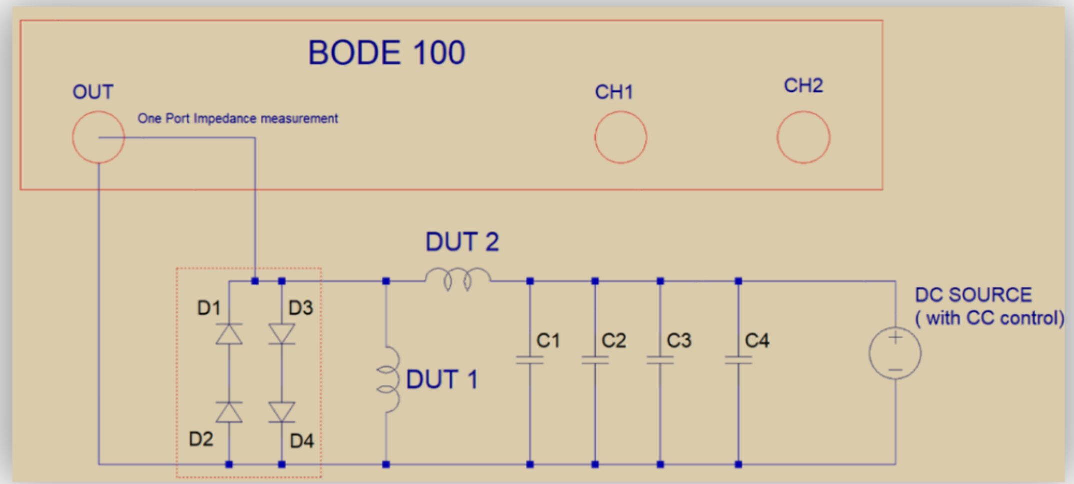
Inductance measurement of Inductors under DC bias using Bode 100

By Vinod Chellat Markose



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1 Executive Summary

This application note describes an inexpensive method for characterizing the drop in inductance of an inductor at any desired DC bias current using the Bode 100 vector network analyzer.

The need for such a measurement is that most inductors' datasheets do not have data on inductance versus current, though some do give data on current corresponding to a 10% drop in Inductance. Likewise, information about Inductance versus frequency is usually unavailable.

The method presented here can be used to gather data on inductance versus current as well as frequency.

2 Measurement Task

In this document, the target is to measure the inductance of Inductors from 1 µH to 100 mH from 10 kHz to 1 MHz with DC bias from 0 A to 50 A (or more).

However, the measurement outside the above parameters range is possible with additional considerations.

3 Measurement Setup and Configuration

3.1 Measurement Equipment

- Bode 100 Vector Network Analyzer
- Measurement accessories (BNC cable, BNC Male-Alligator clip, and BNC-Thru or T connector)
- DC variable power supply with adjustable Constant Current limit

3.2 Test Object Specification

The inductor used: Two identical inductors with 22 turns wound on toroidal core C055120A2 from Magnetic Inc.

