Agilent
New Generation Analyzer Offers Exceptional and Powerful Analysis Functions for RF Impedance Measurement

Product Note E4991A-1

Agilent E4991A
RF Impedance/Material Analyzer

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 increasingly important not only for R&D engineers of component manufacturers but also circuit designers of equipment manufacturers. The E4991A RF Impedance/Material Analyzer offers 3 GHz measurement frequency range that covers hot applications such as W-CDMA, *Bluetooth™* and wireless LAN. The E4991A offers impedance measurement capabilities for your needs today and into the future.

This product note describes the following topics.

- **Features of the E4991A**
- **Examples of RF component evaluation**
- **Offering of a more effective test environment**

Features of the E4991A

Highly accurate RF impedance measurement

The E4991A uses the RF I-V technique for highly accurate impedance measurement in the RF frequency range. As figure 1 shows, the E4991A achieves a wider and accurate impedance measurement up to 3 GHz. The RF I-V technique is different from the reflection coefficient method used by a network analyzer. This technique measures voltage and current directly at the DUT (Device Under Test) thus the E4991A can achieve higher and wider impedance measurement range when compared to a network analyzer.

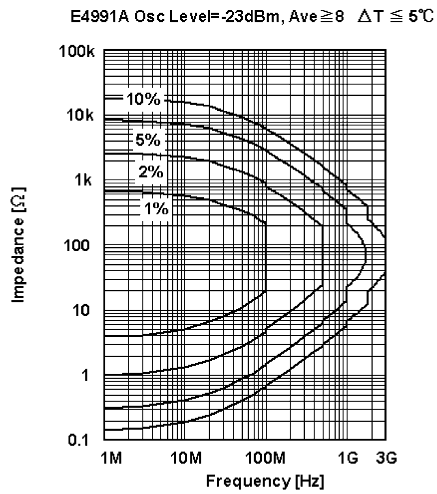


Figure 1. Impedance measurement range

The E4991A can calibrate with the low-loss air capacitor standard in addition to the regular 1-port standards. Using the low-loss air capacitor, phase measurement accuracy is drastically improved, as shown in figure 2, because it can determine a reference to the reactance axis (–90 degrees) in the impedance plane with its near-zero resistance. As a result, the E4991A can measure high Q inductors and low loss capacitors accurately.

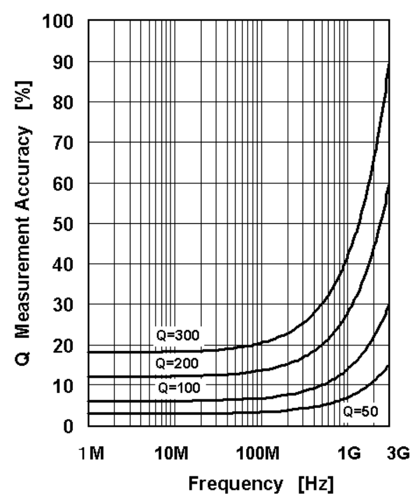


Figure 2. Q Measurement accuracy (Typical)

By using a torque wrench, which is furnished with the standard calibration kit, each standard can be tightened up with a constant torque. This will minimize the engineer's dependency on calibration. In particular, short calibration with the torque wrench brings high repeatability and stability in calibration and in low impedance measurements.

Various sweep functions are available

The E4991A is capable of sweeping in various parameters such as frequency signal level (voltage or current), and DC bias level[1] (voltage or current) in order to evaluate a device behavior under various signal conditions. The level monitor function enables you to monitor the actual signal level applied to the device and therefore, you can apply the appropriate voltage or current to the DUT.

The segment sweep function is also available for improvements in productivity. It can enable a maximum of 16 different measurement setups in a single sweep including frequency range, number of points, averaging factor, DC bias level (voltage or current), and test signal level. With segment sweep, you can avoid the repetition of changing instrument setups when applying various conditions in a wide frequency range.

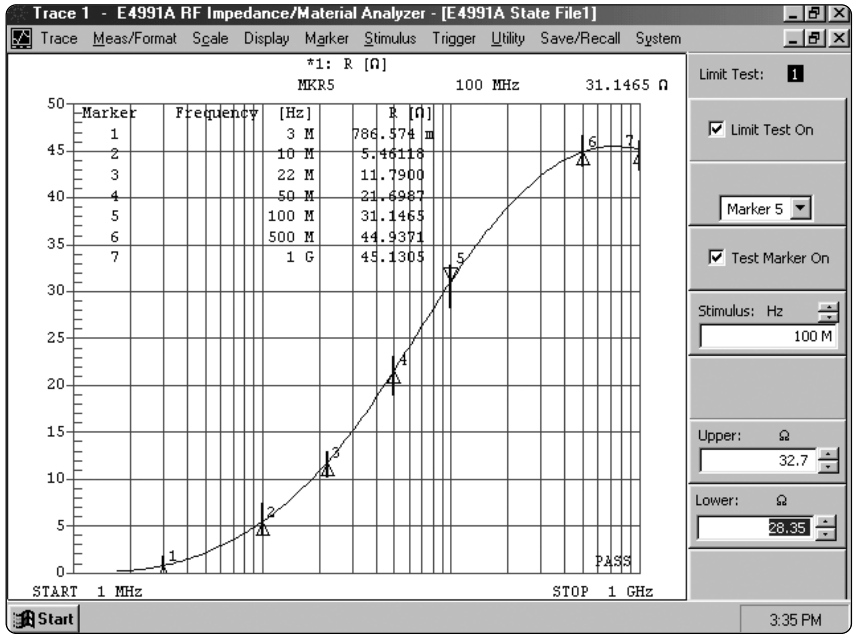


Figure 3. Marker limit function

Marker limit function for effective device selecting

Required performance of mobile communication and digital equipment is becoming stringent, making it necessary for devices used in the circuitry of the equipment to have a higher quality performance. In accordance with this trend, these devices must be selected under strict test conditions.

The marker limit function contributes to an effective device sorting by enabling markers to have an upper and lower limit value for total of 9 markers for each measurement trace. The E4991A automatically selects a device, whether it meets the limit values or not. Test results can be displayed as “Pass” or “Fail” on the screen so that you can easily select a device that meets the required performance. As figure 3 shows, by using the marker limit function, you can drastically reduce a device selecting time.

