Tweezer LCR-Meter Technology for Sub-1 pF and 10 nH Measurements

Use of proprietary open/short calibration boards eliminates offsets and lead to improved accuracy and measurement ranges

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Introduction

In recent years, various studies have been conducted to enhance the accuracy of tweezer-style LCR meters for measuring small capacitance and inductance values. While improving capacitance measurements was relatively straightforward, refining inductance measurements proved more challenging.

The primary source of inaccuracy in both cases is the parasitic capacitance and inductance of unshielded test leads. Without shielding, the AC signal generated by the meter interacts electromagnetically with the test leads, creating parasitics. While negligible for larger components, these parasitic effects can exceed the values of smaller components, leading to significant measurement errors.

Figure 1. Parasitics in Tweezer Meters

Developing a method to compensate for parasitic capacitance and inductance offsets enables LCR meters to measure much smaller components accurately. Siborg Systems has addressed this challenge by introducing Open and Short Calibration Boards, which have proven to be an effective solution for extending the measurement range down to 0.1 pF and 1 nH.

Tweezer-style LCR meters have become increasingly popular in recent years. However, a common challenge across all models is the presence of parasitic inductance and capacitance in unshielded test leads, which limits the accurate measurement of very small inductances and capacitances. These parasitic effects vary based on the distance between the test leads and the size of the component being measured.

To overcome this limitation, Siborg Systems (Canada) provides proprietary calibration fixtures that allow to effectively compensate for these parasitics, greatly enhancing measurement accuracy and range.

Previous State of the Art

Since the launch of the original Smart Tweezers LCR meter in 2005, many successors have entered the market. Some newer models offer higher test frequencies, improved accuracy, and expanded functionality, surpassing the original design. Notably, the LCR-Reader series—including the MPA, R2, and R3—has further advanced the capabilities of tweezer-based multimeters.

Despite these advancements, most tweezer meters share a similar structural design and continue to face the same limitations when measuring extremely small capacitances and inductances due to the parasitic effects of their test leads, as illustrated in Figure 1. Proper offset adjustments using these Calibration Boards significantly improve measurement accuracy.

Siborg Systems recently highlighted the importance of properly calibrating two-wire measurement setups in IEEE publications, including AutoTestCon 2022 and the IEEE Instrumentation & Measurement Magazine (August 2023). These studies underscored the critical role of calibration in accurately measuring small inductances and capacitances. Tests using an HP benchtop LCR meter demonstrated that for inductances below 10 nH, the relative measurement error could exceed 100% without proper calibration.

This issue is even more pronounced in tweezer-style LCR meters, as demonstrated by Siborg in recent presentations at Nepcon Tokyo (January 2024) and the SMTA International Conference in Minneapolis (October 2024). At the latter event, it was shown that performing a proper short and open calibration using Siborg's proprietary calibration fixtures (illustrated in Figure 1) virtually eliminates parasitic offsets, enabling accurate measurements of capacitance and inductance below 1 pF and 10 nH, respectively.

Further details and related publications can also be found on the LCR-Reader website.

Measurement Offsets and Corrections

The table below presents capacitance and inductance offset values for the LCR-Reader MPA, R2, and R3 models. These offsets are comparable across all tweezer-style LCR meters and are often unaccounted for, leading to significant measurement errors. Without proper offset adjustment, parasitics of up to 0.25 pF and 19 nH can strongly impact measurement accuracy.

Table 1. Capacitance and Inductance Offset Values for LCR-Reader

Size	Length mm	C (pF)	L (nH)
01005	0.4	0.249	2.8
0201	0.6	0.225	3.8
0402	1.0	0.177	5.2
0603	1.5	0.138	6.6
0805	2.0	0.115	7.8
1008	2.5	0.098	9.3
1206	3.0	0.077	10.5
1806	4.5	0.042	13.3
2010	5.0	0.031	14.7
2512	6.3	0.014	17.0
2920	7.4	0	18.6

To eliminate measurement offsets, Siborg Systems has introduced proprietary Open and Short Calibration Boards (patent pending), as shown in Figure 1. These boards significantly reduce measurement offsets—to below 0.003 pF for capacitance and 0.3 nH for inductance.

