AN12339

Antenna design guide for NTAG 5 Boost

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Document information

Information	Content
Keywords	NTAG 5 Boost, antenna theory, antenna design, measurement methods, antenna design procedure
Abstract	NTAG 5 Boost needs to be connected to an antenna to access NTAG 5 via NFC interface. This application note provides guidance for designing such an antenna.

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 and match antennas for NTAG 5 Boost with active load modulation.

The main use of NTAG 5 Boost is in "NFC inhospitable environments". Typically a small NFC antenna in a metal environment. Here, standard passive NFC tags would perform poorly or not at all. But with active load modulation (ALM), the NTAG 5 Boost can operate with sufficient performance in these environments.

Disclaimer: Environmental Use and Performance Limitation

The **NTAG 5 Boost** is designed for optimal performance under defined operating conditions. **Functionality and performance may be limited when used in open or uncontrolled environments**, such as different readers or interaction with mobile phones. Environmental factors including temperature fluctuations may impact the tag's reliability and communication range also.

In such cases, customers are also required to perform robustness testing at the application level with the targeted reader or mobile systems to ensure compatibility and performance under their specific use conditions. The manufacturer does not guarantee full functionality or performance outside of recommended usage environments.

2 NTAG 5 Boost use case examples

As highlighted in the introduction, the NTAG 5 Boost is primarily intended for environments where conventional passive NFC tags would struggle to operate effectively or fail entirely.

See a few examples below:

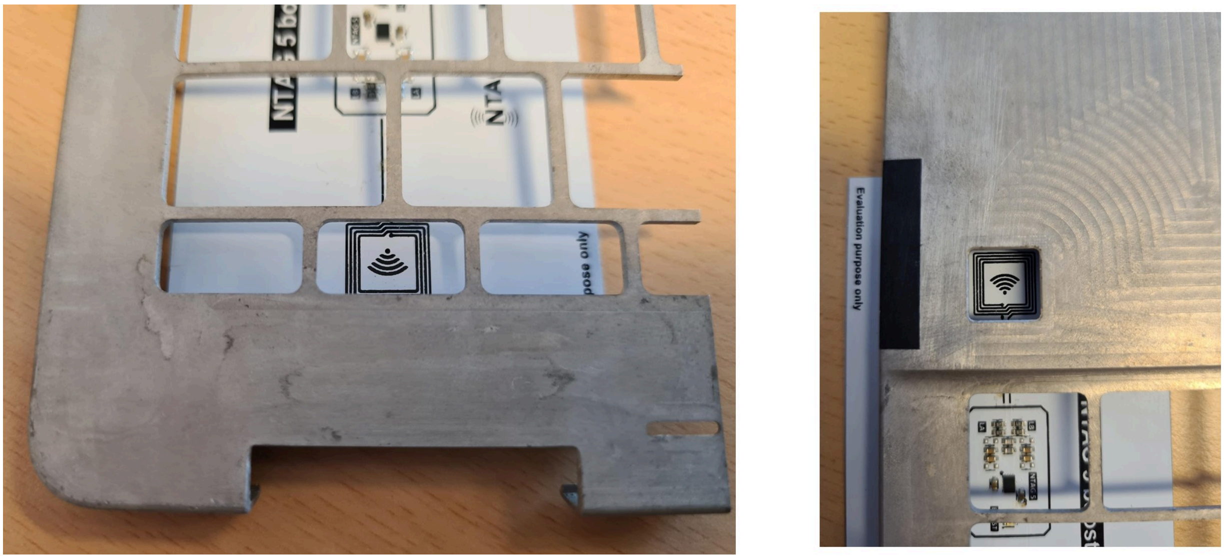

Figure 1. NTAG 5 Boost in a metal environment (keyboard)

NTAG 5 Boost can also be helpful if the NFC antenna cannot be placed directly under the device surface. See an example below.

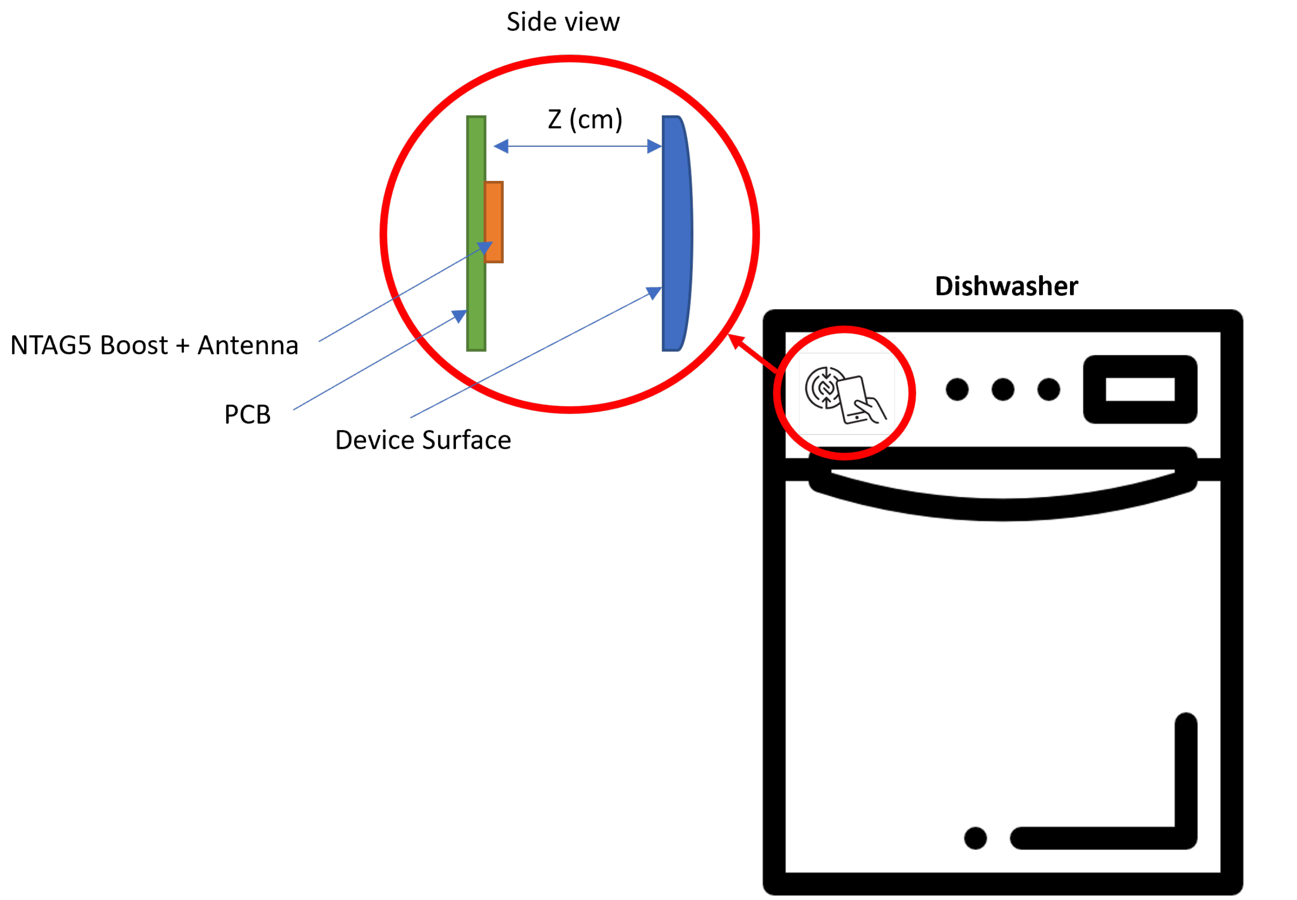

Figure 2. NTAG 5 Boost - Spacing example

3 Antenna basics

3.1 Series and parallel equivalent circuits

3.1.1 Series equivalent circuit of the antenna

The antenna can be described by an inductance L_{sc} in series to a loss resistance R_{sc}. 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.

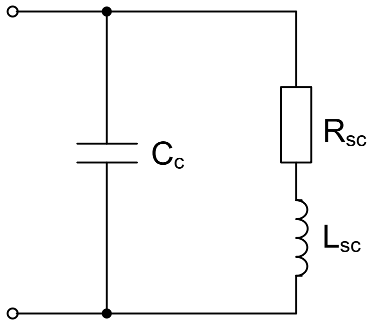

Figure 3. Series equivalent circuit of the antenna

The antenna quality factor is calculated by

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

with operating frequency f_{op} = 13.56 MHz.

3.1.2 Parallel equivalent circuit of the antenna

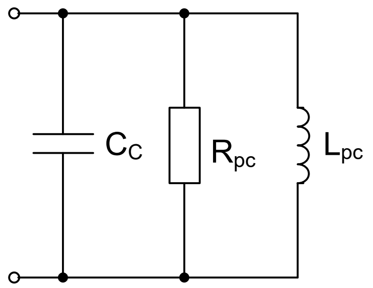

Figure 4. Parallel equivalent circuit of the antenna

The following applies:

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

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

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

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

3.2 Q-factor adjustment

To get a proper shaping in terms of fall and rise time of the pulse, the Q-factor needs to be optimized. The target Q-factor should not be above 14. The Q-factor should also not be too low as this reduces the performance. To check the proper values of the damping resistors, check the answer shaping (see Figure 5). The target here is to have a proper shaping as shown on the signal on the right (Figure 5).

