AN1445

Antenna design guide for MFRC52x, PN51x and PN53x

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Application note
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Document information

Info	Content
Keywords	NFC, MFRC522, MFRC523, PN511, PN512, PN531, PN532, Antenna Design, RF Design, constant current design
Abstract	This application notes provides guidance on antenna and RF design for NFC devices MFRC522, MFRC523, PN511, PN512, PN531, PN532

Revision history

Rev	Date	Description
1.2	20101011	Update with MFRC522 and MFRC523
1.1	2008/02/22	Selection Guide and all topologies added
1.0	2007/10/31	Initial Release

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1. Introduction

1.1 Purpose and Scope

This application note is intended to give a practical guide to design and dimension antennas and RF parts for contactless reader as well as NFC devices. The application note will provide the required understanding to design application specific antennas and dimensioning RF parts to achieve the best performance for a communication according to the different communication schemes of the ICs.

The RF part covers the required matching circuit to match an application specific antenna coil to the output driver of the MFRC522/MFRC523/PN51x/PN53x as well as the receiving circuit in order to detect a received RF signal.

1.2 MFRC52x/PN51x/PN53x features

The MFRC522/MFRC523/PN51x/PN53x devices are designed to communicate in three different operation modes:

1. Reader/Writer mode to communicate to an ISO/IEC14443A, MIFARE card up to 100 mm depending on the antenna size and tuning. (MFRC52x /PN51x/PN53x).
2. Reader/Writer mode to communicate to a ISO/IEC14443 B card up to 100 mm depending on the antenna size and tuning (MFRC523/PN51x/PN53x).
3. Reader/Writer mode to communicate to a FeliCa card up to 100 mm depending on the antenna size and tuning (PN51x, PN53x).
4. NFCIP-1 mode to communicate to another NFC devices up to 100 mm depending on the antenna sizes and tuning (PN51x, PN53x).
5. ISO/IEC14443A, MIFARE card or FeliCa card mode to communicate to ISO/IEC14443A, MIFARE or FeliCa reader up to 100 mm depending on the generated external field strength. (PN51x, PN53x)

The MFRC52x/PN51x/PN53x's overall functionality can be separated into three functions:

6. **Generate the RF field**: The generated magnetic field has to be maximized within the limits of the transmitter supply current and general emission limits.
7. **Transmit data**: The coded and modulated data signal has to be transmitted in a way, that every card and MFRC52x /PN51x/PN53x device is able to receive it. The signal shape and timing according to relevant standards has to be considered.
8. **Receive data**: The response of a card or MFRC52x /PN51x/PN53x device has to be transferred to the receive input of the PN51x/PN53x considering various limits, e.g. maximum voltage and receiver sensitivity.

The operating distance for the MFRC52x/PN51x/PN53x depends on

- the matching of the antenna,
- the sensitivity of the receiving part,
- the antenna size of the device,
- the antenna size of the communication partner and
- external parameters, such as metallic environment and noise.

Note: MFRC52x devises are Reader/Writer devises only. So these are not able to operate in target mode.

2. How to use this document

The application note is intended to give a practical guide to choose the matching topology, to design antennas and calculate the matching components for the MFRC52x/PN51x/PN53x RF part. It gives a guideline starting with the recommended RF matching circuitry description as well as a dedicated description of the transmitter matching resistance and matching procedure in each chapter. The appendix of this document provides an introduction in the overall antenna design theory for the system.

Depending on the target applications, different design decisions can be made in order to optimize the antenna topology. The environmental constraints of a device/antenna are the influencing detuning parameters for the RX-path and have to be investigated. Conditions for a detuning are determined by the type of an application and housing, e.g. peer-to-peer mode, card mode, metal or composite plastic housing. These effects can cause large voltage drops at the RX-site and therefore may affect demodulation of the signal.

The user needs to follow the selection guide in chapter 3 to choose the appropriate antenna topology!

This application note is outlined as followed

1. Antenna Selection Guide
2. Antenna Topology I
3. Antenna Topology II
4. Adoptions of Antenna Topology I or II
5. Antenna Topology III
6. Appendix

    a. The appendix includes information describing the calculation of the inductance of an antenna coil and gives basic hints on symmetry and environmental influences. The calculation of the equivalent circuits and an overview of all relevant formulas are give as well as Tips and hints to check the antenna and RF part design.

Each Antenna Topology provides information about

a. The RF part block diagram. It shows a recommended circuitry design with all relevant components required to connect an antenna to the PN51x/PN53x. It also ensures the transmission of energy and data to the target device as well as the reception of a target device answer.

b. The TX matching resistance R_{match} is explained which is required to calculate the remaining components and to optimize PN51x/PN53x power consumption.

c. Formulas to calculate the EMC filter and the matching circuit
d. Antenna tuning procedure
e. Design and calculation of the receiving part
f. Example calculations

Note: This application note does not replace the relevant datasheets referenced in chapter 9.

“Card” in this document means a contactless smart card according to the ISO/IEC14443A (or MIFARE) or a contactless card according to the FeliCa scheme. Design hints on how to place the components on a PCB are not included.

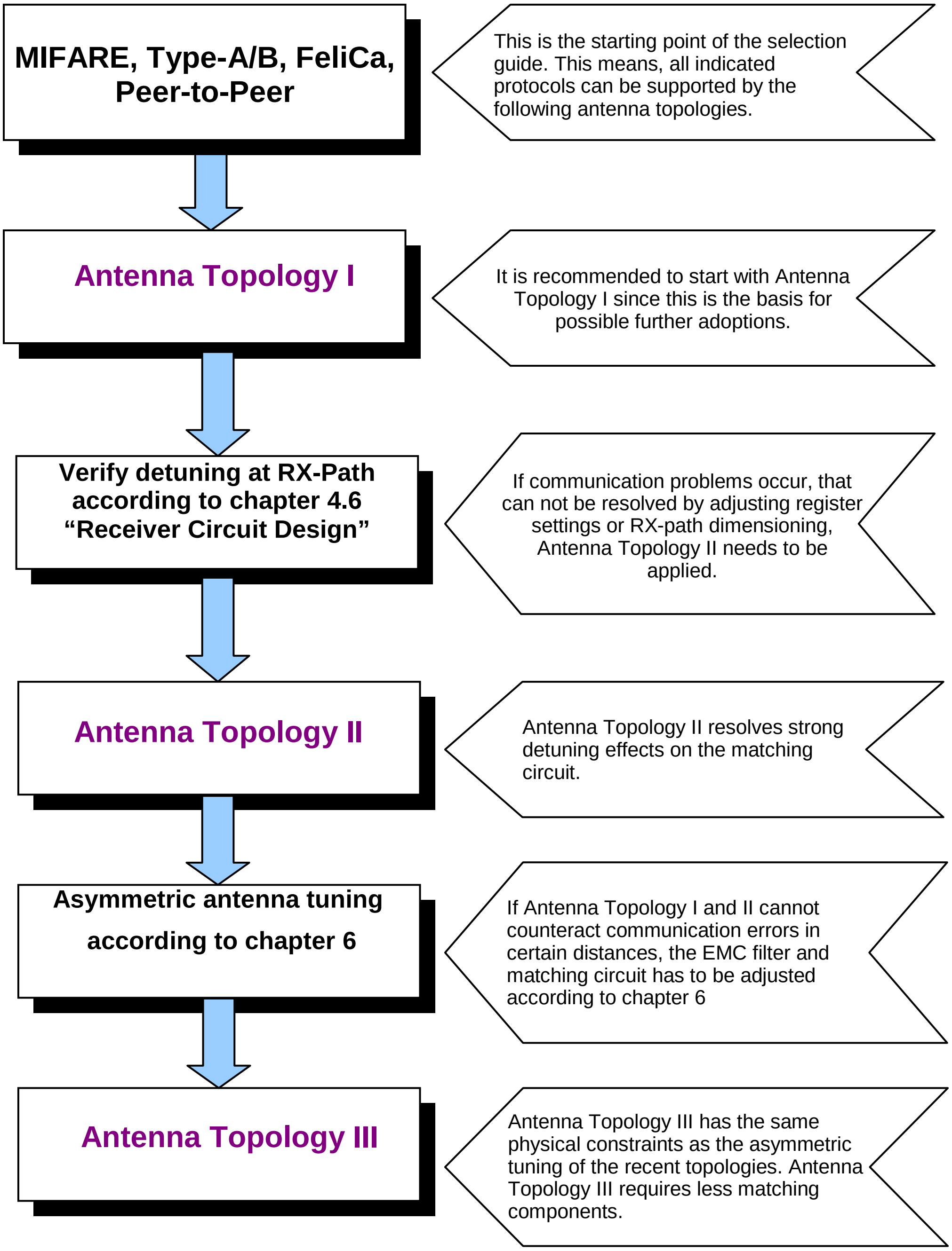
Tuning and measurement of the antenna has always to be performed at the final mounting position to consider all parasitic effects, e.g. metal influence on quality factor, inductance and additional capacitance.

