SCALING OF INDUCTANCE TO THE pH-LEVEL

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Introduction

The demand for traceability of wideband power measurement is addressed in the IMERA+ project “The Next Generation of Power and Energy Measurements.” One of the tasks is to improve the design of current shunts and comparison of the phase angle errors of different designs is needed. Within the project a wideband phase comparator for high current shunts has been developed by INRIM, see poster. SP has earlier shown that the absolute phase angle errors of 4-terminal current shunts can be determined by measuring the equivalent inductance of the shunts but for high current shunts the inductance can be <100 pH. Inductors with calculable value can easily be made on printed circuit boards (PCB) in the range 10 nH to 100 nH but values <1 nH demand sub-mm design. This poster is a progress report on a scaling method to calibrate an impedance meter at the pH-level using inductance standards in the pH-range and a resistive voltage divider.

Measurement setup

The measurements are made with a four-terminal pair impedance meter having a resistive voltage divider and an adapter is a 4TP test lead modified to have one voltage connector and one current resolution <1 pH. To be able to connect 4-terminal current shunts and inductance standards an adapter from four-terminal pair (4TP) to four-terminal (4T) is used. The model can be used to 1 MHz for low value inductances with low self-capacitance. The inductance standard and resistive voltage divider are modeled as shown in Figure 2. The ratio of the divider is characterized to 1 kHz. The magnitude is calibrated by ac-dc transfer measurement and the phase displacement is calibrated by a new phase measuring system, see poster.

Method

The wideband resistive voltage divider, made for ac-dc transfer, with ratio 100:1 is used to scale the voltage of the inductors so the impedance meter will measure a 100 times lower inductance. The ratio of the divider is determined as:

\[
L_{\text{div}} = L_{0} \left( \frac{R_{21}}{R_{21} + R_{12}} \right) = L_{0} D
\]

and

\[
R_{\text{div}} = R_{0} \left( \frac{R_{21}}{R_{21} + R_{12}} + \frac{R_{12}}{R_{21} + R_{12}} \right) \frac{L_{0}^2}{L_{0}} \]

where symbols according to Figure 1 and where D is the ratio of the divider

\[
D = \frac{R_{21}}{R_{21} + R_{12}}
\]

and \( \tau \) is a time constant determined by measuring the phase displacement \( \phi \) of the divider

\[
\tau = \frac{L_{0}}{R_{21}} \frac{L_{0} + L_{1}}{R_{21} + R_{12}} \]

The model can be used to 1 MHz for low value inductances with low self-capacitance. The correction factor for the error due to loading of the divider \( b \) is so far not modeled but determined by measurement.

Test of method

The method was evaluated by step-down measurements from 100 µH to 1 µH and to 10 nH (approx.). Three standards are used: 100 µH and 1 µH standards calibrated at 1 kHz and a calculable 18 nH standard. The error of the 100 µH+100/1 divider relative the value determined by the model was measured at 0.1 kHz to 100 kHz using an impedance meter calibrated by the 1 µH standard. The error is within a few percent even when the correction for the divider is 70%, at 100 kHz. Similarly the error of the 1 µH+100/1 divider relative the value determined by the model was measured from 1 kHz to 500 kHz using an impedance meter calibrated by the calculable 18 nH standard.

Phase comparison

The table below show preliminary results of a comparison of the phase displacement of three 100 A current shunts at 10 kHz, as measured by INRIM and by SP, with and without correction for the phase error of the impedance meter. INRIM has made a realization of absolute phase of a shunt at the current level 1 A - 5 A and made a step-up using a phase comparator, see poster. The shunt V1280A2 was measured by INRIM and V1680A5 was measured by SP but both shunts are of the same model.

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<td></td>
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<td>corr.</td>
<td>SP</td>
<td>corr.</td>
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The shunt V1280A2 was measured by INRIM and V1680A5 was measured by SP but both shunts are of the same model.

Conclusion

A method to calibrate four-terminal pair inductance meters at the pH-level and at frequencies up to 1 MHz has been developed. The calibration is done using inductance standards in the pH-range and a wideband resistive voltage divider for scaling. Preliminary results looks promising.

Acknowledgement

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