Application Note

What is the Accuracy Anyway?

Let's take a close look at how accuracy is specified in an impedance-measuring instrument and how to calculate the accuracy of two different LCR meters. An LCR meter measures the primary impedance parameters—Inductance (L), capacitance (C) and resistance (R), and secondary parameters—dissipation factor (D), quality factor (Q), phase angle, and equivalent series resistance (ESR).

Definitions

Accuracy	The difference between the measured value or reading and the true or accepted value. The accuracy of an LCR meter is typically given as a ± percentage of the measured value for primary parameters and ± an absolute value for secondary parameters. For example: ±0.05% for L, and ±0.0005 for D.
Resolution	The smallest value that can be shown on the display.
Repeatability	The difference between successive measurements with no changes in the test setup or test conditions.
Reproducibility	Similar to repeatability with the addition of real life conditions such as the variability in fixtures when the DUT is removed from the fixture and then re-inserted.
Impedance	The AC resistance (Z) of the DUT; a Vector summation of resistance R and reactance (X). For capacitors reactance is defined as $X_C = 1/j\omega C$ For inductors reactance is defined as $X_L = j\omega L$ For resistors resistance is defined as R Impedance is defined as $Z = \sqrt{(X^2 + R^2)}$

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How an LCR meter works

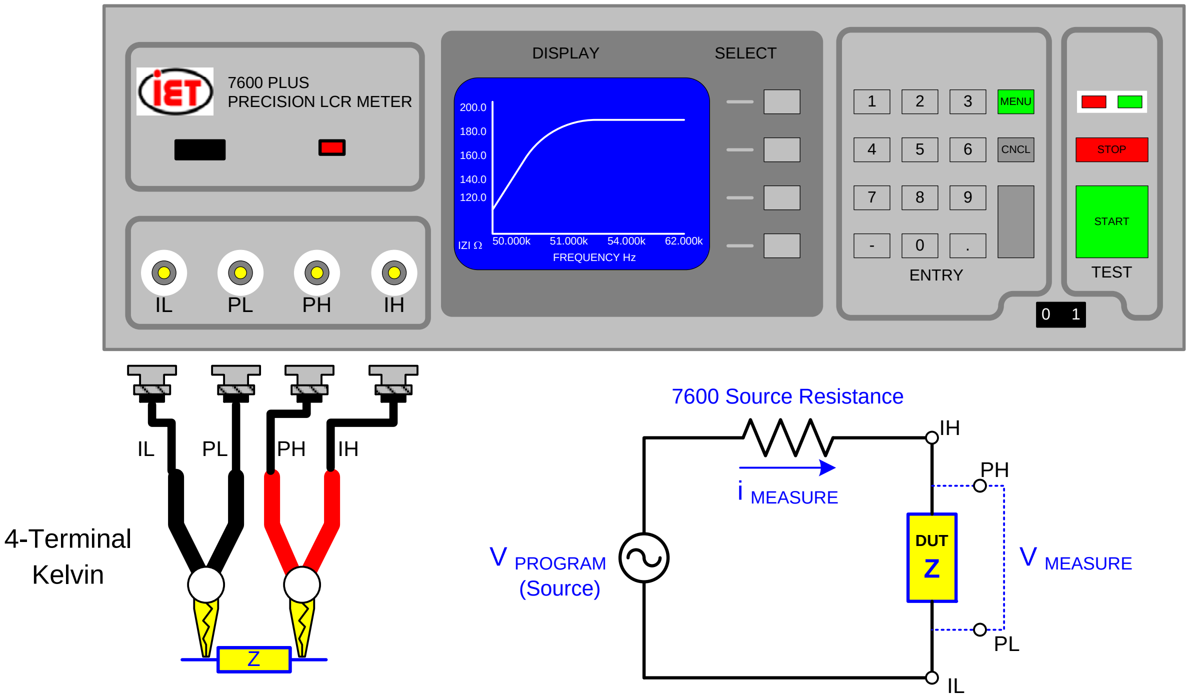

Figure 1.0: Four-Terminal Connection and Source Resistance

There are four terminals on an LCR meter. PH and PL are the two terminals that measure the voltage across the DUT. IH and IL are the two terminals that provide the signal and measure the current flowing through the DUT. It also needs to be noted that in order to measure the current a resistor is placed in series with the signal source. This is referred to as the source resistance. These connections are shown in Figure 1.0.

An LCR meter measures the current flowing through the DUT and voltage across the DUT using the four-terminal connection. The phase shift between the voltage and current signals is also determined. Knowing the voltage and current allows the LCR meter to use Ohm's Law (Z = V/I) to calculate the magnitude of the impedance. The impedance combined with the phase angle allows the determination of impedance and resistance using the following formulas

$X = Z * \sin(\phi)$ and $R = Z * \cos(\phi)$

Using these values all other parameters can be calculated such as L and C.

