# Bode 100 - Application Note

# RFI Power Inlet Filter Insertion Loss Measurement



By Florian Hämmerle & Benjamin Mößlang

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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 V3.23. 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 to measure the common mode and the differential mode insertion loss of an RFI[1] or EMI[2] power inlet filter using the Bode 100 vector network analyzer. RFI power inlet filters are a specific type of EMC[3] filters. All the principles shown in this document do apply for all types of EMC filters.

# 2 Measurement Task

## 2.1 General

EMC filters are used to prevent electronic devices from emitting disturbances and to ensure proper functionality of the device when electromagnetic disturbances are present. A power inlet filter helps to achieve sufficient RFI or EMI quality by blocking conducted emissions and interference from the power line. This is done by filtering the radio frequency spectrum. Generally, these filters are specified with the common mode and differential mode insertion loss.

## 2.2 Common Mode Insertion Loss

The following picture shows how the common mode insertion loss is measured according to the information of the manufacturer of the DUT:

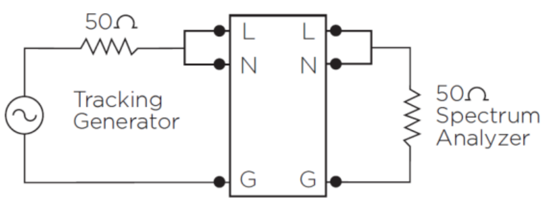


Figure 1: test connection common mode. Source (1), Page 268

The reference setup is shown in the following picture. The RFI filter is replaced by a thru connection, the 50 Ω termination stays active.

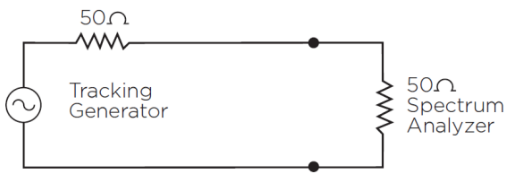


Figure 2: reference connection common mode. Source (1), Page 268

[1] Radio Frequency Interference
[2] Electro-Magnetic Interference
[3] Electro-Magnetic Compatibility

## 2.3 Differential Mode Insertion Loss

The differential mode insertion loss, according to the manufacturer, is measured as shown in the figures below. 180° splitter/combiners are used to convert the unbalanced signal from the generator into a balanced (symmetrical) signal. This means the two voltages at the filter input have the same amplitude but are 180° shifted.

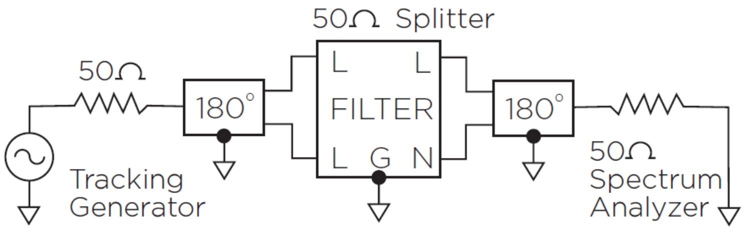


Figure 3: test connection differential mode. Source: (1), Page 268

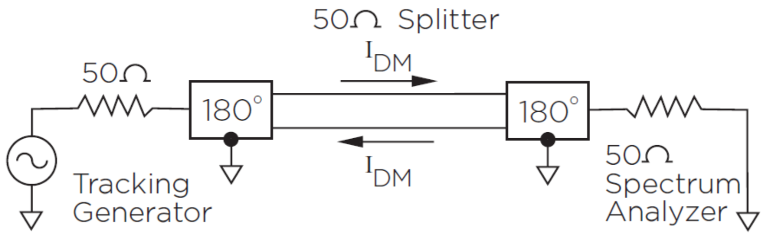


Figure 4: reference connection differential mode. Source: (1), Page 268

This 180° phase shift can be generated e.g. by using a BALUN[4] transformer. The differential mode insertion loss can therefore be measured with the Bode 100 using two BALUN transformers connected back to back. The following figure shows the principle of a center-tapped BALUN with its impedances. The differential mode impedance $R_{diff}$ depends on the turns ratio and the input impedance $R_{diff} = N^2 R_{in}$.

