# Agilent AN 1300-2

# Evaluating Chip Inductors using the 4291B

Application Note

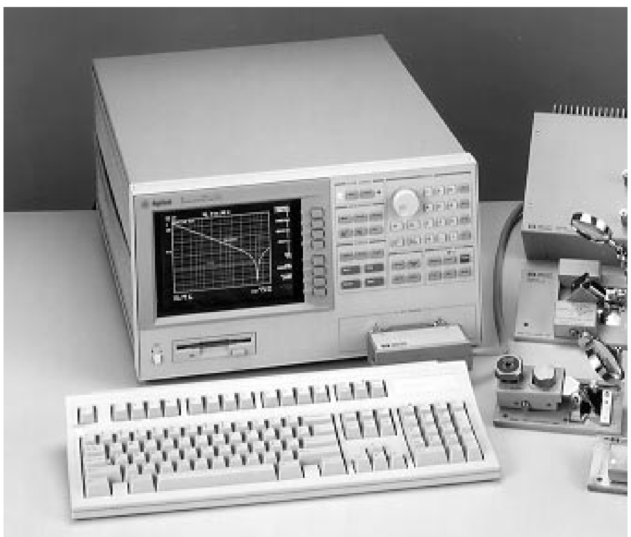

Figure 1. The 4291B RF Impedance/Material Analyzer

## Agilent Technologies 4291B RF Impedance/ Material Analyzer

### 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 the SMD components that make it possible to provide these features. The evaluation of chip inductors is particularly important because they are used in a wide rage of applications (including oscillation circuits and EMI filters). They must be evaluated over a very wide range of frequencies to determine their characteristics.

This application note describes how the 4291B RF Impedance/Material Analyzer can be used to make highly accurate evaluations of chip inductors.

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## Conventional methods of chip inductor evaluation

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

### 1. Evaluating frequency characteristics

A chip inductor is usually represented by one of the equivalent circuits shown in Figure 2.

The chip inductor acts as an inductor at low frequencies. However, as the frequency increases, it is more seriously affected by parallel capacitance (C) causing parallel resonance. Above the resonant frequency, the chip inductor operates not as an inductor, but as a capacitor. The evaluation of frequency characteristics includes measurements such as the change in inductance up to the resonant frequency and changes in the quality factor (Q).

When using the chip inductor as an EMI filter, the impedance is evaluated by measurement (mainly for the resistance component) to determine the correct frequency range for effective filtering.

### 2. Evaluating current dependance

Although the inductance of chip inductors depends on their shape, type of core material and number of turns, some inductors also vary their inductance as a function of current flow. For example, inductors that have cores made of highly permeable materials have a high inductance, but as the AC signal current and DC bias current increase, magnetic saturation can occur, decreasing the inductance value. In considering the actual operating environment, this dependence on current (AC signal/DC bias) becomes a very important item for evaluation of today's chip inductors.

### 3. Evaluating temperature characteristics

Variations in inductance due to temperature changes depend on the core material used. For example, if a highly permeable core material is used, the rate that the inductance changes with temperature is very high. Temperature characteristics are therefore another critical item for evaluation when considering the actual operating environment of a chip inductor.

## Problems with conventional evaluation methods

The methods described previously for evaluating chip inductors have some problems, which are described as follows:

### 1. Problem when evaluating frequency characteristics

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

*(a) Low accuracy of impedance measurement*

Impedance measurements at high frequencies generally employ 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 over wide ranges with an accuracy of 10% or less. This is particularly true of low impedances (10 or lower) and high impedances (200 or higher). Another problem is that the reflection method can have large phase errors, making it impossible to measure the quality factor (Q) accurately. This is especially true for high Q values.

