Agilent Accurate Impedance Measurement with Cascade Microtech Probe System

Application Note 1369-3

1. Introduction

More ICs or circuit modules are used in electronic circuits to save spaces, more capacitors or inductors, such as thin dielectric layers and pattern inductors, tend to be developed on wafer or substrate. These devices usually have a small capacitance or inductance like pF, nH range. The Agilent E4991A RF Impedance/ Material Analyzer and Agilent 4294A Precision Impedance Analyzer have a wide impedance coverage as well as a good accuracy and offer an accurate on-wafer or micro-component impedance measurement solution with probe stations. In this application note, details of installation and calibration methods are discussed.

2. 1-Port Impedance Measurement Application using Probe Station

Table 2-1 shows major 1-port impedance measurement applications. Capacitance or inductance needs to be evaluated in these applications. In many cases, the wide impedance coverage and the good accuracy are required to make these measurements. Agilent impedance analyzer series with a probe station can provide very good performances for these applications. Agilent has two impedance analyzers that cover different frequency ranges. Each solution is discussed from next chapter.

Table 2-1. 1-Port Impedance Measurement Application using Probe Station

Application	Parameter	Final product	Frequency	Measurement requirement
Spiral inductor	L, Q	RFIC for mobile phone	GHz	- Low inductance (nH range) - High Q
IC package	C, L	IC package	GHz	- Low inductance (nH range) - Low capacitance (pF range)
Transistor diode	C	CMOS FET Pin diode Transistor/diode for optical	MHz, GHz	- C-V measurement
Memory	C, D	FRAM, DRAM, SRAM	MHz, GHz	- Low capacitance (pF)
Loop inductors of circuit pattern, stray capacitance of circuit patterns	L, C	High-speed digital	GHz	- Low inductance (nH range) - Low capacitance (pF range)
Dielectric material	C, D	Thin film layer, PC board	MHz, GHz	- Wide impedance range - Low-loss
Disk head	L, Q	GMR head, magnetic head	MHz, GHz	- Low inductance

3. RF Measurement Solution with Agilent E4991A (1 MHz - 3 GHz)

3.1. Theory

The E4991A employs an RF I-V method as a measurement technique, which allows us to do accurate and wide impedance measurements up to 3 GHz. Figure 3-1 shows the simplified block diagram of the theory. Impedance of a device under test (DUT) is derived from measured voltage and current values.

The current that flows through DUT is calculated from the voltage measurement across a known low value resistor(R). In practice, a low loss transformer is used in place of the low loss resistor. Refer to "Impedance Measurement Handbook, 2nd Edition" (P/N 5950-3000) for more details.

Besides the measurement theory, the E4991A has an unique receiver configuration, in order to increase a temperature stability. The E4991A's 2 voltmeters are switched each other, and the voltage and current data are always measured twice by switching voltmeters (See figure 3-2). With it, the tracking error of vector voltage measurements are cancelled out. This enables us to minimize the temperature drifts of measurement circuits.

