Application Note:

Analysis of a RFID Reader Antenna using Bode 100

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Introduction

This app note deals with the alignment of a 13.56MHz RFID antenna using ferrite material. The question is whether it makes a difference to calibrate an antenna with a small signal or using a real signal >13dBm (20mW). This procedure is also of interest when designing 13.56MHz wireless power charging systems.

The standard procedure to match RFID reader antennas toward e.g. a 50Ω power source is using a S11 reflection measurement. I was interested in the question whether this procedure also works well using ferrite materials, that tend to show non-linear effects, especially when they are saturated due to high magnetic field strength.
The aim of every antenna design is to enable a communication in a predetermined area. RFID is a near-field communication in which not only the information but also the energy for the communication partner is made available through the RF field.
Customers want ever smaller designs, but the performance of an RFID reader, should not be reduced. This applies in particular to the operating range of the antenna. In order to realize this requirement, more and more ferrite materials are used with the aim of concentrating the magnetic RF field in the material, conducting it and minimizing attenuation through nearby circuit boards with GND planes for instance.
The selection and use of magnetic material is not an easy task. For the frequency range above 10 MHz practically only very fine-grained nickel zinc (NiZn) ferrite materials are considered.
The decisive factors for the achieved performance of a design are at first hand the geometry of the ferrite used, second the permeability of the magnetic material and third the magnitude of the signal.

Measurement plan and expectations

The matching of an RFID Antenna toward 50 Ω is to be checked. The standard configuration to do so is a one-port S11 reflection measurement. In this Application Note we want to perform the reflection measurement using a much higher signal strength than usual. The question to be answered is whether or not there are nonlinear effects related to the power level.

The device under test (DUT) is a small RFID reader, consisting of one PCB holding the circuitry and a second PCB with a loop antenna. The construction of the DUT requires the antenna PCB to be in close distance mounted on top the circuitry board. This leads to a close vicinity of ground planes toward the antenna causing antenna power being absorbed by that metal plate.
The best design practice to prevent losses would be to move all metal parts away from the antenna. However, in this case ferrite material is used to concentrate the magnetic flux to keep it away. Details of the DUT construction are shown in Figure 1 and Figure 2.

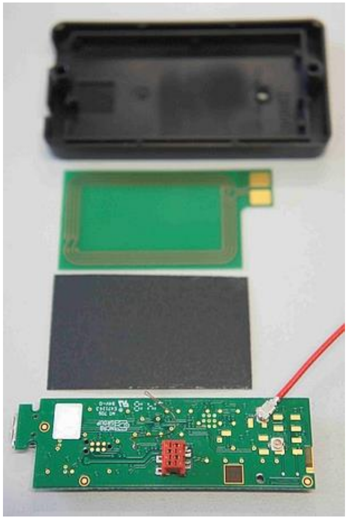

Figure 1: RFID Reader DUT

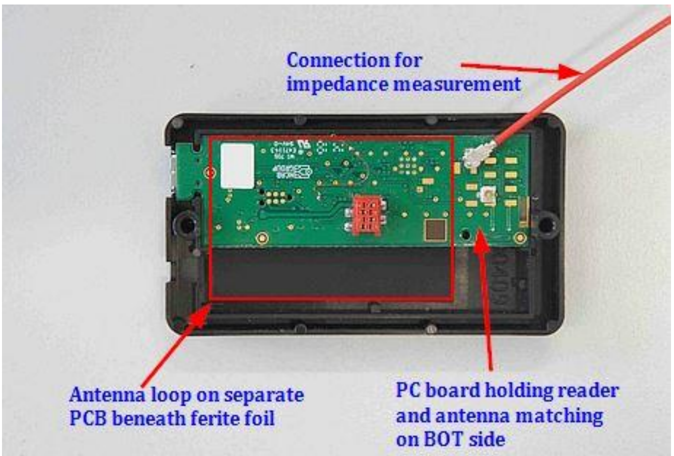

Figure 2

Figure 1: RFID Reader DUT

Figure 2: DUT details

Now as the DUT construction is introduced we want to analyze the effect of the chosen ferrite material toward the antenna matching. To do so I have prepared three reader variants. One holding no ferrite, a second one made with a 0.1mm thick ferrite foil and a third variant with 0.5mm ferrite material attached to the antenna.
All three variants do have a different matching circuitry. Each being matched to 50Ω through a reflection measurement made with 0dBm (1mW or 224mV) signal strength.

