Highly Accurate Evaluation of Chip Capacitors using the Agilent 4291B RF Impedance/Material Analyzer

Application Note 1300-1

Agilent Technologies

Introduction

The latest electronic devices feature reduced size and weight, lower power consumption and higher performance. In accordance with this trend, more emphasis has been placed on the evaluation of surface-mounted components, that make it possible to provide these features. The evaluation of chip capacitors is particularly important because they are used in a wide range of applications (including oscillation circuits and LC filters). They must be evaluated over a very wide range of frequencies, to determine their characteristics. This application note describes how the Agilent 4291B RF impedance/material analyzer can be used to make highly accurate evaluations of chip capacitors.

Conventional Methods for Evaluating Chip Capacitors

The following items describe some conventional methods for evaluating chip capacitors:

1.Evaluating frequency characteristics

A chip capacitor is usually represented by the circuit shown in figure 1.

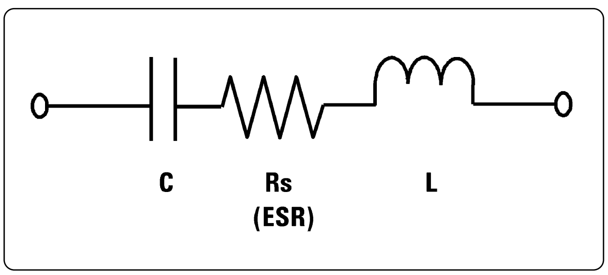

Figure 1. Equivalent circuit of a chip capacitor

The chip capacitor acts as a capacitor at low frequencies, however as the frequency increases, it is more seriously affected by the series inductance (Ls) causing series resonance. Above the resonant frequency, the capacitor operates not as a capacitor but as an inductor. The evaluation of frequency characteristics includes measurements such as the change in capacitance up to the resonant frequency, low-loss/stability of loss factor (D), and equivalent series resistance (Rs or ESR). When using the chip capacitor as a bypass capacitor, the impedance is evaluated by measurement to obtain the correct bypass frequency range.

2. Evaluating voltage dependence

Although the capacitance of chip capacitors depends on the shape and the dielectric material used, the capacitance may also vary as a function of the applied voltage. Capacitors that use low permittivity materials are called temperature-compensating capacitors. These capacitors change their capacitance values only slightly with the fluctuations in the ac signal voltage or dc bias voltage. On the other hand, capacitors with high permittivity materials are called high permittivity capacitors. They have a high ratio of capacitance to volume and their capacitance values change with changes in the ac signal voltage and dc bias voltage. In considering the actual operating environment, this dependence on voltage (ac signal/dc bias) becomes very important in the evaluation of today's chip capacitors.

3. Evaluating temperature characteristics

As stated previously, variations (due to temperature changes) in the capacitance of a chip capacitor depends on the dielectric material used. The rate of change of capacitance to temperature is very low for temperature-compensating capacitors (using low-permittivity materials). It is higher for high-permittivity capacitors. Regardless of the degree of change in capacitance, these temperature characteristic are another critical item for evaluation when considering the actual operating environment of any electronic device using a chip capacitor.

Problems with Conventional Evaluation Methods

The methods described previously for evaluating chip capacitors have some problems that are described in the following paragraphs:

1. Problems when evaluating frequency characteristics

Because the impedance of the chip capacitor changes with frequency, the evaluation of the frequency characteristics must be based on highly accurate measurements covering a wide range of impedance. The test fixture, which seriously affects the actual measurement, must not present problems such as residual error. Individual problems are described below.

(a) Low accuracy of impedance measurement

Impedance measurements at high frequencies generally employs a measuring instrument based on the reflection coefficient method (for example, network analyzer and directional coupler). Using the reflection coefficient method, it is difficult to measure impedance with an accuracy of about 10 % or less. This is particularly true of low impedance (10 Ω or lower) and high impedance (200 Ω or higher). Another problem is that the conventional method produced a large phase error, making it impossible to measure the loss factor accurately.