All topologies and design methods described in this document assume antenna and tuning components are not accessible to end user. Therefore no additional ESD protection methods are described. In case antenna wiring is accessible from device housing or after user removable parts are detached, additional ESD protection has to be evaluated. Methods described here are then no more generally valid.

Increased RF output power and communication distance could be achieved by integrating the RF amplifier for NXP’s contactless Reader IC’s ([13]).

3. Selection Guide

The following flow chart describes a selection guide for different antenna topologies. The user needs to start from the top rectangle going downwards. Due to different detuning effects on the antenna only one of the following topologies may apply to the type of reader integration.



This is the starting point of the selection guide. This means, all indicated protocols can be supported by the following antenna topologies.

It is recommended to start with Antenna Topology I since this is the basis for possible further adoptions.

If communication problems occur, that can not be resolved by adjusting register settings or RX-path dimensioning, Antenna Topology II needs to be applied.

Antenna Topology II resolves strong detuning effects on the matching circuit.

If Antenna Topology I and II cannot counteract communication errors in certain distances, the EMC filter and matching circuit has to be adjusted according to chapter 6

Antenna Topology III has the same physical constraints as the asymmetric tuning of the recent topologies. Antenna Topology III requires less matching components.

4. Antenna Topology I

The **RF block diagram** in Fig 1 shows a recommended circuitry design with all relevant components required to connect an antenna to the MFRC522/MFRC523/PN51x/PN53x. It also ensures the transmission of energy and data to the target device as well as the reception of a target device answer.

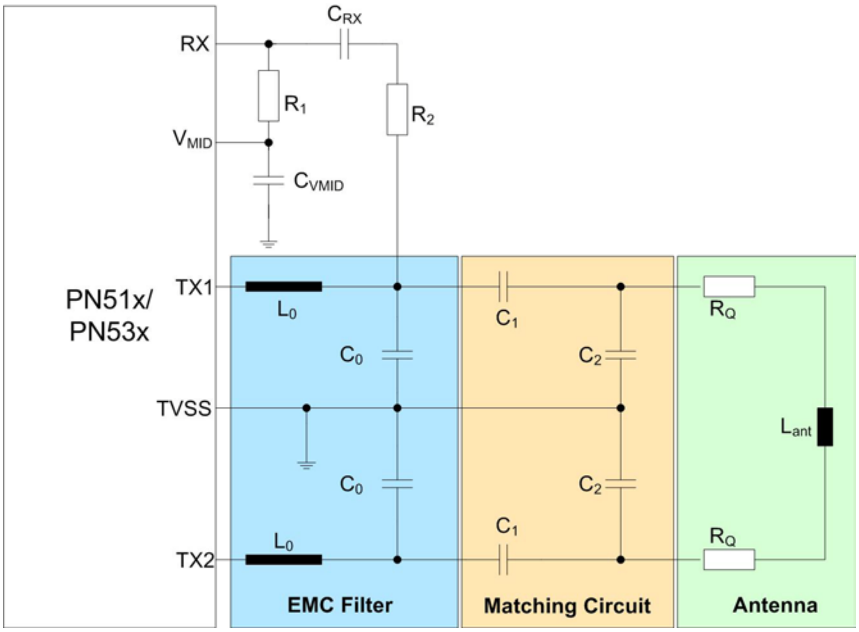


Fig 1. Block diagram of the complete RF part

Note: Fig 1 shows only the RF part and the related power supply (TVDD and TVSS). For a proper operation the analog and digital supplies and the host interface have to be connected too.

Note: Topology I is the preferred RF part topology for MFRC522 and MFRC523

Although some of theses blocks may contain only a few passive components, it is important to consider all these blocks and all their functionality to guarantee the proper working of the complete device.

The **EMC filter** reduces 13.56 MHz harmonics and performs an impedance transformation.
The **Matching Circuit** acts as an impedance transformation block.
The antenna coil itself generates the magnetic field.
The receiving part provides the received signal to the MFRC522/MFRC523/PN51x/PN53x internal receiving stage.

Basically this complete RF circuitry consists of at least 8 capacitors (max. voltage ~50V types), 2 inductors, 2 resistors (the part size determines the maximum power which the resistor can withstand) and the symmetrical antenna coil as shown in Fig 1.

4.1 Equivalent circuit

The following subchapters describe the matching procedure. It starts with the determination of the antenna parameters and ends with a fine tuning of the antenna circuitry.

4.1.1 Determination of series equivalent circuit

The antenna loop has to be connected to an impedance or network analyzer to measure the series equivalent components.

Note: The equivalent circuit (see Fig 2) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

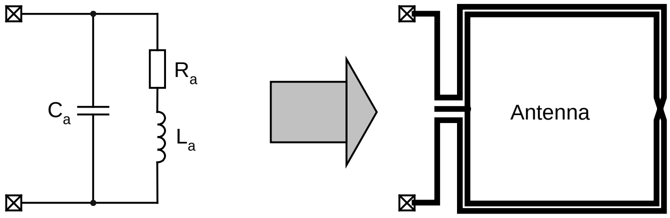


Fig 2. Series equivalent circuit

Typical values:

L_a = 0.3...3 µH

C_a = 3...30 pF

R_a = 0.3...8 Ω

4.1.2 Calculation of antenna quality factor damping resistor R_Q

The quality factor of the antenna is calculated with

$$Q_a = \frac{\omega \cdot L_a}{R_a} \tag{1}$$

If the calculated value of Q_a is higher than the target value of 35, an external damping resistor R_Q has to be inserted on each antenna side to reduce the Q-factor to a value of **35 (±10%)**.

The value of R_Q (each side of the antenna) calculates as

$$R_Q = 0.5 \cdot \left(\frac{\omega \cdot L_a}{35} - R_a \right) \tag{2}$$

4.1.3 Determination of parallel equivalent circuit

The parallel equivalent circuit of the **antenna together with the added external damping resistor R_Q** has to be measured. The quality factor should be checked again to be sure to achieve the required value of Q=35.

Note: The equivalent circuit (Fig 3) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

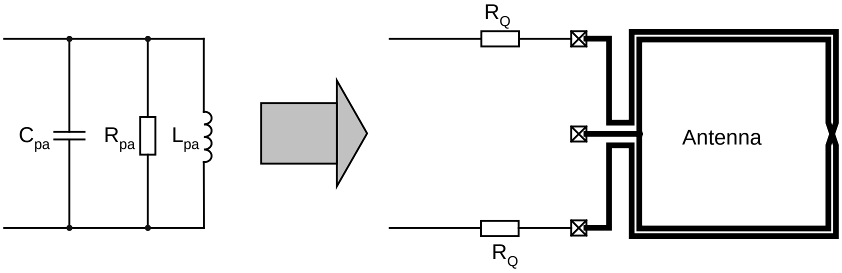


Fig 3. Parallel equivalent circuit

The following formula applies

$$
\begin{aligned}
L_{pa} &\mathrel{\hat{=}} L_a \\
C_{pa} &\mathrel{\hat{=}} C_a \\
R_{pa} &\mathrel{\hat{=}} \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q}
\end{aligned}
\tag{3}
$$

4.2 EMC filter design

The EMC filter circuit for the MFRC522/;MFRC523/PN51x/PN53x fulfills two functions: the filtering of the signal and impedance transformation block. The main properties of the impedance transformation are:

- Decreasing the amplitude rise time after a modulation phase
- Increasing the receiving bandwidth

The EMC filter and the matching circuit must transform the antenna impedance to the required TX matching resistance $Z_{match}(f)$ at the operating frequency of f = 13.56 MHz.

