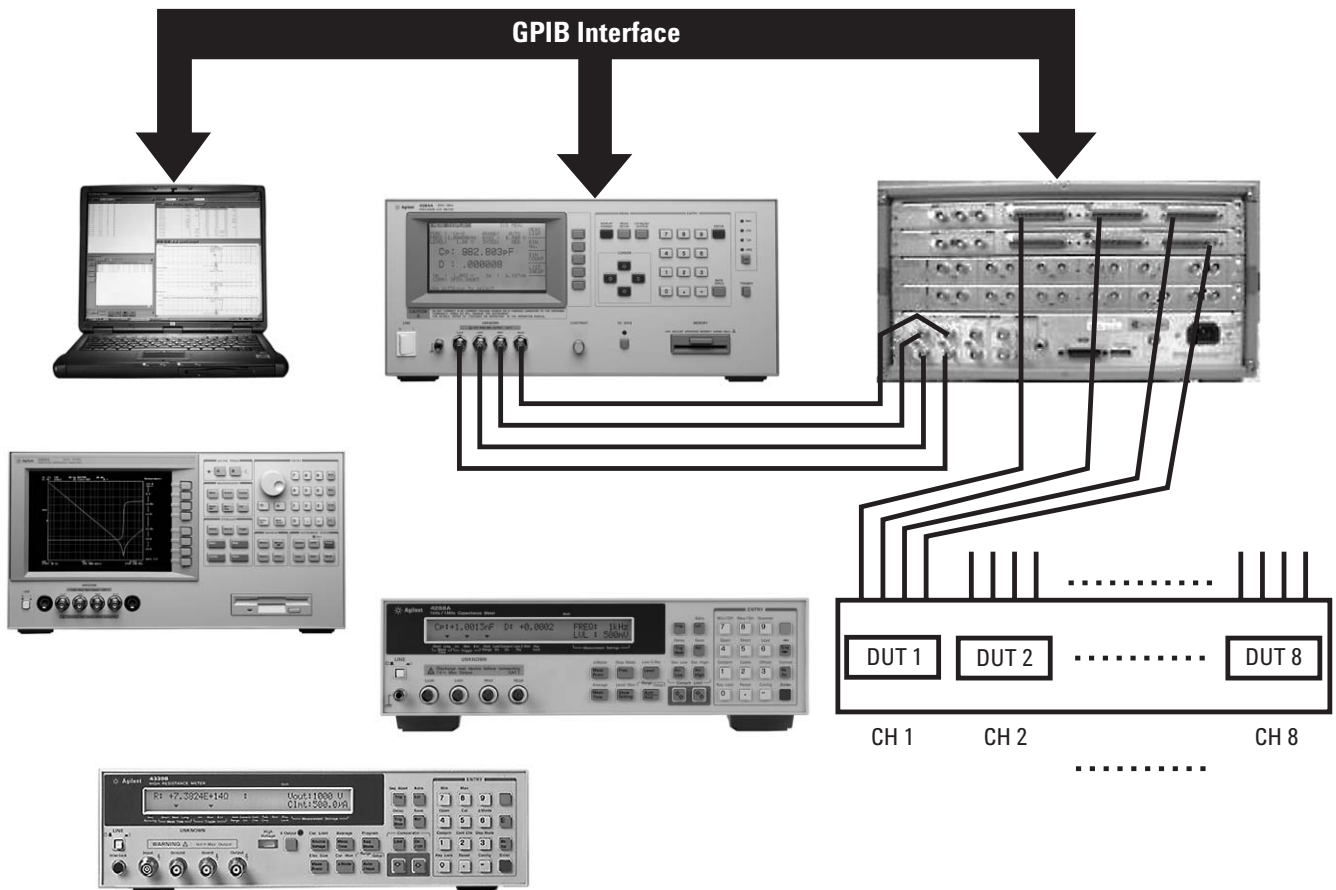


Efficient Impedance Measurement of a Large Amount of Components by Using a Scanning System

Application Note 1369-4



Agilent Technologies

1. Introduction

Today, component manufacturers need higher productivity and component yields in order to supply lower cost products with faster delivery and higher reliability to compete against very tough competition. Consequently, most component manufacturers require impedance testing using a scanner to improve productivity and to control the quality of their products. However, making measurements with a scanner is different from measuring with common test fixtures. It is necessary to reduce the measurement errors due to the residual impedance that exists in the extension cable and the scanner.

This application note describes how to adopt measurement systems using an LF LCR meter and an LF impedance analyzer with a scanner and how to solve problems related to residual impedance, which can occur when using a scanning system. In addition, this note covers actual scanning system examples such as temperature characteristics evaluation and insulation resistance measurement for electronic components.

2. Design of the scanning system

This section initially introduces key points for designing your scanning system. Next, it explains system configurations, special considerations, and solutions devised to deal with these issues.

2.1 Reviewing required specifications

An example of the scanning system is shown in Figure 1. This scanning system allows one measurement instrument to measure many devices under test (DUT) by switching from one to another.

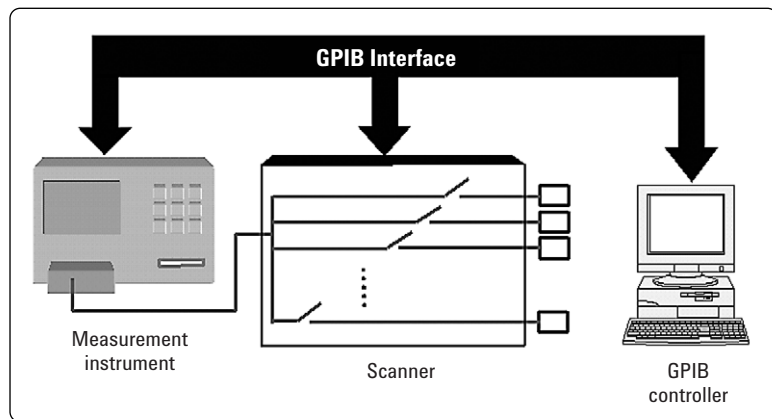


Figure 1. Example of the scanning system

When you design a scanning system, you have to select the scanner and cable configuration. To do this, you should clarify your measurement requirements (specifications) for the system. The specifications to review include measurement accuracy, impedance of the DUT, test frequency, and the number of scanner channels. The required measurement accuracy will determine the maximum residual impedance and stray capacitance allowed in the scanning system. In addition, the measurement value and test frequency requirements are determined by the cable configuration. The number of channels determines the type of scanner you should select.