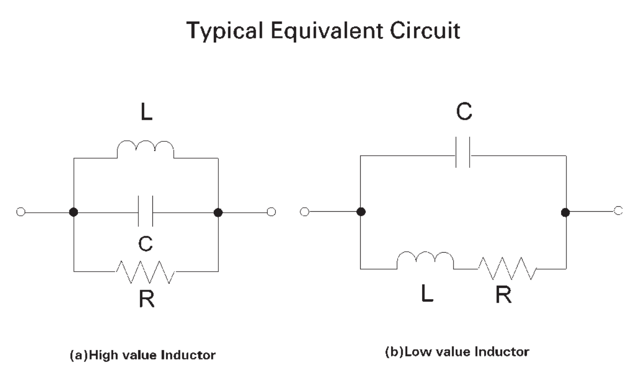


**Figure 2. Equivalent circuits of chip inductors**

*(b) Repeatability lowered by the test fixture*
Remarkable progress has been made in reducing the size of chip inductors. The dimensions of practical chips have now been reduced to 1608 (1.6 mm x 0.8 mm) for layered types and 2012 (2.0 mm x 1.25 mm) for wound types. With chip inductors of these dimensions, not only the measuring instrument, but also the test fixture becomes very important for accurate evaluation. The 16092A Spring Clip Fixture, which is currently used to measure these chip inductors, has the following problems that prevent accurate evaluation:

- Frequency range limited to 500 MHz max
- Because the electrodes of the 16092A are designed to make surface contact, the contact position changes at every connection, resulting in poor repeatability.
- The metallic surface of the GND is positioned immediately below the device being tested. Consequently, the magnetic flux from the inductor produces eddy currents, thereby causing measurement errors.

**2. Problem when evaluating current dependence characteristics**
The current (AC/DC bias) dependence of chip inductors must be evaluated using a constant current. For low-frequency measurement (under 30 MHz), this can be done using an LCR meter (for example the Agilent 4285A). For evaluating at higher frequencies, however, no measuring instruments are capable of constant-current measurements. Therefore, the current dependence is currently represented by only low frequency evaluations.

**3. Problems when evaluating temperature characteristics**
Evaluating the temperature characteristics of a chip inductor 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 accuracy must also be considered. Extending the cable leading from the measuring instrument to the temperature chamber can increase measurement error.

## Solution provided by the Agilent 4291B

The 4291B RF Impedance/Material Analyzer provides the following solutions:

**1. Improved evaluation of frequency characteristics**
*(a) Highly accurate impedance measurements at frequencies up to 1.8 GHz*
On the basis of Agilent's 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, is uses state-of-the-art calibration technology for measuring the quality factor (Q) to achieve a typical accuracy of ±15% for Q = 100 at 1 GHz. Figure 3 shows an example measurement of frequency characteristics (L-Q) up to 1.8 GHz.

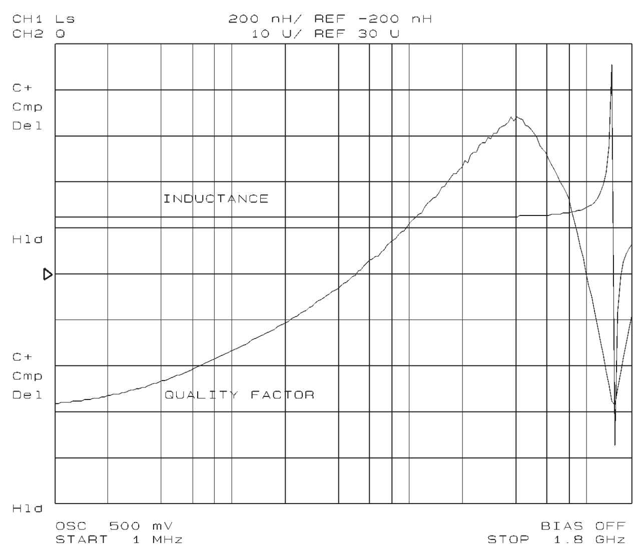


**Figure 3. Frequency characteristics of a chip inductor**

As shown in Figure 4, the 4291B consists of the mainframe, a 1.8 m cable, the test station, and a test head.

With the 4291B, the measurable impedance range can be selected by replacing the test head installed at the tip of the measuring probe (test head). When measuring a low-impedance inductor (for example, a 2nH inductor), the low-impedance test head (Option 012) can be used instead of the standard high-impedance test head to achieve a more accurate measurement. (The impedance range that can be measured with an accuracy of ±10% when using each test head as shown in Figure 5.)