1 Option 001 is required

Device characterization at high frequencies

The equivalent circuit analysis function, which is included with the E4991A, can automatically extract equivalent circuit parameters of devices (See figure 4). There are five different multi-parameter models accommodating different types of devices such as capacitors, inductors, resistors, and crystal resonators. After taking measurement data, the E4991A calculates the approximate values for the parameters of each equivalent circuit; then the frequency characteristics are simulated on the screen, enabling the comparison with actual measurement data. You may also enter your own design values of the DUT into each equivalent circuit parameter for simulation. This functionality makes it easier to compare design values with actual values achieved on a prototype device.

It has become common to use EDA (Electronic Design Automation) tools such as the Agilent EEsof Advanced Design System (ADS) to simulate a device's characteristics at high frequencies. It is easy to download impedance data from the E4991A to the ADS in terms of CITIFILE format of S-parameters (1-port and 2-port). The following equations and models (See figure 5) are used in the E4991A's firmware to convert the measured impedance values into S-parameters.

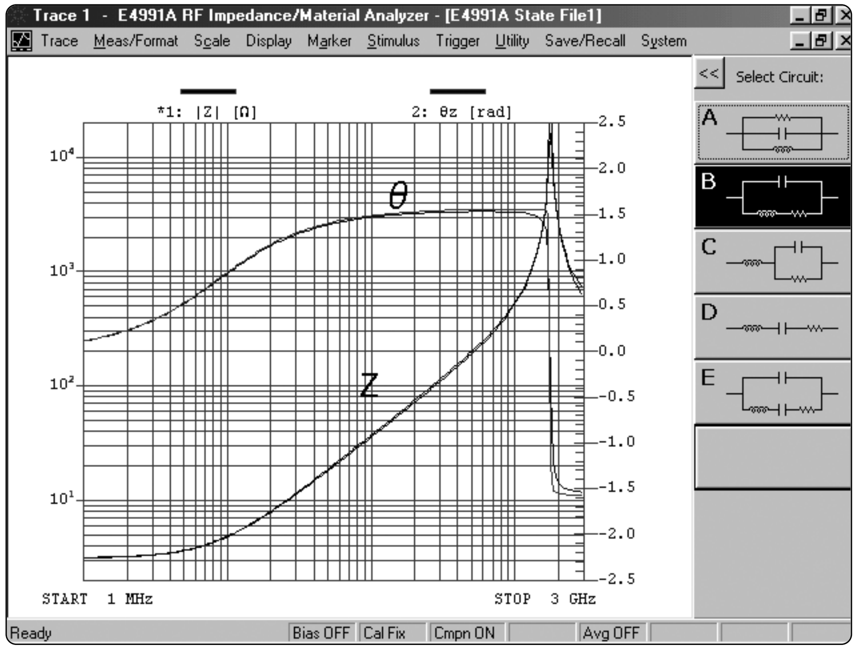


Figure 4. Equivalent circuit analysis function

1-Port Model: Reflection coefficient (S11)

$S_{11} = (Z - Z_0) / (Z + Z_0)$

2-Port Model: 2 port S-parameter

You can chose Series-through model or Shunt-through model.

Series-through model

$S_{11} = S_{22} = (Z) / (Z + 2 Z_0)$

$S_{12} = S_{21} = (2 Z_0) / (2 Z_0 + Z)$

Shunt-through model

$S_{11} = S_{22} = -(Z_0) / (Z_0+2 Z)$

$S_{12} = S_{21} = (2 Z) / (2Z+ Z_0)$

Z :Measured impedance value

Z_0:Characteristic impedance value

Usually a device is mounted on a microstrip transmission line with coaxial interface and 2–port S–parameters are measured using a network analyzer. The 2–port S–parameter data is often used for the components' data library provided for simulation tools. The data is similar to the actual mounting conditions of the device, but the conditions are very specific. Since there are a variety of printed circuit transmission lines, it is difficult to apply the data taken under a particular condition. On the other hand, the S–parameters obtained with impedance analyzers, which are close to the theoretical or intrinsic device characteristics, have an advantage of allowing the customization of any device's mounting conditions in the simulation.

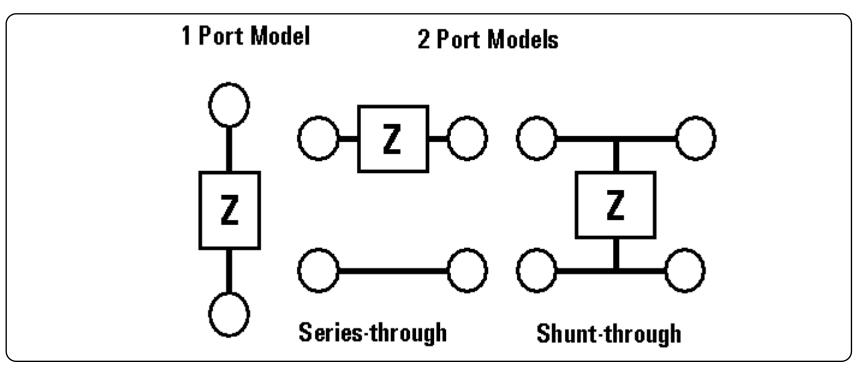


Figure 5. Device characterization models

SMD test fixtures offers excellent repeatability

The latest electronic devices are featuring reduced size and weight, lower loss and stricter tolerance. In accordance with this trend, it is becoming very difficult for engineers to evaluate the SMD with high accuracy and repeatability. In order to solve these problems, various SMD test fixtures are available for the E4991A. The new SMD test fixtures 16197A and 16196A/B/C provide highly repeatable measurement results in the range of 3 GHz.

The new product 16197A can accommodate various sizes between 0.02 inch (0.6 mm)*2 and 0.12 inch (3.2 mm). This fixture has good cost-performance because it can accommodate many different sizes SMD.

The 16196A/B/C have been designed to simplify the task of inserting the SMD and enhance measurement repeatability to the greatest extent. This has been accomplished by specifying the applicable SMD size; and as a result greatly increases the positioning repeatability.

In addition, the fixture compensation functions (open, short, and electrical length) built into the E4991A firmware is capable of eliminating the fixture's residual impedance and thus low impedance measurements can be performed precisely.