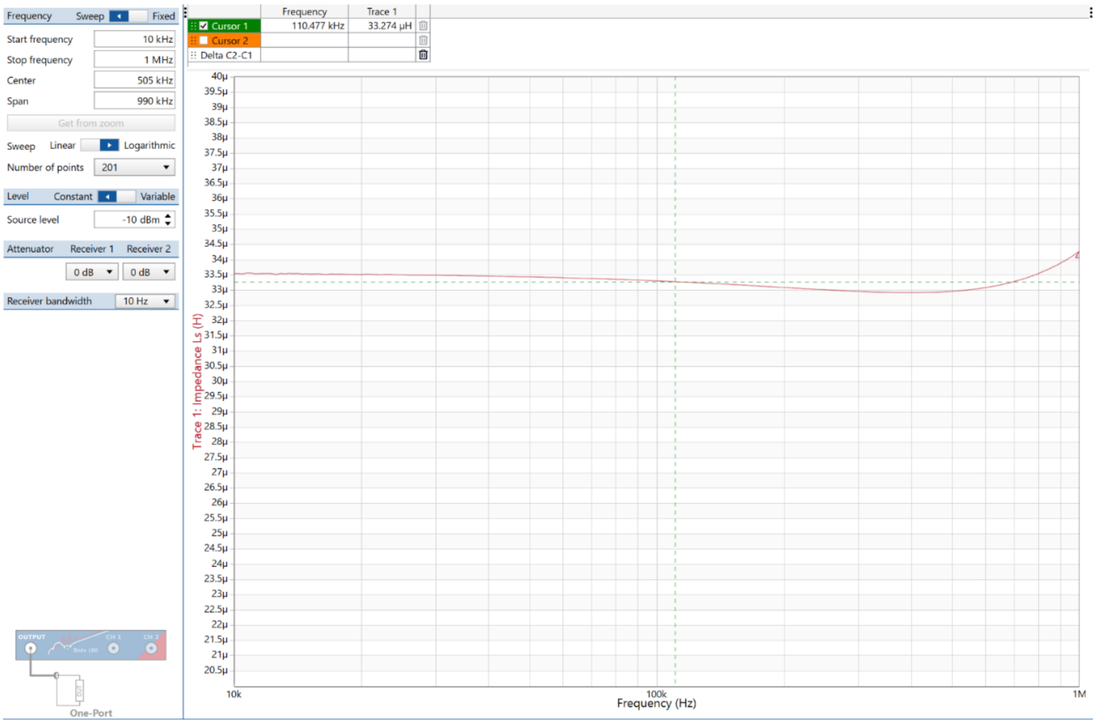
Figure 1: Test objects

Their inductane, when measured using the regular One-Port method, is around 33 µH at 100 kHz, as shown below.

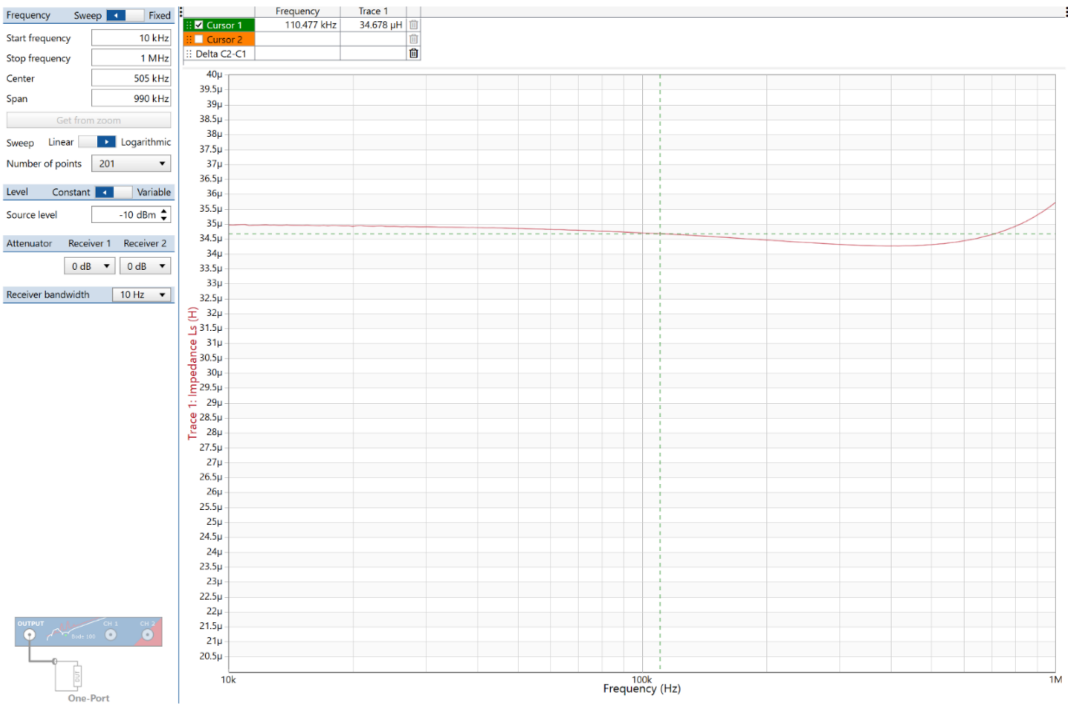
[DUT1 : 33.2 µH   DUT2 : 34.5 µH at 100 kHz , DCR =14 mΩ]

The figures on the following page show the Inductance versus frequency without any DC bias current.

