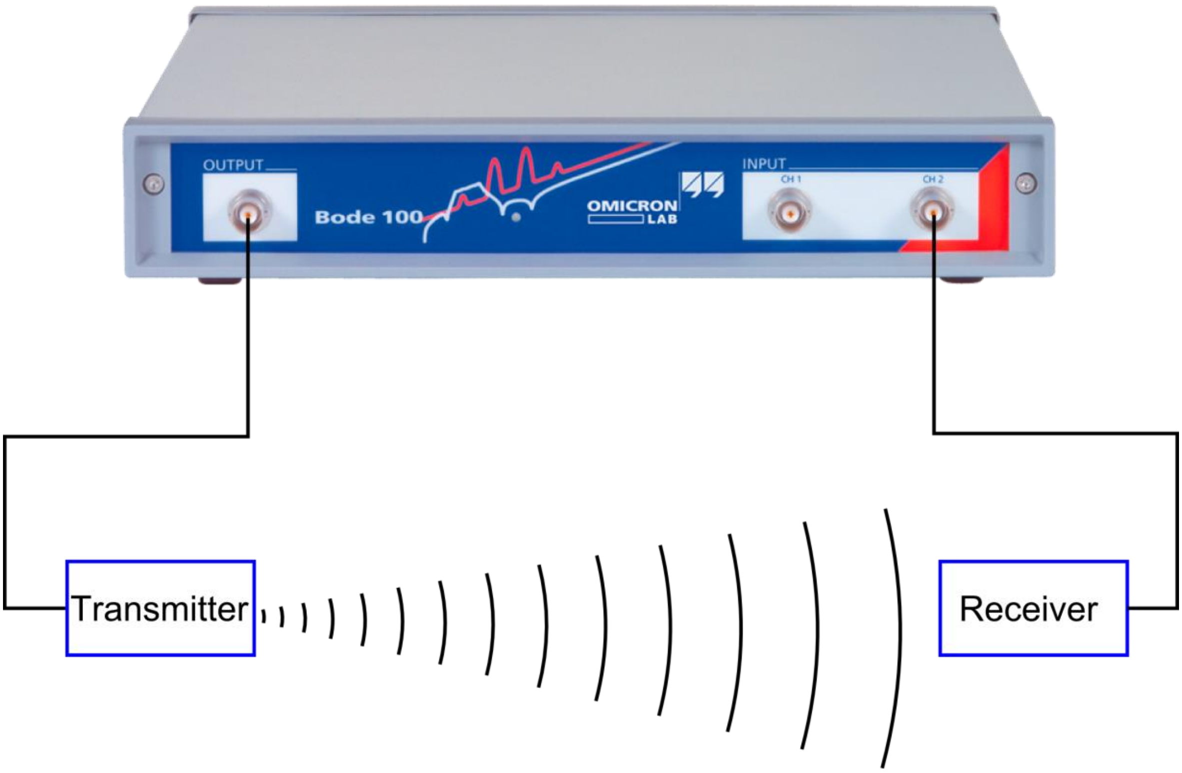
Bode 100 - Application Note

Radio Transmission Analysis using the Bode 100



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

Table of Contents

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 V3.0. 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 analyze **radio links** and **antennas** in their environment with the Bode 100. For wireless data transmissions it is necessary to get the best transfer attributes and the highest power efficiency. Therefore **impedance matching** is required.
The **operating range** of a wireless system is an important aspect which can be evaluated using the Bode 100.

2 Measurement Tasks

The Bode 100 provides a frequency range from 1 Hz up to 50 MHz. Especially for LF to HF applications like inductive coupled RFID (**R**adio **F**requency **ID**entification) systems the Bode 100 can be used very efficiently. Based on the following measurements on a demo application (a 27 MHz antenna) the following topics are considered:

1. Adjustment of the antenna for optimum performance
2. Assessment of the operating range of the wireless system

3 Measurement Setup & Results

3.1 Used Equipment

The following equipment was used to perform the measurements described in this application note.

Vector Network Analyzer Bode 100 (including measurement accessories)
Two RF-antennas (transmitter and receiver)
Two matching-networks
BNC-Cables (1 m, m - m, 50 Ω)

3.1.1 Datasheet of the Antenna TCA51B

Manufacturer:	Tricom
Center frequency:	27 MHz
Bandwidth:	400 kHz
Operating temp. range:	-20 °C to 70 °C
Weight:	1.2 g

Figure 1: Antenna TCA51B

3.2 Antenna Adjustments

3.2.1 Antenna Measurement

First we did mount the antenna on a test board. Then we measured the reflection coefficient of the antenna without a matching network using the Bode 100.

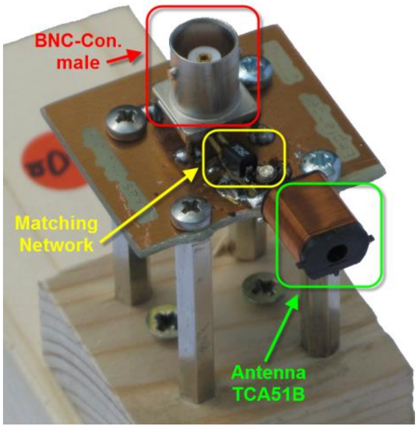


Figure 2: Antenna setup

To perform this measurement please set the Bode 100 as follows.
Select the "Transmission / Reflection" mode

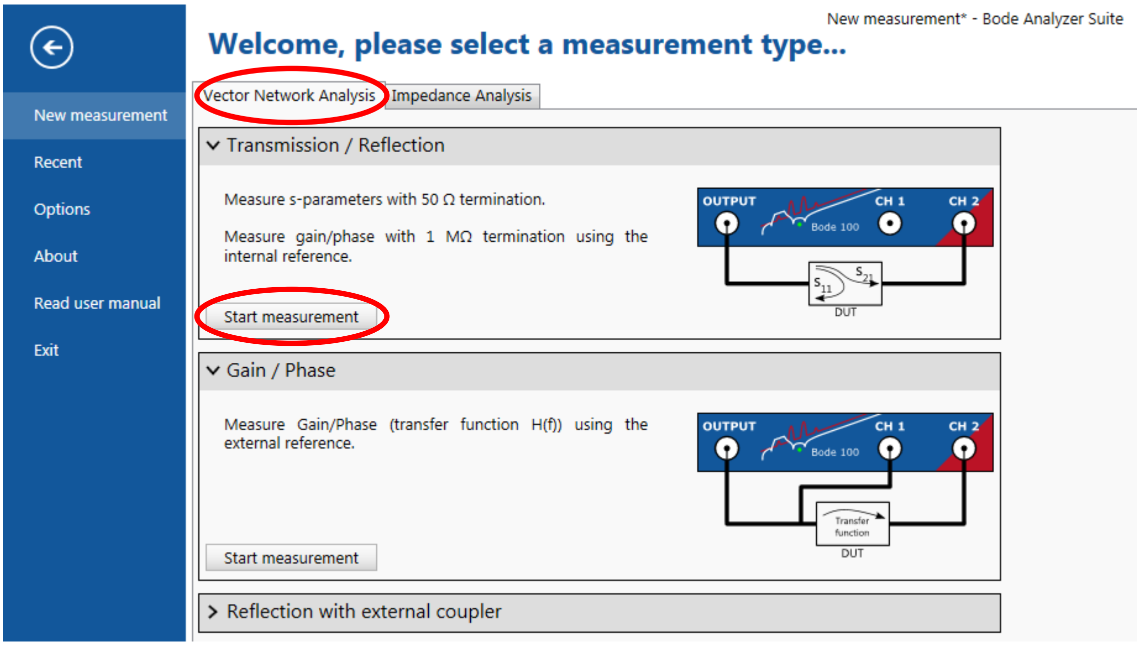


Figure 3: Start window - Bode Analyzer Suite

To measure the transmission/reflection of your antenna please select Measurement and Smith as shown below

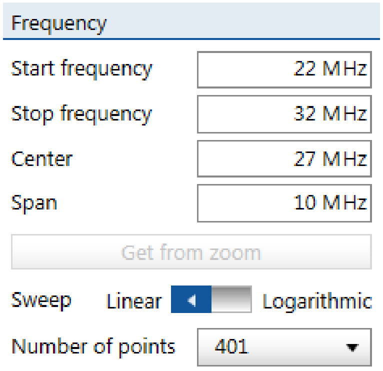


Figure 4: Sweep settings

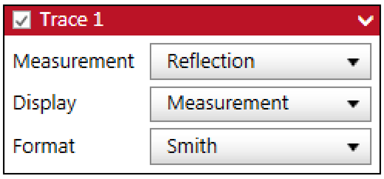


Figure 5: Trace settings

Note: In our application a 27 MHz antenna is used. Therefore the center frequency is set to 27 MHz. If your application has a different operating frequency range you will have to set the frequency range of the measurement based on your system's center frequency.

To ensure precise measurement results and to remove the influence of the cable on the measurement results, calibrate the Bode 100 using the Open/Short/Load calibration function as described in the Bode 100 user manual.

The next step is to connect the antenna to the Bode 100. In the following two pictures you can see the antenna is connected to the Bode 100.

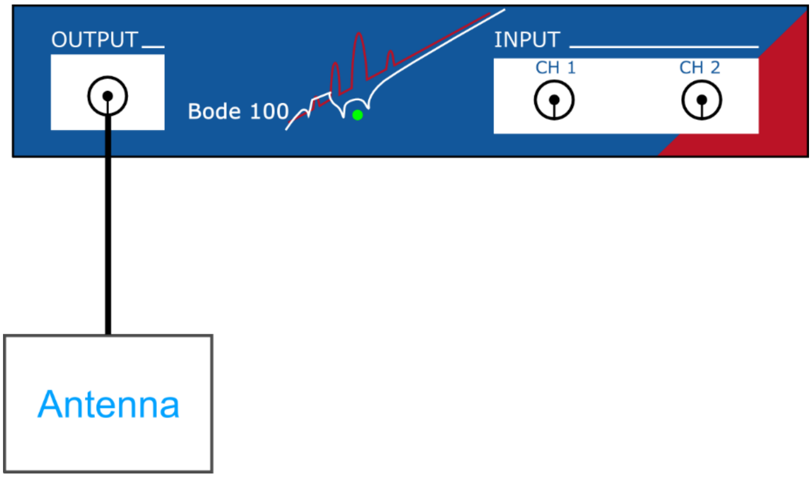


Figure 6: Measurement setup - Image

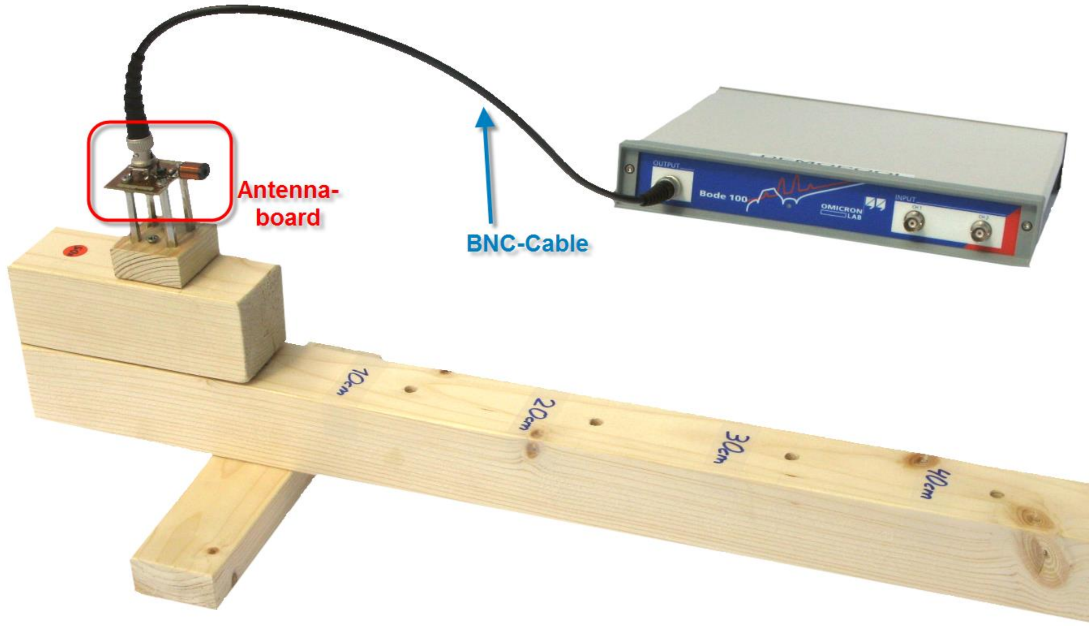


Figure 7: Measurement setup

Now press the "Single Measurement" Button to start a measurement.

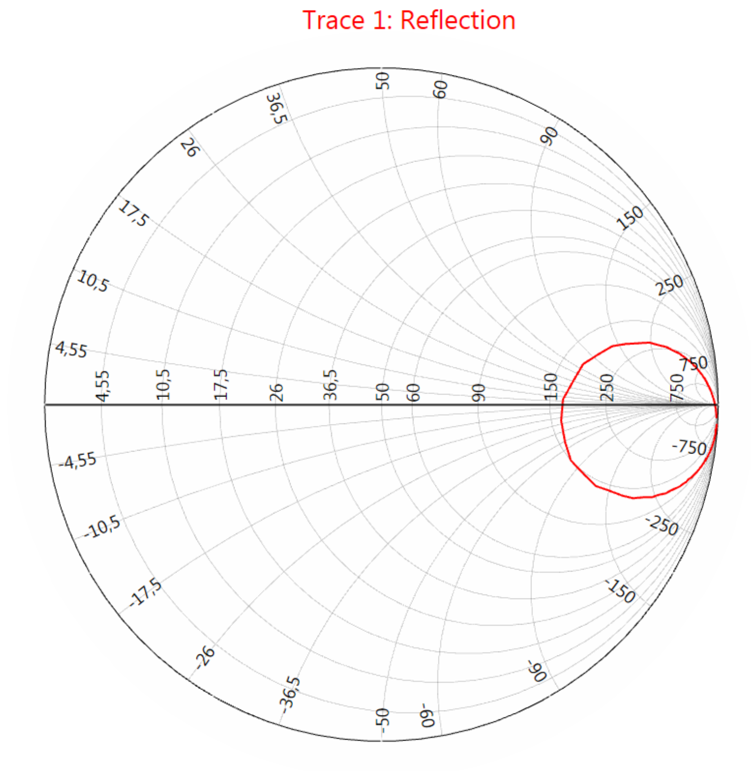


Figure 8: Reflection of the antenna

With this measurement result it is possible to calculate the matching network. The following section contains some basic theory about the matching networks.

3.2.2 Impedance Matching

To transfer the maximum power from a source (e.g. the Bode 100 output) to a sink (e.g. the antenna or a resistor), it is necessary to achieve impedance matching. This means that the impedance of the source Z_0 and the sink Z_A have to be equal.

Matching condition:

$$Z_0 = Z_A \tag{1}$$

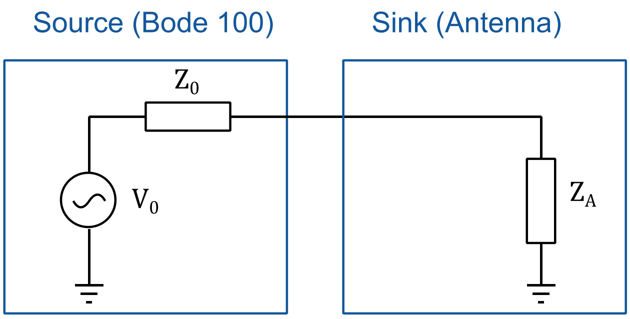


Figure 9: Network without a matching network

The reflection coefficient r is an indicator of how well the source and sink impedances are matched.

$$r = \frac{Z_A - Z_0}{Z_A + Z_0} \tag{2}$$

If the two impedances are equal, meaning the system is perfectly matched, the reflection coefficient equals zero.

The Bode 100 can measure the reflection coefficient and also the impedance of the sink. With the Smith-Chart you can display the reflection coefficient of your antenna in a frequency range between 1 Hz and 50 MHz.

3.2.3 Calculation of the Matching Network

In our application a 27 MHz antenna is used. As you can see from the measurements in the beginning, the antenna is not matched to the impedance of the Bode 100 (50 Ω). It is therefore necessary to transform the impedance of the antenna to equal 50 Ohm. In our application we used a serial inductance in combination with an adjustable parallel capacitance.

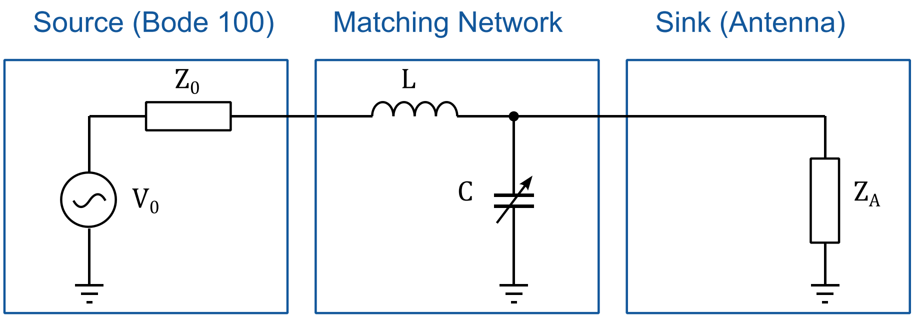


Figure 10: Network with a matching network

For the calculation of the matching network it is necessary to know the impedance of the antenna at the desired operating frequency. The measured impedance at 27 MHz is $Z_A = 44.5\ \Omega - \mathrm{j}\ 1046\ \Omega$. With two defined equations it is possible to calculate the needed inductance and capacitance. In the following the calculation is shown in detail:

Basic Definitions:

Measurement frequency	$f = 27\ \mathrm{MHz}$	**No table of figures entries found.**
Source impedance of the Bode 100	$Z_0 = 50\ \Omega$	
Impedance of the antenna (@ 27MHz)	$Z_A = R + jX$	(3)
Measured resistance of the antenna (@ 27MHz)	$R = 44.5\ \Omega$	
Measured reactance of the antenna (@ 27MHz)	$X = -1046\ \Omega$	
Reactance of the serial inductance	$X_L = 2\pi f L$	(4)
Reactance of the parallel capacitance	$X_C = -\frac{1}{2\pi f C}$	(5)

With the matching condition it is possible to calculate the needed inductance and capacitance. The input impedance has to equal the impedance of the Bode 100.

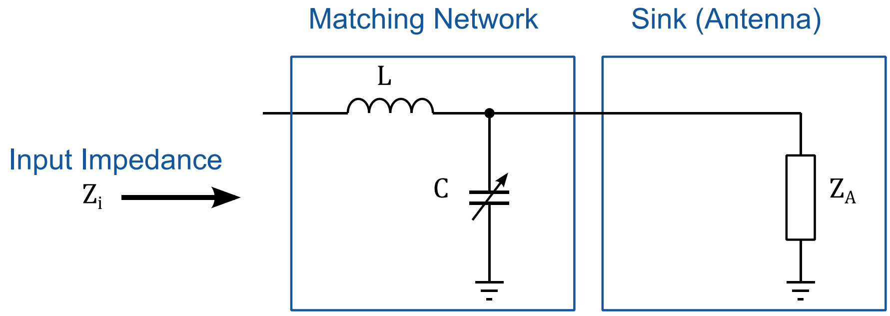


Figure 11: Network for measuring the Input Impedance

Matching condition $$Z_i = jX_L + Z_A \,//\, jX_C \qquad (6)$$

Impedance of the antenna $$Z_A = R + jX \qquad (7)$$

If we insert the impedance of the antenna into the matching condition, separate the real and imaginary part and solve the matching condition, we get two new equations.

Calculated reactance of the inductance $$X_L = Z_i\sqrt{\frac{R^2+X^2}{Z_iR}-1} \qquad (8)$$

Calculated reactance of the capacitance $$X_C = -\frac{R^2+X^2}{Z_i\sqrt{\frac{R^2+X^2}{Z_iR}-1}-X} \qquad (9)$$

Now we insert the measured impedance and calculate the needed inductance and capacitance of the matching network.

$$X_L = Z_i\sqrt{\frac{R^2+X^2}{Z_iR}-1} = 1108.6\ \Omega$$

$$X_C = -\frac{R^2+X^2}{Z_i\sqrt{\frac{R^2+X^2}{Z_iR}-1}-X} = -508.7\ \Omega$$

$$L = \frac{X_L}{2\pi f} = \frac{1108.6\ \Omega}{2\pi \cdot 27\ \mathrm{MHz}} = \underline{6.5\ \mu\mathrm{H}}$$

$$C = -\frac{1}{2\pi f X_C} = -\frac{1}{2\pi \cdot 27\ \mathrm{MHz} \cdot (-508.7\ \Omega)} = \underline{11.6\ \mathrm{pF}}$$

3.3 Matching Process

In the first step we put the parallel capacitance on the application board. We chose a trim capacitor with a range from 5 pF to 40 pF. So the theoretically calculated value can be adjusted as needed. In the second step we add a serial inductance. The calculated value is 6.53 µH. In our application we used a 2.2 µH inductance. We decided to choose this inductance because it had a better Q-factor than a bigger inductance. With a variation of the trim capacitance it is still possible to reach the 50 Ω matching point.

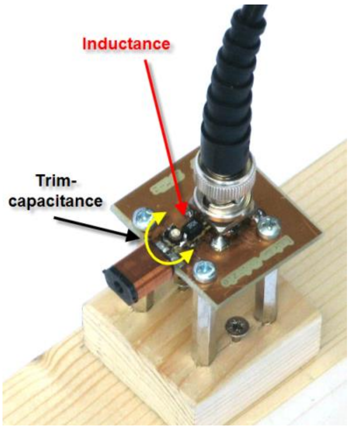


Figure 12: Setup of the antenna

Before the impedance matching:

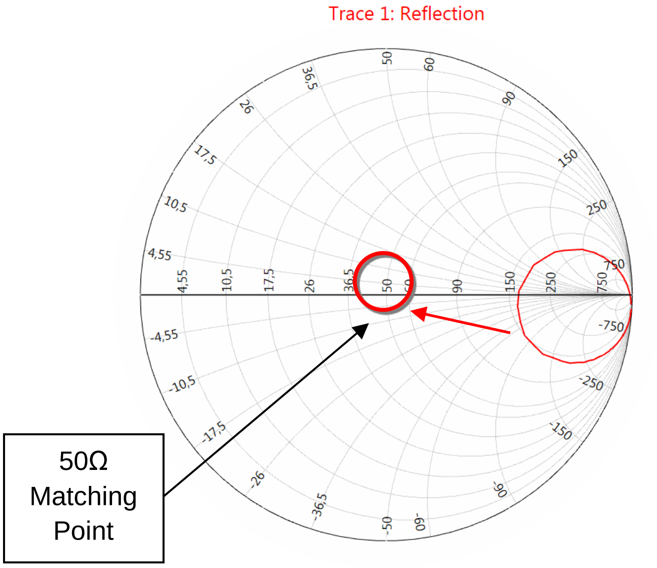


Figure 13: Impedance without matching network

After the impedance matching:

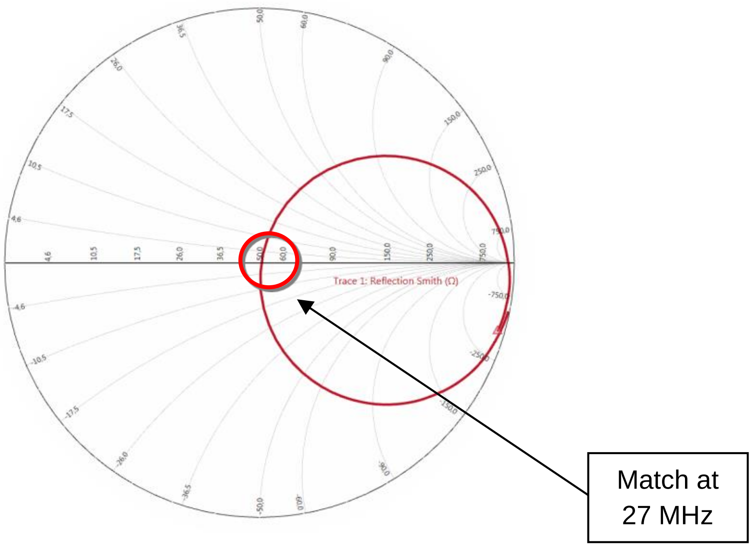


Figure 14: Impedance with matching network

3.4 Measurement of the Operating Range

For the successful operation of a wireless system it is very important to know its operating range. For our application note we created a pseudo system. With two matched antennas (50 Ω) we measured the attenuation of the system as shown in the picture below.

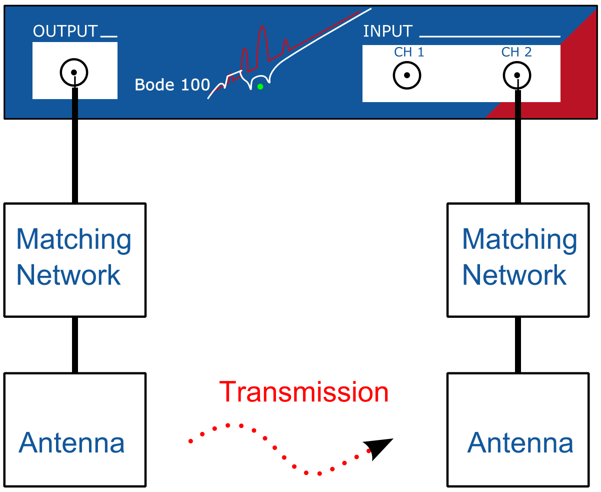


Figure 15: Picture of the following setup

Technical Data of the Radio Transmission Line

- Bode 100 output-power (transmitter): 0 dBm
- distance transmitter-receiver: 0.1 m, 0.2 m…0.6 m
- Antenna: TCA51B (transmitter and receiver, 50 Ω matched)

To measure the attenuation as a function of the distance between transmitter and receiver, it is necessary to configure the frequency sweep mode as shown in the pictures below:

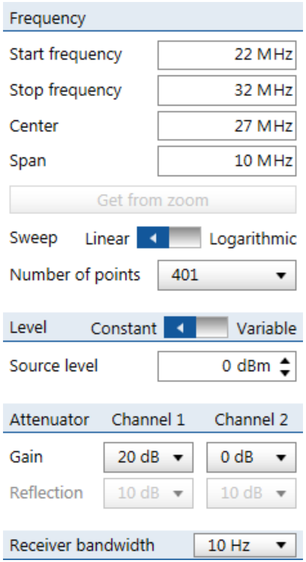


Figure 16: Settings for the measurement

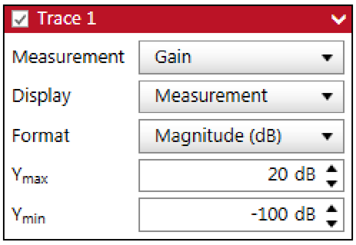


Figure 17: Settings for Trace 1

Now connect the two adjusted antenna boards to the Bode 100 as shown in the following figure. Because of the distance range (0.1 - 0.6 m) we used BNC-Cables (Type-RG58, 50 Ω) with a length of 1 m.

Note: Perform a THRU calibration to remove the influence of the cable before connecting the antennas.

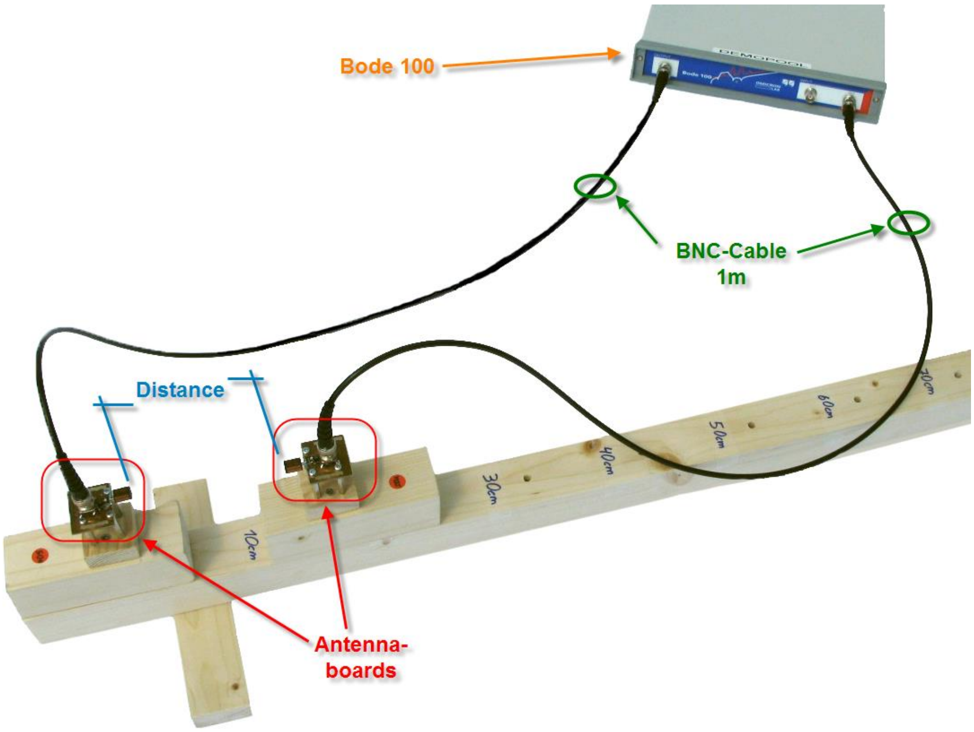
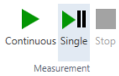


Figure 18: Measurement setup

3.5 Measurement with influence of the distance

We can now measure the attenuation of our signal (generated by the Bode 100) for a radio link distance of 0.1 m. To do so we press the single sweep button. 

Wait until the single measurement has finished. Now a curve with a peak at approximately 27 MHz appears as shown in the next picture. To detect the maximum of this curve activate cursor 1 and right-click the curve, point to cursor 1, and then click Jump to Max. The cursor jumps to the maximum value in the curve and enables to read the minimum attenuation value.

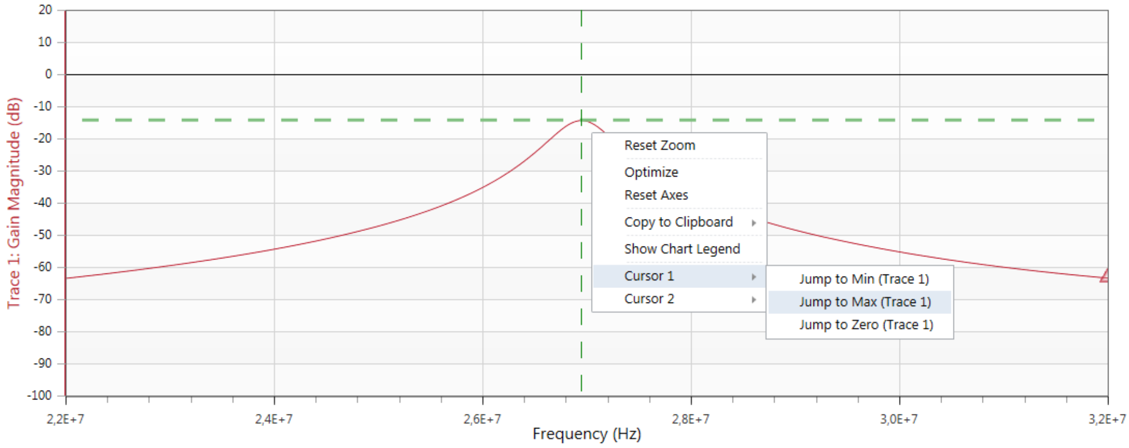


Figure 19: Gain Magnitude - 0.1 m

To see the difference between 0.1 m and 0.6 m transmission distance we put two curves into one diagram. Therefore, the “measurement to memory” function is used. The upper curve was measured at a distance of 0.1 m and the lower curve at a distance of 0.6 m.

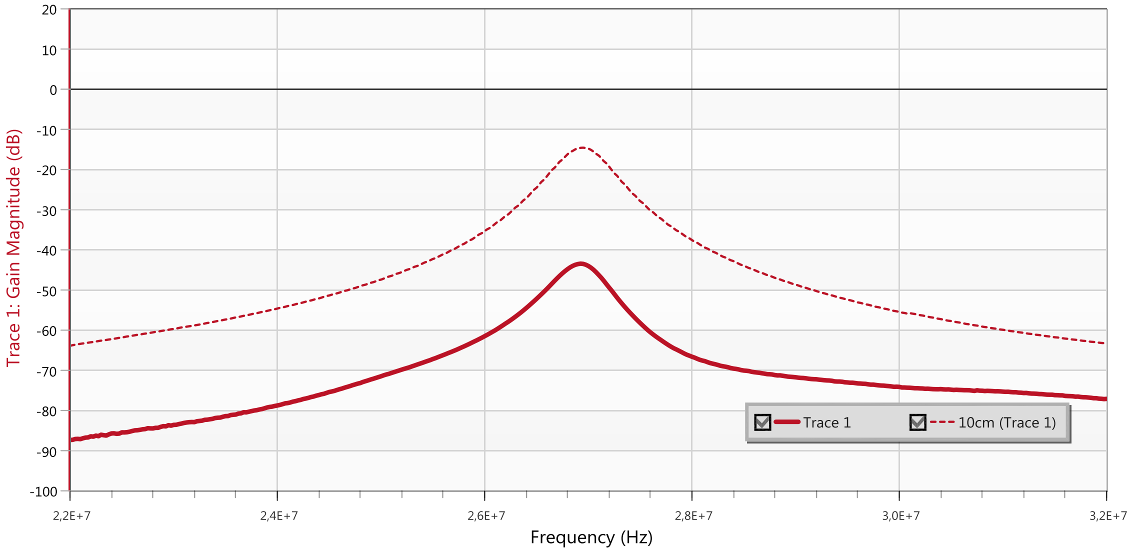


Figure 20: Gain Magnitude - Comparison of 0.1 m to 0.6 m

We did repeat the described measurement for various distances and summarized the result in the table below.

Distance	maximum Gain	Frequency (max. gain)
0.1m	-14.453dB	26.9 MHz
0.2m	-24.787dB	26.9 MHz
0.3m	-32.159dB	26.9 MHz
0.4m	-37.761dB	26.9 MHz
0.5m	-41.451dB	26.9 MHz
0.6m	-43.684dB	26.9 MHz

With the measured data (loss = function (distance)) we can draw a diagram to visualize the attenuation as a function of the antenna distance.

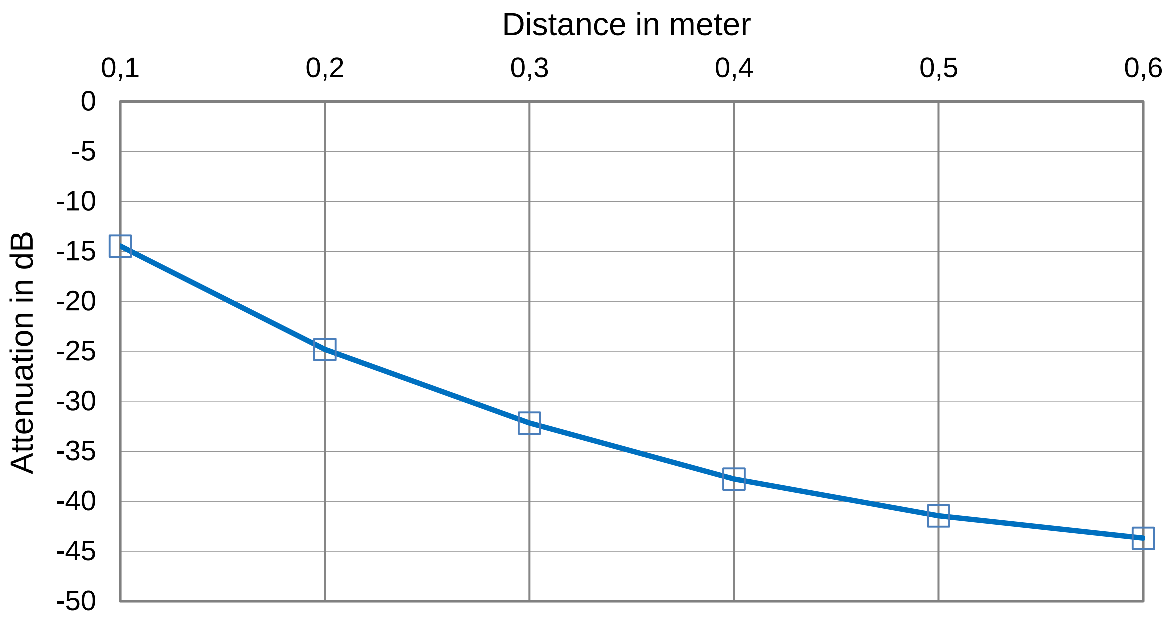


Figure 21: Attenuation to Distance curve

4 Conclusion

With the Bode 100 the basic characteristics of wireless transmission lines can be easily measured. All required steps including the matching of the antennas and the assessment of the operating range can be performed with the Bode 100.

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