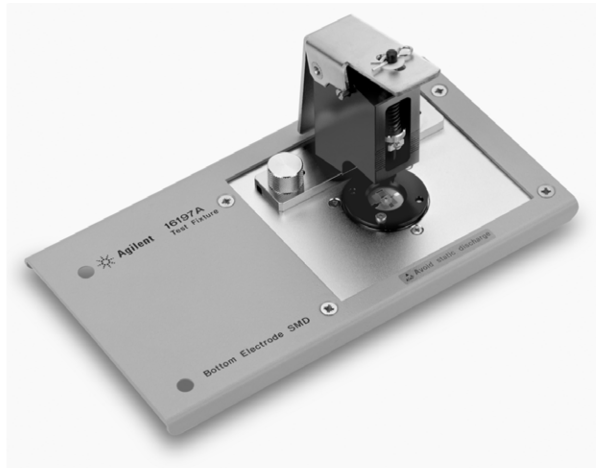


Figure 6-1. 16197A Bottom electrode SMD test fixture

Figure 6-2. 16196B Parallel electrode SMD test fixture

*2 Option 001 is required for the 0201(inch)/0603(mm) size.

A glance at RF components evaluation

Recent RF chip components are used at high frequency applications such as mobile phone and wireless LAN. It is very important to evaluate RF chip components under operating frequencies and conditions.

Issues when evaluating RF chip components

Impedance measurement at high frequencies is generally performed by a measuring method based on reflection coefficient. However it is difficult for the reflection coefficient method to measure high impedance (200 Ω or higher) or low impedance (10 Ω or less) with accuracy better than 10%. Another problem is that the reflection method has large phase errors, making it impossible to measure high quality factor (Q).

Solution for impedance measurement of RF chip components

RF I-V technique, breakthrough impedance measurement technology, is used in the E4991A making it possible to measure impedance at frequencies up to 3 GHz with high accuracy (±0.8 %). Furthermore, calibration using low-loss air capacitor mentioned above achieves a typical accuracy of ±15 % for Q=50 at 3 GHz (See figure 2).

Figure 7 shows a measurement example of ESR characteristics of a chip capacitor. Figure 8 shows Ls-Q characteristics of a chip inductor.

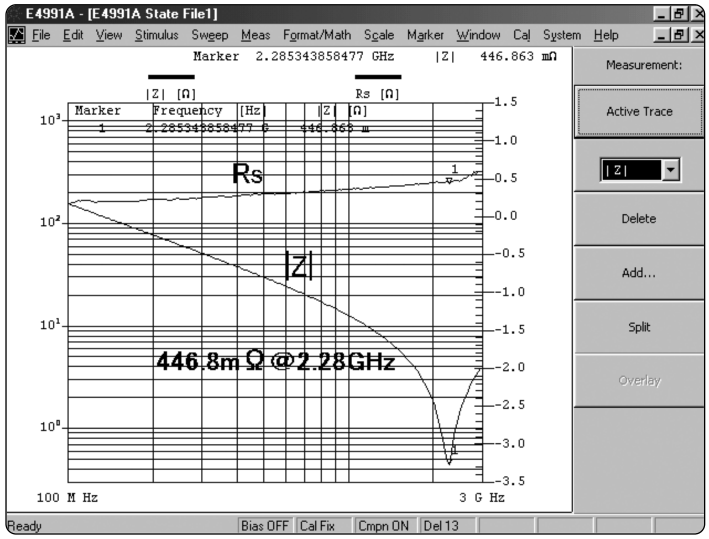


Figure 7. ESR characteristics of a chip capacitor

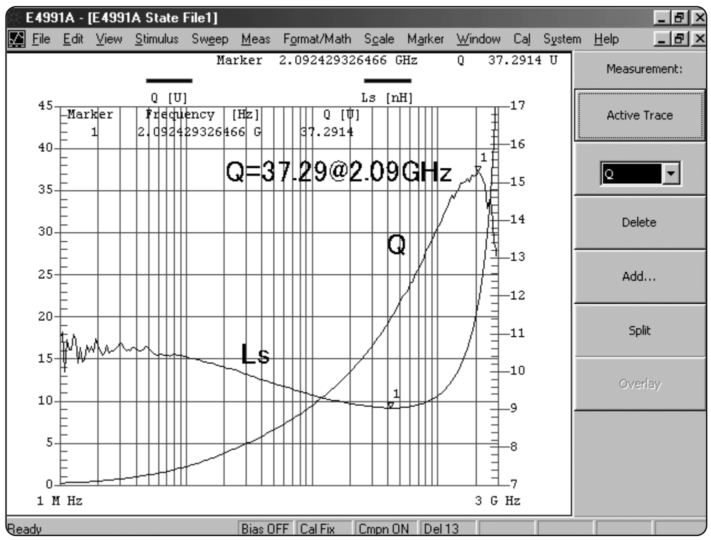
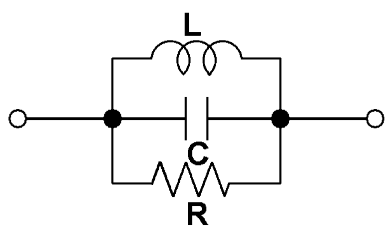


Figure 8. Ls-Q characteristics of a chip inductor

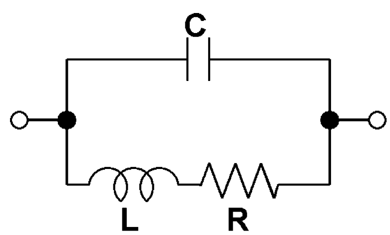
Chip inductor evaluation

Evaluating frequency characteristics

A chip inductor is usually represented by one of the equivalent circuits shown in figure 9



(a)



(b)

Figure 9 (a). High value chip inductor (b). Low value chip inductor

The chip inductor acts as an inductor at low frequencies. However, as the frequency increases, the effect of parallel capacitance (Cp) is significant and ultimately causes parallel resonance. Above the resonant frequency, the chip inductor acts not as an inductor, but as a capacitor. The evaluation of frequency characteristics includes measurements of inductance, Q (quality factor) or D (dissipation factor) up to the resonant frequency. The evaluation of a chip inductor for an EMI filter is to determine the correct frequency range for effective filtering.