Figure 5. ALM answer shaping

3.3 Antenna sizes

Depending on possible antenna sizes, NTAG 5 link/switch with passive load modulation (PLM) and NTAG 5 Boost with active load modulation (ALM) will be used. NTAG 5 Boost should be used for antennas smaller or equal class 6. For larger antennas NTAG 5 link/switch should be used (see Figure 6). The active load modulation can also be changed from ASK to BPSK mode to increase the response strength even further for the smallest antenna sizes.

Figure 6. Antenna size vs load modulation technologies

The maximum recommended antenna size for NTAG 5 Boost is 25 mm vs 20 mm (square) or ⌀ 25 mm (circle). We also recommend keeping the antenna inductance lower than 600 nH.

3.4 Antenna design

After fixing the antenna outline, the number of turns shall be chosen in a way to meet the inductance target value. The antenna inductance can be calculated with the help of the NFC Antenna Design Hub tool available on NXP webpage.

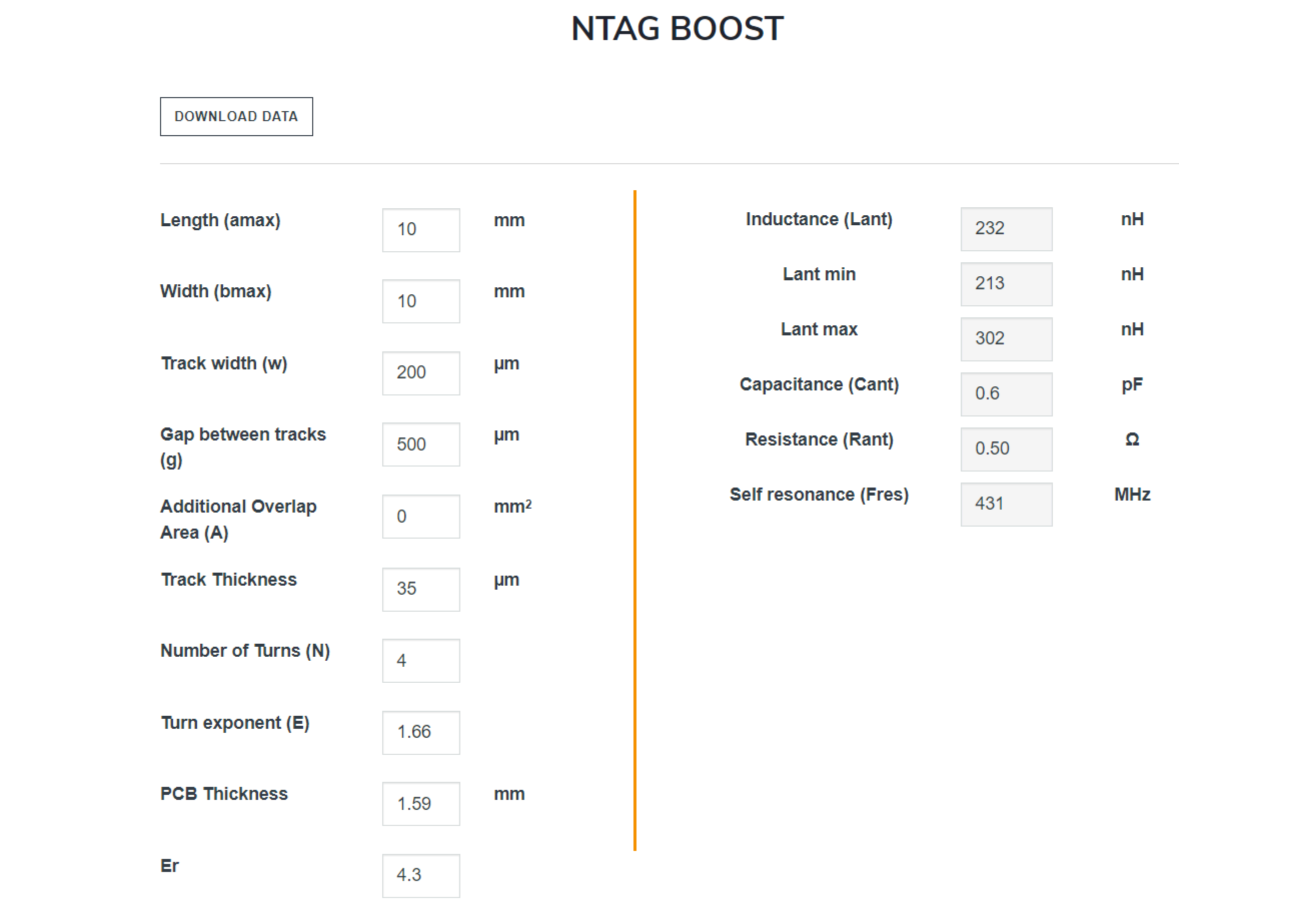

Figure 7. NFC antenna design tool

The tool calculates the inductance with the given size and shaping a big influence has also the rounding of the edges to the inductance.

In this case, an inductance approx. 232 nH is calculated.

In this case it is within our targeted range so the antenna prototype can be produced, and the measurement and matching can be done on the prototype.

4 Antenna matching

4.1 Matching topology

The ALM matching topology contains a capacitive voltage divider to guarantee a maximum voltage at the La/ Lb Rx pins below 1.4Vp during ALM (The receive phase). This ensures reliable functionality for 10% amplitude modulation.

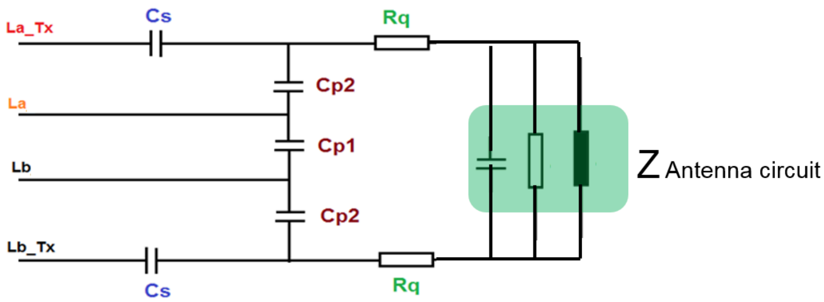

Figure 8. ALM topology

4.2 General antenna matching procedure and preparation

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. 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 equivalent circuit parameters
2. Calculate the matching components
3. Simulate the matching
4. Assembly and measurement
5. Adaptation of simulation
6. Correction and assembly

Note that the antenna equivalent circuit must be determined under the final environmental conditions, especially when the antenna is operated in a metal environment

4.2.1 Measure the antenna equivalent circuit parameters

The antenna coil must be designed as described in Section 3 be measured. The measurement is required to derive the inductance L, the resistance R_{Coil} and the capacitance C_{pa} as accurately 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 13.56 MHz and to calculate L and R out of it:

$$\underline{Z} = R + j\omega L_{Coil} \tag{1}$$

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

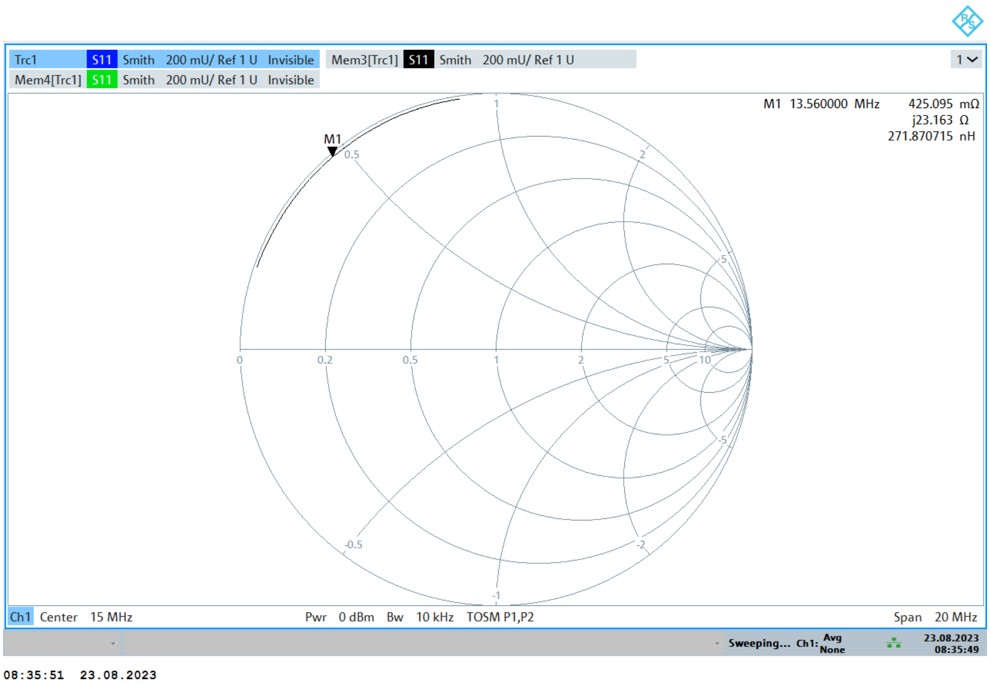

Figure 9. Measurement 1 Antenna coil

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

L = 271 nH

R_{Coil} = approx. 0.42 Ω

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

The inductance can be measured quite accurately, but the resistance is not very accurate due to the relationship between R and jωL. Also note that 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 accurately.

