



# Agilent AN 1300-5

## Electronic Characterization of IC Packages

Application Note

### Agilent 4291B RF Impedance/Material Analyzer

#### 1. Overview

This application note describes in broad terms how to use the Agilent Technologies 4291B RF Impedance/Material Analyzer in determining the impedance characteristics of IC packages up to 1.8 GHz. This information is useful for high speed digital designers, component evaluation engineers, RF design engineers, IC package users in the analog or digital design environment, and for IC package manufacturers. This measurement solution will accurately measure the impedance, inductance, and capacitance characteristics of IC package conductors and leads.

#### 2. Packaging Affects Performance

The frequencies that ICs operate at are growing higher. In computer systems, clocks that now operate at 100 MHz will increase to 1 GHz by the year 2000. Refer to Figure 2-1, Digital Rate Trends. When chips run at high frequencies (above 50 MHz) and the signal edges consist of frequency components that are much higher, the lead conductors of IC packages that link the chips to the circuit boards start behaving like transmission lines. The conductor will have inductance, capacitance, and resistive elements.

The leading implication is that the impedance characteristics of the IC package leads will dramatically contribute to reflections, overshoot, undershoot, and crosstalk distortions of the signal. This situation is compounded by the rapidly shrinking physical size of the IC packages leads, the processing of low level signals, and the ever increasing pin density.

#### 3. The IC Package

IC packages can vary in size, topology, number of pins, substrate material, geometry, and lead length. Each has its own strengths and limitations. Within all IC packages are lead frames, the conductors that connect the internal IC to a pc board. The lead frame is imbedded on a rigid structure that becomes the IC package.

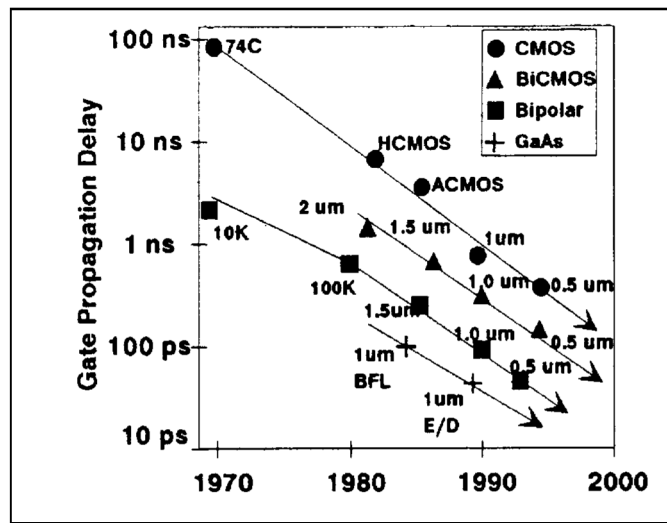


Figure 2-1. Digital rate trends



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The lead frames are usually made up of copper alloy and have fine traces with different lengths and dimensions. These traces can have ends that terminate near the IC with a width of 0.10 mm. The intrinsic properties of the IC conductive and insulative elements directly impact the extrinsic characteristics (i.e., impedance) of an IC package. Although these characteristics can be estimated and modeled, modeling is not totally effective in describing the complete electrical performance of a specific IC package. Therefore, a measurement of the package must be made to fully quantify how an IC package will behave under operating conditions.

#### 4. Defining the Impedance Test Parameters

The IC package impedance test parameters that the 4291B can measure are discussed below.

##### Impedance ( $Z_0$ )

This is the total opposition the conductor offers to the flow of an alternating current. The impedance represents the total effects of self-inductance, mutual inductance, leads resistance, interlead capacitance, and interlead conductance. The IC package in Figure 4-1 is an example of a four element model.

##### Self inductance ( $L_{xx}$ )

This is the number of magnetic field lines around a single conductor (lead) per amp of current flowing through it. Typical values for a lead can range from 2 to 20 nH, depending upon the length of the conductor and the physical geometry of the lead.

##### Lead resistance ( $R_{xx}$ )

This is an extrinsic property which relates the resistance of a structure to the material and its geometry. It can be derived from basic solid state principles, and is related to the free charge carrier density and mean-free path.