2.2 Selecting the cable configurations

The cable configuration used for a scanner depends on the impedance value to be measured. As shown in Table 1, two cable configurations are available: the four-terminal pair (4TP) and the shielded two-terminal (2T). Using the 4TP configuration will achieve the highest accuracy over wide impedance and frequency ranges. However, the hardware cost increases because it requires many cables and switches for each measurement channel. On the other hand, the shielded 2T configuration can be used if the impedance of the DUT is larger than 100 ohms and the measurement frequency range is higher than 100 kHz. The shielded 2T configuration allows you to have the maximum number of measurement channels at a lower system cost.

Table 1. Cable configurations

		Measurement frequency range	
		Typically 100 kHz and below	Typically 100 kHz and above
Impedance range	Low impedance (typically 100 ohm and below)	4-terminal pair (4TP)	4-terminal pair (4TP)
	High impedance (typically 100 ohm and above)	4-terminal pair (4TP)	Shielded 2-terminal (2T)

Examples of the 4TP and shielded 2T configurations are shown in Figure 2.

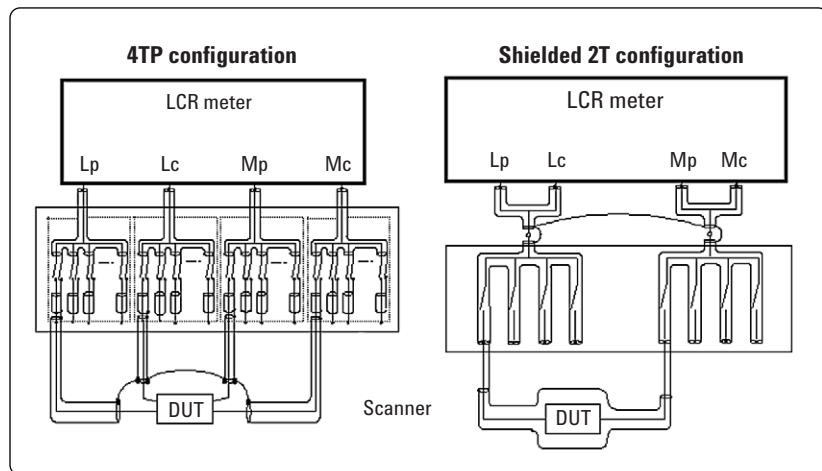


Figure 2. Examples of cable configurations

2.3. Special considerations to in building a scanning system

The following special considerations should be taken into account when you build a scanning system.

- Ensure that the outer conductor (shield) of the test cable and the shield (guard) of the switch are not connected to the ground if you use the auto balancing bridge (ABB) type LCR meters such as the E4980A, 4284A and 4285A. In the ABB method, the return current flows through the shield of the coaxial cable, so if the shield were connected to the ground, the auto balancing bridge circuit would not operate correctly.
- Set both the inner conductor and the outer shield to be switched at the same time when the 4TP configuration is used.
- Keep the 4TP configuration very close to the measurement electrodes in order to minimize the residual impedance and the stray capacitance that exist at the exterior of the shield. This is important because the impedance measurement range of this configuration depends on how strictly you adhere to the 4TP configuration up to the connection point of the DUT. If the cables are not connected properly, the measurement range will be degraded or, in some cases, measurement cannot be made.

2.4. Scanning measurement issues and solutions

Typical issues and solutions are described when a scanning system is used.

Issue 1

A discrepancy in measurement values among channels occurs. The measurement results obtained using a scanner do not always correspond with the values obtained without a scanner because each channel has different electrical characteristics. Even if ideal devices with identical impedance values could be measured at multiple channels, as shown in Figure 3, the measurement result for each channel might be different.

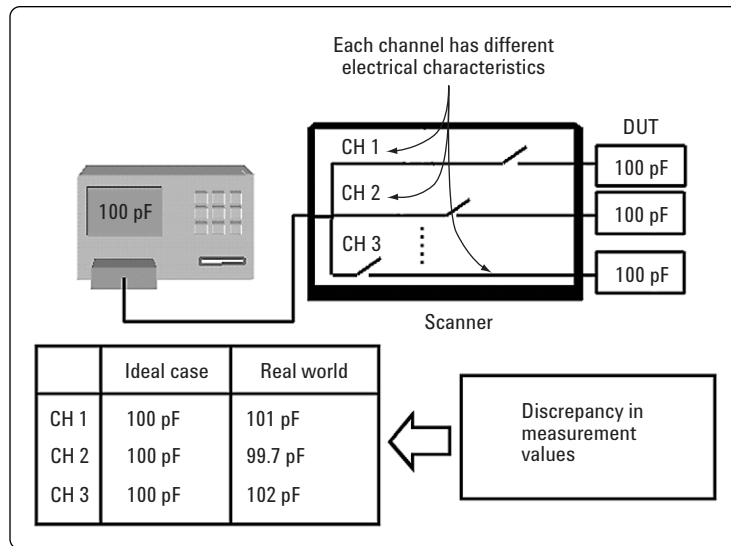


Figure 3. Discrepancy in measurement values

Solution 1

To solve this problem, we recommend using the multi-channel compensation function for the scanning test. The E4980A, 4284A and 4285A can store multi-compensation data to reduce the discrepancy in measurement value among channels. Figure 4 shows the measurement results with and without multi-channel compensation. From these results, the effectiveness of the multi-channel compensation could be confirmed.