Inductance of DUT 1:



Inductance of DUT2:



3.3 Measurement Method

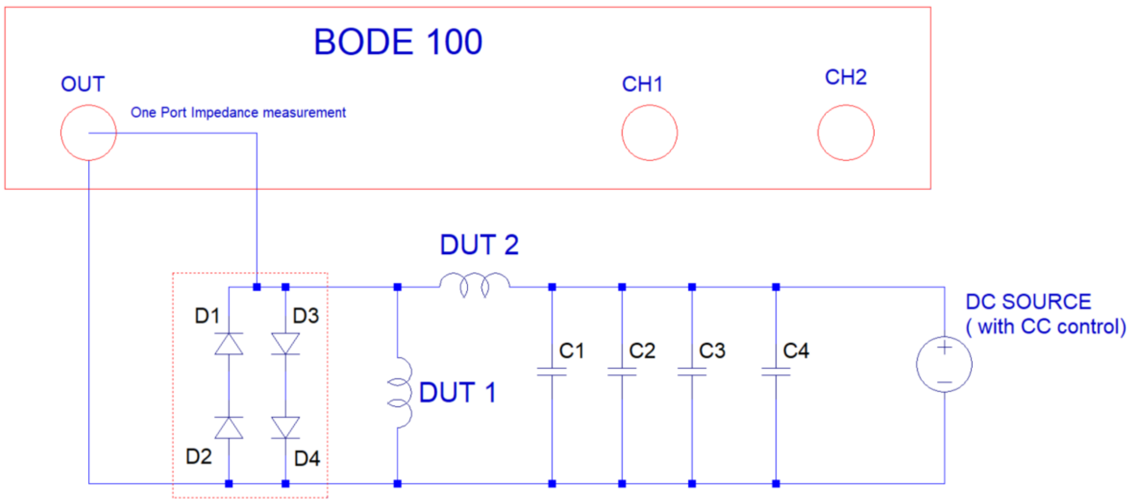


Figure 2: Measurement setup

Here we have used two identical Inductors connected as shown above. The DC current flows thru the inductors in a series path whilst the AC current flows thru the inductors in a parallel configuration.

C1=4700 µF 16 V Electrolytic, C2=C3=C4= 10 µF 16 V Electrolytic.

The reason for such a large capacitor and few capacitors in parallel is to get nearly 0 Ω capacitive reactance at the lowest frequency of interest (i.e., 10 kHz) and for attaining low ESR.

Diodes D1, D2, D3, D4: MUR480E.

These diodes **protect** the Output section of Bode 100 by clamping the voltage to *less than 3.3 V*. (say, in case DUT2 gets disconnected during the test, the diode banks provide free-wheeling path for the current of DUT1). Their equivalent capacitance = **102 pF** (measured at 100 kHz at source power level of -10 dBm). The capacitive reactance of this small capacitance is negligibly small compared with the Inductive reactance of the lowest inductance (of 1uH) that we intend to measure (at even 1 MHz).

The equivalent circuit what Bode 100 sees from 10 kHz to 1 MHz can be approximated as shown below.

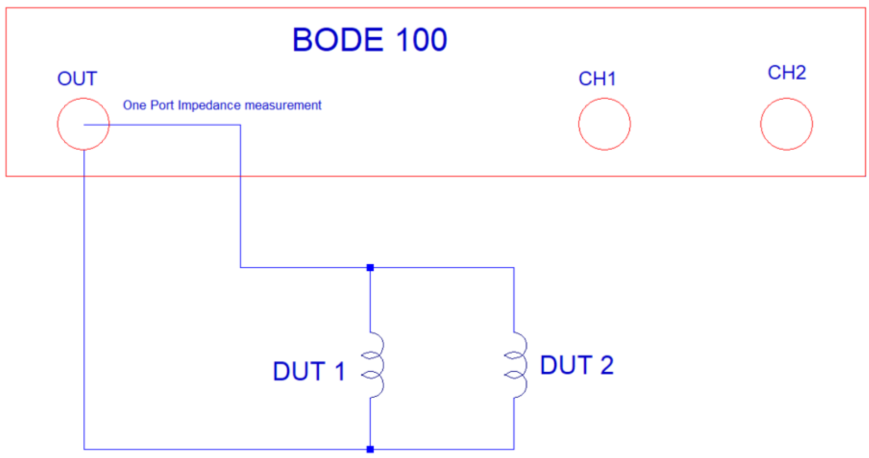


Figure 3: Equivalent circuit model

This is because, the impedance of capacitors bank is nearly 0 Ω (say less than 50 mΩ).