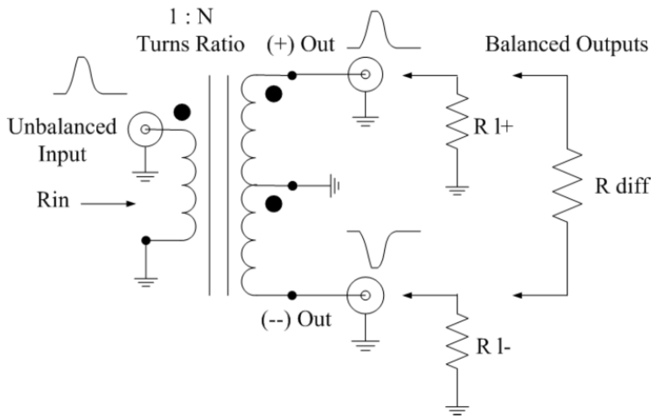


Figure 5: Center-tapped BALUN transformer. Source: (2), Page 2

[4] BALUN...BALanced-UNbalanced

# 3 Measurement Setup & Configuration

## 3.1 Measurement Equipment

- Bode 100 Vector Network Analyzer
- Test Object (standard RFI power inlet filter or other EMC filter)
- BALUN Transformer (50 Ω, 10 kHz – 80 MHz)
- Measurement accessories (BNC cable, BNC connectors)

## 3.2 Test Object Specifications

The manufacturer's datasheet of the filter provides information about the insertion loss of the RFI filter. The following table shows the guaranteed minimum insertion loss.

Minimum insertion loss of the filter measured in a closed 50 Ω System:

| Frequency in MHz | 0,15 | 0,5 | 1 | 5 | 10 | 30 |
|---|---|---|---|---|---|---|
| Common Mode Insertion loss in dB | 14 | 23 | 30 | 41 | 45 | 50 |
| Differential Mode Insertion loss in dB | 3 | 15 | 20 | 31 | 35 | 34 |

Table 1: Test Object Specifications

The following figure from the datasheet shows the typical common mode insertion loss (black line) and the typical differential mode insertion loss of the filter (gray line):

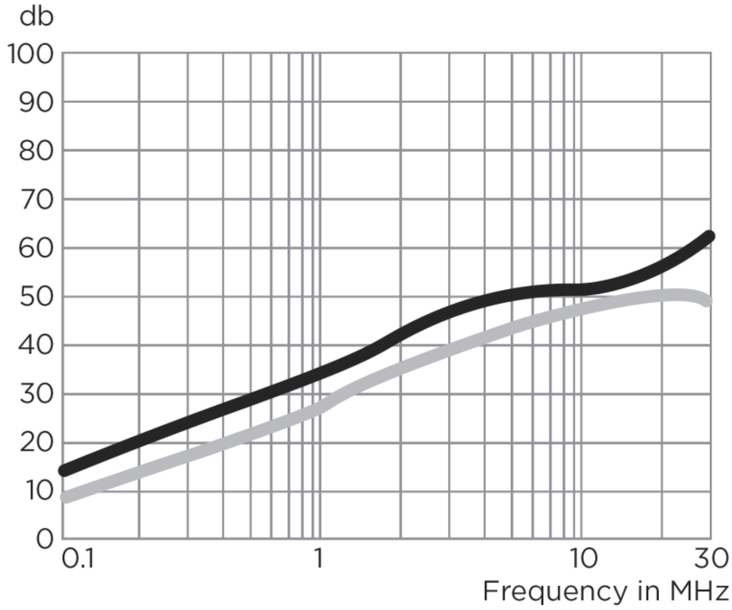


Figure 6: Test Object Typical Insertion Loss

In the following the typical common mode insertion loss data is compared with the measured data from the Bode 100.

