ACCURACY ESTIMATION FOR R&S®LCX LCR METERS

White paper | Version 01.00 | Simon Bauer, Shivam Arora

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CONTENTS

1 INTRODUCTION

The R&S®LCX LCR meters set a new standard for passive component measurements in the frequency range from 4 Hz to 10 MHz. Comprehensive analysis functions and versatile test fixtures mean the meters can measure a broad range of components with a basic accuracy of 0.05%.

Calculating impedance accuracy at different frequencies can be particularly challenging when values must be obtained based on calibration accuracy, measurement speed, cable length and applied bias. The absolute impedance and phase accuracy of a component under test are calculated in real time and shown directly at the lower right side of the R&S®LCX display. This document highlights the sequence of steps for the R&S®LCX to display absolute accuracy for the measured impedance. This is useful when the R&S®LCX or the device under test (DUT) is not available for making real-time measurements. The calculations described here also illustrate how to calculate accuracy for secondary parameters (e.g. Cs or Ls) measured by the R&S®LCX LCR meters.

2 ACCURACY CALCULATION

The first step is to obtain the **accuracy** from the accuracy chart in the data sheet. There are three chart variants:

- ▶ R_{source} = 10 Ω (low Z mode) for both R&S®LCX100 and R&S®LCX200
- ▶ R_{source} = 100 Ω (high Z mode) for R&S®LCX100
- ▶ R_{source} = 100 Ω (high Z mode) for R&S®LCX200

Fig. 1 shows the accuracy chart of the R&S®LCX200 for R_{source} = 100 Ω. From this diagram, the accuracy can be determined for any impedance and frequency combination. This is used to calculate the basic accuracy (BA).

BA in % = accuracy in % + (Z_m/Z_o × 100) + (Z_s/Z_m × 100), where Z_m is the measured impedance, and Z_o and Z_s are the open and short impedances mentioned in the data sheet.

The basic accuracy (BA) is multiplied with up to six factors, depending on the voltage level (K_{sl}), measurement speed (K_{ms}), cable extension (K_{cl}), bias voltage (K_b), temperature (K) and measurement frequency (K_f). This results in **impedance measurement accuracy**. The respective values for all six factors based on the operating state of the R&S®LCX are available in the data sheet.