Hence the Inductance measured by Bode 100, **L = 0.5 x Inductance of DUT 1**

The **Inductance of DUT1** (or DUT2) **= 2 X L**

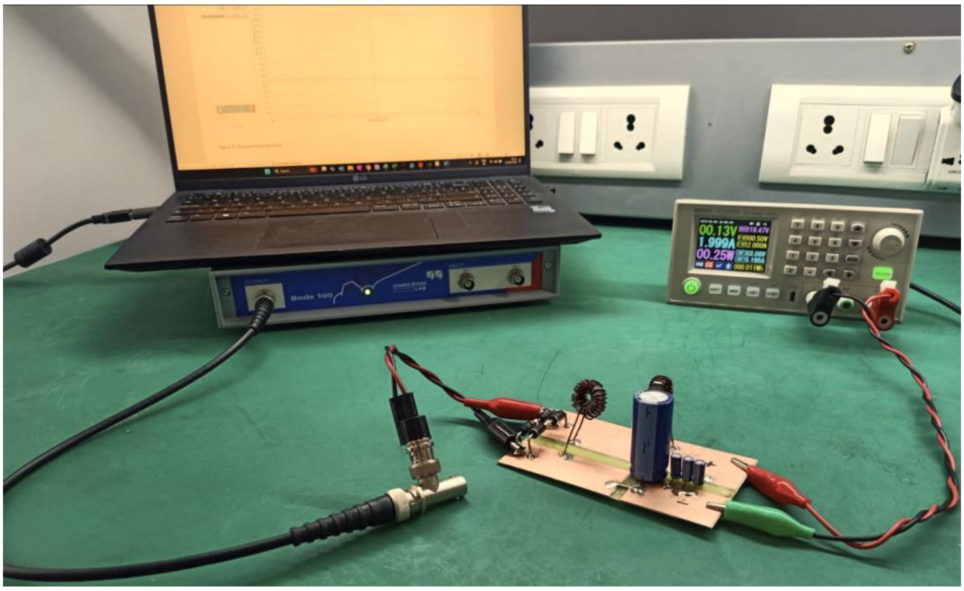


Figure 4: Physical test setup

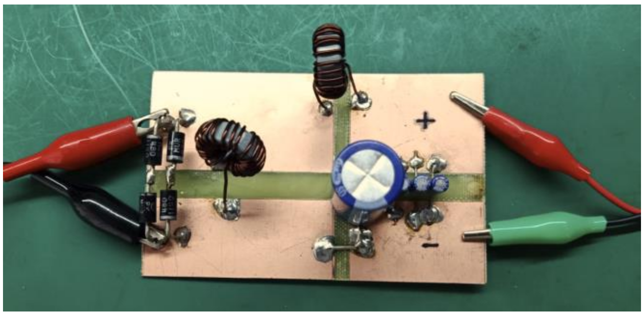


Figure 5: Test board

3.4 Bode 100 Device Configuration

In Bode Analyzer Suite, select the measurement type as "Impedance Analysis" and select One-port Measurement.

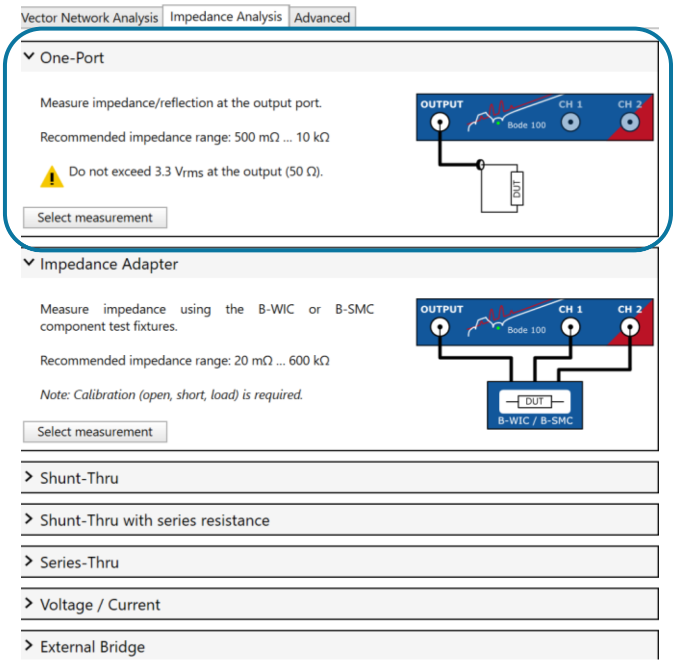


Figure 6: Measurement selection

Configure the Bode 100 as shown below.

The source level is set to -10 dBm. The purpose of such a low level is to avoid the protection diodes from conducting.

Attenuator 1 and Attenuator 2 are set to 0 dB, to ensure that enough signal is available at the receivers. The receiver bandwidth is set to 10 Hz and the number of measurement points to 201. Trace 1 is configured to display the Inductance Ls.