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Accuracy: Basic or Actual?

The **basic** accuracy is specified at optimum conditions: 1VAC RMS signal level, 1kHz frequency, 1 measurement/second, and a DUT impedance between 10Ω and 100kΩ.

Manufacturers of LCR meters specify basic accuracy which does not account for error due to fixtures or cables. (There are also techniques that improve measurement accuracy. These techniques will be discussed in another article on averaging, median mode and load correction.)

Typical LCR meters have a basic accuracy between ±0.01% and ±0.5%.

If the measurements are to be made outside of "optimum" conditions, the **actual** accuracy of the measurement is calculated using a formula or by looking at a graph of accuracy vs. impedance and frequency.

The accuracy formulas take into account each of the conditions effecting accuracy. Most common are measurement range, accuracy/speed, test frequency, and voltage level. There are addition errors including dissipation factor of the DUT, internal source impedance and ranges of the instrument, that effect accuracy.

It is also important to understand that the measurement range is really more a display range. For example an LCR will specify a measurement range of 0.001nH to 99.999H this does not mean you can accurately measure a 0.001nH inductor or a 99.9999H inductor, but you can perform a measurement and the display resolution will go down to 0.001nH or up to 99.999H. This is really why it is important to check the accuracy of the measurement you want to perform. Do not assume that just because the value you want to measure is within the measurement range you can accurately measure it.

Factors Affecting Accuracy Calculations

DUT Impedance

High impedance measurements increase the error because it is difficult to measure the current flowing through the DUT. For example, if the impedance is greater than 1MΩ and the test voltage is one volt there will be less than 1μA of current flowing through the DUT. The inability to accurately measure the current causes an increase in error.

Low impedance measurements have an increase in error because it is difficult to measure the voltage across the DUT. Most LCR Meters have a resistance in series with the source of 100, 50, 25, 10 or 5 ohms. As the impedance of the DUT approaches the internal source resistance the voltage across the DUT drops proportionally. If the impedance of the DUT is significantly less than the internal source resistance then the voltage across the DUT becomes extremely small and difficult to measure causing an increase in error.

Frequency
The impedance of reactive components is also proportional to frequency. For example, measurement of a 1µF capacitor at 1 kHz would be within basic measurement accuracy, where the same measurement at 1MHz would have significantly more error. Part of this is due to the decrease in the impedance of a capacitor at high frequencies; however there generally is increased measurement error at higher frequencies inherent in the internal design of the LCR meter.

Resolution
Resolution must also be considered for low value measurements. If trying to measure 0.0005 ohms and the resolution of the meter is 0.00001 ohms then the accuracy of the measurement cannot be any better than ±2% which is the resolution of the meter.

Accuracy and Speed
Accuracy and speed are inversely proportional. That is the more accurate a measurement the more time it takes. LCR meters will generally have 3 measurement speeds. The measurement speed can also be referred to as measurement time or integration time. Basic accuracy is always specified with the slowest measurement speed, generally 1 second for measurements above 1kHz. At lower frequencies measurement times can take even longer because the measurement speed refers to the integration or averaging of at least one complete cycle of the stimulus voltage. For example, if measurements are to be made at 10Hz, the time to complete one cycle is 1/frequency = 1/10Hz = 100 milliseconds. Therefore the minimum measurement speed would be 100ms.

Dissipation Factor (D) or Quality Factor (Q)
D and Q are reciprocals of one another. D = 1/q and Q = 1/D. The importance of D or Q is the fact that they represent the ratio of resistance to reactance or vice versa. This means that the ratio Q represents the tangent of the phase angle. As phase is another measurement that an LCR meter must make, this error needs to be considered. When the resistance or reactance is much greater than the other, the phase angle will approach ±90° or 0°. As shown in Figure 2.0, even small changes in phase at -90° result in large changes in the value of resistance, R.

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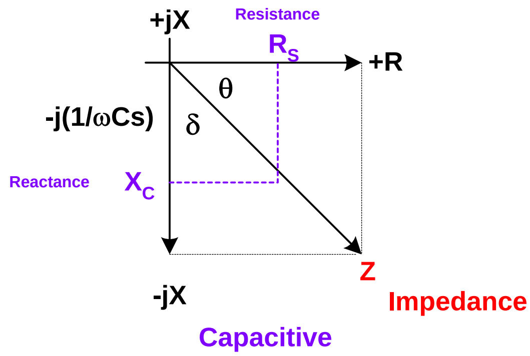

Figure 2.0: Phase Diagram for Capacitance

Overall, it means that the LCR meter may be able to accurately measure the primary parameter such as inductance (L) or capacitance (C), but be unable to accurately measure the secondary parameter such as resistance (R) or dissipation factor (D).

Application Note

Example: 7600 Accuracy Calculation & Graph

Calculated Accuracy using the formula is ±3.7%.