(b) Repeatability lowered by the test fixture

Remarkable progress has been made in reducing the size of chip capacitors. The dimensions of practical chips have now been reduced to 1005 (1.0 mm x 0.25 Vrms). With chip capacitors of these dimensions, not only the measuring instrument, but also the test fixture becomes very important for accurate evaluation. The Agilent 16091A coaxial fixture set, which is currently used to measure these chip capacitors, has the following problems which prevent accurate evaluation:

- The frequency range is limited to 1 GHz max.
- Because soldering is required, the operation is complicated.
- When evaluating characteristics, the effect of the solder must also be included in the evaluation. The effect of solder can change at each solder joint, reducing repeatability.

2. Problems when evaluating voltage dependence characteristics

The voltage (ac/dc bias) dependence of chip capacitors at low frequencies (less than 100 MHz) can easily be evaluated using an LCR meter or an impedance analyzer. For evaluation at high frequencies, however, no measuring instruments with a voltage sweep capability (dc bias sweep capability in particular) are available, and therefore, the voltage dependence is currently represented by low frequency evaluations.

3. Problems with evaluating temperature characteristics

Evaluating temperature characteristics of a chip capacitor is complicated. For example, software must be developed to control the temperature chamber and measuring instrument. Also, the durability of the cables and the fixture in the temperature chamber must be evaluated. System configuration accuracy must also be considered. Extending the cable leading from the measuring instrument to the temperature chamber increases the measurement error.

Solutions Provided by the Agilent 4291B

The 4291B RF impedance/material analyzer provides the following solutions to these problems:

1. Suggested solutions for evaluating frequency characteristics

(a) Highly accurate impedance measurements at frequencies up to 1.8 GHz

On the basis of Agilent Technologies newly developed RF I-V method, the 4291B makes it possible to measure impedance at frequencies up to 1.8 GHz with high accuracy (basic accuracy: ±0.8 %). In particular, it uses state-of-the-art calibration technology for measuring the loss factor (D) to achieve a typical accuracy of ±0.0007 for D = 0.002 (100 MHz). Figure 2 shows an example measurement of frequency characteristics (C-D) up to 1.8 GHz.

With the 4291B, the measurable impedance range can be selected by replacing the tip of the measuring probe (test head). The impedance ranges that can be measured with an accuracy of ±10 % when using a high-impedance test head and a low-impedance test head (option 012) are shown in figure 3.

When measuring a high-impedance capacitor (for example a 1pF capacitor), the high-impedance test head that is included in the standard package can be used to achieve high accuracy.

(2) Excellent repeatability: SMD test fixtures

The SMD test fixtures shown in figure 4 can be used at frequencies up to 2 GHz. Operation has been simplified by eliminating the need for soldering, allowing evaluation of SMD components. The SMD test fixtures use a device holder for accurate positioning of the device under test.

At the same time, the open/short compensation and electrical length compensation capabilities of the 4291B can be used to carry out measurements that eliminate errors from the test fixture. These advantages combine to provide high repeatability and accuracy for the measurement of 1005-sized chip capacitors. Also, the durability of the cables and the fixture in the temperature chamber must be evaluated. System configuration accuracy must also be considered. Extending the cable leading from the measuring instrument to the temperature chamber increases the measurement error.