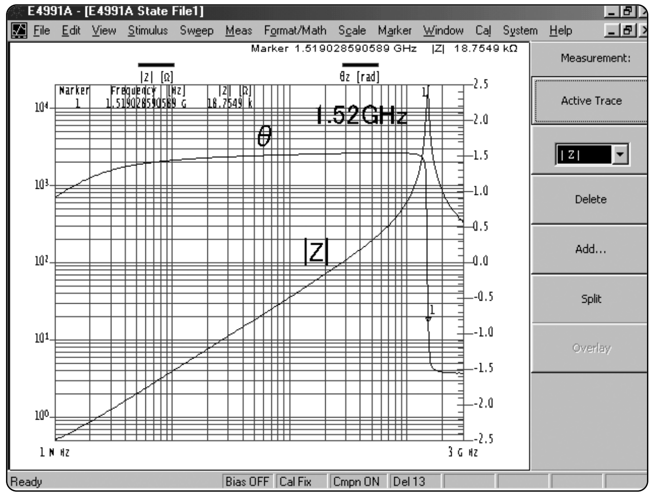


Figure 10. Frequency characteristics of a chip inductor

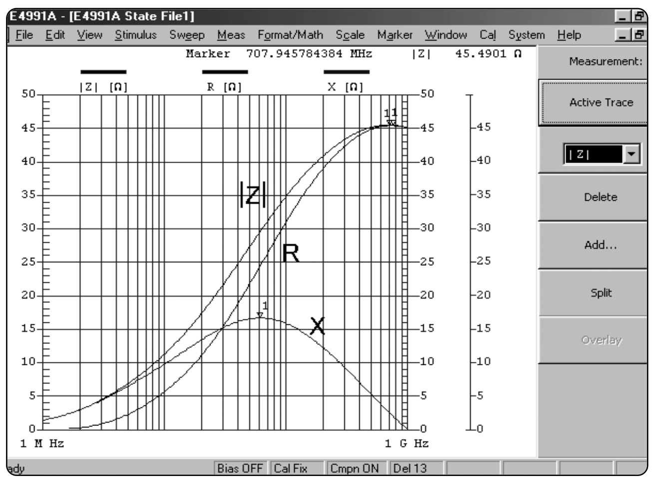


Figure 11. Frequency characteristics of a chip bead

Issues when evaluating frequency characteristics

In a case of using a chip inductor in wireless communication equipment, impedance characteristic measurement is required at the operating frequency range. The reflection coefficient method used in a network analyzer does not cover a wide impedance range with high accuracy.

Solutions for frequency evaluation

The RF I-V technique used in the E4991A offers highly accurate impedance and Q measurement up to 3 GHz (See figure 1 and 2). Figure 10 shows an example of frequency characteristics of a chip inductor in the range of 3 GHz. In this example, a resonance occurs at 1.52 GHz while above this point it behaves as a capacitor.

Figure 11 shows frequency characteristics of a chip bead, which is used for EMI filtering. The E4991A can display up to 3 scalar parameters (|Z|, R, X, Q, etc.) simultaneously so that key parameters (|Z|, R and X) of the chip bead can be observed at the same time.

Evaluating DC bias current dependence

Characteristics of a chip inductor are determined by its shape, type of core material and number of turns. Some inductors also vary their inductance values as a function of current flow. In particular, inductors whose core is made of high permeability materials have a high inductance, but magnetic saturation easily occurs and inductance value decreases with the DC bias current. Considering the actual operating environment, this inductance dependence on the DC bias current is a very important item of a chip inductor evaluation.

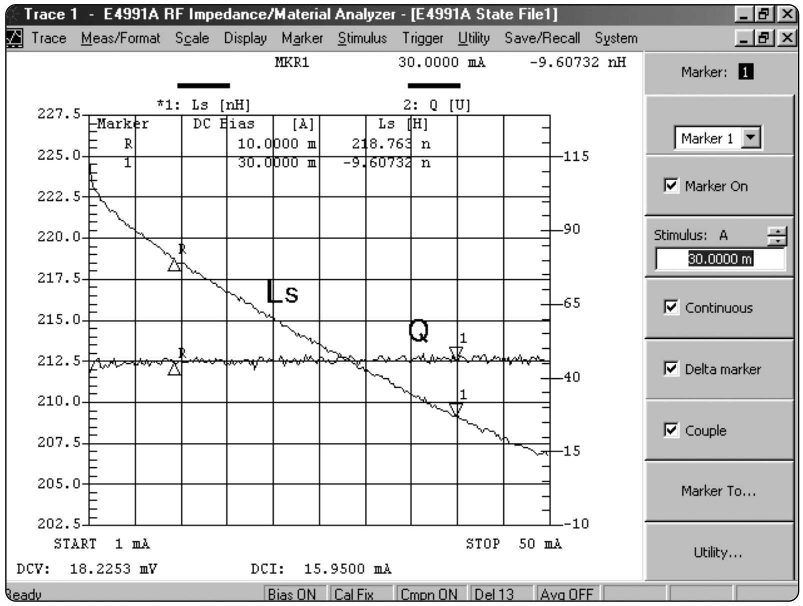


Figure 12. DC bias current dependency

Issues when evaluating characteristics of DC bias current dependence

The DC bias current dependence of chip inductors have been evaluated by 4291B. However, it does not cover hot wireless applications such as the cellular phone. Component and equipment manufacturing engineers need to evaluate components under–operating frequencies.

Solutions for DC bias current measurement

With option 001 (DC bias function), DC bias (±50 mA) can be applied or swept to an inductor. This built-in DC power source can be used as a constant current source so that it can apply the constant DC bias current to an inductor. The level monitor function enables you to monitor the actual DC bias current level applied to an inductor. The DC bias function enables you to evaluate the DC bias current dependence of an inductor very easily.

Figure 12 shows a DC bias current dependence of a ferrite chip bead. You can easily observe inductance values change due to ferrite core saturation with DC current.

The segment sweep function can display Ls-Q frequency characteristics under various AC current signal level on the same display either with traces superimposed (See figure 13) or with traces side by side (See figure 18).

Some inductors require higher DC bias current level than that of the built-in DC bias source. The 16200B[3] (external DC bias adapter) is applicable for these requirements. The 16200B with an external DC power source is used to apply maximum ± 5 A DC current to a DUT through the 7 mm test port.

