Calibration of Tweezer Meters Enabling Sub 1 pF and Sub 10 nH Measurements

Michael S. Obrecht, Ph.D.
Siborg Systems Inc
Ontario, Canada
obrecht@siborg.ca

ABSTRACT
The increasing popularity of tweezer meters has highlighted the need for calibration tools to mitigate the inherent parasitic capacitance and inductance in test leads. Due to their similar mechanical design, most tweezer meters face the same limitations when measuring very small capacitance and inductance values, caused by these parasitics.

Properly compensating for parasitic effects is crucial for enhancing measurement accuracy and extending the measurement range. Parasitic capacitance can reach up to 0.3 pF, while parasitic inductance can exceed 15 nH, making accurate measurement of small components nearly impossible. These parasitics are influenced by the distance between the test leads - parasitic capacitance increases as the distance decreases, while parasitic inductance increases as the distance grows. A straightforward but effective calibration method is available to address these issues.

Key words: Inductance, capacitance, measurement

INTRODUCTION
The growing popularity of tweezer meters has increased the demand for calibration tools that can mitigate the inherent parasitic capacitance and inductance in test leads. Since the original Smart Tweezers LCR-meter was introduced in 2005, many successors have entered the market, some outperforming the current version with higher test frequencies, improved accuracy, and added functionality, such as the LCR-Reader line of multimeters. Despite these advancements, most tweezer meters share a similar structural design and thus face the same limitations when measuring very small capacitances and inductances due to parasitic effects in the test leads.

The importance of properly calibrating two-wire measurement setups was highlighted in [1], where the significance of calibration for accurately measuring small inductances and capacitances was emphasized. Using an HP benchtop LCR-meter, it was demonstrated that for inductances below 10 nH, the relative error could exceed 100%. This issue is even more critical for tweezer meters.

SMALL CAPACITANCE MEASUREMENTS
A typical tweezer meter consists of a high-precision LCR meter integrated with a compact display and a set of tweezers with test leads. For example, the LCR-Reader R2 is shown in the Figure 1 below.

Figure 1. Capacitance offset introduced by test leads of LCR-Reader R2.

The tweezer handles are shielded and therefore do not contribute to parasitic effects, unlike the unshielded test leads. As can be easily seen, the parasitic capacitance of the test leads is connected in parallel with the component under test and must be accounted for when performing measurements. While this is not critical when testing resistance or inductance, it is essential for capacitance measurements, particularly for values below 10 pF. To eliminate parasitic capacitance, an open calibration must be performed. In the LCR-Reader line of LCR meters, this is done by simply pressing the joystick to the right; however, it must be done separately for each component size.

Table 1. Capacitance offset for LCR-Reader R2.

Size	L mm	C (pF)
01005	0.4	0.249
0201	0.6	0.225
0402	1.0	0.177
0603	1.5	0.138
0805	2.0	0.115
1008	2.5	0.098
1206	3.0	0.077
1806	4.5	0.042
2010	5.0	0.031
2512	6.3	0.014
2920	7.4	0

Table 1 above shows parasitic offsets for different component sizes when open calibration is performed for the 2920 size. If calibration is not redone for a different component size, an offset will occur, such as 0.249 pF for the 01005 component size.

This offset is not critical when the measured capacitance value is higher than 100 pF, as the relative accuracy of the LCR-Reader is 0.2%. However, it becomes highly significant for capacitors below 10 pF, where it can contribute to more than 100% error, as shown in Figure 2 below.

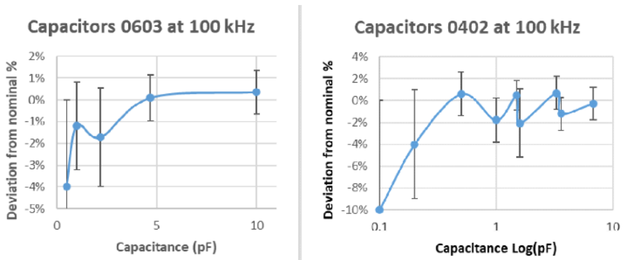

Figure 2. Accuracy of small capacitor measurements for 0603 and 0402 component sizes using capacitance offset calibration board.

The figure above shows measurement results for 0402 and 0603 highly accurate SMD capacitors in the sub-10 pF range. The vertical axis represents the relative deviation from the nominal component value, with error bars indicating the component's tolerance. As demonstrated, proper calibration using the calibration board enables reliable measurement of a 0.1 pF capacitor. In contrast, if proper calibration is not performed, the measurement error can exceed 100%.

The open calibration is performed using the Capacitance Offset Calibration Board, shown in Figure 3 below, which is a dummy PCB with holes spaced at various distances to represent different component sizes (0201, 0402, etc.).

Figure 3. Capacitance offset calibration board.

When the LCR-Reader is set to 10 kHz or higher, and the test lead tips are placed at the minimum distance in the respective holes for the component size being measured, the device will display the actual offset capacitance. This value should then be subtracted from the component's measured value to achieve higher accuracy. For later models, such as the LCR-Reader-MPA, R2, and R3, the open calibration is performed by pressing the joystick to the right until you hear two beeps.

SMALL INDUCTANCE MEASUREMENTS

Similar to parasitic capacitance, parasitic inductive elements are also caused by the unshielded test leads, as illustrated in the Figure 4 below. As shown, the parasitic inductances of the test leads are connected in series with the component under test and must be considered when taking measurements. Parasitic inductance varies significantly with the distance between the test leads. This variation arises because the magnetic field produced by the test leads increases as the distance between them grows. When the leads are close together, their magnetic fields cancel each other out because the electrical currents flow in opposite directions, creating opposing magnetic fields according to the Biot-Savart law. As the distance between the probes increases, the mutual cancellation of these magnetic fields diminishes, resulting in a higher overall magnetic field and, consequently, higher inductance.

Figure 4. Inductance offset introduced by test leads of LCR-Reader R2.

A board for short calibration was designed to eliminate inductance offset, similar to the open calibration board. It features a solid layer of copper connecting all the holes on the board. To perform a short calibration, insert the test leads into the appropriate holes on the calibration board and push the joystick to the right.

To determine the actual parasitic inductance of the test leads, the following experiment was conducted: a regular short calibration was performed using shorted test leads, and then the inductance of the short calibration board was measured for different component sizes.

Table 2. Inductance offset for LCR-Reader R2.

Size	L mm	L (nH)
01005	0.4	2.8
0201	0.6	3.8
0402	1.0	5.2
0603	1.5	6.6
0805	2.0	7.8
1008	2.5	9.3
1206	3.0	10.5
1806	4.5	13.3
2010	5.0	14.7
2512	6.3	17
2920	7.4	18.6

The parasitic inductance of the LCR-Reader multimeter varied from 2.8 nH to 19 nH, depending on the distance between the tweezer probes, ranging from 01005 to 2920 sizes, as shown in the Table 2 above. Clearly, the suggested short calibration significantly reduces the parasitic inductance offset.

To test the accuracy of the inductance measurement, single-wire inductors were measured, for which accurate analytical formulas are available [2]. Figure 5 below presents the results.

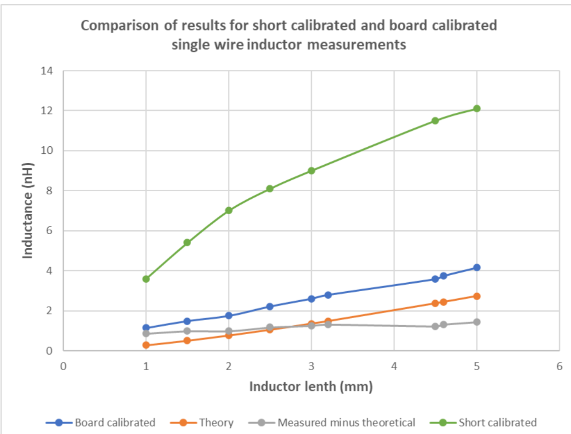

Figure 5. Single wire inductance measured using LCR-Reader R2 with and without short calibration using Short Calibration Board compared to theoretical value [2].

As clearly observed, measurements taken with a standard short calibration revealed a significant overestimation. In contrast, measurements performed with the board calibration are much closer to the theoretical values, though they deviate by approximately 1 nH. While this deviation is notable, it is not critical and may be attributed to the mutual inductance between the test leads and the wire inductor. Additionally, it is important to note that LCR-Reader measurements are only accurate within a few tenths of a nH due to device instability, which is affected by variations in the applied pressure on the tweezer handles.