The question to be answered by this measurement is whether or not there is a difference in the antenna matching when switching from a small signal to a high-power signal.
My expectation is that there is little to no change when no ferrite is involved, because I do not expect nonlinear effects with increased power. A thin layer of ferrite may show some loss at high power whereby a larger layer should show less.

Measurement setup

For a high-power reflection measurement an amplifier and an external reflection bridge must be connected to a VNA. The receiver inputs of the VNA need to be directly accessible. Bode 100 is chosen because it offers direct receiver access.

Figure 3 and figure 4 on the next page show the setup. The DUT is connected, using an ultra-miniature U.FL coax connector and cable.

At first the output power at the directional coupler is checked. For protection reasons 16dB of attenuation is introduced at the input port of the power amplifier to not overload the amplifier or DUT even in case of mislead settings. Table 1 shows the measured output power and its related Bode 100 source level setting for this configuration.

Table 1: Voltage versus source level

AMP Out Power		**V_{rms} at 50Ω**	**Bode 100 source level setting**
0dBm	1mW	0.22V	-18.2dBm
13dBm	20mW	1.00V	-5.1dBm
26dBm	400mW	4.47V	7.7dBm
30dBm	1000mW	7.07V	11.7dBm

Next, a calibration has to be performed. To measure impedance on the DUT a calibration is required that includes all introduced test equipment and hence moves the calibration plane toward the point of interest. In this app-note a custom build U.FL equipped calibration PCB as shown in figure 4 was used. Open Short and Load calibration at 13dBm power is used. The frequency range is chosen from 12MHz to 15MHz.

It is always a good recommendation to do as many consistency checks as possible. With this setup first a known test-DUT (shown in figure 4) was measured and the result was compared to a documented simple S11 one port measurement of that same test-DUT.
Second, calibration was repeated several times using varying power levels. Each time a test-DUT, known to be linear with respect to power was measured afterwards. At all power levels the results had to be the same.

What about the limits of this setup?
At 15MHz a 1° phase error relates to an electrical length of roughly 6.14cm. (Wavelength of 15MHz divided by 360°). So, the reference plane position of this calibration is not as critical, as in GHz VNA measurements and calibrations. The measurement error of Bode 100 is of ±1% in the range from 1Ω to 3kΩ. Further the custom build U.FL calibration PCB was crosschecked using a 3.5mm Cal Kit and found to be ±1% in a range 1MHz to 50MHz. So, as a conservative estimate the overall error is assumed to be well below ±5%