Kt = 1

Zm = 1/(2*π*frequency*C) = 1/(2*π*1000000*1x10^{-12}) = 159kohms

Zrange = 400 ohms

Vfs = 1

Multiply A% = 8

$$A\% = +/- \left[0.025 + \left(\left(0.025 + \left| \frac{.05}{159000} \right| + \left(\left| 159000 \right| \times 10^{-7} \right) \right) \times \left(\frac{.02}{1} + .08 \times \frac{1}{1} + \frac{(1-1)^2}{4} \right) \times \left(0.7 + \frac{1000000}{10^5} + \frac{300}{1000000} \right) \right) \right] \times 1$$

A% = 0.46%

Multiply A% times 8 due to Zm > 64 times Zrange

A% = 0.46% * 8 = 3.68%

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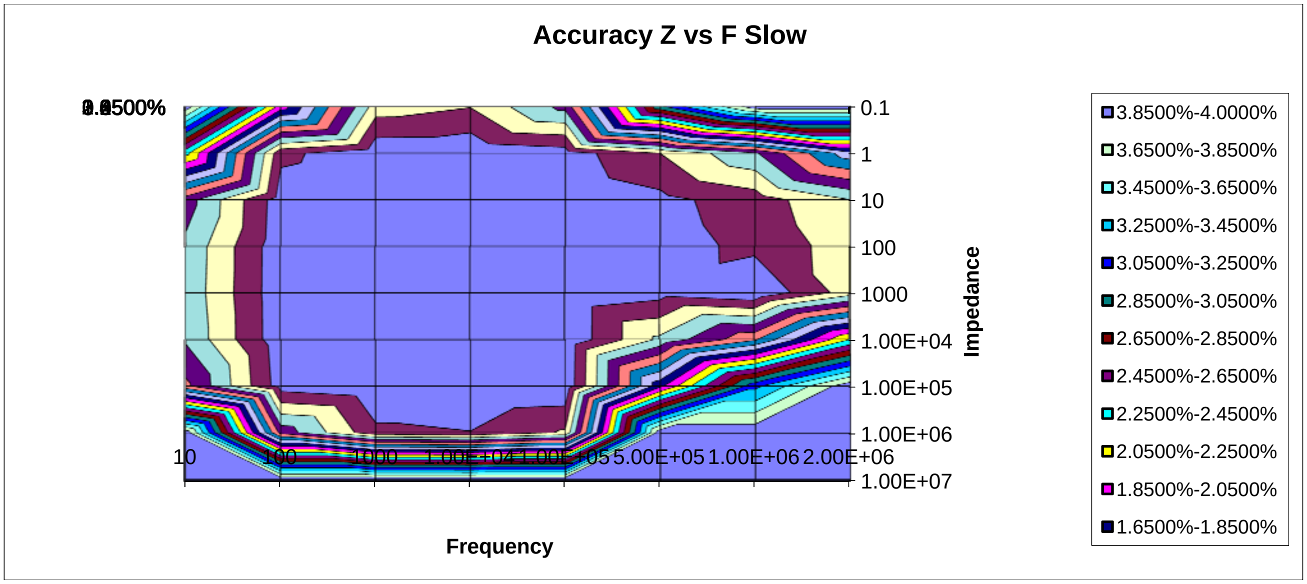
7600 Graph

The accuracy could have been predicted without the use of a formula. If we calculate the impedance of a 1pF capacitor at 159 kHz we get a value of:

$Z \approx Xs = 1/(2\pi * frequency * capacitance)$

$Z \approx Xs = 1/(2\pi * 1{,}000{,}000 * 0.000{,}000{,}000{,}001) = 159kohms$

Use the graph below and substitute Z for R. If we find the position on the graph for an impedance value of 1591ohms at 100kHz we see a light blue or teal representing an accuracy of 3.45% to 3.65%. Overall the graph and formula point to the same accuracy of ±3.5%.



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Application Note

Example: 1910 Accuracy Calculation

Conditions: 33nH Inductor at 1MHz, 1VAC signal, Auto Range, Non-Constant Voltage, and Slow Measurement Speed.

Basic Accuracy of the 1910 is ±0.1%

Accuracy Formula for the 1910 is:

Basic Accuracy For AC:

High 0.10%
Medium 0.25%
Low & Low No Display 0.5%

The actual accuracy at a given test condition is defined by the following formula:

$$\text{Accuracy} = \text{Acc}_{\text{Basic}} \sqrt[3/2]{\frac{1}{V}} \left[\left(1 + \frac{50}{\text{Freq}} + \frac{\text{Freq}}{200k} \right) \left(1 + \frac{|Z|}{Z_{MAX}} + \frac{1}{|Z|} \right) \right]$$

V = Programmed test voltage (V_{SOURCE})
Note: For frequencies above 100kHz V_{DUT} must be at least 20mV.
That is:
|Z| = DUT impedance
$V_{DUT}=V_{SOURCE}*(Z_{DUT}/Z_{DUT}+R_{SOURCE})$

Z_{Max} is $4*10^5$ for Frequency less than 10kHz
$2.5*10^4$ for Frequency less than 250kHz
$1.5*10^3$ for Frequency above 250kHz

1910 Calculated Accuracy

Calculated Accuracy using the formula is ±3.5%.