**Figure 4. Configuration of the 4291B**

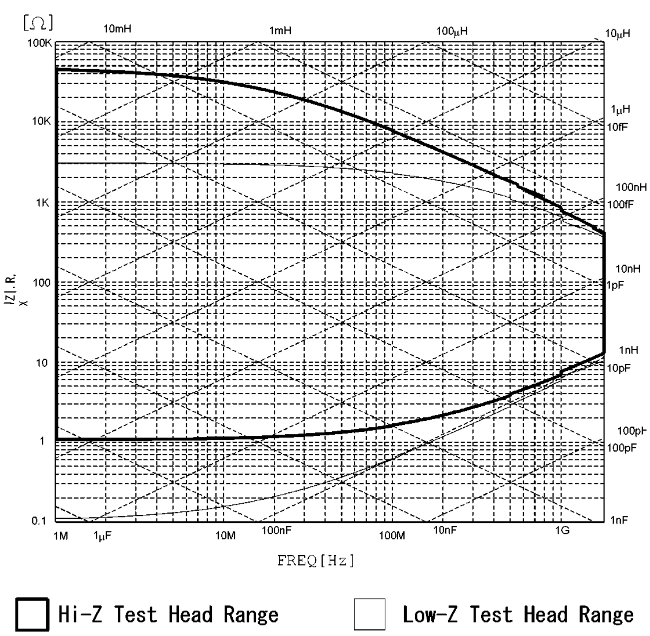


**Figure 5. Impedance ranges measurable with ±10% accuracy**

*(b) SMD test fixture offer excellent repeatability:*
The SMD test fixtures are shown in Figure 6. These fixtures:

- Can be used at frequencies up to 2 GHz
- Use a device holder for accurately positioning the SMD component under test.
- Use a point contact electrode to maintain the position of the contact with the SMD component.
- Cover the GND surface with Teflon or similar coating to eliminate metallic surfaces, preventing the generation of eddy currents.

These features combine to achieve highly repeatable measurements at high frequencies. At the same time, the open/short compensation and electrical length compensation capabilities of the 4291B can be used to make measurements that eliminate errors from the test fixture. The fixtures and advanced calibration/compensation make it now possible to measure 1608- and 2012-sized chip inductor with high accuracy and repeatability.

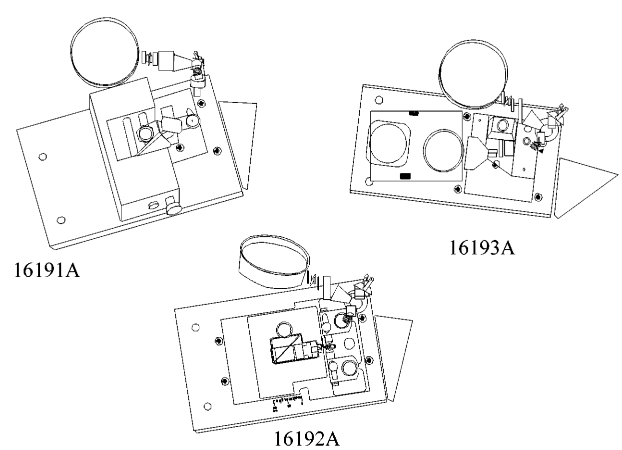


**Figure 6. SMD test fixtures cover a wide range of chip component sizes**

## 2. Evaluating current dependence is simplified

The Agilent 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 to higher). Test signal constant current sweep is available using the built-in HTBasic and an application program furnished with the standard 4291B. A level monitoring function is included that monitors the actual current low though the device under test. The built-in HTBasic is available for program-controlled, constant-current measurement.