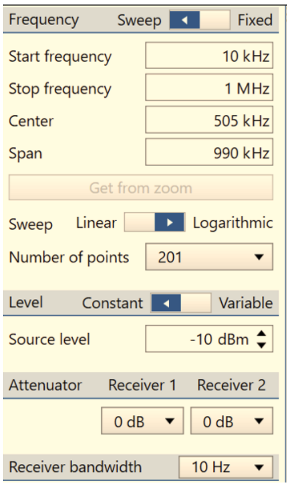


Figure 7: Bode 100 Configuration

Do the open, short and load calibration before starting to measure the DUT.

3.5 Test Procedure

Please make sure to follow the test procedure as outlined below to protect your Bode 100 from back-EMF spikes when changing the DC current bias in the DUT.

Step 1: Set the open circuit voltage of DC power supply to 500 mV.

Step 2: Set the constant current limit to 0 A.

Step 3: Connect the alligator clips from Bode 100 to the test board.

Step 4: Start a Bode 100 measurement to plot the inductance.

Step 5: Disconnect Bode 100 by removing the alligator clips.

Step 6: Adjust the Constant Current limit to desired current.

Step 7: Connect the alligator clips from Bode 100 to the test board and plot the inductance.

Note:

1. For best results, use a test frequency from 100 kHz to 1 MHz for inductors lower than 10 µH. Smaller inductance values have a lower reactance at low frequency, therefore the error from the capacitors can become bigger.

2. It is better to connect around 10 lower-ESR 1µF 10 V SMD ceramic capacitors parallel to the capacitor bank to achieve ultra-low ESR and ESL as it would benefit when measuring low value inductors around 1 µH.

4 Measurement Results

4.1 Inductance measurement at 0 A

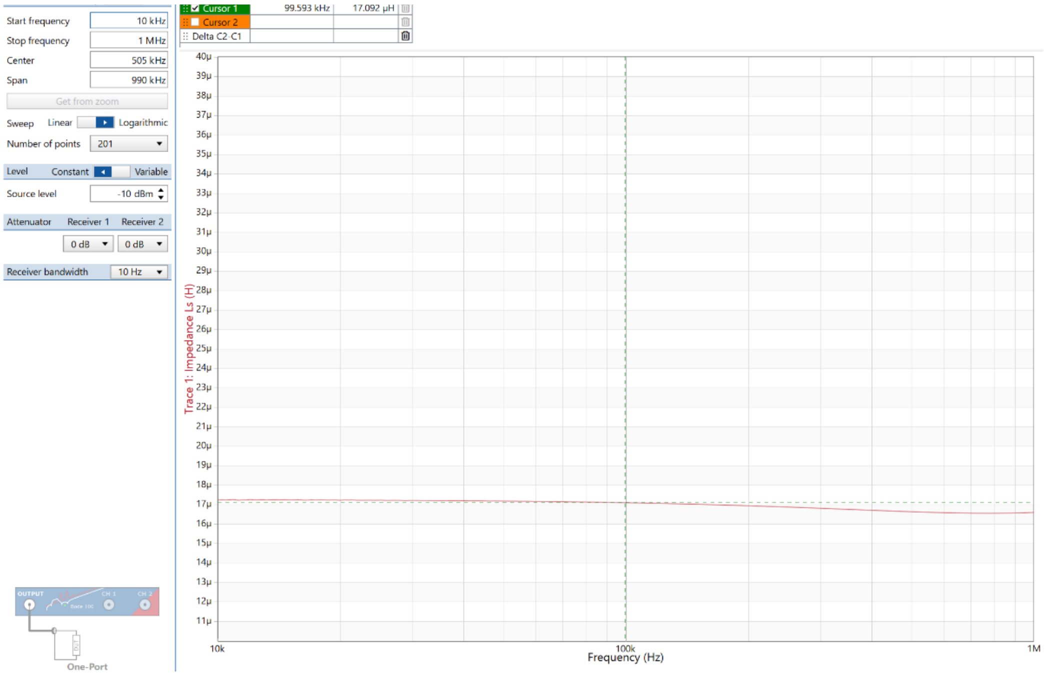


Figure 8 : Inductance measurement at 0A DC.

At 100kHz, the inductance L =17uH.

Hence, the inductance of DUT 1 (or DUT2) = 17u x 2 = 34uH.

This agrees with the data sheet specification and with what we have already measured in section 3.2.

This also proves that the DC-bias test setup has ***not introduced significant errors*** to the One-Port Impedance measurement setup.