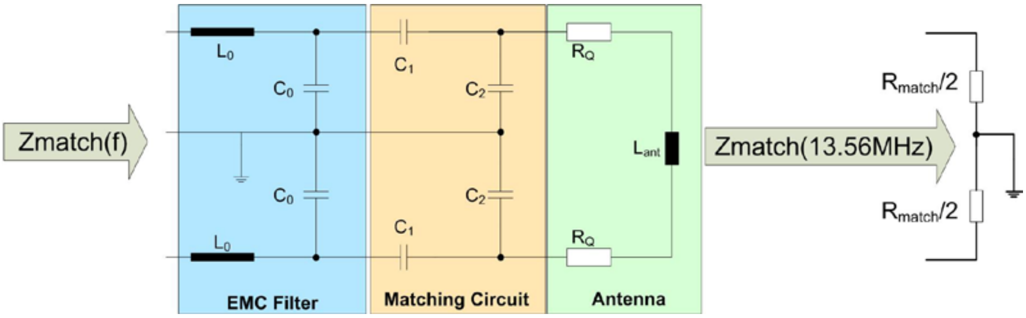


Fig 4. Impedance transformation

When splitting the circuit between EMC Filter and Matching Circuit the following applies if instead of the IC two resistors with the value $R_{match}/2$ would be applied:

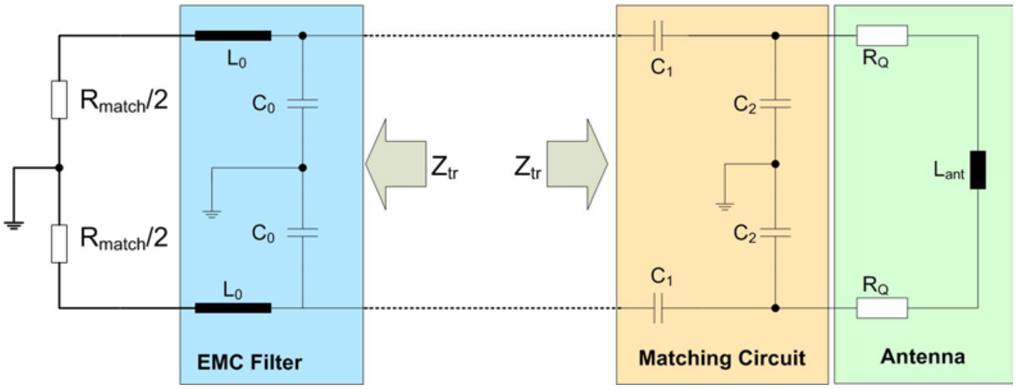


Fig 5. Definition of transformation impedance Z_{tr}

$$Z_{tr} = R_{tr} + jX_{tr} \tag{4}$$

$$Z_{tr}^{*} = R_{tr} - jX_{tr} \tag{5}$$

EMC filter general design rules:

L_0 = 390 nH - 1 µH

Filter resonance frequency f_{r0} = 14.1 MHz ...14.5 MHz, => C_0

$$C_0 = \frac{1}{(2 \cdot \pi \cdot f_{r0})^2 L_0} \tag{6}$$

The EMC filter resonance frequency f_{r0} has to be near the upper sideband frequency determined by the highest data rate (848 kHz sub carrier) in the system to achieve a broadband receiving characteristic.

Example:

L_0 = 560 nH

f_{r0} = 14.3 MHz

C_0 = 221.2 pF => chosen: 220 pF

A recommended value of 560 nH for L_0 is chosen to calculate the capacitance C_0. The following formulas apply for Z_{ant} = Re(Z_{ant})+Im(Z_{ant}) and are needed to calculate the matching components.

$$R_{tr} = \frac{R_{match}}{(1 - \omega^2 \cdot L_0 \cdot C_0)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2} \tag{7}$$

$$X_{tr} = 2 \cdot \omega \cdot \frac{L_0 \cdot \left(1 - \omega^2 \cdot L_0 \cdot C_0\right) - \frac{R_{match}{}^2}{4} \cdot C_0}{\left(1 - \omega^2 \cdot L_0 \cdot C_0\right)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2} \quad (8)$$

4.3 Matching circuit design

4.3.1 Component calculation

The following formulas apply for the series and parallel matching capacitances:

$$C_1 \approx \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{tr} \cdot R_{pa}}{4}} + \frac{X_{tr}}{2} \right)} \tag{9}$$

$$C_2 \approx \frac{1}{\omega^2 \cdot \frac{L_{pa}}{2}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{tr} \cdot R_{pa}}{4}}} - 2 \cdot C_{pa} \tag{10}$$

Finally, a fine tuning of the matching circuit is often necessary, since the calculated values are based on simplified equations and the equivalent circuit values can not be determined 100% correct.

4.4 Tuning procedure

The matching circuit elements C_1 and C_2 must be tuned to get the required matching resistance R_{match} ($X_{match} = 0$) at the PN51x/PN53x TX pins. The matching impedance $Z_{match} = R_{match} + jX_{match}$ is measured with an impedance or network analyzer. The Z_{match} point between TX1 and TX2 as shown in Fig 6 is the probing point for the network analyzer.

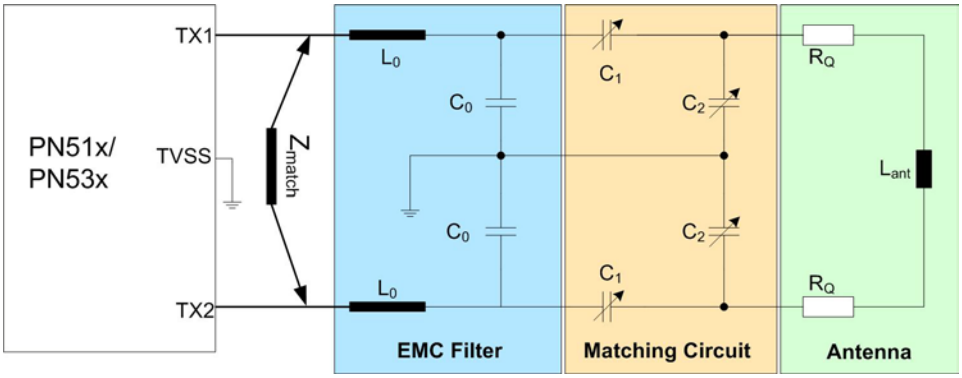


Fig 6. Measurement of matching impedance

The following Fig 7 shows a simulation example for the matching impedance Z_{match}.

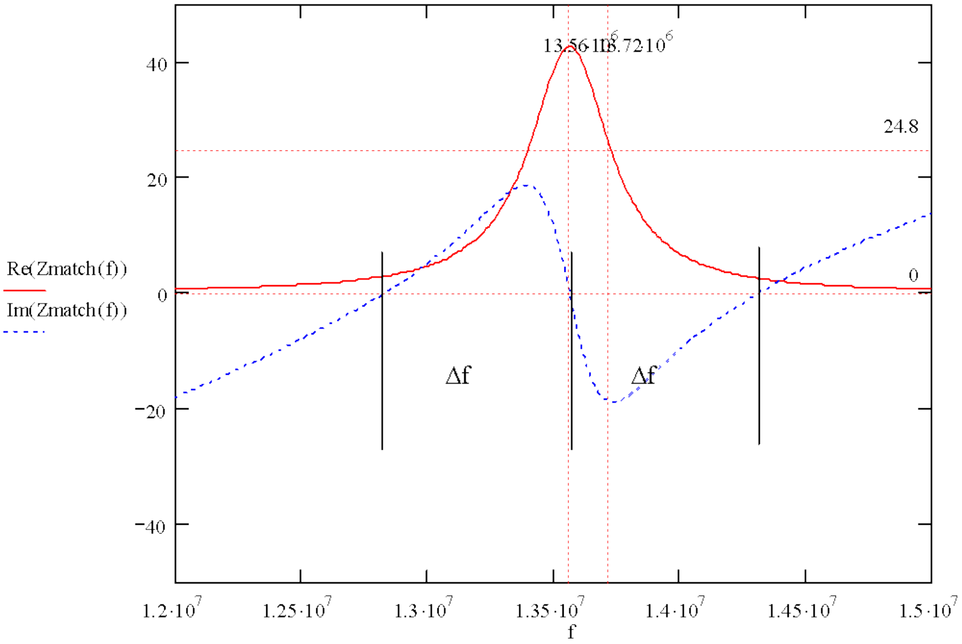
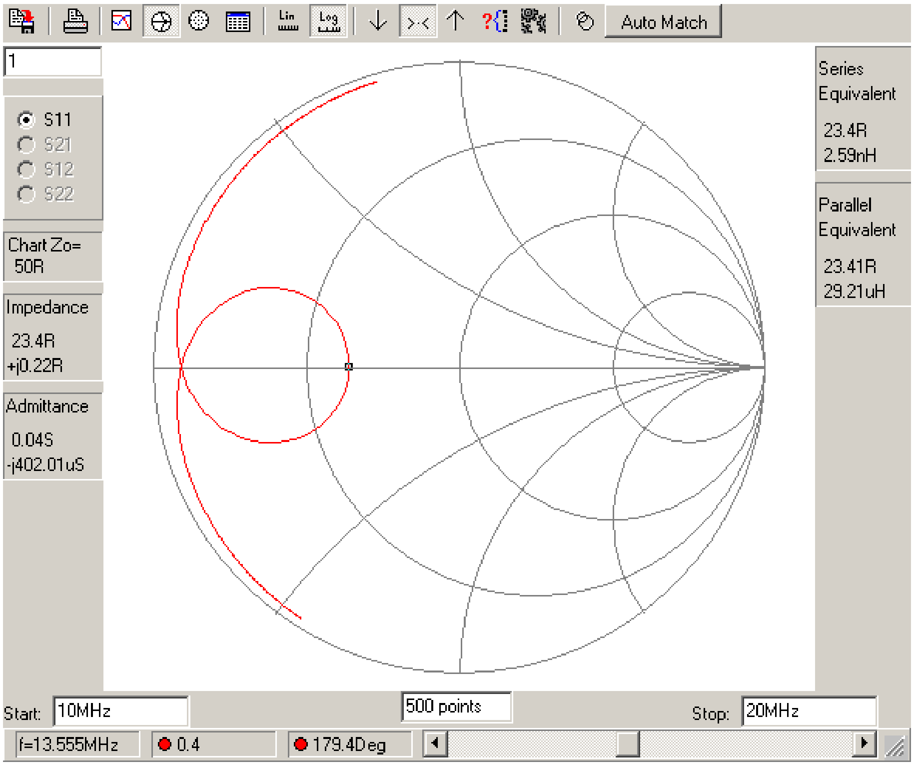