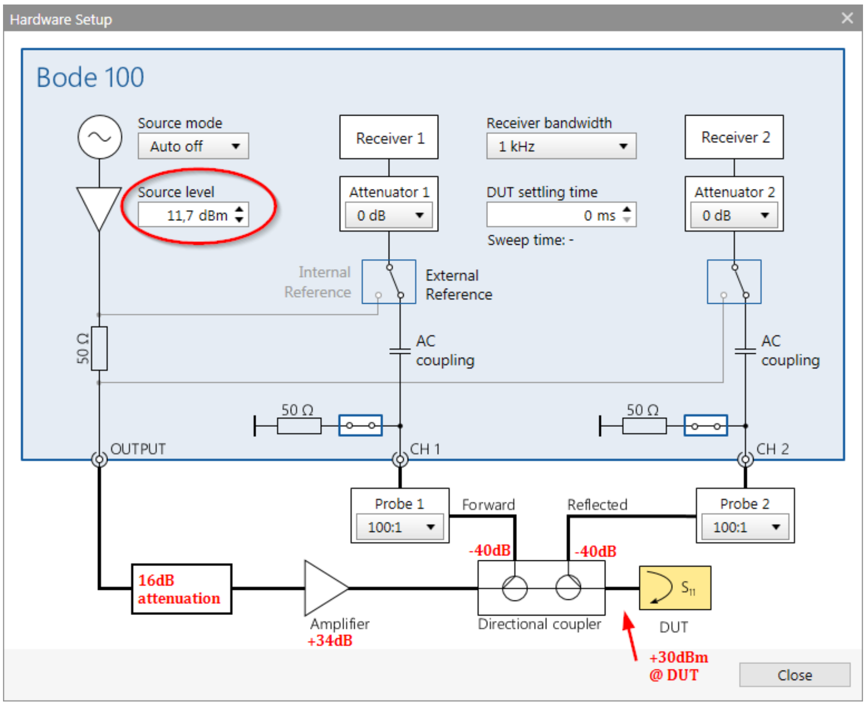

Figure 3: Bode 100 configuration

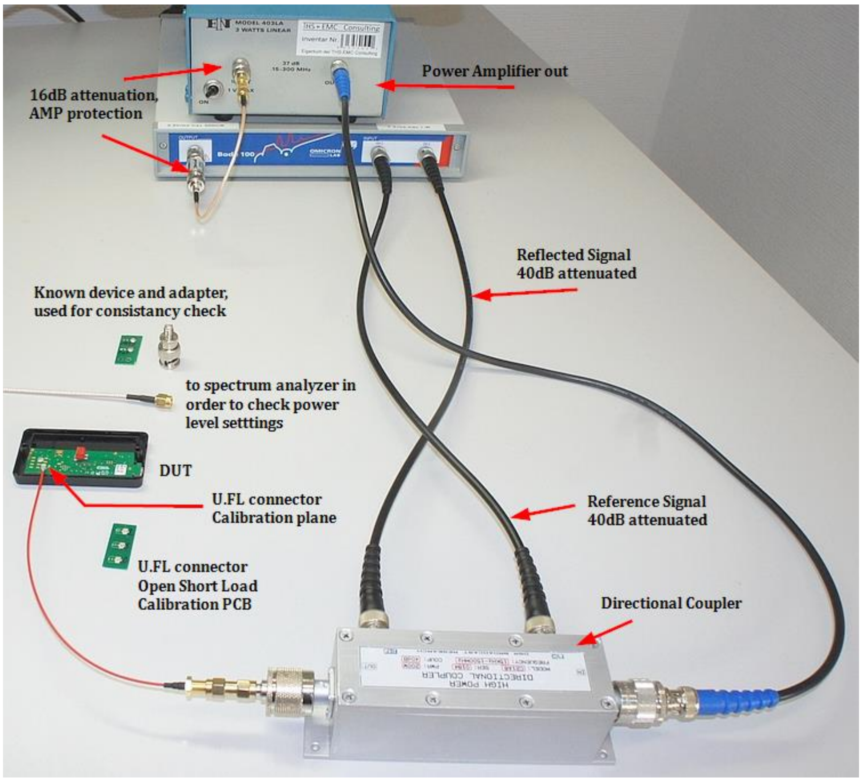

Figure 4: Measurement setup

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Measurement result

Three different DUT configurations are measured. Each DUT configuration is measured at four different power levels as shown in table 1.
Figure 5 shows the measurement results and data. The upper row plots show reflection magnitude which gives an indication of the antenna matching quality or vice versa the losses.
The bottom row plots are Smith Chart impedance plots, they do show the matching towards 50Ω.