A typical value can be up to hundreds of milliohms, depending upon the type of lead material, lead length, and surface area.

##### Interlead Capacitance ( $C_{xo}$ )

Lead capacitance is the amount of electrical charge stored over the differential voltage between leads. Excessive lead capacitance can cause crosstalk on adjacent channels. A typical value can be about 1.8 pF per inch of conductor, depending upon the dielectric constant of the IC package, lead length, lead cross-sectional area, lead separation, and number of leads.

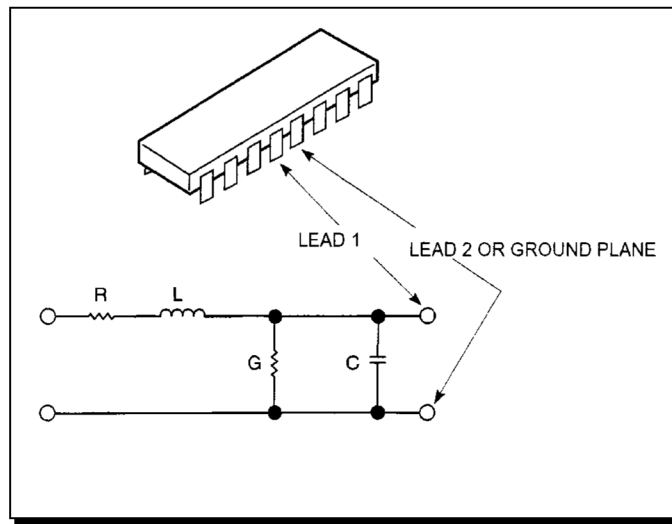


Figure 4-1. IC package model

## 5. Choosing an Instrument

It not uncommon to characterize an IC package from 1 MHz to 500 MHz, 1 GHz, or higher. Signal integrity about the IC package is tested at the operating frequency for analog design, like 900 MHz for cellular RF applications.

Digital signal performance at nine times the fundamental is important and needs to be characterized at the odd-harmonic frequencies.

For example, a 50 MHz clock means the test frequencies start at 50 MHz for the fundamental and stop at 450 MHz for ninth harmonic characteristics. Measuring the impedance, inductance, and capacitance characteristics of an IC package can be quite frustrating. Conventional impedance analyzers are highly accurate but lack the needed high-end bandwidth. Vector network analyzers have the high frequency bandwidth, but lack the low-end bandwidth and can be inaccurate when

operating away from a 50  $\Omega$  test environment. Also, the swept data must be mathematically converted to Z, L, R, and C by using a computer.

Fixtures and probes add inductive, capacitive, and resistive parasitics that add error to the measurement. The ability to compensate for these parasitics is extremely important; often the fixture parasitic values overwhelm the conductor impedance values. Port extension is also very critical. IC packages do not easily mount onto conventional 7 mm fixtures, so a cable must be connected from the measurement port to a fixture/probe.

From these measurement constraints, an instrument must have these minimum capabilities:

- 1 MHz to 1.5 GHz frequency range
- Wide impedance range accuracy beyond 50  $\Omega$
- Direct swept impedance results ( $|Z|$ , L, C, R)
- Error correction at probe tip
- Cable extension

The Agilent 4291B Impedance Analyzer is designed to address all of these issues. Refer to Figure 5-1, Measurement Accuracy. This chart shows the typical 10% accuracy zones of a 4-terminal pair impedance analyzer, a vector network analyzer, and the 4291B over frequency and impedance.

The 4291B can also directly display any two of the many impedance parameters available, is specified to operate from 0.1 to 50 k $\Omega$ , has the distinctive capability of performing compensation to remove probe parasitics, and can easily extend the measurement port.

## 6. The Probe

Using traditional handheld probes on today's high-density technologies can limit measurement accuracy and damage fragile devices. The Cascade Microtech FPM-1X Fine Microprobe achieves a level of accuracy for characterizing high-speed MCMs and SMT assemblies. Refer to Figure 6-1, Fine Microprobe. The FPM-1X combines electrical and mechanical accuracy needed for fine-pitch applications. By minimizing capacitance and ground inductance, the FPM-1X enables state-of-the-art probing of modules with pads as small as 1 mm.

