Bode 100 - Application Note

Power Inductor Modelling

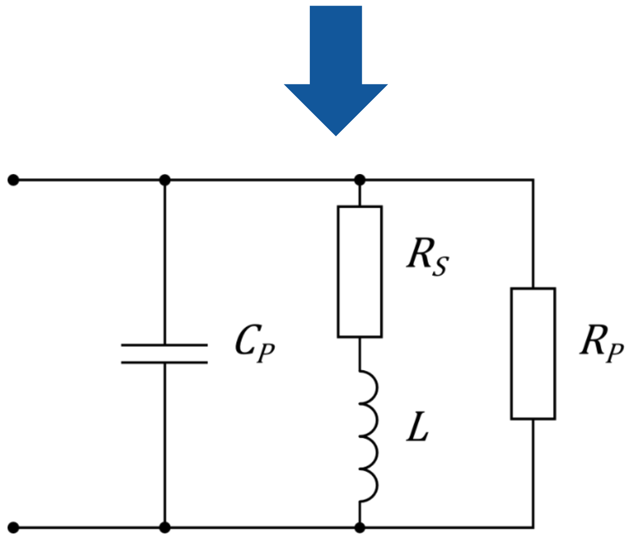

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Table of Contents

Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual. You can download the Bode 100 user manual at www.omicron-lab.com/bode-100/downloads#3

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V3.0. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version at www.omicron-lab.com/bode-100/downloads

1 Executive Summary

This application note describes how a power inductor AC model can be created using the Bode 100. The developed schematic diagram contains the most important parasitic elements of the DUT[1]. The calculated and measured parasitic elements and the resulting entire schematics can be used for equivalent circuit simulation purpose.

2 Measurement Task

We try to derive the equivalent circuit parameters of the power inductor shown in the following picture:

Figure 1: Power inductor DUT

The following circuit diagram was chosen to model the frequency response of the inductor:

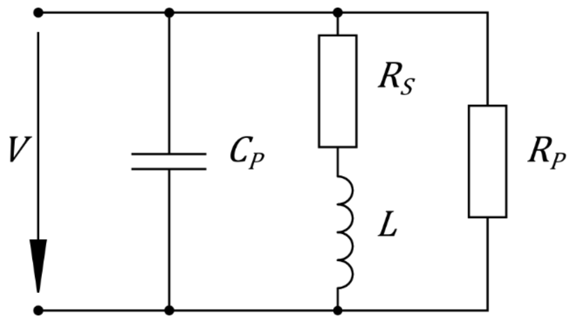

Figure 2: Circuit model with parasitic elements

L…ideal inductance of coil

R_S…coil wire resistance

C_P…parallel capacitance

R_P...parallel resistance (magnetic loss)

[1] Device Under Test

3 Measurement Setup

In order to measure the impedance of the inductor the Bode 100 is used in conjunction with the B-WIC impedance test fixture.

Figure 3: Measurement setup

After starting the Bode Analyzer Suite the Impedance Adapter measurement type has to be selected.

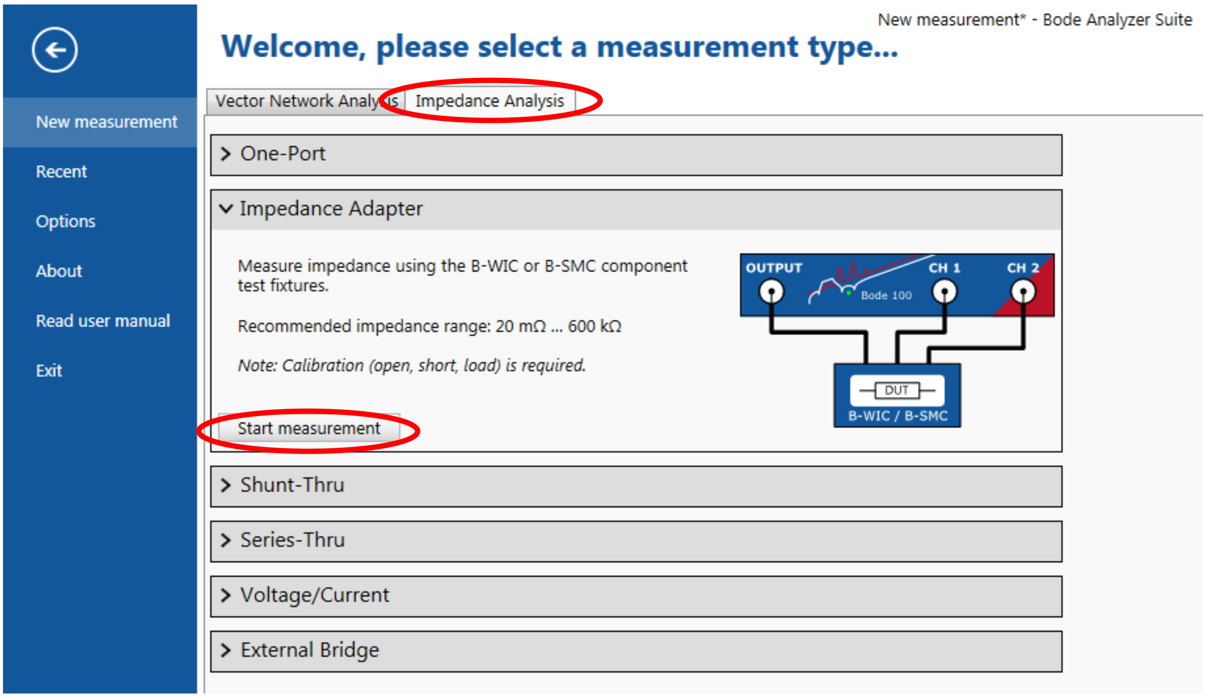

Figure 4: Start menu

4 Measurement

4.1 Device Settings

As we need the winding resistance at nearly DC we choose $1\ Hz$ to be the start frequency for the first measurement. And because the resonance frequency is not known the measurement will be conducted over the full frequency range to 50 MHz.

The parameters are chosen to be:

Start Frequency:	1 Hz
Stop Frequency:	50 MHz
Sweep Mode:	Logarithmic
Number of Points:	201 or more
Level:	13 dBm
Receiver Bandwidth:	30 Hz

With these settings set in the Bode Analyzer Suite the calibration can be performed.
A Full-Range Calibration is recommended for the following measurement. To perform the Calibration, click on the Full-Range Calibration icon.
The calibration procedure is described in the Bode 100 user manual.

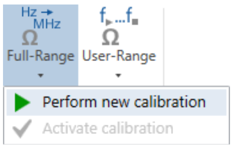

Figure 5: perform calibration

After the calibration, setup the parameters for Trace 1 and Trace 2 as shown below.

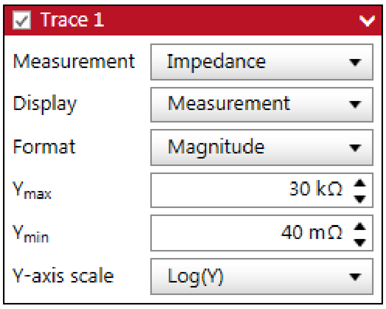

Figure 6: Settings Trace 1

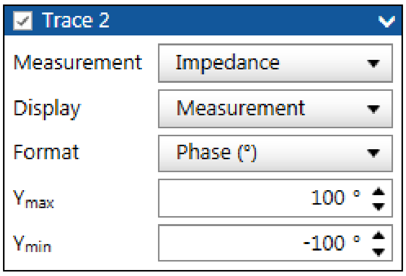

Figure 7: Settings Trace 2

4.2 Results

After the performed calibration the power inductor is connected to the B-WIC. The leads should be kept as short as possible, otherwise the lead length will influence the measurement results. Performing a single sweep measurement with all the settings and calibration mentioned above leads to our measurement result shown below. We can clearly identify the low frequency resistive region, the inductive region and the resonance frequency of the inductor.

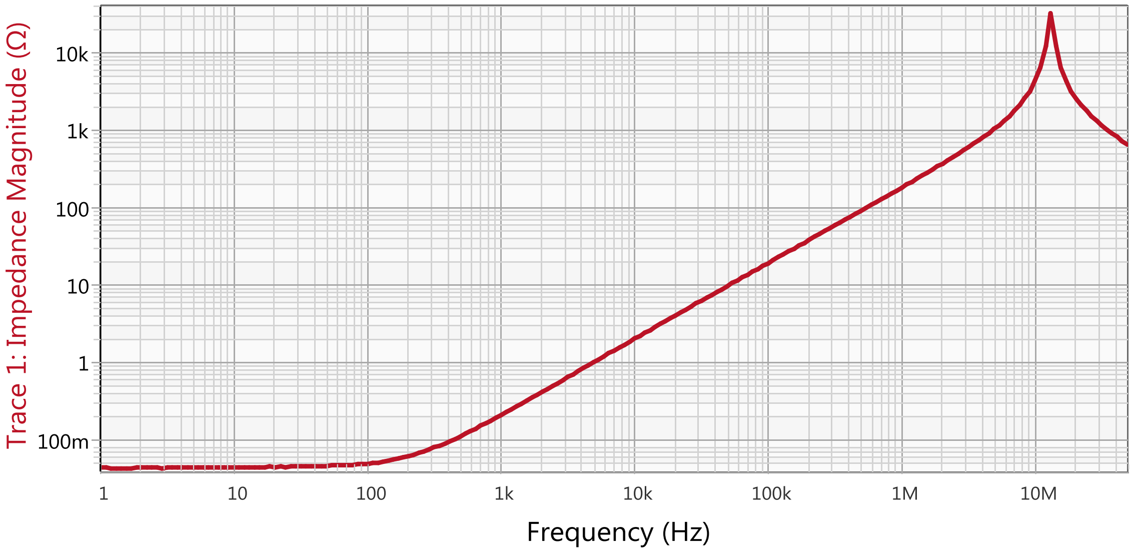

Figure 8: Measurement result – Magnitude

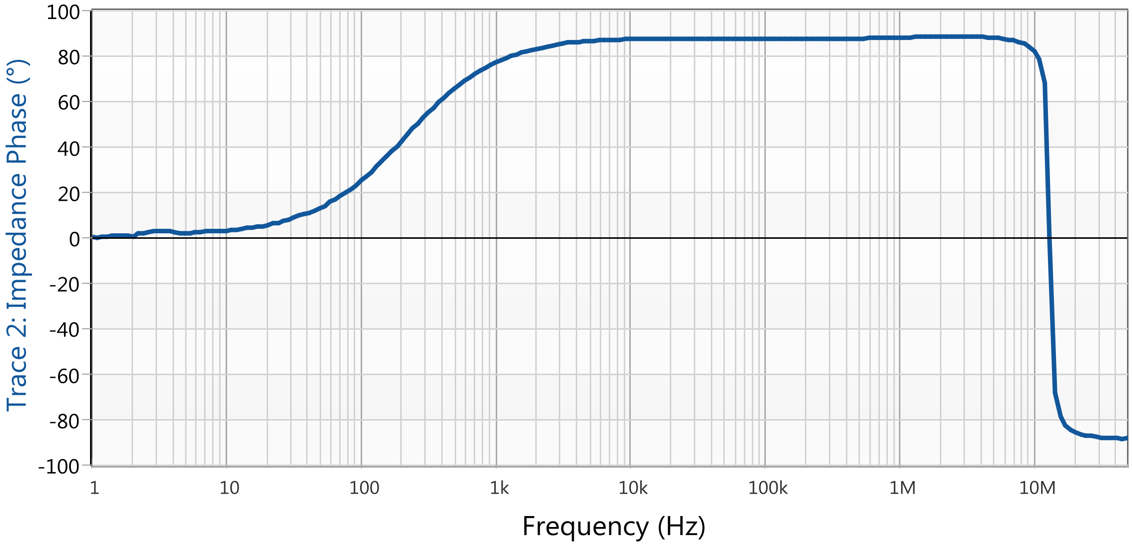

Figure 9: Measurement result - Phase (°)

4.2.1 Coil Wire Resistance R_s Measurement

For the next measurement, please set “Format” to “Rs” as shown in Figure 10.

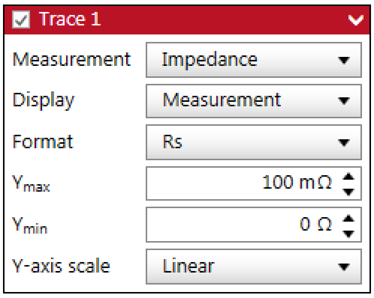

Figure 10: Settings Trace 1

Actually R_S is measured at DC voltage, but $1\ Hz$ is low enough, so that inductance and skin effects are negligible. For verification purpose we have measured the DC resistance using a 4-wire ohmmeter and the result matches the result from the $1\ Hz$ measurement with the Bode 100. To measure the series resistance at $1\ Hz$ type the frequency into the cursor grid to place the cursor at $1\ Hz$.

Note: The y-axis was changed for better visibility from 0 Ω to 1 Ω.

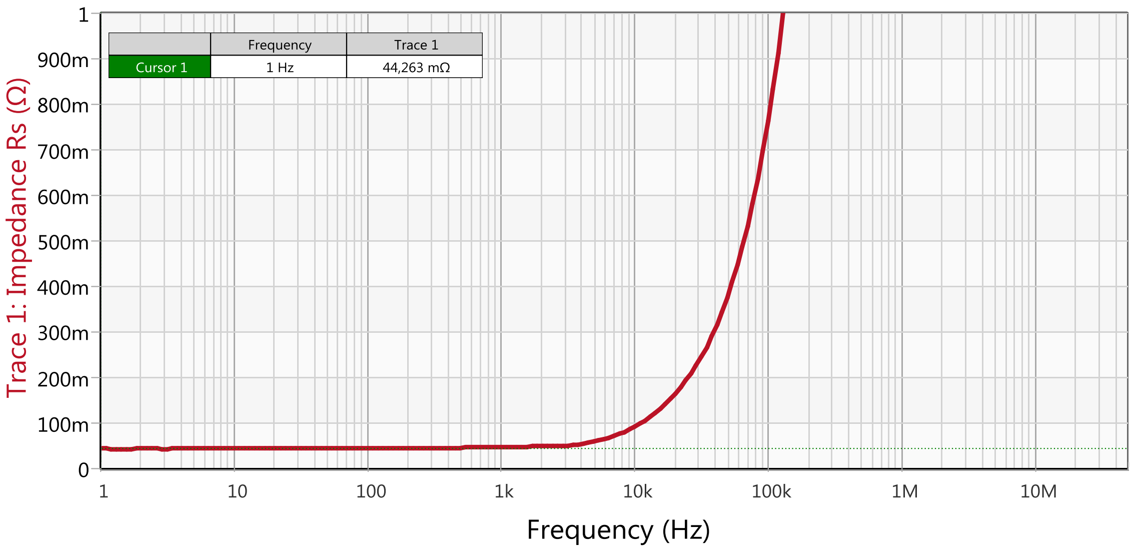

Figure 11: Measurement result – series resistance

Our measured wire resistance is:

$$R_S = 44\ m\Omega$$

4.2.2 Inductance L Measurement

At low frequencies the winding resistance dominates the measured inductance. At higher frequencies the inductance dominates the measurement result and therefore it can be measured more precise at higher frequencies. Hence a compromise has to be made. It depends on the inductor, at which frequency the inductance is measured best. The impedance plot gives an indication for the best measurement frequency. A rule of thumb is to measure the inductance in a region where the impedance curve shows a constant slope respectively is linearly.

To display the series inductance “Format” has to be set to “Ls”. Furthermore we set the start frequency to $10\ Hz$ since the reactance below $10\ Hz$ is very small and extremely difficult to measure.

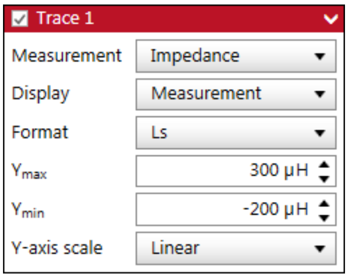

Figure 12: Settings Trace 1

We chose the frequency to be about $300\ Hz$. As it can be seen in the diagram below, at this frequency the inductance is quite constant and the signal is not interfering anymore.

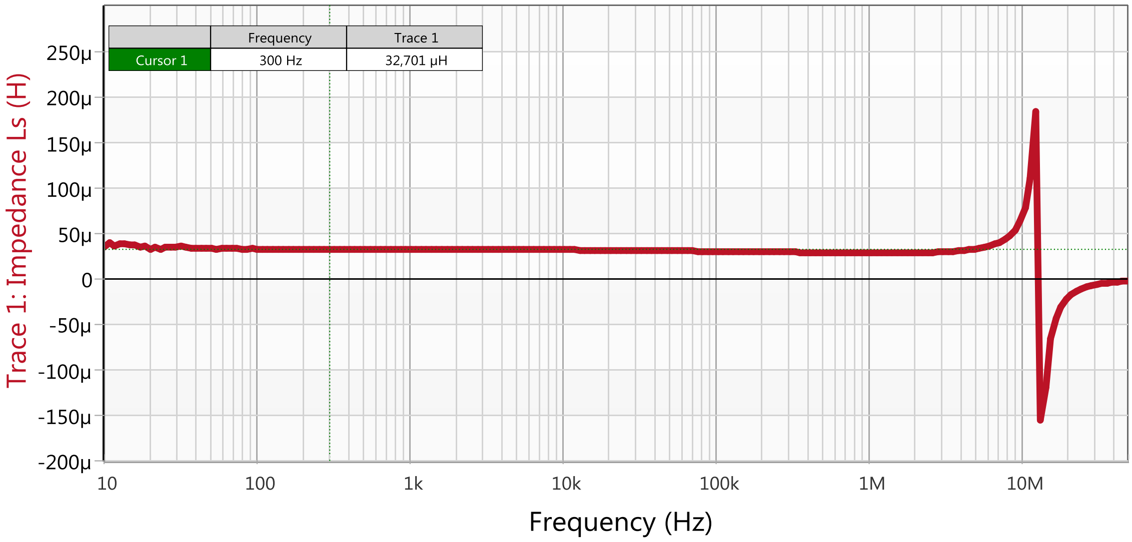

Figure 13: Measurement result - inductance

The measured inductance is:

$$L = 33\ \mu H$$

4.2.3 Parallel Capacitance C_P Measurement

The parallel capacitance C_p forms a parallel resonance tank together with the inductance of the inductor. By including the parallel capacitance, the first self-resonance frequency of the inductor can be modelled.

Derivation of the resonance frequency

It can be quite challenging to directly measure the parallel capacitance. But by some calculation the capacitance can easily be determined quite exactly.
The calculated admittance of our inductor model is:

$$Y = \frac{1}{R_P} + \frac{R_S}{R_S^2 + \omega^2 L^2} \quad + \quad j\omega \cdot (C_P - \frac{L}{R_S^2 + \omega^2 L^2}) \tag{1}$$

By looking at the imaginary part we see that an ω exists which forces the imaginary part to zero. For this zero frequency ω_0 respectively f_0 the equation rewrites to

$$for\ Im\{Y\} = 0: \quad C_P = \frac{L}{R_S^2 + (2\pi f_0)^2 \cdot L^2} \tag{2}$$

Usually for inductors it is adequate to neglect the coil wire resistance R_S. Hence the simplified equation is:

$$for\ Im\{Y\} = 0: \quad C_P = \frac{1}{(2\pi f_0)^2 \cdot L} \tag{3}$$

Measurement

For a better resolution the measurement is performed again with a smaller frequency range. The center frequency should be the measured resonance frequency now.

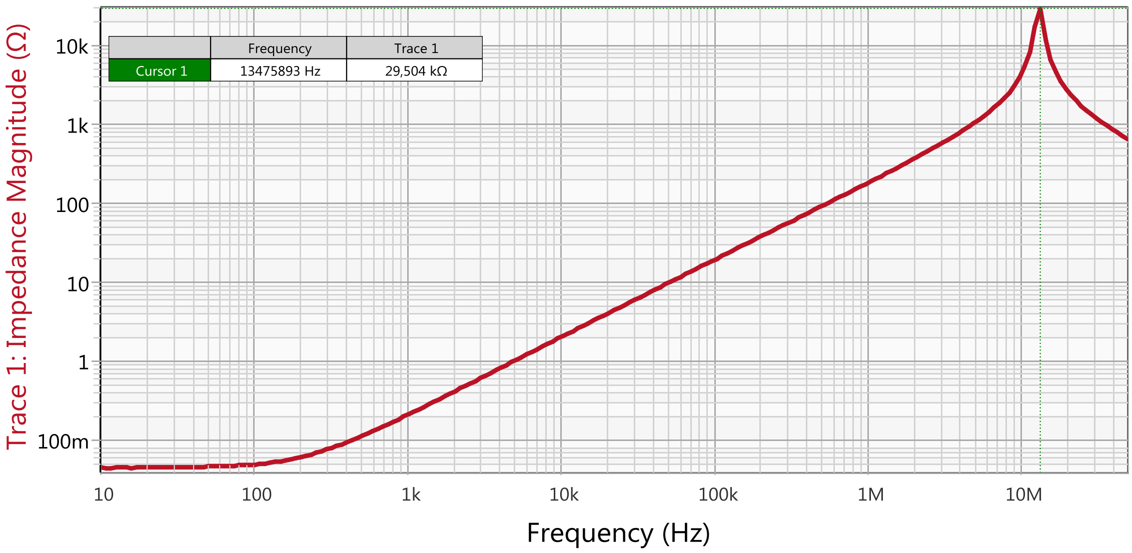

Figure 14: Frequency sweep over the whole frequency range

As the resonance frequency of our power inductor is somewhere around $13.5\ MHz$. Therefore we pick the frequency range from 5 MHz to 25 MHz.

If a Full-Range calibration was performed before, the calibration remains active even when the frequency range is changed. A User-Range calibration has to be performed again after the change of the frequency range. Therefore look into the Bode 100 user manual.

To measure the frequency f_0 “Format” is set to “Phase (°)”

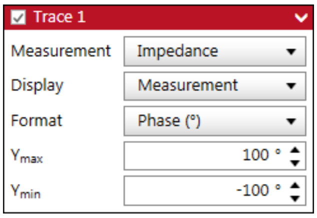

Figure 15: Settings Trace 1

Performing a single sweep measurement with all the settings and calibration mentioned leads to our measurement result shown below:

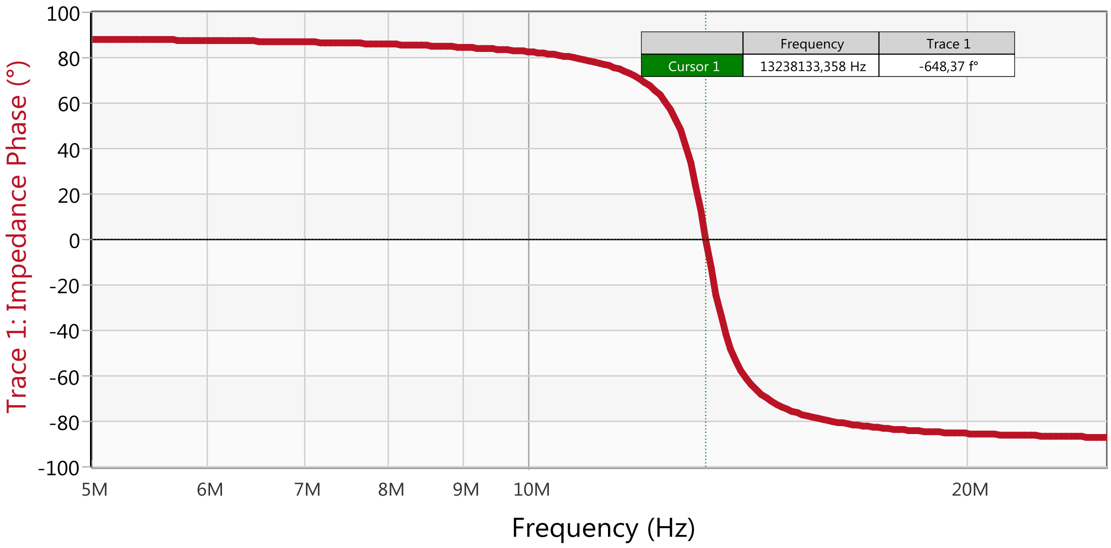

Figure 16: Measurement result – Phase (°)

The frequency at the zero crossing point can simply be measured with the “Jump to Zero” cursor function. Thereto right-click into the diagram → chose a cursor → click on “Jump to Zero”

The measured zero crossing frequency for our power inductor is:

$$f_0 = 13.238\ MHz$$

According to equation (3) the parallel capacitance C_P is:

$$C_P = \frac{1}{(2\pi f_0)^2 \cdot L} = \frac{1}{(2\pi \cdot 13.238\ MHz)^2 \cdot 33\mu H} = 4.38\ pF$$

4.2.4 Parallel Resistance R_P

The last element to be ascertained is the parallel resistance R_P. It is used to model the magnetic losses. Hereto it is sufficient to simplify the model to a parallel resonant circuit. The admittance of a parallel resonance circuit is:

$$Y = \frac{1}{R_P} + j(\omega C_P - \frac{1}{\omega L}) \quad (4)$$

At resonance only the real part is left. Hence the parallel resistance R_P must be equal to the impedance maximum.

To measure R_P we change “Format” to “Magnitude” as shown in Figure 17.

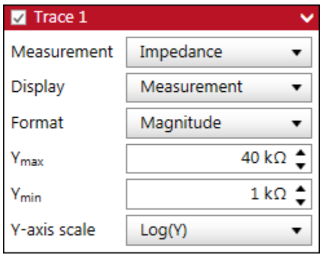

Figure 17: Settings Trace 1

Starting a single sweep leads to the following diagram:

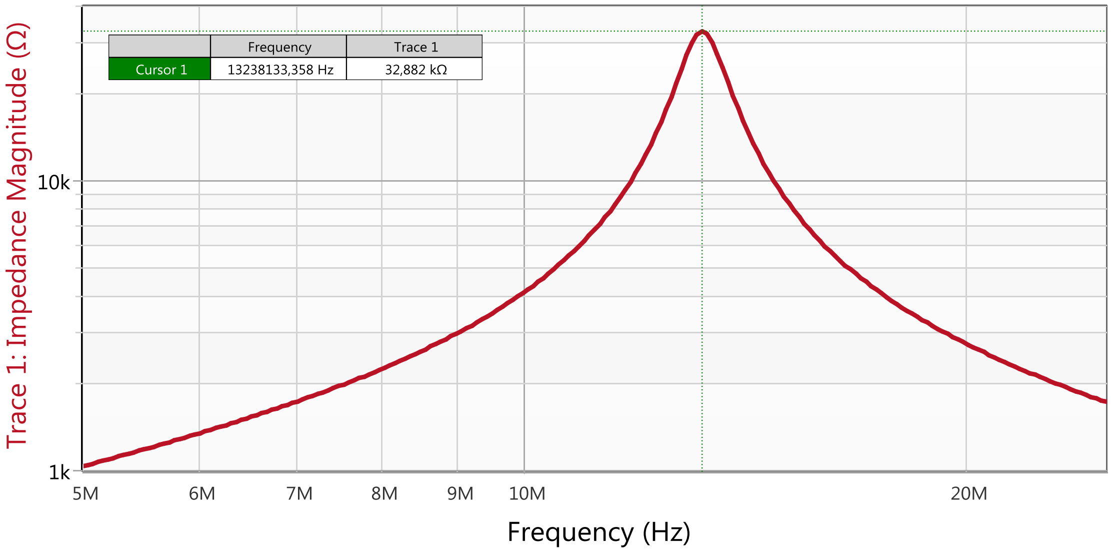

Figure 18: Measurement result - Magnitude

According to the diagram our parallel resistance R_P is:

$$R_P = 32.882\ k\Omega$$

5 Comparing Simulation and Measurement

For comparison the derived inductor model was modelled in a Spice simulator. The calculated and measured AC small signal impedance curves are plotted in the same chart.

