Application Note

Calibration of 7000 Series Precision LCR Meters

Ever consider just how a precision impedance meter is calibrated? How the accuracy values are attained or what is meant by the uncertainty? What is the method to this measurement madness? Examine this discussion of the 7600 Plus and 7000 Series calibration procedure for information on basic calibration principles, zero correction and instrument calibration.

Also discussed is the thought process and method of calibrating the master cal kit. An instrument's calibration is only as accurate as the calibration of the reference standards used to perform that calibration.

Figure 1.0: 7000-09 Calibration Kit

7000 Series Instrument Calibration Procedure

Calibration Adjustment
The 7000-09 Calibration kit containing 4 resistance standards, 1 open standard and 1 short standard is used adjust the 7600 Plus LCR Meter. The nominal calibration kit values are 24.9Ω, 374Ω, 5.97kΩ and 95.3kΩ for the resistance standards which are identical to the internal resistance standards inside the 7600 Plus.

Adjustments are made on all measurement ranges at several frequencies. These values are then entered into instrument memory. Refer to Figure 2.0 for connection diagram. Interpolation formulas are used for all values between the calibrated frequencies. Instrument calibration and adjustment is recommended annually.

Calibration
After calibration adjustment, each 7600 Plus is calibrated using various GenRad 1406 and 1406 coaxial capacitance standards, and another 7000-09 calibration kit. Each standard is connected to the instrument, measured automatically at

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many frequencies (some at 27 frequencies from 10 Hz to 2MHz) and at many different test signal levels. A total of over 2500 measurements are made in a little less than 8 hours.

Instrument Accuracy

The basic accuracy specification of 0.05% states only the accuracy at optimum test conditions. Comprehensive accuracy formulas are detailed in the 7000 Plus Instruction Manual. The "AutoAcc" feature displays the accuracy for any specific measurement conditions on the instrument front panel. This accuracy does not include the uncertainty of the calibration standards used however the 7000-09 calibration kit uncertainties are 40 ppm which has a negligible effect on the overall accuracy specifications.

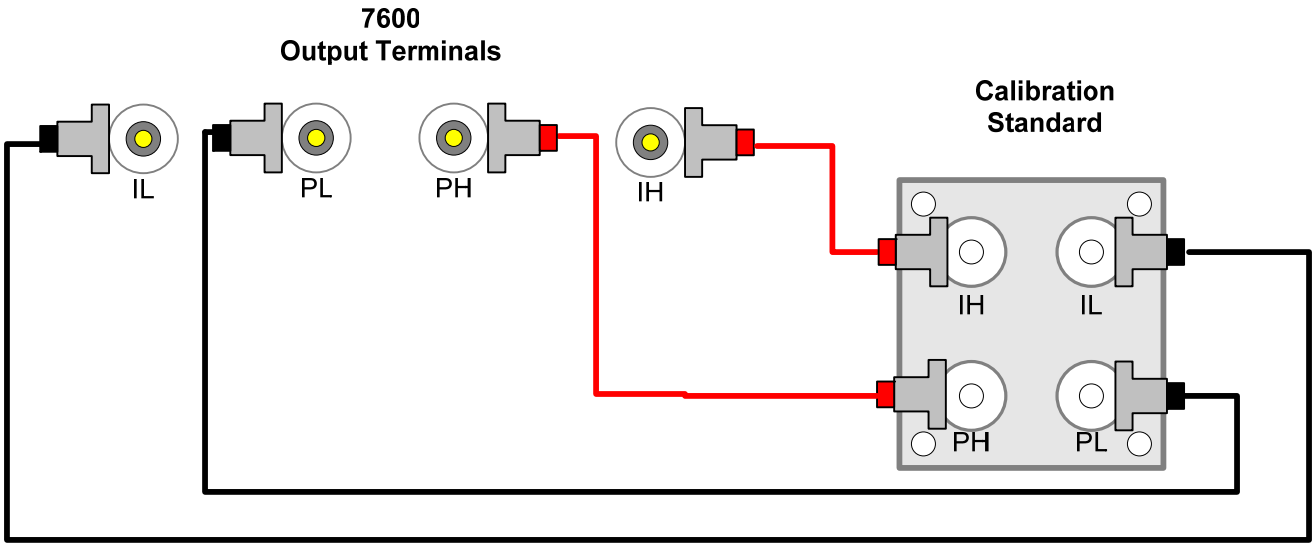

Figure 2.0: Connection of Cal Standard to 7600 Plus Instrument

Calibration Principles

The IET Labs 7600 Plus Precision LCR Meters are calibrated using a 7000-09 Calibration Kit which consist of a set of four 4-terminal standard resistors, see Figure 1. These standards are calibrated at DC using a precision DMM and transfer methods. The accuracy of each instrument is also verified using capacitance and resistance standards whose values are traceable to an SI.

Measurement Circuit

Resistance standards are used to calibrate the 7000 Series instrument due to the fact that the meter itself derives the value of the unknown by measuring the complex voltage across the DUT and across an internal resistance standard connected in series.

