Bode 100 - Application Note

DSL-Cable Measurements

This application note was developed with strong support from Mr. Dick Gigon, AESA SA.
Thank you very much!

By Lukas Heinzle

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Table of Contents

1 EXECUTIVE SUMMARY 3
2 MEASUREMENT TASKS 3
3 MEASUREMENT SETUP & RESULTS 3
3.1 USED EQUIPMENT 3
3.1.1 DSL-Cable 3
3.1.2 BALUN 4
3.1.3 Connection accessories 5
3.1.4 Calibration cable 7
3.1.5 Thru Connector 7
3.2 IMPORTANT NOTES 7
3.3 ATTENUATION OF DSL-CABLES 8
3.4 CROSSTALK, NEXT, FEXT & ELFEXT 10
3.4.1 NEXT 10
3.4.2 FEXT 10
3.4.3 ELFEXT 10
3.5 NEXT MEASUREMENT 11
3.6 FEXT MEASUREMENT 12
3.7 ELFEXT MEASUREMENT / CALCULATION 14
3.7.1 ELFEXT Calculation 14
3.7.2 Direct ELFEXT Measurement 15
3.8 IMPEDANCE MEASUREMENTS 18
3.9 RETURN LOSS (RL) OF DSL-CABLES 20
3.10 GROUP DELAY & VELOCITY FACTOR 21
4 CONCLUSION 22

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 V3.21. 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 to measure electrical parameters of DSL-Cables such as attenuation, crosstalk and phase delay. This is necessary to determine if a cable complies with a certain normative standard like e.g. IEC 62255-3.

The application note was done in cooperation with AESA Cortaillod. AESA Cortaillod has over 30 years of experience in cable testing and quality control of telephone and LAN cabling as well as power lines or coaxial cabling. The company's headquarters is located in Colombier, Switzerland. For more information feel free to visit: www.aesa-cortaillod.com

2 Measurement tasks

During the process of selecting a cable for a specific application, it is advisable to verify the electrical characteristics outlined in the cable's datasheet.
By analyzing one DSL-Cable pair, the measurement of the following parameters is shown in this application note (the parameters for the other pairs are measured the same way).

- Attenuation
- Impedance
- Near End Cross Talk (NEXT) and Far End Cross Talk (FEXT)
- Return Loss (RL)
- Phase delay

3 Measurement Setup & Results

3.1 Used Equipment

The following equipment is required to perform the measurements described in this application note.

- Vector Network Analyzer Bode 100 (incl. measurement accessories)
- DSL-Cable (DUT)
- BALUNs (3x)
- Connection accessories
- Calibration cable

The used items are explained in the following sections.

3.1.1 DSL-Cable

The DSL-Cable used for the measurements in this application note had the following properties:

- Type: Copper cable 4x4x0.5 vDSL (CAT3)
- Manufacturer: Nexans Fumay France
- Physical properties: 4 quads 0.5 mm with general braid/alu foil SF-UTQ (QIMF)
- Trademark: ET 392121
- Model/marking: Nexans-Alcatel-Lucent 1 ACxx
- Length: 100 m

During the measurements, the DSL-Cable is wrapped on a wooden cable reel.

Figure 1: DSL Cable DUT

3.1.2 BALUN

A BALUN as shown in the picture below is used to match the output impedance of the Bode 100 (50 Ω) with the cable impedance of 110 Ω. The used BALUN generates a balanced output signal and offers a frequency range from 30 kHz up to 120 MHz.

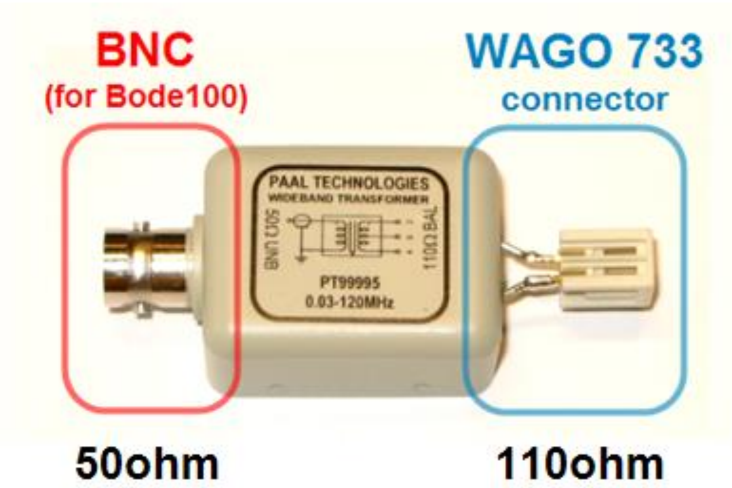


Figure 2: BALUN type used for the measurements

3.1.3 Connection accessories

To connect the BALUN to the DSL-Cable the following 2-pin Wago-733 connectors are used.

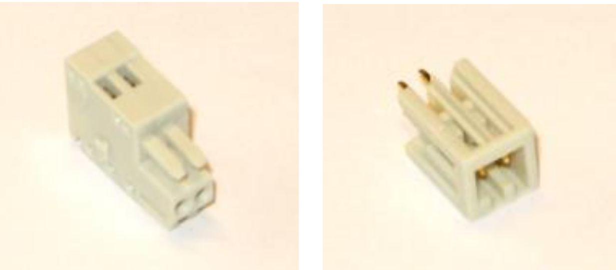


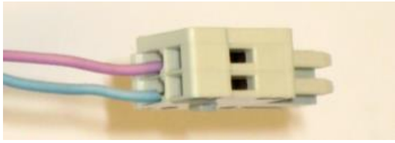
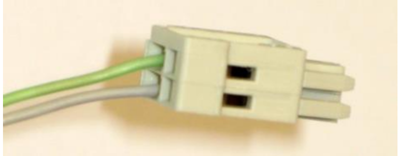
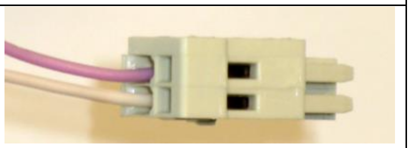
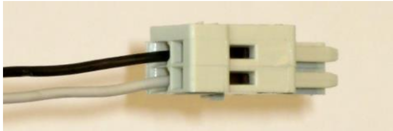
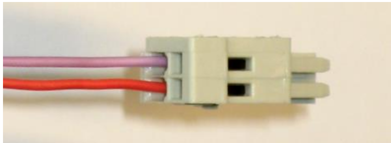
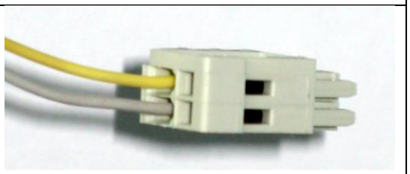
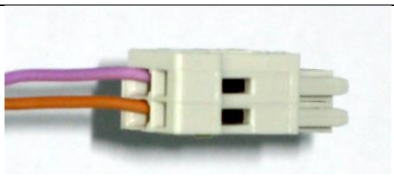
Figure 3: female plug & male plug for the balanced signal

Three special connectors **O**pen, **S**hort and **L**oad are used for the calibration later on. The load resistor has a value of 110 Ω whereas the short connector is shorted using solder.

Figure 4: OPEN, SHORT, LOAD calibration connectors

Connection table

The different cable-pairs of the DSL-Cable are connected using WAGO-733 female plugs. The following table lists all the pairs of the DSL-Cable and assigns short names that are used in the following sections of this document.

Pair Nr.	Quad	Short name	Color	Picture
1	1	Q1/1	White Grey	
2	1	Q1/2	Orchid Blue	
3	2	Q2/1	Green Grey	
4	2	Q2/2	Orchid White	
5	3	Q3/1	Black Grey	
6	3	Q3/2	Orchid Red	
7	4	Q4/1	Yellow Grey	
8	4	Q4/2	Orchid Brown	

3.1.4 Calibration cable

The measurement setup must be calibrated, to compensate the influence of the BALUNs the BNC-cables and the connectors. To perform the THRU calibration, a calibration cable with two female plugs is required. The use of the calibration cable will be shown in section 0.

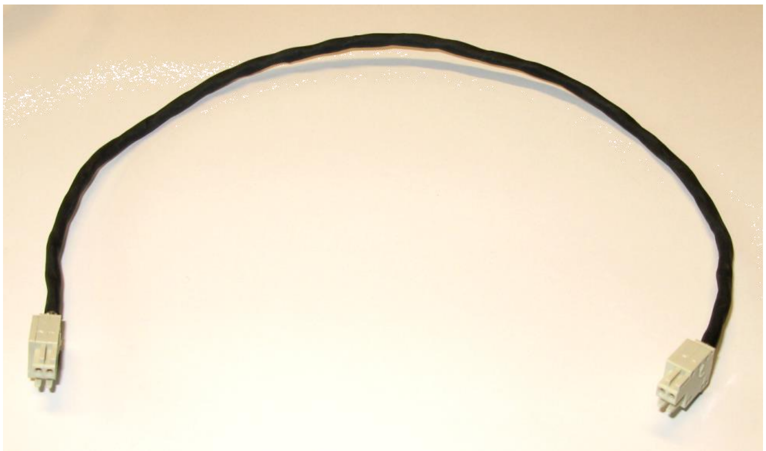


Figure 5: Calibration cable for THRU calibration

3.1.5 Thru Connector

For the calibration of the ELFEXT measurement, a thru connector is needed. All male plugs are connected in a thru configuration as shown in the figure below.