The Offset Calibration Boards are specialized dummy PCBs with holes positioned at various distances to simulate different component sizes (e.g., 0201, 0402, etc.). By placing a tweezer meter's test leads into the corresponding holes, the device displays the actual offset capacitance. This offset value should then be subtracted from the measured component value for improved accuracy.

For LCR-Reader models—such as the award-winning LCR-Reader MPA (Product of the Year 2020), R2, and R3—performing Open/Short calibration is straightforward. When the device is connected to the Open/Short Calibration Board, pressing the joystick to the right until two beeps initiates the calibration process.

However, calibration accuracy can be influenced by the pressure applied to the tweezer handles, potentially causing variations of up to 0.005 pF and 0.3 nH. Maintaining consistent pressure during both calibration and measurement ensures greater accuracy.

The figures below illustrate the importance of offset adjustments for small capacitance and inductance measurements. The results, obtained using a Hioki IM3536 and an LCR-Reader R2, show measurements with and without correction. For the Hioki IM3536, correction was performed using linear regression analysis to extract the offset, which was found to be approximately 0.8 nH and remained consistent for smaller inductance values (labeled as “Hioki-Nom” in the figure).

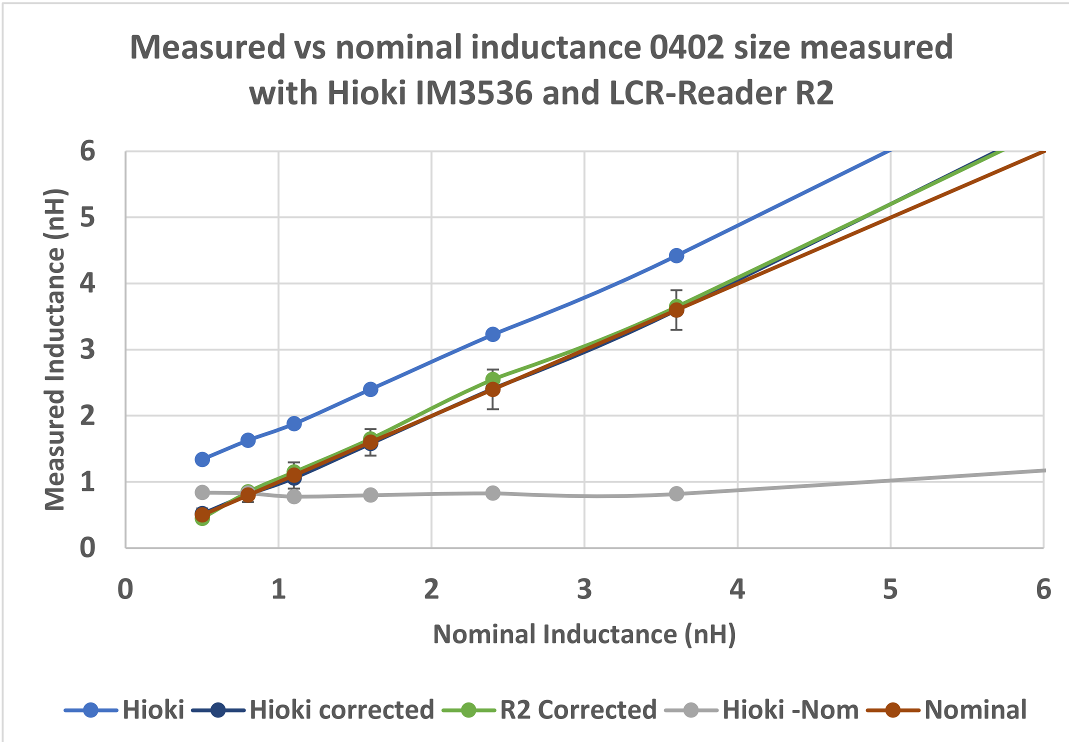


Figure 2. Measured vs nominal small inductance values with and without correction

All corrected measurements agree well with one another and fall within the tolerance range indicated by the error bars. Notably, the parasitic inductance of the tweezer test leads is 5.2 nH, as shown in the Table 1 above. Failing to account for this offset could result in measurement errors of up to 10× for a 0.5 nH inductance and a 160% error for a 3.6 nH inductance.