4.3 Antenna matching

4.3.1 Matching circuit calculation

The matching can be calculated using the NXP Antenna Design Hub Tool as shown below.

Due to the manufacturing tolerances the antenna length, width and gap between tracks can be adjusted to get approx. the same antenna inductance as measured in Figure 9. The antenna resistance is not the critical parameter as the measurement accuracy is limited.

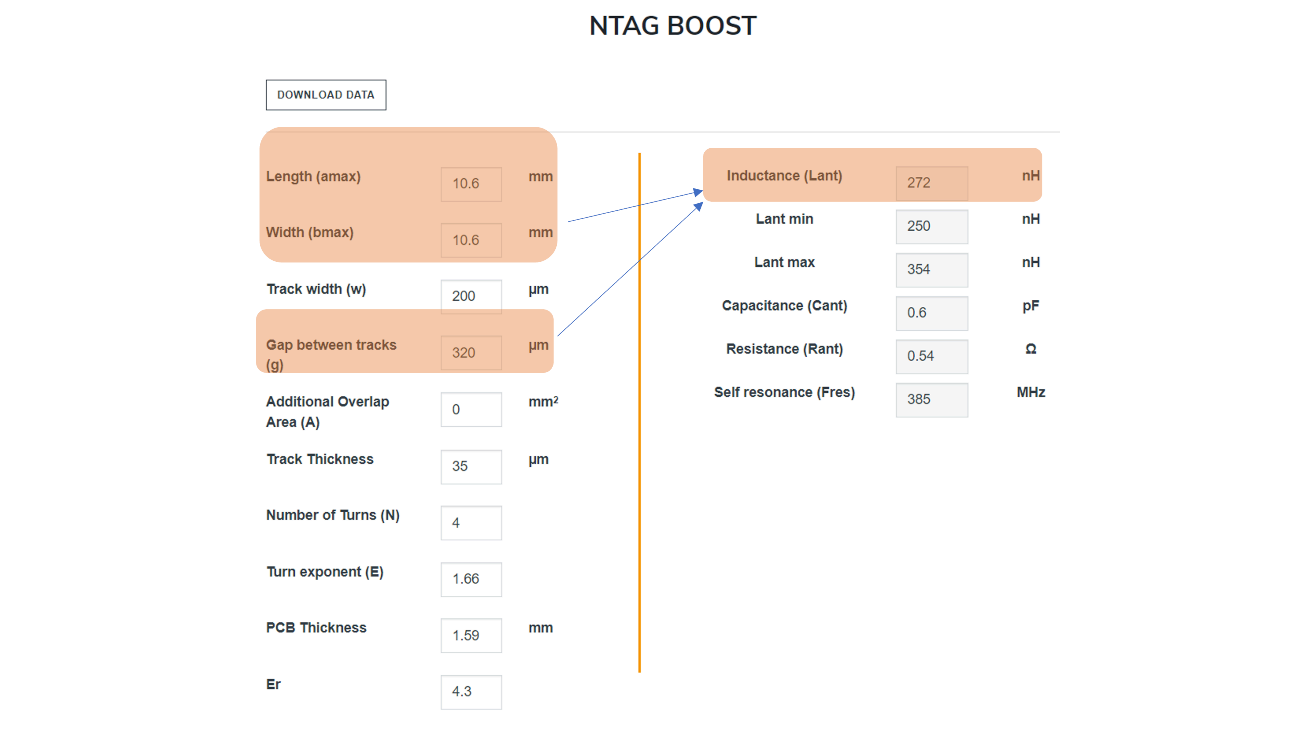

Figure 10. Antenna parameters adjustment

The next step is to calculate the matching values. Typically, there is no need to change the input default values (only the Receiver Resonance Frequency).

Figure 11. Calculate the matching values

4.3.2 Simulate the matching

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

A simple matching simulation tool like, for example, RFSIM99, can be used to support the antenna tuning.

Since there are two paths, which must be tuned (TX and RX path). Sometimes, it can be very challenging to tune them exactly at 13.56 MHz.

The recommendation is that the RX path (Antenna resonance) should be tuned approx. **13.56 MHz - 14 MHz.** The Tx path is not so critical due to the ALM. For the TX path, the recommended value is between **13.56 MHz -16 MHz**.

For simulations, the NTAG 5 Boost receiver (La, Lb) is represented as 865 Ω || 18.5 pF.

See the Rx path simulation in Figure 12. For this simulation, the NTAG 5 Boost transmitter (Latx, Lbtx) is in "High Z" (10K resistor).

The values obtained from Figure 11 have been used as input for the simulation. These values were slightly adapted to fit with the standard "E" series capacitors values.

- Cp1= 873.2 pF → 820 pF + 56 pF
- Cp2= 2411.8 pF → 2200 pF + 220 pF
- Cs= 618.1 pF → 560 pF + 56 pF

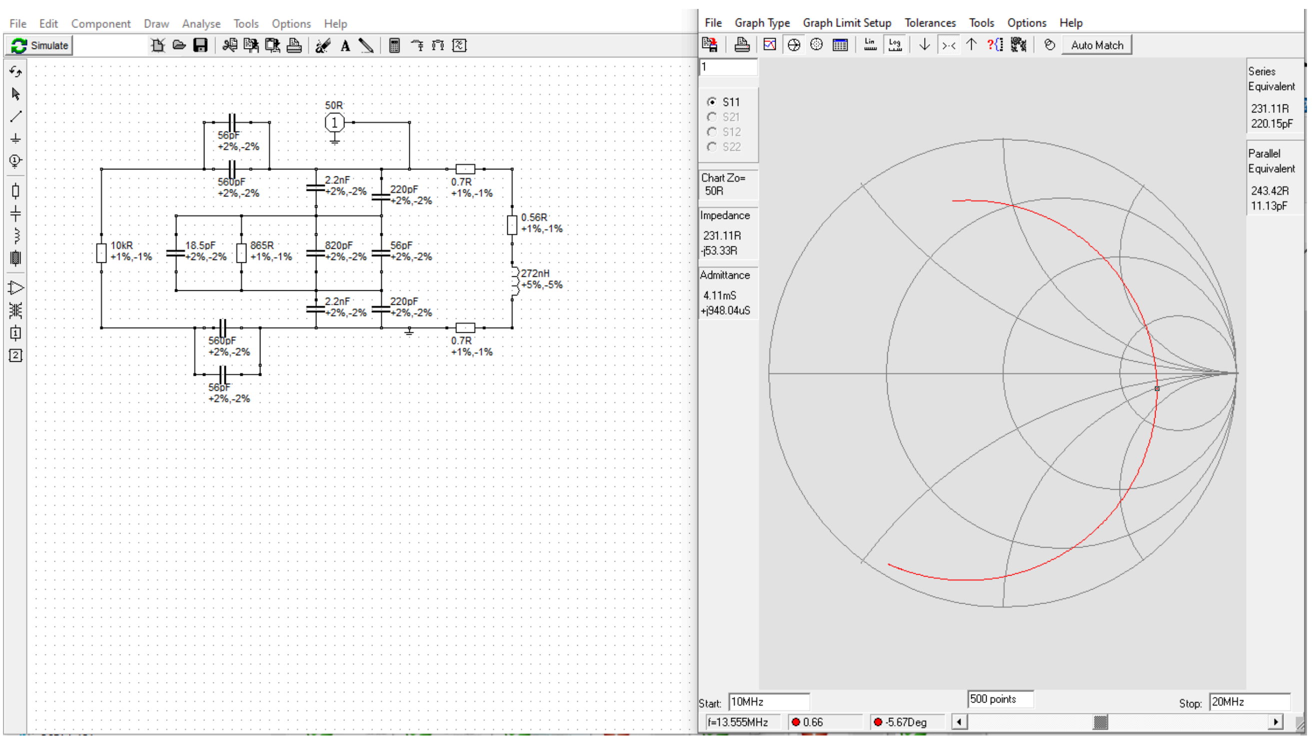

Figure 12. "RX" path tuning simulation before optimization

The Tx path simulation is shown in Figure 13.