Figure 6: THRU connector for ELFEXT measurement calibration

3.2 Important Notes

Please consider the following notes when reading this document, especially when trying to reproduce the measurements:

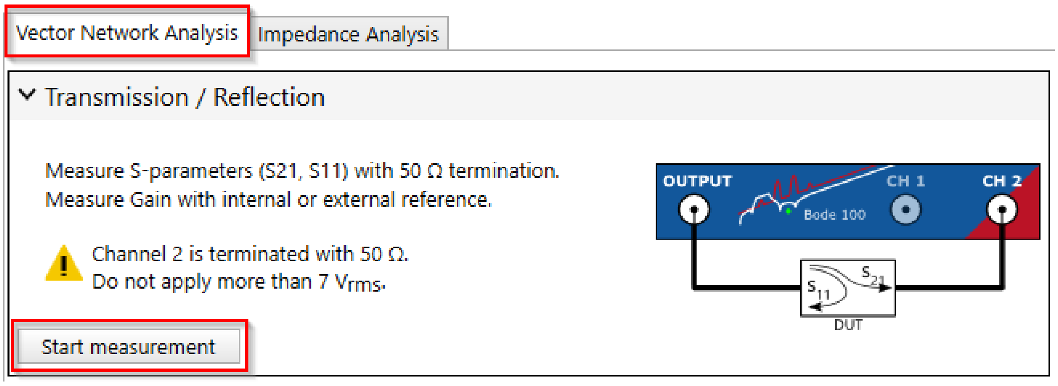
- The measurement examples outlined in this application note are only performed for **one** pair. All other wire pairs can be measured in exactly the same way.

- The used DSL-Cable consists of 4 quads. Every quad has 2 pairs. To obtain an accurate measurement result, all unused pairs (of every quad) should be terminated with a LOAD resistor at the near end and at the far end. This information will not be repeated for each setup shown in the following.

3.3 Attenuation of DSL-Cables

All signals are attenuated when transmitted thru a cable. Excessive attenuation could cause signals to be lost in noise and therefore corrupt the data-transmission. To measure the attenuation of a DSL-Cable, follow the steps below:

Start the Bode Analyzer Suite an open a transmission/ Reflection measurement in the Vector Network Analysis tab.



Then apply the following settings:

- Start Frequency: 10 kHz
- Stop Frequency: 50 MHz
- Receiver Bandwith: 300 Hz
- Number of Points: 401

To minimize the influence of the BALUNs and cables used to connect the DUT to Bode 100 it is recommended to perform a Full-Range THRU calibration as shown below:

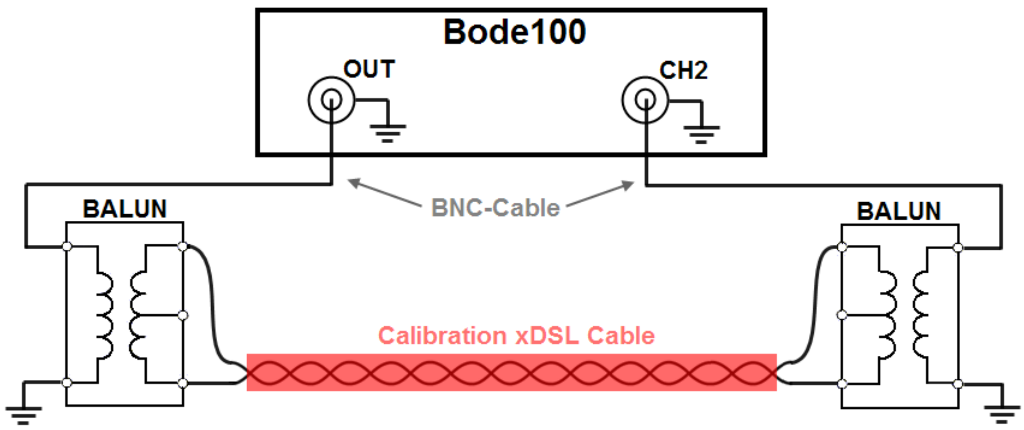


Figure 7: Calibration setup for THRU calibration using a short calibration cable

After finishing the calibration, connect the Bode 100's output and input (CH2) as shown in the figure below:

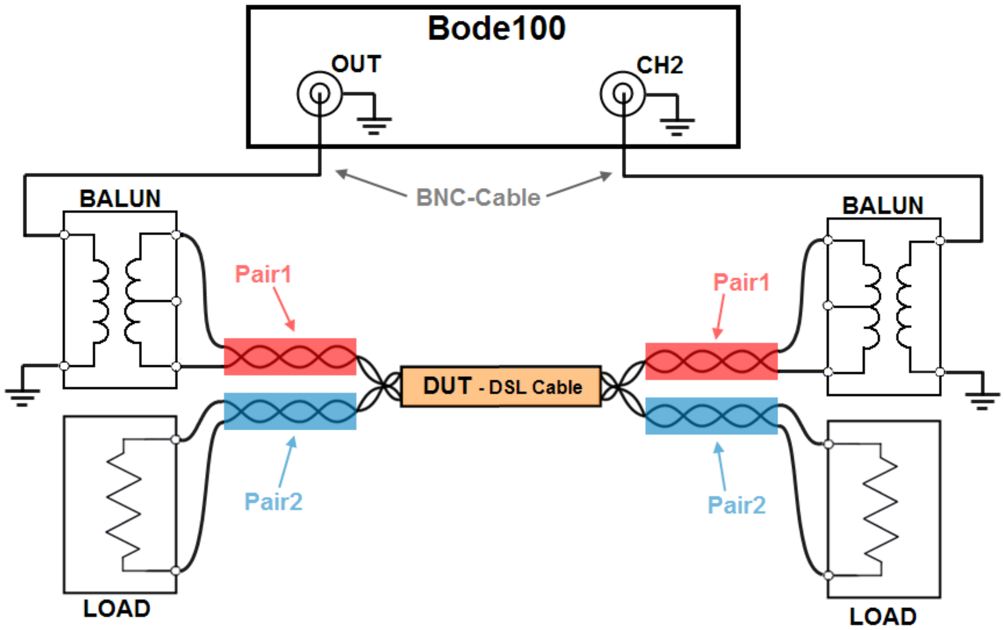


Figure 8: Measurement setup for attenuation measurement

Note: Pair1 and Pair2 are in the same quad.

Activate Trace 1 and set it to Gain, Magnitude (dB) to measure the attenuation of the DSL-cable. Now start a frequency sweep to measure the attenuation.

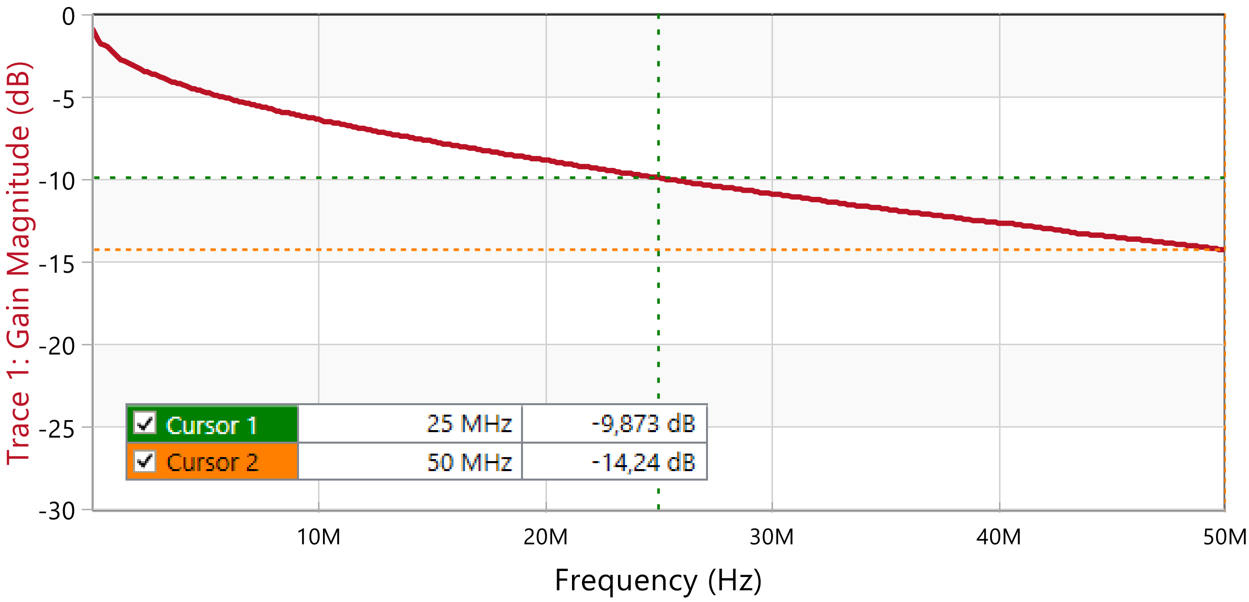


Figure 9: Measurement result

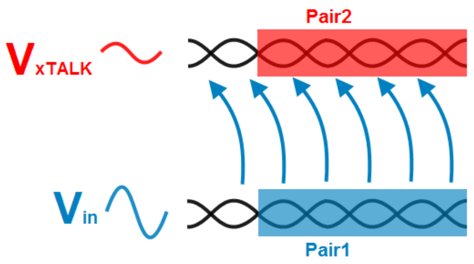
Result: The attenuation at 25 MHz is about 9.9 dB/100m. The maximum attenuation at 50 MHz is apprximately 14.2 dB/100m.