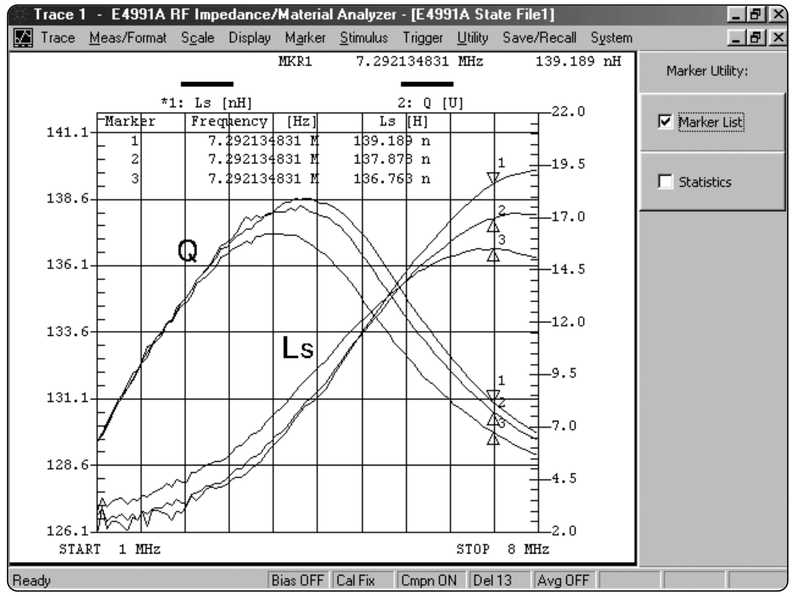


Figure 13. Ls-Q frequency characteristics using segment sweep

Additional features for chip inductor measurement

The E4991A offers the following functions that are also useful for chip inductor evaluation.

Equivalent circuit analysis function

The E4991A provides the equivalent circuit analysis function that enables you to easily extract approximate values of each equivalent circuit parameter of an inductor by using measurement data. Therefore, it is easier to make the difficult comparison between design values and actual values achieved with a prototype. This helps to reduce the time required for research and development of inductors and their applications.

Figure 14. 16200B external DC bias adapter

Magnetic materials analysis function

The material evaluation function (Option 002) can be added to the E4991A. The permeability of core material used in an inductor is easily evaluated, in the frequency range of up to 1 GHz, by combining this option with the magnetic material test fixture (16454A).

3 Frequency range is limited to 1 GHz

Chip capacitor evaluation

Evaluating frequency characteristics

The circuit shown in figure 15 usually represents a chip capacitor.

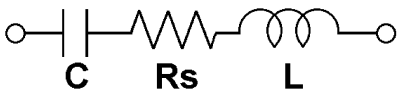


Figure 15. Equivalent circuit of a capacitor

The chip capacitor acts as a capacitor at low frequencies, however as the frequency increases, the effect of series inductance (Ls) is significant and eventually causes series resonance. Above the resonant frequency, the capacitor operates not as a capacitor but as an inductor. The evaluation of frequency characteristics includes measurements of capacitance, low-loss/stability of loss factor (D), and equivalent series resistance (Rs or ESR). To demonstrate the evaluation of a chip capacitor as a bypass capacitor, the impedance is evaluated by measurement to obtain the correct bypass frequency rage.

Issues when evaluating frequency characteristics

Similar to the chip inductor, the impedance of a chip capacitor also changes with frequency therefore; an instrument that covers a wide range of impedance with high accuracy is required.

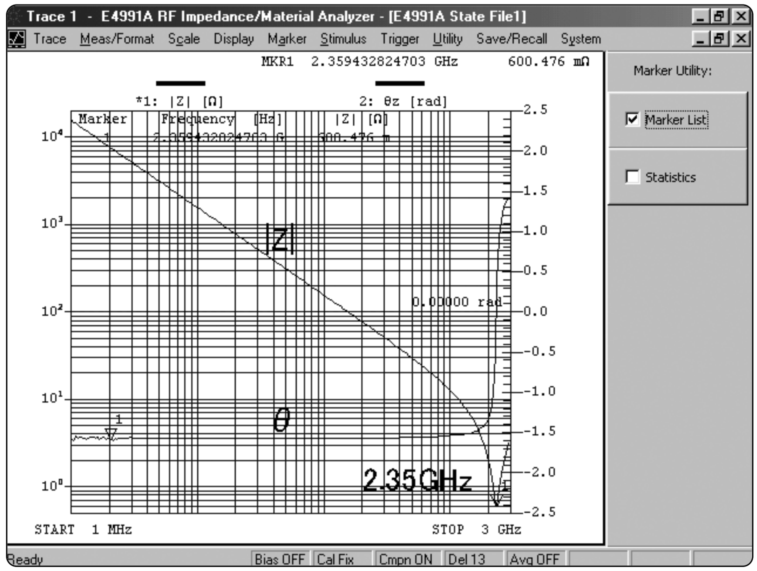


Figure 16. Frequency characteristics of a chip capacitor

Solution for evaluating frequency characteristics

The RF I-V technique used in the E4991A offers highly accurate impedance measurement up to 3 GHz (See figure 1 and 2). Figure 16 shows a measurement example of frequency characteristics of a chip capacitor in the range of 3 GHz. In this example, a resonance occurs at 2.35 GHz while above this point it behaves as an inductor.

Evaluating voltage dependence

The shape and type of dielectric material determine the characteristics of a chip capacitor. Some capacitors also vary their capacitance values as a function of applied voltage. In particular, capacitors made of low permittivity materials are called temperature-compensating capacitors. These capacitors change their capacitance values only slightly with the fluctuations of the AC signal voltage or DC bias voltage. On the other hand, capacitors made of high permittivity materials are called high permittivity capacitors. They have a high ratio of capacitance to volume and their capacitance values easily change with the AC signal voltage and DC bias voltage. Considering the actual operating environment, this capacitance dependency on voltage (AC signal/DC bias) is a very important item of chip capacitor evaluation.

Issues when evaluating characteristics of voltage dependence

The voltage (AC signal/DC bias) dependence of chip capacitors has been evaluated up to 1.8 GHz by using 4291B. However, it does not cover hot applications such as wireless communication equipment and *Bluetooth*.

Solutions for voltage dependence measurement

The E4991A can do the AC voltage swept measurement from 4.47 mV to 502 mV (447 mV above 1 GHz). Figure 17 shows an example of AC voltage dependence of a ceramic capacitor. In this example, capacitor value (Cp) is measured using swept AC voltage from 150 mV to 500 mV.