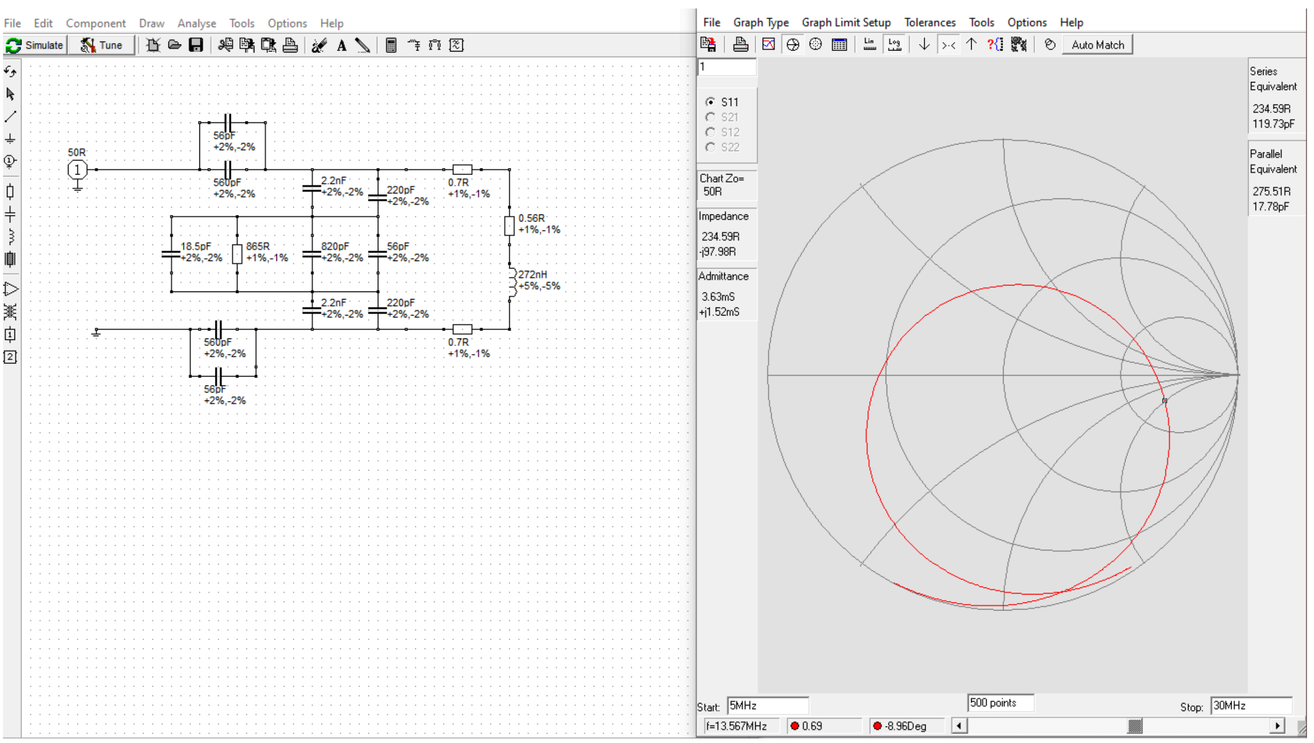

Figure 13. "TX" path tuning simulation before optimization

For both paths, the resonance is below 13.56 MHz (approx. 13.2 MHz). So, fine tuning of the Cp1 and Cp2 will be required.

4.3.3 Assembly and measurement

Just to illustrate, the values from Figure 12 have been assembled. The measurement is shown in Figure 14.

The corelation with the simulations described in Section 4.3.2 is obvious.

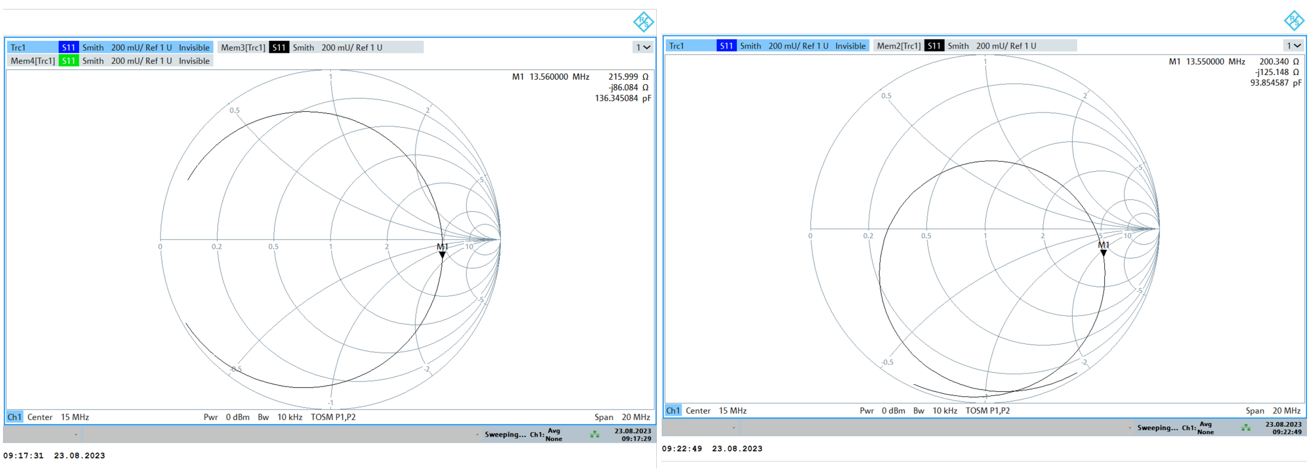

Figure 14. Measurement before optimization (NTAG 5 Boost is not powered)

Note that the impedance tuning must be measured under the final environmental conditions, especially when the antenna is operated in metal environment.

4.3.4 Impedance fine-tuning

For the fine-tuning, the RFSIM99 can also be used. To **increase** the resonance frequency, the Cp1 and Cp2 must be **decreased**.

Pay attention to the right ratio between Cp1 and Cp2 (both values must be changed, but the ratio should approx. be the same).

→ Values calculated using Antenna Design Hub → Cp1=873.2 pF, Cp2=2411.8 pF → Ratio = 873.2/2411.8 ≈ **0,36**

→ New Cp1 and Cp2 values after the optimization → Cp1=820 pF, Cp2=2200 pF → Ratio = 820/2220 ≈ **0,37**

After the Cp1 and Cp2 adjustment, the RX simulated resonance is approx. at 13.66 MHz (Figure 15).

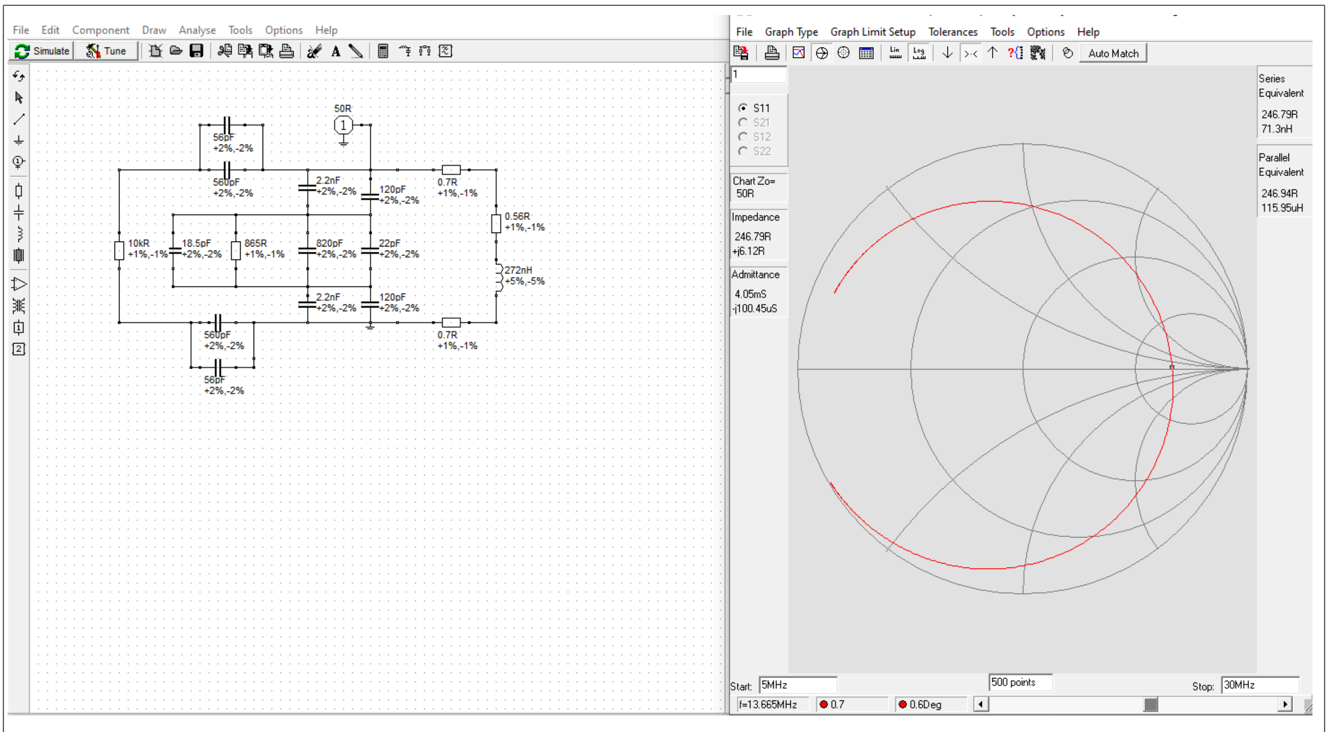

Figure 15. "RX" path tuning simulation after optimization

For the TX, the resonance is apprrox. at 13.56 MHz (Figure 16)