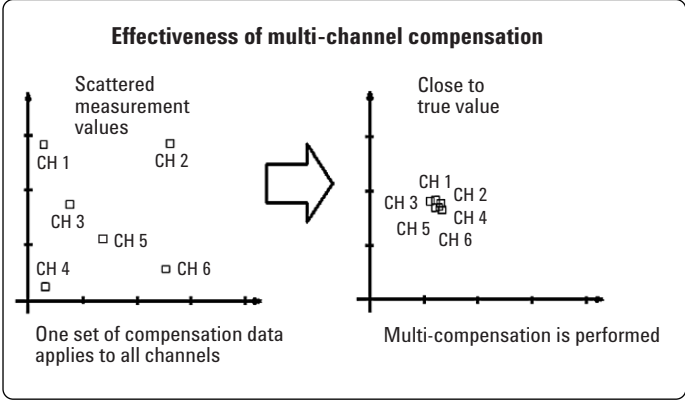


Figure 4. Effectiveness of the multi-channel compensation

Issue 2

The measurement error increases due to the residual impedance and the stray admittance in the scanning system as shown in Figure 5. When the DUT is measured at the end of a long cable in the scanning system, both error factors become very large, and these errors cannot be eliminated even with the open/short compensation.

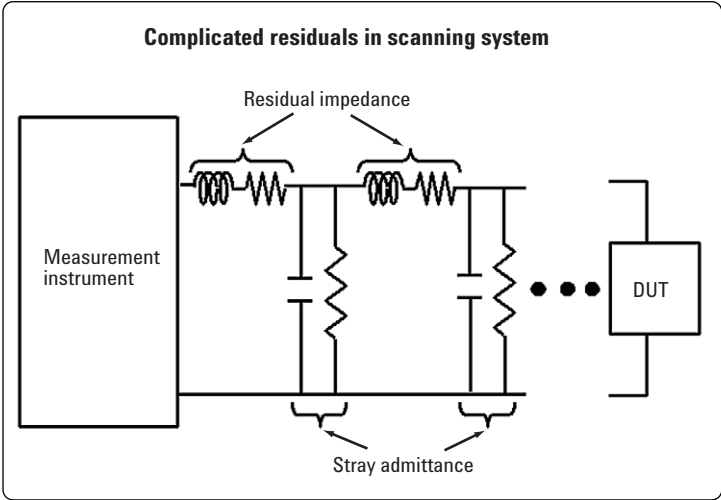


Figure 5. Complicated residuals in scanning system

Solution 2

To solve this problem, we recommend using the open/short/load compensation¹ function for the scanning test. The open/short/load compensation is an advanced compensation technique that is applicable to complicated residuals, but it requires the measurement data of a standard DUT with known values in addition to the open/short measurement data. The residuals of a test fixture, cables or an additional circuit can be defined as a four-terminal network expressed with A, B, C, D parameters. The key point of the open/short/load compensation is to select a load with an impedance value that is accurately known. The criteria of choosing the load are as follows.

- Use an accurately known impedance value of load.
- Use a stable resistor or capacitor as the load device.
- Use a load of the same size and measure it in the same way as the DUT will be measured.

¹ For more information, please refer to the related literature: Impedance Measurement Handbook (P/N: 5950-3000).

To confirm the effectiveness of the open/short/load compensation, a comparison the additional error (typical) among compensation techniques is shown in Figure 6. This figure shows the additional error when a capacitor (47 pF) is measured with the open/short compensation, the open/short/load compensation, and without compensation. These results demonstrate that the open/short/load compensation is effective in reducing errors due to the complicated residuals in the scanning system.

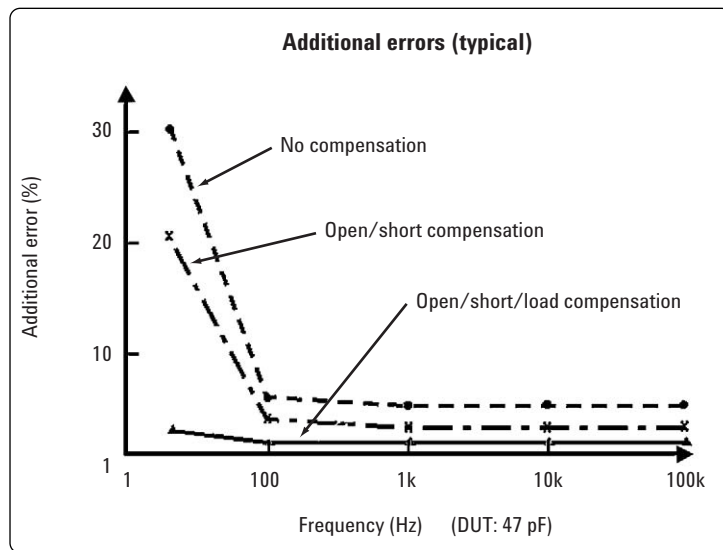


Figure 6. Additional error (typical)

Consequently, almost all error factors can be corrected by using the open/short/load compensation function. However, it cannot zero out the errors if the residuals in the scanning system are too large when the shielded 2T configuration is used. As shown in Figure 5, residuals consist of the series impedance and the parallel admittance that exist in the scanner and the interconnecting cables up to the DUT, and these values should be less than 1/100 of the DUT's value. To find these residual values, directly measure them by measuring with the test fixture terminals open and shorted. If the residuals in your scanning system exceed the limits, try to minimize the residuals by adopting the 4TP configuration, changing the wires to shielded cables, and guarding the test fixture.

3. Building of a Scanning System Using an LCR Meter

This section describes how to build a scanning system using an LCR meter. The instrument selection, cable configuration, and an actual compensation procedure are explained.

3.1. Selection of an LCR meter

Figure 7 shows the LCR meter and scanner lineup that can be provided by Agilent Technologies.