Fig 7. Calculation of matching impedance

Fig 8 shows the smith chart simulation for Z_{match} / 2:



1

● S11
○ S21
○ S12
○ S22

Chart Zo= 50R

Impedance
23.4R
+j0.22R

Admittance
0.04S
-j402.01uS

Series Equivalent
23.4R
2.59nH

Parallel Equivalent
23.41R
29.21uH

Start: 10MHz

500 points

Stop: 20MHz

f=13.555MHz

● 0.4

● 179.4Deg

Fig 8. Smith chart for matching impedance

Conditions for the tuning:

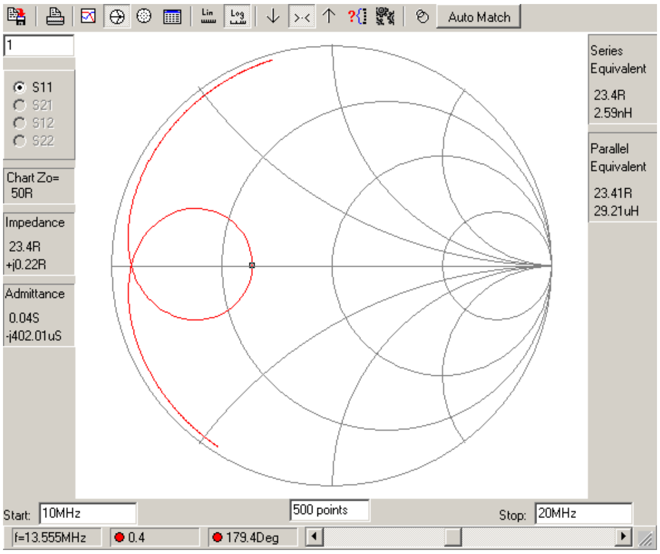
→ R_{match} curve symmetric around the operating frequency

→ X_{match} curve conjugate complex symmetric around the operating frequency

Note: All tuning and measurement of the antenna always has to be performed at the final mounting position to consider all parasitic effects like metal influence on quality factor, inductance and additional capacitance.

4.4.1 Tuning of series matching capacitance C_1

The smith charts in Fig 9 show the matching impedance Z_{match} / 2 vs. frequency.



1
● S11
○ S21
○ S12
○ S22

Chart Zo=
50R

Impedance
23.4R
+j0.22R

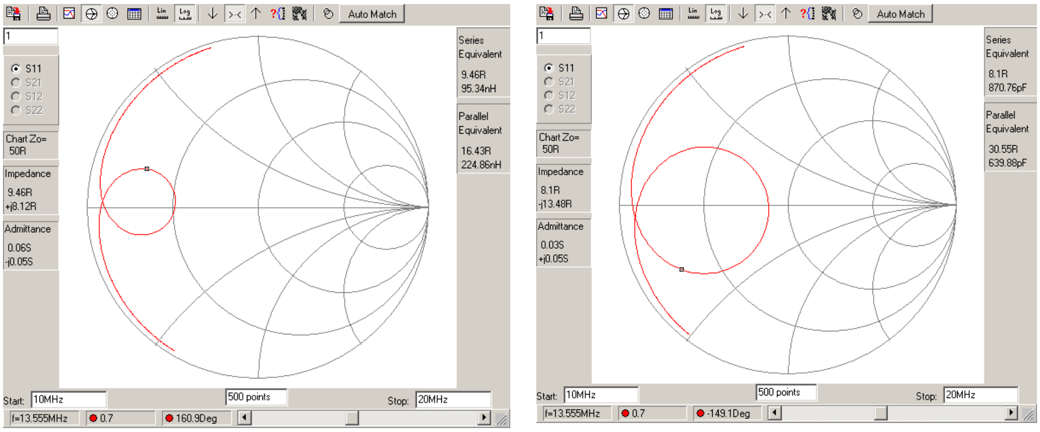
Admittance
0.04S
-j402.01uS

Series Equivalent
23.4R
2.59nH

Parallel Equivalent
23.41R
29.21uH

Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
● 0.4
● 179.4Deg

a. Optimum C1



1
● S11
○ S21
○ S12
○ S22

Chart Zo=
50R

Impedance
9.46R
+j8.12R

Admittance
0.06S
-j0.05S

Series Equivalent
9.46R
95.34nH

Parallel Equivalent
16.43R
224.86nH

Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
● 0.7
● 160.9Deg

1
● S11
○ S21
○ S12
○ S22

Chart Zo=
50R

Impedance
8.1R
-j13.48R

Admittance
0.03S
+j0.05S

Series Equivalent
8.1R
870.76pF

Parallel Equivalent
30.55R
639.88pF

Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
● 0.7
● -149.1Deg

b. C_1 too low

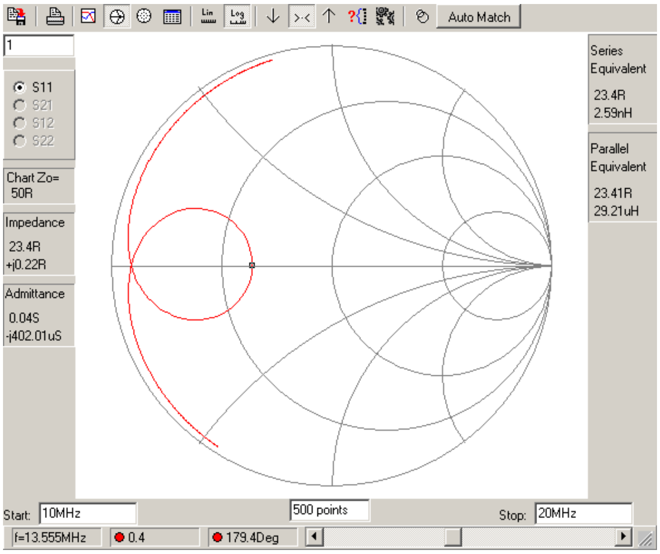
c. C_1 too high

Fig 9. Smith charts for C_1 tuning

C_1 changes the magnitude of the matching impedance. After a change of C_1 the imaginary part of Z_{match} must be compensated by adjusting C_2.

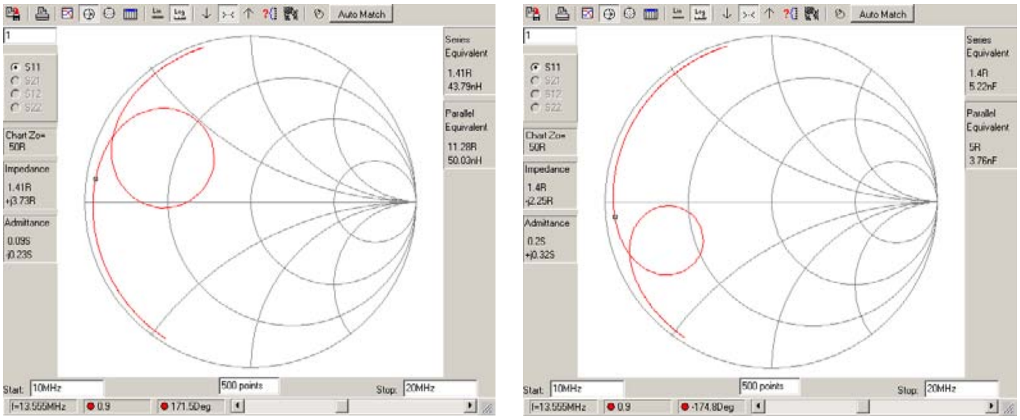
4.5 Tuning of parallel matching capacitance C_2

The smith charts show the matching impedance Z_{match} / 2 vs. frequency.