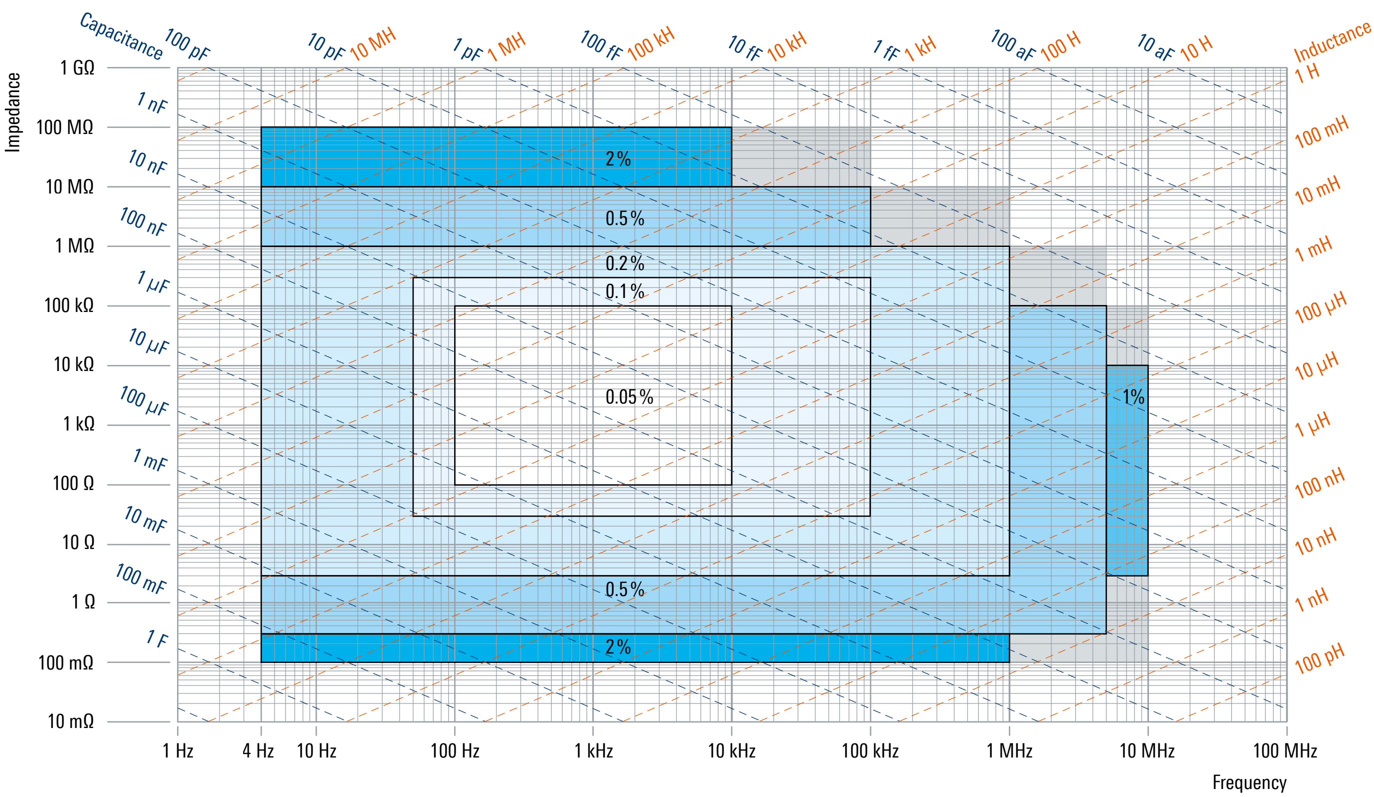
The **phase measurement accuracy** in deg (°) is calculated from the impedance measurement accuracy as (180/π) × impedance measurement accuracy (%)/100. The minimum **phase measurement accuracy** is limited to 0.03°.

The **absolute impedance accuracy** in % is calculated from the impedance measurement accuracy by adding the calibration accuracy, which depends on range, frequency and voltage.

The **absolute phase accuracy** in deg (°) is determined by adding the **phase measurement accuracy** in deg (°) and the phase calibration accuracy in deg (°), which again depends on range, frequency and voltage.

Subsequently, the minimum and maximum values for the secondary parameter (R, Cs or Ls) are evaluated based on the **absolute impedance accuracy** and **absolute phase accuracy**.

Fig. 1: Basic accuracy (BA) of R&S®LCX200 for R_{source} = 100 Ω



3 EXAMPLES

The following examples show how to determine **absolute impedance accuracy**, **absolute phase accuracy** as well as accuracy for secondary parameters (R, Cs, Ls).

3.1 Resistor, R = 4.7 kΩ

In this example, the accuracy of a resistance measurement with an assumed reading of 4.7 kΩ is determined. The measurement is executed using a test frequency of 15 kHz, 1 V test signal and speed set to SLOW at room temperature. For DUTs above 100 Ω, low Z is deactivated, so R_{source} is 100 Ω in this case.

