusions

This application note describes the SMD measurement procedure by using the ENA RF network analyzer with the ICM test fixture. The TRL calibration and actual SMD measurement procedures are also explained. We hope this application note is useful for engineers as they evaluate RF components using the ENA with ICM test fixtures.

## References

*ENA 2, 3 and 4 Port RF Network Analyzers*,  
Product overview, Literature number 5988-3765EN

*Advanced Impedance Measurement Capability of the RF I-V Method  
Compared to the Network Analysis Method, Application Note 1369-2*,  
Literature number 5988-0728EN

## Ordering Information

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## Web Resources

Get the information on ENA Series and impedance parameter display software:  
[www.agilent.com/find/ena](http://www.agilent.com/find/ena)

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