A unique ground system provides the low-inductance required to effectively troubleshoot high density applications. Refer to Figure 6-2, Probe Ground System. To minimize loading effects, the probes provide as little as 0.15 pF of tip capacitance.

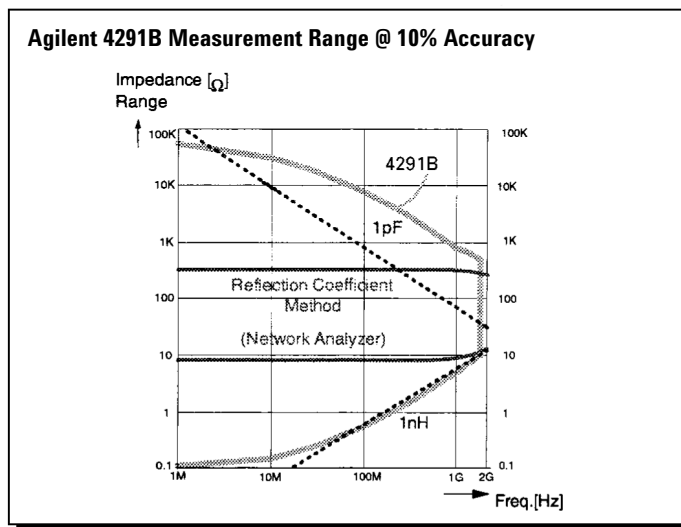


Figure 5-1. Measurement accuracy

## 7. Setup For a Swept Frequency Measurement

It is understood that the user will have a firm understanding of the initial test conditions:

- Start Frequency
- Stop Frequency
- Test Signal Level
- Number of Points (NOP)

The Start and Stop frequencies are based on the IC package operating conditions. The Test Signal Level should be set at 1 V so that the instrument can avoid operating at the noise floor. The number of measurement points (NOP) can be set at 801 points to gain the maximum amount of swept information.

Later, the NOP can be reduced once a swept area has been fully characterized and no anomalies are located.

The key benefit of a small NOP, frequency or test signal level of the Agilent 4291B, the calibration correction factors have to be internally recalculated. This tends to reduce accuracy. For the absolute best accuracy, always perform calibration under the exact test conditions needed; otherwise a SOLA calibration may have to be performed again. For the best accuracy, it is recommended that the 4291B test environment be set with the following conditions before the performance of calibration:

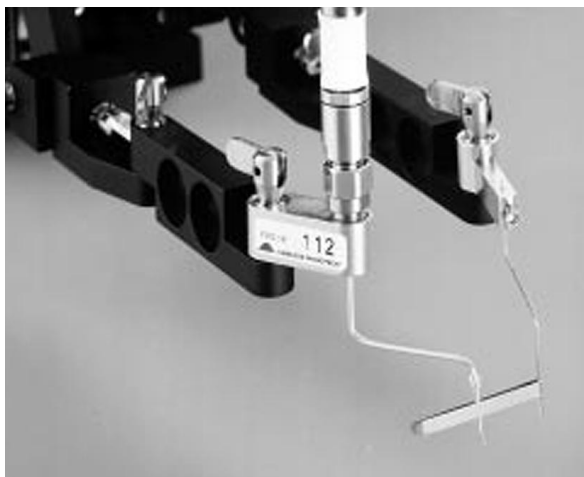
- Fixture Selection
- Point Average Factor
- Test Head

Fixture selection is found under the MEAS menu. Fixture selection optimizes the calibration modeling for greater accuracy by using a different model number for each standard fixture. Selecting the fixture to the [None] mode allows users to use their own unique fixture or probe.