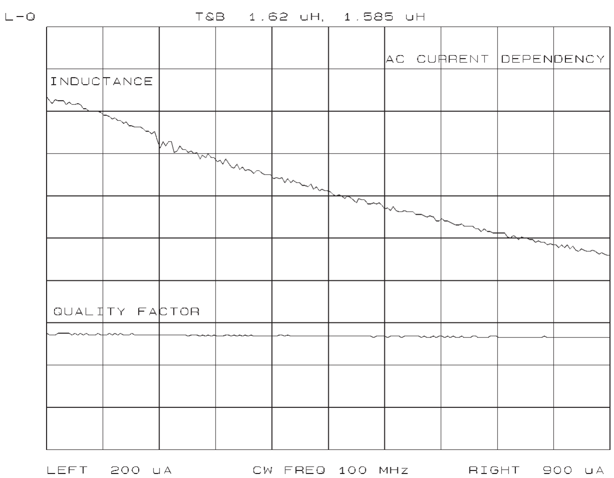


**Figure 7. An example of a program-controlled constant AC current sweep measurement**

*(b) DC bias current sweep function (Option 001)*

A DC bias of up to 100 mA can be applied or swept by adding Option 001. Like general power sources, this internal power supply can be used as a constant-current supply. With this option, you can apply the operating condition DC bias current through the inductor. Using this capability, it is easy to evaluate the DC bias current dependence of L-Q (see Figure 8).

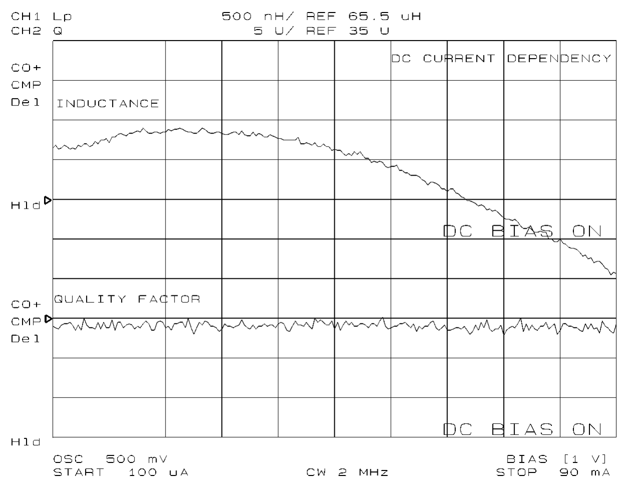


**Figure 8. Evaluation of DC bias current dependence**

**3. Solution for evaluating temperature characteristics**
The 4291B provides the following features and options to simplify evaluating temperature characteristics:

- A 1.8 m cable allows flexibility for system configuration with a chamber. Does not degrade the accuracy of the measurement.
- The High Temperature test head options for high impedance (Option 013) and low impedance (Option 014). A heat-resistant cable that can be used from -55 °C to 200 °C to expand the 7-mm calibration plane while at the same time maintaining high accuracy.
- An IBASIC application program for temperature characteristics evaluation/temperature chamber control. This program is compatible with the Tabai Espec temperature chamber (described later) and is included with the optional heat-resistant test heads.

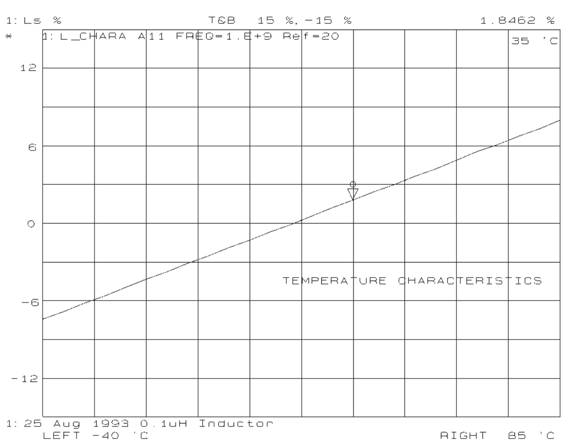


**Figure 9. Temperature characteristics evaluated using the 4291B**

- The GPIB function and HTBasic (controller function) allows automating the temperature measurement system.
- Graphic display that displays temperature characteristics based on measured results when using IBASIC (see Figure 9).

