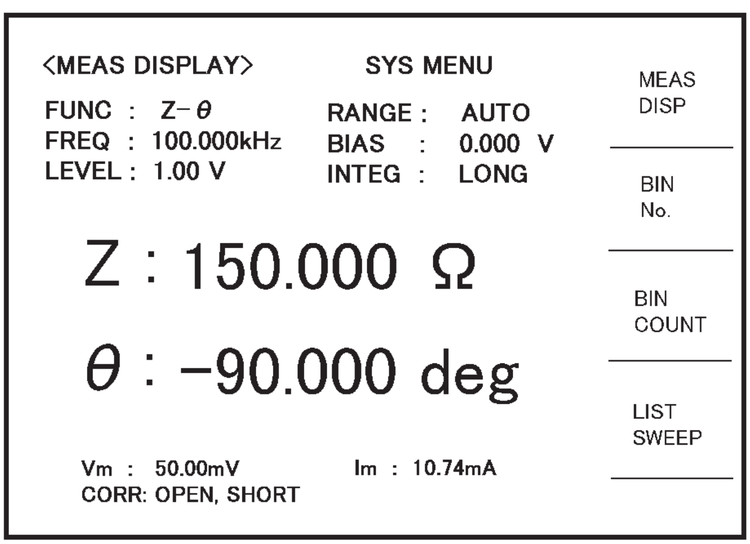
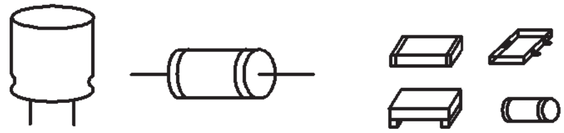
8 Hints for Successful Impedance Measurements

Application Note 346-4





How to evaluate electronic devices used in circuits in order to achieve design performance.

Impedance is measured using a variety of techniques. The advantages of each technique depend on test frequency, the impedance to be measured, as well as preferred display parameters.

The **Auto Balancing Bridge** technique is exceptionally accurate over a broad impedance range (mΩ to the order of 100MΩ). The frequency range this technique can be applied to is from a few Hz to 110MHz.

The **IV** and **RF-IV** techniques are also very accurate over a broad impedance range (mΩ to MΩ). The frequency range this technique can be applied to is from 40Hz to 1.8GHz.

The **Transmission/Reflection** technique is applied over the broadest frequency range (5Hz to 110GHz). This technique delivers exceptional accuracy near 50Ω or 75Ω, depending on the system.

LCR Meters and Impedance Analyzers are differentiated primarily by display properties. An LCR Meter displays numeric data, while an Impedance Analyzer can display data in either numeric or graphic format. The techniques employed by these instrument types are independent of analyzer type, and can be RF-IV, IV or Auto Balancing Bridge (depending on frequency).

Engineers perform impedance measurements for a variety of reasons. In a typical application, an electronic device used in a designed circuit is characterized. Normally, a manufacturer states only the nominal value of the electronic device.

Engineering concerns as well as production, procurement and distribution decisions are based on the quality of measurements. The value of every electronic component is determined by its performance and/or stated values. This performance determines the quality of assembled products.

This guide provides useful information when using the Auto Balancing Bridge, IV or RF-IV techniques.

'*8 Hints for making Better Network Analyzer Measurements*' is available as a guide to the Transmission/Reflection technique.