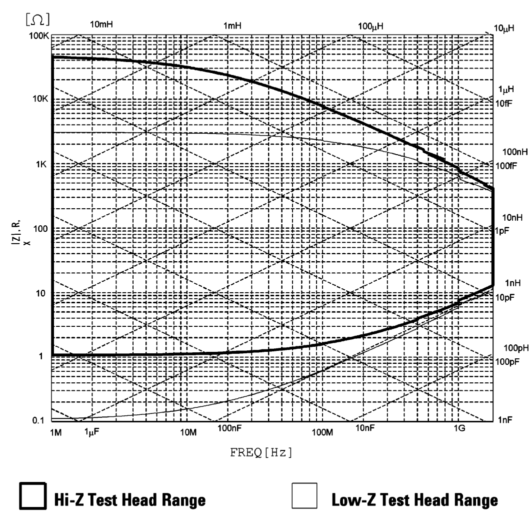

Figure 3. Impedance ranges measurable with a ±10 % accuracy

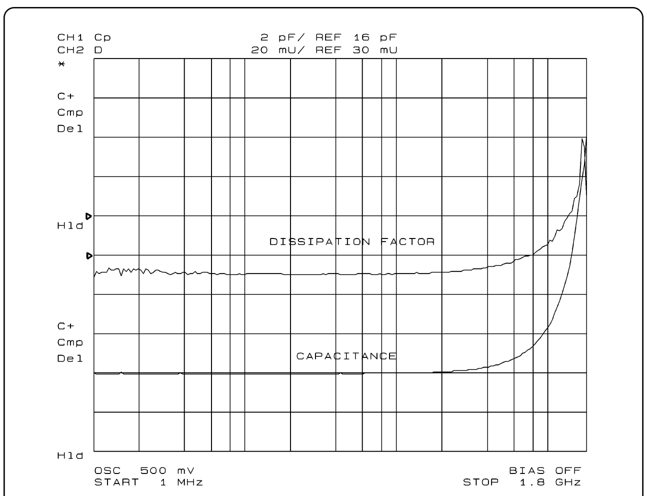

Figure 2. Frequency characteristics of a chip capacitor

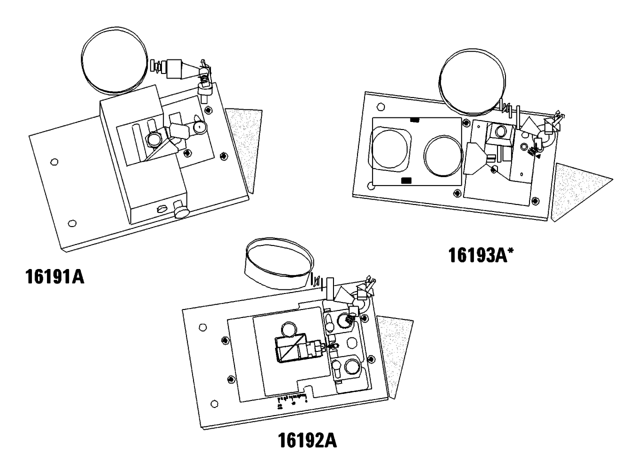

Figure 4. SMD test fixtures cover a variety of chip components sizes

2. Powerful capabilities for evaluating voltage dependence

The 4291B is capable of making a measurement while sweeping the ac voltage from 0.2 mV to 1 V (up to 0.5 V for 1 GHz or higher). Figure 5 shows a highly accurate evaluation of the ac voltage dependence. A level monitoring function is included, which monitors the voltage actually applied to the device under test. Built-in IBASIC is useful for program-control of measurements and/or external equipment and constant-voltage measurement applications (An application program for constant-voltage measurement is included in the standard 4291B.)

A dc bias of up to 40 V can be applied or swept by adding option 001. Like general power sources, this internal power supply can be used as a constant-voltage supply. Using the dc bias option is possible to apply the rated or operating dc bias voltage to the capacitor. (It is also possible to monitor the actual dc bias voltage applied.) This option simplifies evaluating the dc bias dependence of capacitance and other parameters (see figure 6).

