AN12380

Antenna design guide for NTAG 5 link and NTAG 5 switch

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Application note
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Document information

Info	Content
Keywords	NTAG 5 link, NTAG 5 switch, Antenna Theory, Antenna Design, Measurement Methods, Antenna Design Procedure
Abstract	NTAG 5 needs to be connected to an antenna to access NTAG 5 via NFC interface. This application note provides guidance for designing such antenna.

Revision history

Rev	Date	Description
1.1	20200130	Antenna matching calculation sheet added in the document
1.0	20200109	First released version

Contact information

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1. Introduction

NTAG 5 family is ISO/IEC 15693 and NFC Forum Type 5 Tag compliant, with an EEPROM, SRAM and I²C host interface. This Application note helps to easily design antennas for NTAG 5 switch and NTAG 5 link (passive load modulation).

2. Antenna theory

2.1 NTAG 5 switch and NTAG 5 link connections

The NTAG 5 needs to be connected to the antenna with the pads L_A and L_B

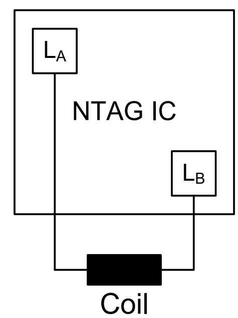


Fig 1. NTAG 5

2.1.1 NTAG 5 IC equivalent circuit

The following simple equivalent circuit describes the properties of the NTAG 5 which are relevant for the antenna design.

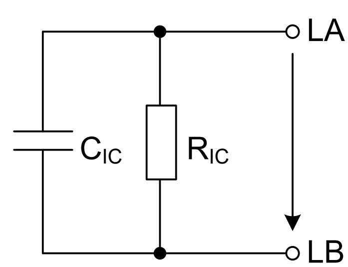


Fig 2. Equivalent circuit of the NTAG 5 IC

2.1.2 NTAG 5 input capacitance C_{IC}

This electrical parameter of the NTAG 5 IC is the most important factor for the antenna design. The form factor and the parameters of the antenna are affected by the input capacitance.

The input capacitance depends on the applied chip voltage. Because the antenna voltage is limited in the operational state which stabilize the input capacitance as well all further calculations should be done in the operational state. The effect of capacitance variations results in different measured resonance frequencies on the network analyzer.

The following table specifies the operational state values of this capacitance for the given type of NTAG 5 IC.

Table 1. Capacitance value of NTAG 5 link and NTAG 5 switch

Type	C_{IC}	Measurement conditions
NTP5332, NTP5312, NTP5210	15pF	V_{LA-LB} = 1.8Vp, Network Analyzer (f = 13.56 MHz) @ room temp.

2.2 Series and parallel equivalent circuits

2.2.1 Series equivalent circuit of the antenna

The antenna can be described by an inductance Lsc in series to a loss resistance Rsc. The antenna capacitance Cc is in parallel to this series circuit. This capacitance consists of the inter-turn capacitance and a possibly designed tag capacitance CIC.

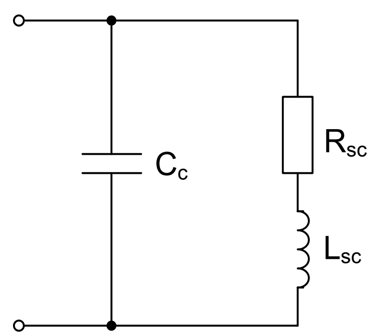


Fig 3. Series equivalent circuit of the antenna

The antenna quality factor is calculated by

$$Q_{sc} = \frac{2 \cdot \pi \cdot f_{op} \cdot L_{sc}}{R_{sc}}$$

with operating frequency f_{op} = 13.56 MHz.