Figure 3-1. RF I-V Method

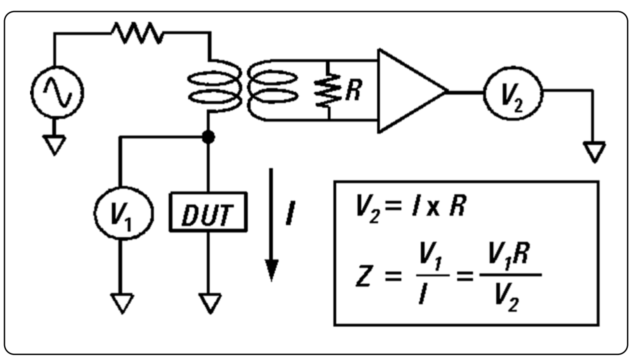


Figure 3-2. E4991A's Receiver Configuration

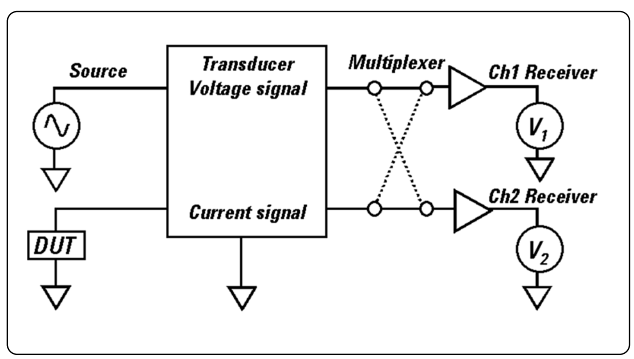
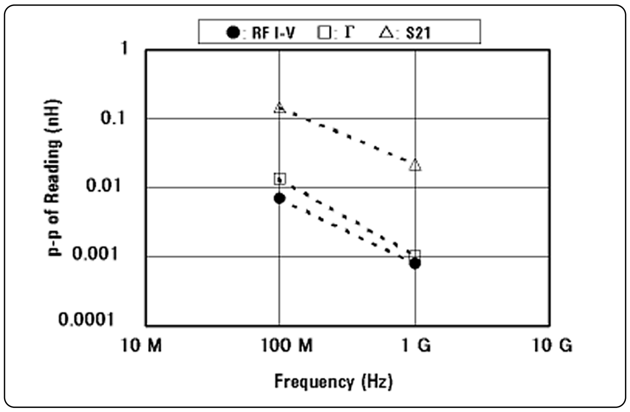


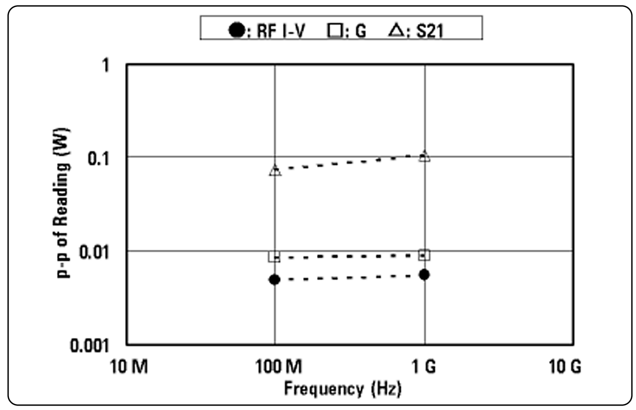
Figure 3-3 and 3-4 shows impedance measurement comparisons between the E4991A and a network analyzer. Figure 3-3 shows the repeatability for 1nH measurements. Figure 3-4 shows the stability over temperature. The RF I-V is more repeatable over time and is stable over temperature. In general, impedance analyzers can provide wider impedance coverage than network analyzers. 1 nH inductor over 100 MHz has a very small impedance, so the wide impedance measurement capability is required.

For more details about the comparison between impedance analyzers and network analyzers, refer Agilent E4991A application note 1369-2 (P/N5988-0728EN).

Figure 3-3. Repeatability of 1nH Measurement

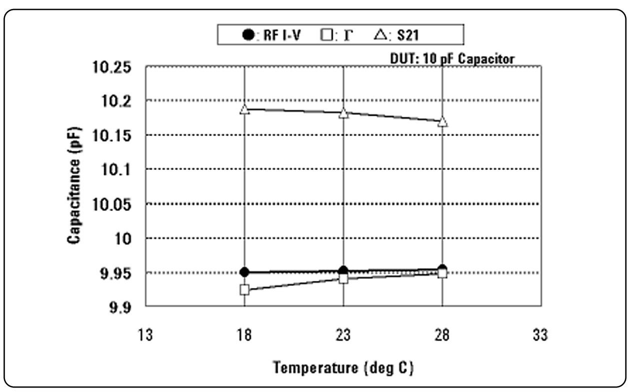


(a) Inductance Variance (p-p)

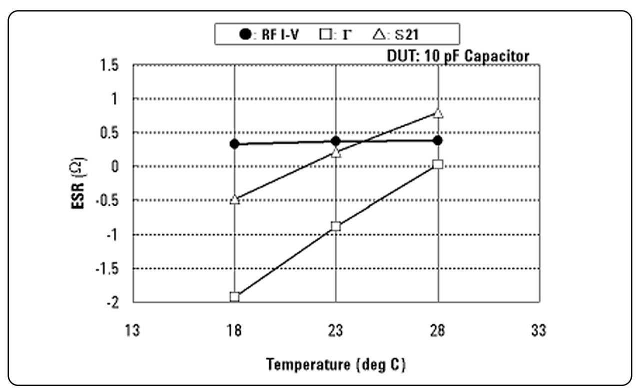


(b) ESR Variance (p-p)

