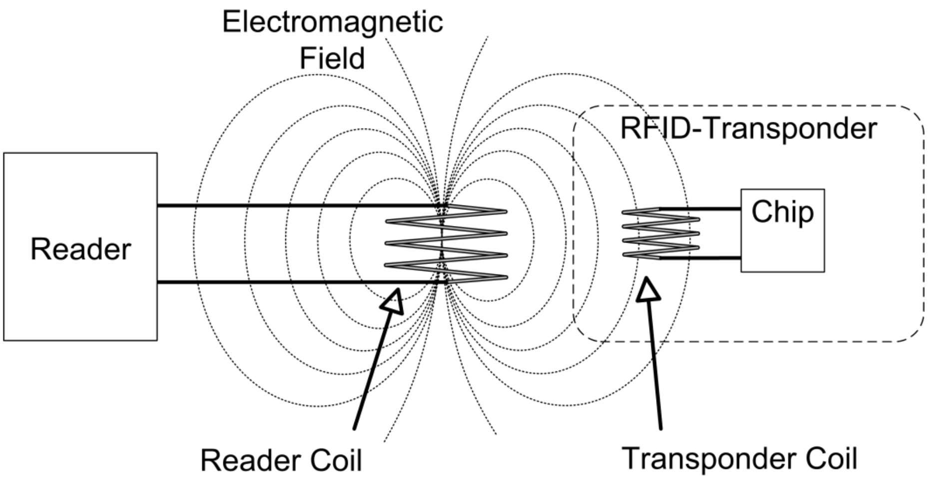
Bode 100 - Application Note

Contactless RFID Tag Measurements



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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 V3.11. 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 shows how the Bode 100 can be used to measure the resonance frequency and quality factor of a 13.56 MHz RFID transponder tag without contacting the DUT[1].
Note that the same method can be applied to a different frequency range (e.g. 125 kHz) as well.

This application note contains all necessary information to these measurements. For additional background information, please refer to (Bitschnau, 2016).

Measuring the exact resonance frequency of a RFID tag can be important during the manufacturing process to guarantee the proper function of the communication between the RFID tag and the RFID reader. Besides the resonance frequency, the quality factor is important for the system performance. Tags with a high Q-factor increase the operating range but might lead to difficulties especially when multiple transponders are present in the reader's field.

Contacting the tag is often difficult and the introduced cable capacitance can strongly influence the resonance frequency. In addition to that, the DUT is not always accessible from outside. The measurements shown in this document are carried out using magnetic coupling between the DUT (transponder) and a measuring coil (reader). This method is therefore called contactless.

2 RFID Tag Resonance Frequency Measurement

2.1 Measurement Task

The resonance frequency of a RFID transponder card (smartcard) shall be measured using the Bode 100. A picture of the DUT (see below) shows that no electric connection can be made to the transponder, antenna or chip.

Figure 1: ID-1 Infineon smart card (Class 1)

[1] Device Under Test

The shown tag operates in the 13.56 MHz band. RFID systems working at this frequency use inductive coupling for the communication. The following two figures show the inductive coupling between the reader and the tag (also called transponder). On the right hand side the equivalent circuit model of the system is shown. M is the mutual inductance describing the magnetically coupled circuits by a circuit diagram containing connected lumped elements. The reader coil is modelled via a series connection of the parasitic copper resistance R_1 and the inductance L_1. The secondary side (elements to the right of the mutual inductance M) shows the equivalent circuit diagram of the RFID card. R_2 describes the copper losses of the RFID antenna. The capacitor C and the resistor R_L represent the RFID-chip. C in combination with the inductance L_2 are designed to resonate at about 13.56MHz. Usually the resonance frequency is higher than 13.56MHz for anti-collision reasons. The resonance frequency often is chosen to be 1 to 5 MHz higher to keep the performance even when two transponders are present in the reader's field.

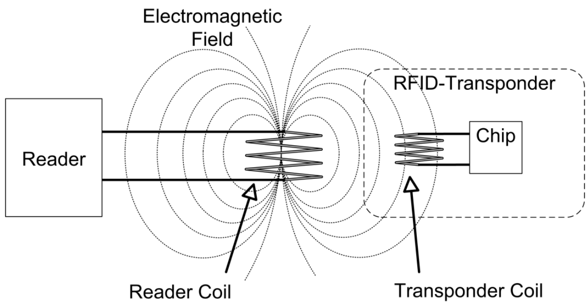


Figure 2: Working Principle

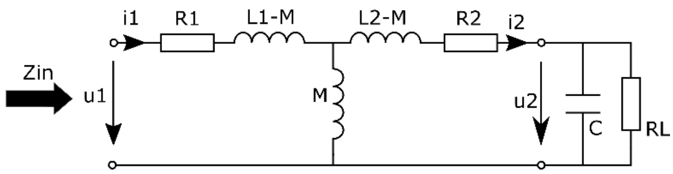


Figure 3: Equivalent Circuit Model

The resonance frequency of an RFID transponder is defined to be at the frequency where the voltage u_2, present at the RFID chip input, is maximal. The resonance frequency of the tag can be measured by measuring the input impedance of the magnetically coupled reader coil. The magnetically coupled circuit of the transponder can be transformed to the reader coil side, as it is shown in Figure 4. The transformed transponder impedance is referred to as $\underline{Z}'$. The derivation of the measured impedance $\underline{Z}_{in}$ shows that it consists of a series connection of the reader coil elements and the transformed transponder impedance $\underline{Z}'$. Details about the mathematical derivation can be found in (Bitschnau, 2016) section 5.2.

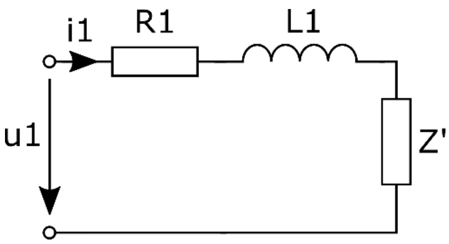


Figure 4: Transformed Equivalent Circuit

From the mathematical derivation, it can be found that the resonance frequency of the transponder correlates with the maximum point of the real part of Z'. **Hence the resonance frequency of the transponder can be measured by finding the maximum of the transformed (measured) transponder impedance Z'.** Note that the impedance of the reader coil must be removed from the measurement.

2.2 Measurement Setup

As mentioned before, a reader coil is needed to excite the RFID transponder. Therefore, the B-RFID-A board is used. This reader coil has two windings and is designed for the measurement of RFID transponders with class 1 and class 2 antennas according to ISO/IEC 14443. The distance between transponder and reader coil is chosen to be 10 mm.

The picture below shows the measurement setup including the reader coil and the DUT.

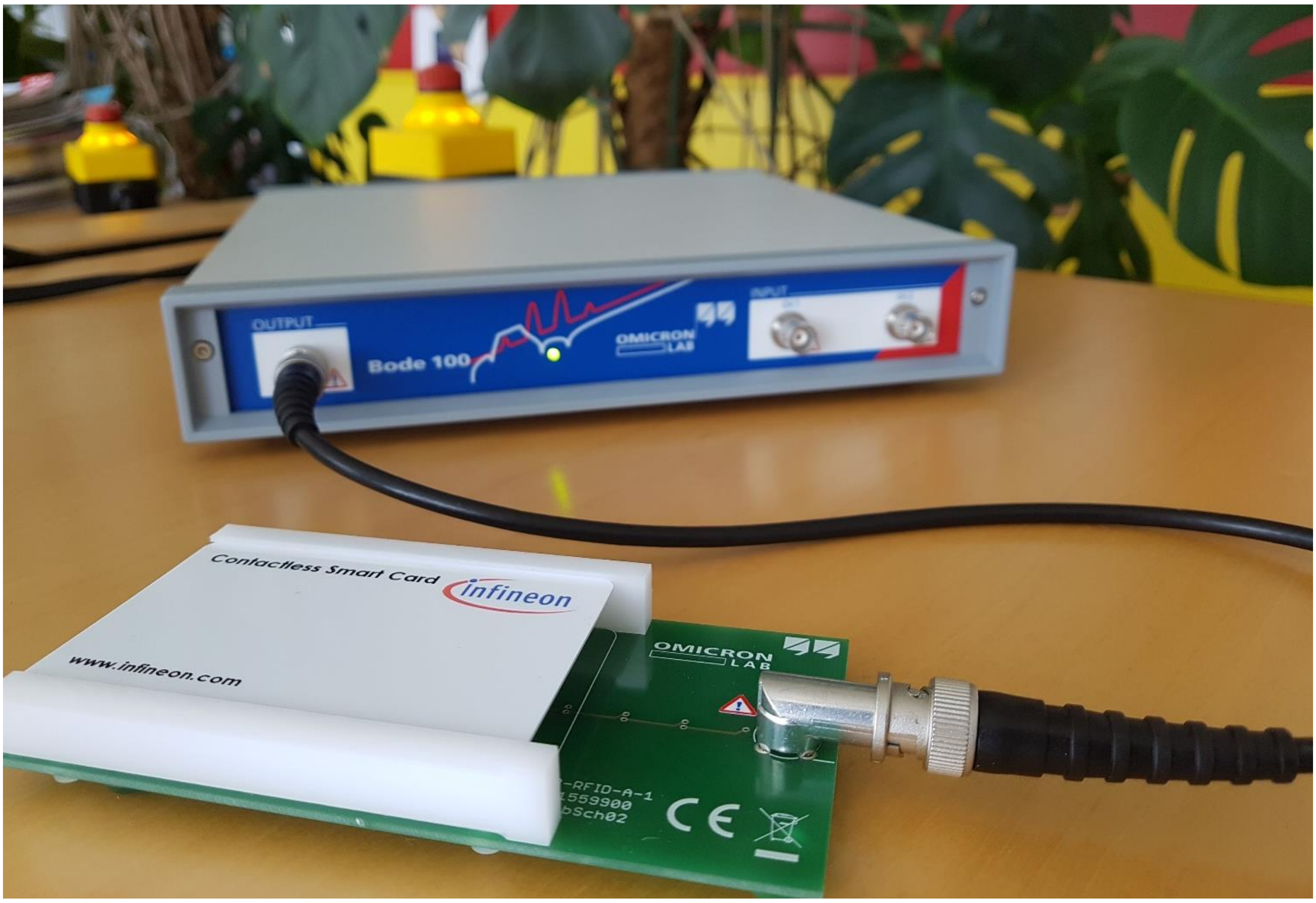


Figure 5: Measurement Setup

Note: To ensure repeatability, keep the position of the card relative to the reader coil constant! In addition, note that permeability and conductivity of the environment (table) can influence the result. Make sure not to place the system on a metal table.

2.3 Device Setup & Calibration

2.3.1 Device Setup:

The resonance frequency correlates with the maximum peak of the real part of the transformed transponder impedance. The Bode 100, therefore, has to be configured to measure an impedance sweep.

The measurement can be performed with the Bode 100 using the measurement type “’One-Port”.

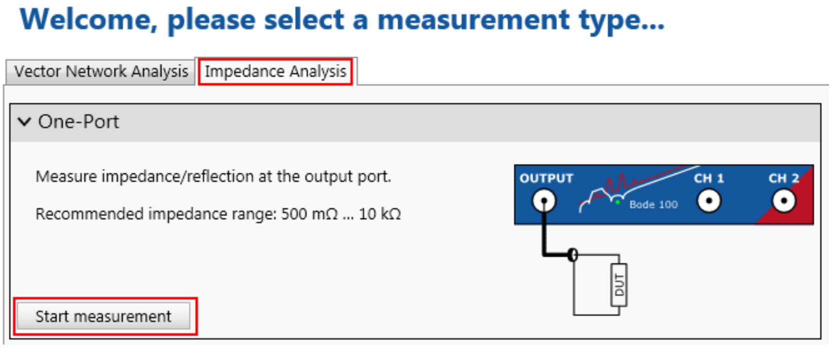


Figure 6: Start menu

Start Frequency:	10 MHz
Stop Frequency:	20 MHz
Sweep Mode:	Linear
Number of Points:	401 or more
Level:	-18 dBm
Receiver Bandwidth:	100 Hz

Set “Format” to “Real” as shown in the following picture:

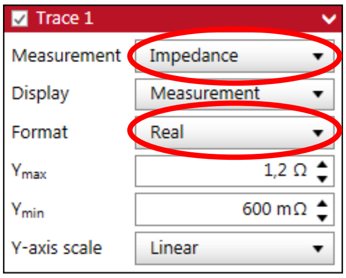


Figure 7: Trace 1 settings

2.3.2 Calibration:

It is recommended to perform open, short and load calibration at the end of the connection cable to remove the cable impedance from the measurement result. The calibration should be done with a source level of 0 dBm to improve signal/noise ratio during calibration.

Note: Information on how to perform the impedance calibration of the Bode 100 can be found in the Bode 100 User Manual.

2.4 Measurement Result

Using the settings and calibration from above, the measurement can be started.
First the reader coil is measured without any mutual induction. To do so, remove the RFID-transponder card (DUT) from the reader coil field to prevent inductive coupling between reader coil and transponder coil.

Measuring the Reader-Coil Impedance

Performing a single sweep leads to the following measurement result. As can be seen the resistance R_1 is not constant over the frequency. This is due to the skin effect.

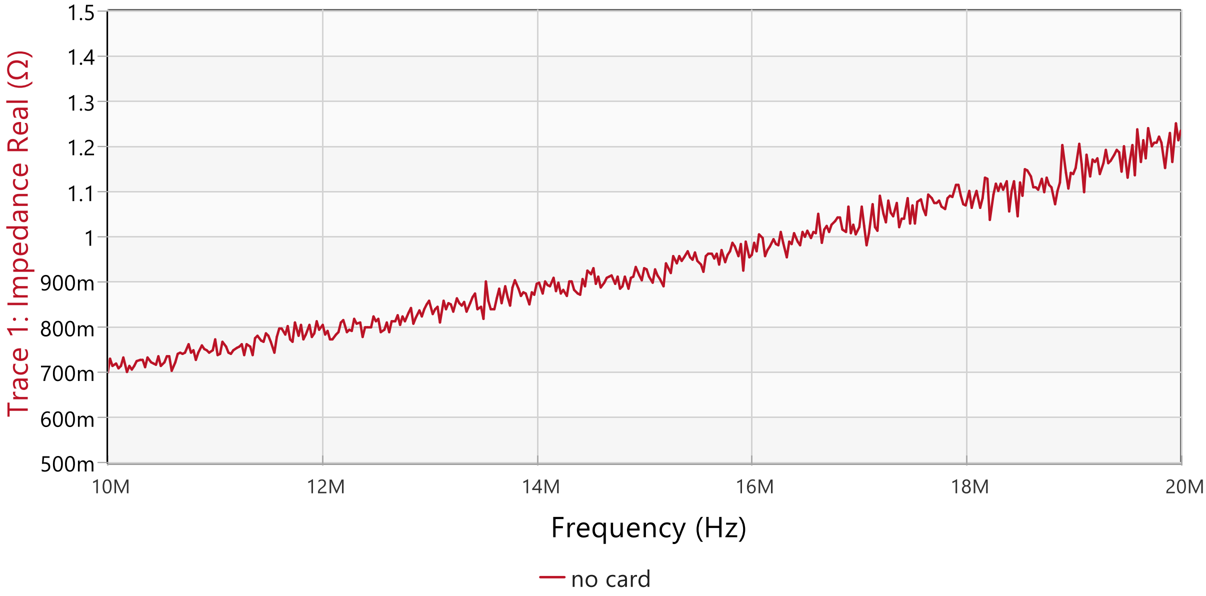
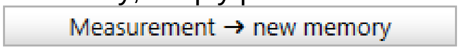


Figure 8: Series Resistance of B-RFID-A Coupling Coil

The measurement result is needed to calculate $\underline{Z}'$. Therefore, it is stored into a memory. To store the measurement data to the memory, simply press the “Measurement -> new memory” button located in the bottom right corner. 

Note: A memory always includes the entire complex number of the measurement data!

Placing the Transponder into the Reader Field

Now the RFID transponder is placed into the reader fixture (see Figure 5).

Since the signal level has a strong influence on the result, we will make two measurements. First, we set the Source level to **-18 dBm** and perform a new sweep. After completing a sweep, the result is stored to a memory trace. We do a similar measurement with a source level of **2 dBm**. Having finished, all three different memory traces should be re-named accordingly:

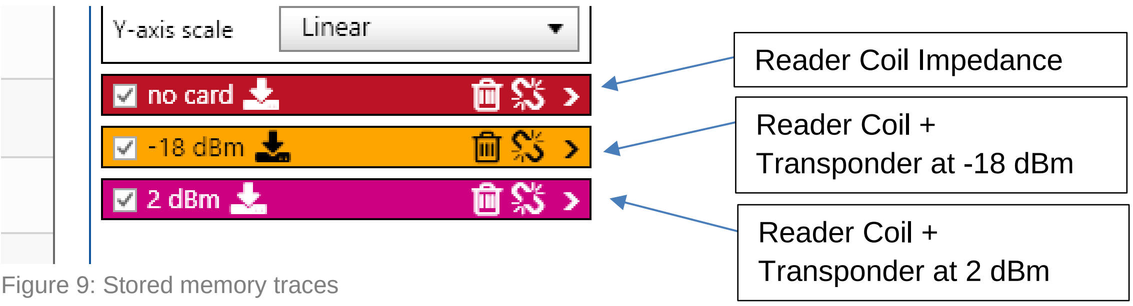


Figure 9: Stored memory traces

Calculating the Transformed Impedance Z'

Now the stored reader coil impedance must be subtracted from the actual measurement to get the transformed impedance $\underline{Z}'$. This computation can be done directly in the Bode Analyzer Suite using the trace settings shown below:

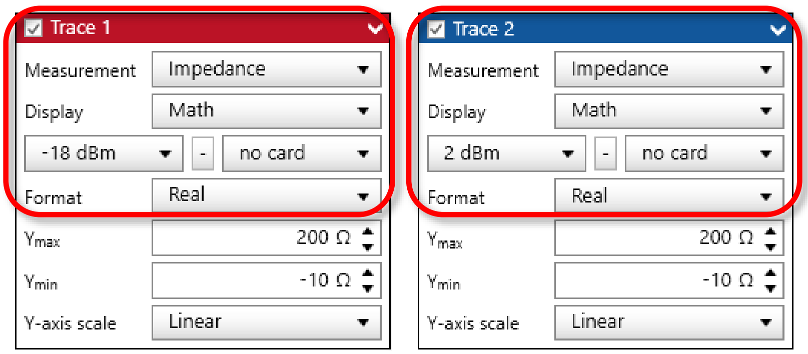


Figure 10: Settings for the Resonance Frequency view (Trace 1 & 2)

Display is set to Math to use the Math function of Bode Analyzer Suite.
Next, the two operands (Memory curves) and the operator (-) must be selected.

In This example, Trace 1 is set to subtract the reader coil impedance (no card) from the measurement performed at a signal level of -18 dBm (-18dBm). This now equals our desired result of the transformed impedance Z' at a signal level of -18 dBm.
Trace 2 results in the transformed impedance Z' at a measurement signal level of 2 dBm.

These settings now result in two resonance curves as shown below:

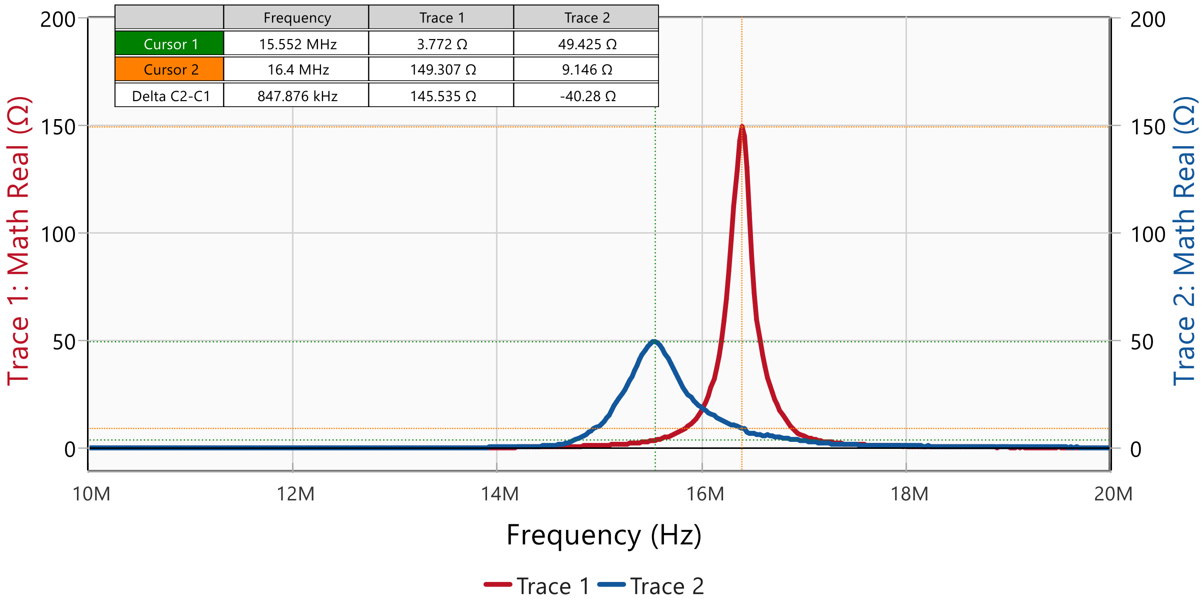


Figure 11: Resonance Frequency Measurement

Note that the resonance of the transponder strongly depends on the signal level that is used to measure. The higher the signal level, the more the RFID chip starts to influence the measurement result.
The resonance frequency can be found by using the “jump to max” cursor function (Right-click on Trace 1 and select Cursor 1 → Jump to Max (Trace 1)). In our case, we get the following results:

Signal Level	Resonance Frequency
-18 dBm	16.40 MHz
2 dBm	15.55 MHz

Hint: The resonance frequency can also be measured with the cursor calculation “resonance frequency – quality calculation” as shown in the next chapter.

3 RFID Tag Q-Factor Measurement

3.1 Measurement Task

Besides the resonance frequency, the quality factor of the RFID transponder also can be determined without directly contacting the DUT. The Q factor is defined by:

$$Q = \frac{f_0}{f_{BW}} = \frac{\omega_0}{\omega_{BW}} \qquad (1)$$

f_0 is the resonance frequency and f_{BW} the bandwidth. The upper and lower bandwidth limits are at the frequencies where the power of the signal of interest is half the power at resonance frequency.

The signal of interest in our case is u_2, the voltage across the RFID chip. The bandwidth limits are measured by measuring the frequencies where $Real\{\underline{Z}'\}$ drops to half the value at resonance. A mathematical proof / derivation of this concept can be found in (Bitschnau, 2016).

3.2 Measurement Result

The measurement setup used for the Q measurement is the same as the one for the resonance frequency measurement. We can use the results from the previous measurement and use the “Fres-Q” feature available with Bode Analyzer Suite 3.11 or newer. The “Fres-Q” Cursor Calculation automatically searches the resonance peak and calculates resonance frequency and Q-factor.

To use the Fres-Q features, select the “Cursor” tab and select “Fres-Q” as shown below:

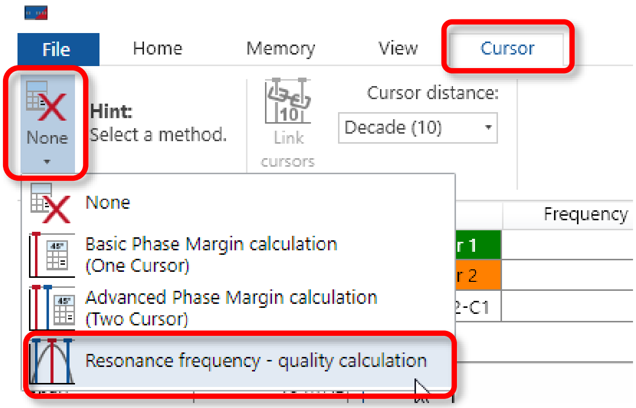


Figure 12: Activate Fres - Q feature

Then select to use “Real” of “Trace 1” and hit the “Find peak” button

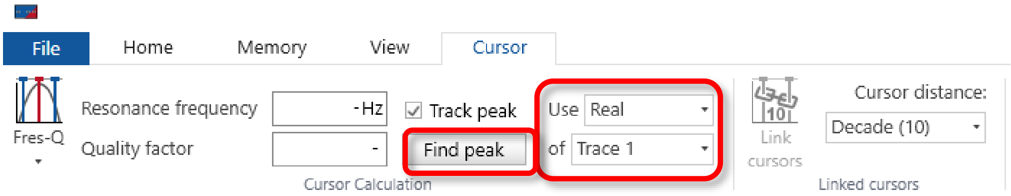


Figure 13: Cursor tab settings

The Bode Analyzer Suite now places three cursors at the resonance curve as shown in the figure below and the calculates the Q factor, using the following equation.

$$Q = \frac{f_0}{f_{BW}} = \frac{16.4\ MHz}{260.048\ kHz} = 63.056$$

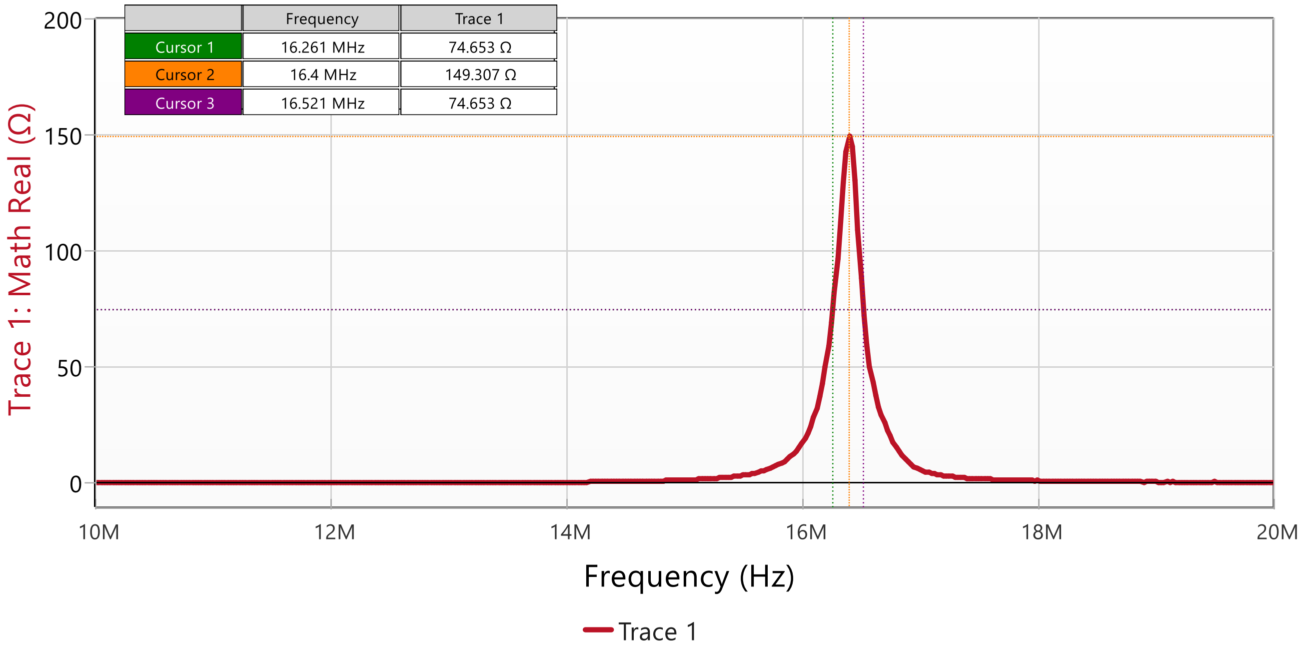


Figure 14: measurement curve and cursors for Q measurement

The result is displayed in the ribbon:

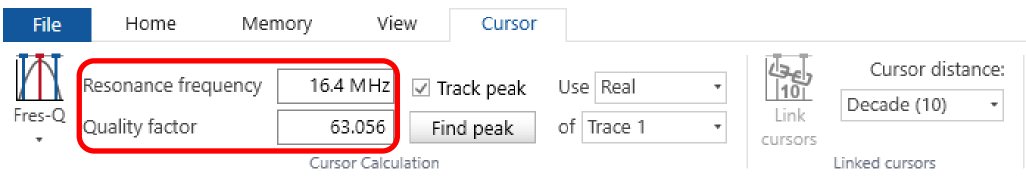


Figure 15: Fres - Q result

We can now extend our result table with the Q-factor as shown below:

Signal Level	Resonance Frequency	Q-Factor
-18 dBm	16.40 MHz	63
2 dBm	15.55 MHz	23

4 Conclusion

The Bode 100 suits perfectly for measuring the resonance frequency of 13.56 MHz RFID transponders. Specific test fixtures B-RFID-A, B and C are available for quick an easy Class 1, 2 and 3 ID-1 card measurements.
Due to its low frequency measurement capabilities, the Bode 100 can also be used for low frequency RFID measurements.
Not only the resonance frequency can be measured, but also the quality factor of an RFID transponder can be obtained by measuring two characteristics of one single frequency response.

5 Bibliography

Bitschnau, M. (2016). *Analysis of Quality Factor and Resonance Frequency Measurements of RFID Transponders.* Klaus in Vorarlberg: Omicron Lab.

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