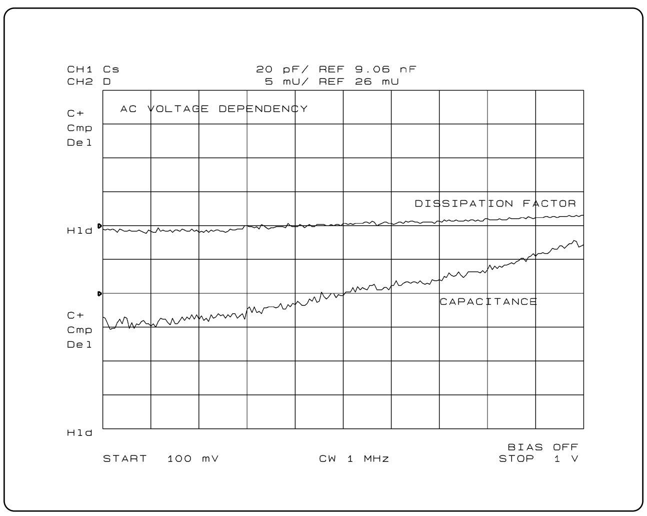

Figure 5. Evaluating ac voltage dependence

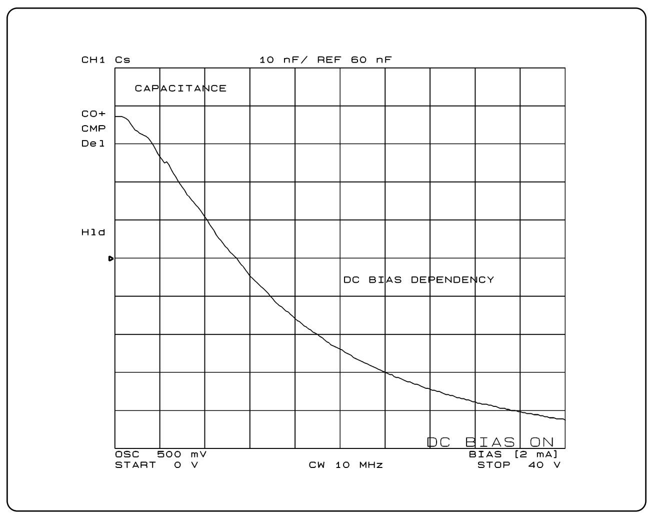

Figure 6. Evaluating dc bias dependence

3. Solutions for evaluating temperature characteristics

The 4291B provides the following features and options to make it easier to establish a system for evaluating temperature characteristics:

- **A 1.8 m cable to the measurement head:** Convenient for system configuration. Does not affect the accuracy of measurement.
- **High temperature test head options (for high-impedance (option 013) and low-impedance (option 014) :** A heat-resistant cable that can be used at -55°C to 200°C to expand the 7 mm calibration plane while at the same time maintaining high accuracy.
- **The GPIB function with built-in IBASIC, and its controller function:** Provide an automatic measurement system in combination with the application program.
- **An application program for temperature characteristics evaluation/temperature chamber control:** This program is compatible with the Tabai Espec temperature chamber (described later), is included with the high-temperature test heads).
- **Graphic display:** Displays temperature characteristics based on measured results (see figure 7).

In addition to the above features, Tabai Espec Corporation offers a temperature chamber (SU-240-Y) compatible with the Agilent 4291B to further enhance the system for evaluating temperature characteristics (see figure 8).

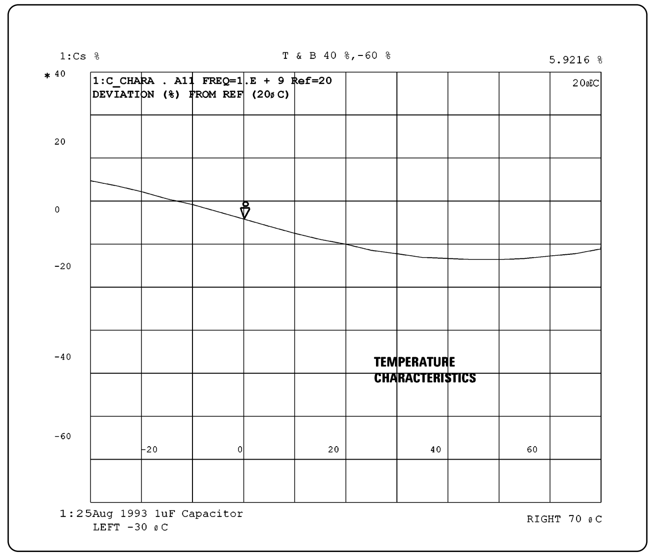

Figure 7. Direct display of temperature characteristics

Figure 8. Configuring a system using a Tabai Espec chamber

Useful Features for Capacitor Measurement

In addition to the above solutions, the 4291B incorporates the following features that are useful for evaluating capacitors.