3.4 Crosstalk, NEXT, FEXT & ELFEXT

Crosstalk is a signal interference between nearby cables or cable pairs. It is caused by capacitive- and inductive coupling between different transmission pairs.

3.4.1 NEXT

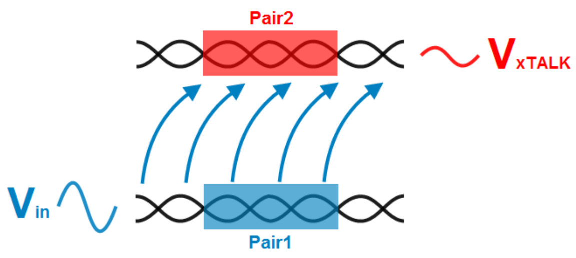
Near-End Crosstalk ($NEXT$) is measured by comparing the signal received at the near end of a neighboring pair (V_{xTALK}) with the Voltage injected into the other pair (V_{in}).



$$NEXT = \frac{V_{xTALK}}{V_{in}} \tag{1}$$

3.4.2 FEXT

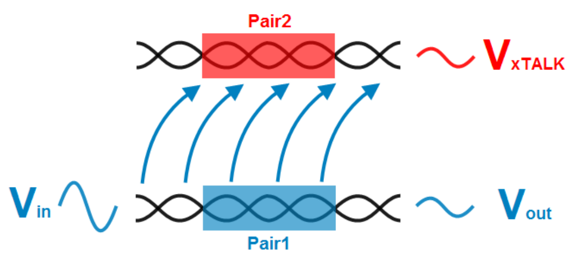
Far-End Crosstalk ($FEXT$) is the coupling between nearby pairs from the input to the far-end of the cable pair and is evaluated using the same expression as above but using a different connection location for V_{xTALK}.



$$FEXT = \frac{V_{xTALK}}{V_{in}} \tag{2}$$

3.4.3 ELFEXT

Far end crosstalk can also be expressed as Equal Level Far End Crosstalk ($ELFEXT$), measured in dB. ELFEXT is measured with respect to the attenuated test signal as shown below.



$$ELFEXT = \frac{V_{xTALK}}{V_{out}} \tag{3}$$

3.5 NEXT Measurement

To measure the NEXT of two pairs, keep the same settings and calibration as used in the attenuation measurement. Only change the Trace1 y-axis range from -100 dB to 0 dB. To measure the NEXT between Pair1 and Pair2, connect as shown below:

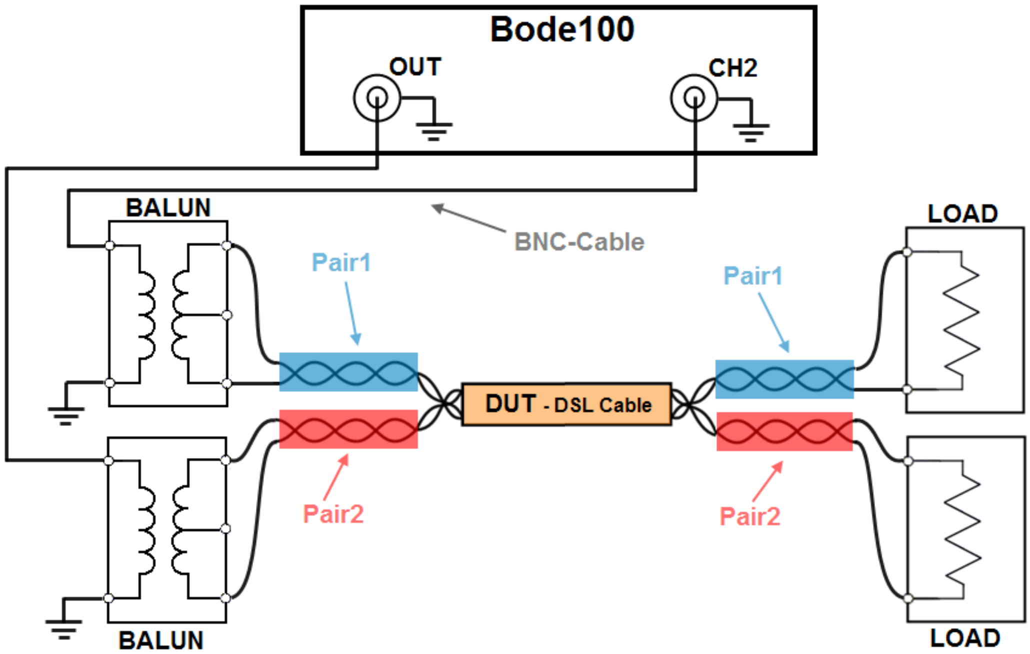


Figure 10: NEXT measurement setup

Now, the frequency sweep measurement is started.

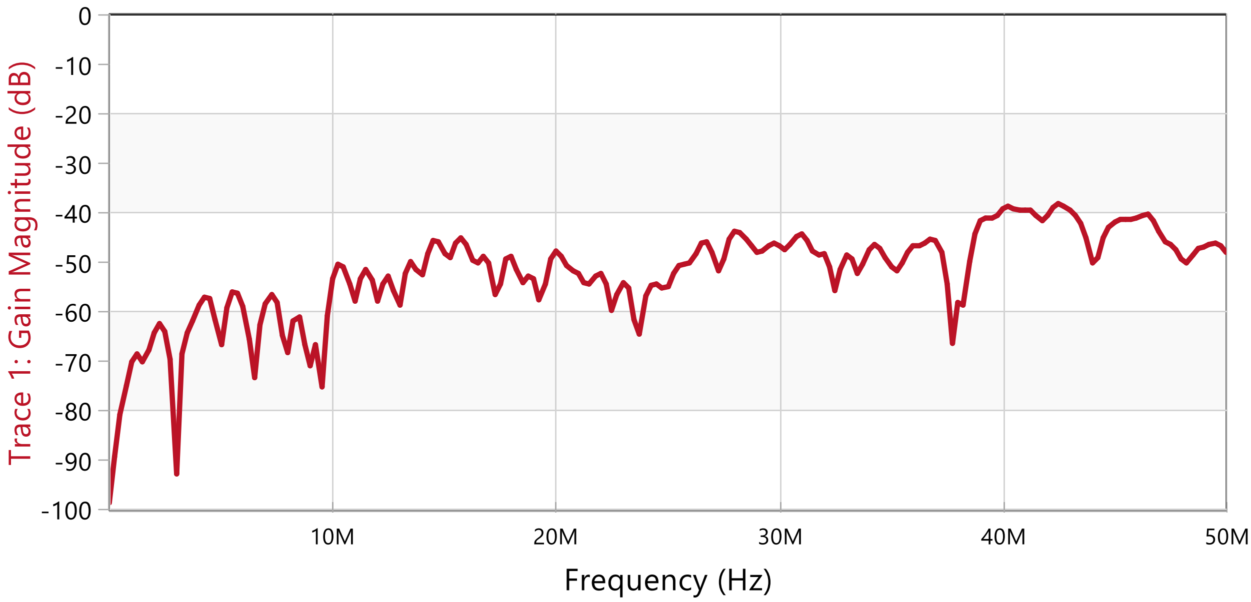


Figure 11: NEXT measurement result

The graph above shows the crosstalk (NEXT) between two neighboring pairs. The measurement result shows that the signal received at the near end of Pair2 is at least 40 dB smaller than the signal sent into Pair1.

3.6 FEXT Measurement

The setup for the FEXT measurement is almost similar to the NEXT setup and the same calibration can be used as in the attenuation measurement. Connect the DSL-Cable as shown and start the FEXT measurement.

