Bode 100 - Application Note

Cable Analysis and Fault Detection using the Bode 100

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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 V2.43. 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 various electrical parameters of coaxial cables using the Bode 100 vector network analyzer. Besides the measurement of typical cable characteristics such as attenuation or shielding, the detection of cable faults like short circuits or a cable break are also investigated.

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 data sheet.

Especially for long cables it is essential to use a suitable measurement method to detect the location of a broken wire or a short circuit, since otherwise an optical and mechanical inspection of the complete cable length is required.

In this application note we show you how you can use the Bode 100 for these measurements.

By analyzing a coaxial cable the following points are investigated:

1. What attenuation does my cable have?

2. Is it possible to measure the dielectric constant of the cable insulation?

3. How does the cable impedance change depending on the frequency and how can I measure the wave impedance of my cable?

4. How can I find the location of a short circuit or a cable break?

5. Is there a measurable difference between a complete cut and a separate break in screen or inner conductor of the cable?

6. How can I measure the efficiency of the cable's electrical shielding?

3 Measurement Setup & Results

3.1 Required data and equipment

To execute the measurements outlined in this application note you require

- your Bode 100 Vector Network Analyzer
- a long[1] coaxial cable with BNC connectors on both ends
- the data sheet of the chosen cable

3.1.1 Data sheet

From the data sheet of the coaxial cable we have chosen we get the following information:

Cable impedance	50 Ω
Inner Conductor	0.49 mm^2 (tinned copper)
Insulation	2.9 mm diameter (polyethylene)
Overall shield	0.10 mm, coverage >90% (bare copper braid)
Dielectric constant	2.30
Maximum attenuation	1.8 dB/100m @ 1 MHz 8.0 dB/100m @ 20 MHz

3.1.2 Physical constants & parameters

For the following measurements and calculations we need the following physical constants:

$C_0 = 2.997\,924\,58 \cdot 10^8 \frac{m}{s} \approx 3 \cdot 10^8 \frac{m}{s}$ Speed of light (in vacuum)

$\pi \approx 3.14159$ Pi (Archimedes' number)

$\omega = 2 \cdot \pi \cdot f$ Angular frequency

3.2 Verification of the electrical cable characteristics

In this section we will measure the following electrical parameters of the cable:

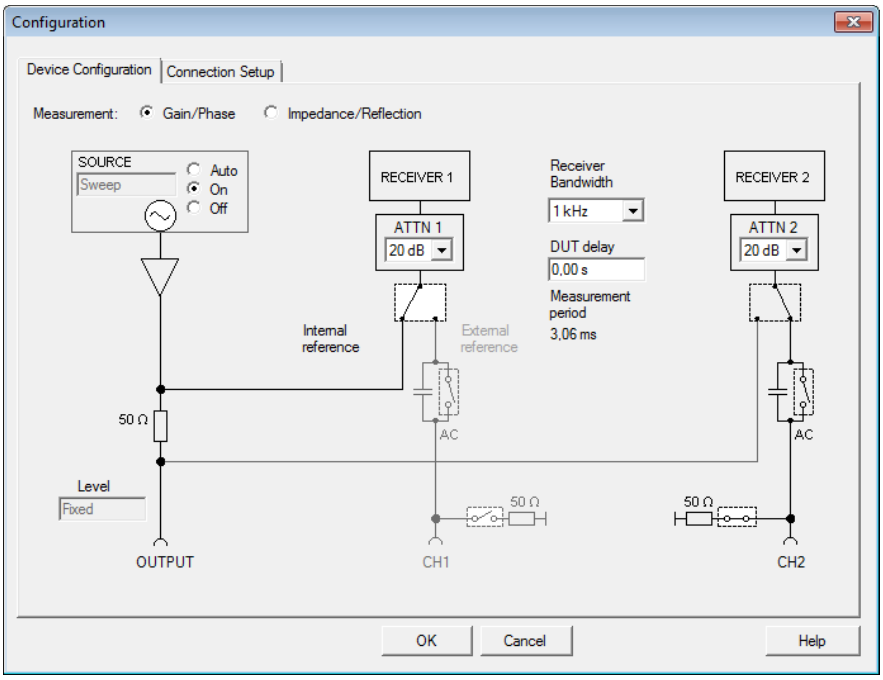
- cable attenuation
- dielectric constant of the cable
- cable impedance

[1] it is advisable to use a cable length of 50 meters or more to get exact results

3.2.1 Cable attenuation

Before the frequency response of the cable can be measured the Bode 100 needs to be adjusted as follows:

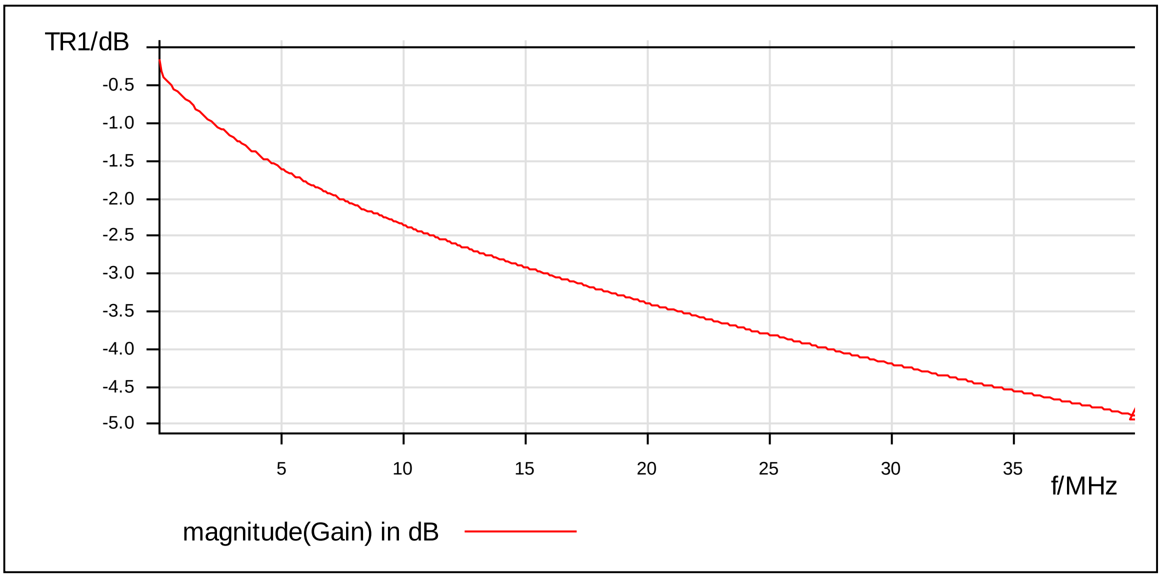
- Apply the following settings in the frequency sweep mode:
  - f(min): 10 Hz
  - f(max): 40 MHz
  - Reference: internal
  - Attenuator CH1 & CH2: 20 dB
  - Receiver Bandwidth: 1 kHz
  - Number of points: 201 or more
  - Input Impedance CH2: 50 Ohms



- If the cable is connected directly to the Bode 100 no further calibration is necessary before the measurement
- Activate **Trace 1** and select the Measurement **Gain** and Format to **Mag(dB)**

Note: To ensure that you get accurate results and to minimize self influences of the cable it is recommended that you unroll the cable as much as the space in your location permits.

Connect one cable end to the Bode 100 output and the other cable end to the CH2 of the Bode 100. A sweep shows the following result:



	Frequency	Trace 1	
Cursor 1	1,000 MHz		-0,66 dB
Cursor 2	20,000 MHz		-3,39 dB
delta C2-C1	19,000 MHz		-2,73 dB

Answer to question 1.):

From the diagram above we can see that the attenuation of the cable (50 meters in this measurement) increases with frequency. The measured values are within the range of the data sheet values.

frequency	max. attenuation (from data sheet)	measured attenuation
1 MHz	0.9 dB	0.66 dB
20 MHz	4.0 dB	3.39 dB

3.2.2 Dielectric constant

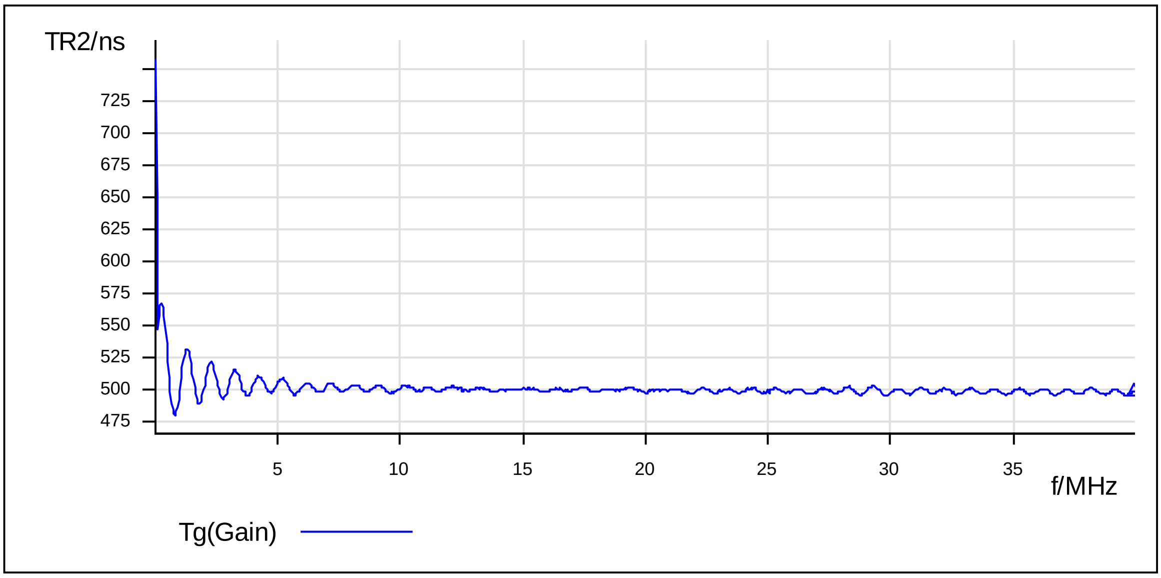
To assess the dielectric constant we need values for the following formula:

$$\varepsilon_r = \left(\frac{c_0 \cdot t_g}{l}\right)^2$$

The cable length can be easily measured and the speed of light is a physical constant. The only remaining unknown parameter, the group delay of the cable, can be measured with the Bode 100.

- Use the same measurement set up and Bode 100 settings as before
- Select the following settings for **Trace 1**: Measurement: **Gain** Format: **Tg**

Note: You may change the lower frequency f(min) to ~ 500 kHz because results are more precise at higher frequencies.



When you have a closer look at the measured curve you immediately detect a ripple. This ripple is caused by the fact that the wave impedance of the cable is not exactly 50 Ohms. The ripple amplitude increases the lower the frequency gets since the series impedance of the cable becomes more dominant at lower frequencies.

- As the measurement shows the group delay for our cable (length: 100m) is ~500 ns. Now you are able to calculate the dielectric constant with the formula.

$$\varepsilon_r = \left(\frac{c_0 \cdot 500\ ns}{100\ m}\right)^2 = 2.25$$

Answer to question 2.):

The measured dielectric constant of the used cable is 2.25. Small deviations from the data sheet value can result from the measured group delay ripple.

3.2.3 Cable impedance

This part of the application note focuses on the behavior of the cable impedance as a function of the frequency.

The impedance $\underline{Z}$ of a cable is defined as follows:

$$\underline{Z} = \sqrt{\underline{Z}_{short} \cdot \underline{Z}_{open}}$$

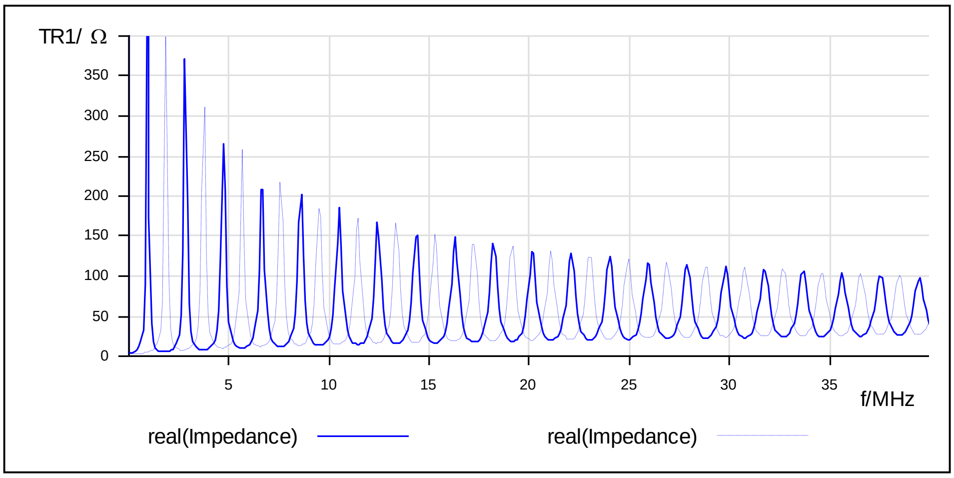
were: $\underline{Z}_{short}$ is the impedance of a cable with a **short** on its far end.
$\underline{Z}_{open}$ is the impedance of a cable left **open** at is far end.

To verify the cable impedance of a 50Ω cable just follow the below procedure:

- Use the same settings for the frequency sweep mode as before.
- Perform an impedance calibration for open, short, load and set the number of points to ≥401.
- Connect one end of the cable to Bode output and leave the other end open.
- Change adjustments for Trace 1 to:
  - Measurement: **Impedance**
  - Format: **real**

  and start a single sweep.
- For later calculations please export the measurement data to a spreadsheet program by using the "Export Traces Data…" function as described in the user manual. Further on please use the "Data → Memory" function to copy your result to the trace memory.
- Now short circuit the end of the cable and perform another single sweep measurement and again export the data.

- By displaying data and memory you should get a graph comparable to the one below:



The dashed curve shows $Re\{\underline{Z}_{open}\}$ while the solid curve shows $Re\{\underline{Z}_{short}\}$

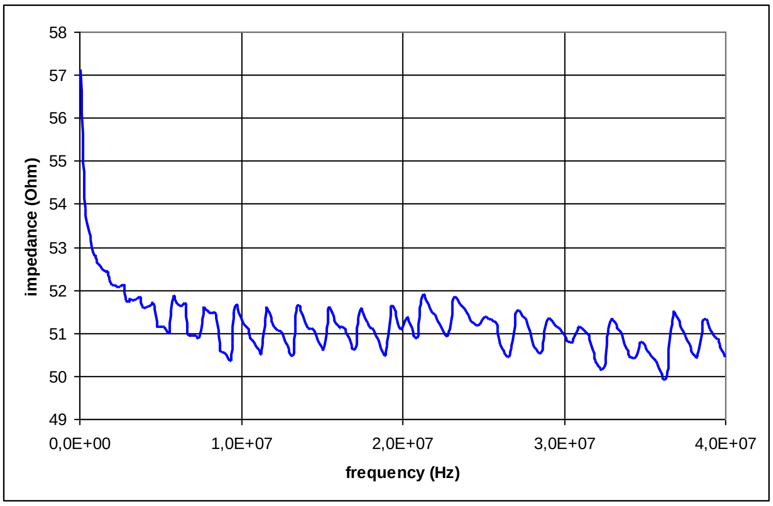
- The two *.csv files you have got when you did the data export contain the Real part as well as the Imaginary part of $\underline{Z}_{open}$ and $\underline{Z}_{short}$.

  By using the formula below you can use these exported values in a spreadsheet program to calculate the magnitude of the cable impedance $\underline{Z}$.

$$|\underline{Z}| = \sqrt{|\underline{Z}_{short}| \cdot |\underline{Z}_{open}|}$$

$$|\underline{Z}| = \sqrt{\sqrt{Re\{\underline{Z}_{short}\}^2 + Im\{\underline{Z}_{short}\}^2} \cdot \sqrt{Re\{\underline{Z}_{open}\}^2 + Im\{\underline{Z}_{open}\}^2}}$$

Below you can see a diagram of the calculated impedance vs. the frequency.

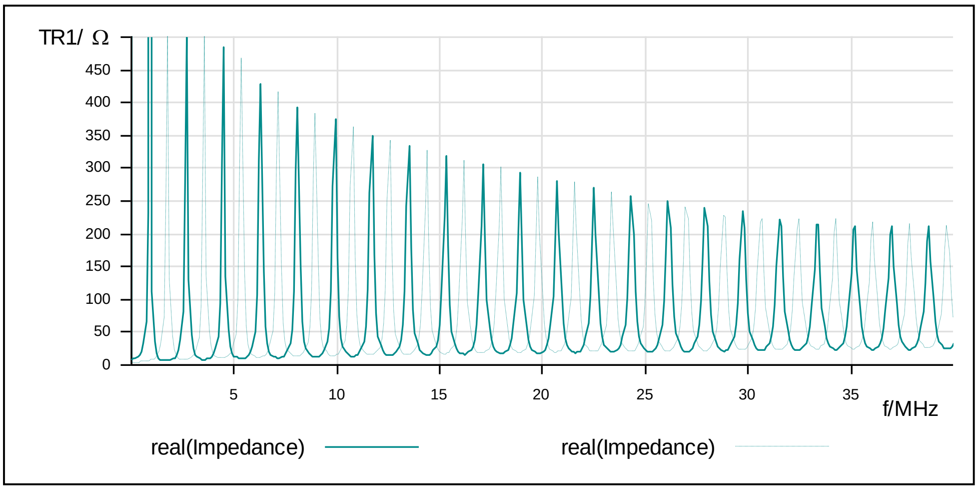


Answer to question 3.):

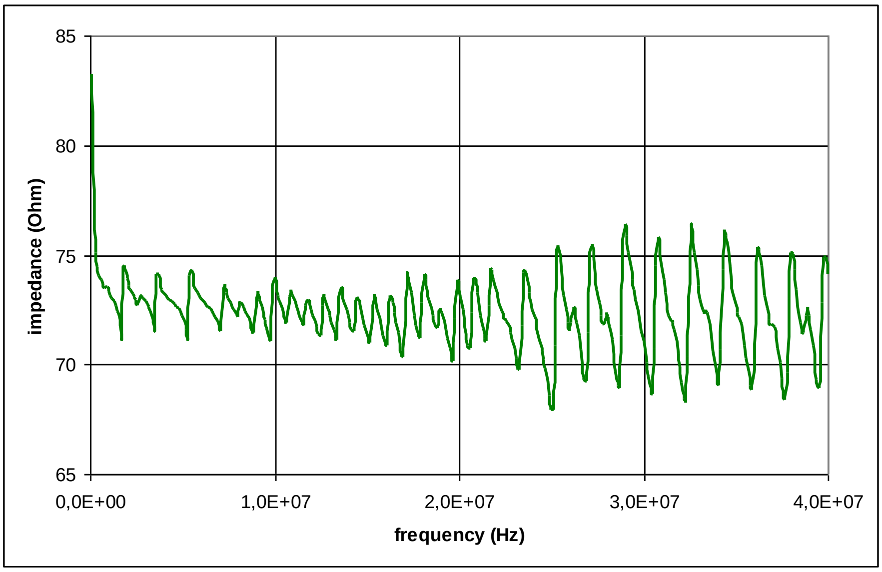
The behavior of the cable impedance is shown at the frequency response curve.
As the diagram shows the Bode 100 can be used to measure the cable's wave impedance.

Note: To reach accurate impedance results it is very important to use cables with a minimum length of 50m or preferably longer.

To demonstrate that this measurement method also works for cables with wave impedances other than 50Ω we did repeat the measurement with a cheap 75Ω television cable.



- Diagram for the measured impedance of a 75Ω cable (50 meters):



3.3 Detecting short circuits and cable breaks

The Bode 100 offers the possibility to measure reflected signals which can be used to calculate the cable length to the cable break and therefore the position of a cable failure.

Formula for the cable's length:

$$l = -\frac{C_0}{\sqrt{\varepsilon_r} \cdot 2\pi} \cdot \frac{\delta\Phi}{\delta f} \cdot \frac{1}{2}$$

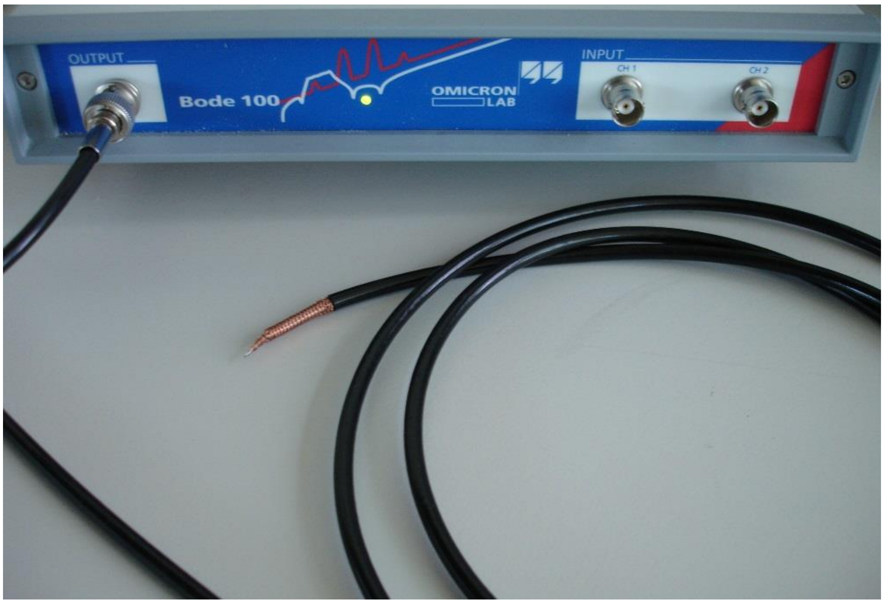
While the speed of light is a physical constant and π a mathematical constant you can find the dielectric constant in the cable's data sheet. $\partial\Phi / \partial f$ needs to be measured.

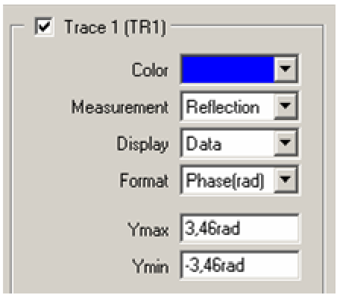
The factor $\frac{1}{2}$ compensates the way back for the reflected signal.

Note: Short circuits and cable breaks are measured and calculated the same way.

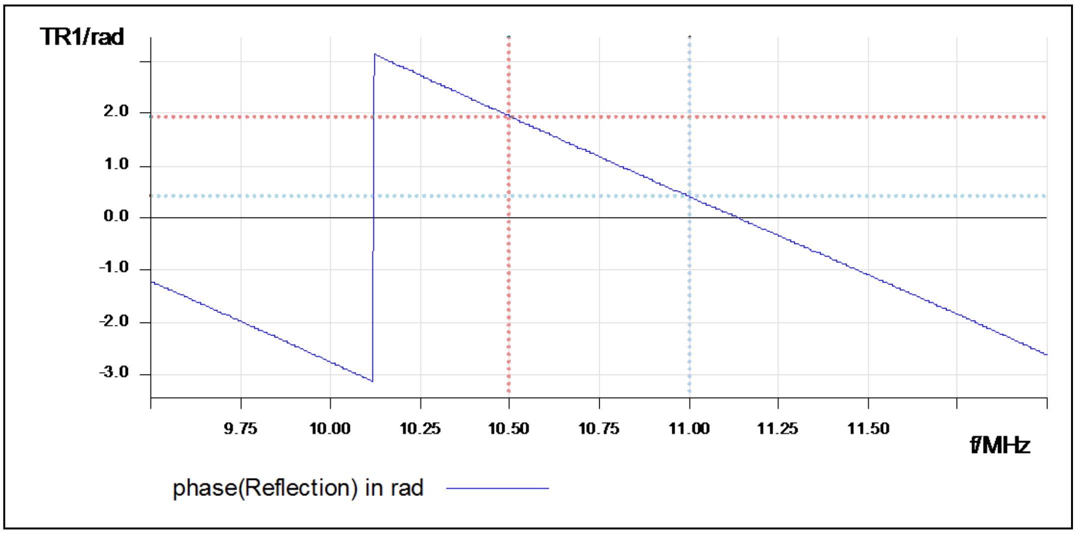
3.3.1 Location of a short circuit

This section targets the detection of a short circuit in the cable. For our example we have connected the inner conductor to the cable shield as shown below. The other end of the cable we connected to the Bode 100.





- Use the same adjustments and calibrations as before.
- Select the format Reflection, Phase(rad) for Trace 1.
- Activate both cursors, which will allow you to read exact values directly. Furthermore you can narrow the frequency range by changing f(min) and f(max) to get even numbers to ease the calculations.



	Frequency	Trace 1	
Cursor 1	10,500 MHz		1,95 rad
Cursor 2	11,000 MHz		412,42 mrad
delta C2-C1	500,000 kHz		-1,53 rad

- Read the values from "delta C2-C1".
  Our values are: ΔΦ = -1.53 rad and Δf = 500 kHz as shown in the screenshot.

Note: By clicking into the frequency cell of the cursors you can enter suitable frequency values.

- Now insert all values into the formula and calculate the cable length. In this calculation the dielectric constant 2.3 from the data sheet is used.

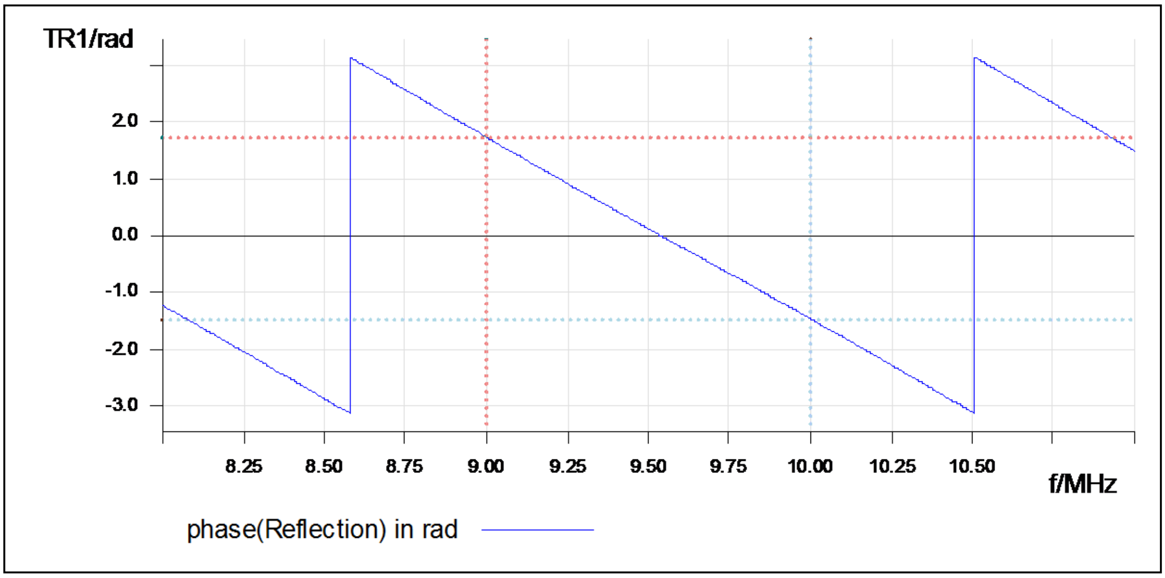
$$l = -\frac{3 \cdot 10^8 \frac{m}{s}}{\sqrt{2.3} \cdot 2\pi} \cdot \frac{-1.53}{500\ kHz} \cdot \frac{1}{2} = 48.17\ m$$

Result: The calculated position of the short circuit is at 48.17 meters. We verified the result by measuring the cable length between Bode and the cable failure with a pocket rule – the result was ~48.3 meters. There is only a minimal deviation (0.3%) between the calculated failure location and the real failure location.

3.3.2 Locating a complete cable break

Cut your cable at any position. Connect the other end to the source output of the Bode 100.

- Use the same adjustments as before.
- Optimize f(min) and f(max) to narrow the frequency range and begin a new measurement



- Shift both cursors to advantageous frequencies and read the values

$$\Delta\Phi = -3.20 \text{ rad}$$
$$\Delta f = 1.0\ MHz$$

	Frequency	Trace 1	
Cursor 1	9,000 MHz		1,73 rad
Cursor 2	10,000 MHz		-1,46 rad
delta C2-C1	1,000 MHz		-3,20 rad

- Calculate the length

$$l = -\frac{3 \cdot 10^8 \frac{m}{s}}{\sqrt{2.3} \cdot 2\pi} \cdot \frac{-3.20rad}{1\ MHz} \cdot \frac{1}{2} = 50.4\ m$$

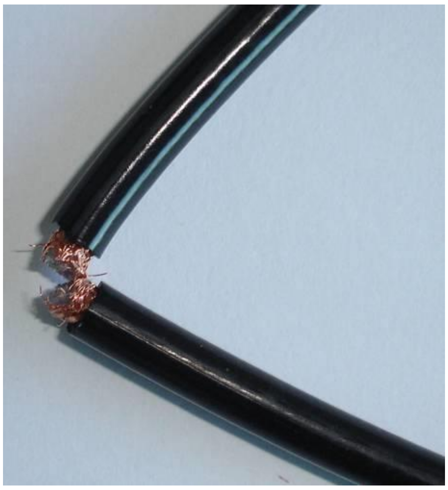
Result: The calculated location of the cable break is at 50.4 meters. Again using our pocket ruler we measured a cable length of ~50.8 meters between Bode and the cable failure. There is only a minimal deviation (0.8%) between the calculated failure location and the real failure location. Small deviations can be caused by influences like the BNC connector.

Answer to question 4.):

The Bode 100 is able to measure the values needed to calculate the location of a cable short or a cut in coaxial cables.

3.3.3 Location of a broken inner conductor

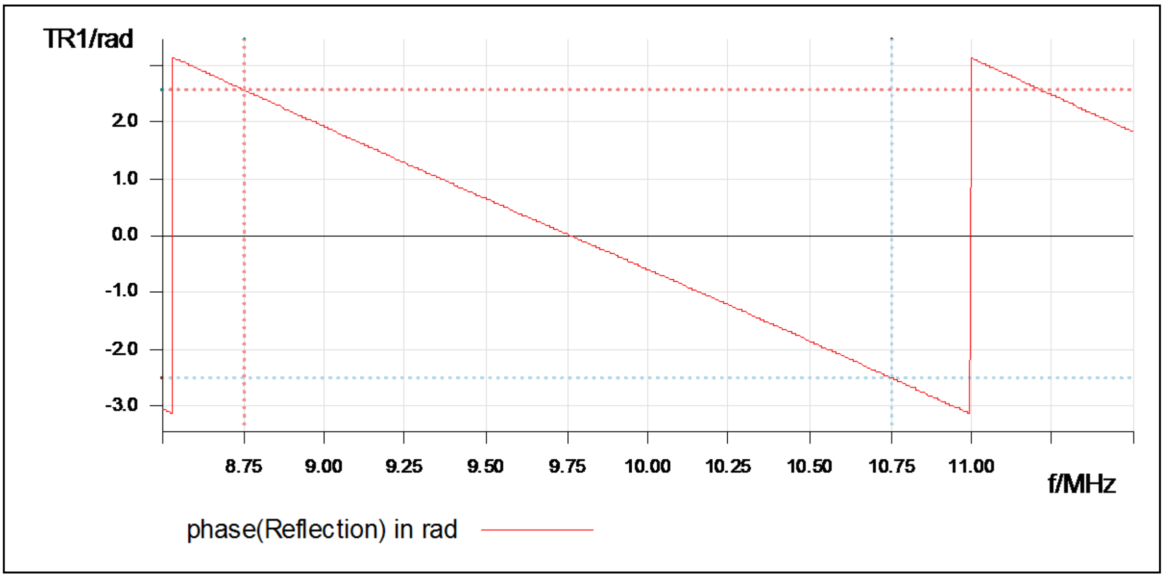
Sometimes it happens that only the inner conductor breaks, while the shielding remains intact (e.g. the cable was exposed to constant movement)



Such failures are very difficult to locate by optical inspections since the outside of the cable might be fully intact.

Cut the inner conductor at a random position, while leaving at least a part of the shielding intact to simulate this kind of cable break. As always connect the other end of the cable to Bode's source output.

- Use the same adjustments as before
- Optimize the range for advantageous frequencies



- The new values: $\Delta\Phi = -5.07 \text{ rad}$
  $\Delta f = 2.0 \text{ MHz}$

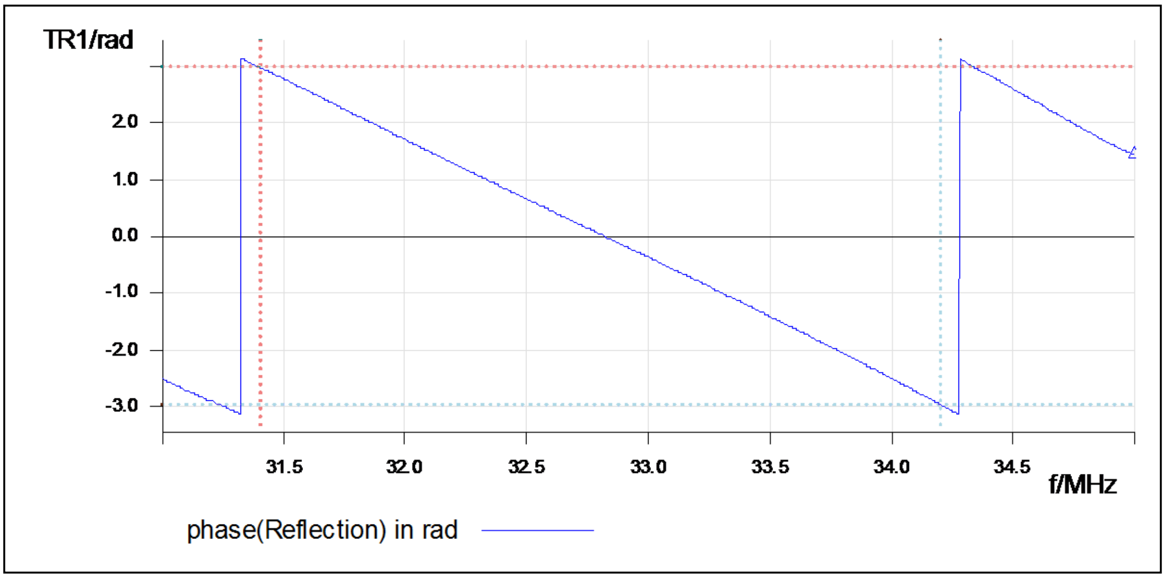
$$l = -\frac{3 \cdot 10^8 \frac{m}{s}}{\sqrt{2.3} \cdot 2\pi} \cdot \frac{-5.07}{2\ MHz} \cdot \frac{1}{2} = 39.9\ m$$

Result: The calculated position of the cable break is at 39.9 meters. The cable length measured with a pocket ruler resulted ~40.1 meters. The measured value equals the expected.

3.3.4 Location of a broken cable screen

Now simulate a screen break. A possible buildup is shown in the picture beside.

The measurement method is the same as before.



- Calculate the cable length ($\Delta\Phi$ = -5.94 rad and Δf = 2.80 MHz)

Result: The calculated position of the cable break is at 33.4 meters. The cable length by measuring with a pocket rule abandoned ~29.7 meters. The measured value differs from the expected.

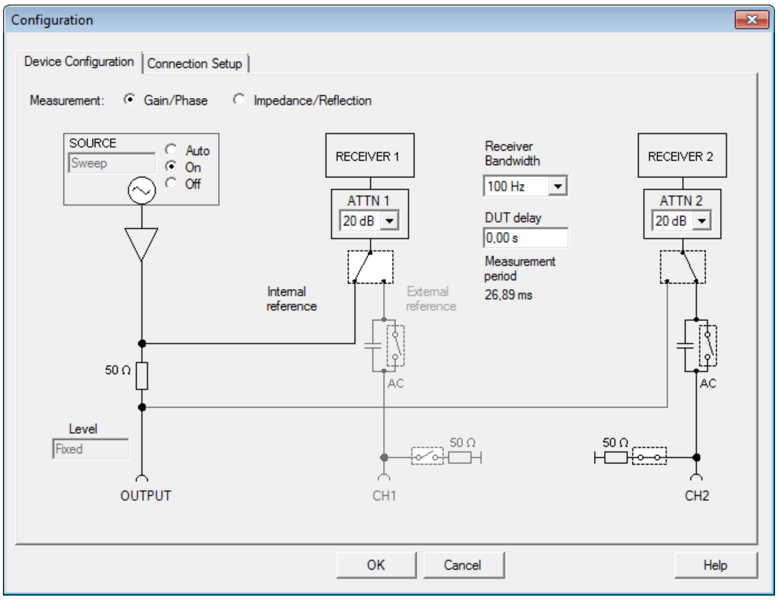
Answer to question 5.):

Yes, there is a difference between a complete cut and a broken screen because of the screen's capacitive character. A broken inner conductor can be measured without problems, while an accurate detection of a shielding break is not possible with the used measurement method.

3.4 Interference measurements

When cables are positioned close to each other they influence each other. The next measurement setup is used to determine the cable's screening quality. You will require two cables of the same kind which are positioned closely together in parallel. For our measurements we used two cables with a length of 18 m each.