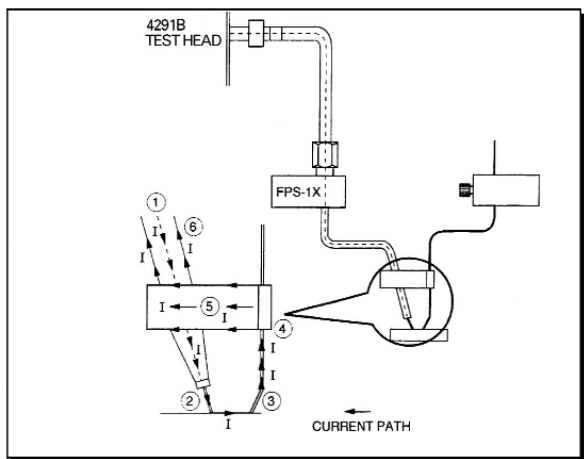
The Point Average Factor will mathematically average acquired data during calibration, compensation, and measurement. Selection of a point average factor of 8 or greater will reduce the noise present in low threshold signal measurements.

The choice of the test head will fundamentally affect the accuracy of a measurement; each test head is optimized for a particular impedance range. A general rule is to use the low-impedance test head for device-under-test (DUT) impedances of 10  $\Omega$  or less, and using the high-impedance test head for DUT impedances greater than 10  $\Omega$ . In our specific application, the low-impedance test head should be used.

As an aside, the impedance function should also be selected at this time. To measure the self inductance of a conductor, set channel 1 to be Ls (series inductance) and set channel 2 to be Rs (series inductance).



**Figure 6-1. Fine-pitch microprobe.** For more information on the fine-pitch microprobe, refer to Product Note publication number 5966-1928E.



**Figure 6-2. Probe ground system**

## 8. Calibration and Compensation

There is a very strong distinction between calibration and compensation. Calibration determines the calibration reference plane for all measurements. The calibration constants are generated at the reference plane and are based on the measurements of the short, open, load, and Air-capacitor (SOLA) standards. The SOLA standards are factory-defined standards. Calibration is performed in the 4291B CAL menu. While in the CAL menu, before executing any of the calibration constant measurements, it is recommended that the CAL POINTS be changed from [FIXED] to [USER]. This permits a faster swept calibration. The penalty is that if the test signal level is changed, then the SOLA calibration must be performed again.

Compensation is different from calibration. Compensation mathematically removes residual capacitance, resistance, and inductance from test fixtures using a user-defined open, short, and  $50\ \Omega$  load. In the compensation sub-menu, before executing any of the compensation constant measurements, it is recommended that the COMP POINT be changed from [FIXED] to [USER] matching the compensation data with the calibration data.

Calibration is always performed at the test head 7 mm connector with the SOLA standards while compensation is always performed at the DUT measurement point.

## 9. The Probing and Measurement System

Essentially these are the steps that mount the 4291B test station to a Cascade Microtech Summit 9000 (or 10000) Analytical Probe Station and fully prepare the instrument to perform a continuous swept measurement, displaying self inductance in this example. Refer to Figure 9-1, Probing

System. The microscope and micro-manipulators (micro-positioners) have been preinstalled.

The probing system assembly should follow in this sequence:

- a. Assemble the test station bracket and bolt it securely to the left rear corner of the probe station. Refer to Figure 9-2, Test Station Bracket.