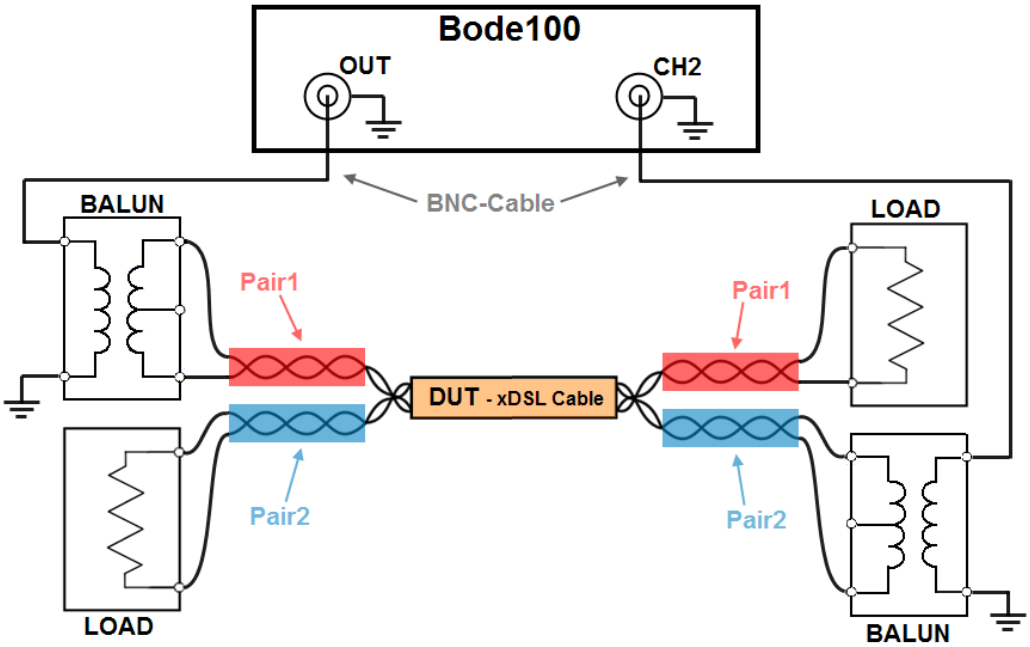


Figure 12: FEXT measurement setup

The diagram below shows the result of the FEXT measurement which indicates a FEXT of less than -40 dB.

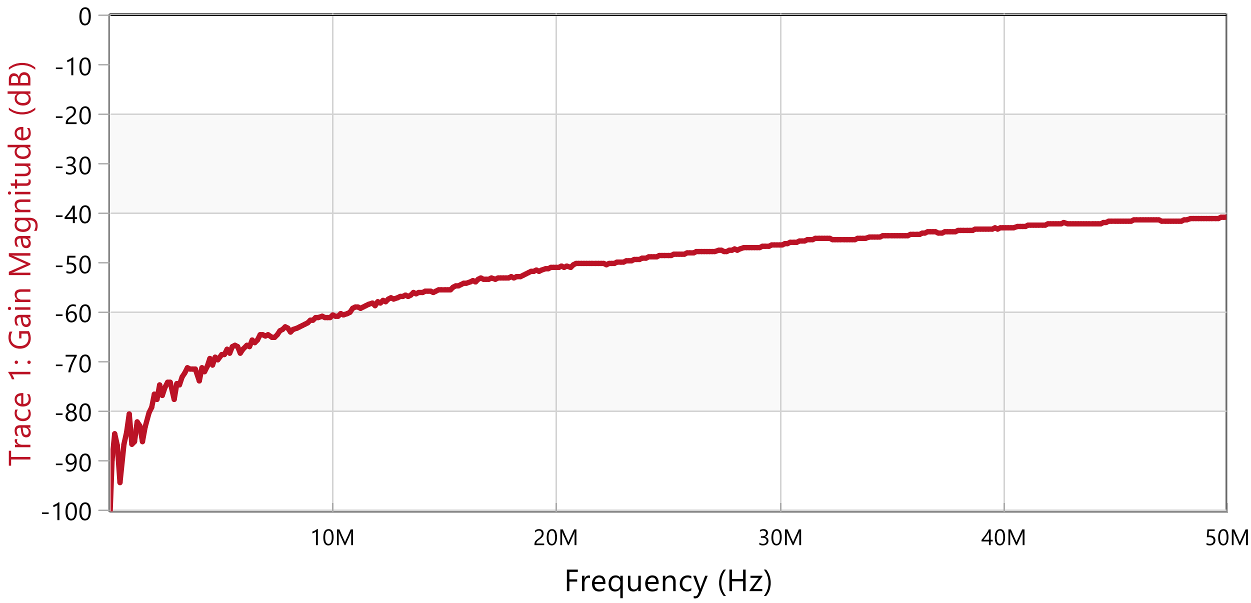


Figure 13: FEXT measurement result

To add an "upper limit" (to find out if the cable passes the requirements defined in the chosen normative std.), export the trace data into CSV File (or directly into an Excel File) which can be processed in a spreadsheet software such as Excel.

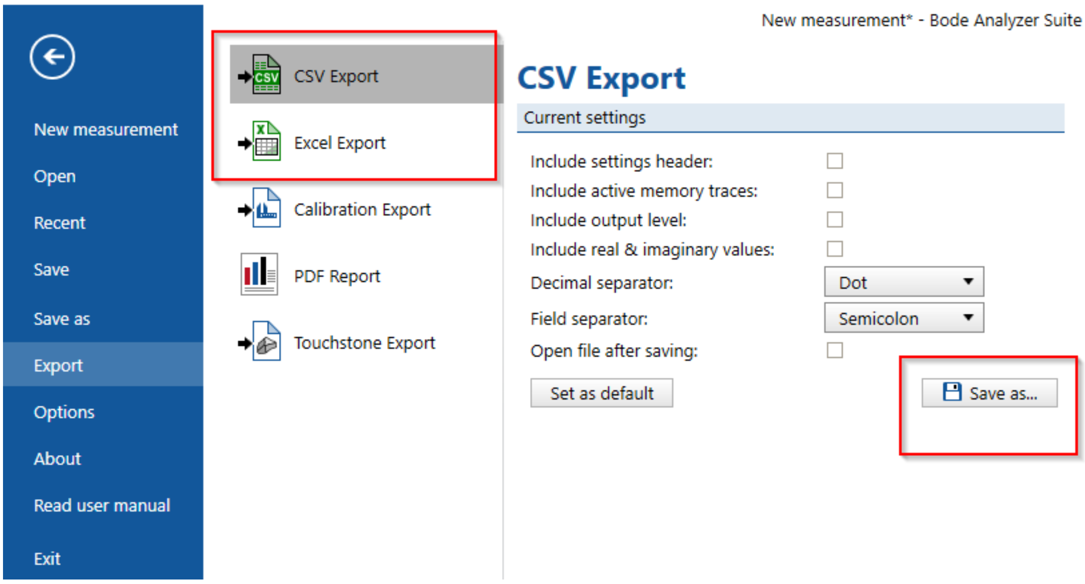


Figure 14:Export Data to CSV or Excel

The following diagram shows that the FEXT is below the required limit. The used DSL-Cable has passed the crosstalk test. The "Upper limit" is according to IEC 62255-3.

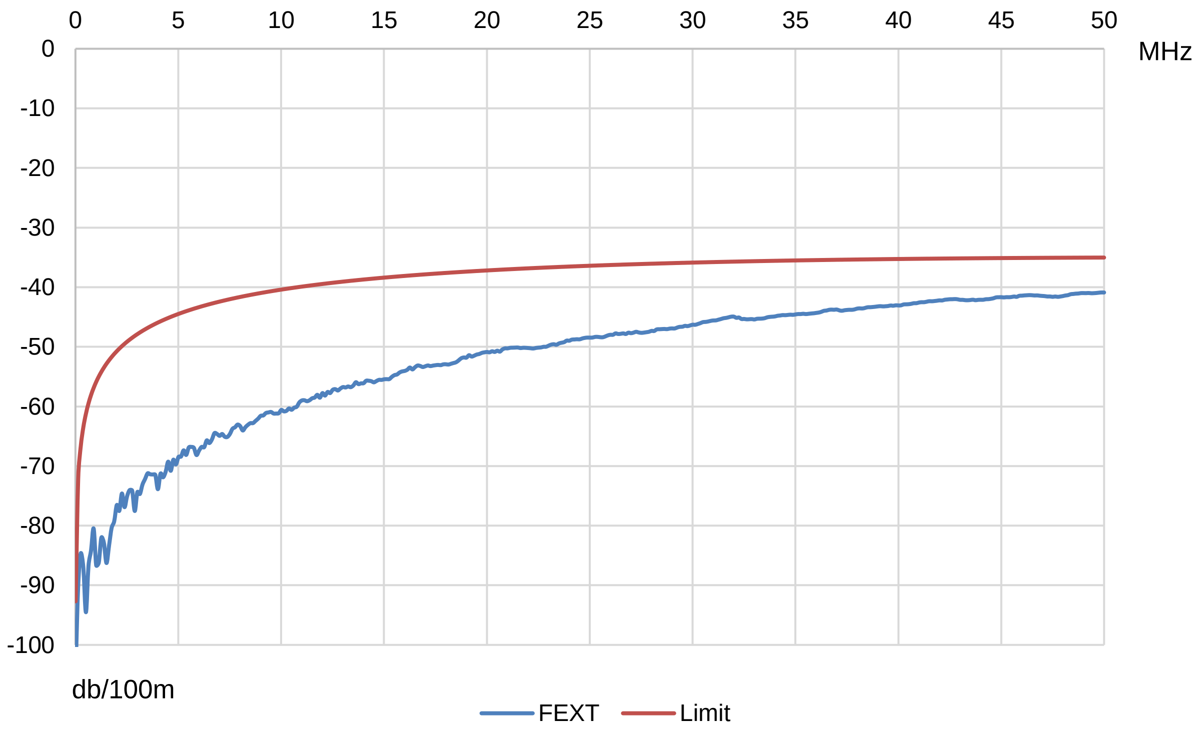


Figure 15: Checking the upper limit for the FEXT

3.7 ELFEXT Measurement / Calculation

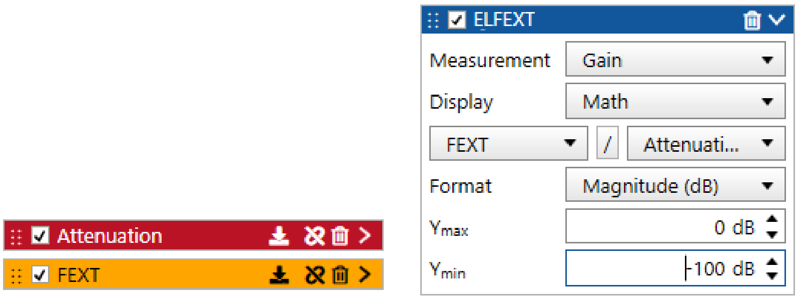
The ELFEXT can either be calculated or directly measured. In the following, the calculation as well as the direct measurement is presented.

3.7.1 ELFEXT Calculation

The $ELFEXT$ can be calculated from the $FEXT$ measurement data and the cable $Attenuation$ as follows:

$$ELFEXT = \frac{FEXT}{Attenuation} \tag{4}$$

This simple calculation can be performed in the Bode Analyzer Suite using the Math function. First, the Attenuation measurement is copied to a memory trace. Second, the FEXT measurement is copied to a memory trace. The two memory traces can then be subtracted from each other using a math operation as shown below.



The calculation result is shown in the diagram below. The blue curve is the ELFEXT result, the red curve the measured attenuation and the orange curve the measured FEXT.

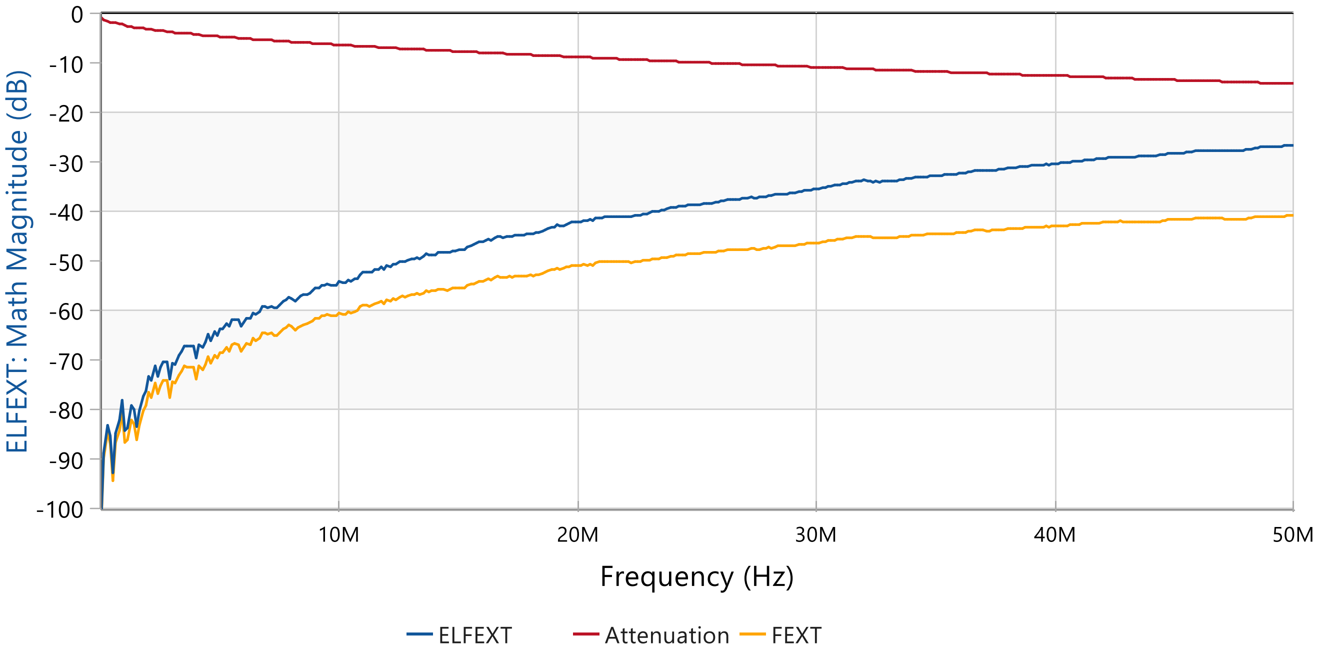
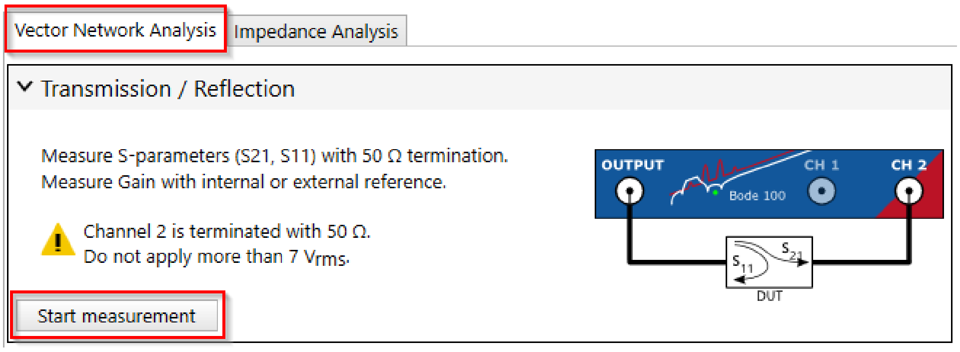


Figure 16: Calculated ELFEXT

3.7.2 Direct ELFEXT Measurement

As the Bode 100 offers two external input channels, the ELFEXT can be measured directly. To perform an ELFEXT measurement, use the Transmission/Reflection measurement mode of the Bode Analyzer Suite.



In the hardware setup change to the external reference and switch on the CH1 termination:

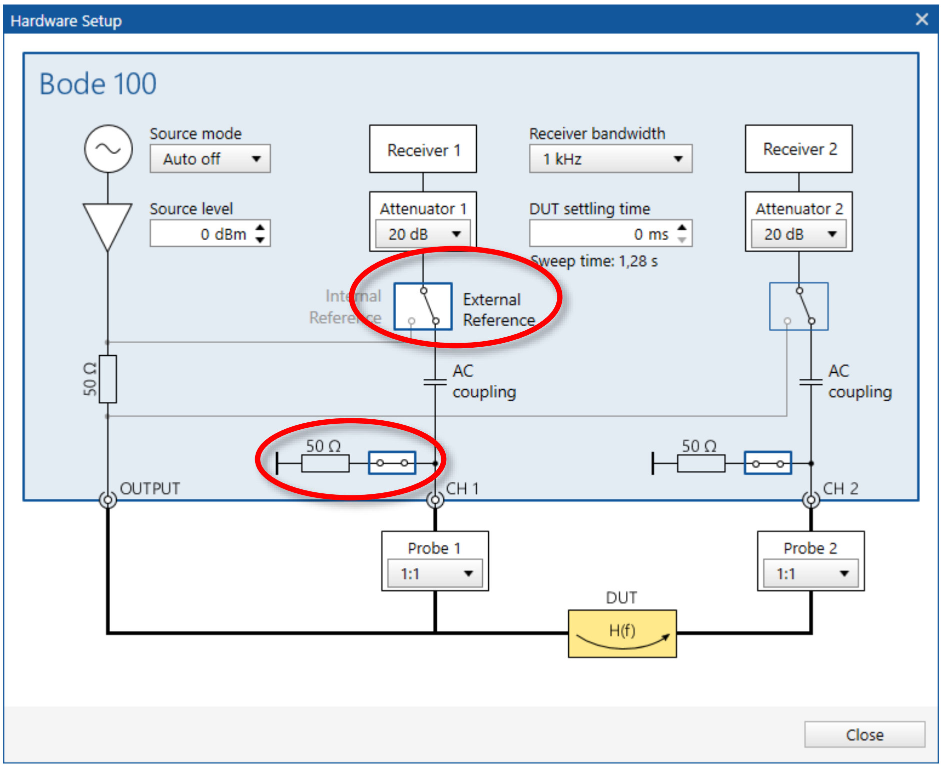


Figure 17: Hardware setup for ELFEXT measurement

Then choose the following settings:

- Number of points: 401
- Start Frequency: 10 kHz
- Stop Frequency: 50 MHz
- Source Level: 13 dBm
- Receiver Bandwidth: 100 Hz

To minimize the influence of the BALUNs and cables used to connect the DUT to the Bode 100 perform a THRU calibration. For the calibration, connect the Bode 100 as shown below:

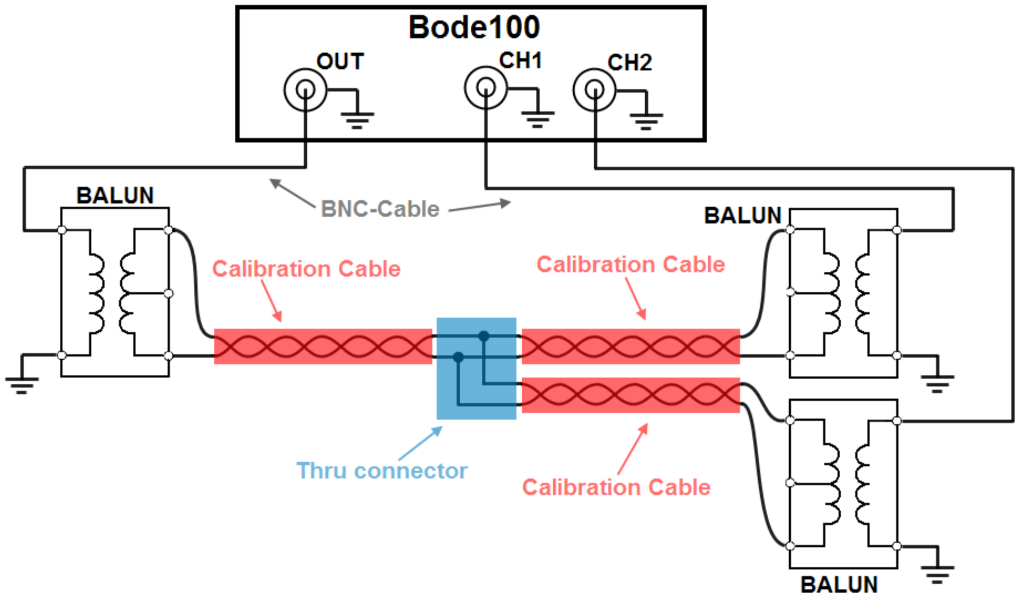


Figure 18: ELFEXT Thru-Calibration setup

Note that this setup causes an impedance-mismatch since two BALUNs are connected in parallel on one side of the setup. A matched power splitter could overcome this issue but in this case it is assumed that the error is negligible at frequencies below 50 MHz.

After the calibration has been performed, start the ELFEXT measurement. To perform the measurement, connect the DUT as shown below:

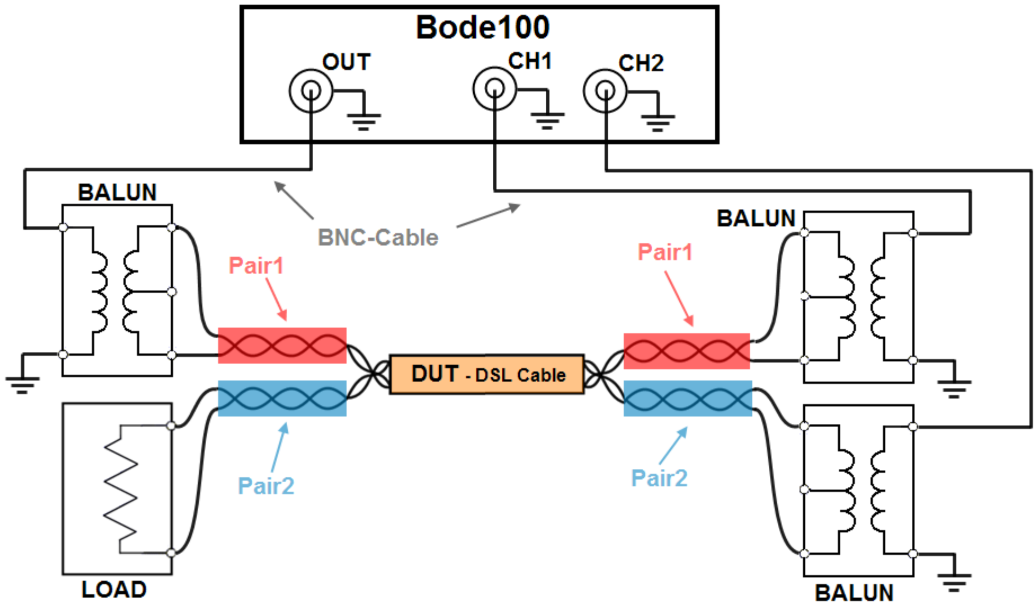


Figure 19: ELFEXT measurement setup

The following diagram shows the result of the ELFEXT measurement.

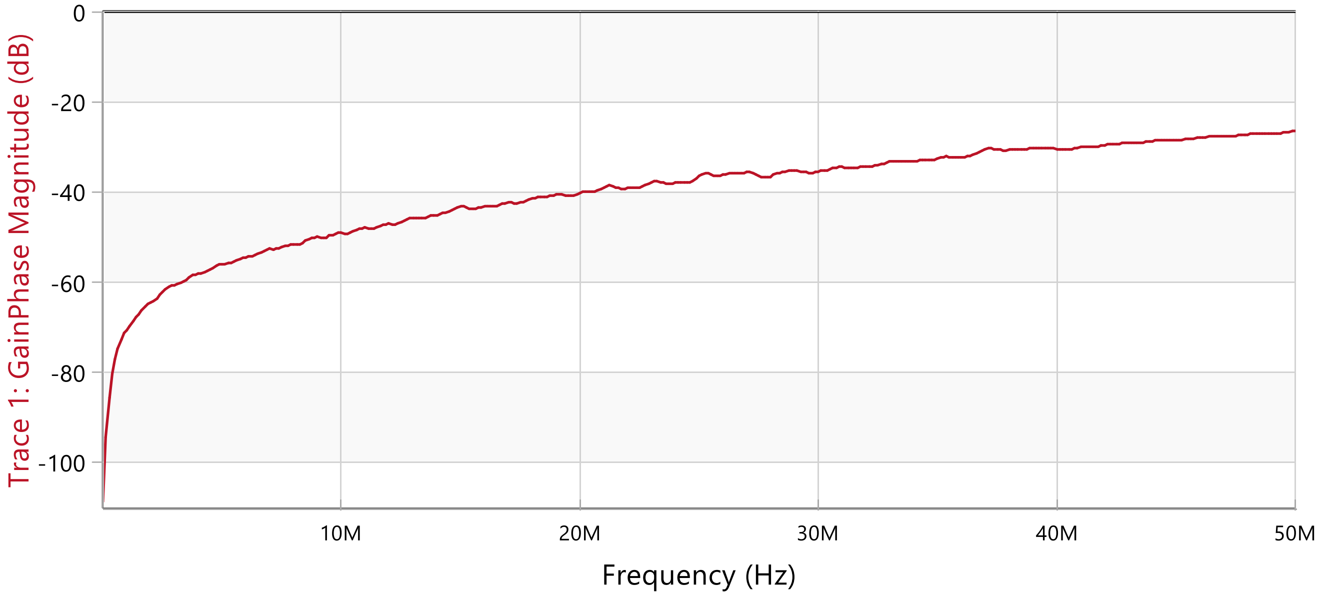


Figure 20: ELFEXT measurement result

The measurement was exported as a csv file to compare the calculated with the directly measured data. The following diagram shows that the calculation and the direct measurement deliver almost the same result.

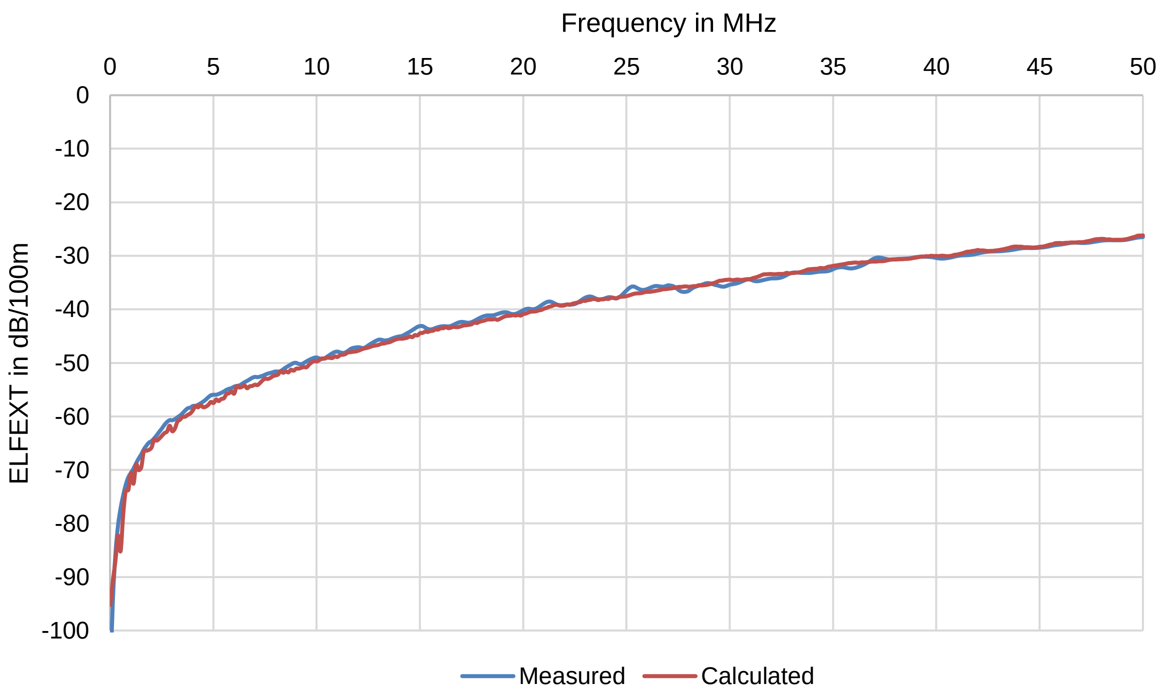


Figure 21: ELFEXT measurement versus calculation

3.8 Impedance Measurements

To match a driver unit (transmitter) or a receiver to a DSL-Cable it is necessary to know the input impedance. To measure the impedance of the used cable proceed as shown below:

For the impedance measurement, the load resistor in the calibration window must be set to 110 Ω.

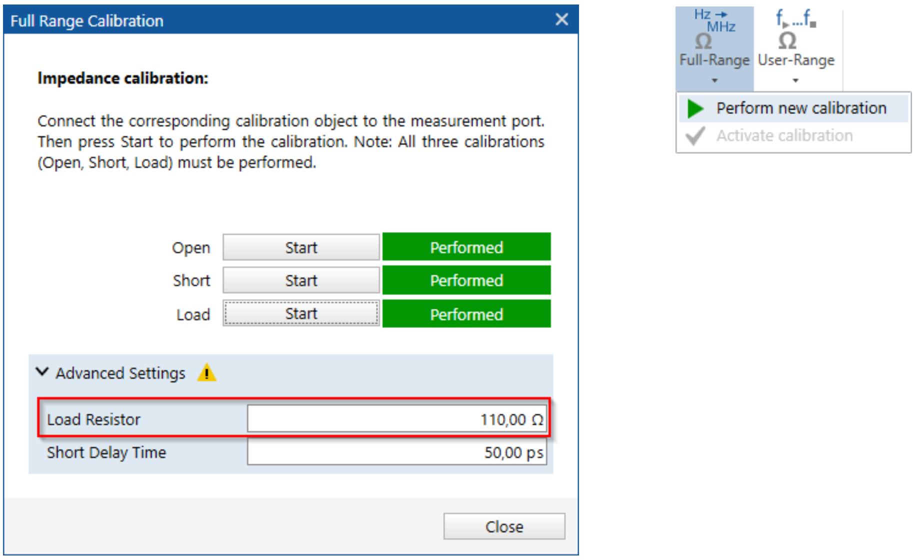


Figure 22: Load-Resistor setting in calibration window

Calibrate Bode 100 by using the **O**pen, **S**hort and **L**oad calibration connectors as shown in the figure below.

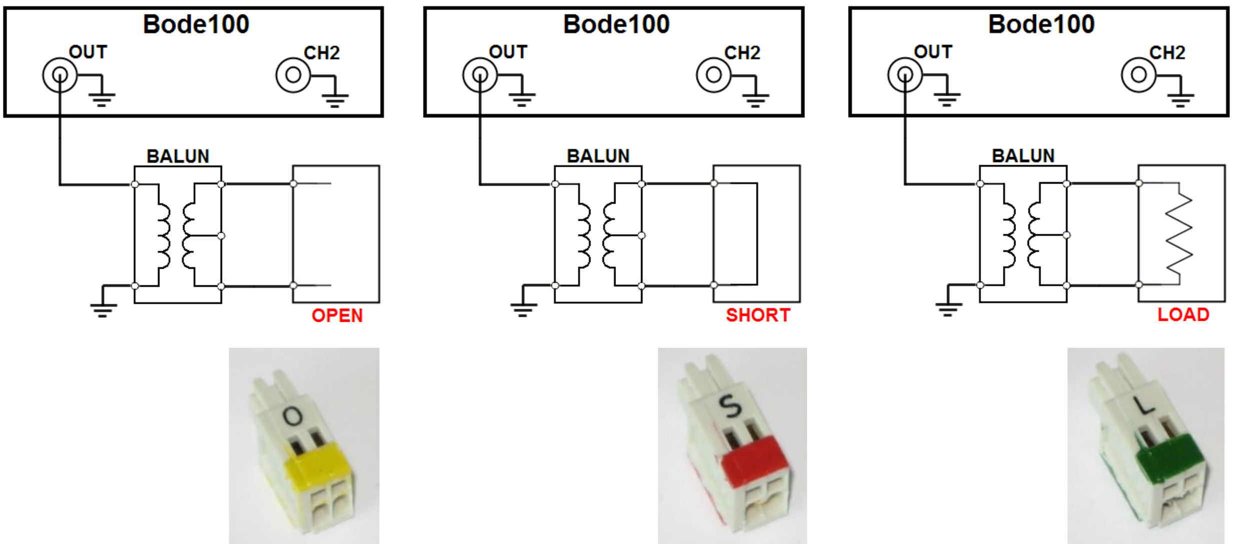


Figure 23: Calibration setup - OPEN / SHORT / LOAD

To measure the cable impedance, the DSL-Cable needs to be connected as follows:

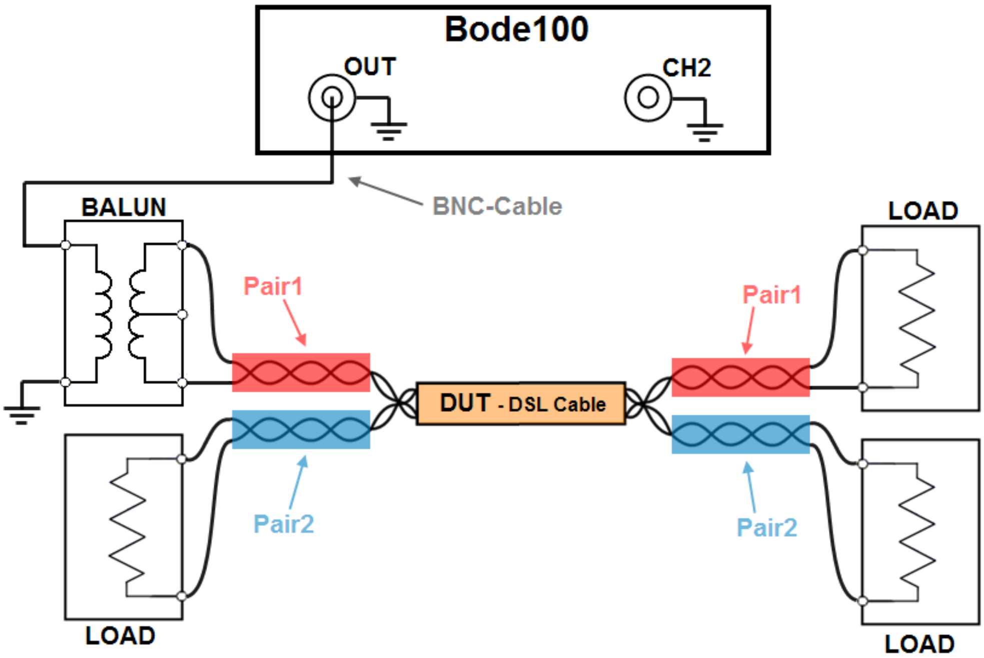


Figure 24: Impedance measurement setup

Now start the measurement by pressing the single measurement button.