Tabai Espec Corporation offers a temperature chamber (SU-240-Y) compatible with the 4291B for evaluating temperature characteristics (see Figure 10).

**Figure 10. Configuring a system using the Tabai Espec SU-240-Y temperature chamber**

## Additional features for inductor measurement

The Agilent 4291B incorporates the following features that are also useful for evaluating inductors:

### 1. Equivalent circuit analyzing capability

The 4291B provides an equivalent circuit analysis capability based on the three-element circuits shown in Figure 2. This capability provides the following:

- Calculation of the approximate values for the parameters of each equivalent circuit.
- Simulation of frequency characteristics based on parameter values entered (see Figure 11).

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 chip inductor and their applications.

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

The 4291B incorporated a limit line function (Figure 12) that provides an efficient Go/No-Go judgment for pass-fail testing. By using IBASIC, and using the GPIB or 8-bit I/0 port to control external handlers or other instruments, automation of inductor 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 an Agilent controller or a DOS Windows-based PC.

### 4. Capability for measuring/analyzing magnetic materials

By installing Option 002 (material evaluation function) and combining it with the 16454A test fixture, the 4291B can easily evaluate the permeability of the core material used in inductors. This option and fixture can be used for a wide range of applications from core materials development to the evaluation of product characteristics.

## Conclusion

The 4291B RF Impedance/Material Analyzer provides highly accurate impedance measurement at frequencies up to 1.8 GHz. These capabilities make it possible to evaluate the frequency, current dependence, and temperature characteristics of chip inductors with high accuracy and repeatability. The integrated solution of analyzer/fixtures/calibration offers ease and convenience not available previously.

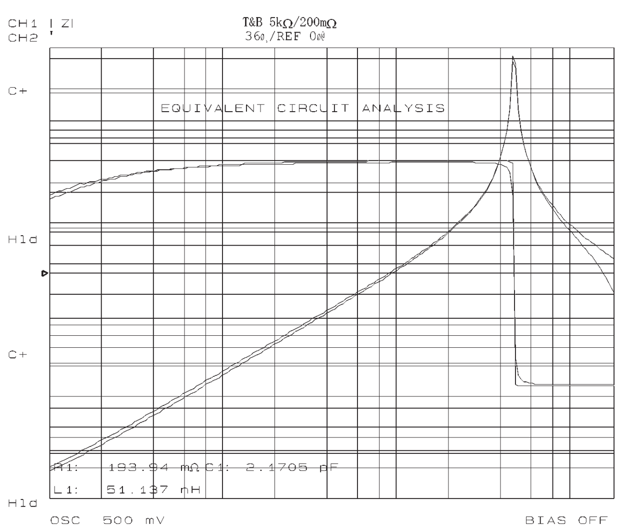


Figure 11. Simulation of frequency characteristics

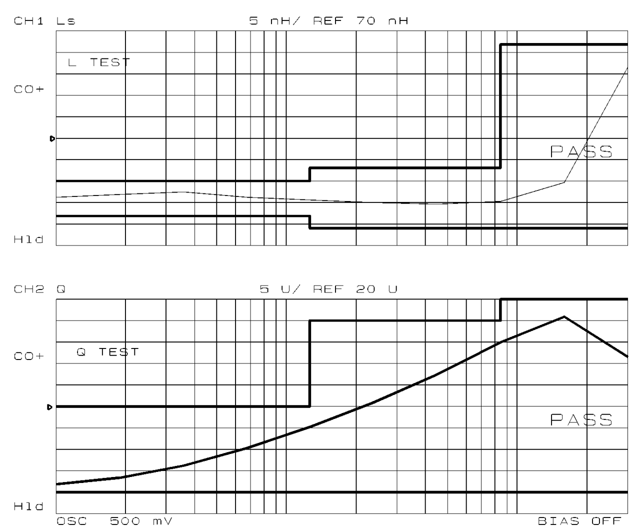


Figure 12. Limit line functions for easy pass-fail indication

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Printed in U.S.A. 10/00
5966-1848E

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