Furthermore, segment sweep function can display AC voltage dependence in a certain frequency range on the same display as shown in figure 18. Using this function, frequency characteristics of capacitance under various AC voltage levels can be observed at the same time.

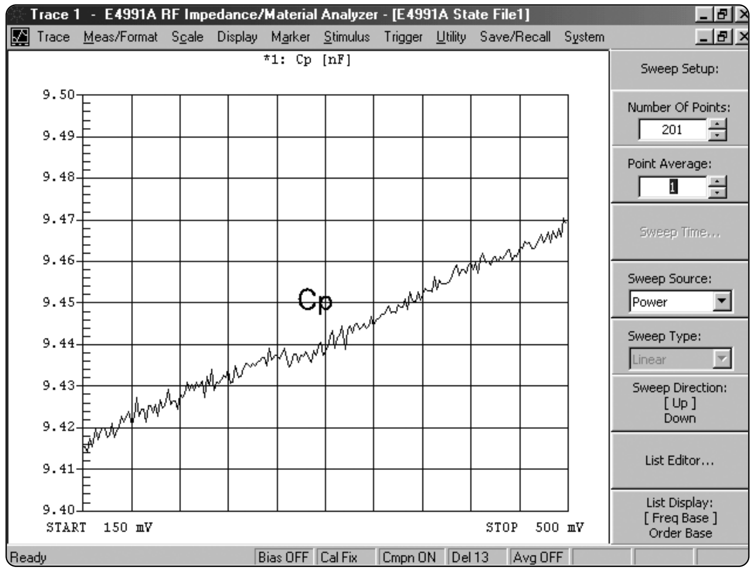


Figure 17. AC voltage dependence

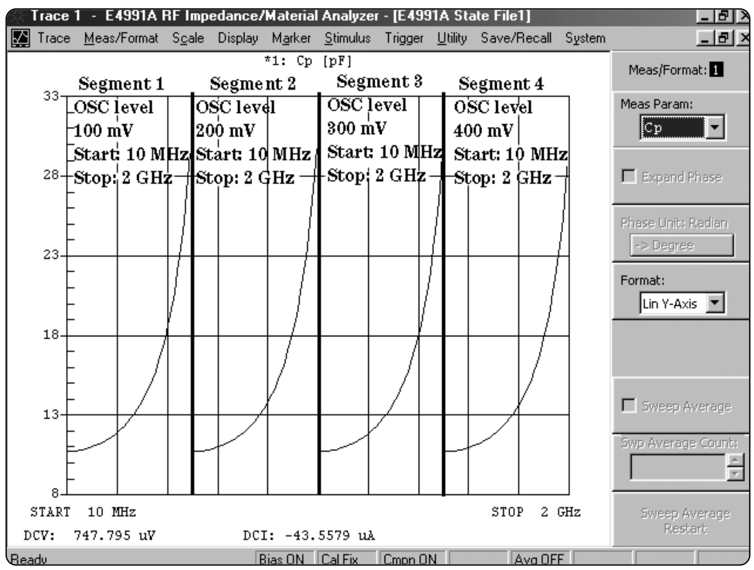


Figure 18. Cp characteristics using segment sweep

Solution for DC bias voltage measurement

With option 001 (DC bias function), DC bias (± 40 V) can be applied or swept to a capacitor. This built-in DC power source can be used as a constant voltage source so that it can apply the constant DC bias voltage level applied to a capacitor. The level monitor function enables you to monitor the actual DC bias voltage level applied to a capacitor. The DC bias function enables you to evaluate the DC bias voltage dependence of a chip capacitor very easily. Figure 19 shows a DC bias voltage dependence of a ceramic capacitor. In this example, Cp-D characteristics are measured using swept DC bias from 5 V to 40 V. You can easily observe capacitance value and dissipation factor change.

Additional features for chip capacitor measurement

The E4991A offers the following functions that are also useful for chip capacitor evaluations.

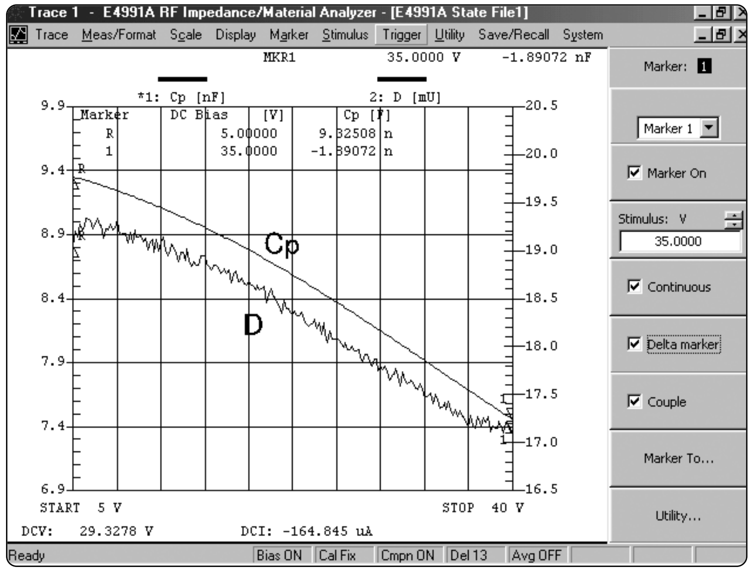


Figure 19. DC bias voltage dependence

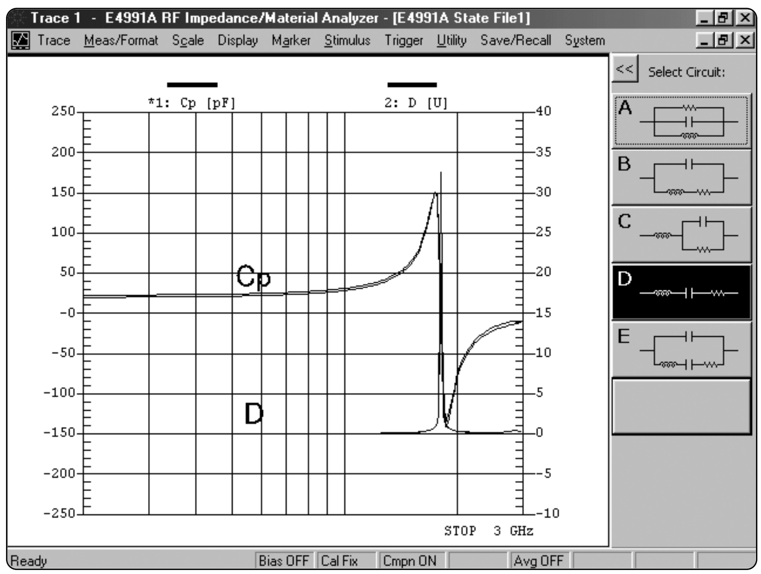


Figure 20. Equivalent circuit analysis of a chip capacitor

Equivalent circuit analysis function

Figure 20 shows an example of the equivalent circuit analysis for a capacitor. It enables you to easily extract approximate values of each equivalent circuit parameter of a capacitor by using measurement data. This helps to reduce the time required for research and development of capacitors.