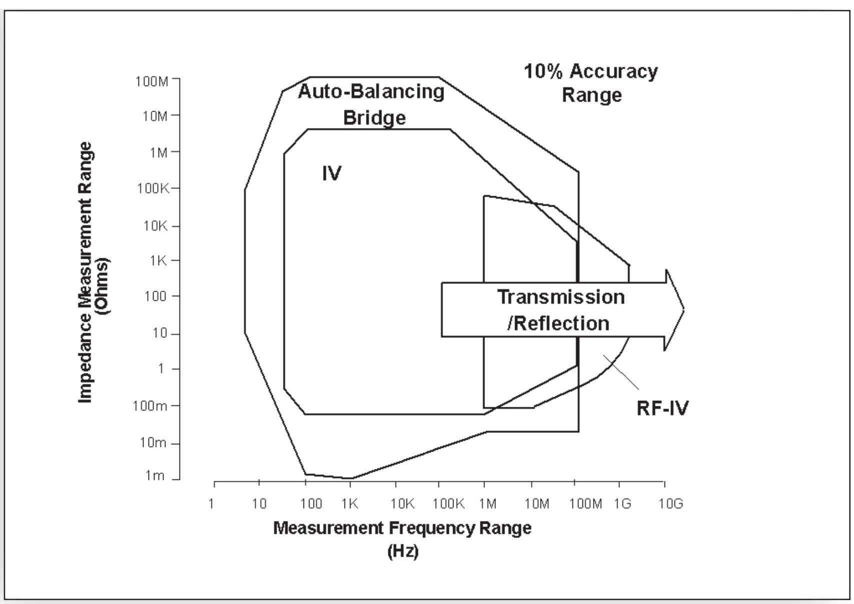


Figure 0-1 Accuracy Profile

Impedance Parameters

HINT 1

Impedance is a parameter used to evaluate the characteristics of electronic devices. Impedance (Z) is defined as the total opposition a device offers to the flow of an alternating current (AC) at a given frequency.

Impedance is represented as a complex, vector quantity. A polar coordinate system is used to map the vector, where quadrants one and two correspond respectively to passive inductance and passive capacitance. Quadrants three and four correspond to negative resistance. The impedance vector consists of a real part, resistance (R), and an imaginary part, reactance (X).

Figure 1-1 shows the impedance vector mapped in quadrant one of the polar coordinate system.

Capacitance (C) and inductance (L) are derived from resistance (R) and reactance (X). The two forms of reactance are inductive (X_L) and capacitive (X_C).

The Quality Factor (Q) and the Dissipation Factor (D) are also derived from resistance and reactance. These parameters serve as measures of reactance purity. When Q is larger or D is smaller, the quality is better. Q is defined as the ratio of the energy stored in a component to the energy dissipated by the component. D is sometimes called "tanδ", since it is the tangent of the complimentary angle (δ) to the phase angle (θ). Both D and Q are dimensionless quantities.

Figure 1-2 describes the relationship between impedance and these derived parameters.

