E4980A-11

Information Only Service Note

Supersedes:
None

E4980A Precision LCR Meter 20Hz to 2MHz

Serial Numbers: All
Manufacturing ID Number: N/A

Concepts of LCR/ Impendence Measurement Techniques and Calibration Methodologies

Parts Required:
None

ADMINISTRATIVE INFORMATION

[[]] Calibration Required	PRODUCT LINE: WN
X Calibration NOT Required	AUTHOR: ls

ADDITIONAL INFORMATION:
Concepts of LCR/ Impendence Measurement Techniques and Calibration Methodologies

KEYSIGHT
TECHNOLOGIES

Situation:

It’s a common question when customer asked for the reason why certain frequency range is not tested in performance verification, on certain identified values, or only Capacitance but not Inductance, Resistance or other parameters are measured in the Impedance Measurement Accuracy test.

The following would provide an overview and concept of the LCR/ Impedance measurement techniques employed in modern LCR meters/ Impedance Analyzers not confined to E4980A.

Solution/Action:

Question #1. What are the concepts of LCR/ Impedance Measurement Techniques and Calibration Methodologies?

Answer #1

We have been explaining the concepts of LCR/impedance measurement techniques and calibration methodologies to customers worldwide for a very long time, since at least 30 years ago. Nowadays, there is the established technical common sense for the theoretical background of measurement techniques and calibration methodologies, which are popularly known by many customers/instrument-users. The need of explaining the calibration concepts to a customer is low (not many). But, when a customer asks questions about instrument calibration, it is a really difficult job to let the customer understand the concepts and practice of LCR/impedance calibration performed to guarantee the specified accuracy of LCR/impedance measuring instruments.

Modern LCR meters and impedance analyzers basically measure complex impedance (or complex admittance which is reciprocal of complex impedance), and calculate other impedance parameters (such as capacitance (C), inductance (L), resistance (R), dissipation factor (D), quality factor (Q), etc) from the measured impedance by using the parameter conversion formulas. (For example, $|Z| = 1/(\omega C)$ for a pure capacitance and $|Z| = \omega L$ for a pure inductance.) The measurement accuracy of LCR meters is specified for impedance. The measurement accuracy for capacitance, inductance, and other impedance parameters is determined from the impedance measurement accuracy, because the C, L, R, D, Q, and other parameter values are the calculated values. Thus, the accuracy of C, L, R, D, Q, and other parameter measurements is same as the accuracy of impedance derived from the C, L, R, D, Q, and other parameter values at the given frequency.

LCR meters (such as the E4980A) have several impedance measurement ranges (9 measurement ranges for standard E4980A units) to cover from low impedance (mΩ level) to high impedance (typically 100 MΩ) with the best possible accuracy. Since capacitance, inductance, and other impedance parameters are all calculated from measured impedance, the measurement ranges for the parameters other than impedance do not exist. When verifying the measurement accuracy of an LCR meter, impedance measurement accuracy test is enough to verify the accuracy for all the impedance parameters. The accuracy tests for capacitance, inductance, and other impedance parameters are not required.

Practically, the measurement accuracy test (calibration) for LCR meters is performed by using capacitance standards (standard capacitors) such as the 16380A/C. Impedance standards which have the calibrated impedance values do not exist. The reason to use standard capacitors is that capacitor can realize ideally excellent characteristics as calibration standard, e.g. pure capacitance with extremely low loss (low dissipation factor), high stability, and flat frequency response over a broad frequency range. These excellent characteristics cannot be obtained from other types standards. Details are explained in the Question#2. In some cases, resistance standards (standard resistors) such as the 42030A are also used to perform supplemental tests on low impedance measurement ranges where standard capacitors cannot be applied.

The number of available standard capacitors is fewer than the number of impedance measurement ranges selectable with LCR meters. However, it is possible to verify the measurement accuracy for all the selectable ranges by using a limited number of standard capacitors. The impedance measurement ranges are determined by the combinations of range resistor values and the gain multiplier (attenuator) settings of the vector ratio detector. (For the details, refer to Section 2.4.3 "Ranging function" on page 2-11 of the Impedance Measurement Handbook: http://literature.cdn.keysight.com/litweb/pdf/5950-3000.pdf). For example, the combinations of 3 range resistors and 3 selectable gain-multiplier settings can create 7 to 11 measurement ranges. Since the gain multiplier accuracy can be verified by measuring a single standard capacitor at the different gain (attenuation) settings, the measurement accuracy for all the impedance ranges (7 to 11 ranges) can be verified with fewer standard capacitors - a minimum of 3 standard capacitors.

The standard capacitors have their calibration values at a few specific frequencies, because national standards/calibration laboratories provide the calibration service for the capacitance/resistance standards at the specific frequencies only - typically 120 Hz, 1 kHz, 10 kHz, 100 kHz and 1 MHz. (The calibration frequencies available from national standards/calibration laboratories are different depending on country. In Japan, additional calibration frequencies of 2 MHz, 3 MHz, 4 MHz, 5 MHz, 10 MHz and 13 MHz are also available.)
Basically, the measurement accuracy of LCR meters are tested (calibrated) at these standard capacitor calibration frequencies in order to ensure the instrument calibration traceable to national standards. The measurement accuracy tests for other frequencies are performed by using the standard capacitor values interpolated from the adjacent calibration data of the standard capacitors.