Frequency Correction Factor

Nominal inductance values below 10 nH show good agreement with measurements. However, for values above 10 nH, a frequency correction factor becomes significant. The deviation is evident in both Hioki and LCR-Reader measurements, which align well with each other.

Inductor manufacturers typically measure small inductors at frequencies not lower than 100 MHz, whereas this study used a 100 kHz test frequency. This discrepancy led to overestimated inductance values compared to manufacturer specifications, a trend observed across brands such as TDK, Würth Elektronik, Murata, Taiyo Yuden, Samsung, and Eaton. The frequency correction factor varies and may reach up to 20%.

Further work is needed to develop a method for predicting high-frequency inductance based on low-frequency measurements. Due to structural and technological differences, different types of inductors may require distinct approaches. Interested readers may refer to publications [1-3] for more details on previously published data on the subject.

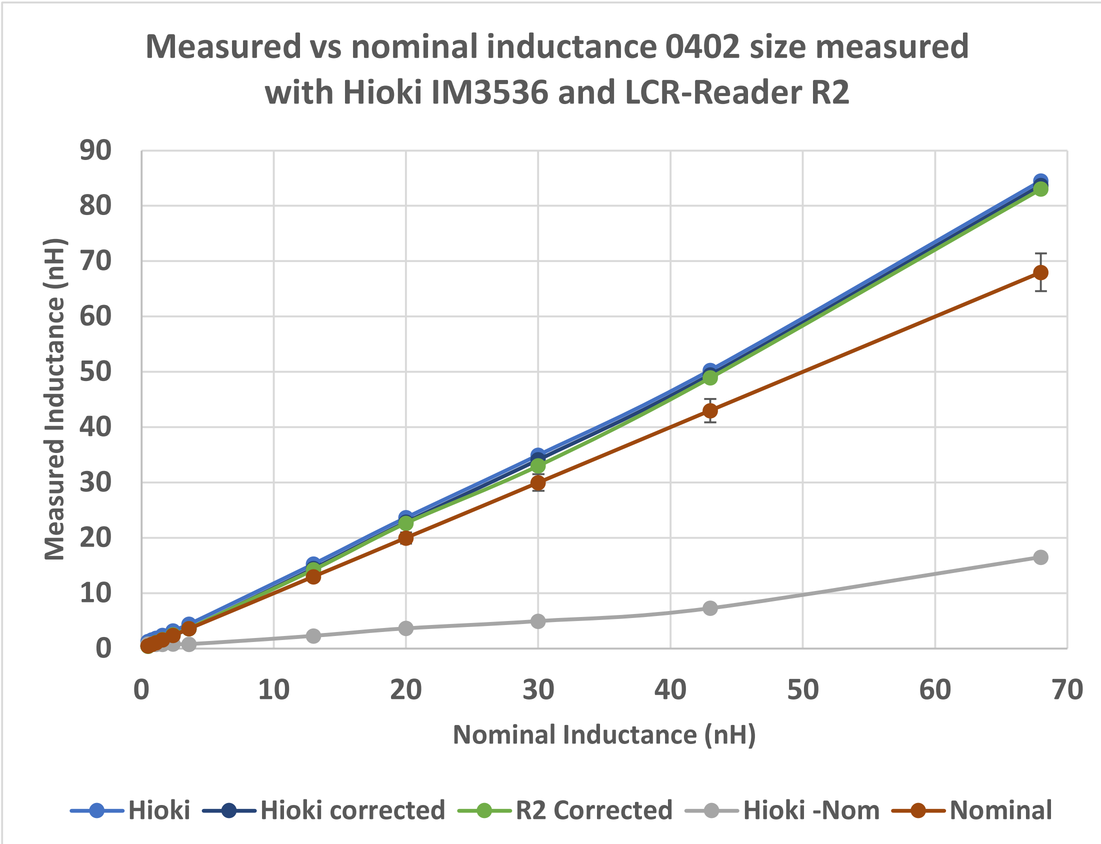


Figure 3. Measured vs nominal inductance values for larger inductance values. Low test frequency of 100 kHz results in overestimated inductance values.