4.2 Inductance Measurement at 2A, 4A, 4.55A, 6A

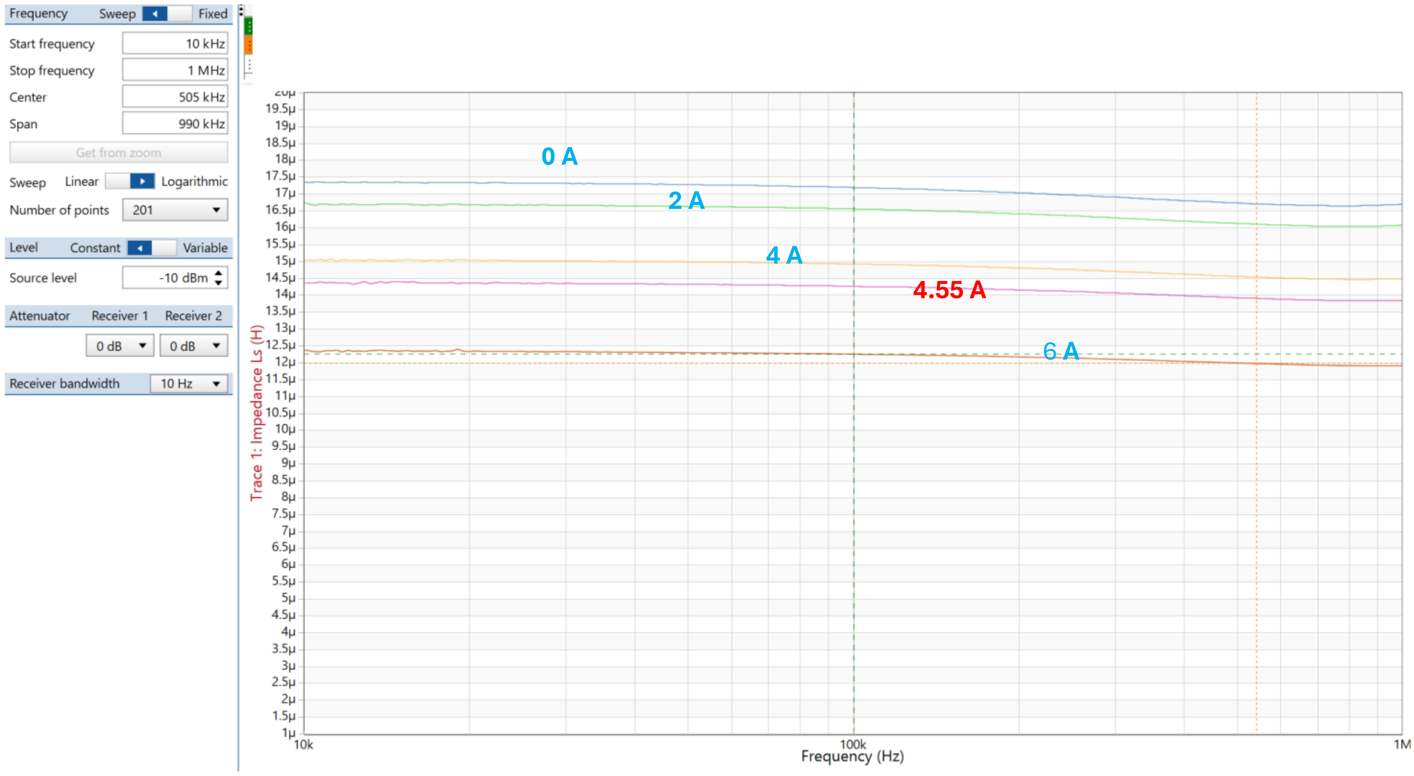


Figure 9: Inductance measurement at 2 A, 4 A, 4.55 A and 6 A

Consider the inductance at 4.55 A.

Inductance measured by Bode 100 at 100 kHz =14.2 µH and hence the actual inductance =14.2 µ x 2 = **28.4 µH**