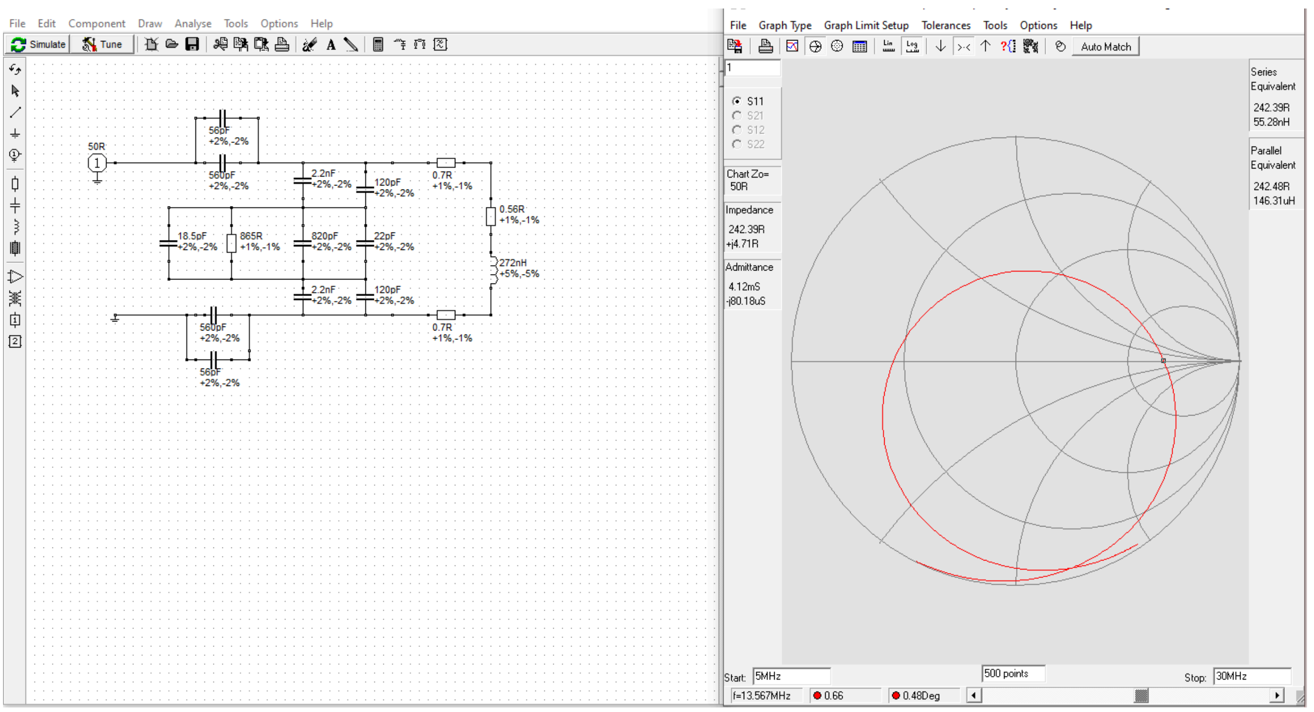

Figure 16. "TX" path tuning simulation after optimization

The new values from the simulations above have been assembled.

- Cp1= 820 pF
- Cp2= 2200 pF
- Cs= 560 pF + 56 pF
- Rq= 1.5 R || 1.5 R

See the resonance frequency measurement in Figure 17.

The measured values are 13.78 MHz for the RX and 13.7 MHz for the TX. These values meet the requirements described in Section 4.3.2 chapter.

Therefore, there is no need to continue with the fine-tuning and the values written above can be used for the final design.

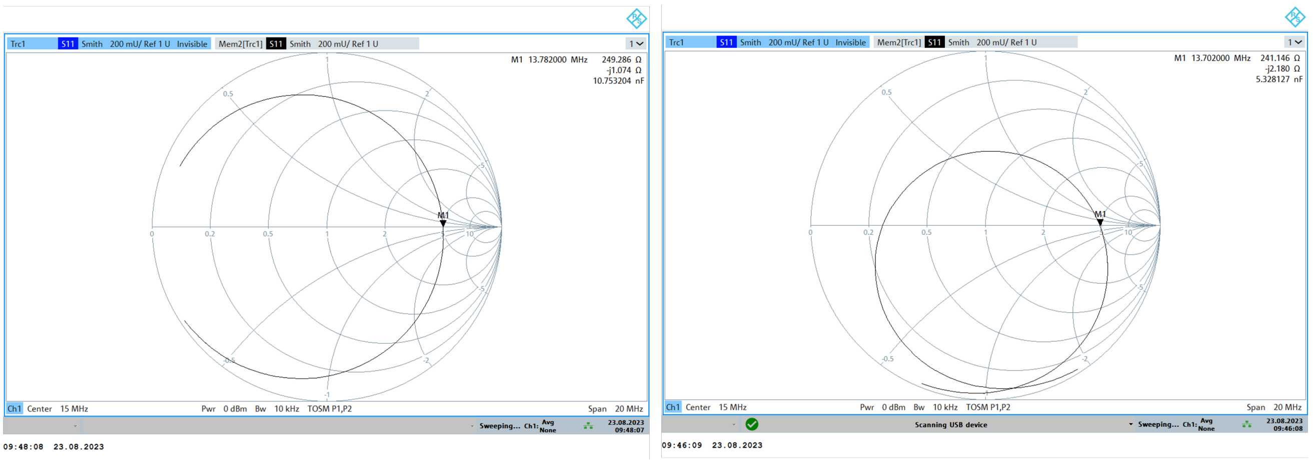

Figure 17. Measurement before optimization (NTAG 5 Boost is not powered)

4.3.5 Receiver voltage (LA / LB Rx) check

The ALM matching topology should ensure that the maximum voltage at the LA/LB Rx pins stays below 1.4Vp during ALM (The receive phase).

This can be measured with the help of the scope and a target reader (for example, a cell phone).

The reader (phone) is placed in the maximum coupled position with the NTAG 5 Boost antenna as shown in Figure 18

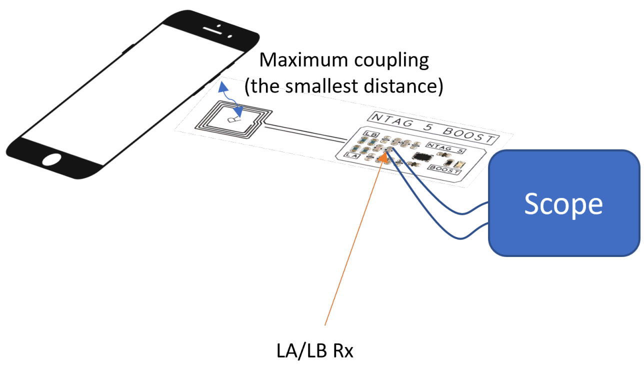

Figure 18. Receiver voltage measurement

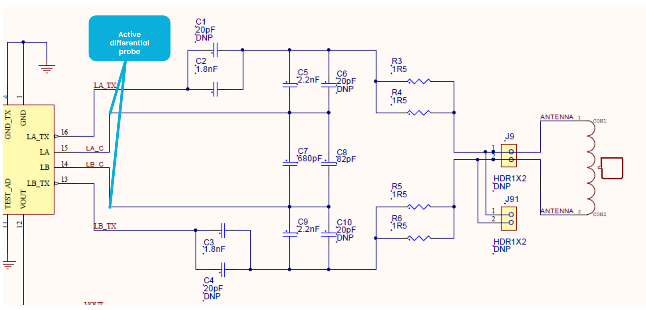

Figure 19. Receiver voltage measurement - schematic view

Then, the tag is read (for example, with the help of the NFC TagInfo by NXP) and the signal is captured using the scope on the LA, LB Rx pins. The signal should not exceed 1.4 Vp during the "receive" phase as shown in Figure 20. If the signal is above 1.4 Vp, the NTAG 5 Boost may not recognize modulation from the reader, and it may lead to the fails in communication. If this is the case, the Cp1 has to be reduced to decrease this voltage.

It is useful when the LA, LB voltage is between 1.2 Vp -1.35 Vp for the maximum coupled position. It ensures a maximum operating volume. Also it is good to repeat the test with a couple of mobile phones/readers from different manufacturers.