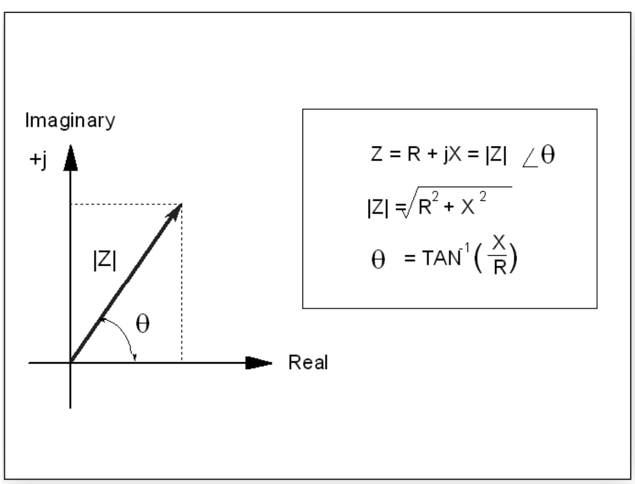


Figure 1-1 Impedance Vector

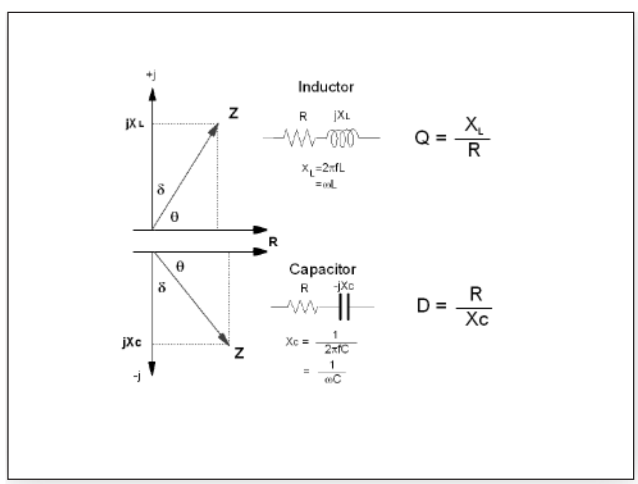


Figure 1-2 Capacitor and Inductor Parameters

HINT 2

Measurements Depend on Test Conditions

Stated values represent the performance of a component under specific test conditions, as well as the tolerance permitted during manufacture. When circuit performance requires more accurate characterization of a component, it is necessary to verify stated values, or to evaluate device performance at operating conditions (usually different than manufacturers test conditions).

Frequency dependency is common to all real-world components because of the existence of parasitics.

Figure 2-1 describes ideal and parasitic frequency characteristics of a real-world capacitor.

Signal level (AC) dependency is exhibited in the following ways (Figure 2-2):
- Capacitance is dependent on AC voltage level (dielectric constant (K) of the substrate).
- Inductance is dependent on AC current level (electromagnetic hysteresis of the core material).

The AC Voltage across the device can be derived from the device impedance, the source resistance, and the signal source output (Figure 2-3).

An automatic level control (ALC) function maintains a constant voltage across the DUT. It is possible to write an ALC program for instruments that have a level monitor function, but not a built-in ALC.

Control of measurement integration time allows reduction of unwanted signals. The averaging function is used to reduce the effects of random noise. Increasing the integration time or averaging allows improved precision, but with slower measurement speed.

Detailed explanations of these test parameters can be found in the instrument operating manuals.

Other physical and electrical factors that effect measurement results include DC Bias, temperature, humidity, magnetic fields, light, atmosphere, vibration, and time.