Dielectric materials analysis function

By installing option 002 (material measurement firmware) and combining it with the dielectric material test fixture (16453A), the E4991A can easily evaluate the permittivity of a dielectric material used in a chip capacitor. This option and fixture combination can be used for a wide range of applications, from dielectric material development to the evaluation of product characteristics.

Varicap diode evaluation

Evaluating C-V characteristics

Varicap diode (variable capacitor diode) can be used in various circuit blocks such as VCOs and tuner circuits. The junction capacitance of a diode depends on the reverse DC voltage. The evaluation of varicap diode characteristics includes measurements such as the change in capacitance relative to the reverse voltage or Q measurement.

Issues of C-V characteristics evaluation

The characteristics of the varicap diode are usually specified at 1 MHz. However, it is very important to evaluate varicap diode under operating conditions when it is used in high frequency circuits.

The 1.8 GHz frequency range, which is covered by the 4291B, is not enough to evaluate a varicap diode that is used in a VCO of recent wireless communication equipment.

Varicap diode device sizes are not conformed to EIAJ/EIA standards. Therefore, a customized test fixture should be prepared.

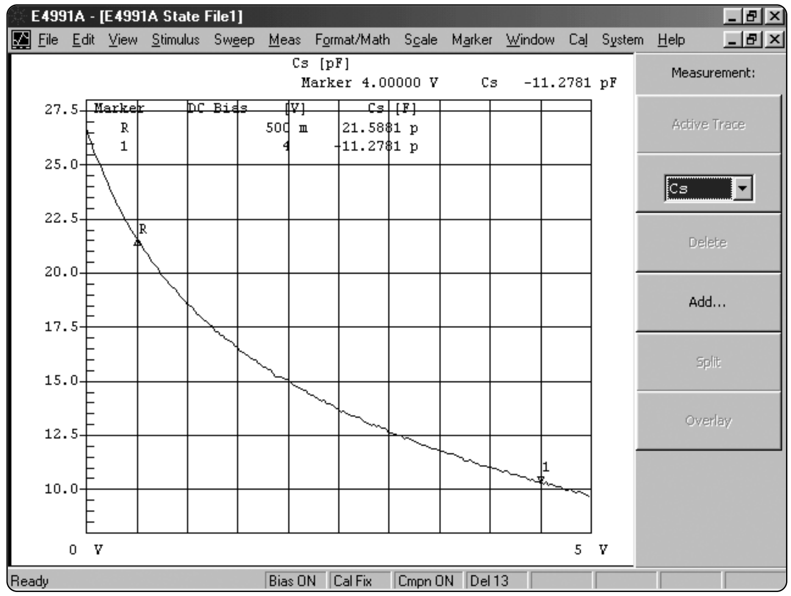


Figure 21. C-V characteristics

Solutions for C-V characteristics evaluation

With option 001 (DC bias function), DC bias (± 40 V) can be applied to a varicap diode in the range of 3 GHz.

Figure 21 shows an example of C-V characteristic measurements of a varicap diode. In this example, C-V characteristics are measured using swept DC bias from 0 V to 5 V. You can easily display a junction capacitance value change (11.27pF) between 0.5 V and 4.5 V by using the delta marker function.

The issue pertaining to the varicap diode's non-conformed size can be resolved by using the new 16197A test fixture. The 16197A includes a blank device guide which offers flexibility for non-standardized devices such as varicap diodes. The device guide is made of thin plastic, making it easy to customize (max size: 3225(mm)/1210(inch)). It eliminates time required for designing custom test fixtures and thus, you will be able to concentrate on your device evaluations.

Offering more effective test environment

The E4991A adopts the Windows® operating system in order to improve usability and PC connectivity. It brings sophisticated user interface, effective data administration and the VBA (Visual Basic® for Applications) programming environment for automation test. The E4991A offers effective test environment with these features.

Advanced connectivity with PC

Windows-styled GUI brings the additional benefits of mouse operation to the E4991A. Using the mouse, you can easily access the instrument menu selection. You can also zoom in measurement traces quickly by simply dragging the mouse over the area you are interested in. Short cut menus are available for mouse operation that reduces tedious use.

Figure 22. Shortcut menus

The E4991A is equipped with the 10 Base-T/100 Base-TX LAN interface as the standard. The primary transfer method for existing instruments such as the 4291B, is the floppy disk drive. However data handling with a floppy disk drive is becoming time consuming since the amount of data collection has been increasing remarkably, with the spread of EDA tools.

