Cable Analysis and Fault Detection with Bode 100

by Stephan Synkule

Visit www.omicron-lab.com for more information.
Contact support@omicron-lab.com for technical support.

Table of Contents

1 Executive Summary

This application note explains how to measure various electrical parameters of coaxial cables with Bode 100. Besides the measurement of typical cable characteristics like attenuation or shielding quality also the detection of cable faults such as short circuits or a cable break are 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 Bode 100 for such measurements.

By analyzing coaxial cables the following questions are answered:

1.) What attenuation does my cable have?

2.) Is it possible to measure its dielectric constant?

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 out the location of a short circuit or a cable break?

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

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

Note: Basic procedures like setting-up, adjusting and calibrating Bode 100 are described in the operational manual of Bode 100. Therefore these procedures are not outlined in detail in this application note.

3 Measurement Setup & Results

3.1 Required data and equipment

To execute the measurements outlined in this application note you require

- your Vector Network Analyzer Bode 100
- 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 cable we have chosen while writing this application note we got the following information

Coaxial cable:		
Cable impedance:		50 Ω
Inner Conductor:	tinned copper	0.49 mm²
Insulation:	polyethylene	2.9 mm diameter
Overall shield:	bare copper braid	0.10 mm, coverage >90%
Dielectric const.:		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 it is of advantage to be aware of the following physical constants:

$C_0 = 2.997\,924\,58 \cdot 10^8$ m/s $\approx 3 \cdot 10^8$ m/s speed of light (in the vacuum)

$\pi \approx 3.14159$ Archimedes' number

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

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

3.2 Verification of the electrical cable characteristics

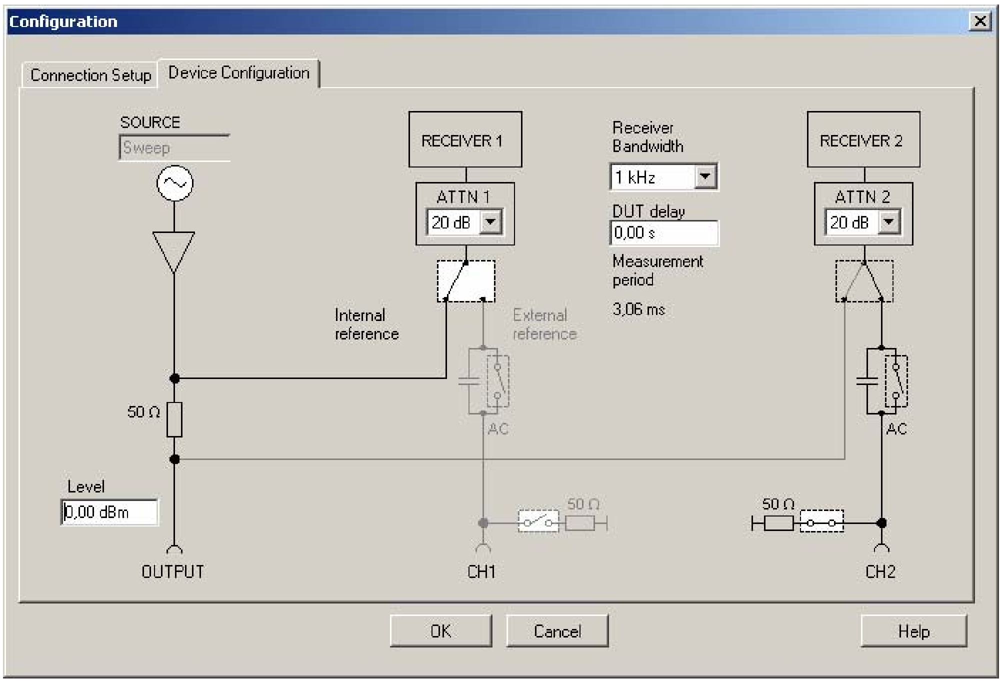
In this section we will measure the following electrical parameters of the cable:

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

3.2.1 Cable attenuation

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

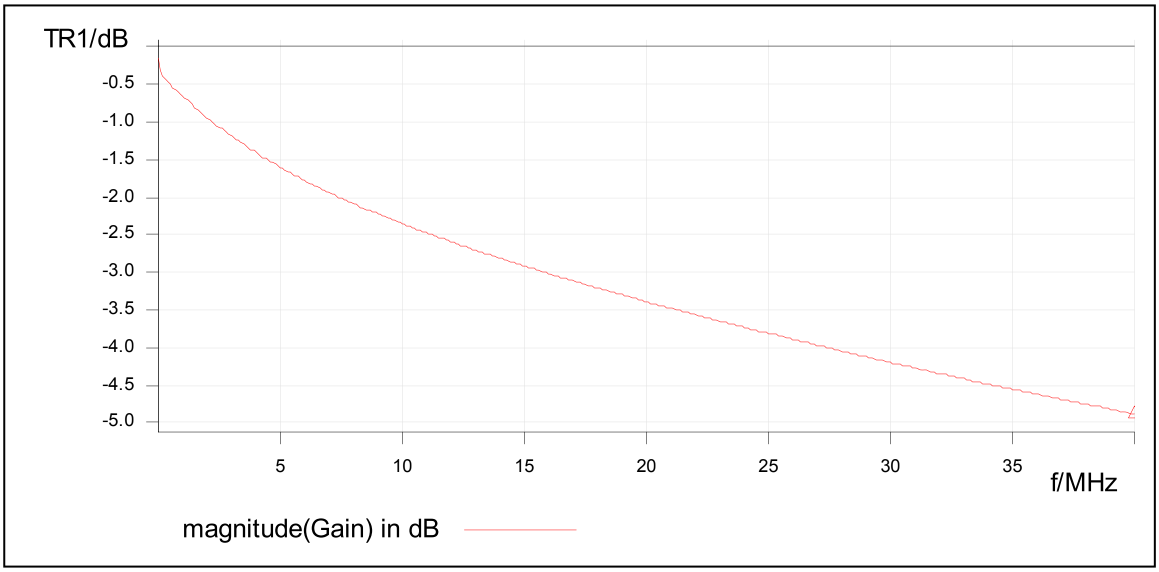
- Apply the following settings in the frequency sweep mode:
    - f(min): 10 Hz
    - f(max): 40 MHz
    - Reference: internal
    - Attn 1&2: 20 dB
    - Receiver Bandwidth: 1 kHz
    - DUT delay: 0 s
    - Number of points: 201 or more
    - Input Impedance CH2: 50 Ohms



- If the cable is connected directly to Bode 100 no further calibration is necessary before the measurement due to the internal calibration executed by Bode 100 during start up.

- Activate Trace 1 and select the format: Gain, 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.



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

frequency	max. attenuation for cable length 50m (from data sheet)	measured attenuation cable length = 50m
1.000 MHz	0.9 dB	0.66 dB
20.000 MHz	4.0 dB	3.39 dB

3.2.2 Dielectric constant

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

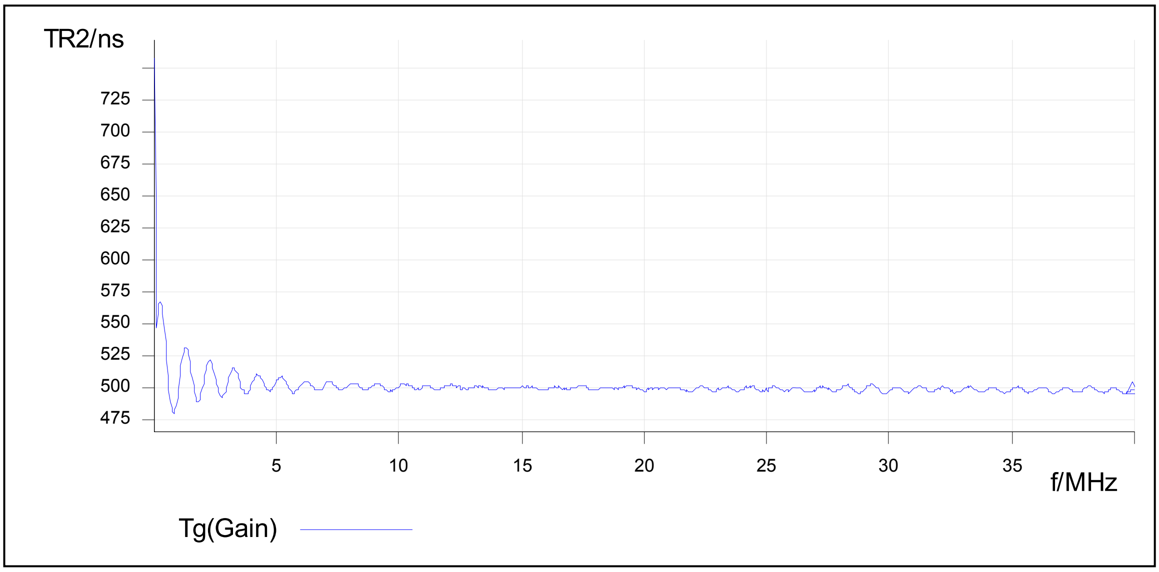
$$\varepsilon_r = \left(\frac{c_0 \cdot t_g}{l}\right)^2$$

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 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 for Trace 1

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

$$\varepsilon_r = \left(\frac{c_0 \cdot 500\text{ns}}{100\text{m}}\right)^2 = 2.25\ \ (\sim 2.3)$$

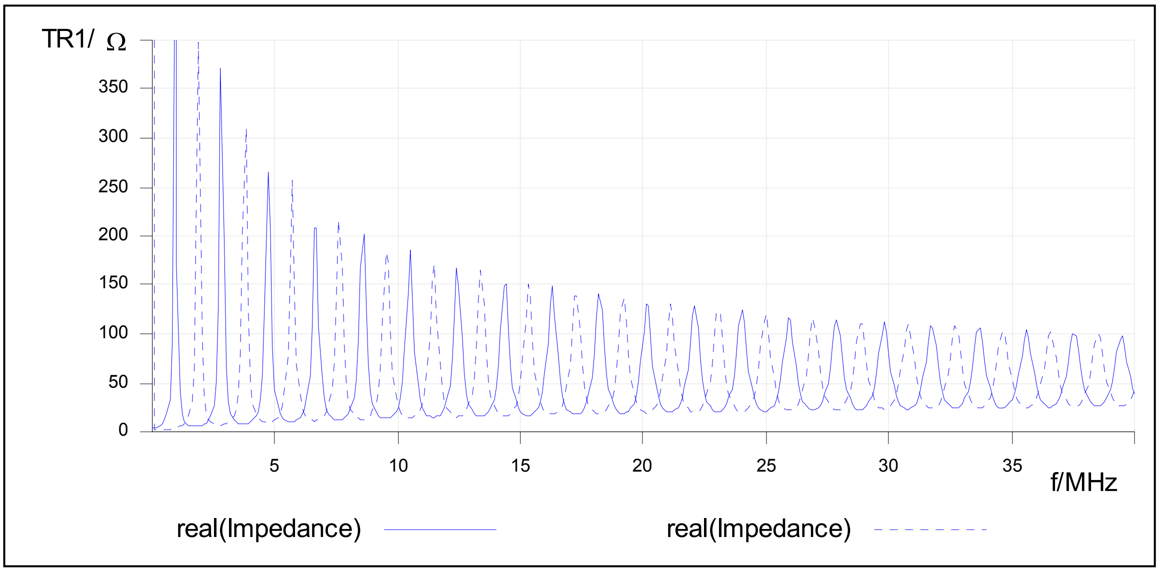
Answer to question 2.):
The measured dielectric constant of the used cable is 2.25. Small deviations from the data sheet value can result from the measured group delay ripple.

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.

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

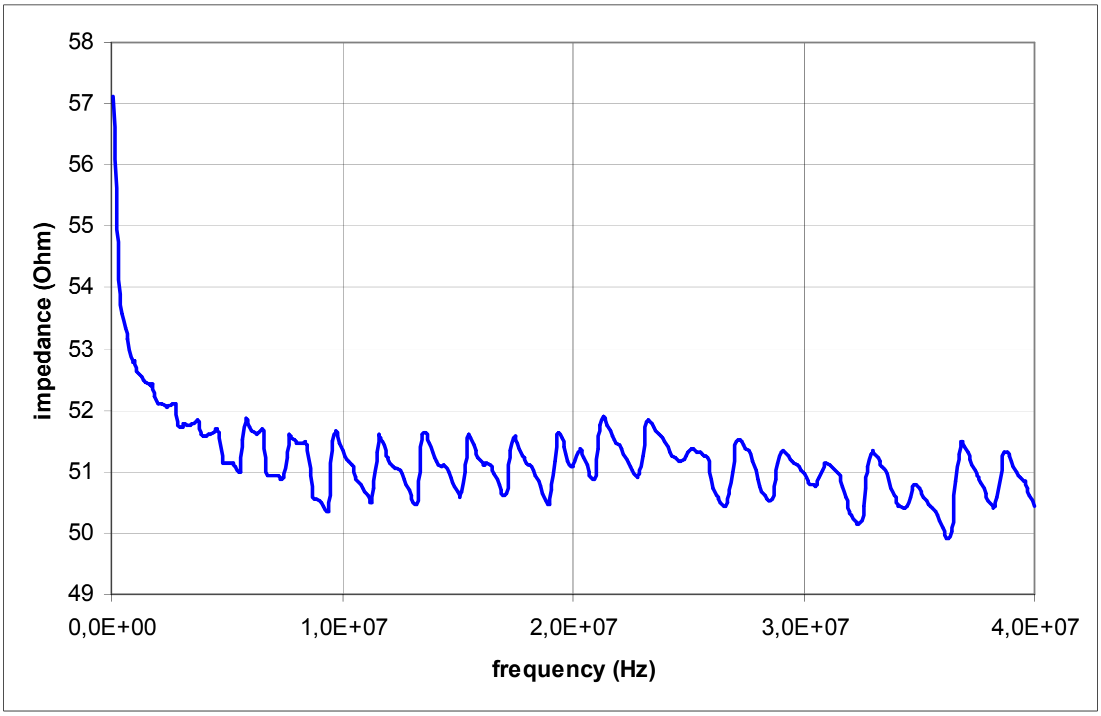
- Use the same settings for the frequency sweep mode as before.
- Perform an impedance calibration for open, short, load and set the number of points to ≥401.
- Connect one end of the cable to Bode output and leave the other end open.
- Change adjustments for Trace 1 to
  Measurement: Impedance
  Format: 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 on page 73 – 75. 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:



- Now use the formula below to calculate the cable impedance with the exported values in your spreadsheet program:

$$\underline{Z} = \sqrt{\sqrt{\mathrm{Re}\{\underline{A}\}^2 + \mathrm{Im}\{\underline{A}\}^2} \cdot \sqrt{\mathrm{Re}\{\underline{B}\}^2 + \mathrm{Im}\{\underline{B}\}^2}}$$

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

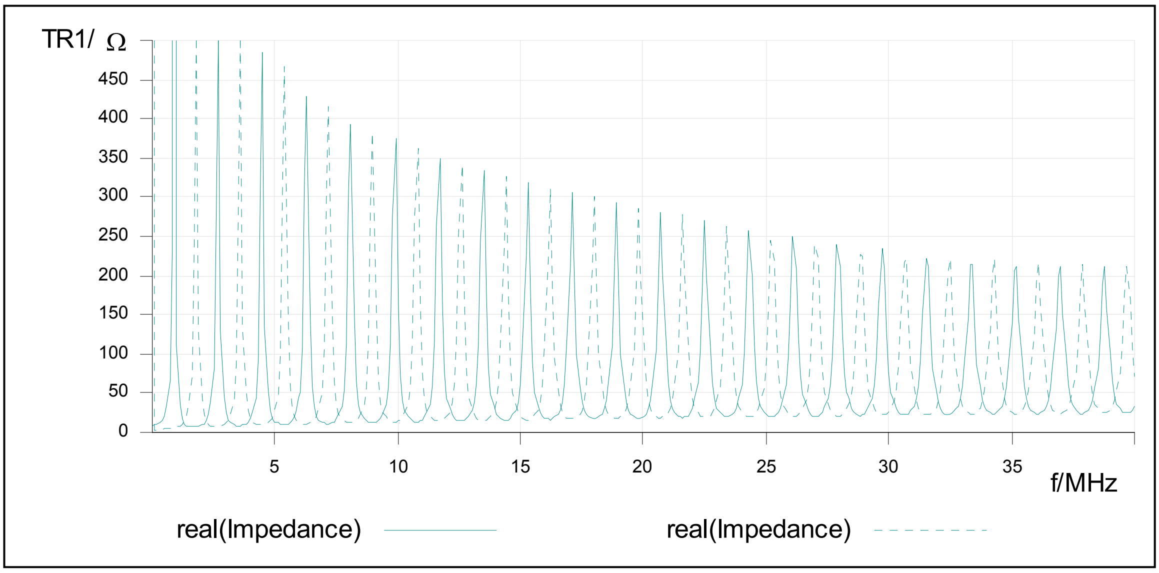


Answer to question 3.):
The behavior of the cable impedance is shown at the frequency response curve. As the diagram shows Bode 100 can be used to measure the cable's wave impedance.

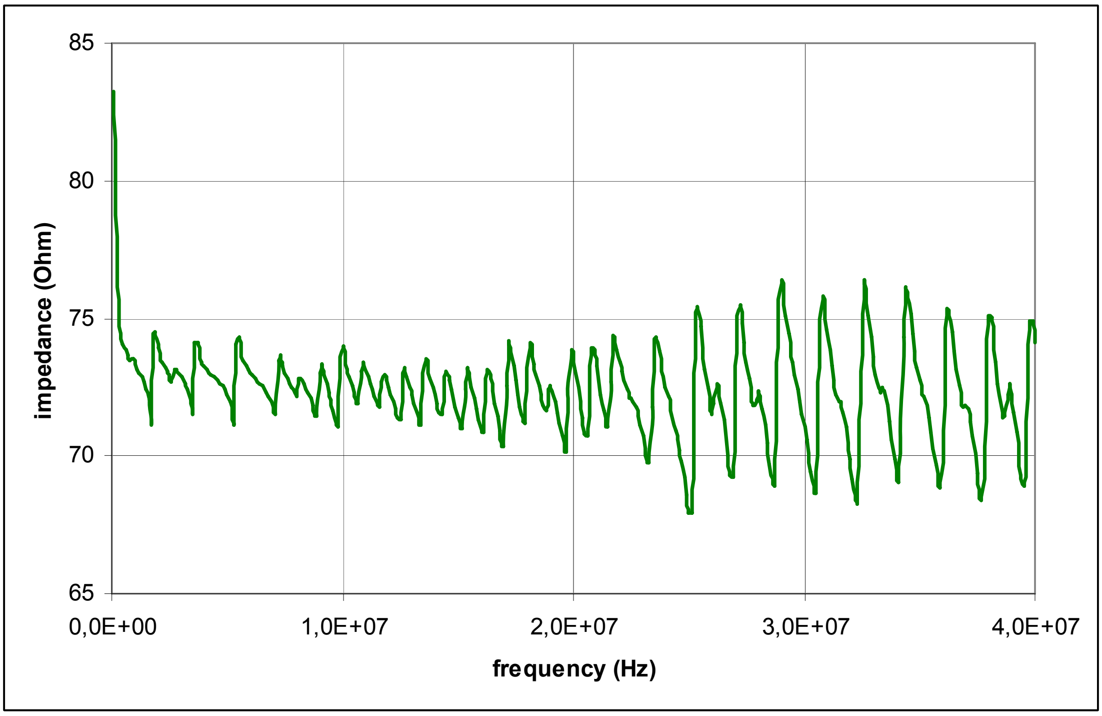
Note: To reach accurate impedance results it is very important to use cables with a minimum length of 50m, preferably longer cables should be used.

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.

- You should get a similar chart of Bode 100



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



Note: You can also calculate the cable's capacitance or inductance by using the exported values and the following formulas:

$$C_p = \frac{|\mathrm{Im}\{\underline{Y}\}|}{\omega} \quad \text{and} \quad L_p = \frac{1}{\omega \cdot |\mathrm{Im}\{\underline{Y}\}|}$$

3.3 Detecting short circuits and cable breaks

If any incident results in shorts or breaks of a long cable it is necessary to locate the position of the cable failure before a repair can take place. 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 the cable failure.

Formula for the cable's length:

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

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. $\partial\Phi/\partial f$ has to be measured.

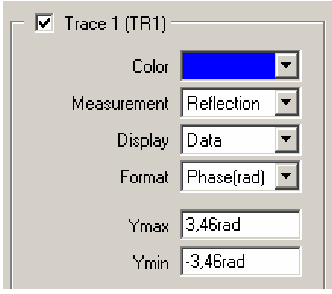
The factor $\frac{1}{2}$ compensates the way back for the reflected signal.

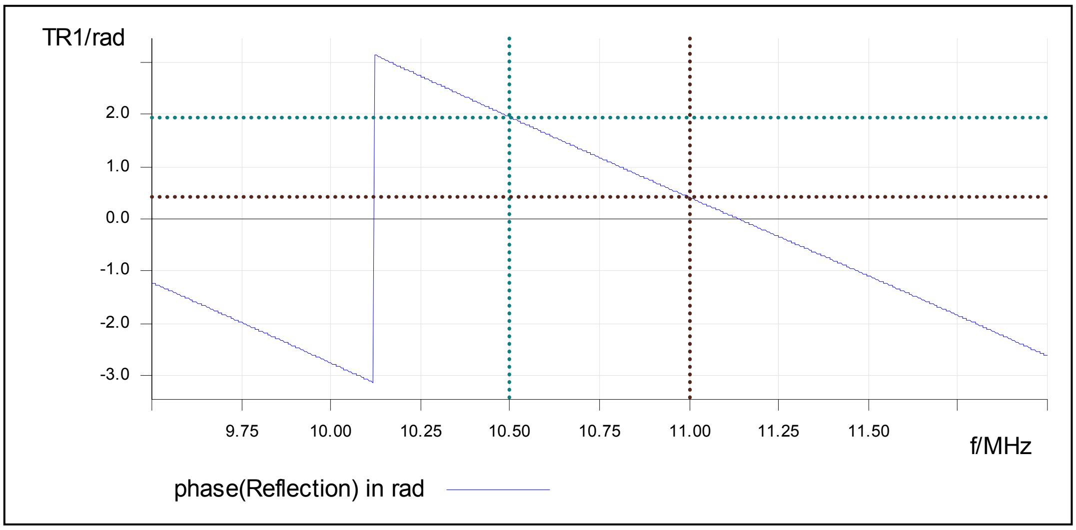
Note: Short circuits and cable breaks are measured and calculated the same way.

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 and of the cable we connected to 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. Further more 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: $\Delta\Phi = -1.53$ rad and $\Delta f = 500$ 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.

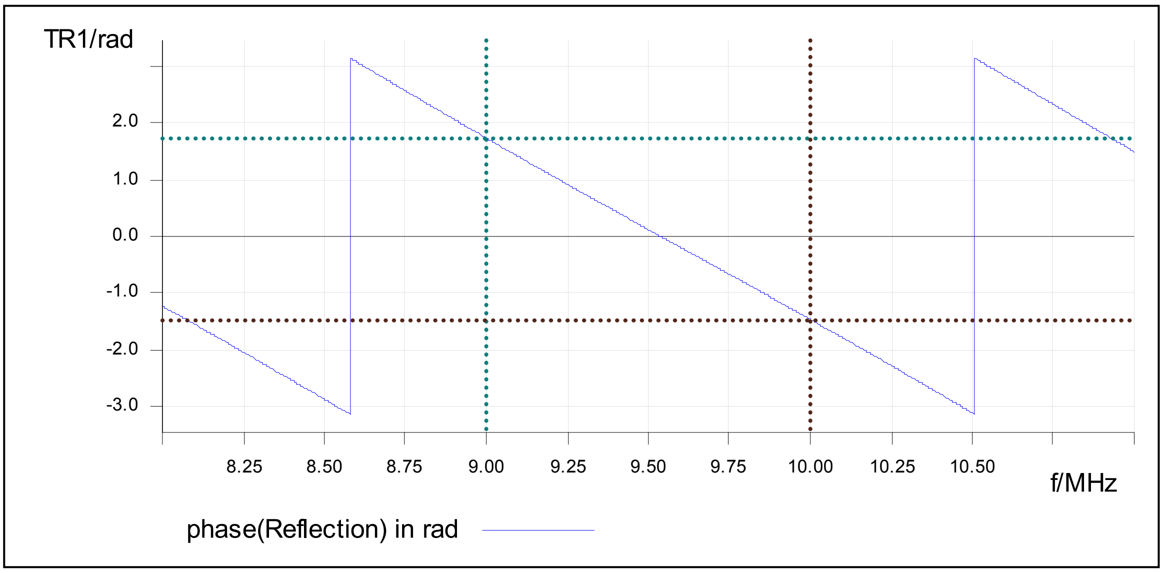
$$l = -\frac{3 \cdot 10^8 \frac{\mathrm{m}}{\mathrm{s}}}{\sqrt{2.3} \cdot 2\pi} \cdot \frac{-1.53}{500\mathrm{kHz}} \cdot \frac{1}{2} = 48.17\mathrm{m}$$

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

Result: The calculated location of the cable break is at 50.4 meters. Again using our pocket rule 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.):
Yes, Bode is able to measure the values needed to calculate the location of a cable shortage or a cut in coaxial cables.

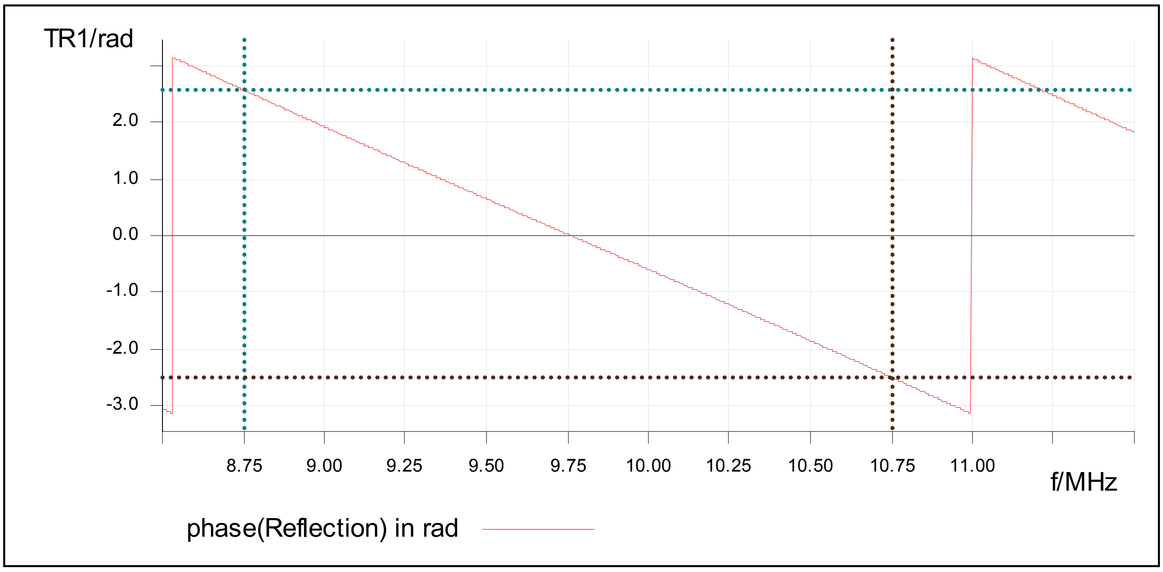
3.3.3 Location of a broken inner conductor

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 rad
  Δf = 2.0 MHz

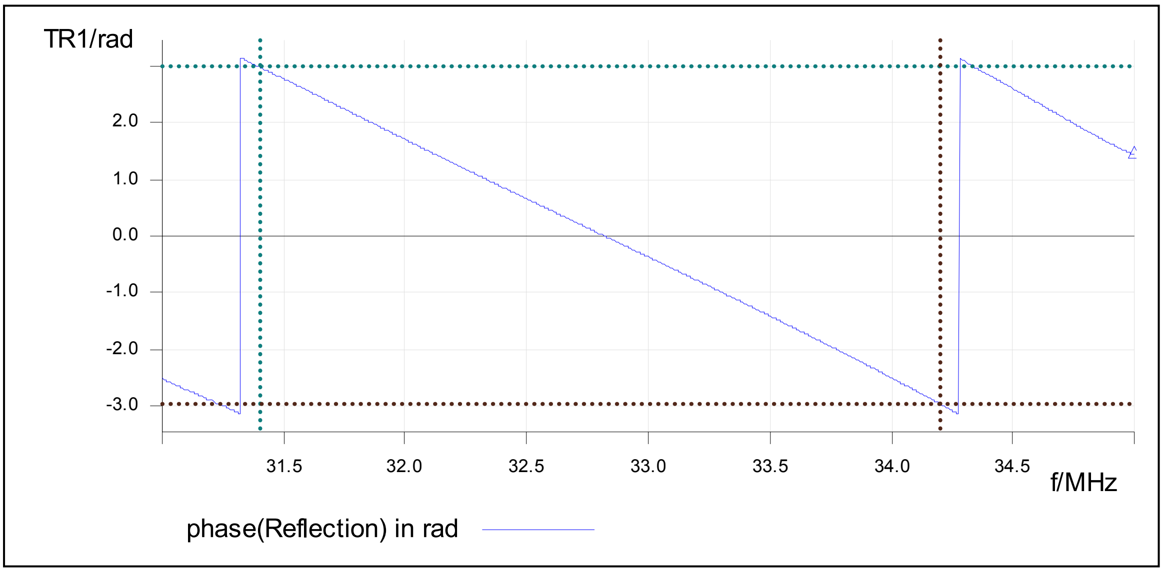
$$l = -\frac{3 \cdot 10^8 \frac{m}{s}}{\sqrt{2.3} \cdot 2\pi} \cdot \frac{-5.07\text{rad}}{2\text{MHz}} \cdot \frac{1}{2} = 39.9\text{m}$$

Result: The calculated position of the cable break is at 39.9 meters. The cable length measured with a pocket rule 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 (ΔΦ = -5.94 rad and Δf = 2.80 MHz)

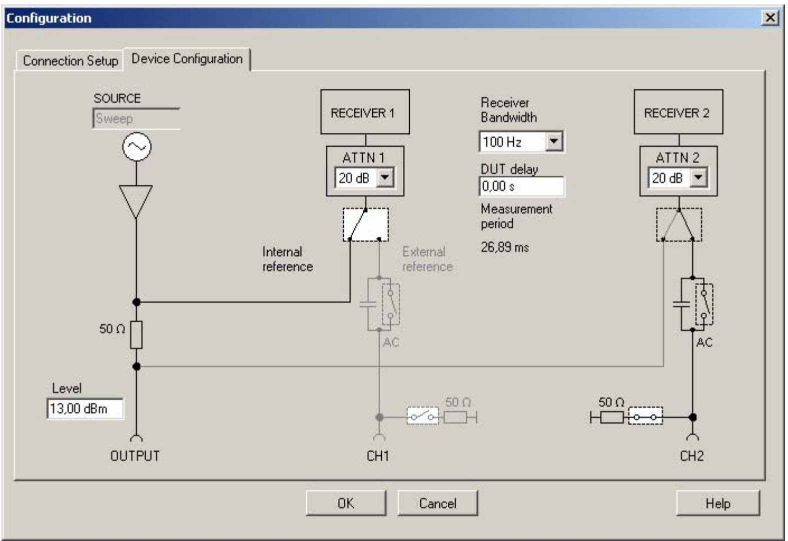
Result: The calculated position of the cable break is at 33.4 meters. The cable length by measuring with a pocket rule abandoned ~29.7 meters. The measured value differs from the expected.

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 another. 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.