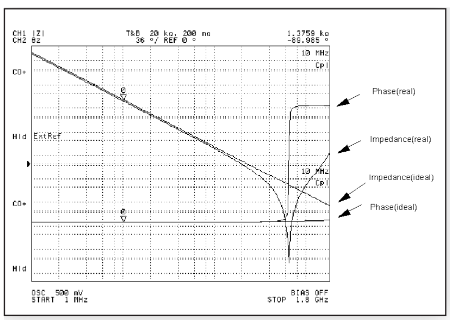


Figure 2-1. Frequency Characteristics of a Capacitor

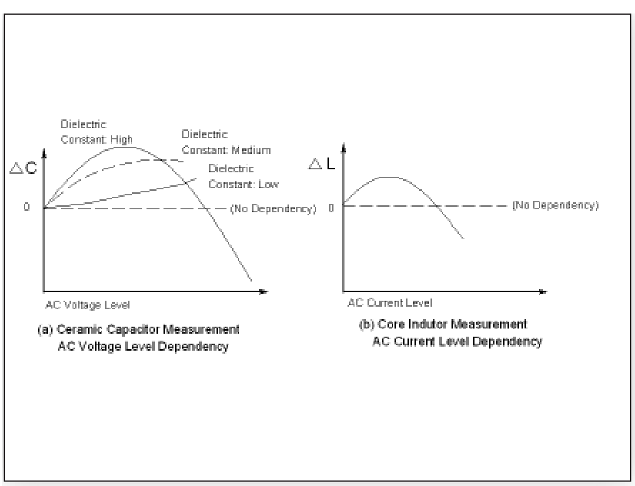


Figure 2-2. Signal Level Dependency

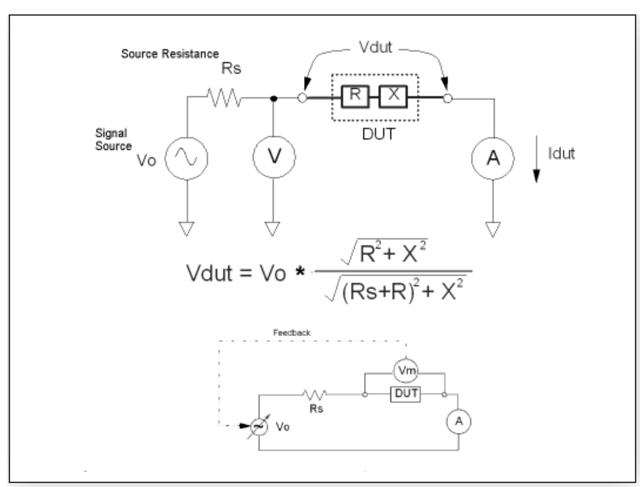


Figure 2-3. Applied Signal & Constant Level Mechanism

Choose Appropriate Instrument Display Parameter

HINT 3

Many modern impedance measuring instruments measure the real and the imaginary parts of an impedance vector and then convert them into the desired parameters.

When a measurement is displayed as impedance (Z) and phase (θ), the primary element (R, C, or L) as well as any parasitics are all represented in the |Z| and θ data.

When parameters other than impedance and phase angle are displayed, a two element representation of the measured data is used. These two element models are based on a series or parallel circuit mode (Figure 3-1), and are distinguished by the subscript p for parallel or s for series (Rp, Rs, Cp, Cs, Lp, or Ls).

All circuit components are neither purely resistive nor purely reactive. A real-world component contains many parasitic elements. With the combination of a component's primary and parasitic elements, a component performs like a complex circuit.

Recent, advanced impedance analyzers have an Equivalent Circuit Analysis Function that allows analysis of the measurement result in the form of three or four element circuit models (Figure 3-2). Use of this function enables a more complete characterization of a component's complex residual elements.

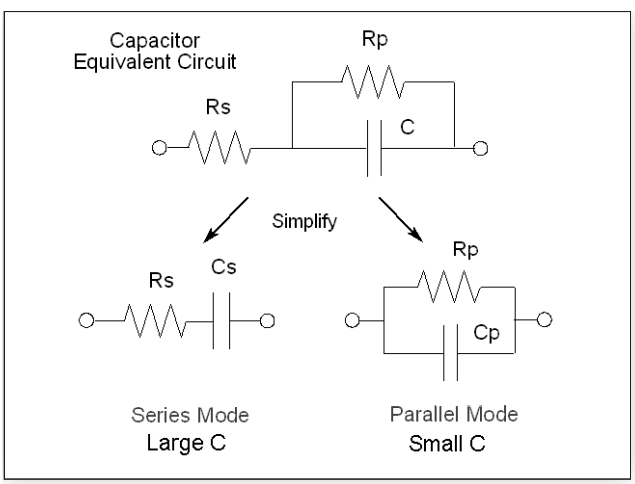


Figure 3-1. Measurement Circuit Mode

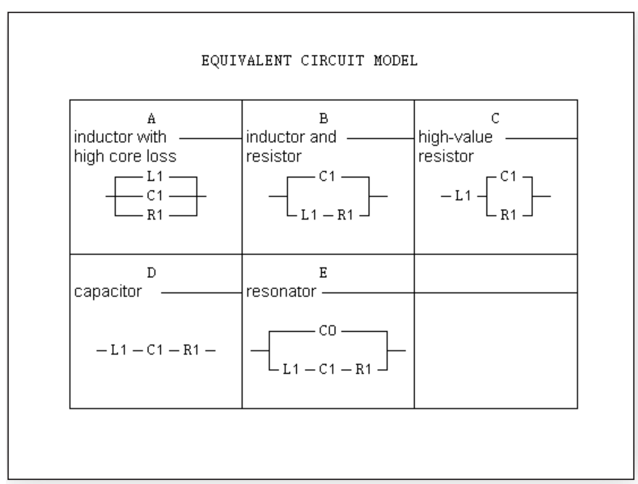


Figure 3-2 Equivalent Circuit Analysis Function

HINT 4

A Measurement Technique has Limitations

What's the number one question from engineering and production?