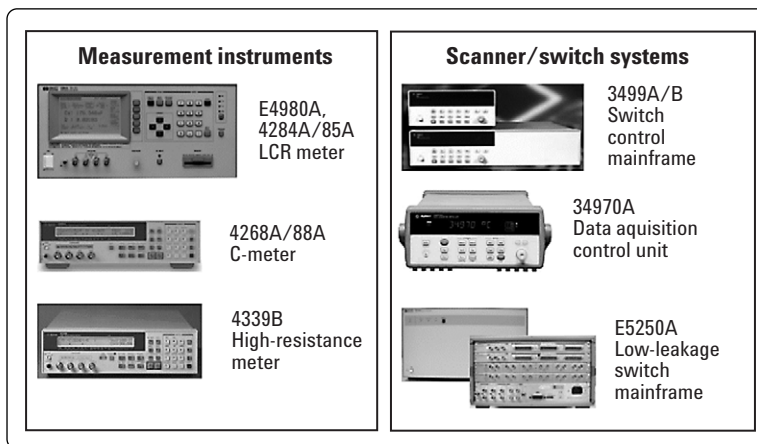


Figure 7. Product lineup for the integration of scanning systems

The E4980A, 4284A/4285A and the 4268A/4288A (C-Meter) provide the scanner interface for easy integration. The scanner interface function of the 4284A (Option 4284A-301) is shown in Figure 8.

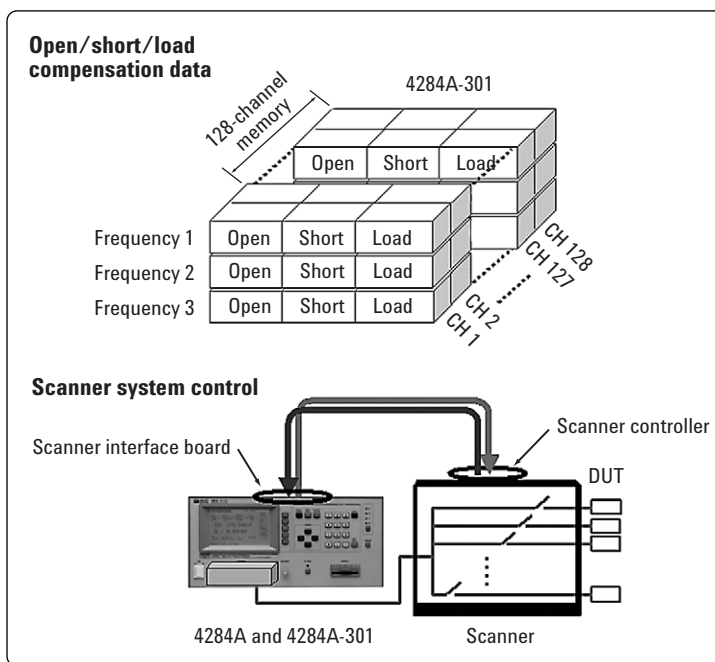


Figure 8. Scanner interface function of the 4284A-301

As shown in this figure, in the case of Option 4284A-301, a complete set of open/short/load correction data can be set for three measurement frequency points per channel, and this correction data can be stored for up to 128 channels. In addition, the scanner interface outputs the measurement end signal to the scanner to achieve synchronization between the 4284A and the scanning system.

Table 2 shows the measurement instruments that have the multi-channel compensation function and the open/short/load compensation function, which are explained in Section 2. Choose the instrument that best fits your measurement needs.

Table 2. Measurement instruments that have the multi-channel open/short/load compensation function

Product number	Scanner interface	Number of channels	Measurement frequency range	Target DUT
E4980A	Option E4980A-301	128	20 Hz to 2 MHz	Electronic component/material
4284A	Option 4284A-301	128	20 Hz to 1 MHz	Electronic component/material
4285A	Option 4285A-301	90	75 kHz to 30 MHz	Electronic component/material
4268A	Option 4268A-001	64	120 Hz/1 kHz	Capacitor
4288A	Standard	64	1 kHz/1 MHz	Capacitor

3.2. Selecting the cable configuration

Two types of cable configurations, the 4TP configuration and the shielded 2T configuration, are available as explained in section 2. In this section, practical examples of scanning system configurations are described by using actual instruments.

Example of a scanning system using the 4TP configuration

Figure 9 shows an example of a scanning system using the 4TP configuration. In this example, an 8-channel scanning system is built by using the GPIB controller, the E4980A or the 4284A (LCR meter), and the E5250A (low-leakage switch mainframe) with the E5255A (multiplexer module (2)). The 16048A is used as the connection cable between the E4980A or the 4284A and the E5250A.

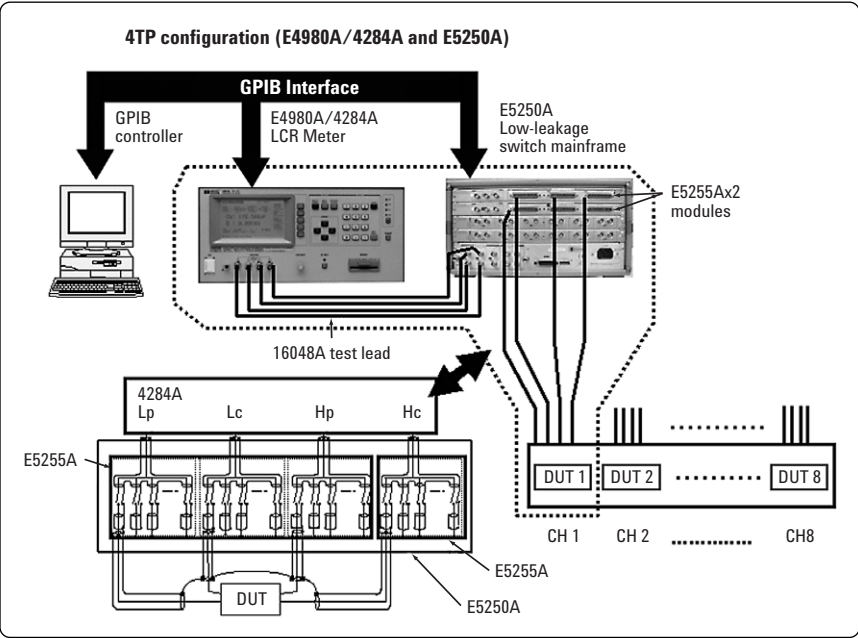


Figure 9. Example of scanning system using 4TP configuration

Example of a scanning system using the shielded 2T configuration

Figure 10 shows an example of the scanning system using the shielded 2T configuration. In this example, a 4-channel scanning system is built by using the GPIB controller, the E4980A or 4284A (LCR meter), and the 3499A (5-slot switch/control mainframe) with 44472A (dual 4-channel switch). The 44472A's shield is isolated from the chassis, so it doesn't influence the operation of the ABB circuit. The 16048A is used as the connection cable, and the transform from the 4TP configuration to the shielded 2T configuration should be done just before the scanning system.