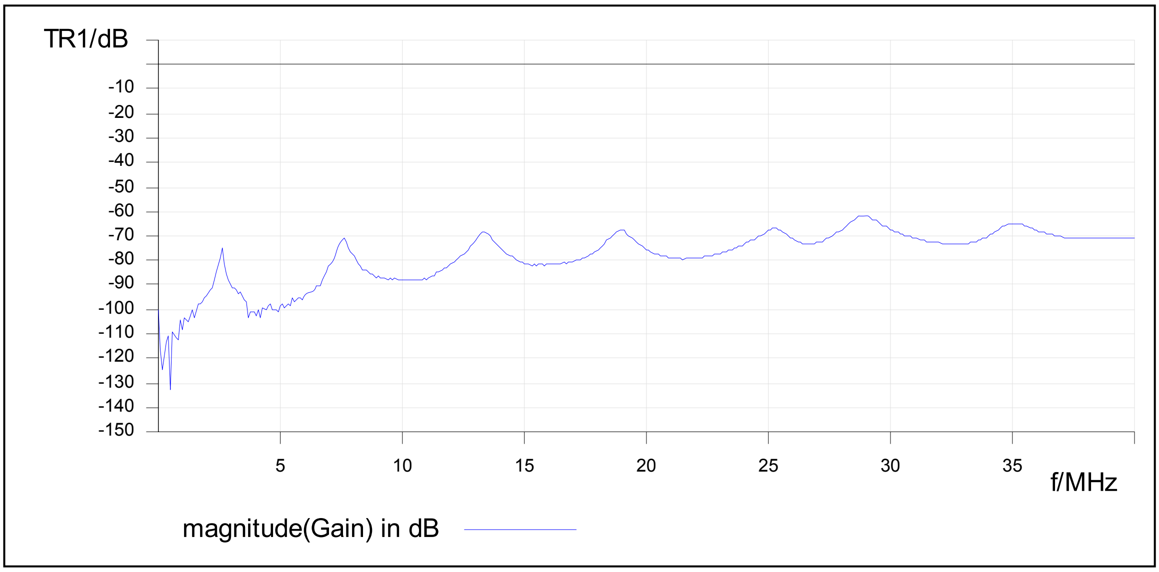
- Apply the following settings in the frequency sweep mode:
  - f(min) = 10Hz
  - f(max) = 40 MHz
  - Reference internal
  - Attn Ch1 & Ch2: 20dB
  - Receiver Bandwidth: 100 Hz
  - DUT delay 0s
  - Level: +13dBm
  - Sweep Mode: Linear
  - Number of points: 201 or more
  - 50 Ω for CH2



- 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

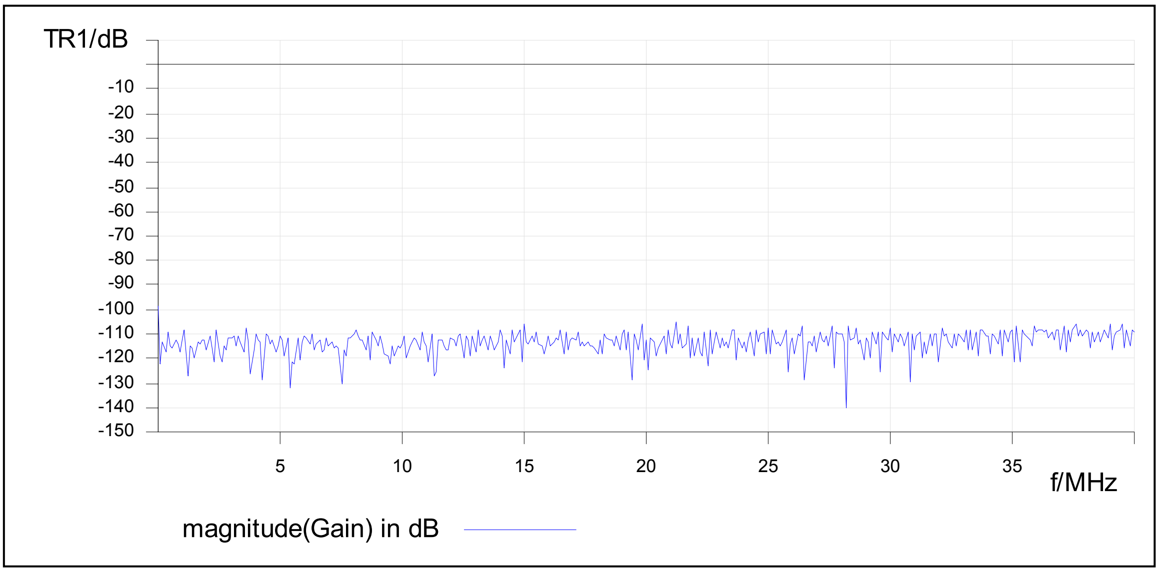
- Bring both cables together as close as possible and fix them in position for example by using adhesive tape.
- Initiate a new frequency sweep



- 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 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 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 to our measurement and that causes deviations in the result.

Finally the cable shielding quality of a single shielded and double shielded cable was compared.