- Apply the following settings in the frequency sweep mode:
  - f(min) = 10Hz
  - f(max) = 40 MHz
  - Reference internal
  - Attn Ch1 & Ch2: 20dB
  - Receiver Bandwidth: 100 Hz
  - DUT delay 0s
  - Level: +13dBm
  - Sweep Mode: Linear
  - Number of points: 201 or more
  - 50 Ω for CH2

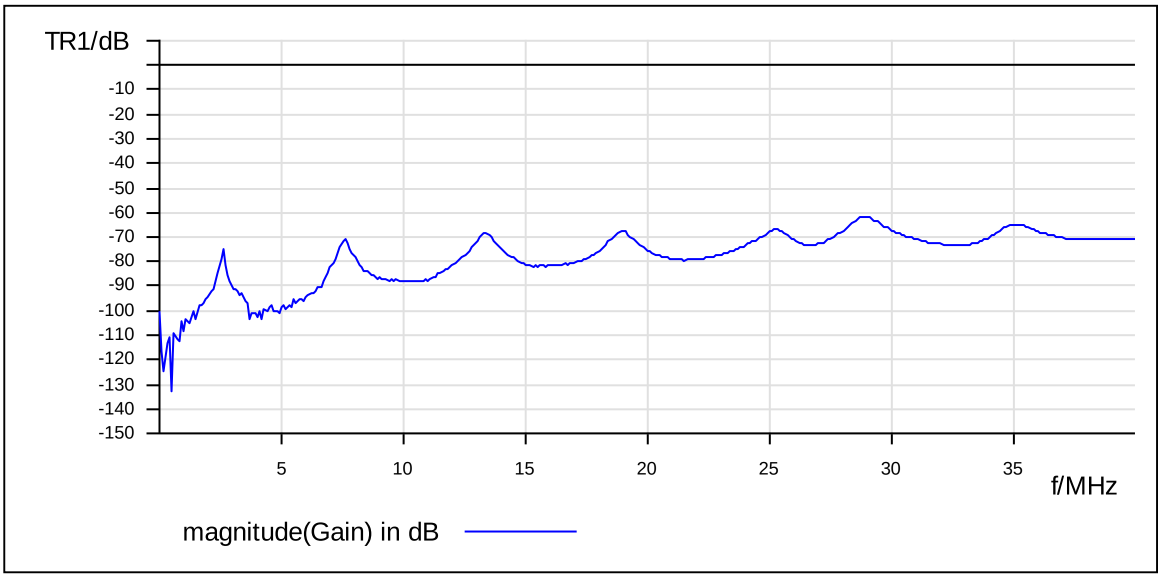


- The left cable, connected to Bode's source output, is sending the disturbing signal and the right cable, connected to CH2, is our DUT receiving the disturbing signal

- To ensure stable measurement conditions please connect a 50 Ohms load to the far end of both cables

- Bring both cables together as close as possible and fix them in position for example by using adhesive tape.

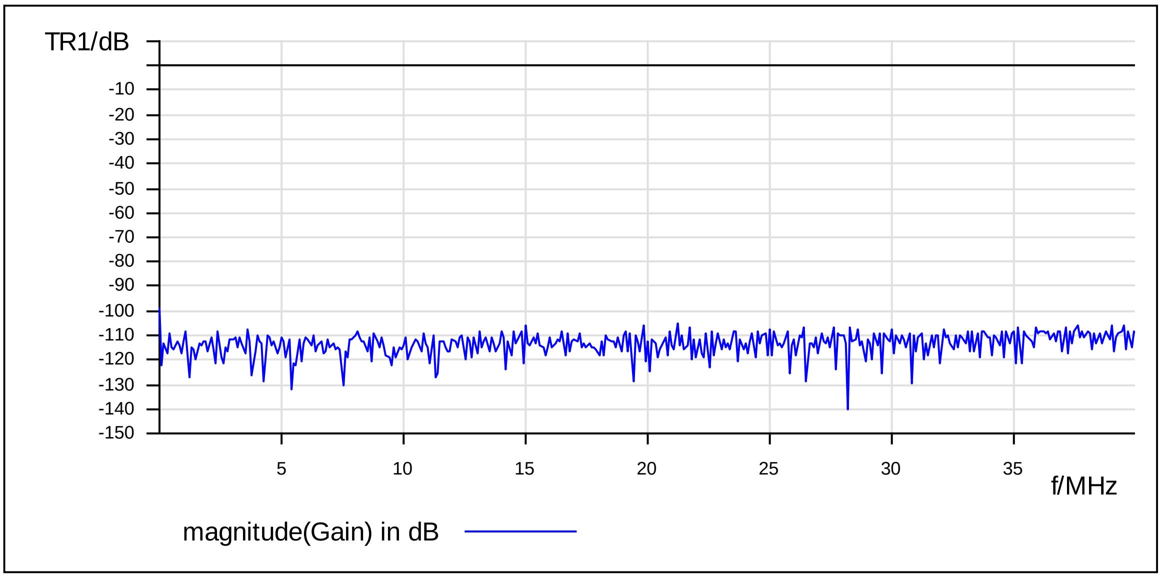
- Initiate a new frequency sweep



- The curve shows the signal injected to our DUT (cable two). As you can see the screening is able to completely block the RF signal injected from cable one.

For our first measurement setup we did use a cable with just one shield. The signal attenuation between the two cables is between -70 dB and -60 dB depending on the frequency.

In a second experiment we used the same measurement setup with two double shielded cables (same length 18m).



- As you can see in the chart above the isolation between the double shielded cables is much better (attenuation > 100dB)

Answer to question 6.):
The above measurements demonstrate that the electrical shielding quality of cables can be easily assessed with the Bode 100. It strongly depends on the intended application to decide if a single shielded cable is sufficient or if a double shielded cable has to be used.

4 Conclusions

In this application note it has been shown how a coaxial cable's electrical characteristics like impedance, shielding quality and dielectric constant can be verified with the Bode 100.

We were able to detect and locate a cable break as well as a cable shorting by length calculation. We also established that a broken screen has additional capacitive influences on our measurement and that causes deviations in the result. Finally the cable shielding quality of a single shielded and double shielded cable was compared.

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