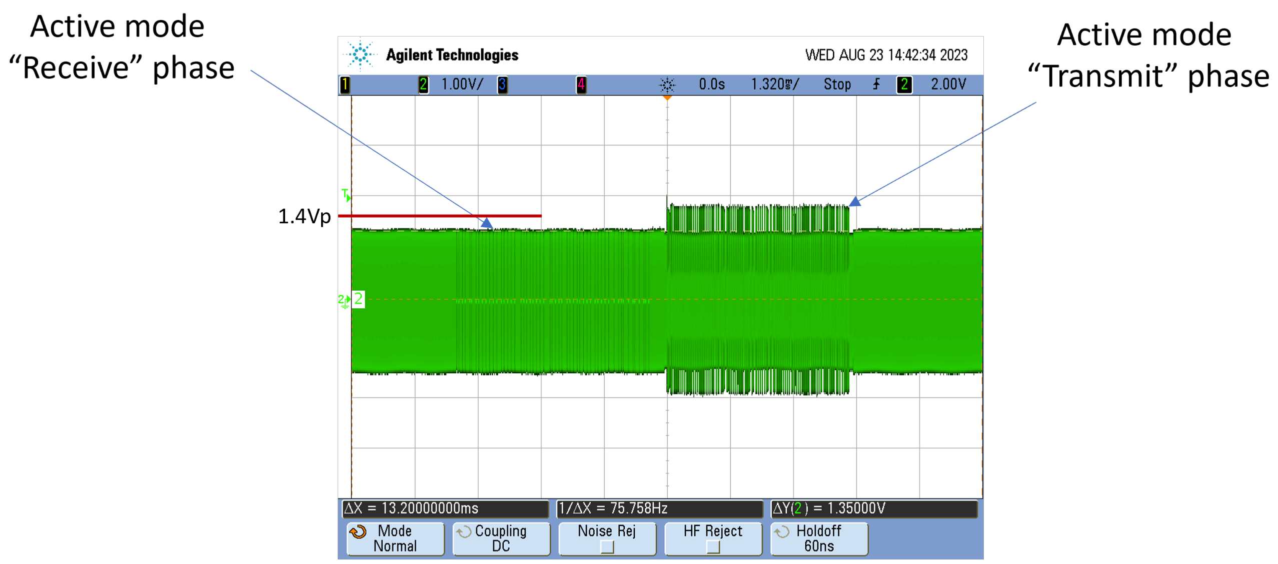

Figure 20. LA, LB Rx voltage for maximum coupled position

For this measurement, we recommend using an active differential probe with low capacitance, for example, ZD200 - Teledyne LeCroy or similar.

4.4 ALM LUT

The ALM lookup table (LUT) is a dynamic setting of the TX power that is used to change the strength of the answer signal. This is used to stay within the NFC limits and reduce the power in close coupling condition, if needed. The ALM LUT is always used if ALM is enabled and the threshold (H-field value) for each step is fixed and cannot be changed.

Simply said, the NTAG 5 Boost can identify the H-field value based on the input voltage and current and set the corresponding LUT value.

The LUT contains 16 entries’ starting at address 41h up to 44h. Each address contains four bytes, so four entries per address. (See Figure 21)

Block Address		Byte 0	Byte 1	Byte 2	Byte 3
NFC	I²C				
40h	1040h	ALM_CONF_00	ALM_CONF_01	ALM_CONF_02	ALM_CONF_03
41h	1041h	ALM_LUT_00	ALM_LUT_01	ALM_LUT_02	ALM_LUT_03
42h	1042h	ALM_LUT_04	ALM_LUT_05	ALM_LUT_06	ALM_LUT_07
43h	1043h	ALM_LUT_08	ALM_LUT_09	ALM_LUT_10	ALM_LUT_11
44h	1044h	ALM_LUT_12	ALM_LUT_13	ALM_LUT_14	ALM_LUT_15

Figure 21. LUT address range

The Figure below shows the ideal behavior of the strength of the answer over H-field. For higher H-field (typically a closer distance between a reader and NTAG 5 Boost), the answer strength is getting lower and creates the "step" pattern as shown below. This can be measured with the help of the ISO test bench (ISO 10373-6 TEST PCD ASSEMBLY 2). The measurements have been obtained using the NFC Xplorer device.

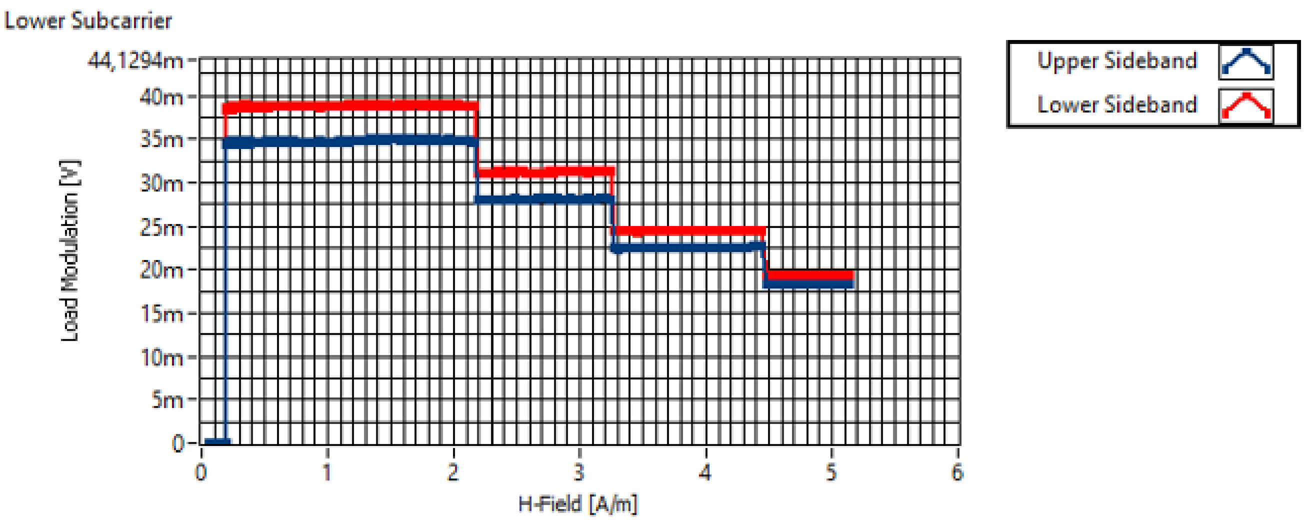

Figure 22. NTAG 5 Boost - Typical strength of the answer signal

Each byte of the ALM LUT contains the option to change the answer strength as well as adjust the bit phase (normally not needed), if necessary. The strength of the answer signal can be adjusted by changing the RON (fine adjustment with small steps) or by changing from BPSK to ASK (substantial change). The RON can be combined with BPSK and ASK mode. (See Figure 24)

- ASK → Less ALM level
- BPSK → More ALM Level (suitable for very small antennas)
- RON
  - 1574 Ω → Max damping
  - 17 Ω Ω → Min damping

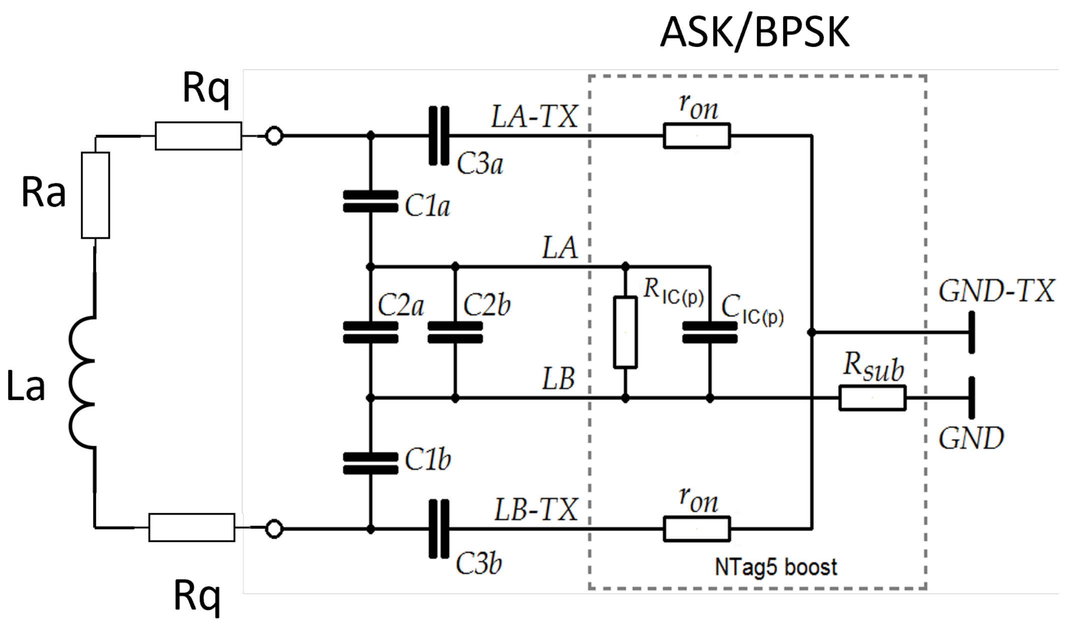

Figure 23. The ALM LUT controls RON value also can switch between ASK and BPSK modulation.