Series Equivalent: 23.4R, 2.59nH
Parallel Equivalent: 23.41R, 29.21uH
Chart Zo= 50R
Impedance: 23.4R +j0.22R
Admittance: 0.04S -j402.01uS
Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
0.4
179.4Deg

d. Optimum C2



Series Equivalent: 1.41R, 43.79nH
Parallel Equivalent: 11.28R, 50.03nH
Chart Zo= 50R
Impedance: 1.41R +j3.73R
Admittance: 0.09S -j0.23S
Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
0.9
171.5Deg

Series Equivalent: 1.4R, 5.22nF
Parallel Equivalent: 5R, 3.76nF
Chart Zo= 50R
Impedance: 1.4R -j2.25R
Admittance: 0.2S +j0.32S
Start: 10MHz
500 points
Stop: 20MHz
f=13.555MHz
0.9
-174.8Deg

e. C_2 too low

f. C_2 too high

Fig 10. Smith charts for C_2 tuning

C_2 changes mainly the imaginary part of Z_{match}.

4.5.1 Tuning flow chart

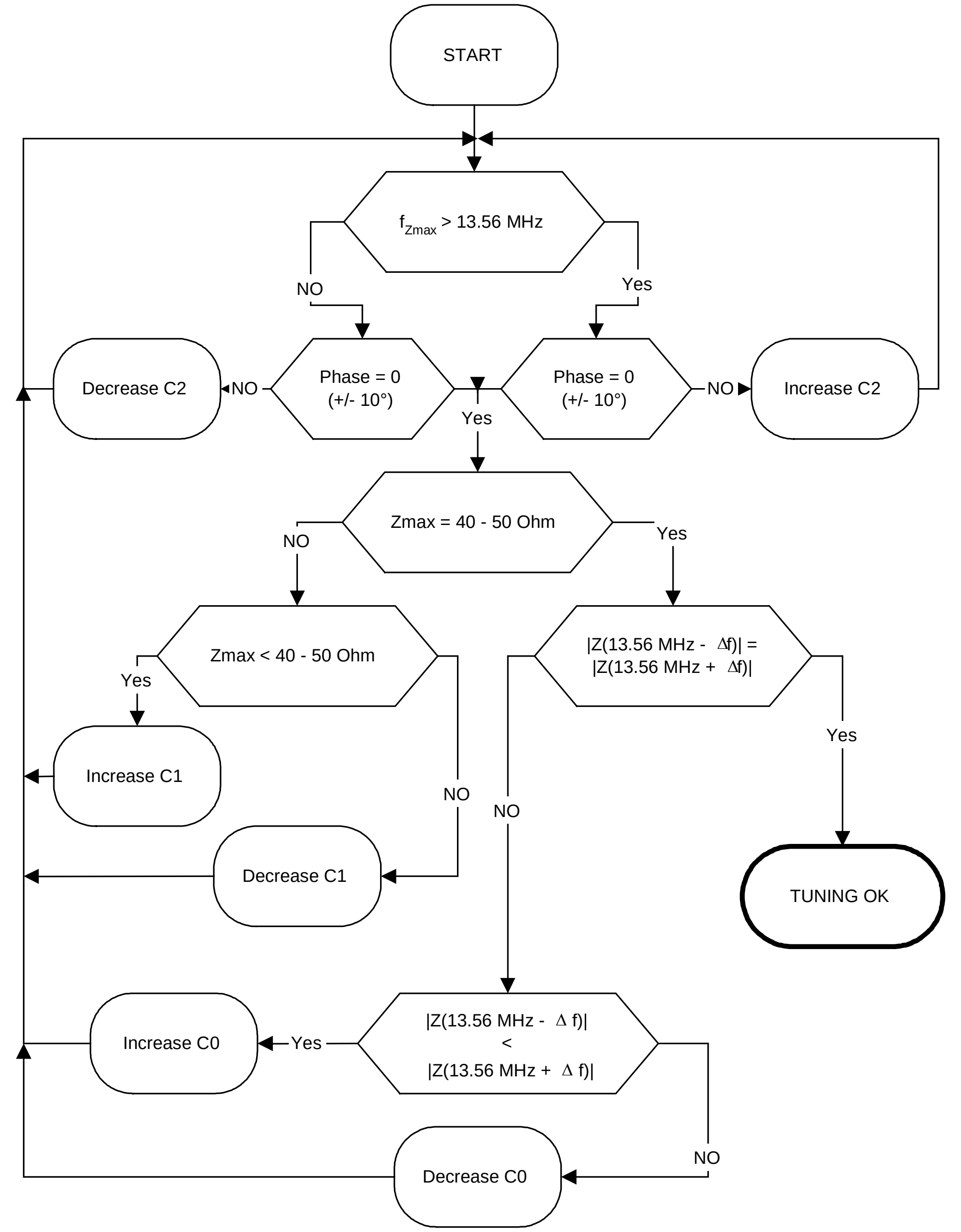


Fig 11. Tuning flow chart

4.6 Receiver circuit design

Next step, after matching and tuning the transmitting antenna, is the design and tuning of the receiver circuit. The investigations need to be carried out for initiator and target mode.

Fig 12 shows the relevant components for the receiver circuit. R_1 and R_2 form a voltage divider which has to be adjusted according to the incoming voltage levels at U_{C0}. Both, Initiator and target mode of the device have to be investigated, since detuning effects on the RX path behave differently.

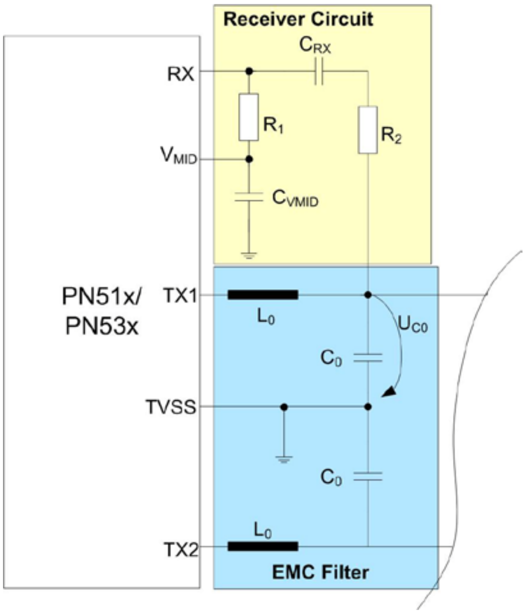


Fig 12. Receiver Circuit

4.6.1 Initiator mode

Step 1:

Predefined components:

C_{RX} = 1 nF: DC blocking capacitor

C_{vmid} = 100 nF: V_{mid} decoupling capacitance

R1 = 1 kΩ: Predefined part of the voltage divider

Step 2:

The transmitter must be switched on in continuous wave mode and the voltage on the EMC filter capacitance U_{C0} has to be measured with a low capacitance probe (< 2 pF). Typically low capacitance probes are terminated with 50 Ohm, thus the scope configuration has to be set correctly!

Step 3:

The voltage divider resistor R_2 can be calculated by:

$$R_2 = R_1 \cdot \left(\frac{U_{C0}}{U_{RX}} - 1 \right) \tag{11}$$

with the target value of U_{RX} = 1 V_{pp} (antenna not detuned)

Step 4:

After inserting the determined resistor R_2 the voltage on RX pin U_{RX} must be measured with a low capacitance probe (< 2 pF) for continuous transmitting mode.

The voltage U_{RX} **must not** exceed the maximum value U_{RXmax} even when the antenna is detuned by a target or passive card.

4.6.2 Target mode

Step 5:

The device must be placed in the test setup according to NFCIP1 test method standard. The magnetic field has to be increased continuously and the voltage on RX checked against the level U_{RXmax}.

$U_{RX} < U_{RXmax}$ for H <= 7.5 A/m

If the voltage level on RX gets higher than the maximum value for field strength below 7.5 A/m, the resistor R_2 must be increased to a value that meets the specification.