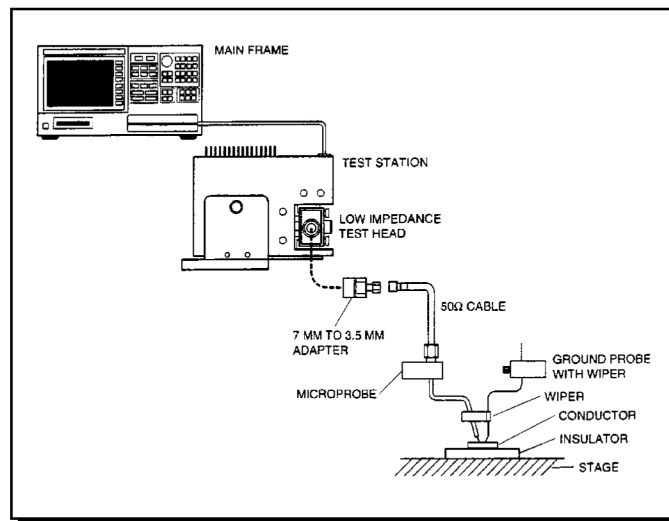


Figure 9-1. Probing system

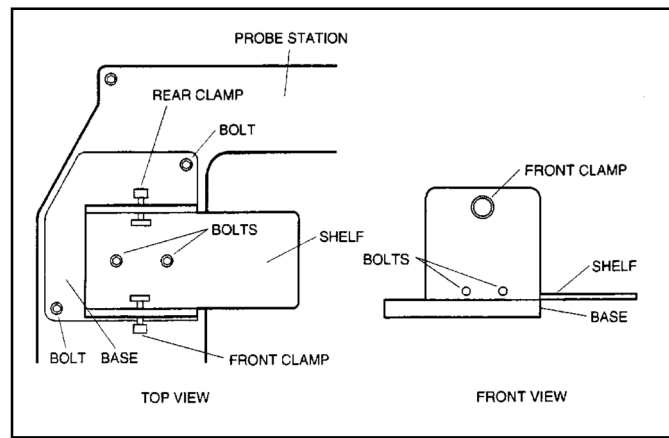


Figure 9-2. Test station bracket

**b.** Verify that the correct test head is connected and mounted in the 4291B test station. Place the test station on the bracket, trying to position the test station so that it is sitting vertically in the bracket. The test head should be within 3 inches of the micro-positioners and the test site. The test site is the exact position on the probe station stage where the IC package is located; refer to Figure 9-3, Mounting Test Station. Mechanically secure the test station by adjusting the bracket clamps so that the test station is firmly held in place.

**c.** After setting up the 4291B for a specific test setup and instrument state (Section 7) and performing SOLA CALIBRATION at the test station/test head (refer to Section 8), the next step is to add a 7 mm-to-SMA adapter (part number 1250-1746 or equivalent) to the 4291B test head.

**d.** Mount the Cascade Microtech FPS-1X and FPG-001 microprobes on the micro-positioners with the WPH Mount-to-FP adapters.

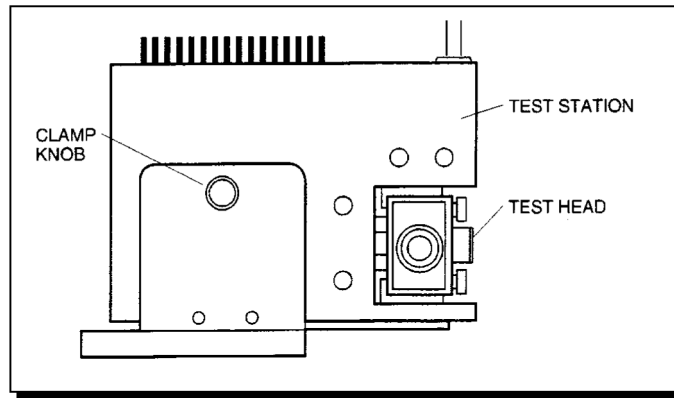
**e.** Connect a cable from the SMA adapter to the Cascade Microtech FPS-1X microprobe. Refer to Figure 9-4, Attaching the Probe. The cable must be a high quality, low loss, 50  $\Omega$  cable, and must have a 3.5 mm male connector and a 3.5 mm female connector. Ideally, the cable should be just long enough to connect from the adapter connector to the microprobe, usually 3 inches. Whether the cable is rigid or flexible will determine the ease of positioning the microprobe on the probe station stage; typically a flexible cable is much more easier to maneuver and use. A rigid cable

has better repeatability characteristics but is much more difficult to maneuver. Connect the FPG-001 grounding microprobe wiper to the FPS-1X microprobe.