Bit	Name	Value	Description
7 to 5	Dynamic phase adjust	xxxb	adjust phase in 11.25° steps
4	Enable BPSK	0b	ASK
		1b	BPSK
3 to 0	RON	0000b	1574 Ω
		0001b	716 Ω
		0010b	414 Ω
		0011b	248 Ω
		0100b	123 Ω
		0101b	82 Ω
		0110b	62 Ω
		0111b	49 Ω
		1000b	41 Ω
		1001b	35 Ω
		1010b	31 Ω
		1011b	27 Ω
		1100b	25 Ω
		1101b	22 Ω
		1110b	21 Ω
		1111b	17 Ω

Figure 24. ALM LUT value content

The settings can be done with the help of the RFID Discover tool that is available through the NXP webpage.

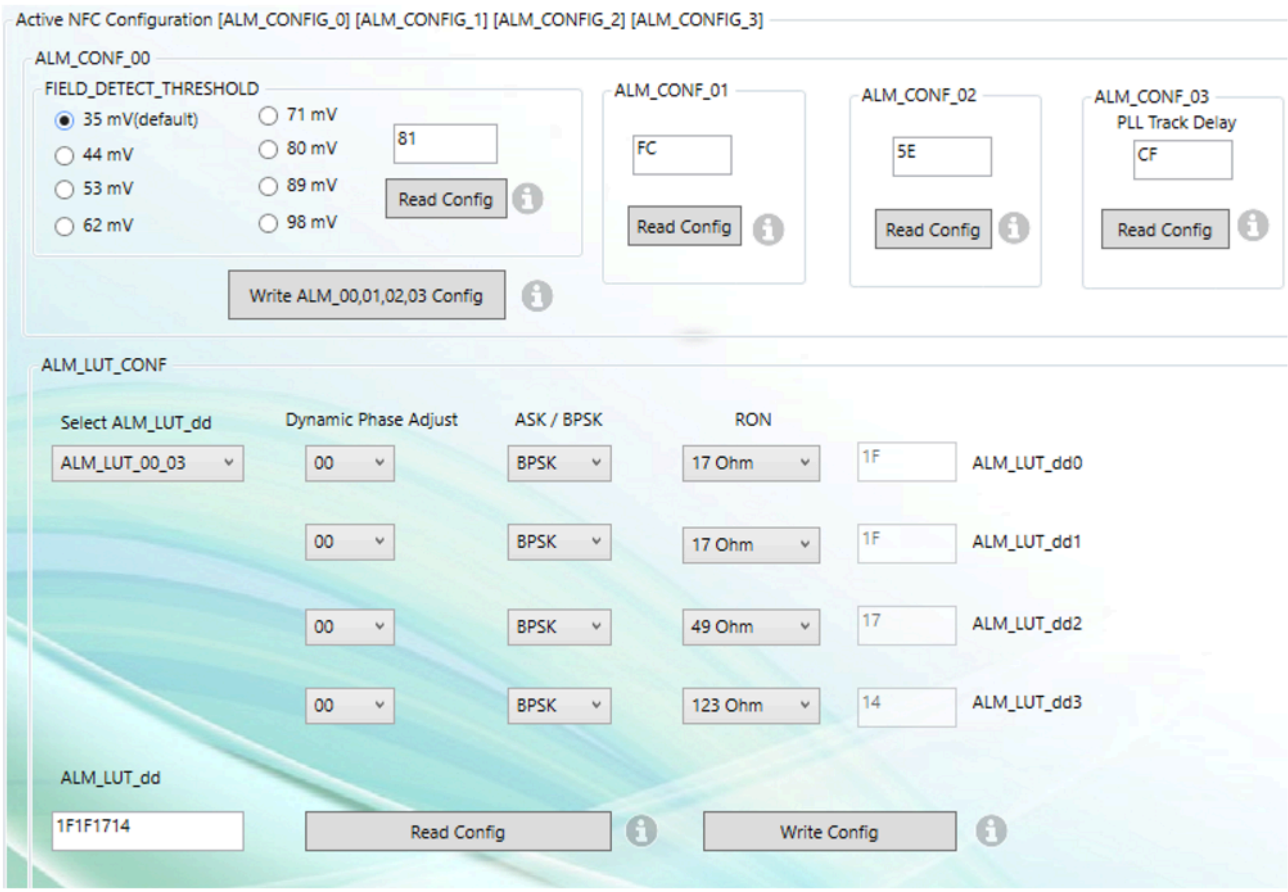

Figure 25. NTAG 5 Boost ALM settings in RFIDDiscover

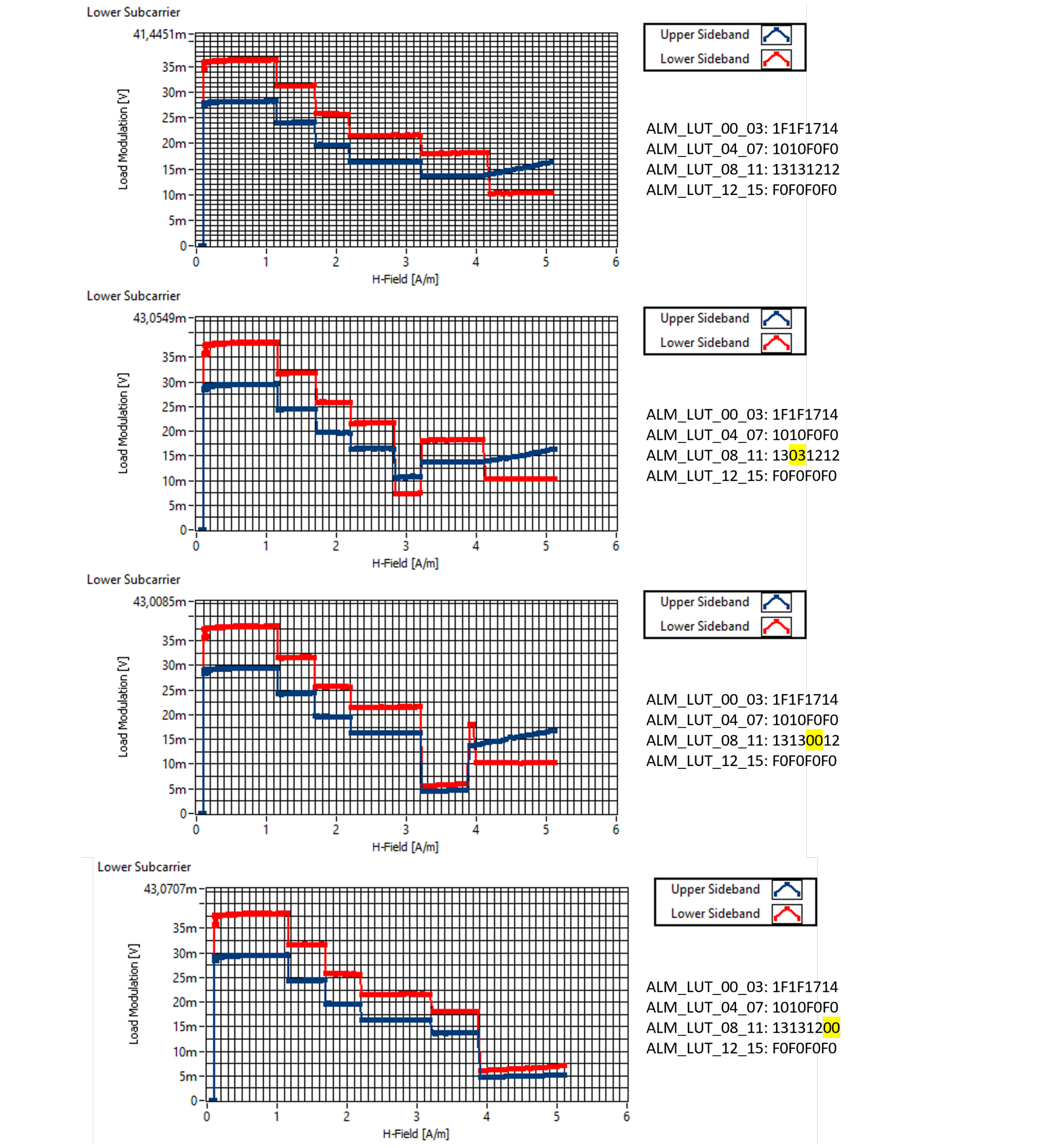

Figure 26. Influence of LUT entries

If you do not have the ISO test bench, the LUT settings can be estimated. The idea is that for the low coupling (bigger distance between a reader and NTAG 5 Boost), the H-field is quite low. So, the ALM should be stronger → BPSK + low value of RON.

Vice versa, if the coupling is high (closer distance between the reader and NTAG 5 Boost), the H-field is high. Then, the ALM shall be reduced by ASK + higher RON value.