4.7 Example

As an example the antenna of the PN51x/PN53x evaluation board Rev. 1.1 will be matched to the transmitter output.

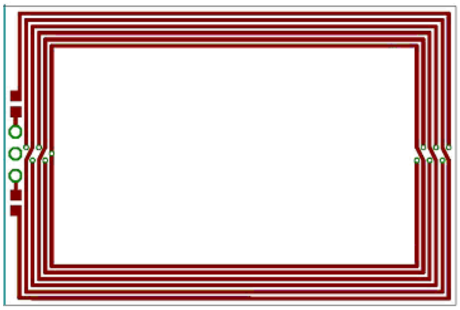


Fig 13. PN51x/PN53x evaluation board antenna

The external RF components should be tuned to a value, that $I_{TVDD} \approx$ 50mA.

Recommended $R_{match} \approx$ 50 Ohm

The series equivalent circuit of the antenna results to:

R_a = 1.9 Ohm

C_a = 11 pF

L_a= 2.9 µH

The calculation for the external damping resistor results to R_Q = 2.57 Ohm. The chosen value for R_Q is 3.3 Ohm and results in a Q-factor slightly below 30.

The parallel equivalent circuit of the antenna including quality factor damping resistors R_Q = 3.3 Ohm is determined with the following values:

R_{pa} = 7148 Ohm

C_{pa} = 11 pF

L_{pa}= 2.9 µH

The EMC filter is determined with:

L_0 = 560 nH

C_0 = 220 pF

Calculation of Z_{tr}:

R_{tr} = 217 Ohm

X_{tr} = -58 Ohm

Calculation of the matching parts C_1, C_2:

C_1 = 19.8 pF -> 18 pF

C_2 = 54.1 pF ->56 pF

For further component calculations please refer to the Excel-Worksheet “Antenna Topology I” in AN1444xx ([9]).

Simulation result:

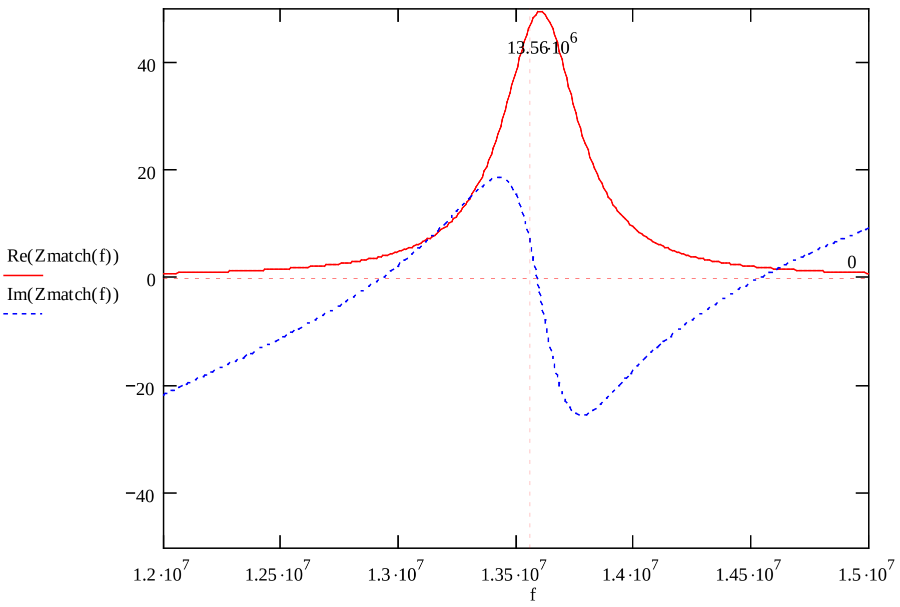


Fig 14. Example: Z_{match} simulation

Measurement result:

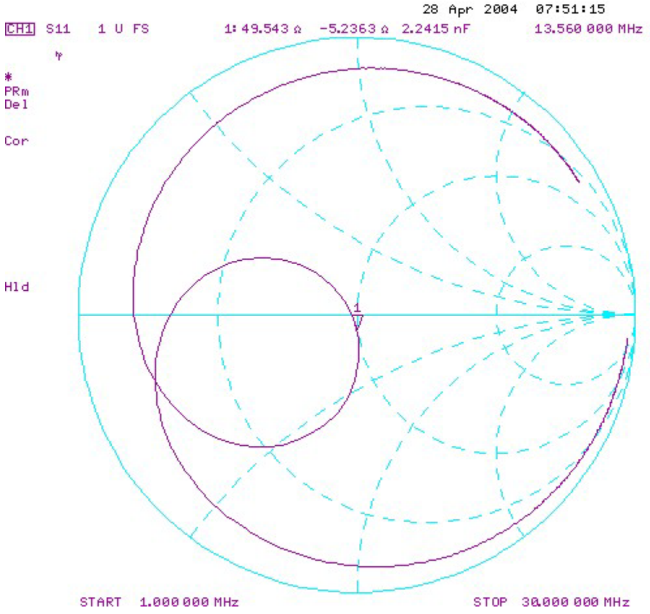


Fig 15. Example: Z_{match} measurement

5. Antenna Topology II

This chapter introduces a capacitor split in the matching circuit to improve large voltage drops at the RX-path. The modifications in the antenna topology are show in Fig 17. The capacitor C_1 at the TX1 pin from Antenna Topology I is replaced by two capacitors C_{S1} and C_{S2}. The RX-Path is then connected in the middle of C_{S1} and C_{S2}, which results in a more constant voltage behavior. The fine tuning of the circuit is equivalent to Antenna Topology I. Please refer to chapter 4.4 for fine tuning details.

5.1 Component calculation

In order to calculate the values of the two capacitors, all other matching calculations have to be done before. To put it more precisely, the capacitor C1 has to be determined before changing the parts. The number of matching parts will not increase since C_{RX} in Fig 17 can be removed after the performing the split of C1.

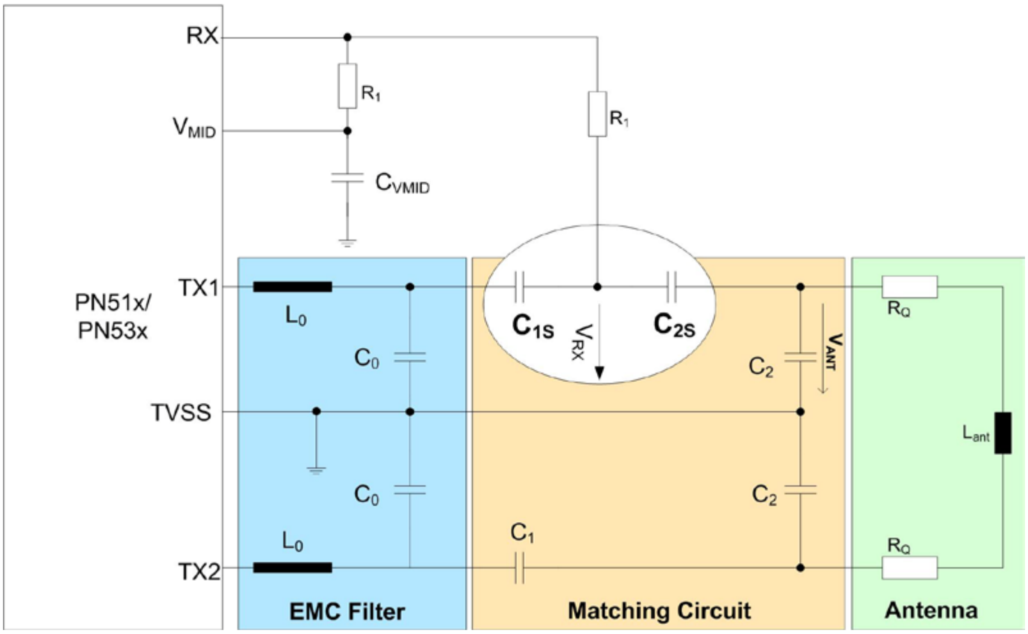


Fig 16. C1 Split Topology

Note: All tuning and measurement of the antenna always has to be performed at the final mounting position to consider all parasitic effects like metal influence on quality factor, inductance and additional capacitance.

Please also refer to the Excel-Worksheet “Antenna Topology II” in AN1444xx ([9]) for further component calculations.

To start changing the matching parts, first measure the voltage at V_{ANT} and V_{EMC} of the Antenna Topology I with and without a target load. Place a 1k MIFARE card in the middle of the final mounted antenna and use a low capacitance probe for the measurements. Refer also to Fig 17 on where to place the measurement probes.