Since the modern multi-frequency LCR meters and impedance analyzers have a large number of selectable test frequencies, it is substantially impossible to perform the accuracy tests (calibration) for all the test frequencies. If it must be done, an extremely long time and enormously large labor cost is required to accomplish such tests. Instrument users would have to bear an extremely expensive calibration fee for annual calibration. In the real world of LCR/impedance calibration, it is popularly recognized that the accuracy tests for a large number of test frequencies is not necessary. The frequency response of the LCR meters/impedance-analyzers is evaluated carefully and in details through the product development process. LCR meter/impedance-analyzer manufacturers (such as Keysight) have a large quantity of evaluation data as the technical background which proves the guaranteed accuracy (though we do not offer the internal evaluation data to customers.) Thus, when LCR meter/Impedance analyzer passes the accuracy tests at several discrete frequencies, the instrument can be guaranteed for the conformance with specified measurement accuracy over the full frequency range.

Question#2. Why isn't the inductance accuracy test included in the performance test of LCR Meters? (Example 4263A/B, 4284A, 4285A, 4294A, E4980A)

Answer#2

There are two primary reasons that the inductance accuracy test is omitted. One of the reasons is that the modern LCR meters have equal measurement accuracy for all the phase components of impedance vectors. The other reason concerns inaccuracy of the inductance standards. First, the equivalence of measurement accuracy is discussed to explain why the inductance accuracy can be guaranteed without directly calibrating the inductance measurements.

LCR meters consist of a signal source, bridge circuit (current to voltage converter), vector ratio detector and digital control section. Access to Figure 1 below to see the basic block diagram of the LCR meters. When a device under test (DUT) is connected to the measurement terminals, the bridge circuit causes the same current as the DUT current (Idut) to flow through the range resistor (Rr) and, consequently, converts the DUT current into an equivalent voltage signal (Err = Idut x Rr) across Rr. The vector ratio detector measures the ratio of the voltage (Edut) across DUT and the voltage (Err) across Rr in order to derive the vector impedance of the DUT as Zx = Rr x (Edut/Err). All the other impedance parameters, such as C, L, R, X, G, B, D, Q, are calculated from the measured vector impedance Zx using the impedance parameter conversion equations.

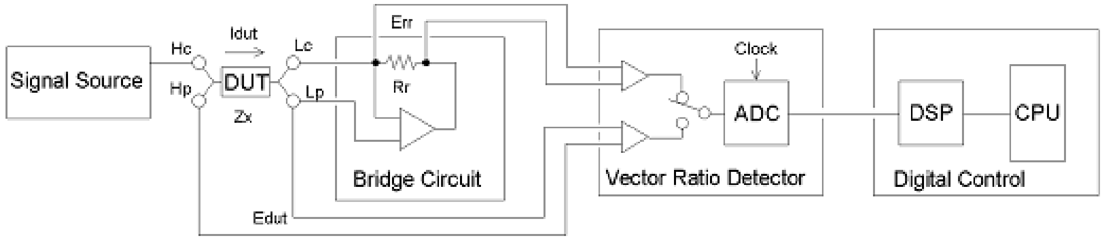

Figure 1. Basic block diagram of LCR meters

Both the +90 degree component (inductance) and opposing -90 degree component (capacitance) of the vector impedance are detected using the same vector ratio detector and reference phase signals. The polarity (plus/minus) of the vector ratio detector output changes depending on the phase angle of the vector impedance. As a result, the same accuracy is obtained for both +90 degree vector of an inductive DUT and -90 degree vector of a capacitive DUT. Based on the equivalence of phase detection for the +90 and -90 degrees, verifying the capacitance accuracy using capacitance standards is equivalent to verifying inductance accuracy.

Modern LCR meters and impedance analyzers detect the orthogonal phase components by using a high speed A-D converter and DSP, in place of the analog phase detector. Since the phase detection accuracy is determined by the timing accuracy of the A-D converter clock which has the same accuracy as the crystal oscillator, the resultant accuracy is exactly the same for both +90 and -90 degree phase components. This is true for not only the +90/-90 degree vectors but also any vectors over 0 to -/-180 degrees.

(Note: Some impedance analyzers employ the phase detectors separately for 0 degree and 90 degrees to increase measurement speed. In this case, the relative phase error of the phase detectors is canceled as a result of vector calculation.)

On the other hand, in the calibration traceability world, there is a sufficient reason for not using inductance standards. Inductors are susceptible to temperature changes, difficult to have a high Q (low loss), and apt to cause a magnetic coupling with an external metallic object by leakage flux. Moreover, the inductors have a frequency dependence due to the effect of unavoidable stray capacitance between windings. The stray capacitance narrows the usable frequency range of the inductors. Such nature of the inductors makes it very difficult to develop stable and accurate standard inductors, which can be used over a wide frequency range. Practically, there are no inductance standards that have high accuracy enough to calibrate the precision LCR meters currently available. Compared to inductors, capacitance standards provide much better accuracy, better stability, low-loss, and excellent flatness of capacitance over a broad frequency range. Regarding the traceability chain, the capacitance standard values can be transferred from national standards with a minimum uncertainty. Therefore, the capacitance standards are used as the primary reference of LCR meter calibration.

Revision History:

Date	Service Note Revision	Author	Reason for Change
20 Dec 2016	E4980A-01	ls	As Published