## 3.3 Common Mode Insertion Loss Setup

The DUT is connected to the Bode 100 via coaxial cable and BNC connectors. These connectors are soldered as close as possible to the DUT, to prevent measuring errors.
Connecting the DUT to the Bode 100 using grabbers did not work out as expected because it showed effects from the parasitics of the connection below 30 MHz.

### 3.3.1 Connection with grabbers

The following picture shows the connection with the grabbers.

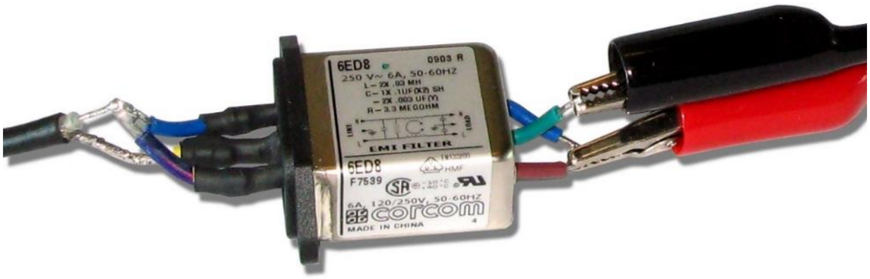


Figure 7: Unsuitable connection using grabbers

Using this configuration, the following measurement results were achieved.

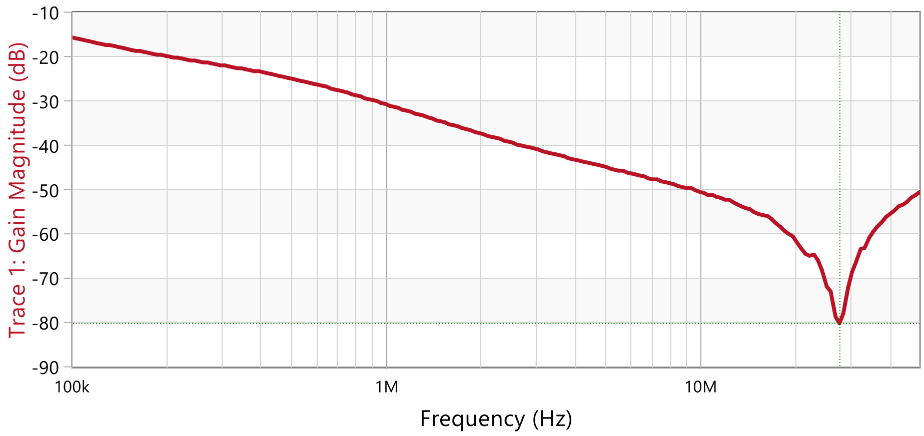


Figure 8: Measurement result with grabbers

This result does not correspond to the expected common mode insertion loss of the datasheet and shows a resonance effect around 28 MHz. Therefore, it is assumed that the connection with grabbers is not suitable for correct measurements at high frequencies.

### 3.3.2 Connection with BNC

To improve the measurement setup a BNC connection for the following measurement is used. The measurement setup is shown in the picture below.

Figure 9: Common mode connection with BNC connectors

The next picture shows, how the calibration was performed.

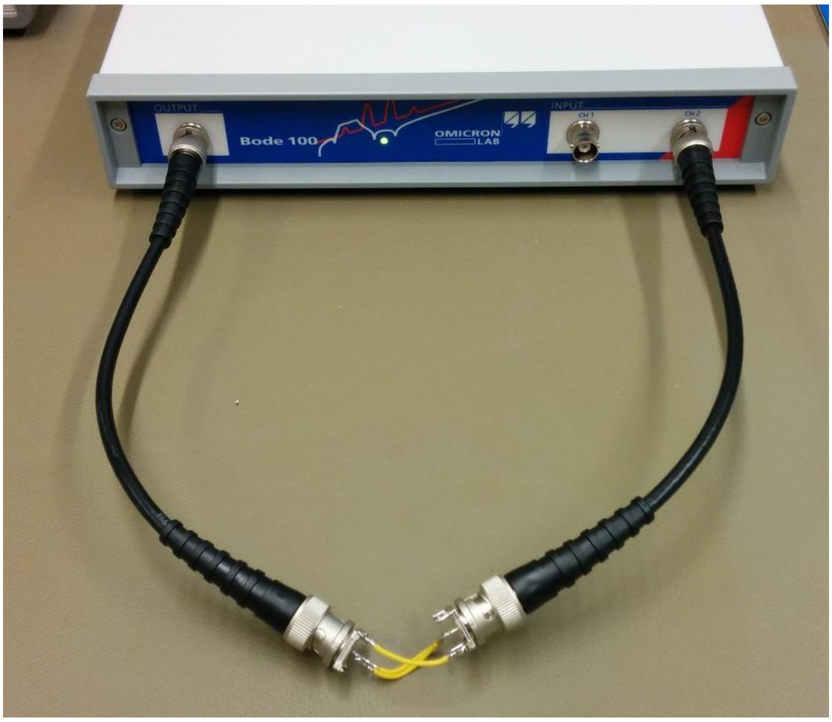


Figure 10: THRU calibration

## 3.4 Differential Mode Insertion Loss Setup

The differential mode insertion loss measurement is performed using two BALUN transformer. These transformers transform a BALanced signal (asymmetrical, referenced to ground) to an UNbalcaned Signal (symmetrical, differential). Soldering these transformers directly to the DUT ensures a minimal influence of the measurement setup.

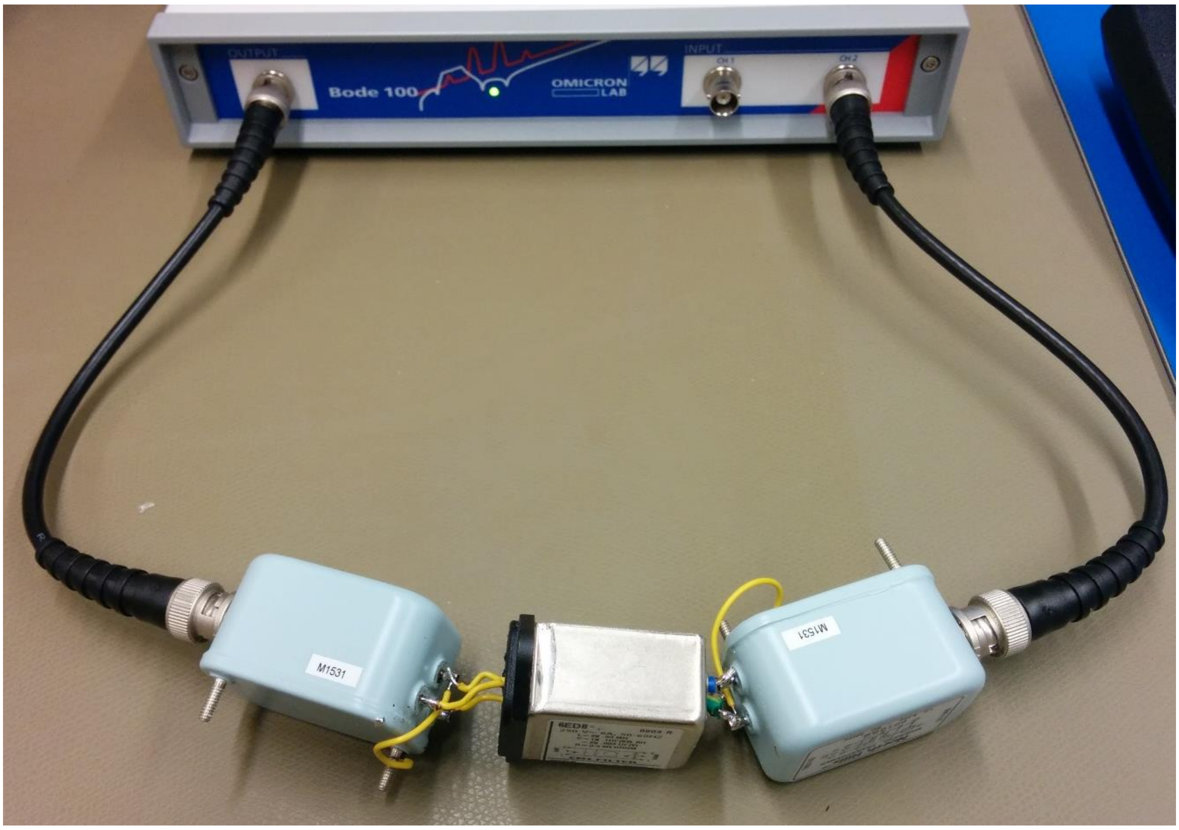


Figure 11: Differential mode measurement setup

It is important to connect the central tapping of the secondary winding to the common ground (casing), otherwise the results are not accurate. It also ensures that pin 3 of the first BALUN corresponds to pin 3 of the second BALUN. Vice versa for pin 4 and pin 5.

The following picture shows the BALUN transformer that was used for the measurements.


Figure 12: BALUN transformer, top side

For the thru calibration, the BALUNs are soldered directly to each other.