How accurate is the data?

Instrument accuracy is different for different impedance values. Instrument accuracy is also different for different measurement technologies (reference Figure 0-1).

To know the accuracy of a measurement, compare the measured impedance value of the DUT to the instrument accuracy for the applicable test conditions.

Figure 4-1 shows that a 1 nF capacitor, measured at 1MHz exhibits an impedance of 159Ω.

Instrument accuracy specifications for D or Q measurements are usually different than specifications for other impedance terms.

In the case of a low loss device (low D/High Q device), the R-value is very small relative to the X-value. Small changes in R result in large Q-value changes (Figure 4-2).

The measurement error is on the order of the measured R-value. This can result in negative D or Q values.

Be aware that measurement error includes error introduced by the instrument as well as by the test fixture.

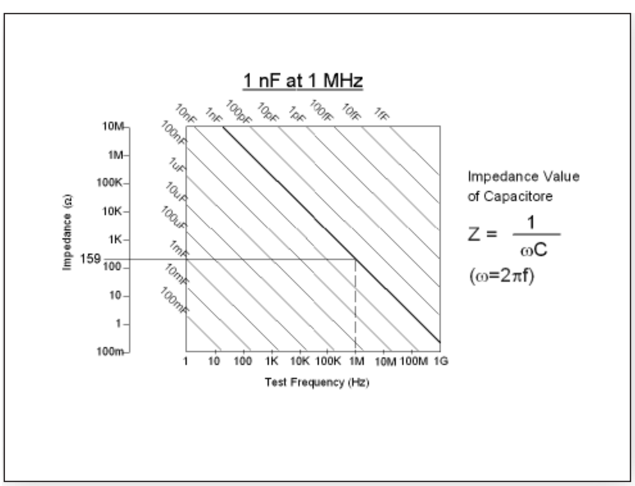


Figure 4-1 Capacitor's Impedance and Test Frequency

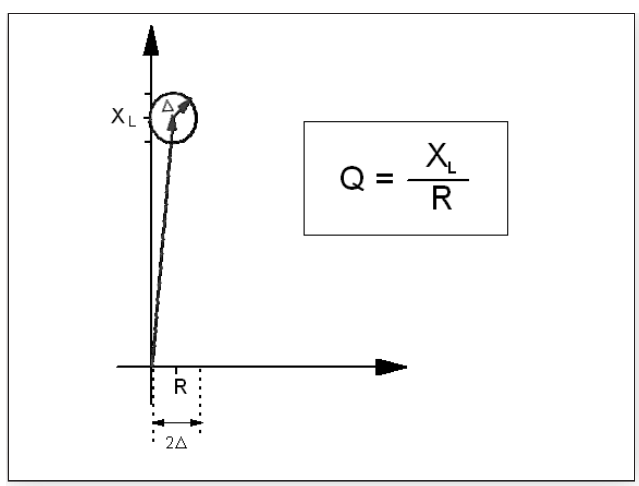


Figure 4-2. Concept of the Q error

Perform Necessary Calibration

HINT 5

Calibration is performed in order to define a reference plane where the measurement accuracy is specified. Normally, calibration is performed at the instrument's test port. Corrections to raw data are based on calibration data.

A baseline calibration is performed at service centers for Auto Balancing Bridge instruments such that the specified accuracy can be realized for a period of time (usually twelve months) regardless of the instrument settings. With these instruments, operators do not require calibration standards.

Baseline calibration for non- Auto Balancing Bridge instruments requires that a set of calibration standards be used after instrument initialization and setup. This hint provides information that may be helpful when using calibration standards to establish calibration for these instruments.

Some instruments offer the choice of Fixed-mode or User-mode calibration. Fixed-mode calibration measures calibration standards at predetermined (fixed) frequencies. Calibration data for frequencies between the fixed, calibrated points are interpolated.

Fixed-mode calibration sometimes results in interpolation errors at those frequencies between the fixed, calibrated points. At higher frequencies these errors can be substantial.