The data sheet specifies following Al value Versus Ampere Turns graph

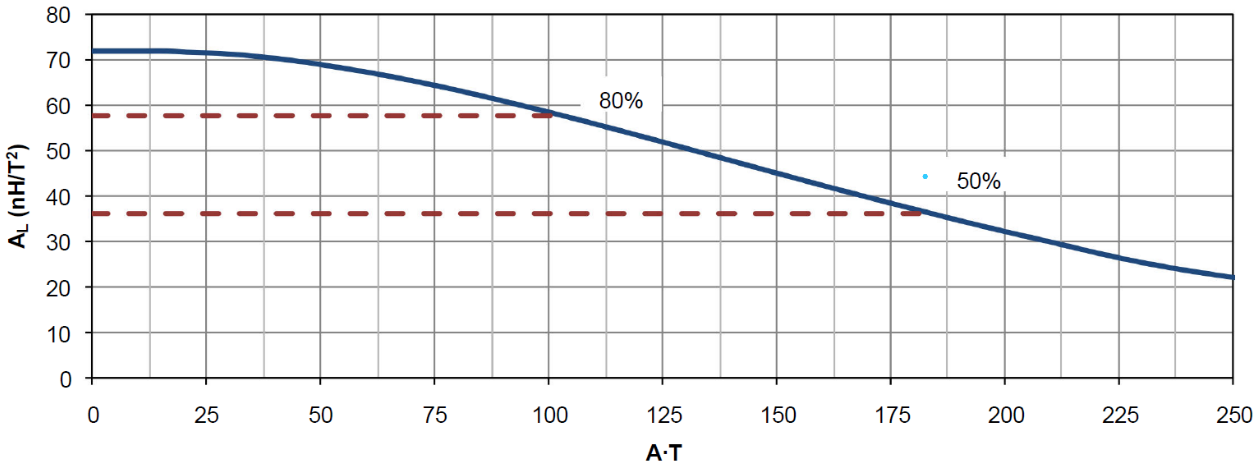


Figure 10: Al versus ampere-turns graph from core manufacturer's datasheet

As per this, the Inductance can drop to around 80% of the initial value when the A-T is increased to around 100.

In our example , AT= 4.55 x 22 =100 and the inductance has dropped to 28.4µ/34µ = 0.83 i.e 83% of initial value.

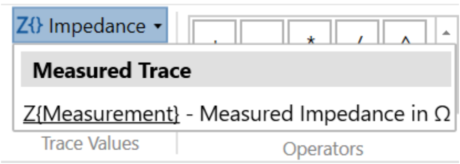
This agrees well with the specification of the core.

4.3 Using “Expression Trace” for direct read

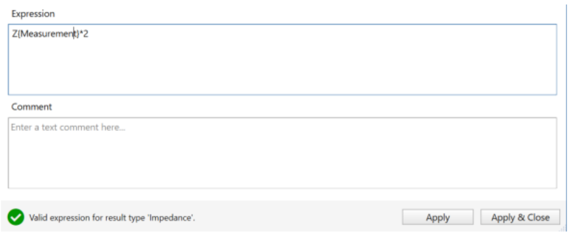
It is more convenient to use the “Expression Trace” feature of the Bode Analyzer Suite for direct reading of inductance to avoid manually multiplying the displayed inductance by 2.

Just click on

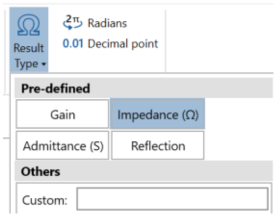
and select **Z{} Impedance** and **Z{Measurement)** under Trace Values