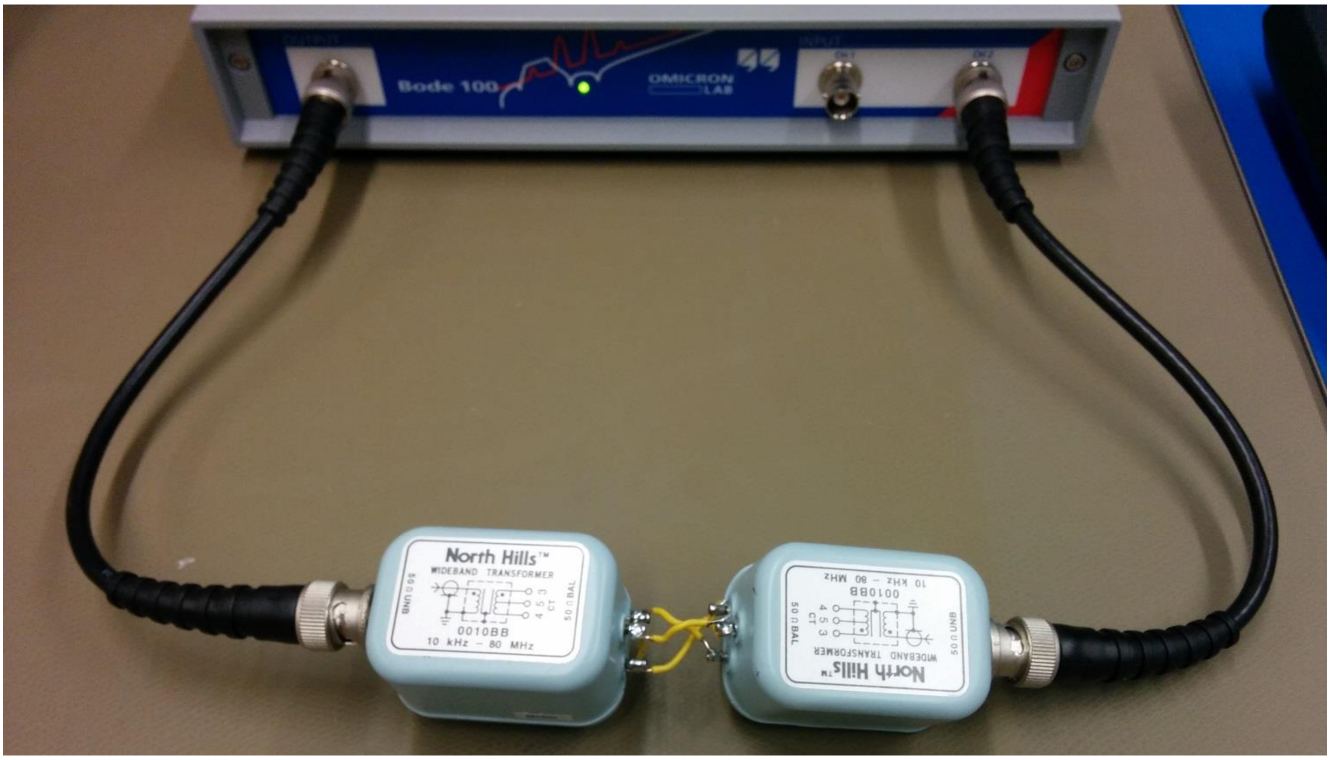


Figure 13: Differential mode Thru-calibration

## 3.5 Bode 100 Device Configuration

To measure the common and differential mode insertion loss of the filter, thescattering parameter S21 is measured. For both measurements, common-mode, as well as differential mode, the same settings were used.

At first start a Transmission / Reflection measurement is selected in the Vector Network Analysis tab. This will set the input impedance of CH2 to 50 Ω to match the BALUN Transformer.

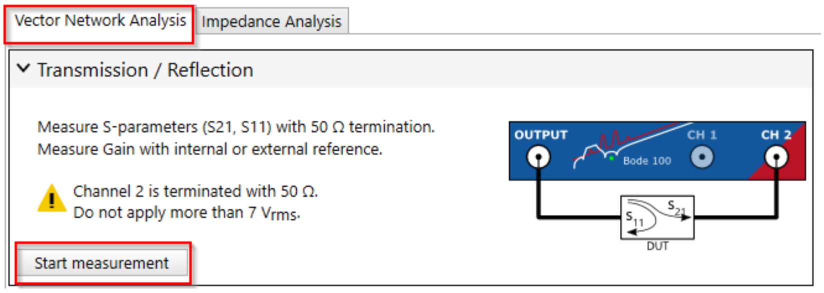


Figure 14: Open Measurement

Configure the Bode 100 as shown below. The source level is set to 0 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 1 kHz and the number of measurement points to 401. Trace 1 is configured to display the Gain Magnitude in dB

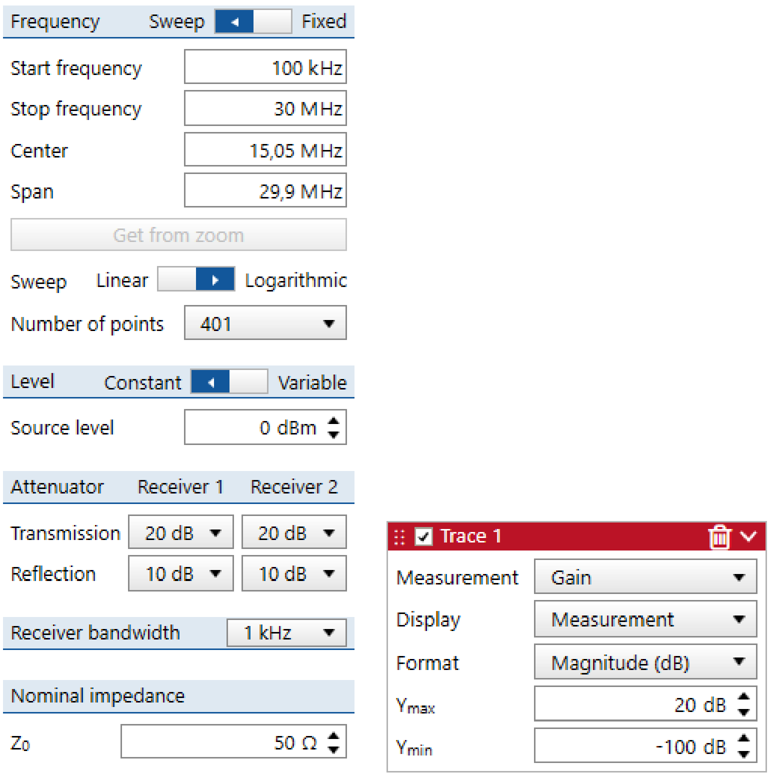


Figure 15: Configuration & trace settings

# 4 Measurement Results

## 4.1 Common Mode Insertion Loss

In the following chart, the measured common mode insertion loss is compared to the minimum insertion loss values from the datasheet.

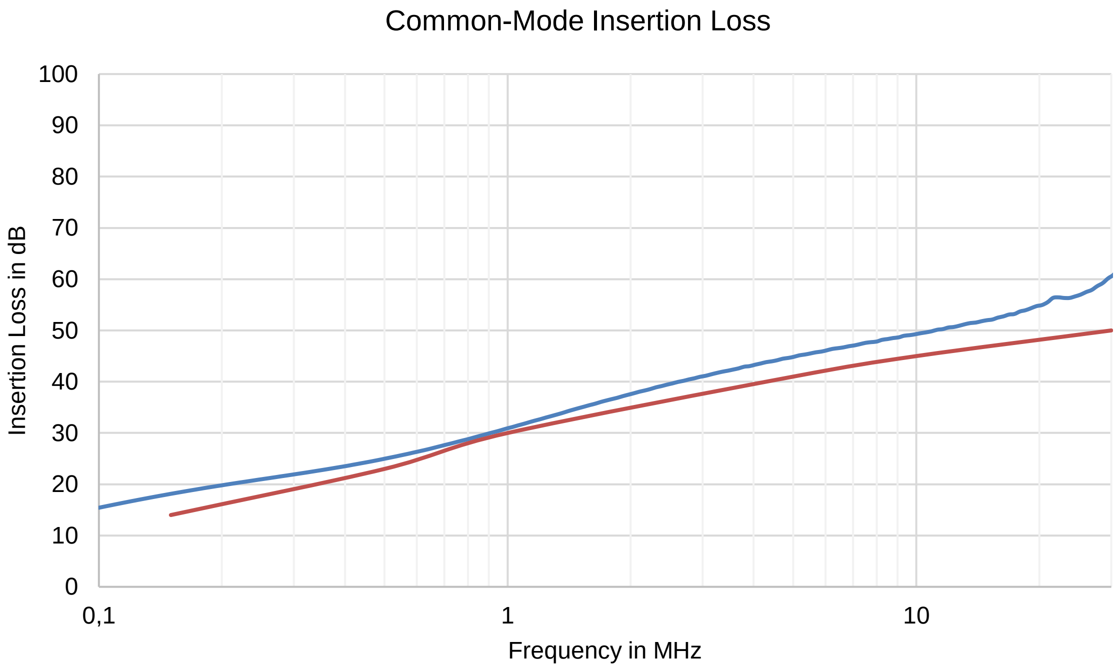


Figure 16: Measured common mode insertion loss (blue) compared to the data from the datasheet (red).

The measurement of the common mode insertion loss was as expected. The common-mode insertion loss of the DUT exceeds the minimum values from the datasheet.

## 4.2 Differential Mode Insertion Loss

The following chart shows the measured differential mode insertion loss compared to the minimum differential mode insertion loss data from the datasheet.