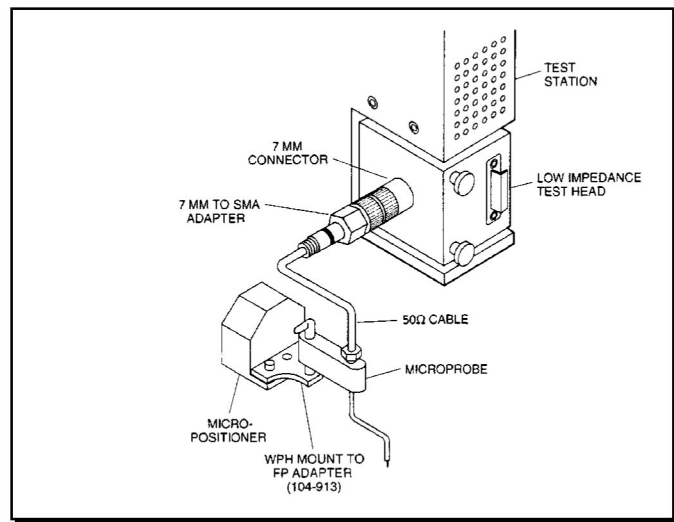
**f.** Place an insulated sheet of material on top of the probe station metal stage and mechanically secure it so that no lateral movement can occur. Refer to Figure 9-5, Insulate Stage. The insulated sheet should be lossy, have a low dielectric constant, and be at least 100 mils (2.54 mm) thick. The

purpose of the sheet is to minimize the effects of stray capacitance and mutual inductance contributed by the probe station's metal stage.

**g.** Place the Cascade Microtech Impedance Standard Substrate on the insulated sheet and mechanically secure it so that the substrate will not move. The substrate must be located in the same area that the IC package will be tested.



**Figure 9-3. Mounting test station**



**Figure 9-4. Attaching the probe**

**h.** Perform fixture COMPENSATION using open, load, and short. For an open, use the exact point-to-point distance and alignment of the IC package conductor to separate the microprobe contacts in the air from each other. For a load, use the 50  $\Omega$  load on the

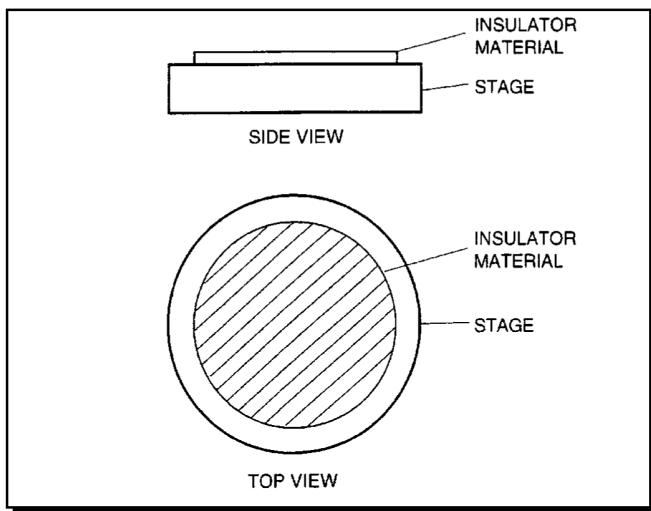
Impedance Standard Substrate. For a short, remove the substrate, use a sheet of clean bright copper as the short, and make contact on the copper sheet using the exact point-to-point distance of the IC package conductor to separate the microprobes.

**i.** Verify that COMPENSATION has been correctly completed by measuring the substrate 50  $\Omega$  load and the copper short. The measured results should be very close to 50  $\Omega$  and 0  $\Omega$ . If not, then perform COMPENSATION again.

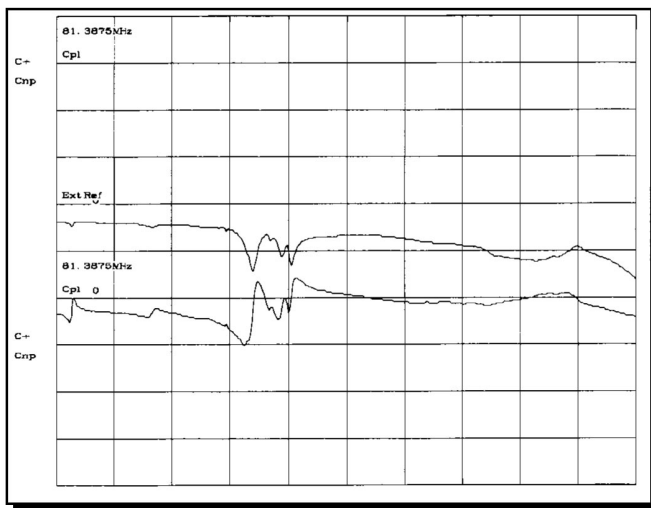
**j.** Remove the Impedance Standard Substrate and copper sheet from the insulated sheet. Place the IC package on the insulated sheet and mechanically secure it so that no movement will occur.