and type in the expression as **Z{Measurement}*2**

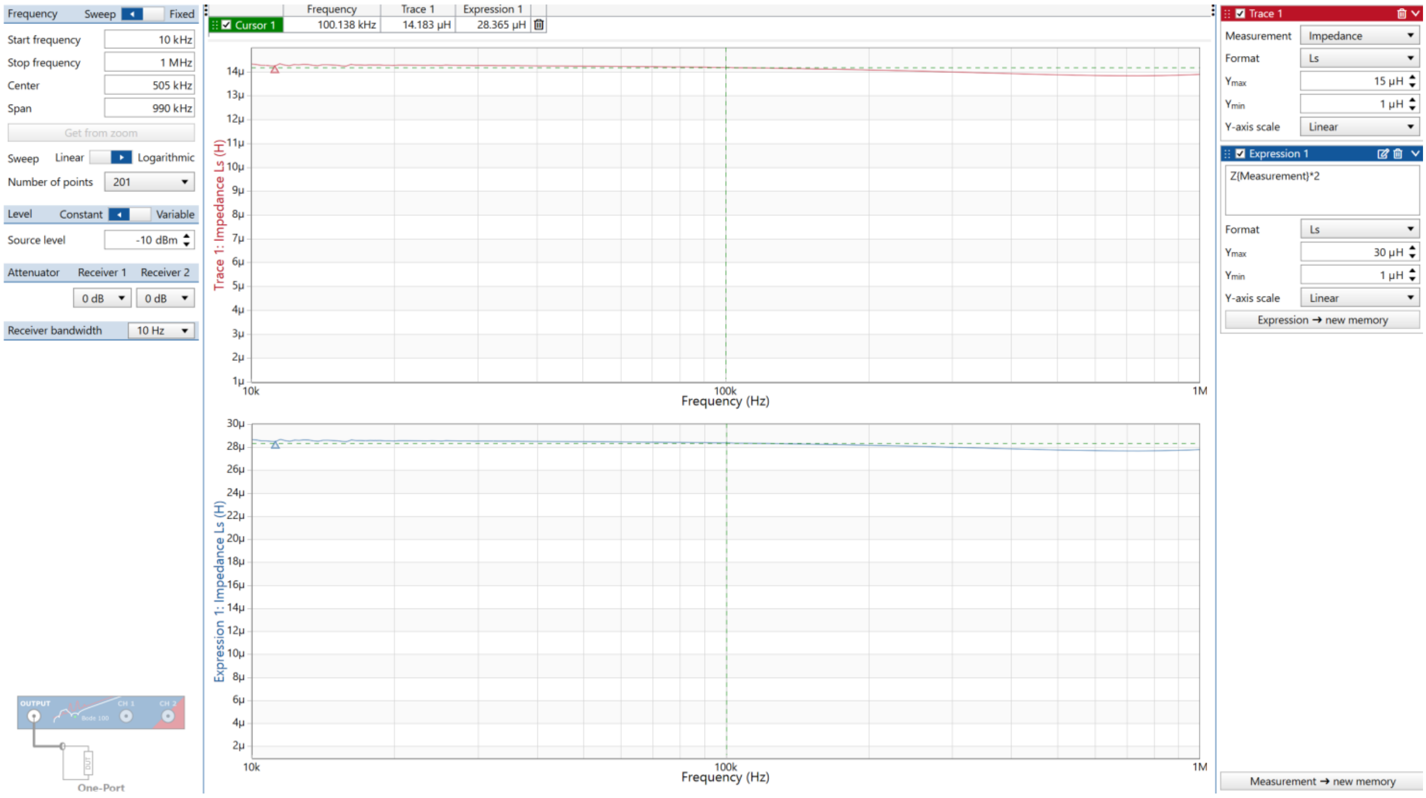


and select the Result type as **Impedance (Ω),** as shown below:



Then click on **Apply & Close.**

The following page shows another example ofan inductor measurement with a DC bias current of 4.55 A, this time with “Expression Trace” added.



The Inductance is 28.36 µH at around 100 kHz.

Note:

1. It is suggested not to increase the open circuit voltage of the DC power supply to more than 500 mV as it would cause the diodes to start conduction (though mild) and can cause measurement errors as a forward biased diode has more capacitance.
2. The above point implies that the Current times DCR of the inductor should not exceed 500 mV.
   Example:
   If the DCR is 10mΩ, the maximum current that can be passed through the inductor is 0.5 V / 10 mΩ =50 A
3. The frequency of measurement should be much below the "Self-Resonant Frequency" (SRF) of the inductor.
4. The maximum Direct Current (DC) that can be pumped into the Inductor is limited by what the DC power supply can source and point no 2.
5. Since the One-Port impedance measurement is used, all the limitations of One-Port measurement are applicable for this method.

5. Conclusion

It was demonstrated how to use the Bode 100 to cost-effectively measure DC bias characteristics of Inductor at various currents and frequencies. The Bode 100 enables a simple and fast measurement of those characteristics.

Acknowledgments

The author would like to thank Tobias Schuster and Florian Hämmerle from OMICRON Lab for providing a Bode 100 for the measurements and for their valuable feedback.

Vinod Chellat Markose is a hardware engineer with more than 21 years of experience in hardware design. He graduated with Bachelor of Engineering in Electrical and Electronics from Visvesvaraya Technological University, India in 2002.Vinod has worked as Power Electronics design engineer in industries like Renewable energy, Automotive, Consumer Electronics and Oil & Gas. He is passionate about analogue electronics, magnetic design, circuit simulations, EMC and protection circuit design with emphasis on robustness to surge.

Vinod enjoys spending extensive time with physical components analyzing the gap between ideal and real-life component behaviors. Since 2019, he has been offering Electronics design consultancy services in Power Electronics and low power analogue (both in product design as well as root cause analysis of mass failures). Vinod enjoys involving in spiritual and humanitarian activities in his free time.

You can reach him at info@salvatoretech.com or get in touch via LinkedIn