Conclusion

Since the launch of the Smart Tweezers LCR-meter project in 2005, Siborg Systems has been at the forefront of innovation in the electronics industry. Recent advancements in accuracy (0.1%), test frequency (up to 250 kHz), and measurement range (0.1 pF to 1 F) have established the LCR-Reader product line as a leader in precision electronic measurements.

Traditionally, measuring extremely small capacitance and inductance values (below 1 pF and 10 nH) required expensive benchtop meters. Now, with the LCR-Reader MPA, R2, or R3 models, using the proposed Open and Short Calibration Boards, these measurements can be performed in under a minute and at a fraction of the cost.

References

[1] “Calibration of Tweezer Meters Enabling Sub 1 pF and Sub 10 nH Measurements”, Michael S. Obrecht, Proceedings of SMTA International, Oct 20 - 24, 2024, Rosemont, IL, USA. p. 177-180

[2] “Simple Offset Elimination Technique for Two-Wire Measurements”, Michael S. Obrecht, IEEE Instrumentation & Measurement Magazine, v. 26, p.45, 2023

[3] “Offset elimination technique for small inductance measurements using two-wire connection”, M. Obrecht, in Proc. IEEE, AUTOTESTCON, Aug. 2022.

Appendix A. Principles of Operation of LCR-Reader

Figure 4. LCR-Reader-MPA testing LED

Fig. 5 shows the LCR meter block-diagram. Voltage from the voltage source through a limiting 100 Ω resistor is applied to the DUT connected at points A and B. The amplitude and frequency of the Test Signal V are adjustable. It is *also possible to apply either positive or negative DC voltage to the DUT. A voltage drop on the DUT is measured by DAu.* The voltage drop on resistor Rj measured by DAj is proportional to the current flowing through the measured component. After digitizing the ADC signals the impedance is calculated according to the formula DUT impedance Z =Rj* Vau/Vaj.

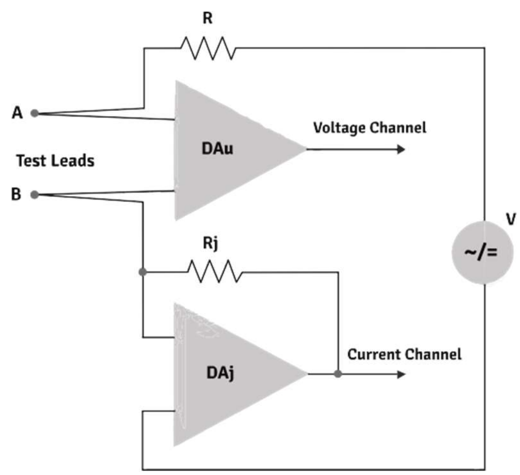
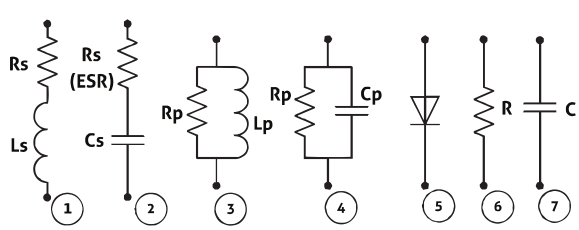


Figure 5. LCR-Reader block diagram

Initial values of Impedance (offsets) obtained during calibration with Open and Short probes are stored in the non-volatile memory of the device and are considered in the calculation of the impedance of the measured component thus eliminating the offsets due to the device internal parasitics.

The measured component can be represented as one of the following equivalent circuits:

(1) and (2): AC measurement series circuits, (3) and (4): AC parallel circuits, (5,6,7) DC measurement of diodes, resistance and capacitance.



Impedance in series circuits is Z = Rs + iXs and in parallel circuits is Z = 1/(1/Rp + 1/iXp) where Xs (Xp) < 0 if the reactance is Capacitive and at Xs (Xp) > 0 the reactance is Inductive.

Calculation of Parameters

Capacitance C = 1/(2π*f*|Xs|) where *f* is the test frequency. Inductance L = Xs/(2π*f*). Q = |Xs|/Rs. D = 1/Q.
|Z| = $\sqrt{Rs^2 + Xs^2}$

In automatic mode the device automatically selects the optimum frequency and the equivalent circuit for measurements. Users can also manually select measurement mode and frequency of the test signal can be selected a range of fixed values from 100 Hz to 100 kHz. Test voltage can be set to 1.0, 0.5 and 0.1 Vrms.