V = 1Volt
AccBasic = 0.1%
Freq = 1MHz
Z_{Max} = 1500 ohms
Z = $2*\pi*$frequency*L = $2*\pi*1000000*33x10^{-9}$ = 0.207ohms

$$\text{Accuracy} = 0.10 \times \sqrt[3/2]{\frac{1}{1}} \left[\left(1 + \frac{50}{1+10^6} + \frac{10^6}{200k} \right) \left(1 + \frac{|0.207|}{1500} + \frac{1}{|0.207|} \right) \right]$$

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Accuracy = 0.1*1[(6.0) * [5.823]] = 3.49%

Example: 1910 Accuracy Graph

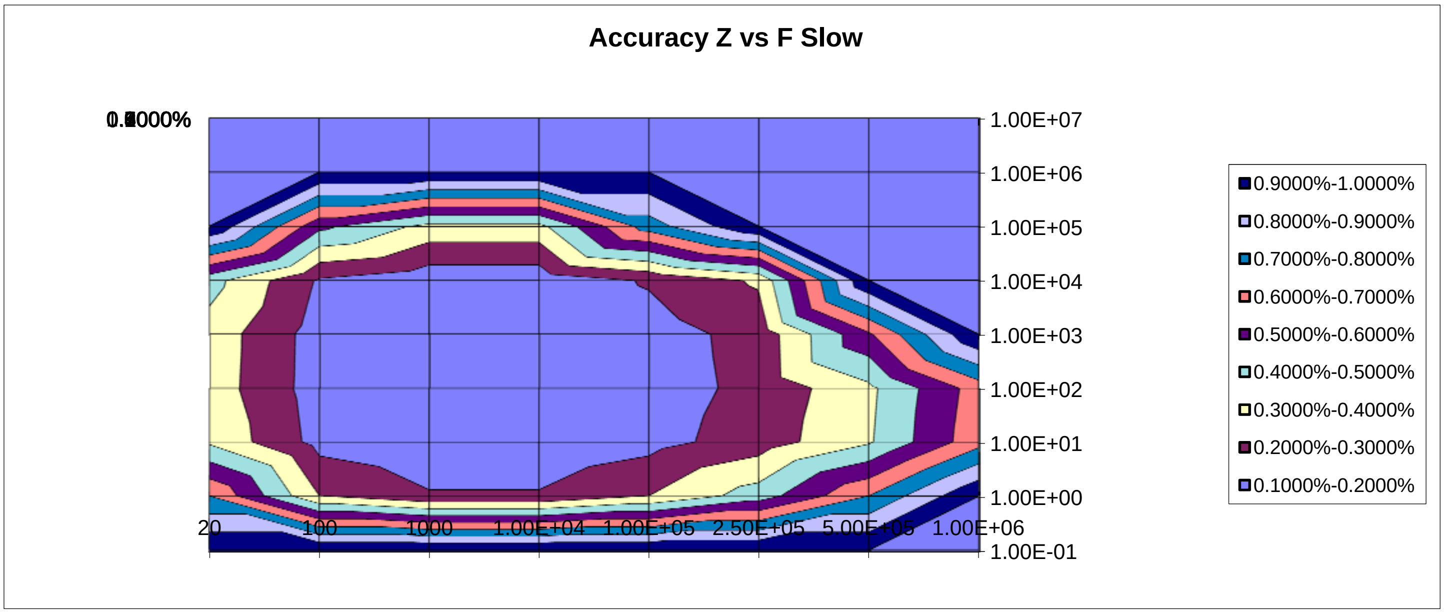
1910 Inductance Analyzer: Graph

The accuracy could not have been accurately determined without the use of a formula. If we calculate the impedance of a 33nH inductor at 1MHz we get a value of:

$Z \approx Xs = 1/(2\pi*frequency*capacitance)$

$Z \approx Xs = (2\pi*1,000,000*0.000,000,033) = 0.207ohms$

Using the graph below and substituting Z for R, we really cannot determine the value other than the error is over 1% which is the maximum value on the graph shown in purple.



For complete product specifications on the 7600 Plus Precision LCR meters or any of IET Lab's products, visit us at www.ietlabs.com.

Do you have an application specific testing need? Call us at 516-334-5959 and we'll work with you on a custom solution. Put IET Labs to the test because we're committed to solving your testing requirements.

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