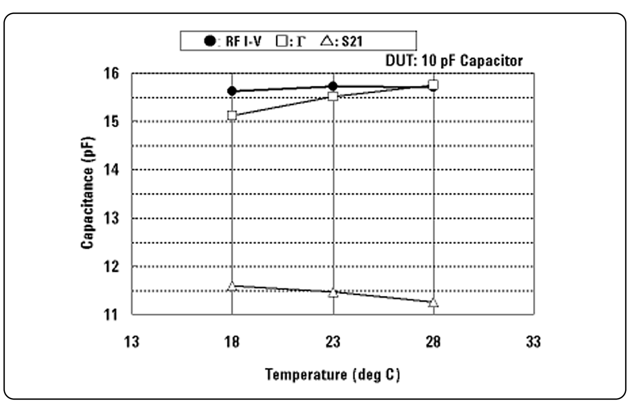
Figure 3-4. Repeatability Over Temperature



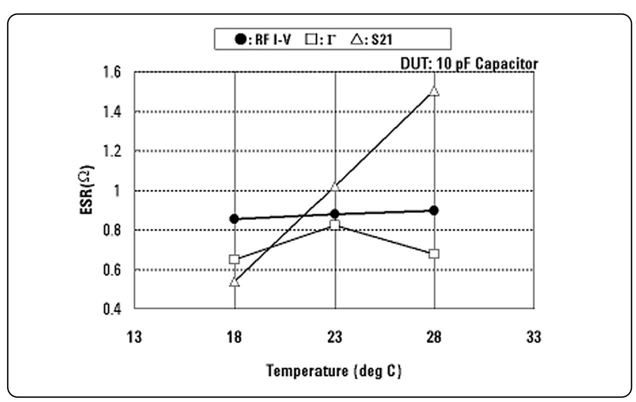
(a) Capacitance (100MHz)



(b) ESR (100MHz)



(c) Capacitance (1GHz)



(d) ESR (1GHz)

3.2. Preparation

Following items are necessary to set up the probe measurement system.

1) Agilent E4991A with option 010 Probe Station Connection Kit (See table 3-1)
2) Cascade Microtech Probe Station, Probe Head, Impedance Standard Substrate (See table 3-2)

The E4991A option 010 makes easier to establish the system. Detailed installation instruction is also included in the E4991A Operation Manual.

This combination is carefully evaluated both by Agilent Technologies and Cascade Microtech. Cascade Microtech products listed in table 3-2 need to be purchased from Cascade Microtech.

Table 3-1. Agilent Products Required for E4991A System

Item	Description	Remarks
E4991A	RF impedance/material analyzer	
Option 010	Probe station connection kit	It includes: - Small test head (1 ea.) - 1 m cable (1 ea.) - N(m)-SMA(f) adapter (3 ea.) - 3.5 mm – 7 mm adapter (1 ea.) - Screw (4 ea.) - Washer (4 ea.)