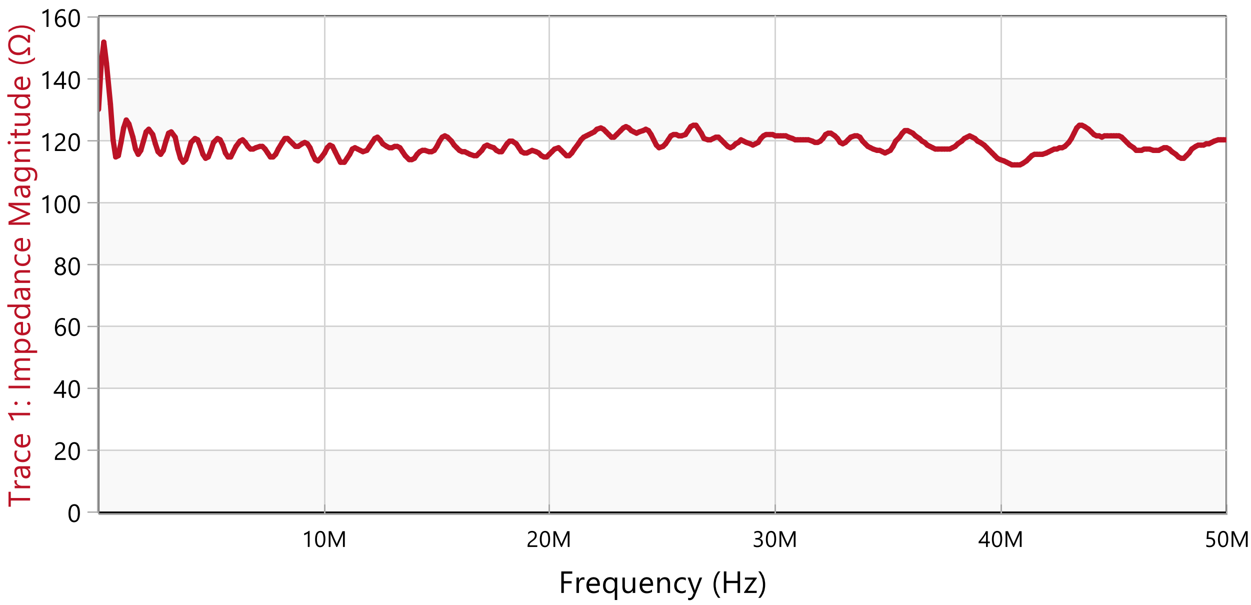


Figure 25: Measurement result – Impedance

Result: The result shows that the characteristic impedance of the DSL-Cable is actually 120 Ω as stated on the cable marking. The ripple is caused by variations and deflections in the cable construction.

3.9 Return Loss (RL) of DSL-Cables

To measure the RL of the DSL-Cable, configure Bode 100 like shown in the previous section “Impedance Measurement”. Set the Nominal impedance to 110 Ω and configure Trace 1 to display Reflection Magnitude in dB.

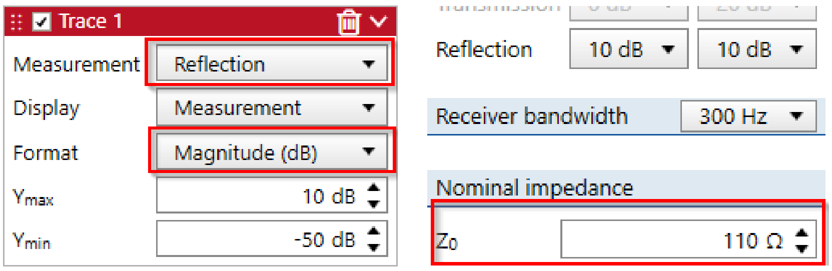


Figure 26: Trace settings and characteristic impedance setting

Starting a frequency sweep results in the following graph showing a return loss of > 20 dB.

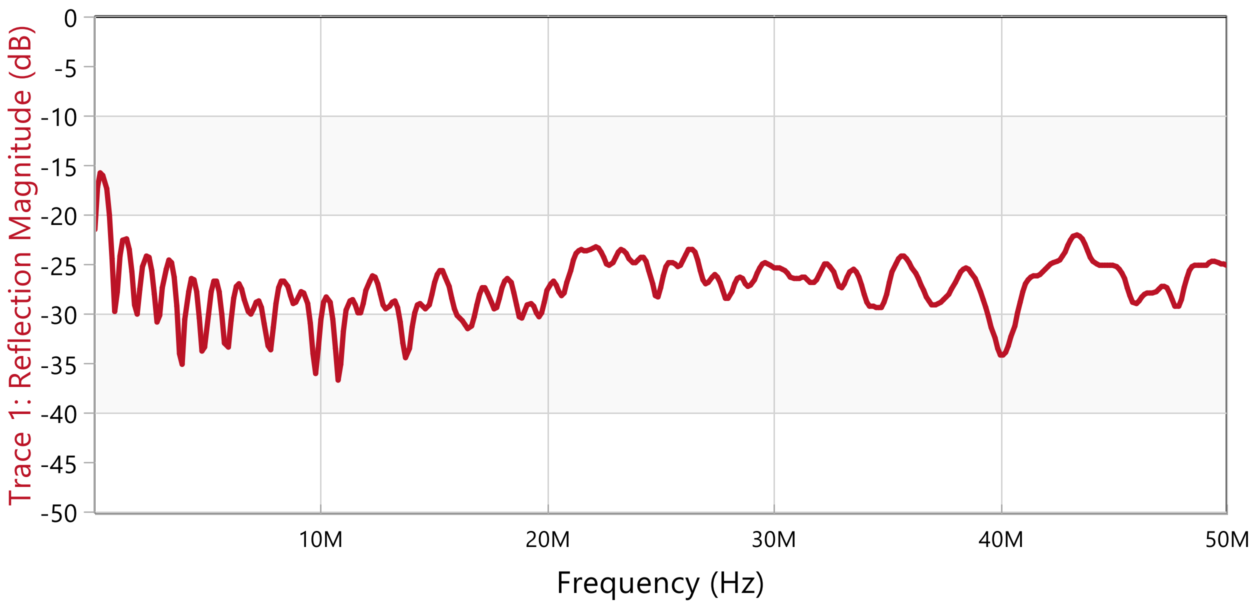
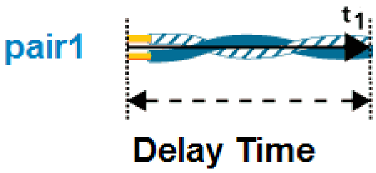


Figure 27: Measurement result – Return Loss

3.10 Group Delay & Velocity Factor

The group delay represents the time which is needed by a signal to pass thru the cable.



To measure the group delay, configure the Bode 100 and calibrate it as shown in the attenuation measurement. Set Trace 1 to format Tg.

Now the measurement can be started. The result is shown below:

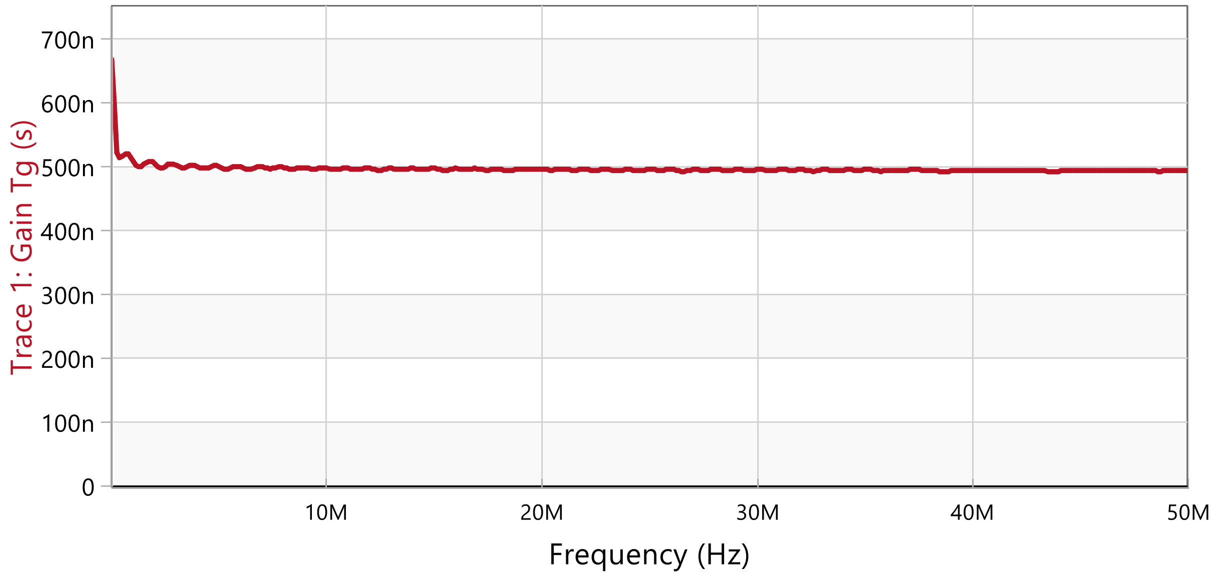


Figure 28: Measurement result - Delay Time

Result: The group delay is around 500 ns for 100 m cable – this is approx. 5 ns/m. It is also possible to calculate the propagation speed or velocity factor as shown below.

The propagation speed v_p is the calculated velocity of a wave passing thru the DUT. In our case it can be calculated using the expression shown below:

$$v_p = \frac{100\ m}{T_g} = \frac{100\ m}{500\ ns} = 200000 \frac{km}{s} \tag{5}$$

The velocity factor equals the propagation speed in ratio to the speed of light in a vacuum C.

$$v_C = \frac{v_p}{C} = 0.66 \tag{6}$$

4 Conclusion

In this application note, it has been shown how electrical characteristics of DSL-Cables can be measured using the Bode 100. All measurements worked out nicely and matched the cable's measurement protocol, which was provided with the cable.

OMICRON Lab is a division of OMICRON electronics GmbH, specialized in providing Smart Measurement Solutions to professionals such as scientists, engineers and teachers engaged in the field of electronics. It simplifies measurement tasks and provides its customers with more time to focus on their real business.

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