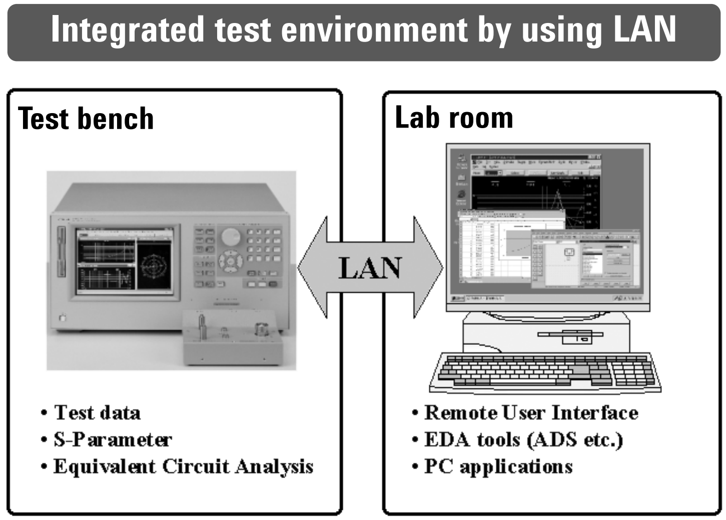


Figure 23. Effective test environment

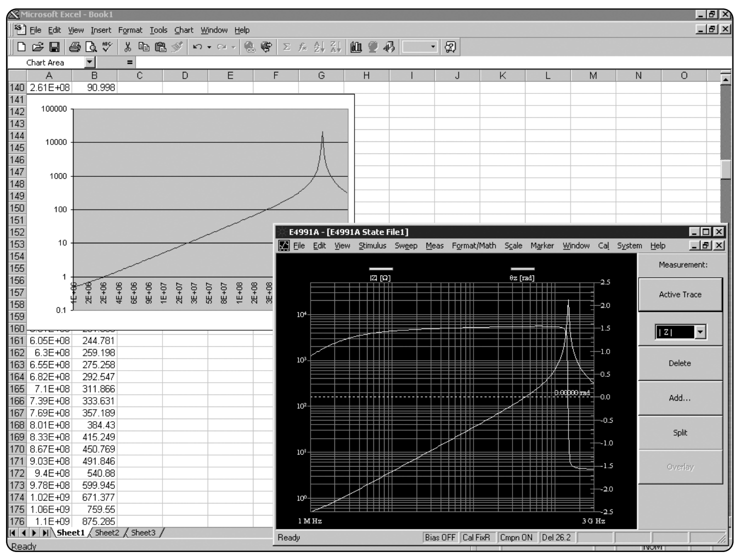


Figure 24. Remote user interface

By using the LAN interface, you can easily collect huge amounts of data from the E4991A even if it is in a physically separate location.

Furthermore, by using the remote user interface software provided with the E4991A, you can drastically improve connectivity with your PC environment.

Remote user interface software brings the instrument control panel to the PC display via the LAN interface. You can easily control or collect measurement data in the same operation as the E4991A. This software enables data sharing easily with other applications, such as spread-sheets, through a file or via the clipboard. By using the LAN interface and the remote user interface software, test efficiency will be increased dramatically.

Automation test using VBA

The built-in VBA programming environment is available with the standard E4991A. VBA stands for Visual Basic for Applications, which is a Microsoft® product, and it enables you to create programming by using the common macro language of Microsoft Office products. You can create a macro program in the Integrated Development Environment (IDE) of the VBA in a similar manner to Visual Basic. As a result, when compared to the IBASIC programming environment, which has no built-in functions for debugging, it definitely increases productivity.

The VBA programming environment is available for the customization of user interfaces, automation of complex measurement procedures and control of external instruments via the GPIB interface with SCPI commands.

Figure 26 shows an example of user interface customization by using VBA. VBA enables you to create more flexible and interactive user interfaces than those of IBASIC.

Conclusion

The E4991A RF Impedance/ Material Analyzer, based on the RF I-V technique, provides highly accurate impedance measurements at frequencies up to 3 GHz.

These capabilities make it possible to evaluate the various types of impedance measurement applications. The integrated result of analyzer, fixtures and PC connectivity offers a total solution satisfying your testing needs.

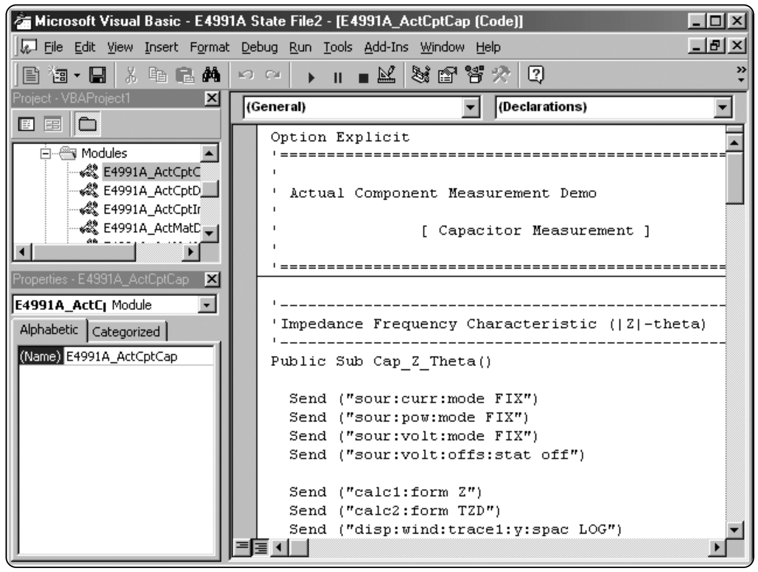


Figure 25. VBA programming environment

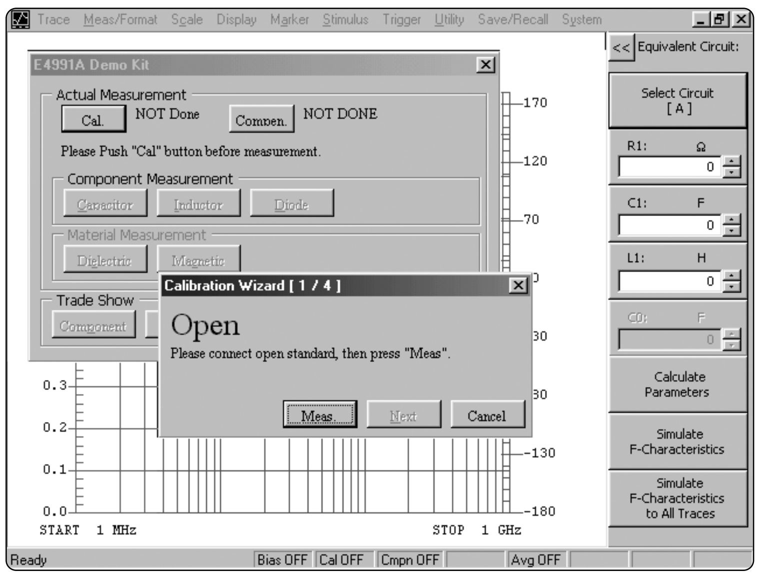


Figure 26. GUI customization by using VBA

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.

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