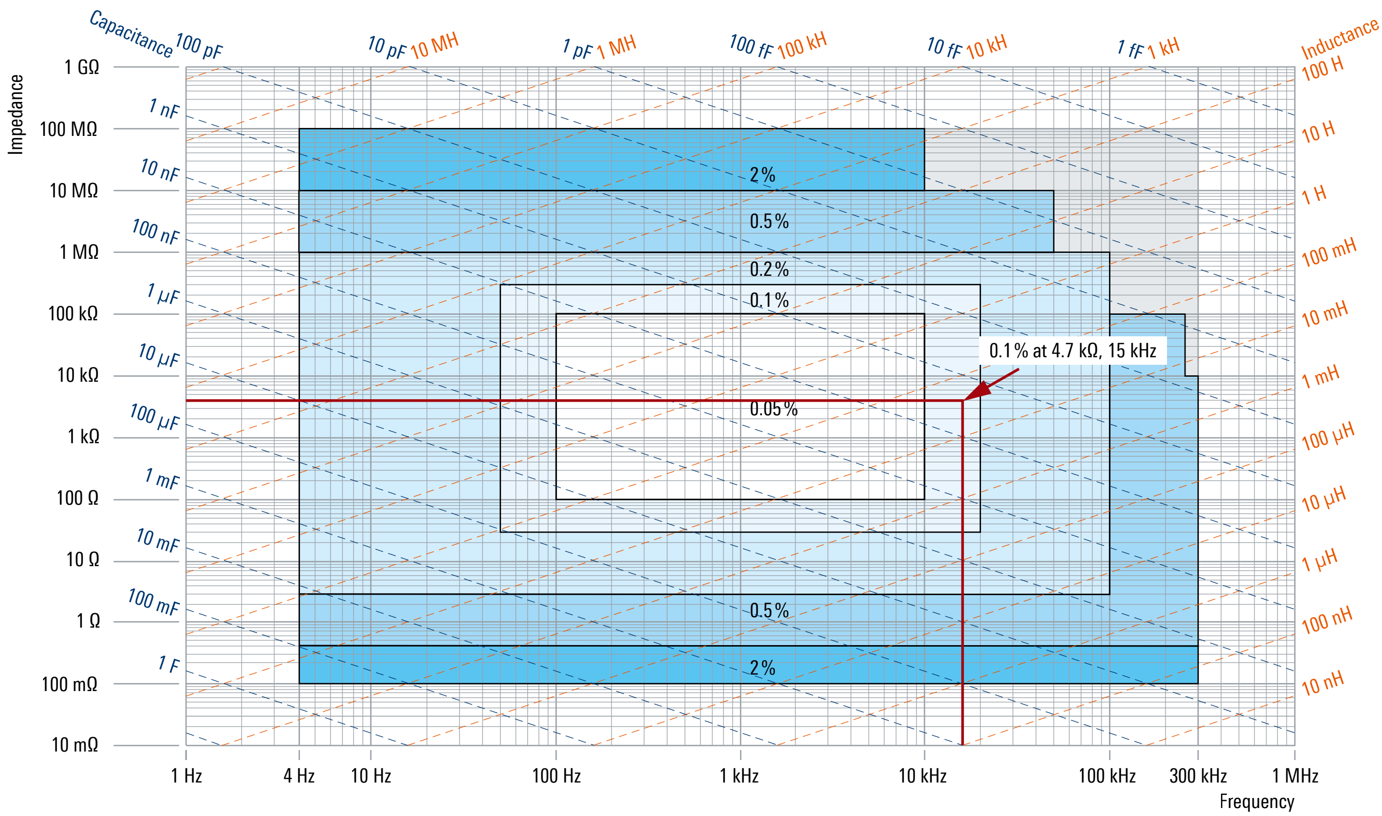
1. From the accuracy chart in Fig. 2, an **accuracy** value of 0.1 % is obtained.
2. Adding the influence of the open/short impedance yields the **basic accuracy**:
   0.1 % + 0.002 % = 0.102 %
3. Under the specified conditions, all factors (e.g. K_{sl}, K_{ms}) evaluate to 1, so the **impedance measurement accuracy** is identical to the **basic accuracy**.

4. Knowing the impedance measurement accuracy, the **phase measurement accuracy** can be calculated:

$$\left(\frac{180°}{\pi}\right) \cdot \frac{0.102}{100} = 0.058°$$

5. The calibration accuracy in the data sheet for the specified conditions is ±0.03% for impedance and ±0.025° for phase. This results in an **absolute impedance accuracy of 0.132%** and an **absolute phase accuracy of 0.083°**.
6. Using these values, minimum and maximum values for R can be calculated:
   R_{min} = 4693.8 Ω (0.13% below the measured value)
   R_{max} = 4706.2 Ω (0.13% above the measured value)
   The actual resistance value of the measured resistor is within R_{min} and R_{max}.