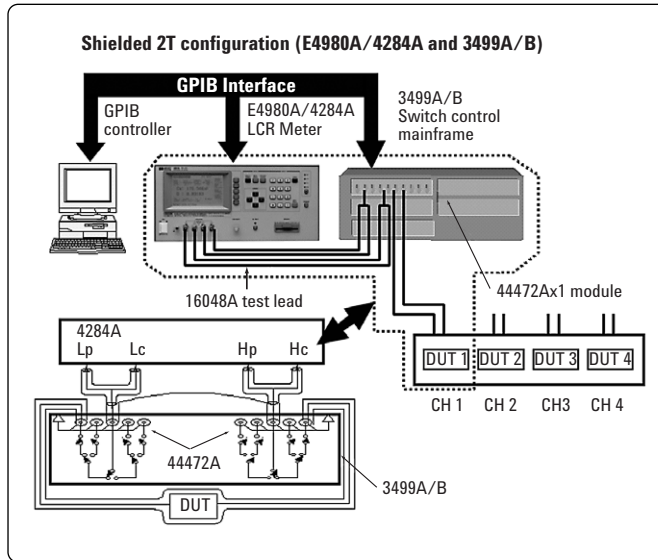


Figure 10. Example of a scanning system using the shielded 2T configuration

3.3. Perform the compensation of the LCR meter

The compensation of the LCR meter is performed by the following procedure.

Step 1: Set the cable length from the cable correction menu. The cable extension function is equipped with the E4980A, the 4284A (with Option 4284A-006) and the 4285A. This function makes the correction plane move to the tip of the extension cable by the user selecting the cable length from the instrument's menu.

Step 2: Perform open/short/load compensation for each channel at the tip of a test fixture. The open compensation is performed while keeping a distance between the test fixture terminals. The short compensation is performed by connecting the test fixture terminals directly together. The load compensation is performed with the load standard DUT. After finishing the open/short/load compensation, the impedance measurement for the multiple channels can be performed.

4. Building of a Scanning System Using an Impedance Analyzer

This section describes how to perform the compensation of a scanning system using the 4294A precision impedance analyzer. For the cable configuration, refer to Section 3.

4.1. Perform the compensation of the 4294A

The 4294A is equipped with a list sweep function that enables 18 different measurement setups in a single sweep by dividing the sweep range into segments. Each segment has open/short/load compensation data, so you can build the scanning system by using the 4294A with the list sweep function. This section describes how to perform multi-channel compensation using the 4294A.

Step 1: Create the segment list from the list sweep function menu as shown in Table 3.

Table 3. List sweep function menu

Segment	Measurement frequency	Measurement points ¹
Segment 1	100 KHz to 200 kHz	20 (1 to 20)
Segment 2	200 KHz to 300 kHz	20 (21 to 40)
Segment 3	300 KHz to 400 kHz	20 (41 to 60)
Segment 4	400 KHz to 500 kHz	20 (61 to 80)

¹ **Note:** Total number of measurement points is limited to 801 points.

Step 2: Set the cable length from the cable correction menu of the 4294A. This makes the correction plane move to the tip of the extension cable. As the extension cable, we recommended that you use the Agilent supplied extension cable (e.g. 16048G/H).

Step 3: Perform phase compensation. The 4294A requires phase compensation when it is used with the extension cable for the first time. Because the phase compensation is common to all channels, perform it only for one channel. The phase compensation should be performed under the condition that Lc and Lp terminals are connected together at the tip of a test fixture.

Step 4: Perform the open/short/load compensation for each channel at the tip of the test fixture. The open compensation is performed while keeping a distance between the test fixture terminals. The short compensation is performed by connecting the test fixture terminals directly together. The load compensation is performed with a load standard DUT.

Step 5: Create a comparison coefficient that corresponds to the scanning system. After calculating the compensation coefficient in Step 4, read out the compensation coefficient array and combine the segments that correspond to individual channels in order to create the scan-aware compensation coefficient. Figure 11 shows a schematic view of creating the scan-aware compensation coefficient. The built-in programming function (I-BASIC) or an external GPIB controller needs to be used for creating a scan-aware compensation coefficient. Extract the compensation coefficient of each segment using the OUTPCOMC command. Read out the part of the compensation coefficient that corresponds to segment 1 into the part of the scan-aware compensation coefficient that corresponds to segment 1. For the other channels, perform a substitute operation from the fixture compensation to the scan-aware compensation coefficient. Finally, write the created compensation coefficient into the 4294A by using the INPUCOMC command to put the scan-aware compensation coefficient into effect.

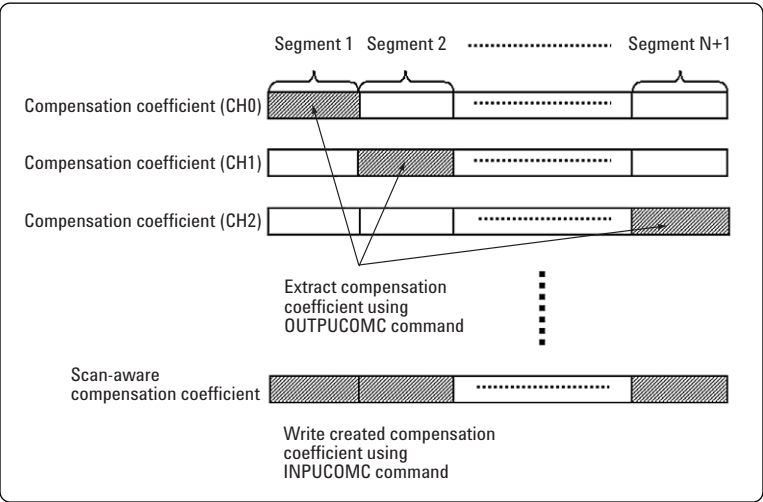


Figure 11 Creating scan-aware compensation coefficient

Step 6: Perform the DUT measurement. Change the sweep range of the manual sweep and the channels and perform impedance measurement for the multiple channels.

For more information on the I-BASIC command, please refer to Chapter 13 (Measuring using scanner) of the 4294A Programming Manual¹.

¹ **Note:** This function is requires firmware rev. 1.10 or later

5. Building a Scanning System for Temperature Characteristics Evaluations

This section describes special considerations for building a scanning system for temperature characteristics evaluations. For the basics of system design and configuration, refer to Sections 3 and 4.

5.1. Special considerations of in building scanning system for the temperature characteristics evaluation

The following special considerations should be taken into account when you build a scanning system.

Figure 12 shows the temperature characteristics evaluation system using the scanner. When the temperature characteristics evaluation is executed, it is very important to remove the error of the measurement path caused by temperature drift.

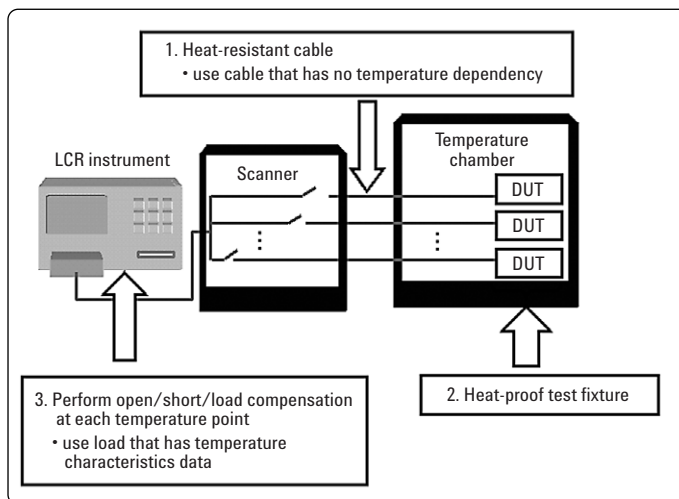


Figure 12. Temperature characteristics evaluation system using scanner and temperature chamber

The following procedure should be used to reduce the influence of temperature drift on measurement accuracy. You can, for example, carry out the temperature characteristics evaluation at three different temperatures (23 °C, 50 °C, and 100 °C) at a fixed measurement frequency by using the 3-channel scanning system. As illustrated in Table 4, the 4284A's scanner interface function and the 4294A's list sweep function can store compensation data corresponding to each temperature, so the temperature drift effect can be minimized at each test channel.

Table 4. Effective memory usage

Memory area	Channel	Temperature
#1 to #3	CH 1 to 3	23 °C
#4 to #6	CH 1 to 3	50 °C
#7 to #9	CH 1 to 3	100 °C

As for the measurement cable and the test fixture, you must confirm the operating temperature range in advance. The operating temperature ranges of test fixtures provided by Agilent Technologies are published in the accessories selection guide¹. This can be used as a reference for your system integration.

¹ For more information, please refer to the related literature: Accessories Selection Guide For Impedance Measurements (P/N: 5965-4792E).

6. Building a Scanning System for Insulation Resistance Measurements

This section describes how to build a scanning system for insulation resistance measurements using the high-resistance meter. The cable configuration, the actual compensation procedure, and special considerations are explained.

6.1. Selecting the cable configuration

For the insulation resistance measurement, the shielded 2T configuration is normally selected. Since the insulation resistance measurement involves high voltage and very small current, it is sensitive to external noise; therefore, a shield is required to protect the measurement system from the external noise. In addition, to make a better shield effect, the triaxial BNC configuration is highly recommended.

Figure 13 shows an example of a system configuration using the shielded 2T configuration. In this example, a 10-channel scanning system is built by using the GPIB controller, the 4339B (high-resistance meter), the E5250A with E5252A (10 x 12 matrix switch module x 2), and the 3499A with N2270A (10-channel multiplexer). In this case, the triaxial BNC configuration is applied to the signal input port in order to improve measurement accuracy while increasing the effectiveness of the shield.

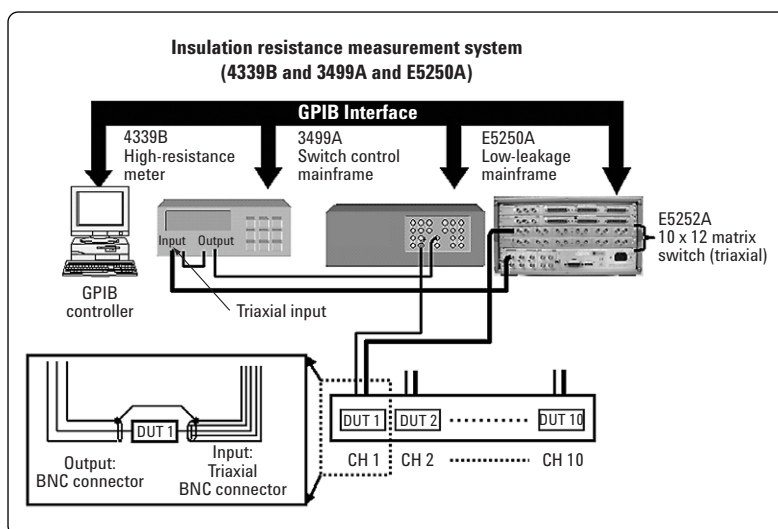


Figure 13 Insulation resistance measurements using the scanning system

6.2. Perform the compensation of the high-resistance meter

The compensation of the high-resistance meter is performed by the following procedure.

Step 1: Maintain constant electrode spacing. The high-resistance meter, which is commonly used, can store only one set of open compensation data, so the contact terminal for each channel should be kept at the same spacing. By keeping the electrode spacing constantly, stable measurement results can be obtained even when using the single set of open compensation data.

Step 2: Perform the open compensation at the tip of a test fixture. The open compensation is performed while keeping the constant distance between the test fixture terminals. After finishing the open/short/load compensation, the impedance measurement for the multiple channels can be performed.

6.3. Special considerations of in building scanning system for insulation resistance measurements

The following special considerations should be taken into account when building a scanning system.

- When executing the insulation resistance measurement using the scanner with the 4339B, the triaxial connector and cable should be used. This is because the 4339B requires the stray capacitance to be lower than 75 pF in the measurement path, but if a BNC-to-triaxial adapter is used at the input port, it will induce additional capacitance.
- When the leakage current of the insulation resistance is measured by using a scanner, the channels other than the tested channel are set to OPEN status, and these are considered to be the insulation resistances. Then, when the DUT's insulation resistance is smaller than the resistance of the scanner relay's OPEN ($> 10^8$ ohm) status, the scanner's OPEN status causes measurement error. In Figure 14, when the leakage current I_{dut1} is measured, the leakage currents ($I_{dut2} + I_{dut3} \dots + I_{dut10}$) through OPEN state channels are added to the I_{dut1} . Therefore, the ammeter measures the sum of I_{dut1} through I_{dut10} , and I_{dut1} cannot be measured correctly.

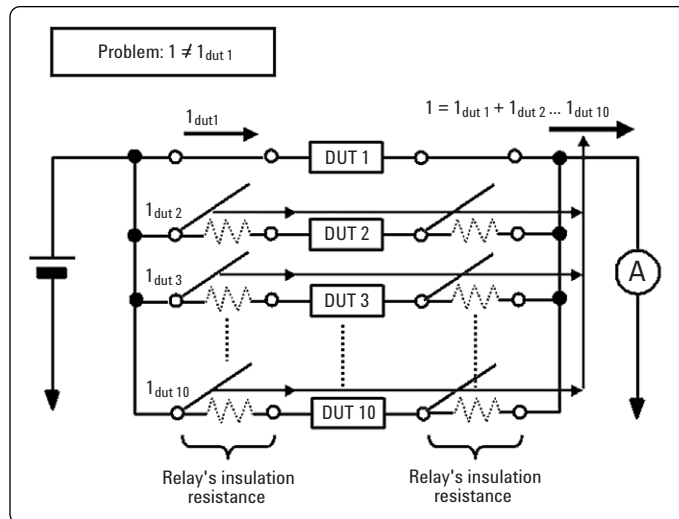


Figure 14. Leakage current in insulation resistance measurement

To solve this problem, a resistor R (typically, 1 Mohm approximately 5 Mohm) must be inserted to absorb the leakage current. Most of the leakage currents of the scanner's OPEN states flow through R, and the ammeter can measure the actual I_{dut1} as shown in Figure 15.

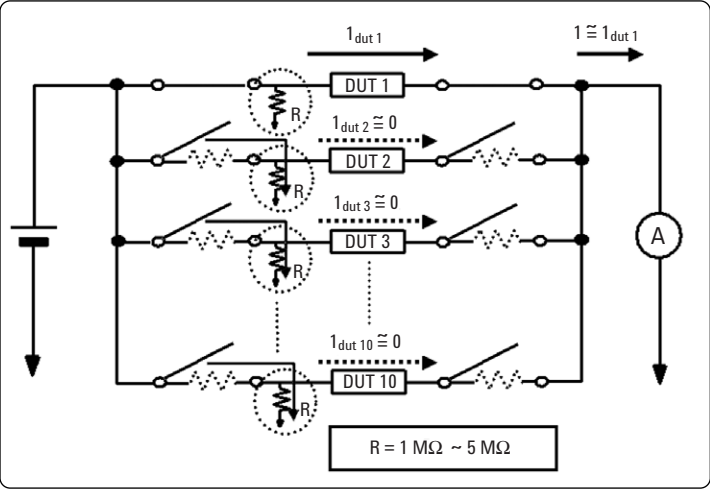


Figure 15 Resistors to absorb leakage current of OPEN status

- The insulation resistance measurement can be easily affected by external noise, which causes unstable measurement results. To make the results stable, we highly recommend that you use a grounded shield case as shown in Figure 16.

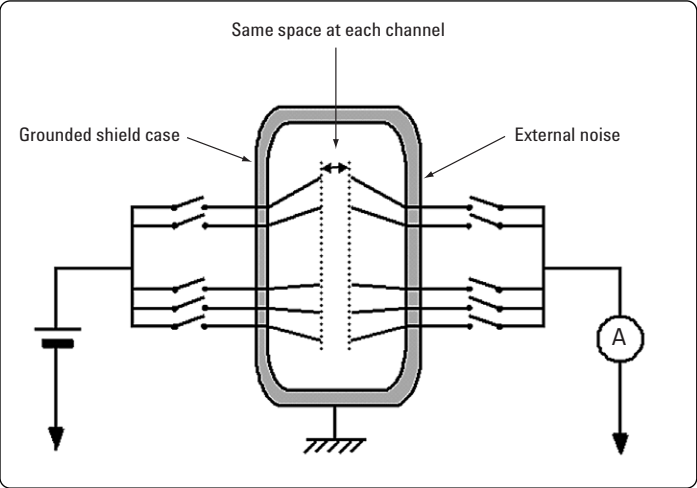


Figure 16. Insulation resistance measurement using the grounded shield case

7. Conclusions

In the production line of electronic components, it has become necessary to carry out multi-channel testing using a scanner to reduce the test time. However, you must carefully consider the system configuration before establishing the scanning system. The Agilent LCR meters and impedance analyzers provide very useful functions, such as the multi-channel open/short/load compensation function and a scanner interface, that enable you to execute efficient testing in the production line.

We hope this application note is helpful for engineers who build scanning systems using our LCR meters or impedance analyzers.

8. Related Literature

Impedance Measurement Handbook (P/N: 5950-3000)

Accessories Selection Guide For Impedance Measurements (P/N: 5965-4792E)

9. Appendix

9.1. Five-terminal (5T) configuration

This section explains the 5T configuration. The 5T configuration is similar to the 4TP configuration since the number of required extension cables is the same, but the switch configuration is different as shown in Figure A-1. The 4TP configuration requires a switch that can cut off both the signal line and the shield. On the other hand, the 5T configuration can use a switch that has a common shield. The 5T configuration has a narrower impedance measurement range than the 4TP configuration.