User-mode calibration measures calibration standards at the same frequency points the user has selected for a particular measurement. There can be no interpolation errors associated with User-mode calibration.

It is very important to recognize that the operator-established calibration is valid only for the test conditions (instrument state) under which calibration is performed.

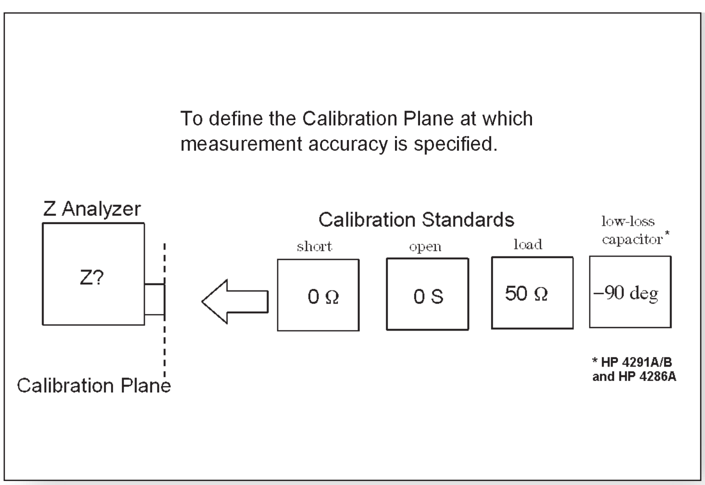


Figure 5-1. Calibration Plane

HINT 6

Perform Necessary Compensation

Compensation is not the same as calibration. The effectiveness of compensation depends on the instrument calibration accuracy, therefore compensation must be performed after calibration has been completed.

When a device is directly connected to the calibration plane, the instrument can measure within a specified measurement accuracy. Since a test fixture or adapter is usually connected between the calibration plane and the device, the residual impedance of the interface must be compensated for in order to perform accurate measurements.

Additional measurement error introduced by a test fixture or adapter can be substantial. The total measurement accuracy consists of the instrument accuracy as well as error sources that exist between the device under test (DUT) and the calibration plane.

It is important to verify that error compensation works properly. In general, the impedance value for an Open condition should be greater than 100 times the impedance of the DUT. In general, the impedance value for a Short condition should be less than 1/100 the impedance of the DUT.

Open compensation reduces or eliminates stray capacitance, while short compensation reduces or eliminates unwanted resistance and inductance of fixturing.

When an Open or a Short measurement is performed, keep the distance between the UNKNOWN terminals the same as when the DUT is contacted. This keeps parasitic impedance the same as when measurements are performed.

Perform Load compensation when the measurement port is extended a non-standard distance, the configuration uses additional passive circuits/components (e.g. balun, attenuator, or filter), or when a scanner is used. The impedance value of the Load must be accurately known. A Load should be selected that is similar in impedance (at all test conditions) and form-factor to the DUT. Use a stable resistor or capacitor as the LOAD device.

It is practical to measure a Load using Open/Short compensation and a non-extended fixture in order to determine the Load impedance. The values measured can then be input as compensation standard values.