1. Equivalent circuit analyzing capability

The 4291B provides an equivalent circuit analysis capability based on a three-element circuit shown in figure 1 instead of the standard two-element circuit, using this feature, you can:

- Calculate the approximate values for the parameters of each equivalent circuit.
- Simulate the frequency characteristics based on the parameter values entered (see figure 9).

These functions make better analysis possible. For example, it is now easier to make the difficult comparison between design values and actual values achieved with a prototype. This helps reduce the time required for research and development of capacitors.

2. Useful features for automatic measurement systems: limit line and controller (IBASIC) facilities

The 4291B incorporates a limit line function (figure 10) that provides an efficient Go/No-Go judgement for the pass/fail testing.

As IBASIC is installed, and using the GPIB or 8-bit I/O port to control external handlers or other instruments, automation of capacitor testing is greatly simplified.

3. Save/recall function

The 4291B can save/recall settings for the measuring instrument and measured results to or from the internal RAM disc, internal non-volatile flash disk or a flexible disk. This is very useful for managing research and development/measurement data. Both LIF and MS-DOS® formats are supported to facilitate easy data transport and analysis using a controller or a DOS/Windows-based PC.

4. Capability for measuring/analyzing dielectric materials

By installing option 002 (material evaluation function) and combining it with the Agilent 16453A test fixture, the 4291B can easily evaluate the permittivity of the dielectric material used in the chip capacitor. This option can be used for a wide range of applications from dielectric materials development to the evaluation of product characteristics.

Conclusion

The Agilent 4291B RF impedance/material analyzer provides highly accurate impedance measurements at frequencies up to 1.8 GHz. These capacities make it possible to perform various evaluations of chip capacitors with high accuracy, high repeatability and with the ease of use available with a completely integrated solution.

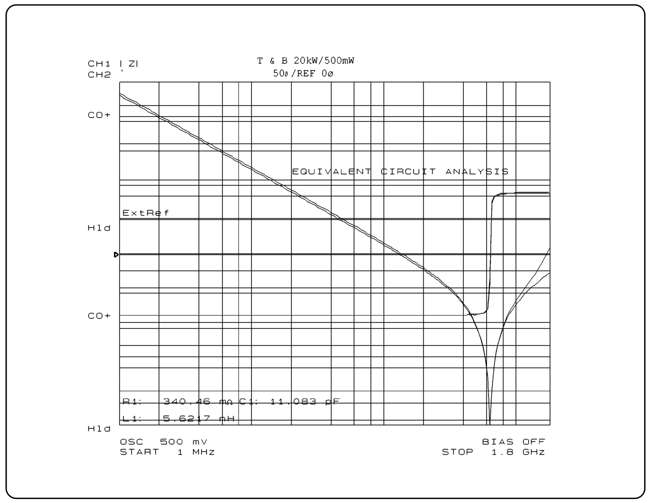

Figure 9. Simulation of frequency characteristics

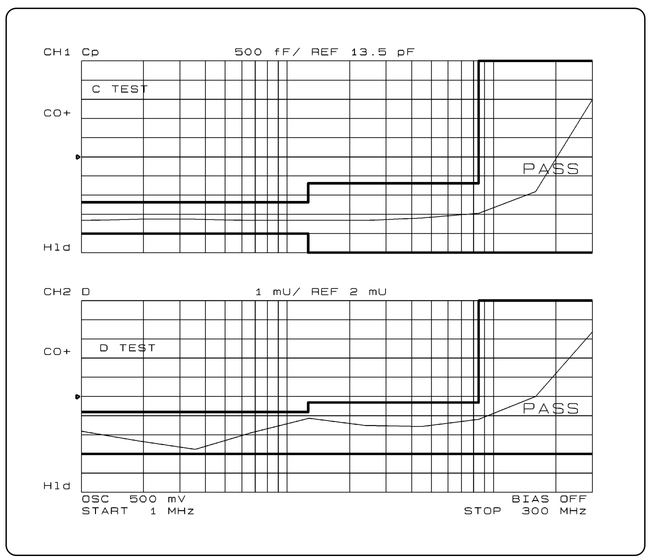

Figure 10. Limit line functions for easy pass-fail indication

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