2.2.2 Parallel equivalent circuit of the antenna

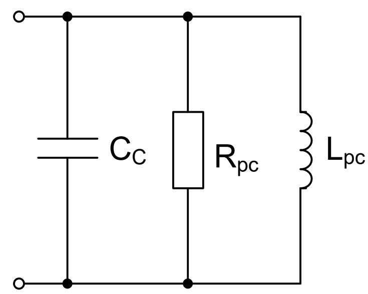


Fig 4. Parallel equivalent circuit of the antenna

The following applies:

$$L_{pc} = \frac{R_{sc}^2 + (2 \cdot \pi \cdot f_{op} \cdot L_{sc})^2}{(2 \cdot \pi \cdot f_{op})^2 \cdot L_{sc}} = L_{sc} \cdot \frac{1 + Q_{sc}^2}{Q_{sc}^2}$$

$$R_{pc} = \frac{R_{sc}^2 + (2 \cdot \pi \cdot f_{op} \cdot L_{sc})^2}{R_{sc}} = R_{sc} \cdot (1 + Q_{sc}^2)$$

$$Q_{pc} = \frac{R_{pc}}{2 \cdot \pi \cdot f_{op} \cdot L_{pc}} = Q_{sc}$$

For the further calculations, the parallel equivalent circuit was chosen to simplify the resonance circuit. This makes calculation easier.

2.2.3 Equivalent circuit of the tag

The following figure shows the equivalent circuit of the whole tag.

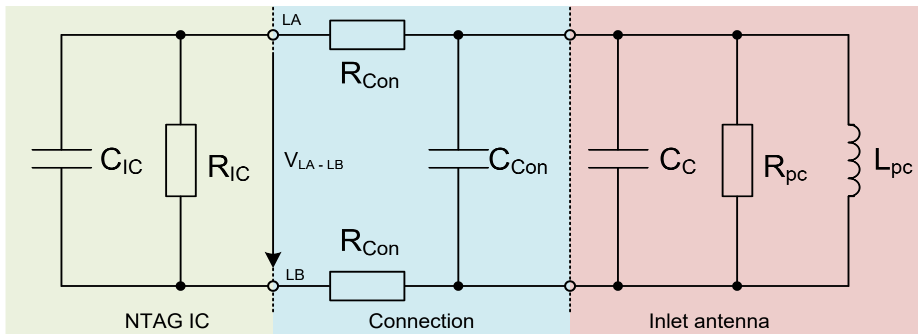


Fig 5. Equivalent circuit of the tag

The NTAG 5 IC capacitance C_{IC} together with the antenna capacitance and the parasitic connection capacitance forms a resonance circuit with the inductance of the antenna.

The NTAG 5 IC input resistance R_{IC} together with the loss resistance of the antenna and the connection resistance defines the quality factor of the tag when it is on its threshold power-on level. This quality factor influences the threshold field strength of the tag and will be explained in the following sections.

R_{Con} should be kept as low as possible in order not to influence the total parallel equivalent resistance of the tag R_{pl}. A relatively high connection resistance will decrease the total parallel quality factor of the tag and therefore decrease the transmission range.

C_{Con} describes the increase of the total tag capacitance due to dielectric changes (under filler, adhesive …) in the connection area when the chip is applied to the antenna.

For R_{Con} << 1Ω the following simplified circuit can be used for the IC:

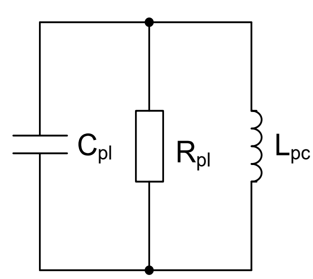


Fig 6. Simplified equivalent circuit of the IC

Parallel equivalent capacitance of the IC

$$C_{pl} = C_{IC} + C_{Con} + C_c$$

Parallel equivalent resistance of the tag

$$R_{pl} = \frac{R_{IC} \cdot R_{pc}}{R_{IC} + R_{pc}}$$

2.3 Resonance frequency and quality factor of the IC

Based on the simplified equivalent circuit the resonance frequency f_R of the IC can be calculated with:

$$f_R = \frac{1}{2 \cdot \pi \cdot \sqrt{L_{pc} \cdot C_{pl}}}$$

The value of the NTAG 5 IC input capacitance C_{IC} depends on the chip input voltage V_{LA-LB}. Therefore, the resonance frequency of the tag changes with the IC input voltage.

Based on the simplified equivalent circuit (Fig 6) the quality factor Q of the IC at the operating frequency can be calculated with:

$$Q = \frac{R_{pl}}{2 \cdot \pi \cdot f_{op} \cdot L_{pc}}$$

The value of the NTAG 5 IC input resistance R_{IC} depends on the chip input voltage V_{LA-LB}. Therefore, also the quality factor of the IC changes with the input voltage.