By passing direct current through the measured component, the voltage and current can be measured. Using Ω's law, the DC current Resistance (RDC) is calculated.

By applying the DC voltage in forward and reverse direction, the diodes are detected, and the polarity of p-n junction is determined.

For capacitors larger than 40 mF the capacitance is calculated using the voltage variation on the measured capacitor when it is charging for a certain time interval and applied current.

The principle of the frequency meter is based on the counting of pulses of the reference generator between the two ramps of the input signal for a certain period of time (by default about 1 second). At the same time, the quantity of periods of the input signal is counted too. Then the frequency f is calculated by the formula f = M/N*fr where M is the number of periods of the input signal, N is the number of pulses from the reference generator and fr is the frequency of the reference generator.

The principle of measuring voltage is based on comparing the input signal with the reference voltage.

Offset elimination technique

The Capacitance (Open) and Inductance (Short) Offset Calibration Boards provide a reliable and accurate method of determining the parasitic offsets between the test leads which depends on the distance between them. The PCBs uses holes to represent various sizes of components (Fig. 6). These boards can be used for evaluation of parasitic capacitance and inductance of any tweezer-meter (Smart Tweezers, LCR-Reader or any other tweezer-meter using AC response approach).

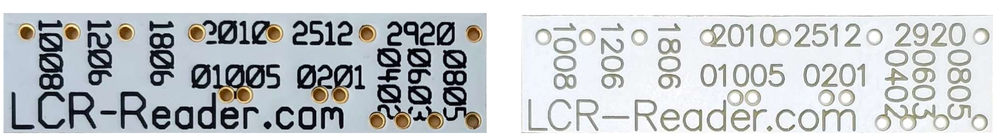


Figure 6. Short (left) and Open (right) Calibration Boards

To use the calibration board, place the test leads into the holes corresponding to the size of component under test; make Open/Short calibration by pushing the joystick to the right, hold for 2 beeps and release.

Table 1 demonstrates dependence of the parasitic capacitance and inductance of the tweezers on the distance between the test leads. The measurements were made at 100 kHz. The Open calibration was made at the component size set to 2920 (7.4 mm between the tweezer tips) and therefore the offset is close to zero at this particular component size. It should be noted that the results vary slightly depending on the distance between the tweezer tips even for a fixed component size (varying with the pressure applied to the tweezers) and surroundings around the tweezers. For example, placing a hand near the tweezers may lead to a few fFs change due to a high sensitivity of the device. For the initial Short calibration test leads were simply shorted.

After we properly perform Open calibration of the device for a specific component size, capacitance value can be measured the with absolute accuracy of about 3 fF. Similarly, after Short calibration is done, accuracy for inductance is about 0.3 nH

Appendix B. LCR-Reader-MPA Functions and Features

Summary of Features

- L-C-R/ESR and LED/Diode Measurements
- AC/DC Voltage/Current Measurements
- Oscilloscope, Signal Generator
- Frequency, Pulse Period, Duty Cycle Meter
- Open/Short Calibration
- Component Sorting
- Super Cap Testing
- Optional Bluetooth Module
- NIST Traceable Calibration Certificate

Technical Specifications

Basic Accuracy: 0.1%
Test Frequency: 100 Hz - 100 kHz
Test Signal Level: 0.1, 0.5, 1.0 Vrms

Measurement Ranges

Resistance R: 5 mΩ to 20 MΩ *Capacitance C:* 0.1 pF to 1 F *Inductance L:* 1 nH to 100 H

Physical Specifications

Size: 18 x 3 x 1.6 cm
Weight: 1.35 oz.
Battery: 3.7V LiPo

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Appendix C. Display of LCR-Reader-MPA in R-L-C-D mode

R-L-C-D mode is the default device mode and it is designated for measurement of Resistors, Capacitors, Inductances and Diodes. To select the mode, select R-L- C-D in the main menu. In order to get access to the mode parameters (hidden sub-menu) push the joystick to the right for one beep. A typical screen for R-L-C-D mode looks as follows: