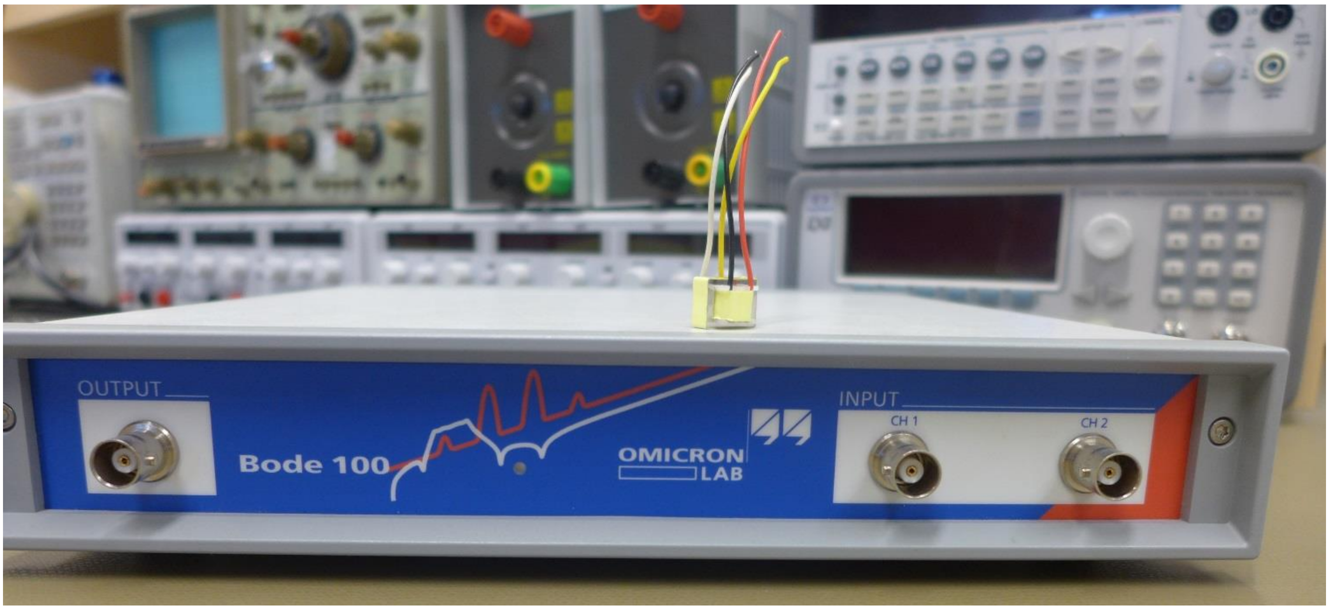
Bode 100 - Application Note

Signal Transformer Measurements



By Stephan Synkule

Visit www.omicron-lab.com for more information.
Contact support@omicron-lab.com for technical support.

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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 explains how Bode 100 can be used to measure and verify various signal transformer parameters. You will be shown how to detect discrepancies in winding numbers of transformers and how to measure resonance frequencies and coupling factors.

2 Measurement Tasks

Sometimes it happens that a signal transformer does not show the exact characteristics as described in its datasheet. Bode 100 offers several functions to verify signal transformer parameters.

The following points are from interest when analyzing a common signal transformer:

1. Transmission ratio
2. Usable frequency range
3. Coupling factor
4. Resonance frequency
5. Parasitic capacitance at the resonance frequency

Note: Basic procedures like setting-up, adjusting and calibrating Bode 100 are described in the manual of the Bode 100 (see: http://www.omicron-lab.com/bode-100/downloads.html#3). Therefore these procedures are not described in detail in this application note.

3 Measuring setup and results

3.1 Measurement of the transformer's transmission ratio

The transformer's transmission ratio is defined as the ratio of its primary and secondary voltage (U_{prim}/U_{sec}). By using the gain/phase mode of Bode 100 the transformer transmission ratio can be measured directly.

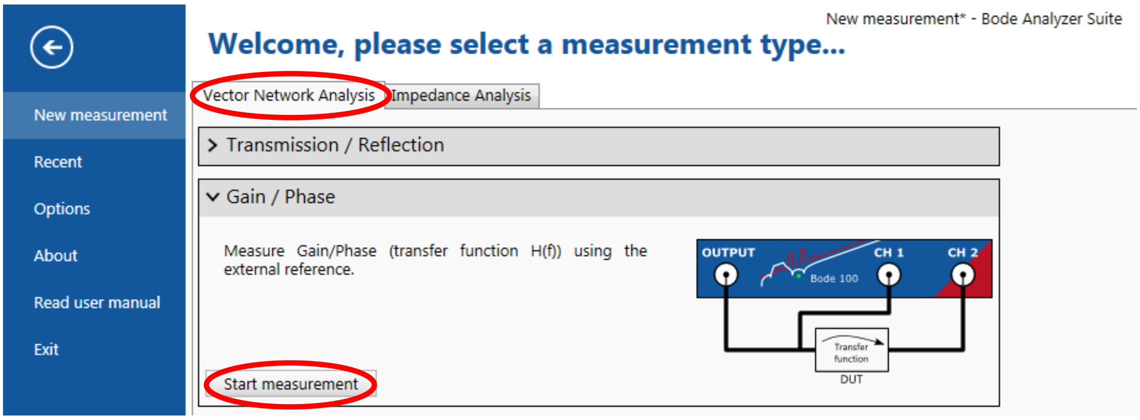

Figure 1: Start menu

Apply the following settings:

Start frequency:	depends on transformer (in this case: 20 Hz)
Stop frequency:	depends on transformer (in this case: 20 kHz)
Sweep mode:	Linear
Number of points:	201
Source level:	0 dBm
Attenuator for CH1 & CH2:	20 dB
Receiver Bandwidth:	1 kHz

Perform a "Full-Range" calibration to remove cable influences as described in the user manual.

Note: In our measurement we use a 1:1 transformer. If you have another transformer ratio, please note the points below.

- To avoid an overload on input Channel 2 (CH2) please use transformers only in the down conversion mode (side with more windings connected to CH1)
- Input CH1 serves as the reference channel and CH2 is connected to the side with less windings

The pictures below show how we have connected our transformer to the Bode 100:

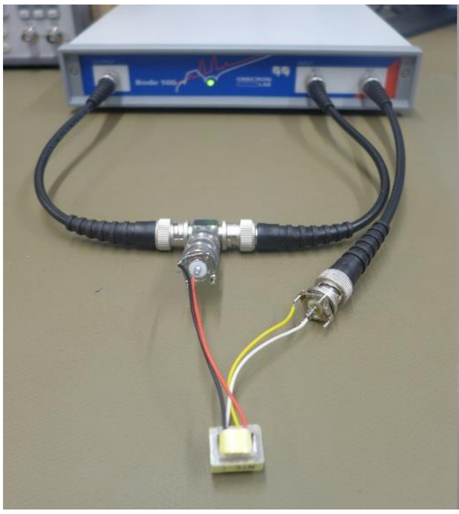

Figure 2: Measurement setup

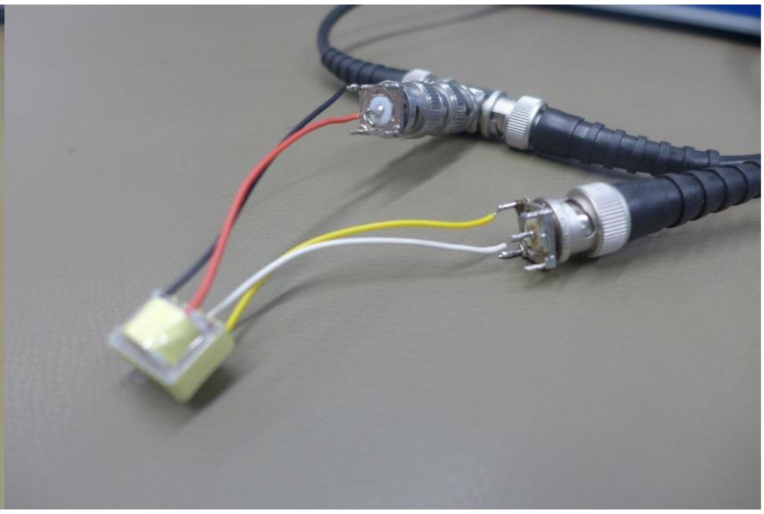

Figure 3: Measurement setup - close-up

Set Trace 1 *Format* to *Magnitude* leads to a chart where the ratio can directly red.

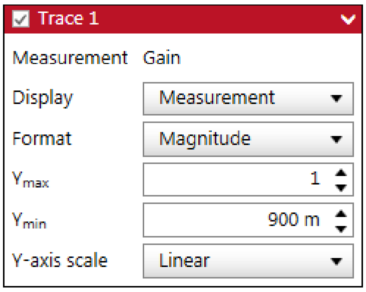

Figure 4: Trace 1 settings

After we set up Trace 1, we can now start the frequency sweep, where you should get a frequency curve comparable to the one below.

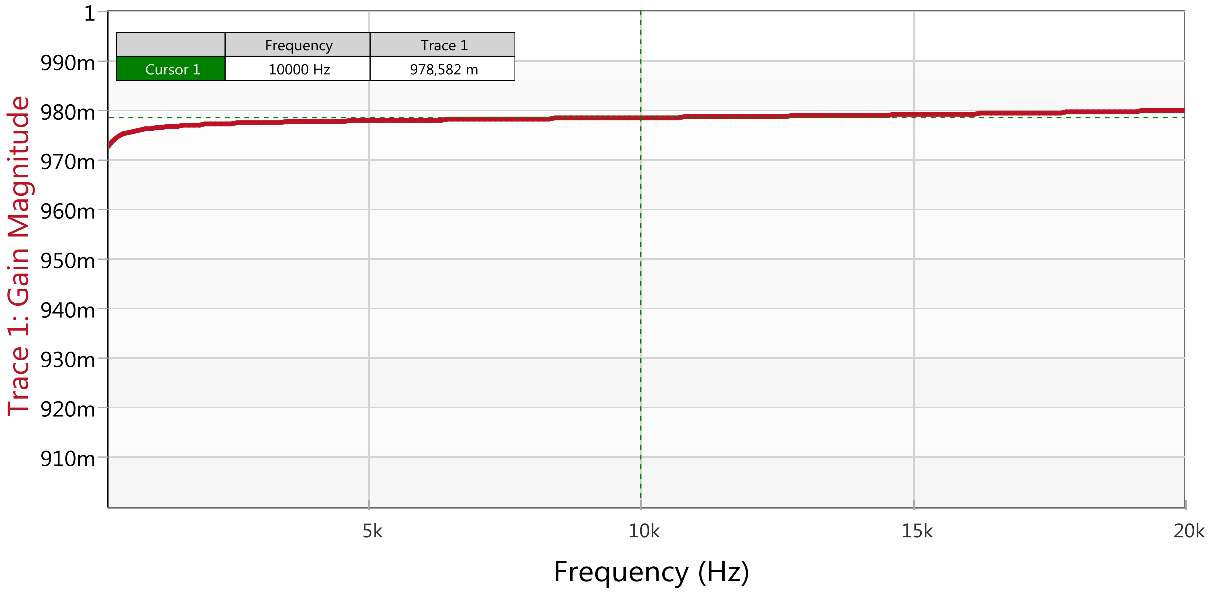

Figure 5: Magnitude measurement

Activating a cursor and put it on the optimal frequency (shown in the data sheet) leads us to get a precise value of the ratio.

Bode 100's gain measurement is defined as the ratio $\frac{U_{CH2}}{U_{CH1}}$. Since we have connected the secondary winding to CH2 and the primary winding to CH1 we have directly measured the transformers transmission ratio: $\frac{U_{prim}}{U_{sec}}$

To find out if the measured value fits the data sheet value we can calculate the transmission function as follows $\frac{U_{prim}}{U_{sec}} = \frac{N_{prim}}{N_{sec}} = \frac{200}{200} = 1$ and compare it with our measurement (0.979), which is acceptable precise.

3.2 Measurement of the usable frequency range of the Transformer

One of the many functions of transformers is to forward signals from one circuit to another while providing galvanic isolation. To find out in what frequency range a certain transformer can be used you need to know the transfer function of your transformer.

For this measurement we applied the following settings in the Gain / Phase measurement:

Start frequency:	10 Hz
Stop frequency:	10 MHz
Sweep mode:	logarithmic
Number of points:	201 or more
Source level:	0 dBm
Attenuator for CH1 & CH2:	20 dB
Receiver Bandwidth:	1 kHz

Check if you have the Bode 100 still calibrated, if not, perform a new THRU calibration. Additionally, the transformer has to be connected as shown in the measurement before (3.1).

Adjust the settings for Trace 1 and Trace 2:

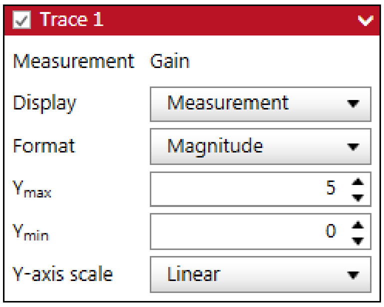

Figure 6: Settings Trace 1

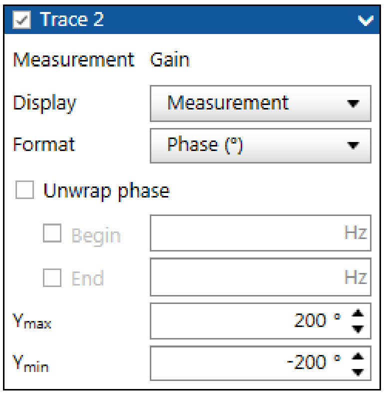

Figure 7: Settings Trace 2

Now we can start a frequency sweep.

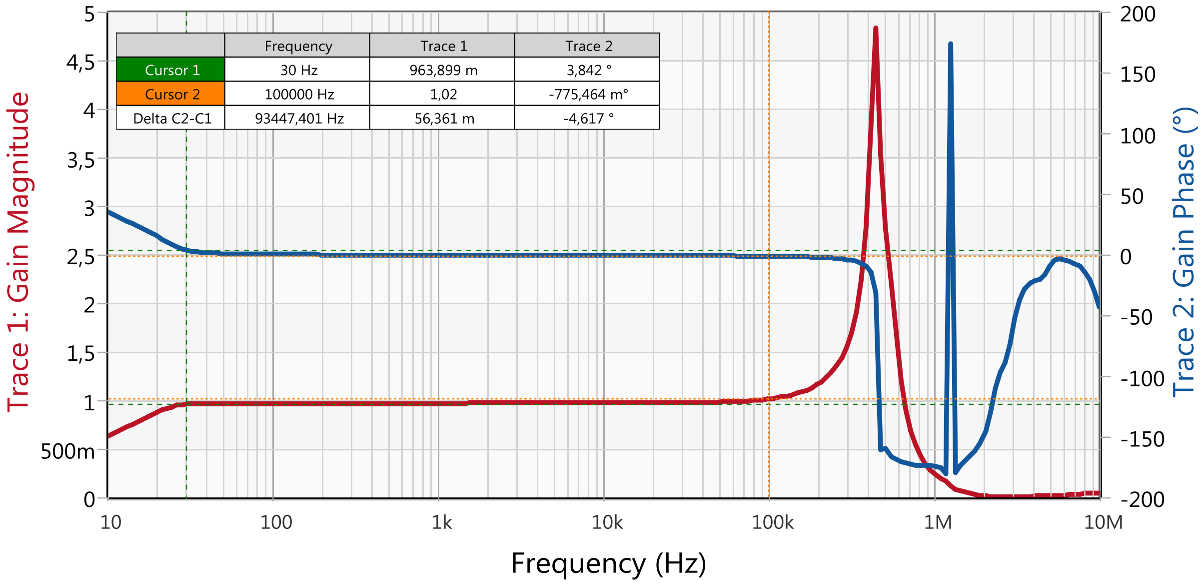

Figure 8: Measurement result – Usable frequency range

The transformer shows a stable magnitude and phase in the range from 30 Hz ~ 100 kHz. Therefore, the transformer we have analyzed can be used in exactly this range (30 Hz to 100 kHz).

3.3 Measurement of the coupling factor

The coupling factor k indicates how much of the magnetic field induced by the primary winding flows through the secondary winding and vice versa. It is therefore a measure for the leakage inductance of a transformer. For an ideal transformer with no leakage inductance the coupling factor equals 1 (k=1). Since real world transformers do have leakage inductances the coupling factor k is always smaller than 1 (k<1). The coupling factor is defined as follows:

$$k = \frac{M}{\sqrt{L_1 \cdot L_2}} \qquad (1)$$

L_1 … primary inductance $\quad$ L_2 … secondary inductance $\quad$ M … mutual inductance

To calculate the coupling factor of a transformer we need to be able to measure the above impedances. Since it is not possible to measure M directly we use the following formulas for the primary and secondary voltages as a starting point:

$$U_1 = j\omega \cdot (L_1 \cdot I_1 + M \cdot I_2) \qquad (2)$$

$$U_2 = j\omega \cdot (M \cdot I_1 + L_2 \cdot I_2) \qquad (3)$$

V_1 = primary voltage
V_2 = secondary voltage

I_1 = primary current
I_2 = secondary current

By shorting the secondary pins of the transformer the secondary voltage equals 0:

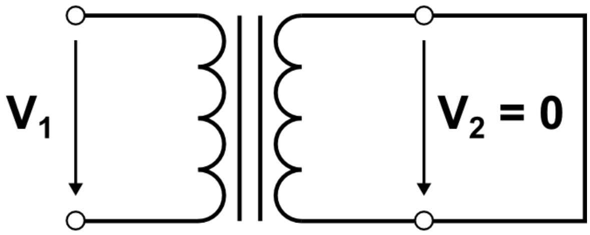

Figure 9: Transformer - one side shorted

In this specific case of operation equation 3 can be adapted as follows:

$$U_2 = j\omega \cdot (M \cdot I_1 + L_2 \cdot I_2) = 0 \quad \rightarrow \quad I_2 = -\frac{M \cdot I_1}{L_2}$$

This new formula for I_2 can be used to replace I_2 in equation 2:

$$U_1 = j\omega \cdot \left(I_1 \cdot L_1 - I_1 \cdot \frac{M^2}{L_2} \right) \quad \rightarrow \quad U_1 = j\omega \cdot I_1 \cdot (L_1 - \frac{M^2}{L_2})$$

This equation can be simplified by replacing the bracket with the new variable L_s.

$$U_1 = j\omega \cdot I_1 \cdot L_s \quad \rightarrow \quad L_s = L_1 - \frac{M^2}{L_2} \quad \rightarrow \quad M^2 = L_2 \cdot (L_1 - L_s)$$

L_s is the inductivity measured at the primary winding of the transformer, with shorted secondary winding. Now we can replace M in equation 1 with $\sqrt{L_2 \cdot (L_1 - L_s)}$

$$k = \frac{\sqrt{L_2 \cdot (L_1 - L_s)}}{\sqrt{L_1 \cdot L_2}} \quad \rightarrow \quad k = \sqrt{\frac{(L_1 - L_s)}{L_1}}$$

After reducing the equation we get the final formula for the coupling factor:

$$k = \sqrt{1 - \frac{L_s}{L_1}} \tag{4}$$

The two unknown inductances L_1 and L_s can be measured by Bode 100. Based on the measurement results it is possible to calculate the coupling factor k.

Note: Due to its design, the Bode 100 is able to measure low impedances very precisely.

To measure these impedances, we have to switch the measurement type to *One-Port*.

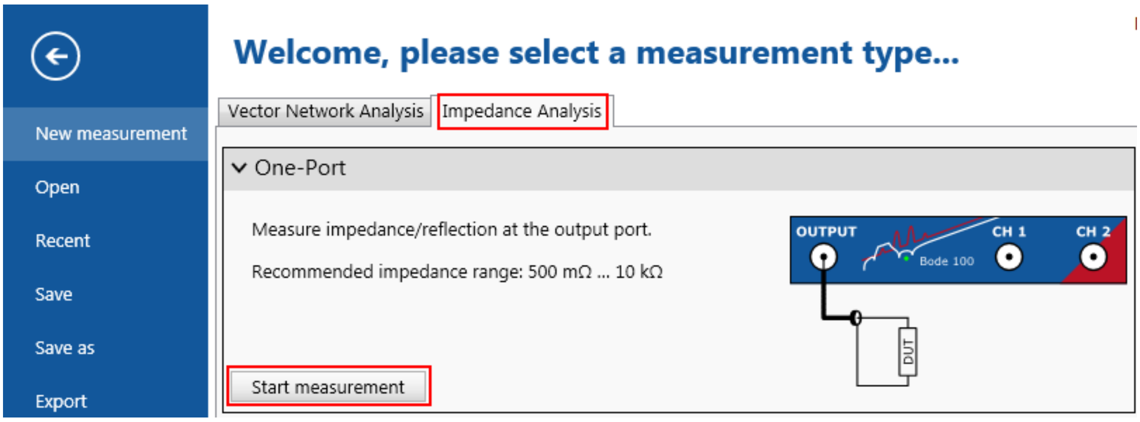

Figure 10: Start menu

Set the Frequency to *Fixed* 1 kHz (or the nominal frequency of the transformer) which is in the linear area of the transformer as well as the measurement settings as follows:

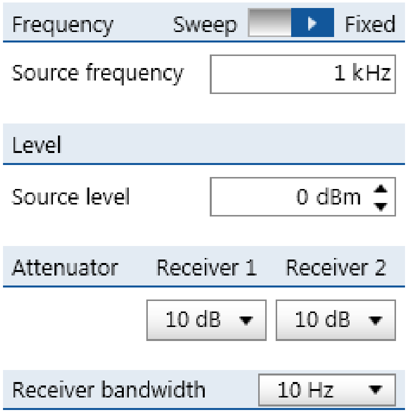

Figure 11: measurement settings

Connect a cable to the source output of Bode 100 and perform an OPEN, SHORT and LOAD calibration to remove the cable influences as described in the user manual.

After you calibrated the Bode 100 connect your DUT (primary winding to source) like shown in the picture below.

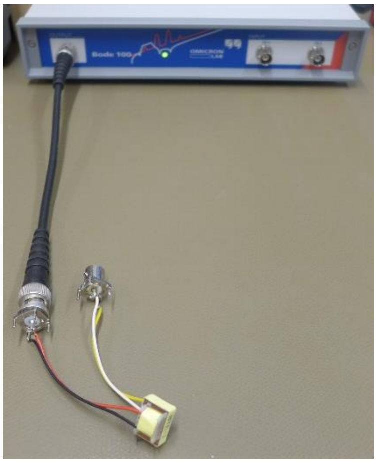
Figure 12: Measurement setup

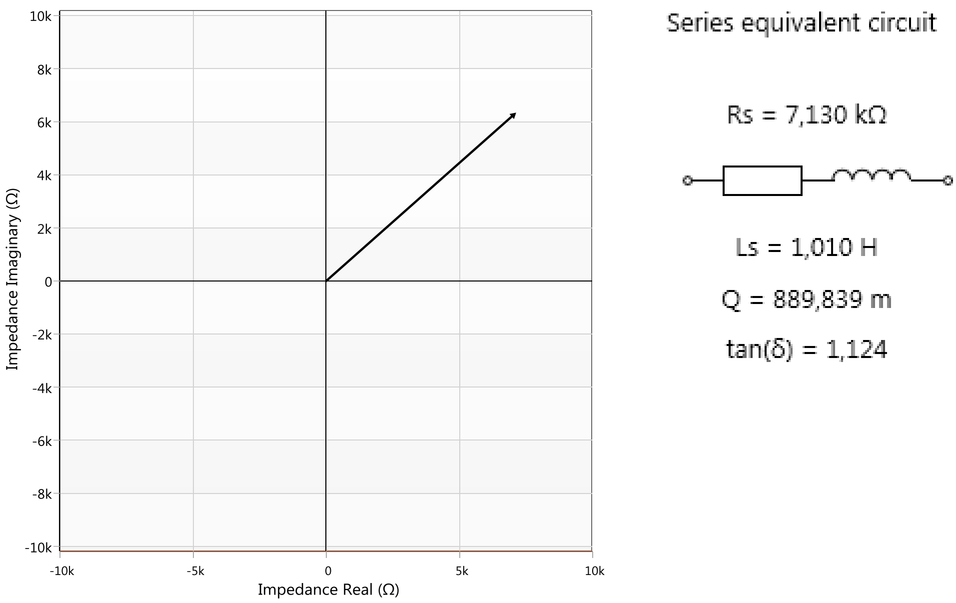

Figure 13: single frequency measurement primary side

Result: Primary inductance L_1 (open secondary winding) = 1 H

To measure L_S you can use the same measurement setup but this time you have to short circuit the secondary winding as shown below.

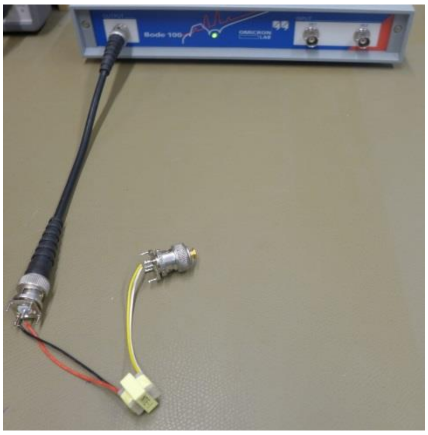

Figure 14: Measurement setup - shorted secondary winding

Repeat the measurement with equal settings leads to:

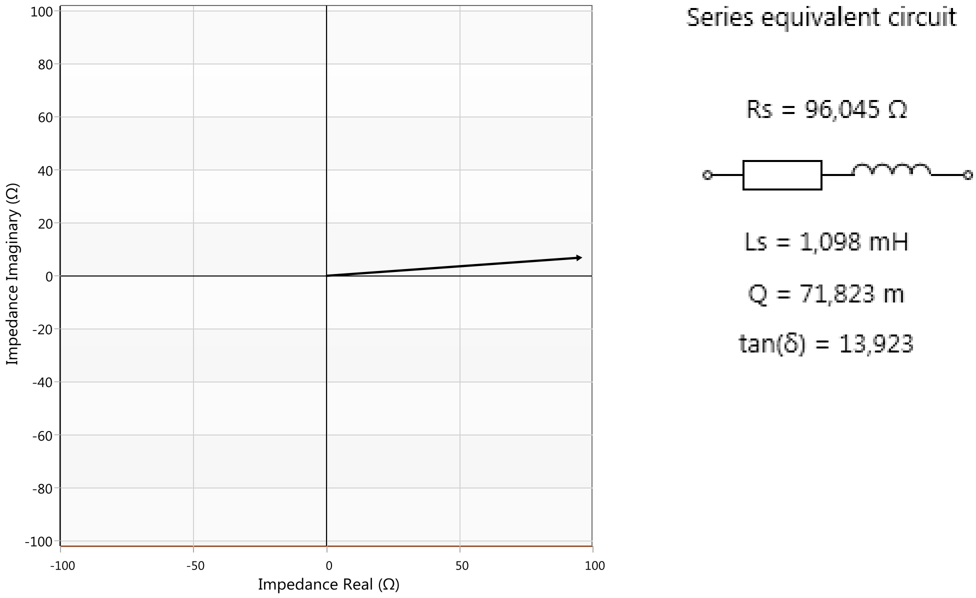

Figure 15: single frequency measurement prim with short sec

Result: The inductance L_s (short circuited secondary winding) = 1.1 mH

With the measured values L_1 and L_s the transformer's coupling factor can be calculated as follows:

$$k = \sqrt{1 - \frac{L_s}{L_1}} = \sqrt{1 - \frac{1.1\,\text{mH}}{1\,\text{H}}} = 0.9994$$

By measuring the inductance on the primary side of the transformer once with open and once with short circuited secondary winding all values required to calculate the coupling factor are available.

3.4 Measurement of the resonance frequency

The transformer's windings also have a parasitic capacity. This capacity, in combination with the winding's inductance, causes a parallel resonance. The next pages show you how to find out the resonant frequency.

Note: The upcoming measurement is also performed by the *One-Port* measurement type as shown in Figure 10.

To measure the resonance frequency of your transformer apply the following settings.

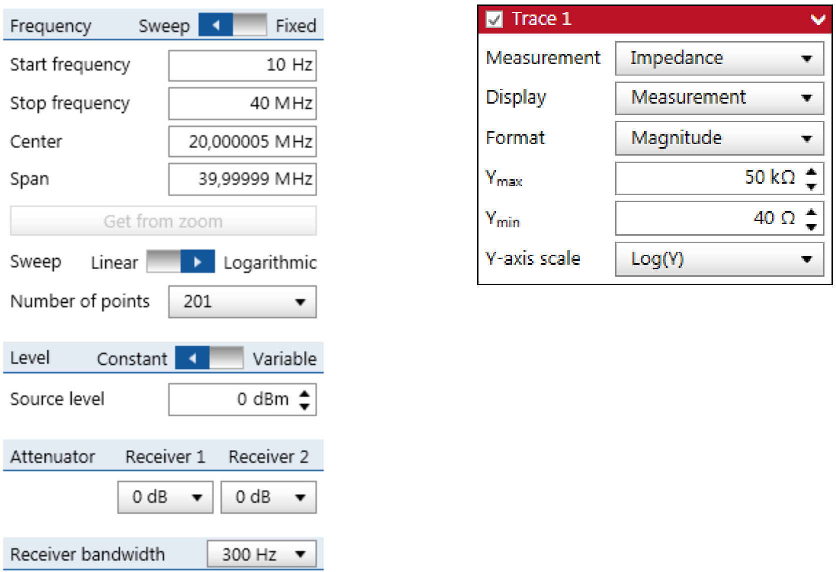

Figure 16: measurement & trace 1 settings

Connect a cable to the source output of Bode 100 and perform an OPEN, SHORT and LOAD calibration to remove the cable influences as described in the user manual.

After the calibration, connect the cable to the primary winding of your transformer and leave the secondary winding open. If you have more than one primary winding connect them in series. The figure below shows the setup with our transformer.

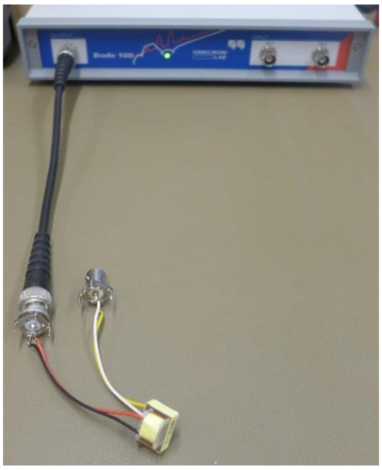

Figure 17: Resonance frequency setup

Start the frequency sweep and use Bode 100's zoom function to optimize the diagram around the peak impedance. By using the cursors you can measure the exact frequency of the highest impedance (Right click into the chart, Cursor 1, Jump to Max (Trace 1)). While zooming, you can adjust the frequency settings with the zoom by pressing the "Get from zoom" button. If the curve is still not precise enough, try to lower the receiver bandwidth or higher the number of points.

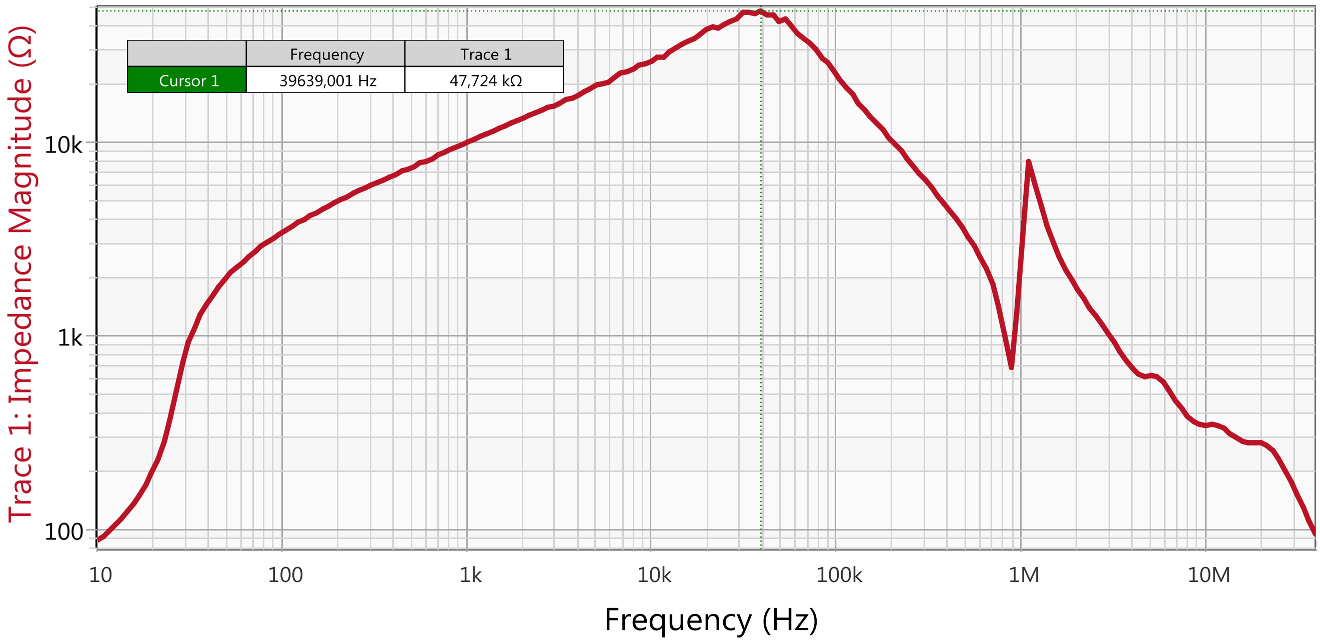

Figure 18: Measurement result

Result: The chart shows a magnitude peak of the impedance curve close to 40 kHz. The cursor function allows measuring the exact resonance frequency – in our case 39.639 kHz.

3.5 Parasitic capacitance of the transformer

Above a parallel resonance was detected at 39.639 kHz. The transformer windings are producing a small capacity. The winding inductance and capacity are specifying the resonance frequency.

Equation for LC-resonance:

$$f_r = \frac{1}{2\pi\sqrt{C \cdot L}}$$

Remark: Since the resonance frequency of the transformer was measured with open secondary winding the inductivity L_1 measured in 3.3 has to be used to calculate the parasitic capacity C.

By converting the resonance formula you get a formula to calculate the parasitic capacity C:

$$C = \frac{\left(\frac{1}{2\pi \cdot f_r}\right)^2}{L} = \frac{\left(\frac{1}{2\pi \cdot 39639\text{Hz}}\right)^2}{1\text{H}} = 16.1\,\text{pF}$$

4 Conclusion

In this application note it has been shown how to measure a signal transformer's characteristics with Bode 100. You were able to measure the transformer ratio, transfer function and the resonant frequency. In addition it was demonstrated that it is possible to calculate the coupling factor and the parasitic capacity based on values measured with Bode 100.

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