2.3.1 Threshold resonance frequency f_{RT} and threshold quality factor Q_T

The threshold resonance frequency f_{RT} is the resulting resonance frequency for the minimum operating input voltage of the IC.

V_{LA-LB} Minimal voltage level for NTAG 5 IC operation

$$C_{plT} = C_{ICT} + C_{Con} + C_c$$

C_{ICT} NTAG 5 IC input capacitance for threshold condition

C_{plT} Parallel equivalent capacitance of the IC for threshold condition

C_{ICT} represents the NTAG 5 IC input capacitance for minimal operating conditions and corresponds to the specified typical value.

$$f_{RT} = \frac{1}{2 \cdot \pi \cdot \sqrt{L_{pc} \cdot C_{plT}}}$$

$$R_{plT} = \frac{R_{ICT} \cdot R_{pc}}{R_{ICT} + R_{pc}}$$

R_{ICT} NTAG 5 IC input resistance for threshold condition

R_{plT} Parallel equivalent resistance of the IC for threshold condition

R_{ICT} represents the NTAG 5 IC input resistance for the minimal operating conditions and corresponds to the shown typical value.

$$Q_T = \frac{R_{plT}}{2 \cdot \pi \cdot f_{RT} \cdot L_{pc}}$$

2.4 Threshold field strength H_T in passive communication mode

This section gives formulas to calculate the threshold field strength H_T which is significant for the transmission range. The influence of the threshold resonance frequency f_{RT} and the antenna quality factor Q_{pc} on this field strength is figured out.

To calculate the Voltage the mutual inductance needs to be calculated. The mutual inductance depends on the coupling between the Tag antenna and the reader antenna and can be calculated as:

$$M = k \cdot \sqrt{L1 \cdot L2}$$

The voltage on the IC generated by the magnetic field of the reader with antenna current I_1 is given by:

$$V_{LA-LB} = \frac{2 \cdot \pi \cdot f \cdot M}{\left(\left(1 - \left(\frac{f}{f_R} \right)^2 \right)^2 + \left(\frac{2 \cdot \pi \cdot f \cdot L_{pc}}{R_{pl}} \right)^2 \right)^{1/2}} \cdot I_1$$

With the assumption that the turns of the tag antenna are concentrated on the average antenna dimensions, the threshold field strength for NTAG 5 IC operation can be calculated with:

$$H_T = \frac{\left(\left(1 - \left(\frac{f}{f_{RT}} \right)^2 \right)^2 + \left(\frac{2 \cdot \pi \cdot f \cdot L_{pc}}{R_{plT}} \right)^2 \right)^{1/2}}{2 \cdot \pi \cdot f \cdot \mu_0 \cdot N_c \cdot A_c} \cdot V_{LA-LB\min}$$

The following figure shows the behavior of threshold field strength H_T versus the frequency f of the inducing magnetic field for a tag with the threshold resonance frequency f_{RT}.

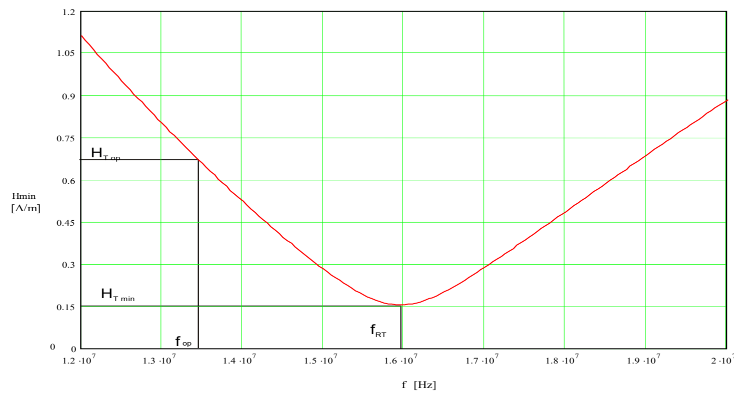


Fig 7. Threshold field strength vs. frequency

The curve of the threshold field strength reaches its minimum at the threshold resonance frequency f_{RT} of the tag. For $f=f_{RT}$ the minimal threshold field strength $H_{T\min}$ results in:

$$H_{T\min} = \frac{L_{pc}}{\mu_0 \cdot N_c \cdot A_c \cdot R_{plT}} \cdot V_{LA-LB\min}$$

At the operating frequency f_{op} the threshold field strength results in:

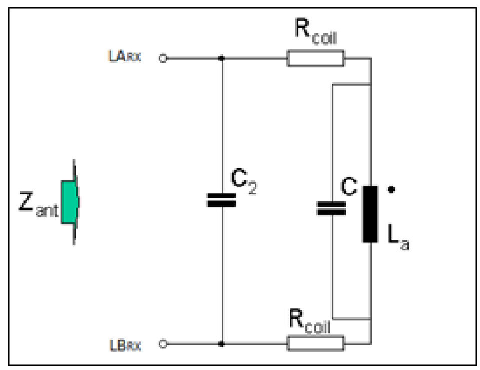
$$H_{Top} = \frac{\left(\left(1-\left(\frac{f_{op}}{f_{RT}}\right)^2\right)^2 + \left(\frac{2\cdot\pi\cdot f_{op}\cdot L_{pc}}{R_{plT}}\right)^2\right)^{1/2}}{2\cdot\pi\cdot\mu_0\cdot f_{op}\cdot N_c\cdot A_c} \cdot V_{LA-LB\min}$$

Lowest operating field strength is reached if f_{RT} = f_{op} = 13.56 MHz resulting in H_T = $H_{T\min}$.

3. Antenna matching

NTAG 5 link/switch with passive load modulation (PLM) is targeted for antennas bigger class 6.

3.1 PLM topology



(1) PLM matching topology

Fig 8. PLM topology

3.2 General antenna matching procedure and preparation ALM and PLM

For a proper antenna design the antenna impedance must be measured using an impedance analyzer or VNA (vector network analyzer). Such a VNA can be a high-end tool from Agilent or Rohde & Schwarz (like the R&S ZVL), as normally used in this document), but might be a cheap alternative with less accuracy like e.g. the miniVNA Pro (see). In any case the analyzer needs to be able to measure the impedance in magnitude and phase (vector).

Such VNA can be used to measure the antenna coil as well as the antenna impedance including the matching circuit.

The antenna matching is done with the following steps:

1. Measure the antenna coil
2. Calculate the matching components
3. Simulate the matching
4. Assembly and measurement
5. Adaptation of simulation
6. Correction and assembly

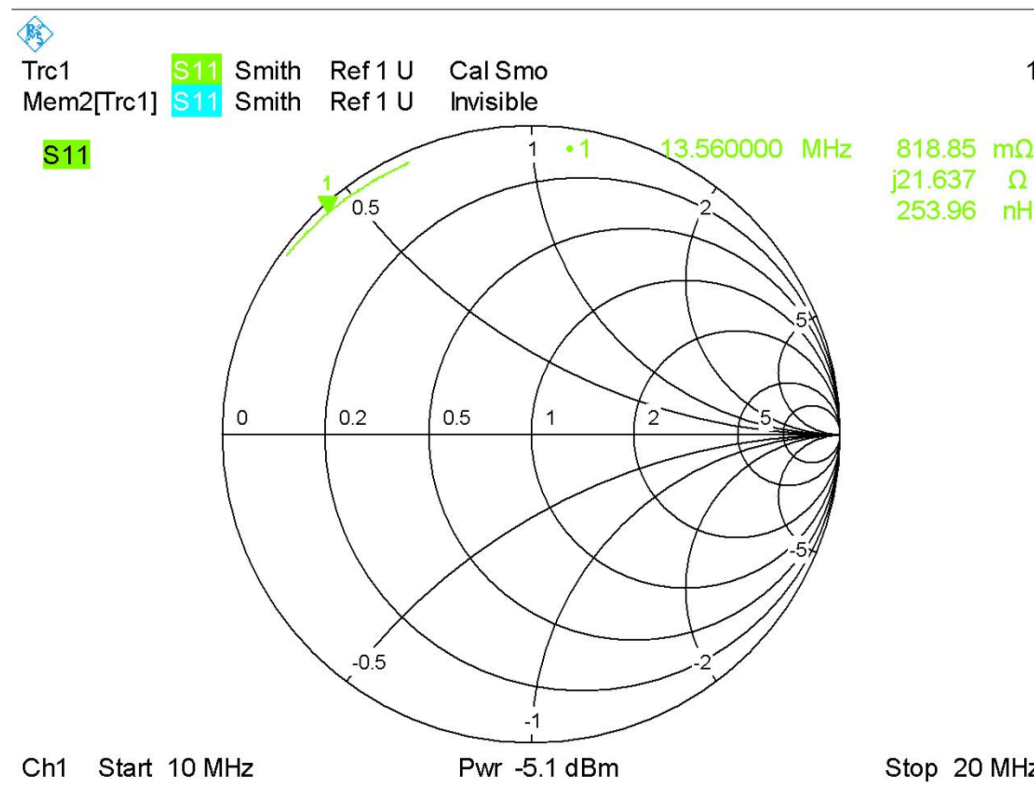
3.2.1 Measure the antenna coil

The antenna coil must be designed as described in section 2 Antenna theory and be measured. The measurement is required to derive the inductance L, the resistance R_{Coil} and the capacitance C_{pa} as accurate as possible.

The easiest even though not most accurate way is to use the VNA to measure the impedance $\underline{Z}$ of the antenna coil at 13.56MHz and to calculate L and R out of it:

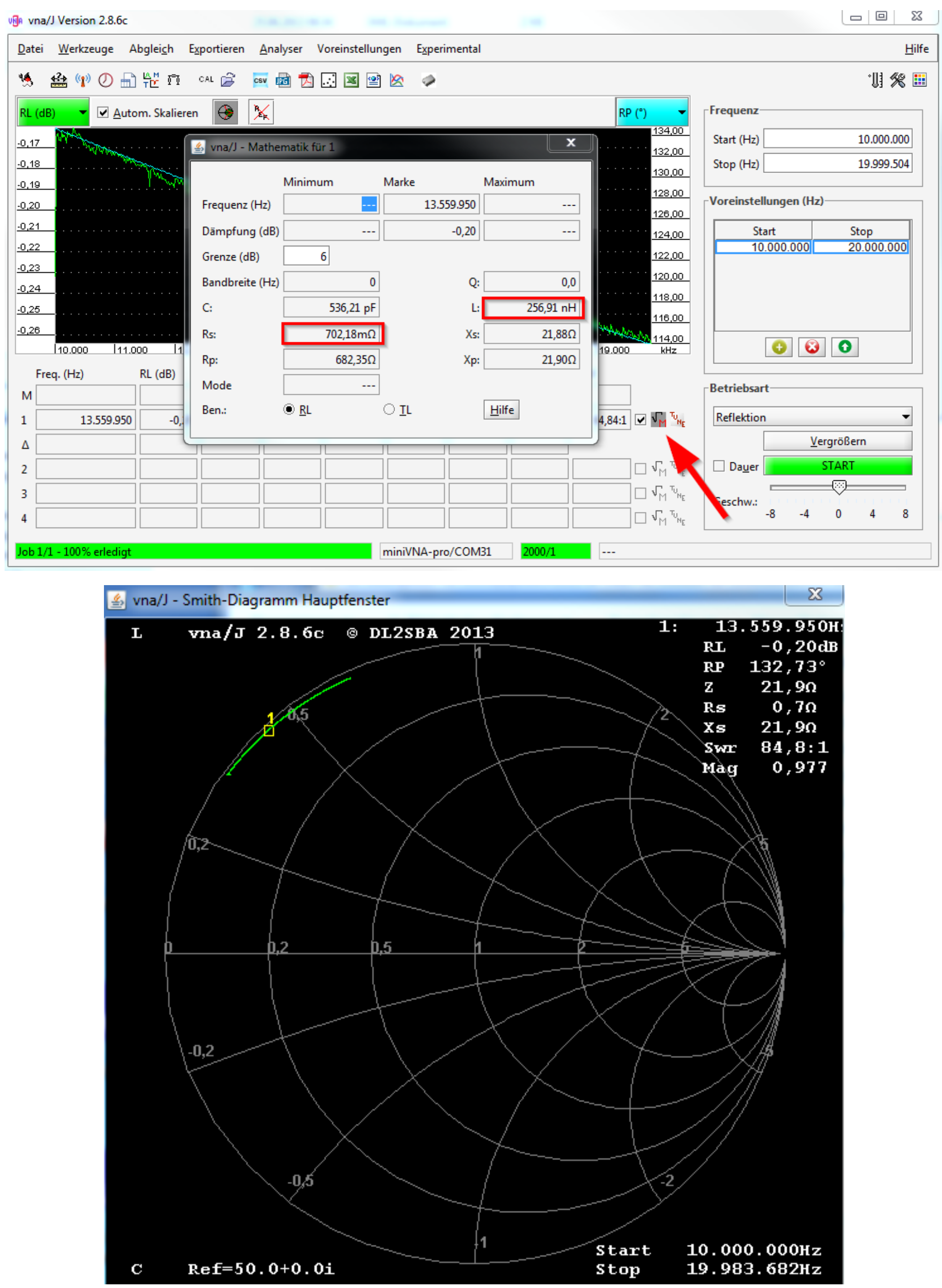
$$\underline{Z} = R + j\omega L_{Coil} \quad (1)$$

Typically the VNA directly can show the L and R, as shown in Fig 9 and Fig 10.



(1) Measurement with R&S ZVL

Fig 9. Measurement 1 Antenna coil



(2) Measurement with miniVNA Pro and vna/J

Fig 10. Measurement 2 Antenna coil

In this example the antenna coil is measured with these values:

L = 253nH

R_{Coil} = 0,7 … 0,82Ω

C_{pa} = not measured, can be estimated (typical in the range of 1-8pF)

The inductance can be measured quite accurate, but the resistance is not very accurate due to the relationship between R and jωL. And the capacitance is not measured at all with this simple measurement.

There are several ways to improve the accuracy and even further derive the capacitance, but these simple results are enough to start the tuning procedure. This tuning procedure needs to be done anyway, so there is no real need to spend more effort in measuring the antenna coil parameters more accurate.

3.3 PLM matching

The next step is to calculate the values of the matching circuit.

To generate the matching values the measured antenna values must be inserted in the calculation sheet (see 0):

3.3.1 PLM antenna measurement and matching calculation

1 Measured" values:

La = L = 250nH (measured antenna coil inductance)

Ca = C_{pa} = 0.1pF (estimated parallel capacitance of the antenna coil)

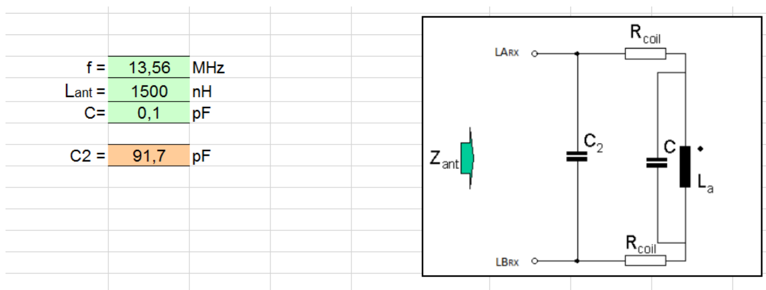
Additional to the measured values, the target values for must be added.

2 Preset values:

f_{Target} = 13,56MHz

3 Calculated Values and components: (Fig 11)

C2 = 91,7pF -> 82pF+10pF (0,3pF additional)



Excel sheet is included in this document as attachment, see Section 5.3

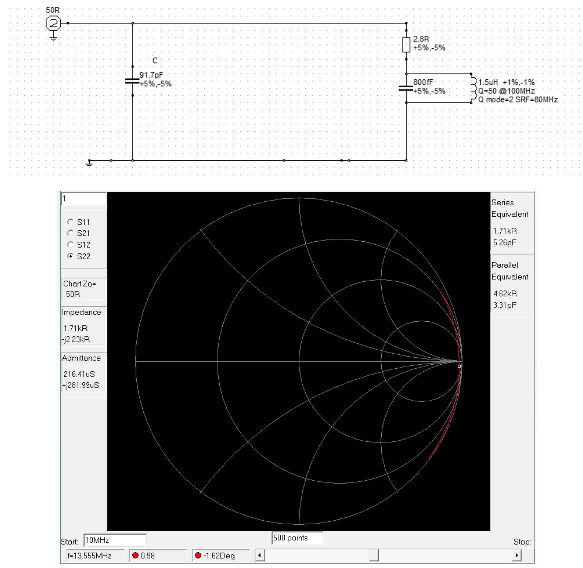
Fig 11. Antenna matching calculation PLM

3.3.2 Simulate the matching

The measurement of the antenna coil itself typically is not very accurate, except the inductance. Therefore a (fine) tuning of the antenna can be required, which might become easier in combination together with a simulation.

A simple matching simulation tool like e.g. RFSIM99 can be used to support the antenna tuning. The simulation input and the result based on the above given start values for the antenna matching is shown in

With these values the assembly can be done,



PLM simulation schematics and smith chart

The “measurement GND” is not the NTAG 5 and evaluation board GND!

Fig 12. RFSIM99 Schematic and smith chart

4. List of abbreviations

This document uses the following list of abbreviations:

A_c	Average antenna area
A_{Active}	Active antenna area
A_i	Area of antenna winding i
a_{avg}, b_{avg}	Average dimensions of the antenna
a_{max}, b_{max}	Maximum dimensions of the antenna
a_o, b_o	Overall dimensions of the antenna
C_c	Antenna capacitance
C_{br}	Bridge capacitance
C_{Con}	Capacitance due the connection NTAG 5 IC – antenna
C_{IC}	NTAG 5 IC input capacitance
C_{ICT}	NTAG 5 IC input capacitance for threshold condition
C_{in}	Designed inlet capacitance
C_{it}	Inter turn capacitance of the antenna
C_{pl}	Parallel equivalent capacitance of the inlet
C_{plT}	Parallel equivalent capacitance of the inlet for threshold condition
d	Antenna wire diameter
f	Frequency
f_{op}	Operating frequency
f_R	Resonance frequency of the inlet
f_{RT}	Threshold resonance frequency of the inlet
g	Gap between the tracks
H_T	Threshold field strength
H_{Tmin}	Minimal threshold field strength
H_{Top}	Threshold field strength at operating frequency
I_1	Reader antenna current
L_{calc}	Inductance calculated out of the geometrical antenna parameters
L_o	Objective inductance of the antenna
L_{pc}	Parallel equivalent inductance of the antenna
L_{sc}	Serial equivalent inductance of the antenna
M	Mutual inductance between the inlet antenna and reader antenna
N_c	Number of turns of the antenna
p	Turn exponent
Q	Quality factor of the inlet
Q_{pc}	Quality factor of the antenna for parallel equivalent circuit
Q_{sc}	Quality factor of the antenna for serial equivalent circuit
Q_T	Threshold quality factor of the inlet
R_{Con}	Resistance of the connection NTAG 5 IC – antenna

R_{IC}	NTAG 5 IC input resistance
R_{ICT}	NTAG 5 IC input resistance for threshold condition
R_{pc}	Parallel equivalent resistance of the antenna
R_{pl}	Parallel equivalent resistance of the inlet
R_{plT}	Parallel equivalent resistance of the inlet at threshold condition
R_{sc}	Serial equivalent resistance of the antenna
t	Track thickness
$V_{LA\text{-}LB}$	NTAG 5 IC input voltage
$V_{LA\text{-}LB\ min}$	Minimal voltage level for NTAG 5 IC operation
w	Track width

5. Reference documentation

NXP provides several documents to support the development of customized antennas.

5.1 Data sheets

NXP provides the following datasheets:

- NTP5210 - NTAG 5 switch, NFC Forum-compliant PWM and GPIO bridge, Product data sheet, doc.no. 544630
  https://www.nxp.com/docs/en/data-sheet/NTP5210.pdf

- NTP53x2 - NTAG 5 link, NFC Forum-compliant I2C bridge, Product data sheet, doc.no. 544530
  https://www.nxp.com/docs/en/data-sheet/NTP53x2.pdf

5.2 Application notes

NXP provides the following application note:

- AN12428 - NTAG 5 design recommendations for FCC and CE certifications
  https://www.nxp.com/docs/en/application-note/AN12428.pdf

5.3 Included antenna matching calculation excel sheet

As attachment you will find a ZIP file containing the antenna matching calculator.

The Excel file is enclosed in a ZIP file which has the file extension .nxp. To access the Excel file, you can do the following:

a. Open the attachment by clicking the paperclip in the left margin.
b. You will find a .nxp file added to this PDF as an attachment. Right-click the file and click Save Attachment. Store it at a permanently available (network) storage location.
c. Open the location where you saved the attachment.
d. Rename the file. Change the extension from .nxp into .zip.
e. Now you can open the zip file which contains the Excel file.

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