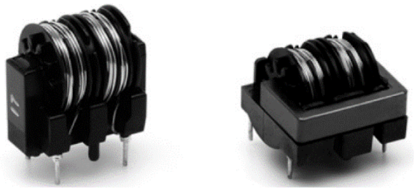
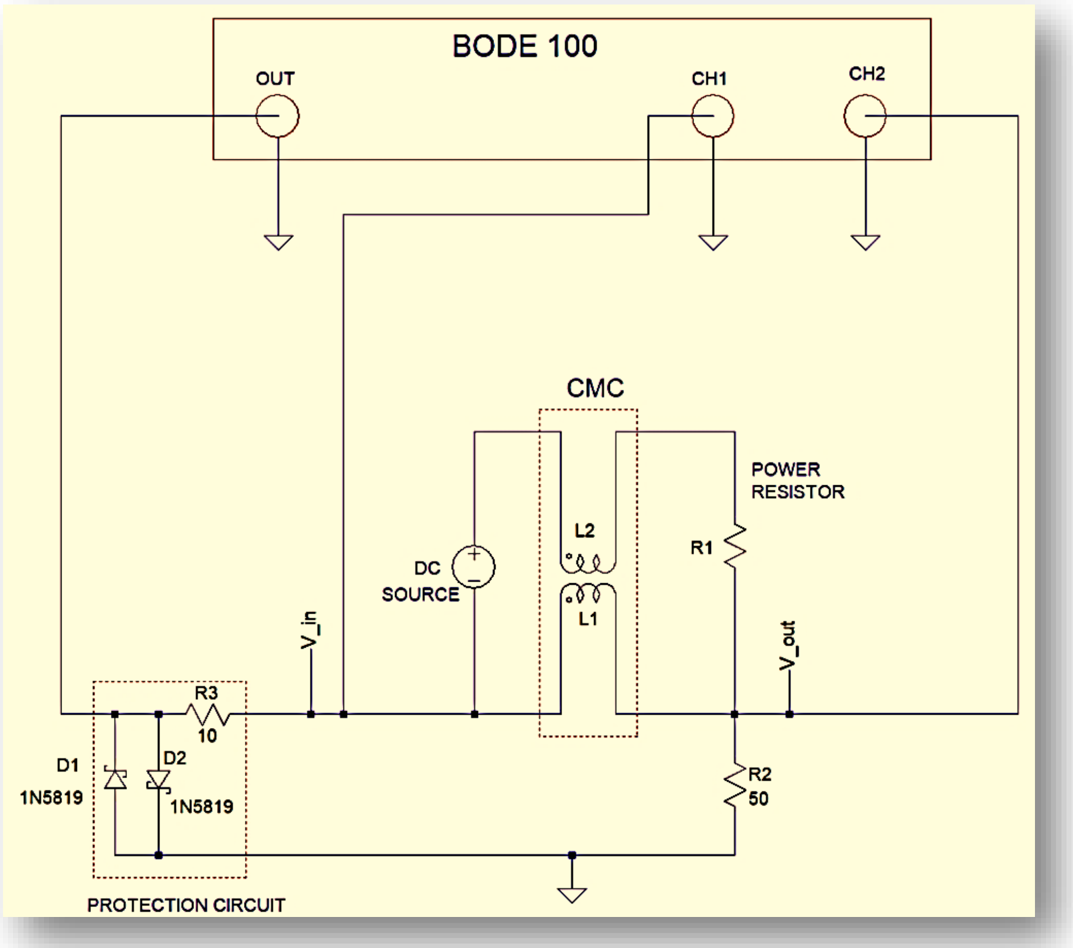
Measurement of Saturation Characteristics of Common Mode Chokes at any Current using Bode 100

By Vinod Chellat Markose





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1 Executive Summary

This application note describes an indirect method to characterize the drop in inductance of a Common Mode Choke (CMC) at any desired differential mode current through the choke, using Bode 100 vector network analyzer.

The need for such a measurement is that most datasheets of CMC do not have the data of the inductance versus differential mode current.

In a CMC ,the magnetic core can get pushed significantly towards saturation due to differential mode inductance (which is not zero henry in a real- world CMC) and differential mode current. In other words, the core *permeability can get drastically reduced* due to high Flux density created by the "peak" current and the differential mode inductance (or the leakage inductance between the two windings). To make the matters worse, the differential mode current through the choke has large crest factor in many applications including the one shown below.

The reduction in core permeability implies reduction of common mode inductance which means reduction in the ability of common mode choke to filter common mode noise.

2 Measurement Task

2.1 General

The common Mode chokes are used to filter out the common mode noise. i.e., the electrical noise common to both the lines, say Line and Neutral in an AC powered product.

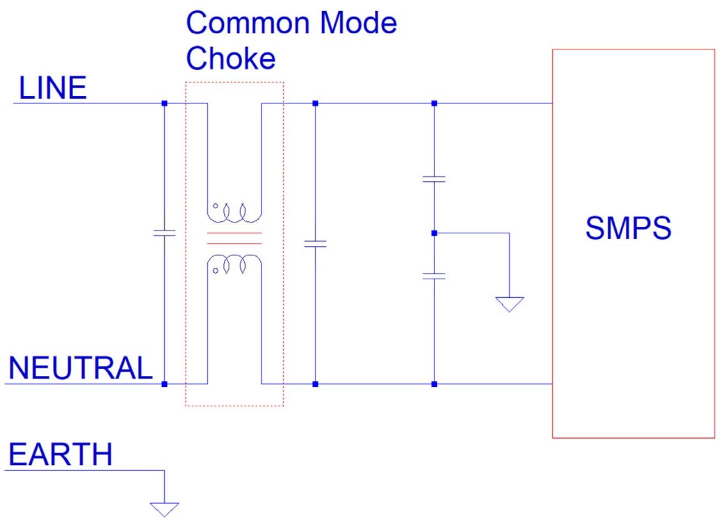


Figure 1 : Common Mode choke in a typical application.

2.2 Common mode choke : Ideal versus real-world.

In an ideal CMC, the magnetic flux created due to current in one winding gets cancelled by the flux created by the other winding; because, the direction of current in these windings are opposite to each other, the windings are perfectly coupled to each other and the windings are identical. In other words, the "differential mode" Inductance of an ideal CMC is zero Henry.

However, in a real-world CMC, due to the facts that the coupling between the windings is not perfect and windings are not identical to each other due to manufacturing tolerances, the differential mode inductance is not zero, though small (say 1% of the single winding's inductance).

This differential mode inductance (also called leakage inductance) can push the magnetic core towards saturation as the differential mode current is increased resulting in drop in inductance of the CMC.

3 Measurement setup and configuration

3.1 Measurement Equipment

- Bode 100 Vector Network Analyzer
- Measurement accessories (BNC cable, adapter-BNC female to binding post, BNC T connector, high impedance passive probe PML111O)
- DC variable power supply
- Power resistor

3.2 Test object specification

Minimum Inductance (mH) measured at 1kHz	Maximum DC Resistance/ Line (Ω)	Self Resonant frequency (MHz)
12.5	0.74	1

3.3 Measurement method

To check whether the Common mode choke is being pushed towards saturation when differential mode current of any amplitude passes through it, all that is needed is measuring the common mode inductance i.e. inductance of one of the windings.

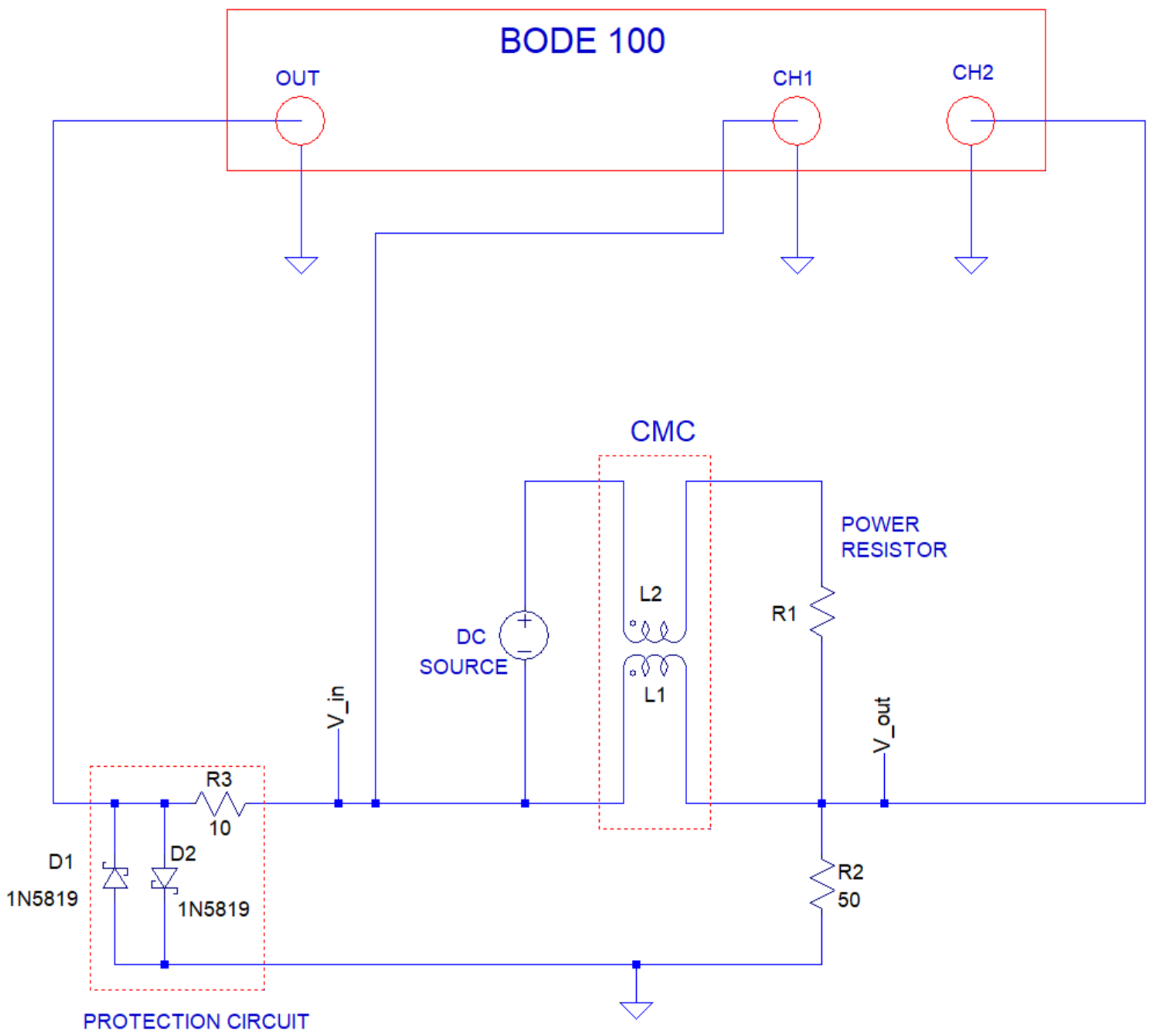


Figure 2 : Measurement setup

Here, we have formed a low pass filter using L1 and R2.

To measure the inductance L1, the frequency response is plotted using Bode 100
[i.e. 20 log (V_out / V_in) dB], and the cut-off frequency is noted.

The **-3dB frequency fc=R/ (2 x Pi x L) Hz** for a low pass filter formed by RL circuit (R in ohms and L in Henry)

Hence inductance **L= R /(2 x Pi x f)** Henry **,** R in Ohm , f in Hz

Initially, the DC power supply's output voltage is set to 0V and frequency response is plotted and for measuring the Inductance at any desired current, the DC power supply's output voltage is increased to a value such that the desired current flows.

In this example, there is no power resistor used, instead a dead short has been used in its place. This is because, each winding has DCR of around 0.74 ohm and this DCR itself has been used to limit the current.

Note :

1. The protection circuit shown in Figure 2 is meant for protecting the output of Bode 100 from high voltage spikes. However, it is optional.

2. CH1 of BODE 100 is connected to V_in node and CH2 to V_out node.

3.4 Bode 100 Device Configuration

In Bode Analyzer Suite, select the measurement type as "Vector Network Analysis" and click on "Select measurement" under Gain/Phase.

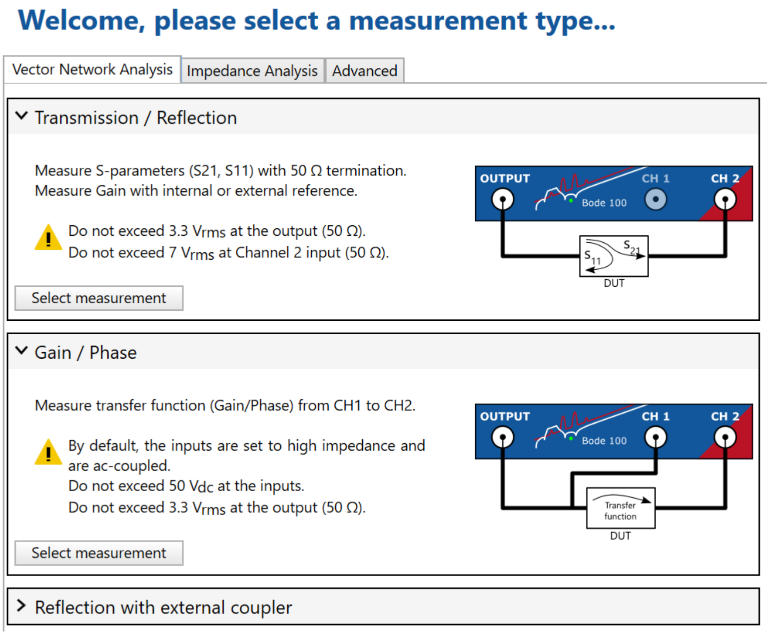


Figure 3 : Measurement selection

Configure the Bode 100 as shown below. The source level is set to -10 dBm. Attenuator 1 and Attenuator 2 are set to 20 dB, to ensure that enough signal is available at the receivers. The receiver bandwidth is set to 30 Hz and the number of measurement points to 401. Trace 1 is configured to display the Gain Magnitude in dB.

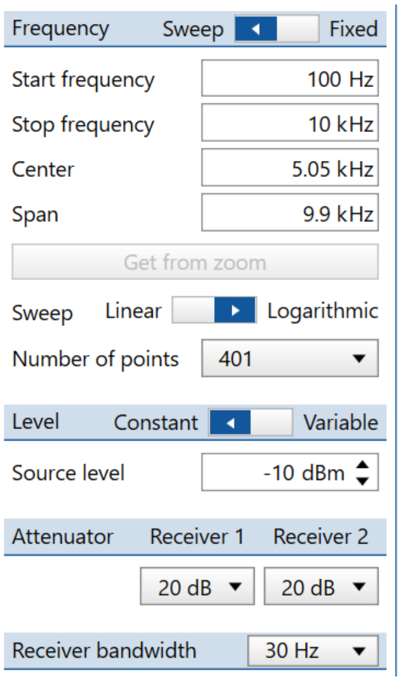


Figure 4 : BODE 100 Configuration

4 Measurement Results

4.1 Inductance measurement at 0A

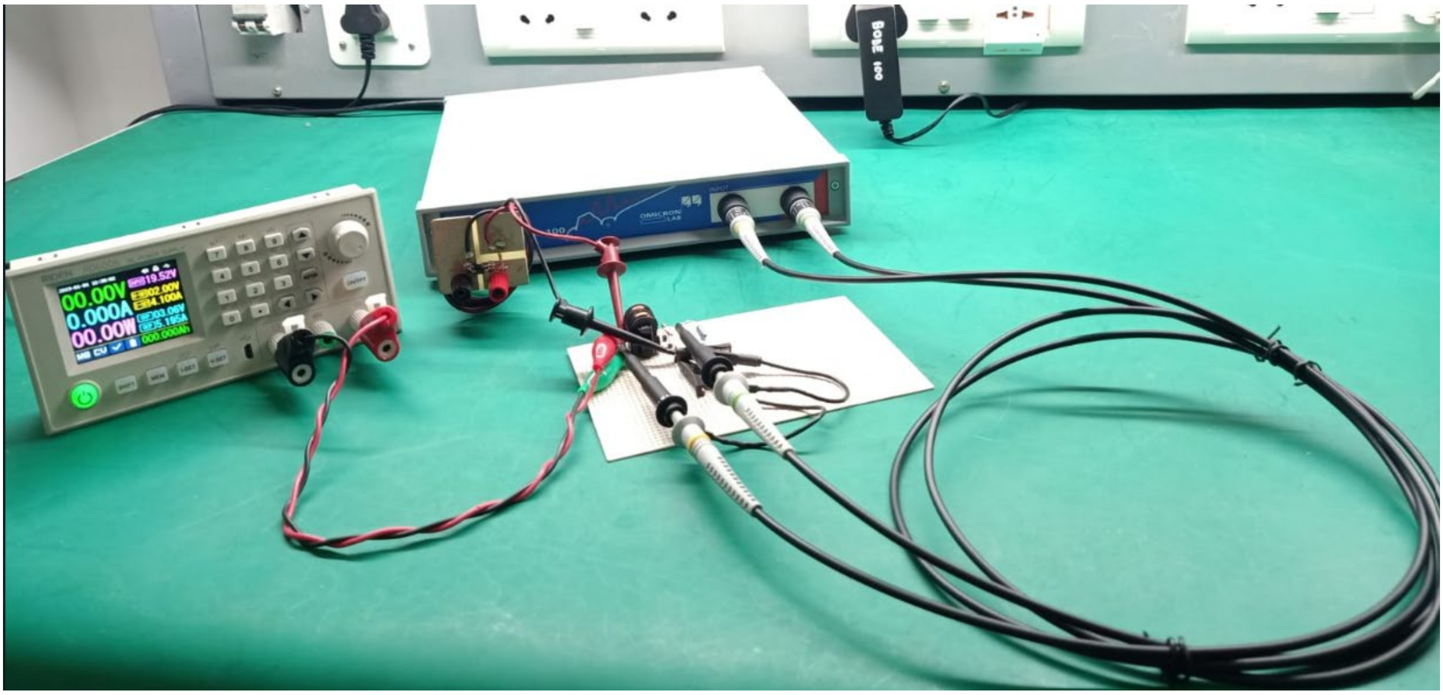
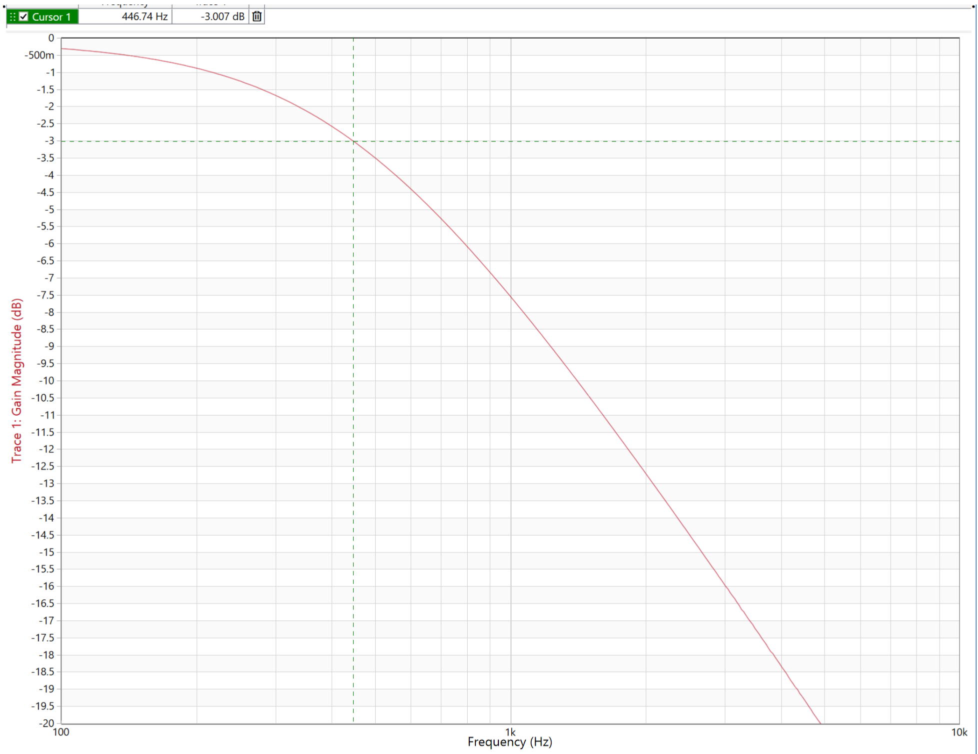


Figure 5 : Test setup



Cut off frequency is at 446.7 Hz

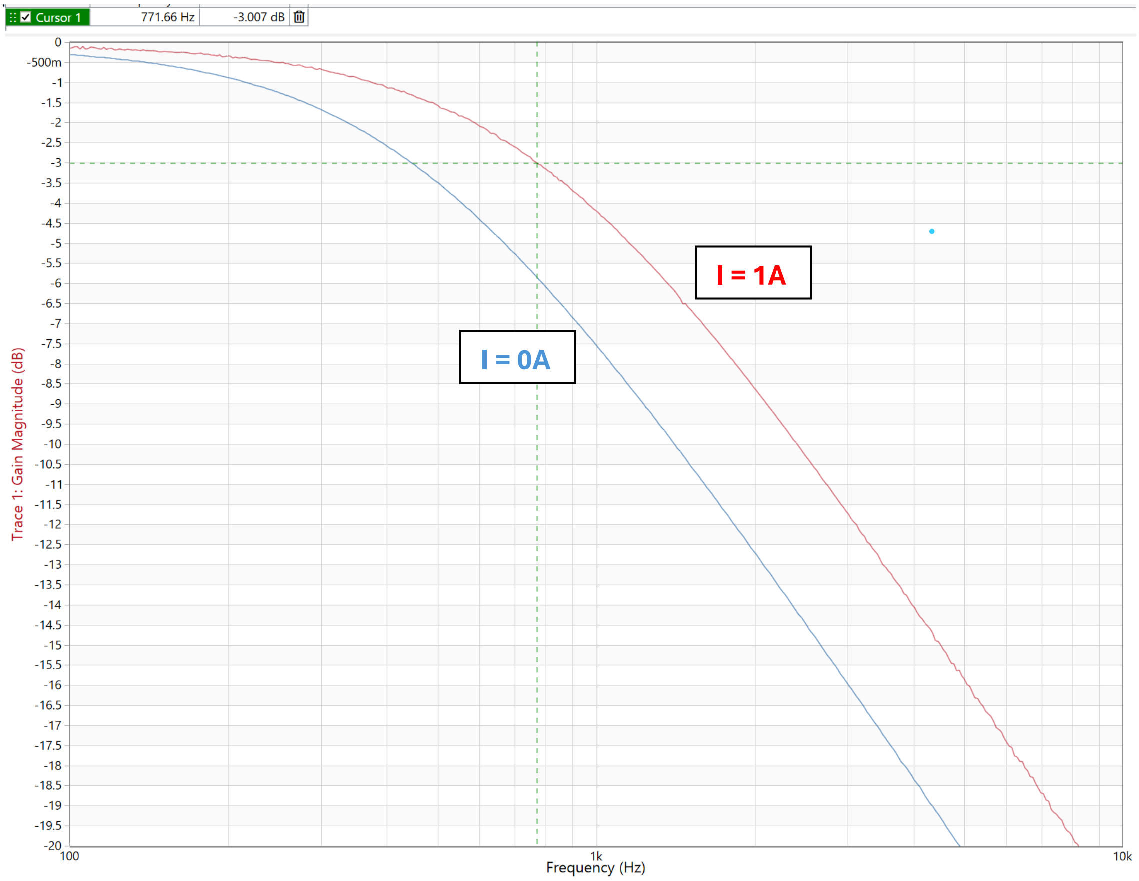
This means that Inductance **L= R/(2 x Pi x f) Henry**

L=50/ (2x3.14 x446.7)

L= 17.8mH

This agrees with the data sheet specification.

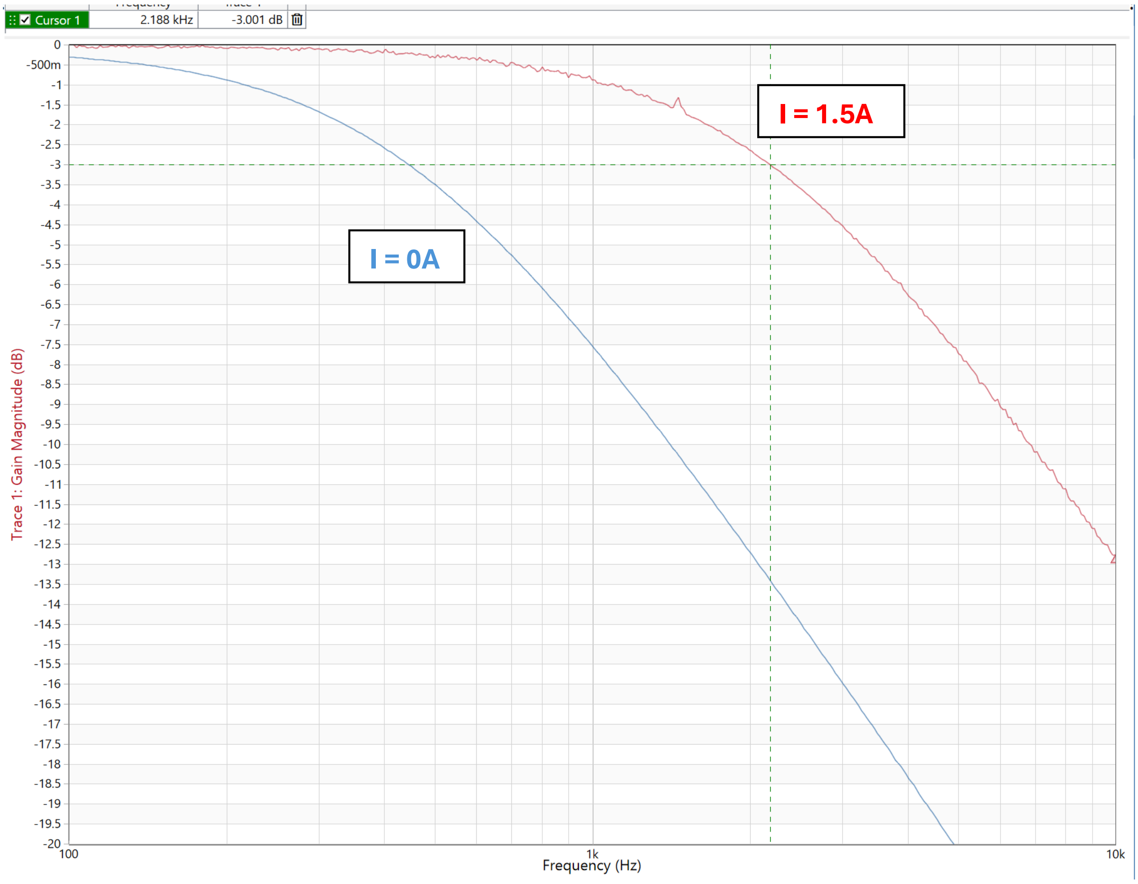
4.2 Inductance measurement at 1A



Inductance = 50 /(2 x 3.14 x771.66) =10.3 mH.

Note that even at 1A of current, the inductance has dropped from 17.8 mH to 10.3 mH.

4.3 Inductance at 1.5A



Cut-off frequency is at 2.188kHz.

Inductance L= 50 /(2 x 3.14 x2.188kHz) = 3.63mH

Now, the inductance has got drastically dropped to about 29% of the data sheet specification.

Note: Please note that in this method, we assess the drop in permeability of the core by measuring the drop in "Inductance" of one of the windings. Hence, the frequency of measurement should be much below the "Self-Resonant Frequency" (SRF) of the winding. This implies that the value of R2 in Figure 2 should not be too high such that the -3dB frequency (cut-off frequency) becomes too high and moves closer to the SRF.

5 Conclusion

It was demonstrated how to measure saturation characteristics of common mode choke at any desired current in a cost-effective way using the Bode 100. The Bode 100 enables a simple and fast measurement of those characteristics.

Acknowledgments

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Vinod Chellat Markose is a hardware engineer with more than 21 years of experience in hardware design. He graduated with a Bachelor of Engineering in Electrical and Electronics from Visvesvaraya Technological University, India, in 2002. Vinod has worked as a 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 offered Electronic design consultancy services in Power Electronics and low-power analog (both in product design and root-cause analysis of mass failures). Vinod enjoys involving himself in spiritual and humanitarian activities in his free time.

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