Measurements of Extremely Small Inductance Values

Offset elimination technique for small inductance measurements using two-wire connection

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Abstract— **Measurement of small inductors is the trickiest compared to other component testing using typical LCR-meters providing test frequency of 100 kHz or lower. Inductance of 1 nH at 100 kHz only produces 6 mOhm impedance that is comparable to a contact resistance of the probes. Even at 1 MHz the impedance would only be 60 mOhms. We demonstrate a simple method of extraction of the two-wire probe parasitic inductance using HP4284A LCR-meter and HP16034E test fixture. The method effectively allows to measure sub nH inductors.**

Keywords—Inductance, measurement, offset, low frequency

I. Motivation

We develop and manufacture high precision low frequency LCR tweezer-meters such as LCR-Reader-MPA [1] and similar products. They usually use test frequencies 100 kHz or lower and this makes measurement of small inductances very difficult. We also needed calibrated components in nH range that could be used for calibration of our devices. So we tried to use the HP5284A bench multimeter to measure small inductances, but we ran into serious problems when measuring inductances below 10 nH, so we came up with the calibration procedure described below.

Since it was not possible to get larger size components (larger than 1008) with small inductance, we used an alternative approach by making inductors of a piece of copper wire of the required size. For those we used a theoretical inductance estimate as the nominal inductance value.

II. Inductance Measurement Methods

Each method has its own advantages and disadvantages as described in the literature, e.g. [2].

III. Inductance Measurement Methods

Impedance measurement methods for inductors are divided into three basic groups:

i. Current and voltage methods implemented by passing a known high-frequency alternating current through the component and recording the resulting voltage across it

ii. Differential/bridge methods based on comparison of the measured and reference impedances

iii. Resonance methods based on measurement of the resonant frequency of the measured inductor connected to a known capacitor

Each method has its own advantages and disadvantages as described in the literature, e.g. [1).

We will discuss the most widely used current and voltage or response method to measure inductance, implemented by passing a known high-frequency alternating current through the component and recording the resulting voltage across it. From the ratio of these the magnitude of the impedance is calculated. The phase angle between the voltage and current is also measured in combination with the impedance, the equivalent capacitance or inductance, and resistance can be calculated.

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IV. Measurement Procedure

A. Calibration using small SMD inductors

Typically smaller inductors should be measured using 100 MHz to 1 GHz test frequency that is not readily available for a typical user. Most of common inexpensive handheld LCR-meters operate at 10 kHz whereas more advanced meters, such as LCR-Reader [1] may offer 100 and 250 kHz test frequency. Bench LCR meters may offer 1 MHz and higher test frequency but they are an order of magnitude more expensive.

Lower test frequencies result in three major outcomes:

i. Much lower impedance values that have to be possible to measure, i.e. much higher measurement accuracy required

ii. This entails a need for an accurate extraction of the parasitic inductance of the two-wire probes

iii. Overestimation of the actual inductance value as it is clear from manufacturer datasheets, typical deviation is about 10% and higher, e.g. [3].

A series of measurements has been performed for six different component sizes: 01005, 0201, 0402, 0603, 0805 and 1008 with inductance values varying from 0.3 to 100 nH and frequencies 100, 250 and 1,000 kHz.

B. Calibration using single wire inductors

Single wire inductors were made in house of 0.65 mm copper wire. We had very limited capability of making a

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precision inductors and only could achieve 5 □ length accuracy. This accuracy level was reasonable for inductors larger than 1 mm, that is 0402 component size equivalent.

Measurement Results

Measurement results are presented in Fig. 1 below. As can be seen from the picture, for small inductances measured values deviate from the nominal values significantly, more than a 100%, and the deviation considerably exceeds the component tolerance range. The deviation varies with the component size as expected because the geometry of the test fixture (in particular, distance between the probes) is adjusted for every size. This deviation is due to the parasitic inductance of the test fixture.

Ideally in order to extract the parasitic inductance one could use an inductor with a known inductance and then the parasitic inductance can be easily calculated. In reality typically inductances are made with some tolerance and we see that on the deviation varying from one component to another. Therefore we used an average value of the deviation obtained by linear regression analysis as the parasitic inductance of the test fixture.

In order to take into account the correction to the actual inductance value due to low frequency, we used the following expression for extraction of the actual inductance from the measured value.

$$L_{measured}=\alpha L_{actual} + L_{offset} \qquad (1)$$

Where the symbols have obvious meaning and α is a coefficient that reflects correction factor due to low frequency used for measurements. The coefficient depends on the component type, manufacturer technology and test frequency used by the manufacturer for their data sheet measurements. Both parameters α and L_{offset} are extracted using linear regression analysis of measurements for a number of components for each of 6 different sizes.

We assume that measured inductance is proportional to the actual inductance value and limited our measurements to smaller indictors in order to limit effect of higher tolerances for larger inductors. The extracted values a and L_offset are presented in Table 1 below. Components tolerances are also shown varying from 0.1 nH to 0.3 nH for smaller inductors and 5% for larger ones. Typical deviation due to the lower test frequency is about 10-20%. It is not identifiable for sub nH inductors but it is clearly visible on inductors of 10 nH and higher. For smaller inductors under 10 nH the main contribution comes from L_offset whereas at higher values the frequency correction factor becomes dominant.

We use (1) along with linear regression analysis to extract actual inductance values for higher test frequency. If this parasitic inductance and low frequency correction are taken into account we get pretty accurate results for inductors as shown in Fig.1.

The following components were used in the experiments; most of them were multilayer inductors: Wurth Elektronik, TDK, Taio Yuden, Murata, Eaton and Abracon.

Extracted inductance offset for both methods shown in Fig.2 are similar for component sizes 0402 and 0603, but the difference increases dramatically for sizes of 0805 and especially 1008. It may possibly be attributed to the absence of small inductors with this size. Larger inductance values lead to higher component tolerance, in particular for 0805 component typical tolerance is 5% which gives 1 nH, for 1008 component the tolerance leads to a typical 2 nH tolerance. As a result, component value fluctuation effect and absence of the lower inductance values when using the regression analysis result in an overestimated offset inductance.

Table 1. Tested components and extracted parameters

Component parameter	***01005***	***0201***	***0402***	***0603***	***0805***	1008
Tolerance	0.1 – 03 nH	0.1 - 0.3 nH, 5%	0.1 - 0.3 nH, 5%	0.1- 0.3 nH, 5%	0.3 nH, 5%	0.3 nH, 5%
Test Frequency	500 MHz	100, 500 MHz	100 Mhz	100 MHz	100 MHz	100 MHz
Manufacturer	Murata, Sunlord	Wurth	TDK Taiyo	Wurth	Eaton Abracon	TDK
L_{offset} Component	0.45	0.636	0.923	1.075	1.661	3.242
α	1.137	1.208	1.136	1.139	1.062	1.0063
L_{offset} Wire	-	-	0.785	0.888	0.877	1.011

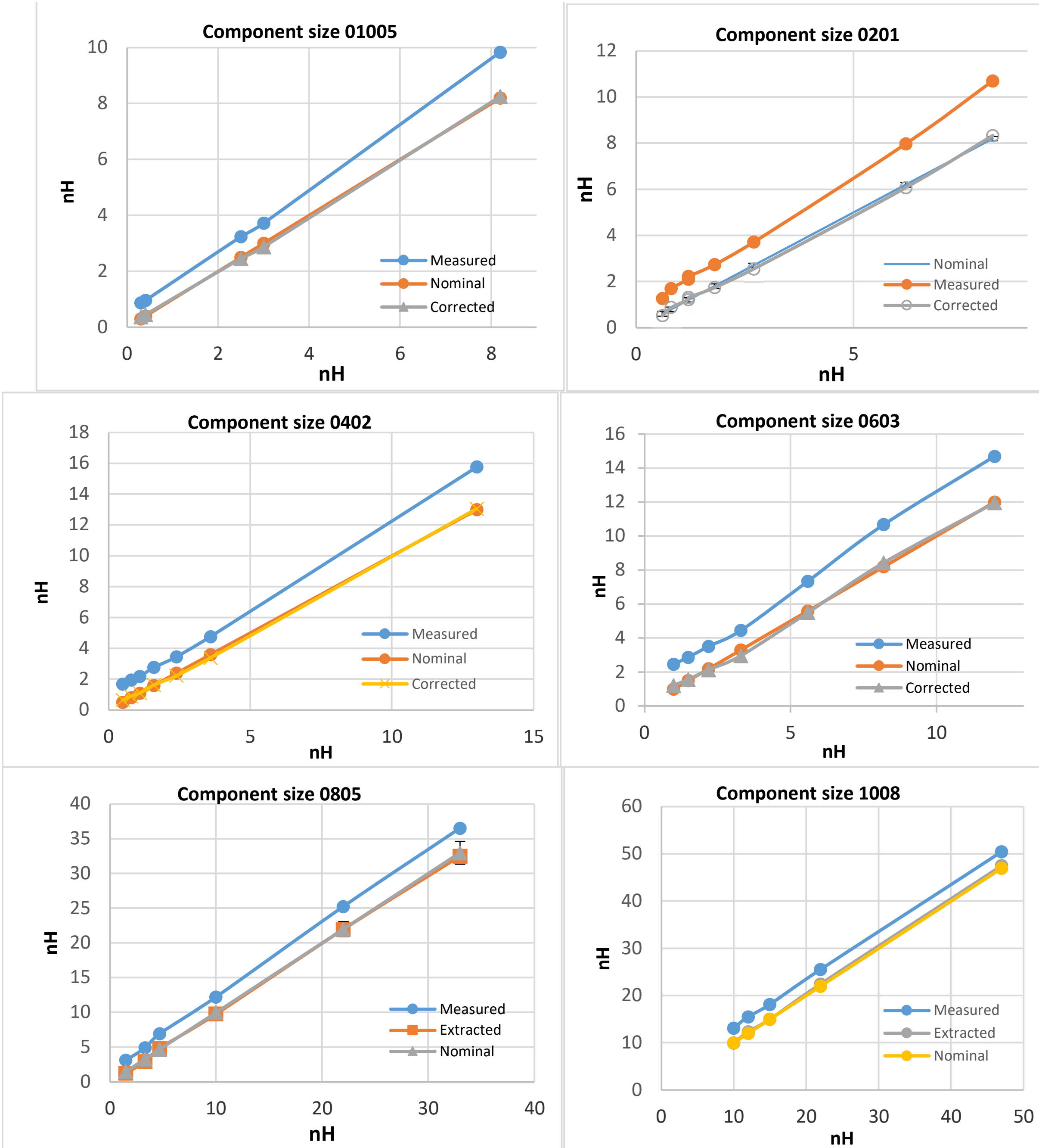

Fig. 1. Typical measurement results for 01005, 0201,0402, 0603, 0805 and 1008 inductors using HP4284A at 1 Mhz test frequency. Measurement results, nominal inductance values and corrected values using (1) are shown.

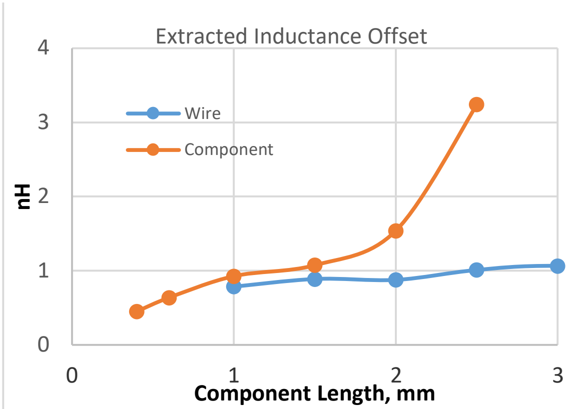

Fig. 2. Extracted inductance offset for two methods of extraction: using SMD inductors and single wire inductors. Reasonable agreement is achieved for 0402 and 0603 components while strong deviation is visible for component sizes 0805 and 1008.

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