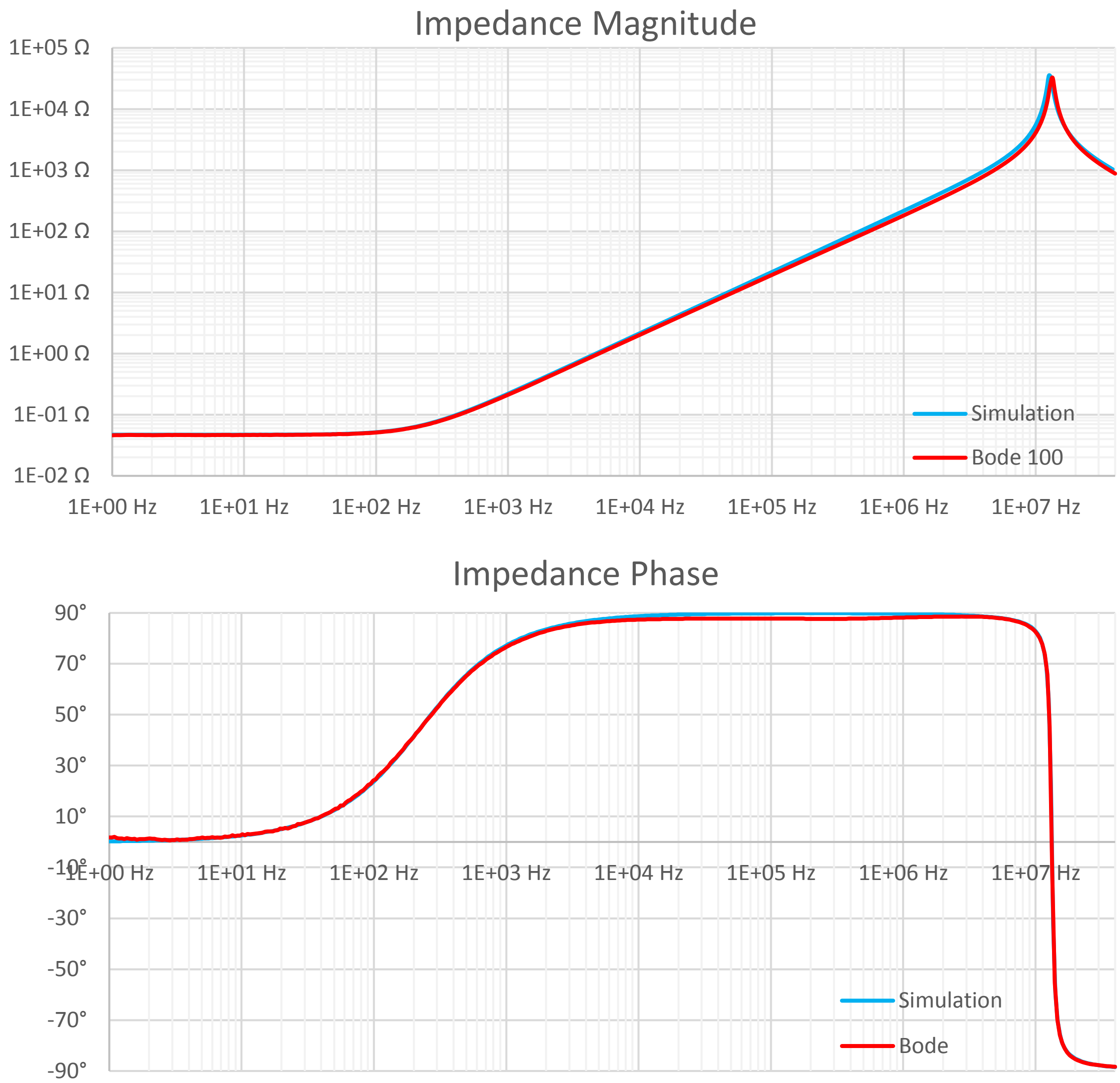

Figure 19: comparing simulation and measurement result

The diagrams show two good matching curves over the whole frequency range.

6 Conclusion

The Bode 100 in combination with the B-WIC impedance adapter are the ideal solution for precise impedance measurements. The measurements can be displayed in numerous formats, so that calculations can often be overcome. The desired equivalent circuit elements can directly be displayed over frequency. This shows important information and helps to choose the right frequencies for the measurements.

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