Fig. 2: Basic accuracy (BA) of R&S®LCX100 for R_{source} = 100 Ω



3.2 Capacitor, C = 10 nF

In this example, the accuracy of a capacitance measurement with a reading of 10 nF is calculated. This is done using the impedance and phase accuracy calculation, which is then converted to capacitance accuracy. The chosen measurement frequency is 1 MHz, the test signal level is 1 V, and the measurement speed is set to SLOW at room temperature. The DUT is a 10 nF X7R chip capacitor and the parameter of interest is Cs.

1. If the accuracy is to be calculated without the R&S®LCX, theoretical values can be used:

$$Z = \frac{1}{2\pi \cdot 1\ \text{MHz} \cdot 10\ \text{nF}} = 15.915\ \Omega$$
$$\theta = -90°$$

2. Since the impedance is below 100 Ω, low Z mode is chosen. From the accuracy chart (Fig. 3), an **accuracy** value of **0.2%** is obtained.

3. Adding the influence of the short impedance yields the **basic accuracy**:
   0.2 % + 0.009 % = **0.209 %**
4. Under the specified conditions, all factors evaluate to 1 but K_f is calculated as:

$$K_f = \frac{1000(\text{kHz}) + 4550}{4850} = 1.1443$$

   The **impedance measurement accuracy** is 0.209 % × 1.1443 = **0.239 %**.
5. Knowing the impedance measurement accuracy, the **phase measurement accuracy** can be calculated:

$$\left(\frac{180°}{\pi}\right) \cdot \frac{0.239}{100} = 0.137°$$

6. The calibration accuracy for the specified conditions is ±0.03 % for impedance and ±0.025° for phase. This results in an **absolute impedance accuracy of 0.269 %** and an **absolute phase accuracy of 0.162°**.

Using these values, minimum and maximum values for Z and Θ can be calculated:

Z_{min} = 15.9530 Ω Θ_{min} = –89.838°
Z_{max} = 15.8769 Ω Θ_{max} = –90.162°

7. Finally, this can be converted to a minimum and maximum value (and thereby accuracy) for the parameter Cs by interpreting the imaginary part as the desired capacitance value: The actual capacitance value of the measured capacitor is within Cs_{min} and Cs_{max}.

$$Cs_{\text{min}} = \frac{1}{2\pi f \cdot Z_{\text{max}} \cdot \sin\theta_{\text{min}}} = 9.973\ \text{nF} \quad (0.27\%\ \text{below measured value})$$

$$Cs_{\text{max}} = \frac{1}{2\pi f \cdot Z_{\text{min}} \cdot \sin\theta_{\text{max}}} = 10.027\ \text{nF} \quad (0.27\%\ \text{above measured value})$$

3.3 Inductor, L = 2.2 µH

In this example, the accuracy of an inductance measurement with a reading of 2.2 µH is calculated based on the impedance and phase accuracy calculation. The chosen measurement frequency is 1 MHz, the test signal level is 1 V, the measurement speed is set to SLOW for maximum accuracy, and the temperature is room temperature. The DUT is a 2.2 µH inductor and the parameter of interest is Ls.

1. If the accuracy is to be calculated without the R&S®LCX, theoretical values can be used:
   Z = 2π × 1 MHz × 2.2 µH = 13.823 Ω
   Θ = 90°
2. Since the impedance is below 100 Ω, low Z mode is chosen. From the accuracy chart (Fig. 3), an **accuracy** value of **0.2 %** is obtained.
3. Adding the influence of the short impedance yields the **basic accuracy**:
   0.2 % + 0.011 % = 0.211 %
4. Under the specified conditions, all factors but K_f evaluate to 1. K_f is calculated as:

$$K_f = \frac{1000(\text{kHz}) + 4550}{4850} = 1.1443$$

   The **impedance measurement accuracy** is then 0.211 % × 1.1443 = **0.241 %**.
5. Knowing the impedance measurement accuracy, the **phase measurement accuracy** can be calculated:

$$\left(\frac{180°}{\pi}\right) \cdot \frac{0.241}{100} = 0.138°$$

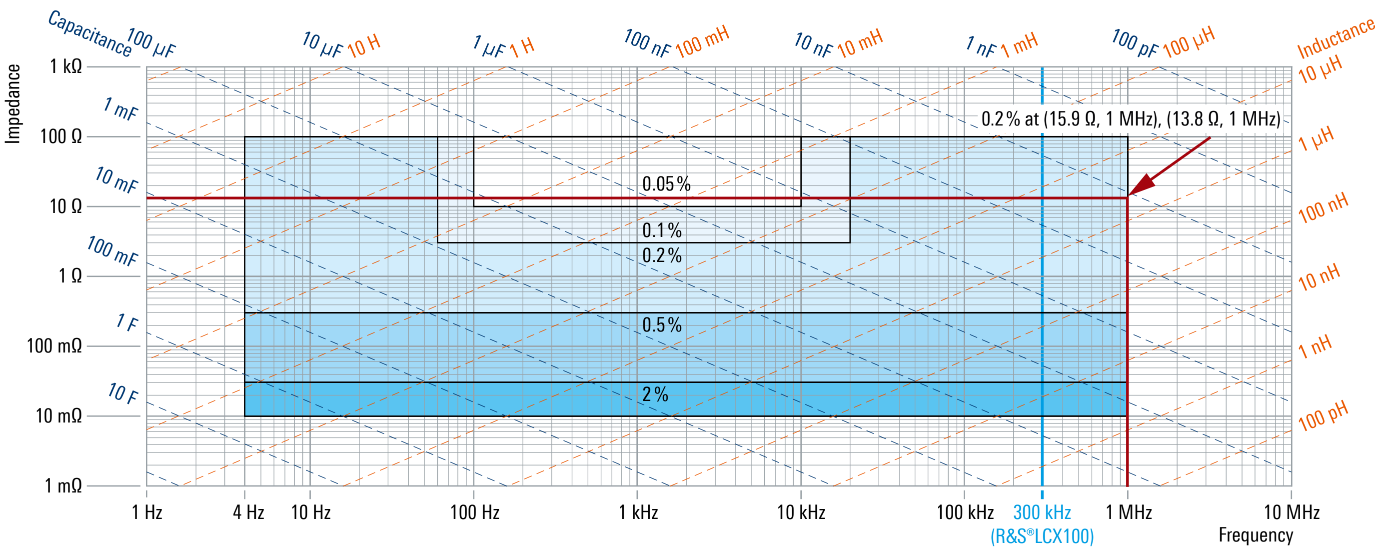
6. The calibration accuracy for the specified conditions is ±0.03 % for impedance and ±0.025° for phase. This results in an **absolute impedance accuracy** of **0.271 %** and **absolute phase accuracy** of **0.163°**.

7. Using these values, minimum and maximum values for Z and Θ can be calculated. Using the measured values from above:
   Z_{min} = 13.785 Ω Θ_{min} = –89.8533°
   Z_{max} = 13.860 Ω Θ_{max} = –90.1467°
8. Finally, this can be used to evaluate a minimum and maximum value for the parameter Ls: The actual inductance value of the measured inductor is within Ls_{min} and Ls_{max}.

$$Ls_{\min} = \frac{Z_{\min} \cdot \sin\theta_{\min}}{2\pi f} = 2.194\ \mu H \quad (0.273\%\ \text{below measured value})$$

$$Ls_{\max} = \frac{Z_{\max} \cdot \sin\theta_{\max}}{2\pi f} = 2.206\ \mu H \quad (0.273\%\ \text{above measured value})$$

Fig. 3: Basic accuracy (BA) of R&S®LCX100/LCX200 for R_{source} = 10 Ω (low Z mode)



4 SUMMARY

The impedance (Z) and phase (Θ) measurement accuracy, which is shown on the R&S®LCX LCR meter's display, is evaluated using the basic accuracy and six factors:

- Voltage level (K_{sl})
- Measurement speed (K_{ms})
- Cable length (K_{cl})
- Bias voltage (K_{b})
- Temperature (K_{t})
- Measurement frequency (K_{f})

The Z and Θ accuracies can be converted to secondary parameter accuracy (e.g. Cs and Ls) by calculating the absolute impedance and phase accuracy. This absolute accuracy is determined based on the operating point specific calibration accuracy given in the data sheet.

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PD 3683.7054.52 | Version 01.00 | January 2024 (sk) | White paper
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