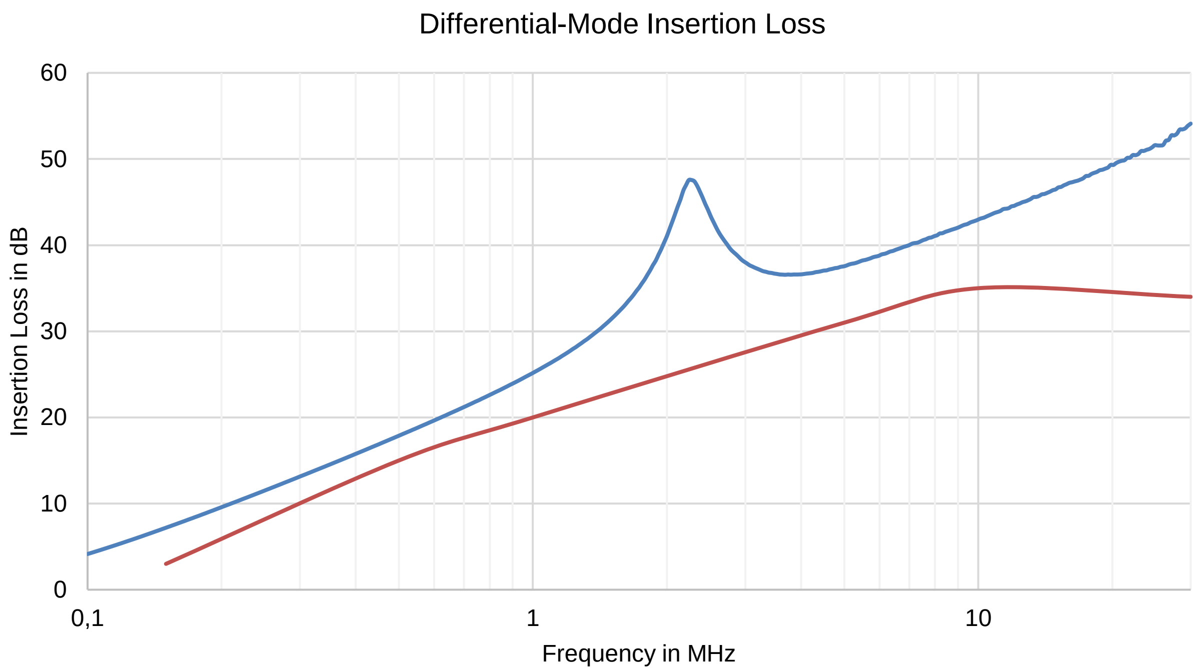


Figure 17: Measured differential mode insertion loss (blue) compared to the data from the datasheet (red)

Interestingly the measurement shows a clear peak at 2.2 MHz with an attenuation of 47 dB. This peak is not mentioned in the datasheet. The filter was simulated, to find out where this peak is coming from. The results of this simulation can be seen in the application note “EMC Filter Insertion Loss Simulation”, available in the application note section at [www.omicron-lab.com](http://www.omicron-lab.com)

# 5 Conclusion

It was demonstrated how to measure common mode and the differential mode insertion loss of an EMC using the Bode 100. The Bode 100 enables a simple and fast measurement of those characteristics.

# References:

Andrews, J. R. (2008, 12). *Application Note AN-21.* Retrieved 11 2010, from Picosecond Pulse Labs: http://www.picosecond.com/objects/AN-21.pdf

Corcom. (2010, 08). *Prduct Guide, Appendix A Technotes.* Retrieved 11 2010, from http://www.cor.com/PDF/AppendixA.pdf

OMICRON Lab. (2016). *EMC Filter Insertion Loss Simulation.* Retrieved from OMICRON Lab "Smart Measurement Solutions": https://www.omicron-lab.com/bode-100/application-notes-know-how/application-notes/rfi-power-inlet-filter-measurement.html


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**Europe, Middle East, Africa**
OMICRON electronics GmbH
Phone: +43 59495
Fax: +43 59495 9999

**Asia Pacific**
OMICRON electronics Asia Limited
Phone: +852 3767 5500
Fax: +852 3767 5400

**Americas**
OMICRON electronics Corp. USA
Phone: +1 713 830-4660
Fax: +1 713 830-4661

**info@omicron-lab.com • www.omicron-lab.com**