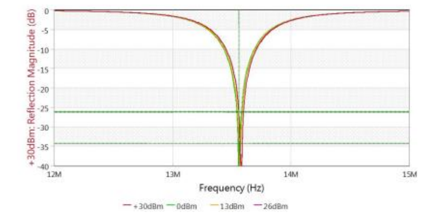
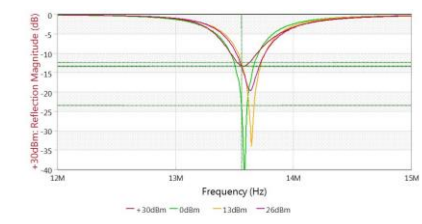
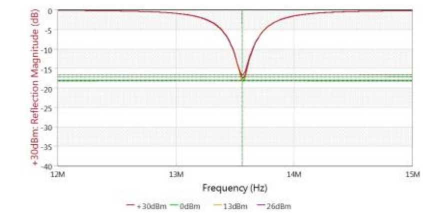
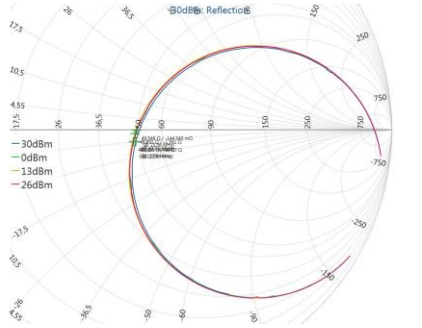
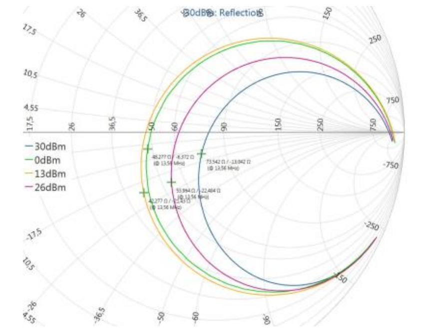
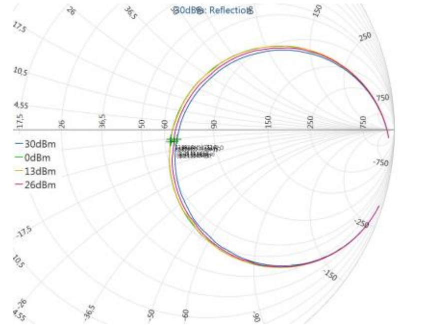
No shielding	0.1mm shielding	0.5mm shielding
		
		
No change with rising power level	Significant change	Negligible change

Figure 5 Measurement Results

The DUT configuration with 0.1mm ferrite foil shielding (mid column) shows a significant effect when adjusting the power level. However, as anticipated, the DUT with no ferrite, does show no changes.
Finally, the DUT with a large layer of ferrite material does as well show no significant nonlinear effects. This can be explained by the assumption that the material is not stimulated at any point in the saturation range.

Figure of Merit:
The measured impedance-change without shielding was 4.6 Ω, with the thick shielding 3.5 Ω and with the thin shielding 26.1 Ω. As can be seen from the smith chart in Figure 5, middle column, the observed change is also non-linear.

Conclusion

This App Note shows a possible setup for high power return loss measurements. Especially when designing resonant systems where ferrite material is involved, nonlinearities due to partial saturation can occur. This does not only apply to RFID Antennas but also to all other kind of inductors, using magnetic material. Wireless Power might be one another applications where this method is useful. Bode 100 provides a possibility for high power return loss measurements thanks to the dedicated receiver inputs.

Reference Dokuments

[1] Klaus Finkenzeller, “RFID Handbuch”, Hanser Verlag

[2] Josef Langer, Michael Roland “Anwendung und Technik von Nearfield Communication (NFC)”, Springer Verlag

Andreas Peterswerth
studied Electrical Engineering at University of applied Sciences Osnabrück, Germany and Universitat Politècnica de València, Spain.
He worked for over 10 years as a hardware development engineer and project manager at Bosch.
In 2015 he started as a consulting engineer.