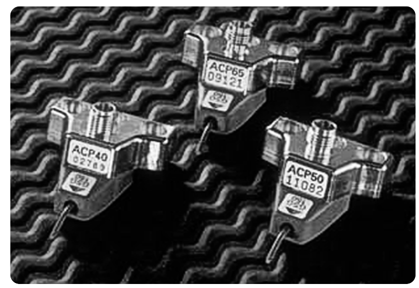


Table 3-2. Cascade Microtech Products Required for E4991A System

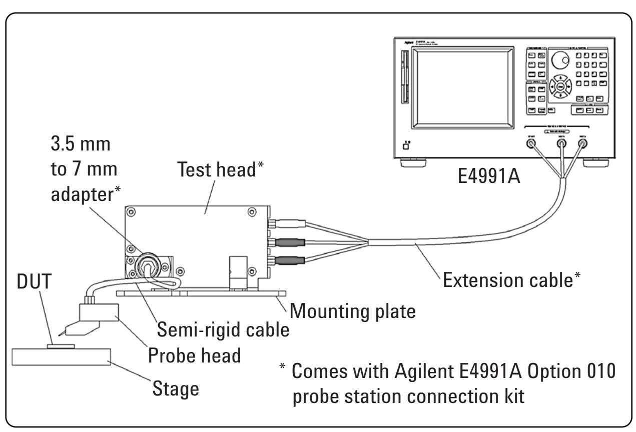
Item	Model	Remarks
Probe station	Cascade Microtech Summit 9000 or 11000 or 12000 series	
Probe head	Cascade Microtech ACP series ACP40-GS ACP40-SG ACP40-GSG HPC series HPC40-GSG	Frequency Range:DC – 40 GHz ACP series probe pitch: 50 – 1250 µm (Standard: 100,125,150, 200, 250 µm) HPC series probe pitch: 100, 125, 150, µm (Standard: 100, 150 µm)
ISS	Impedance standard substrate	
Other required parts	Mounting plate and Semi-regid cable set	Cascade P/N 123-723 (for Summit 9000) Cascade P/N 123-724 (for Summit 11000/12000)

3.3. System Installation

Figure 3-5 shows the system configuration and its cable connection.

The E4991A's accuracy is guaranteed at the 7mm connector of the E4991A's test head. An extension cable needs to be used to connect the E4991A's test head to a probe head. The length of the cable should be as short as possible, because this cable can be an error source for the entire system. The test head of the E4991A option 010 is small enough for you to bring closer to the probe head, so the extension cable length can be easily minimized.

Figure 3-5. E4991A with Option 010 Probe Station Connection Kit



3.4. Calibration

The open/short/load calibration needs to be done at the tip of the Cascade's probe head using the Cascade's ISS (Impedance Standard Substrate).

Before doing the calibration, calibration kit values need to be entered in the E4991A. This enables you to make more accurate calibration. The calibration kit value is provided from Cascade Microtech together with probe heads. The E4991A's calibration kit entering menu is found under the calibration menu hardkey.

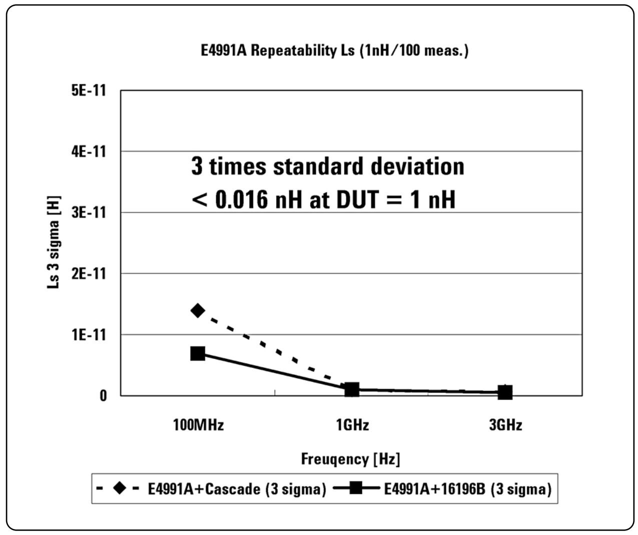
For calibration points, the E4991A has 2 different modes. One is "FIXED Cal" mode, which measures calibration data at the pre-specified frequency points and the calibration is effective at any other frequency points using interpolation technique. The another mode is "USER Cal", which measures calibration data at the frequency points you actually set. In this case, you can make accurate measurements, but calibration need to be done again if the frequency is changed. For probe measurement, the "USER Cal" is recommended to completely remove residual impedance of extension cable and probe head.

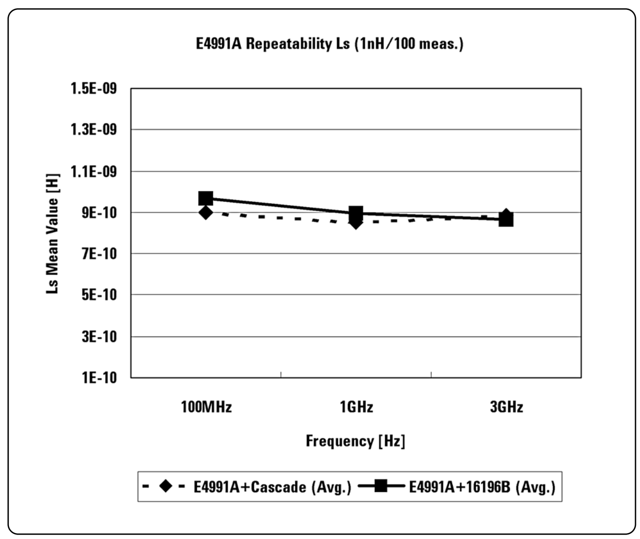
3.5. Measurement Result

Measurement results are shown in figure 3-6. 1 nH SMD inductor is measured as DUT using 2 different test fixtures. One is Cascade probe, and the another is Agilent 16196B SMD test fixture. Agilent 16196B is a test fixture for SMD components and is considered as the most reliable test fixture for SMD. The purpose of this measurement is mainly to see how much error we have due to the cable extension. So, we'd like to compare these 2 test fixture results.

Looking at figure 3-6, both results have very good correlation and the deviation from mean value is only 0.016 nH (3 times standard deviation) for 1nH measurement. This is a very good result for such a small inductance measurement.

Figure 3-6. Agilent E4991A Measurement Result with Cascade Probe





Agilent E4991A Setting	
DUT:	1 nH Inductor
Osc Level:	100 mV
Point Averaging:	8
Calibration:	open/short/load calibration (User Freq&Pwr)
Measurement:	100 meas./point

SMD Test Fixture	
	Agilent 16196B SMD Test Fixture

Cascade Microtech Probe Station	
Probe Head:	ACP40-GS 900 µm pitch
Calibration Standard:	Impedance Standard Substrate

4. LF/HF Measurement Solution with Agilent 4294A (40 Hz - 110 MHz)

4.1. Theory

The 4294A employs the auto-balancing-bridge method as a measurement technique, which provides the best accuracy for impedance measurements up to 110 MHz. Figure 4-1 shows the simplified block diagram. The current, flowing through the DUT, also flows through resister R_1. The potential at the “Low” point is maintained at zero volts (thus called a “virtual ground”), because the current through R_1 balances with the DUT current by operation of the I-V converter amplifier. The DUT impedance is calculated using voltage measurement at High terminal and that across R_1.

To increase the measurement accuracy, the auto-balancing-bridge is used with the 4-Terminal Pair configuration cabling technique as shown in figure 4-2. When connecting DUT to the 4294A, there are 2 important points that need to be aware.

1) At the cable ends, outer conductors (guard) of four cables need to be connected together to have a return path of measurement current. It is much better if this connection point is as close to DUT as possible, because in this way we can maximize a benefit of 4-Terminal Pair cabling technique.

2) The whole measurement system should be floated from the actual ground level. This is very important to have the auto-balancing-bridge work properly.

For more details about the measurement theory, refer to “Impedance Measurement Handbook, 2nd Edition” (P/N 5950-3000).

Figure 4-1. Auto-Balancing-Bridge Technique

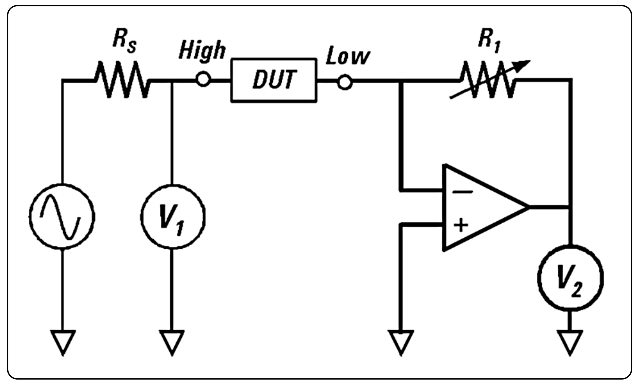
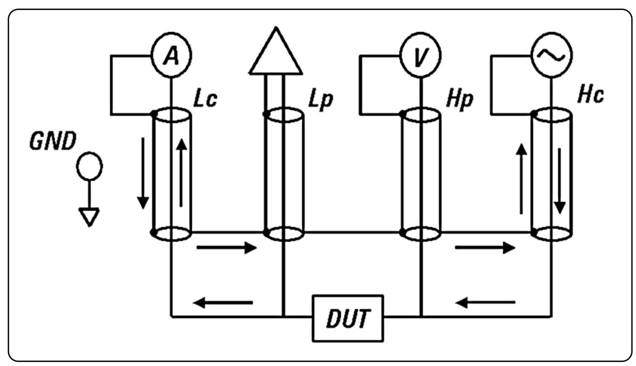


Figure 4-2. Measurement Circuit with 4-Terminal Pair Cabling Technique



4.2. Preparation

The following items are necessary to set up the probe system.