Two additional tests were conducted, comparing the Hioki LCR-meter IM3536 with the LCR-Reader R2 for small chip inductors of 0402 and 0603 sizes.

Figure 6 below shows the inductance measurements for 0402-sized inductors, with the measured values on the Y-axis and the nominal component values on the X-axis, both on a logarithmic scale.

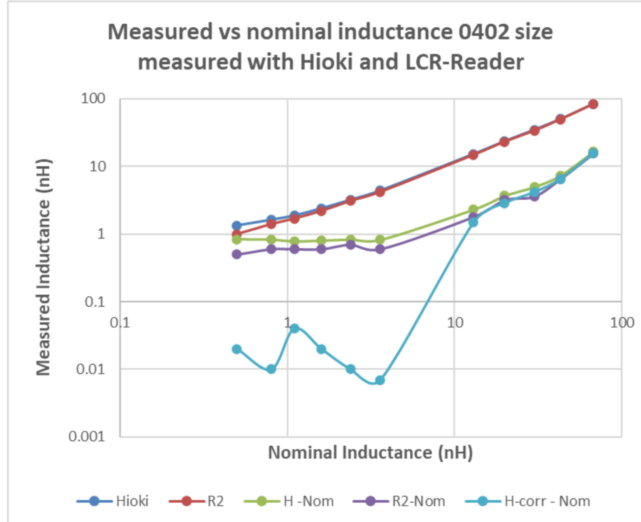

Figure 6. Inductance of 0402 components measured using LCR-Reader R2 with and without short calibration using Short Calibration Board. Compared to measurement results using Hioki IM3536 with and without test fixture offset subtraction.

The curves are marked as follows: Hioki and R2 denote the respective LCR meters, H-nom and R2-nom represent the difference between the measured and nominal inductance values, and H-corr nom indicates the corrected value measured with the Hioki, accounting for the offset inductance. This offset, approximately 0.82 nH, represents the parasitic inductance of the test fixture. As shown, accounting for this offset significantly improves accuracy for small-value inductors.

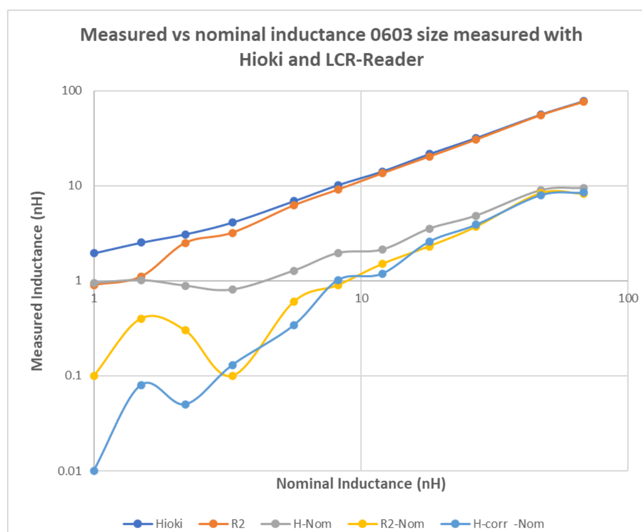

Figure 7. Inductance of 0603 components measured using LCR-Reader R2 with and without short calibration using Short Calibration Board. Compared to measurement results using Hioki IM3536 with and without test fixture offset subtraction.

It is important to note the substantial deviation of the measured values from the nominal values, as observed in [1]. This discrepancy is due to the low test frequency used in measurements, known as the low-frequency correction factor. Both LCR meters exhibit excellent agreement in their results.

Similar results were obtained for 0603-sized chip inductors, as shown in Figure 7 above. The notation used is consistent with the previous figure. For the Hioki test fixture, the offset was slightly higher, at 0.95 nH.

CONCLUSIONS

The importance of proper calibration for two-wire measurement setups is reaffirmed. For tweezer meters, this issue is even more critical due to the potentially higher offset values, which can be as large as 19 nH.

REFERENCES

[1] M. S. Obrecht, "Simple Offset Elimination Technique for Two-Wire Measurements", IEEE Instrumentation & Measurement Magazine, v. 26, p.45, August 2023

[2] H. A. Aebischer, B. Aebischer, "Improved Formulae for the Inductance of Straight Wires", Advanced Electromagnetics, Vol. 3, No. 1, September 2014