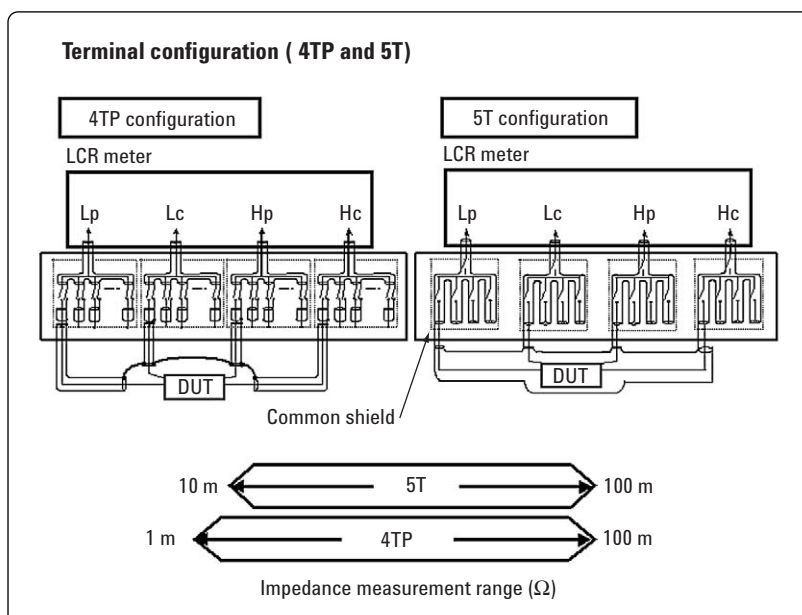


Figure A-1. Terminal configuration and the impedance measurement range

9.2. Information of additional error

Additional error information on the scanning system is given in this section. Please see this information when you build a scanning system.

Additional error when the E4980A or 4284A are used with the E5250A:

Measurement instruments and accessories

E4980A/4284A	Precision LCR meter
16048A	1-m test lead (BNC)
E5250A	Low-leakage switch mainframe
E5250A-501	24-channel (8 x 3) multiplexer
16494E	Wide-temperature 8-ch shielded coaxial cable
16494E-001	Cable length: 1.5 m_Guard capacitance: 125 pF
16034G	SMD test fixture

Measurement conditions

Signal level	500 [mV]
Temperature	25 ±2 °C
Compensation	Cable length 1-m compensation, open/short/load compensation

9. Appendix - continued

The additional error using the above setup conditions is shown in Figure A-2.

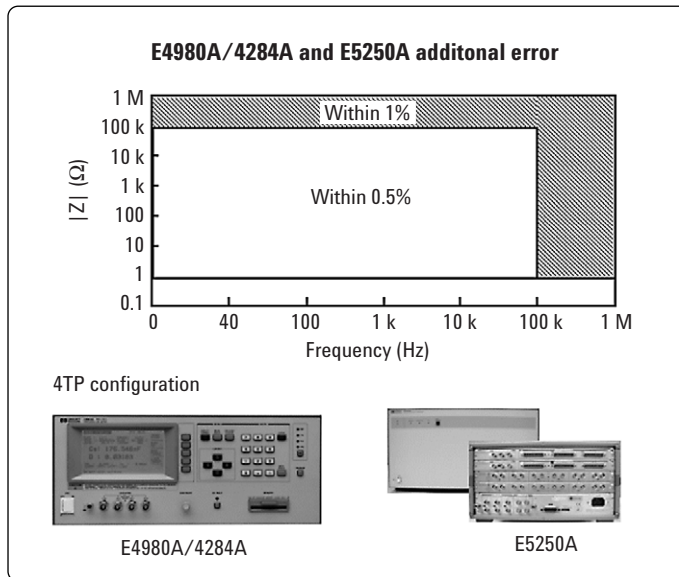


Figure A-2. Additional error (E4980A or 4284A+E5250A)

Additional error when the 4294A is used with the 3499A:

Measurement instruments and accessories

4294A	Precision impedance analyzer
16048G	1-m test lead (BNC)
3499A	5-slot switch control mainframe
44472A	Dual 1x4 VHF multiplexer (300 MHz, 50 Ohm) x 2
	BNC 2.4-m cable x 4
16034G	SMD test fixture

Measurement conditions

Signal level	500 [mV]
Temperature	25 ±2 °C
Compensation	Cable length 1-m compensation, open/short/load compensation

9. Appendix - continued

The additional error using the above setup conditions is shown in Figure A-3.

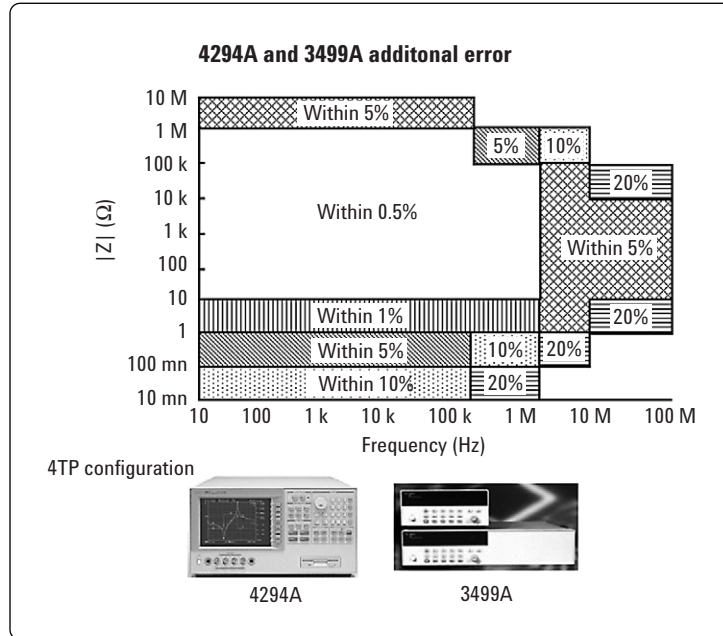


Figure A-3. Additional error (4294A+3499A)



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