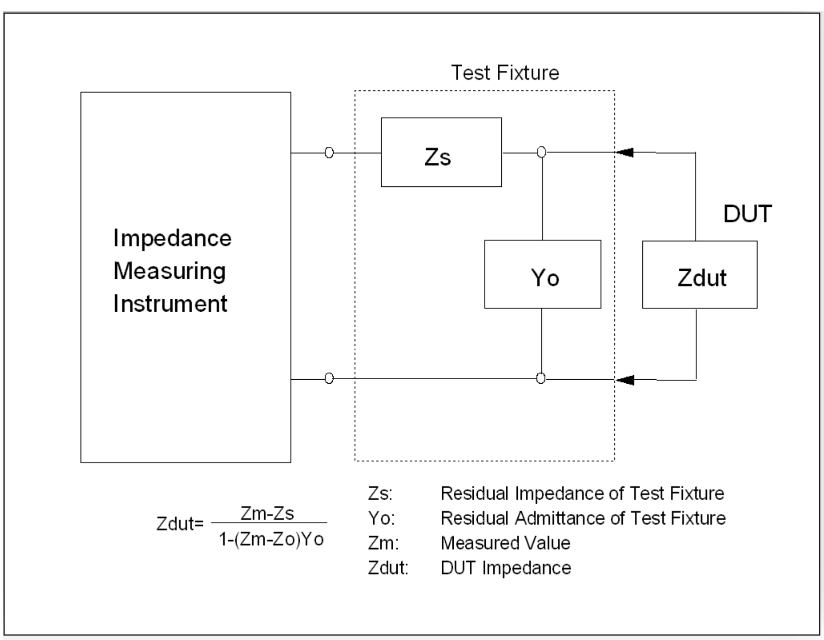


Figure 6-1 OPEN/SHORT Compensation

Understanding Phase Shift and Port Extension Effects

HINT 7

Cable Length correction, port extension, or electrical delay is used to extend or rotate the calibration plane to the end of a cable or the surface of a fixture. This correction reduces or eliminates phase shift error in the measurement circuit.

When the measurement port is extended away from the calibration plane, the electrical characteristics of the cable effect the total measurement performance.

To reduce these effects:
- Make measurement cables as short as possible.
- Use well-shielded, coaxial cables to prevent influence from external noise.
- Use low-loss coaxial cables to keep from degrading accuracy, since the port extension method assumes lossless cable.

A phase shift induced error occurs due to the test fixture, which can not be reduced using OPEN/ SHORT compensation.

When working in the RF region, calibration should be performed at the end of an extension cable. If calibration standards cannot be inserted, port extension can be used in this region for short and well-characterized distances.

An Auto Balancing Bridge and using non-standard cables or extensions, Open/Short/Load compensation should be performed at the terminus of an extension or fixture. HP Auto Balancing Bridge products use cable length compensation for standardized test cables (1, 2, or 4 meters). At the terminus of the standardized extension cable, the shields should normally be connected together.

Port Extension in any form has limitations. Since any extension will contribute to losses in the measurement circuit and/or phase error, it is imperative that the limitations of the measurement technique be fully understood prior to configuring an extension.

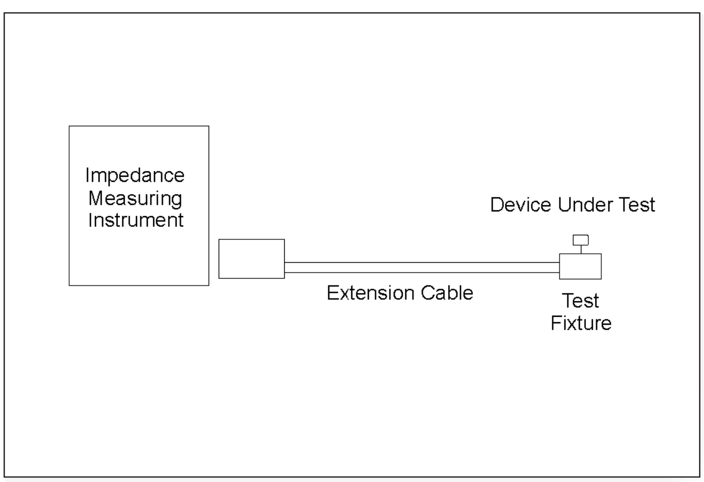


Figure 7-1 Measurement Port Extension

HINT 8

Fixture and Connector Care

High quality electrical connections insure the capability to make precise measurements. At every connection, the characteristics of the mating surfaces vary with the quality of connection. An impedance mismatch at mating surfaces will influence propagation of the test signal.

Attention should be paid to the mating surfaces at test ports, adapters, calibration standards, fixture connectors, as well as test fixture surfaces.