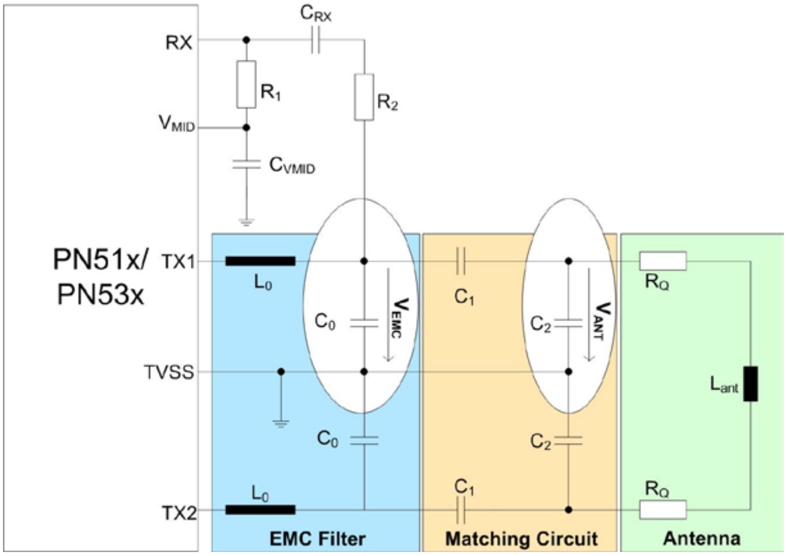


Fig 17. Measurement points for C1 Split

Fig 18 shows the visualization of the voltages V_{ANT} and V_{EMC} with and without a target/detuning. The aim of a C_1 split is to reduce the detuning at the RX-path, thus getting smaller voltage drops at the RX-site. Therefore, the intersection point V_{avg} of the two lines has to be calculated.

$$V_{avg} = \left(\frac{V_{EMC} - V_{ANT}}{V_{ANT\_D} - V_{ANT} - V_{EMC\_D} + V_{EMC}} \right) \cdot \left(V_{EMC\_D} - V_{EMC} \right) + V_{EMC} \quad (12)$$

with

V_{ANT} … *Voltage at antenna **without** target*

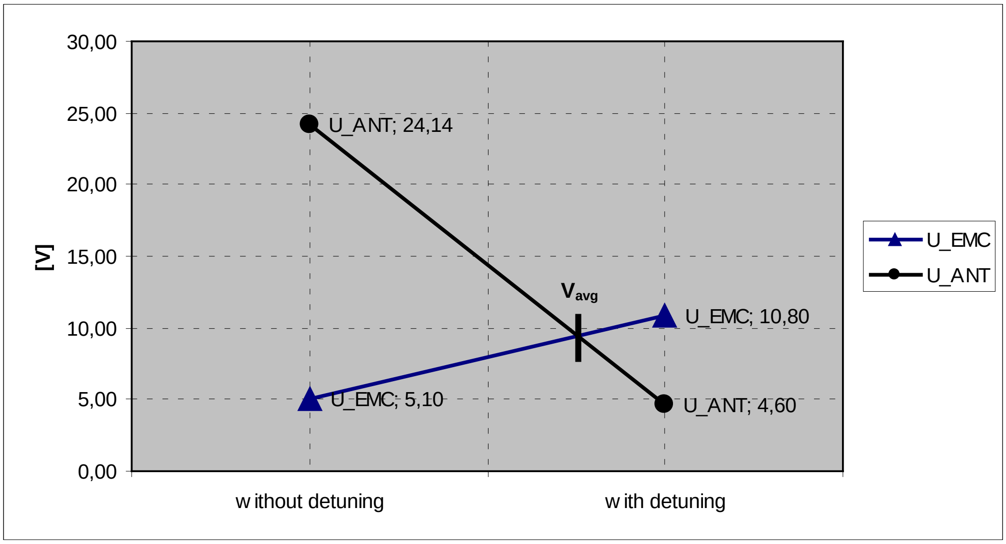
V_{ANT_D} … *Voltage at antenna **with** target*

V_{EMC} … *Voltage at EMC point **without** target*

V_{EMC_D} … *Voltage at EMC point **with** target*

According to the point V_{avg}, the separation factor S_{C1} for the capacitor values C_{1S} and C_{2S} will be calculated as:

$$S_{C1} = \frac{V_{avg} - V_{EMC}}{V_{ANT} - V_{EMC}} \qquad S_{C1} \ldots Percentage\,Seperation\,of\;C1 \quad (13)$$



(1) The intersection point is calculated with V_{avg}

Fig 18. Detuning at V_{EMC} and V_{ANT}

The values for the two capacitors derived from the original C1 is:

$$C_{1S} = \frac{C1}{S_{C1}} \qquad (14)$$

Table 1 gives an example of the above made calculations with a value of 18 pF for C1.

$$C_{2S} = \frac{C1}{1 - S_{C1}} \qquad (15)$$

Table 1. Example of C1-Split

Measurements	Values
U_{EMC} without detuning	5,10 V
U_{EMC} with detuning	10,80 V
U_{ANT} without detuning	24,14 V
U_{ANT} with detuning	4,60 V
V_{avg}	9,39 V
Percentage seperation of C1	**22,58 %**
C_{1S}	79,71 pF
C_{2S}	23,25 pF

Now choose appropriate values for C_{1S} and C_{2S}, such that the back transformation to a series capacitance gives C1 again. Thus, always check if

$$C1 \cong \frac{C_{1S} \cdot C_{2S}}{C_{1S} + C_{2S}} \qquad (16)$$

Otherwise the antenna will be mismatched. Replace only the capacitor C_1 in the TX1-path as shown in Fig 17.

As an example, 78 pF for C_{1S} and 23 pF for C_{2S} has been chosen, which gives a total series capacitance of 17.76 pF for C1.

Note that the decoupling capacitor C_{RX} was removed in the C1-split topology. See also Fig 17 on how to setup the C1-split.

Fig 19 shows the results by measuring again the voltages V_{RX} and V_{ANT} with and without a load. It can be seen that the voltage swing on V_{RX} with/without target load is much smaller than on a single C1 topology.

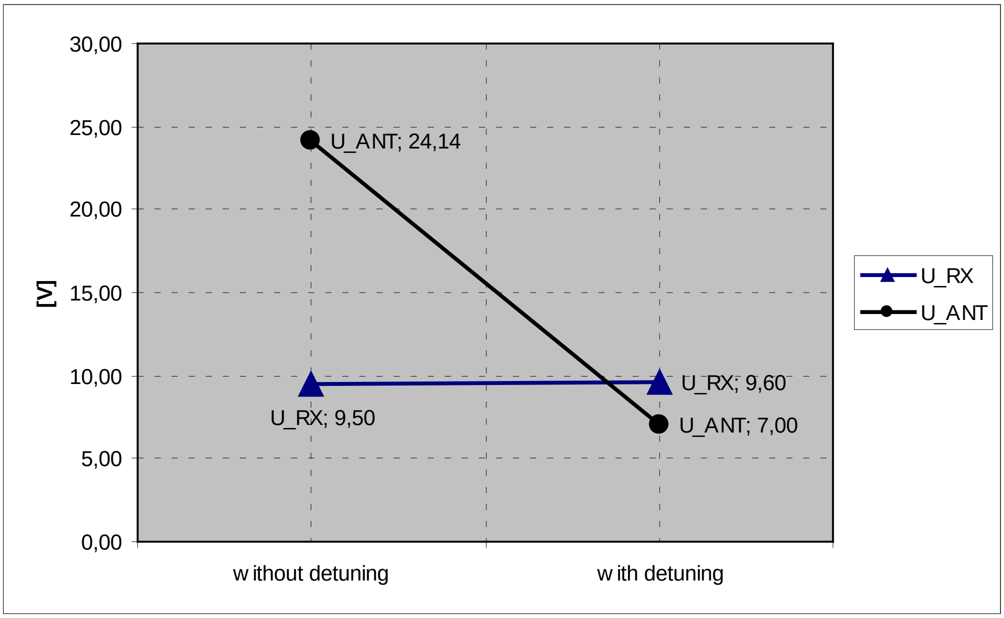


Fig 19. The voltage at RX is more stabilized

5.2 Features and hints of using antenna topology II

By using the antenna topology II it is possible to counteract very strong voltage level variations on the RX-path in reader mode. Although there is no disadvantage in regard to communication constraints when using antenna topology II, it is trickier to tune it. In the worst case this means when using the antenna topology II, at least one more capacitor has to be reserved for the parallel capacitor C1. Remember, that both paths TX1 and TX2 have to be equal in component value. Thus, to retrieve full equivalence in the matching circuit, C1S combined with C2S needs to be equivalent to C1. The capacitance value of C1S and C2S can not always be achieved by a standard value. Mostly, a second capacitor placed in parallel to C1 (see Fig 20) or in parallel to both capacitors C1S and C2S has to be considered to get full symmetry.