The complex ratio of the impedance of the DUT (Z_X) to the impedance of the standard (Z_{IS}) is Z_X/Z_{IS}. Refer to Figure 3. So if the impedance of the internal standard Z is known then the unknown impedance can be determined. Measuring the impedance of an external standard (Z_{EX}) provides the relationship Z_{EX}/Z_{IX} where the value of Z_{IX} is calculated if Z_{EX} is known. To obtain the values of C_X, L_X, D_X or Q_X from the value of Z_X it is necessary to know the precise frequency value. The 7600 Plus LCR Meter's frequency is determined by a quartz oscillator and the actual measured value, and then entered into memory

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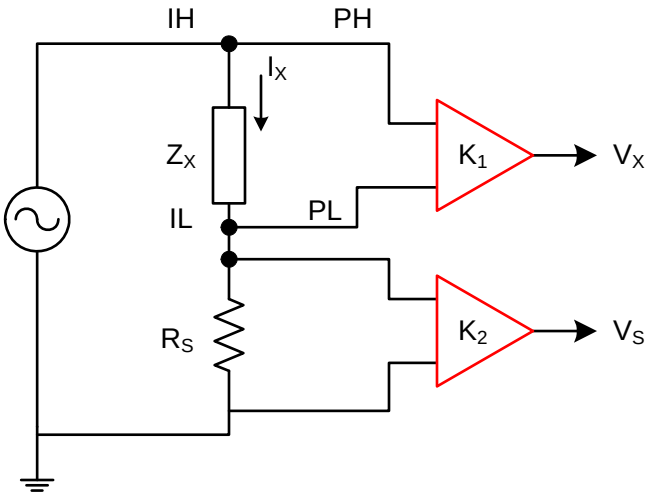

$$Z_X = \frac{V_X (R_S)}{V_S}$$

Figure 3.0: 7000 Series Measurement Circuit, Simplified

The same circuit is used to measure L, C, and R so the instrument can be calibrated with any standard of known value.

IET Labs. uses resistance standards for many reasons: calibration accuracy, stability, wide-range, compactness and the fact that their impedance is more constant with frequency. Four resistance standards are sufficient for all measurement ranges of the 7000 Series instrument. Although it is not necessary to use C or L traceable standards for *calibration*, capacitors are used for to check for non-linearity, excess noise, or other adverse measurement affects.

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Interpolate, Model and Zero

There are more than four measurement ranges in the 7600 Plus due to the use of different gain amplification (K_1 and K_2) in the two measurement channels. The ratio of the complex voltages after amplification is K_1Z_{EX}/K_2Z_{IS}. K_1 and K_2 are the two voltage gains. Calibration calculations are made with all possible gain configurations.

It is impossible to calibrate an instrument at every value so we rely on the linearity of the instrument for measurements made between the actual calibrated values. Making verification measurements above and below the actual calibrated values, checks the instrument's linearity.

Likewise, no instrument with thousands of possible test frequencies can be practically calibrated at each individual frequency. The known behavior of the instrument is used to interpolate between frequencies. The 7600 Plus is calibrated at several frequencies and tested at many more. Engineering verification tests have assured that this method is valid and ensures the LCR meter is well within the specified accuracy.

Interpolation is also used with external standards. The external standards have better frequency characteristics than the effective internal standards (due to simple wiring and no voltage gain) so their values may be interpolated over wider frequency ranges. The Vishay Z-foil resistors were chosen for their good frequency behavior and stability and in both the 7000-09 and 7600 Plus.

Air capacitors have a very simple model: their change in value with frequency is almost completely dependent on the series inductance. In calibrating its reference standards, IET Labs. uses GenRad 1404 Reference Standard Capacitors, GR Type 1406 air coaxial capacitors for high frequency verification measurements plus the higher valued GR Type 1407 mica capacitor.

The frequency behavior of these standards is mathematically calculated and together with the 1 kHz calibrated value are used to calibrate the 7600 Plus a various frequencies.

1407 Capacitor

1406 and 1407 Capacitance Standards

Zero Corrections

Standards and components are measured using different connection methods. The 7000 Series instrument makes a 4-terminal measurement using BNC connectors. Some components are measured in test fixtures connected to BNC connectors. Calibration must be valid for all connections even though the hardware used may have different series resistance and inductance and shunt capacitance. To make sure the raw measured value is corrected for these series and shunt parameters, open circuit and short circuit measurements are made. These 'zero corrections' must be made each time the connection configuration (hardware) is changed.

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Substitution measurements comparing 2-terminal coaxial standards to 4-terminal 7000 standards of similar value can be made if the proper zero corrections have been made for each standard. For ease of and concise connection, a 4-terminal open standard and a 4-terminal short standard are included in the 7000-09 Calibration kit.

Calibrating the Master Cal Kit Resistance Standards

Now the discussion takes a historical turn as to the method with which the four resistance standards of the master calibration kit were originally calibrated. To ensure the precision of the master (reference) calibration kit, true value measurements of the 4 resistors at DC & low frequency and high frequency were essential.

DC and Low Frequency Calibrations

DC transfer measurements are made using a transfer method that calibrates each resistor.

There is negligible change in values of the resistors between dc and 1000 Hz. The maximum change in resistance from dc to 1 kHz is less than 20 ppm. This was verified by comparison of the master kit to a calibration kit that was calibrated at 1 kHz by NPL.

The 7600 Plus LCR Meter was designed simply to make highly accurate impedance measurements over a wide frequency range. The original method of calibrating the master reference standards illustrates the extent to which IET Labs. went to ascertain the precision of this instrument. The unit is capable of measuring 14 different parameters with 0.05% accuracy.

Figure 4.0: 7600 Precision LCR Meter

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