The quality of connections depend on the following

- composition
- technique
- maintenance
- cleanliness
- storage

Composition:
It has been said that a chain is as strong as the weakest link. The same is true for a measurement system. If low-quality cables, adapters or fixtures are used in a test circuit, the quality of the system is reduced to the lowest quality interface.

Technique:
The use of a torque wrench and common sense insures that damage does not occur when making repeated connections. Damage includes scratching and deformation of the mating surfaces.

Maintenance:
Many mating surfaces are designed to allow for the replacement of parts that degrade with use. If a mating surface cannot be repaired, regularly scheduled replacement is advised.

Cleanliness:
The use of non-corrosive/destructive solvents [de-ionized water, pure isopropyl alcohol (IPA)] and lint-free wipes insures that the impedance at mating surfaces is not influenced by residual oils or other impurities. Note that some plastics are denatured with the use of IPA.

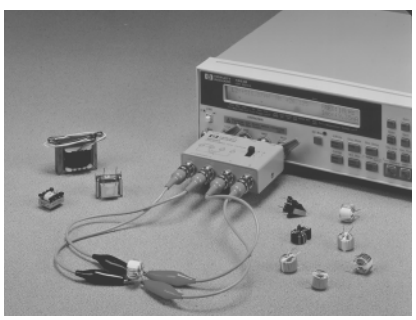
Storage:
If a case is not provided with an accessory, plastic caps should be used to cover and protect all mating surfaces when not in use.

HP Impedance Product Lineup

The HP impedance product lineup offers the widest selection of equipment for your application. Major impedance measuring instruments are introduced as follows. For more information, refer to "LCR meters, Impedance analyzers, and Test Fixtures Selection Guide" (P/N 5952-1430E), "RF Economy Network Analyzer " (P/N 5967-6316E) etc.

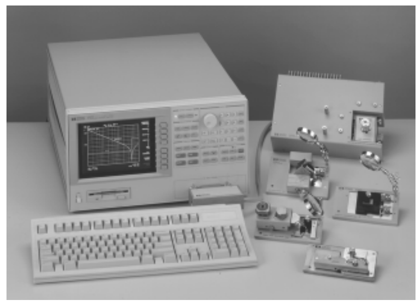
LCR meter series

The HP LCR meter series provides the capability to easily and accurately evaluate components such as, capacitors, inductors, transformers and electromechanical devices. The ability to apply specific measurement conditions (test frequency, signal level, etc.) is important in the R&D, production test and QA environments.



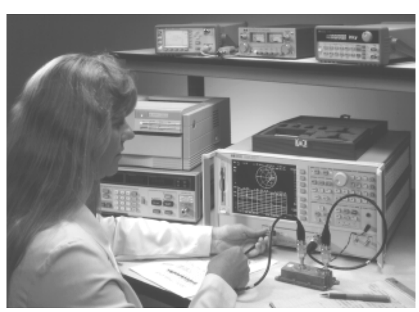
Impedance analyzer series

The HP impedance analyzer series delivers the capability to observe characteristic changes in device performance as result from changes in specific measurement conditions. The characteristic changes in device performance can be displayed in a graphical format on the instrument display. This series provides various sophisticated functions, such as a marker function and programming function that ease evaluation of measurement results. The features provided within this series enable characteristic evaluations at Lab/ R&D sections, as well as reliability evaluations (temperature characteristic evaluation, etc.) for QA purposes.



Network analyzer series

The HP network analyzer series allows impedance measurements in higher frequencies like RF and MW. The measuring technique, the transmission/reflection technique, can go to a much higher frequency than is available with other techniques. This series also provides various sophisticated functions, such as a graphical display, marker function, and programming function that ease evaluation of measurement results. The features provided within this series enable evaluations in Lab/ R&D as well as QA departments.



Combinations analyzer series

The HP combination analyzer series provides three capabilities (network measurement, spectrum measurement, and impedance measurement) in one box. These instruments deliver broad functionality to engineers (from circuit design to device evaluation). Graphical displays are provided, which enable analysis of device characteristics for not only impedance, but also network and spectrum measurements.

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