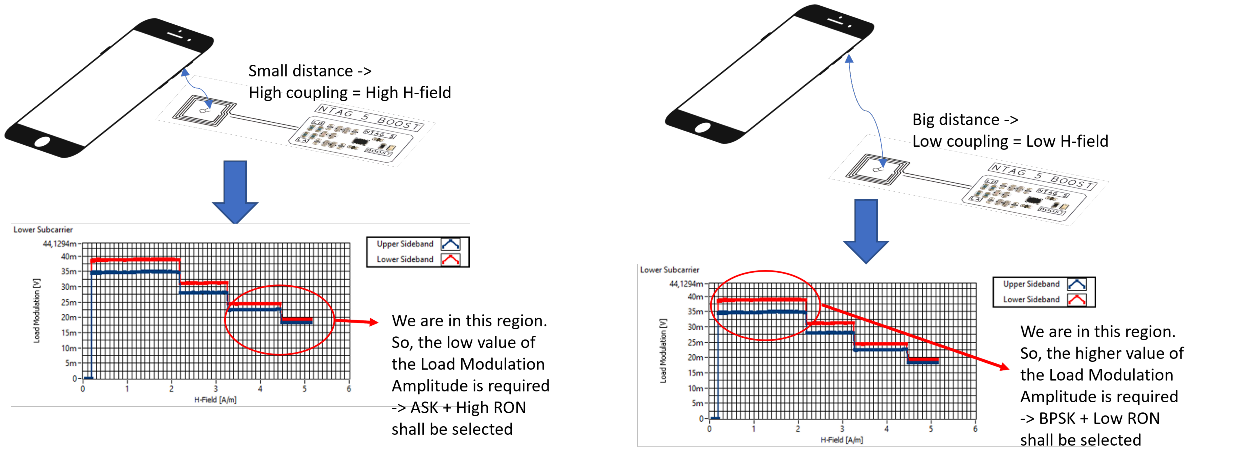

Figure 27. ALM regulation principle

The default entries of the ALM LUT can be used and they are a good starting point as such. They only need to be changed if the card answer is too strong, in respect to the field strength during the certification test.

If the antenna is for any reason larger than recommended in Section 3.3 and coupling is too high. User can face an issue with the NFC communication. If this is the case, then the user is recommended to set all ALM LUT (0-15) entries as **0x00** (ASK & RON= 1574 Ω) and test the performance.

4.5 LUT values for 10 mm x 10 mm antenna

The LUT values need to be set according to antenna size and the supply.

Below are the default values for the 10 mm x 10 mm antenna of the evaluation board.

Table 1. LUT for 3,3 V supply with 10 mm x 10 mm antenna (L= 272 nH, R = 0,47Ω)

Address (I²C)	Byte 0	Byte 1	Byte 2	Byte 3
1041h	0x1F	0x1F	0x17	0x14
1042h	0x13	0x13	0x12	0x12
1043h	0x10	0x10	0xF0	0xF0
1044h	0xF0	0xF0	0xF0	0xF0

Table 2. LUT for 1.62 V supply with 10 mm x 10 mm antenna (L= 272 nH, R = 0,47Ω)

Address (I²C)	Byte 0	Byte 1	Byte 2	Byte 3
1041h	0x1F	0x1F	0x1F	0x1F
1042h	0x1F	0x1F	0x1F	0x12
1043h	0x10	0x10	0x10	0x10
1044h	0x10	0x10	0x10	0x10

4.6 LUT values for 25 mm x 18 mm antenna

Below are the recommended values for the 25 mm x 18 mm antenna with the standard matching.

Table 3. LUT for 5 V / 3,3 V supply with 25 mm x 18 mm antenna (L= 528 nH, R = 1,2Ω)

Address (I²C)	Byte 0	Byte 1	Byte 2	Byte 3
1041h	0x1F	0x1F	0x17	0x14
1042h	0x13	0x13	0x12	0x12
1043h	0x10	0x10	0xF0	0xF0
1044h	0xF0	0xF0	0xF0	0xF0

5 SMT Antenna for very small designs

With active load modulation (ALM), very small antennas can be used. If thee design does not allow a PCB antenna, the SMT inductor could be a suitable alternative.

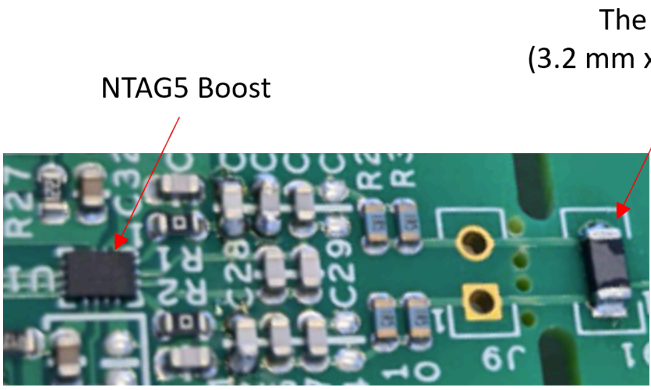

Figure 28. An example of the NTAG 5 Boost + SMT Antenna

The SMT inductor type has to be **z-axis wirewound inductor** or **multilayer inductor** (both unshielded). Its values should not exceed 600 nH.

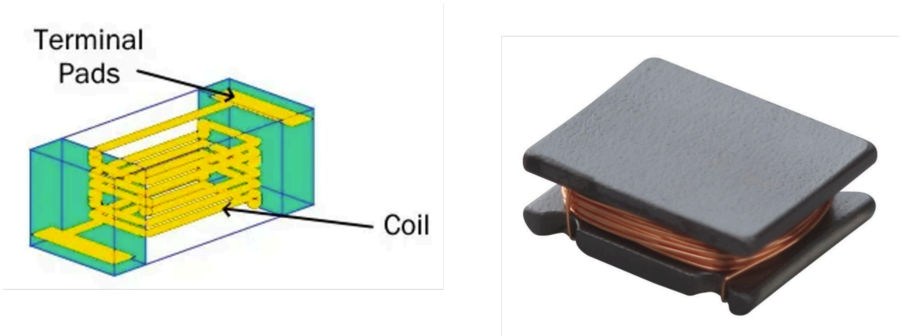

Figure 29. Multilayer inductor (left), z-axis wirewound inductor (right)

Recommended types are, for example, MCQ1V3216-R270-R, LQH2HNHR56K03L or similar

The reading distance for typical phones is approximately **20 mm - 25 mm.**

For such small antennas, we recommend keeping R_{ON}=17 Ω and BPSK for all LUT entries.

Table 4. LUT for 5 V / 3.3 V supply with SMT antenna

Address (I²C)	Byte 0	Byte 1	Byte 2	Byte 3
1041h	0x1F	0x1F	0x1F	0x1F
1042h	0x1F	0x1F	0x1F	0x1F
1043h	0x1F	0x1F	0x1F	0x1F
1044h	0x1F	0x1F	0x1F	0x1F

To further increase the RX sensitivity, the RX voltage divider can be replaced by one parallel capacitor.

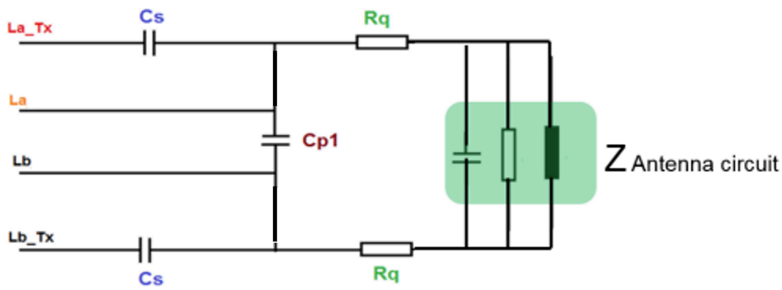

Figure 30. NTAG 5 Boost tuning circuit for very small antennas (SMT coils)

6 List of abbreviations

Table 5. Abbreviations

This document uses the following list of abbreviations:

Acronym	Description
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 to 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

Table 5. Abbreviations*...continued*

This document uses the following list of abbreviations:

Acronym	Description
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

7 References

1. Datasheet - NTA5332 - NTAG 5 Boost, NFC Forum-compliant I2C bridge for tiny devices, doc.no. 5447xx (link)
2. Application note - AN12428 - NTAG 5 design recommendations for FCC and CE certifications (link)

8 Revision history

Table 6. Revision history

Document ID	Release date	Description
AN12339 v.1.2	1 July 2025	Editorial changes (typos, etc.). Document updated to comply with the latest NXP guidelines. Document security status changed to "public". • Section 1 "Introduction": updated. • Section 2 "NTAG 5 Boost use case examples": added. • Section 3.4 "Antenna design": updated. • Section 4.3 "Antenna matching": updated • Section 4.4 "ALM LUT": updated. • Section 4.5 "LUT values for 10 mm x 10 mm antenna": updated. • Section 4.6 "LUT values for 25 mm x 18 mm antenna": added. • Section 5 "SMT Antenna for very small designs ": added. • Section 7 "References": updated.
AN12339 v.1.1	30 January 2020	Antenna matching calculation sheet added in the document.
AN12339 v.1.0	16 January 2020	First release.

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