**k.** Maneuver the microprobes to the desired conductor and make firm contact to it.

**l.** The test system is now ready for a swept inductance measurement.



**Figure 9-5.** Insulate stage



**Figure 10-1.** Series inductance

## 10. The Test Data

The Agilent 4291B should be displaying data corresponding to  $L_s$  and  $R_s$  as a function of frequency. Refer to Figure 10-1, Series Inductance. In this particular measurement, the IC package sample is a quad flat pack, has copper leads, and is normally used with digital circuitry using a 50 MHz clock rate. A start frequency of 50 MHz and a stop frequency of 500 MHz were used in the test. The conductor has a length of about 8 mm. Typical results were a series inductance of 1nH and a series resistance of about 10 m $\Omega$ , which fits in for theoretical values. These are some evidence that the anomalies centered at 215 MHz may have been caused by the grounding probe wiper arm. An alternate way of characterizing an IC package is to look at the impedance magnitude and phase data. Refer to Figure 10-2, Impedance.

## 11. Summary

It is clear that the electrical characterization of IC packages is an accomplished art. It requires the patience of a saint, the fine motor skills of a gymnast, the craftsmanship of a watchmaker, and the latest design knowledge of an IC packaging engineer. The purpose of this application note is not to fully describe in great detail how to make a specific type of measurement, although it may be interpreted as such. Instead, the objective is to give enough general information for people to feel comfortable using the 4291B Impedance/Material Analyzer with a Cascade Microtech Probe Station for this application. Other key related subjects that have not been addressed here are testing guidelines, computer modeling, data analysis and conversion, ground plane measurements, and evaluating multiple pin array matrices. Each of these topics are worthy of deep exploration and are well beyond the scope of this document. The following references provide more in-depth information:

- “Standard Measurement Guidelines for Electronic Package Inductance and Capacitance Model Parameters” by JEDEC Solid State Products Engineering Council
- “High Performance Packaging Solutions” by Dr. Eric Bogatin, published by Integrated Circuit Engineering

## 12. Recommended List of System Components

- 4291B Impedance/Material Analyzer with Option 012 Low Impedance Test Head (1)
- Cascade Microtech Summit 9000 (or 10000) Analytical Probe Station (1)
- Micro-positioners with East and West orientations (1 of each)
- 7 mm to SMA adapter (1)
- 3 inch cable, SMA male to SMA female (1)
- Cascade Microtech WPH Mount-to-FP adapter (2)
- Cascade Microtech Impedance Standard Substrate (1)
- Insulator substrate (6 inches x 6 inches, various thicknesses)
- Copper sheet or strip

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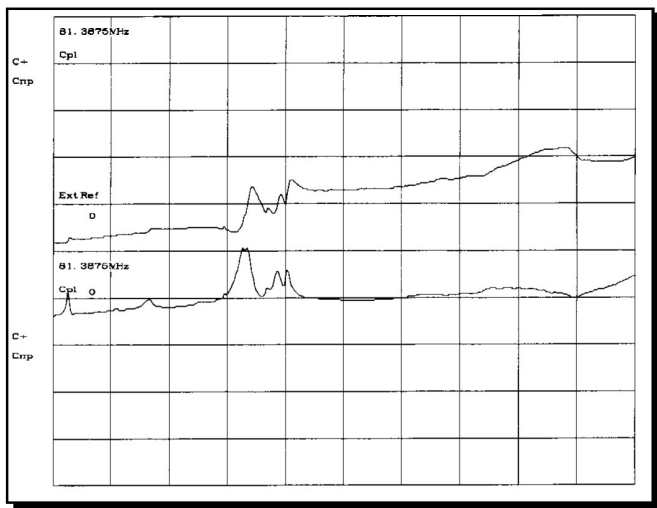


Figure 10-2. Impedance



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