1) Agilent 4294A Precision Impedance Analyzer with 16048G or H Test Leads (table 4-1)

2) Cascade Microtech Probe Station, Probe Head and Impedance Standard Substrate (table 4-2)

This combination is carefully evaluated both by Agilent and Cascade Microtech. Cascade Microtech products listed in table 4-2 need to be purchased from Cascade Microtech.

4.3. Installation

The cable connection method is shown in figure 4-3. The actual connection example is shown in figure 4-4. There are 5 steps to be done for better cabling. Follow these steps.

1) Use Agilent 16048G or H cables and connect it to the connecting plate of probe station. Use adapters as shown in figure 4-4(b). Agilent Technologies and Cascade Microtech can provide these adapters.

2) Use additional four short tri-axial cables to extend the ports. These cables are provided from Cascade Microtech. Connect the inner guard of each pair of the cable and maintain the structure of the signal path. This additional tri-axial cables should be as short as possible.

3) Connect four tri-axial cables to probe heads. 2 tri-axial cables are connected to the probe's high terminal and others are connected to the probe's low terminal.

4) Connect high and low guards together at probe head (shown as (A) in figure 4-4) .

Table 4-1. Agilent Products Required for 4294A System

Item	Description	Remarks
4294A	Precision impedance analyzer	
16048G or H	Test leads, BNC (1m or 2m)	
Other required parts	BNC(m)-BNC(m) adapter (4 each)	Agilent P/N 1250-0216

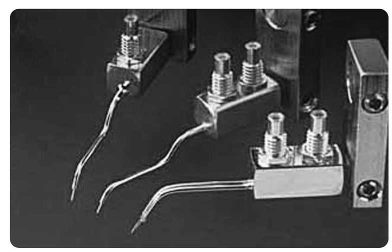


Table 4-2. Cascade Microtech Products Required for 4294A System

Item	Model	Remarks
Probe station	Cascade Microtech Summet 9000 or 11000 or 12000 series	
Probe head	Cascade Microtech DCP-100 series or DCP-HTR series	Frequency range: DC – 100MHz Probe type: Single-tip or dual-tip (Kelvin)
Other required parts	Tri-axial cables (4 each) Tri-axial BNC(m) – BNC(f) adapter (4 each) Shielded cable (1 each)	Cascade P/N 104-330-LC Cascade P/N 103-837 Cascade P/N 123-625

Figure 4-5 shows 2 different contact methods. If you measure the impedance smaller than 100 Ω, the 4-Terminal contact (Kelvin contact) is recommended. Cascade Microtech provides 2 different probe heads for this purpose. “Single-tip” is for 2-Terminal contact and “Dual-tip” is for Kelvin contact. For the measurement, you need 2 probe heads for high and low terminals.

If you don’t measure a high impedance and the current is not very small, four BNC cables can be used instead of four tri-axial cables. Even in this case, the cable connection theory is same as above.

Figure 4-3. Cable Connection

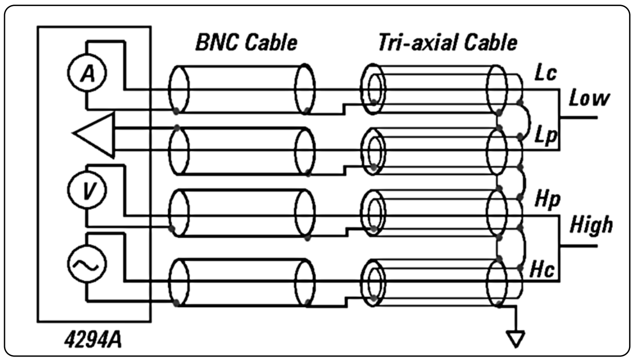
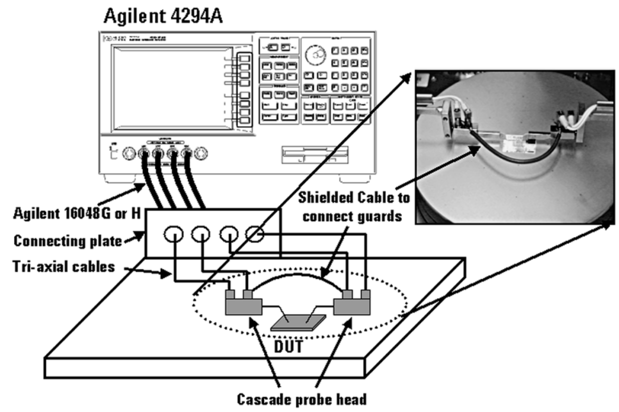
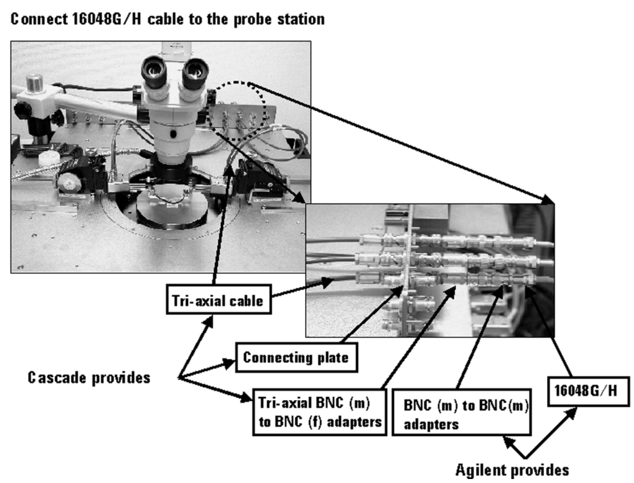


Figure 4-4. Actual Cabling Example

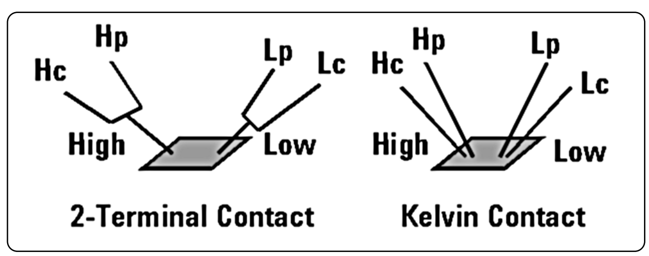


(a) Agilent 4294A System



(b) Cable Connection Example

Figure 4-5. 2-Terminal and Kelvin contact



4.4. Cable Correction

When using extension cable with the 4294A, the cable correction (adapter setup) needs to be done before the measurement. This makes the 4294A possible to make the circuit balanced with the extension cable up to 110 MHz. Perform the phase compensation mentioned in the “Adapter Setup” section of the 4294A operation manual.

1) Go to “Adapter” menu and choose cable length from either 1 m or 2 m. Choose closer length to your total cable length including Agilent cable and additional extension cable.

2) Connect two low terminals (Lp and Lc) together. If you use the Kelvin contact, do it using the short pad on the ISS in order to connect both low (Lp and Lc) terminals. If you use the 2-Terminal contact, it has been already done in the probe head, so any extra work is not required.

3) Perform the phase compensation.

In the 4294A’s operation manual, the load compensation is also mentioned. But, for this application, it’s not necessary because the load compensation will be performed later.

4.5. Compensation

The open/short/load compensation needs to be done at the tip of the Cascade’s probe head using the Cascade’s ISS.

When doing compensation, it is better to select “Compen Point : User” mode on the 4294A. For compensation, the 4294A has 2 different modes. One is “Compen Point : Fixed” mode, which measures compensation data at the pre-specified frequency points and the compensation is effective at any other frequency points using interpolation technique. The another mode is “Compen Point : User”, which measures compensation data at the frequency points you actually set. In this case, you can make accurate measurements, but compensation need to be done again if the frequency is changed. For probe measurement, the “Compen Point : User” is recommended to completely remove residual impedance of extension cable and probe head.

4.6. Measurement Result

The measurement result is shown in figure 4-6.

1 pF SMD capacitor is measured as DUT using 2 different fixturing techniques as follows: 1) Cascade probe with 1 m extension and Kelvin contact, 2) Agilent 16034G test fixture. The 16034G is a test fixture for SMD components and is considered as the most reliable test fixture for SMD. The purpose of this measurement is mainly to see how much error we have due to the cable extension part. So, we'd like to compare the probe measurement result with the 16034G result.

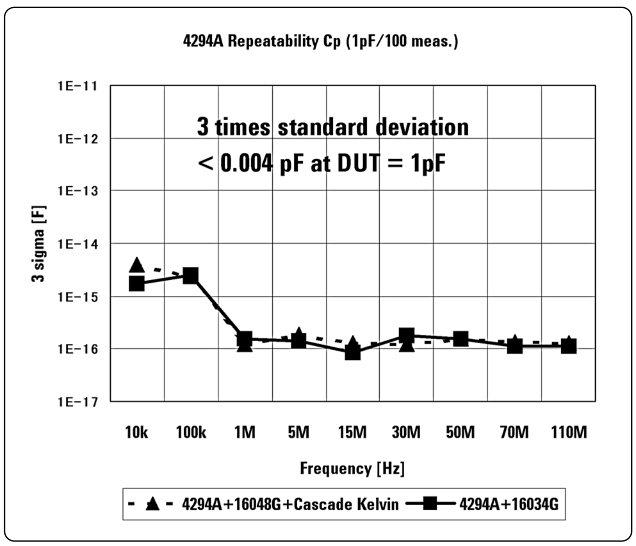
Looking at figure 4-6, the result is considered very good. The Cascade probe setup gives us a very similar result as the SMD test fixture. The mean values have a good correlation and the 3 times standard deviation is less than 0.005 pF for 1 pF measurement.

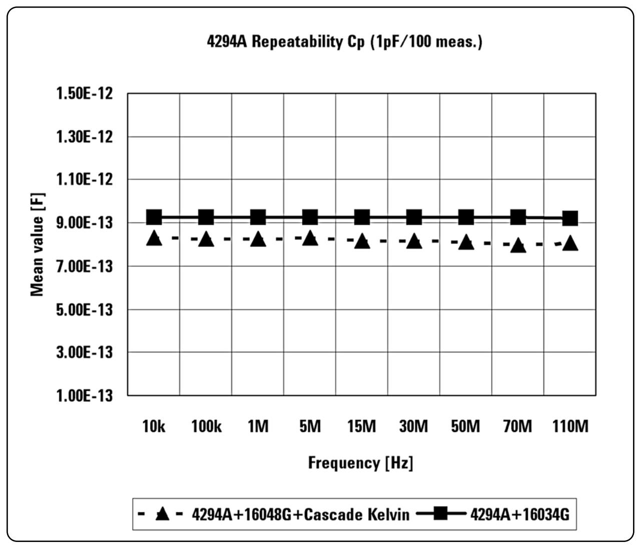
Agilent 4294A Setting	
Osc Level:	500 mV
IFBW:	Precision (5)
Compensation:	open/short/load compensation (Compen point: user)
Measurement:	100 meas./point

SMD Test Fixture	
	Agilent 16034G test fixture

Cascade Microtech Probe Station	
Probe Head:	DCP-100 dual-tip (Kelvin type)
Calibration Standard:	Impedance standard substrate

Figure 4-6. Agilent 4294A Measurement Result with Cascade Probe





5. Summary

In this application note, we discussed about the impedance measurements with probe station, using Agilent E4991A and 4294A. Proper cabling and calibration are very important to configure an optimum measurement system. We hope this note makes it easier for you to establish the measurement system.

References

"Agilent Technologies, Impedance Measurement Handbook, 2nd Edition" (P/N 5950-3000)

Agilent E4991A RF Impedance /Material Analyzer, Product Overview (P/N 5980-1234E)

Agilent E4991A Application Note 1369-2, "Advanced impedance measurement capability of the RF I-V method compared to the network analysis" (P/N 5988-0728EN)

Agilent 4294A Precision Impedance Analyzer, Product Overview (P/N 5968-3808E)

Agilent 4294A Product Note 4294-2, "New Technologies for Accurate Impedance Measurement up to 110MHz" (P/N 5968-4506E)

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

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Taiwan:	(tel) 080-004-7866 (fax) (886-2) 2545-6723
Other Asia Pacific Countries:	(tel) (65) 375-8100 (fax) (65) 836-0252 Email: tm_asia@agilent.com

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