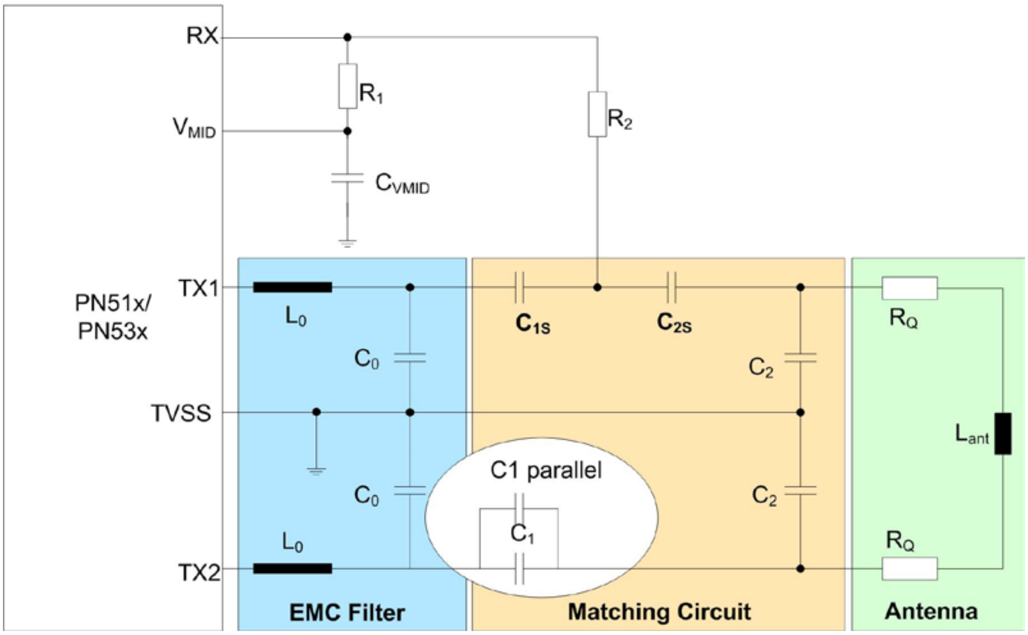


Fig 20. Parallel capacitor to C1

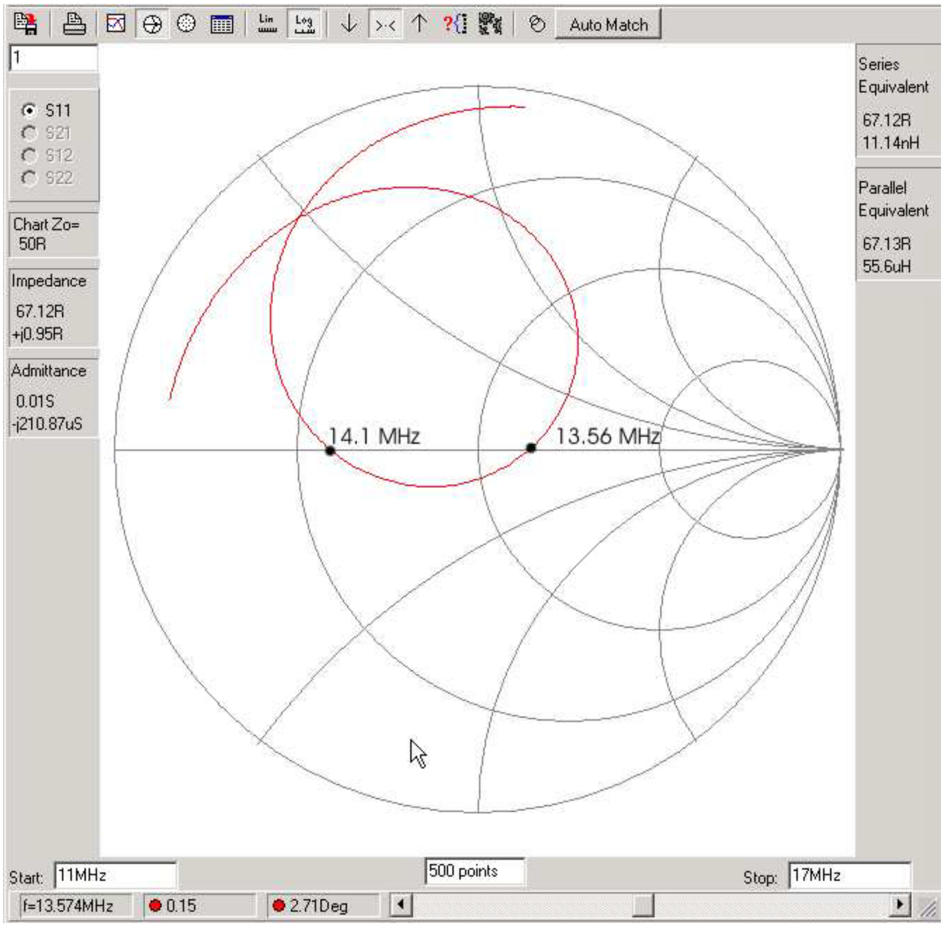
6. Asymmetric tuning of antenna topology I or II

The **antenna topology I and II** was tuned to have a matching of around 50 Ohms and an impedance curve symmetric around the operating frequency. When loaded with a target, the 13.56 MHz point shifts close to the short circuit point of the Smith Chart when strong detuning of the antenna occurs. Detuning effects arise when target(s) are placed above the reader device and load the reader antenna. The symmetric impedance curve of the antenna matching circuit may cause undesired communication failures.

One possibility to anticipate the effect of a short circuit at the real part of the impedance network is to tune the antenna matching asymmetric around the operating frequency (see Fig 21). The two resonance points of 13.56 MHz and 14.1 MHz still needs to be on the real axis of the smith chart but the crossing section moves up to the inductive part.

In order to move up the intersection point to the inductive part the capacitance C_0 of the EMC filter has to be increased by about 50 pF when using the values as recommended in the example matching in chapter 4.7.

Fig 21 shows the smith chart of Z_{match} vs. frequency of Antenna Topology I or II



1

● S11
○ S21
○ S12
○ S22

Chart Zo= 50R

Impedance
67.12R
+j0.95R

Admittance
0.01S
-j210.87uS

Series Equivalent
67.12R
11.14nH

Parallel Equivalent
67.13R
55.6uH

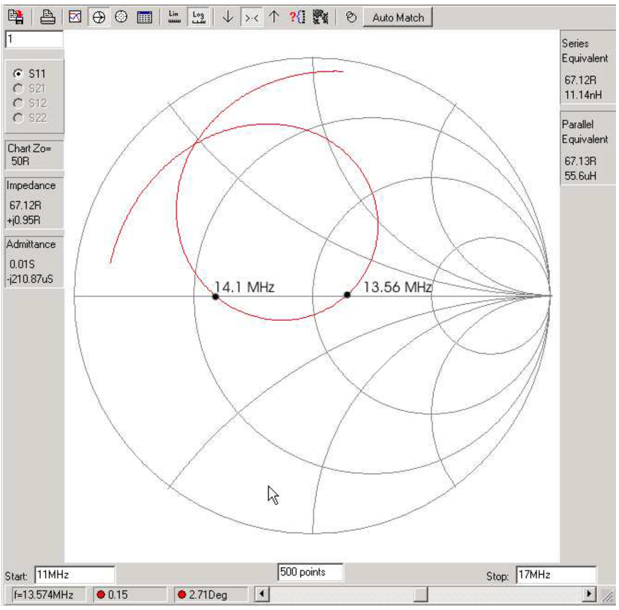
Start: 11MHz
500 points
Stop: 17MHz

f=13.574MHz
● 0.15
● 2.71Deg

Fig 21. Asymmetric tuning of antenna topology I and II

6.1 Tuning of series matching capacitance C_1

The smith charts in Fig 22 shows the tuning effect on the impedance curve by adjusting C1.



1

● S11
○ S21
○ S12
○ S22

Chart Zo= 50R

Impedance 67.12R +j0.95R

Admittance 0.01S -j210.87uS

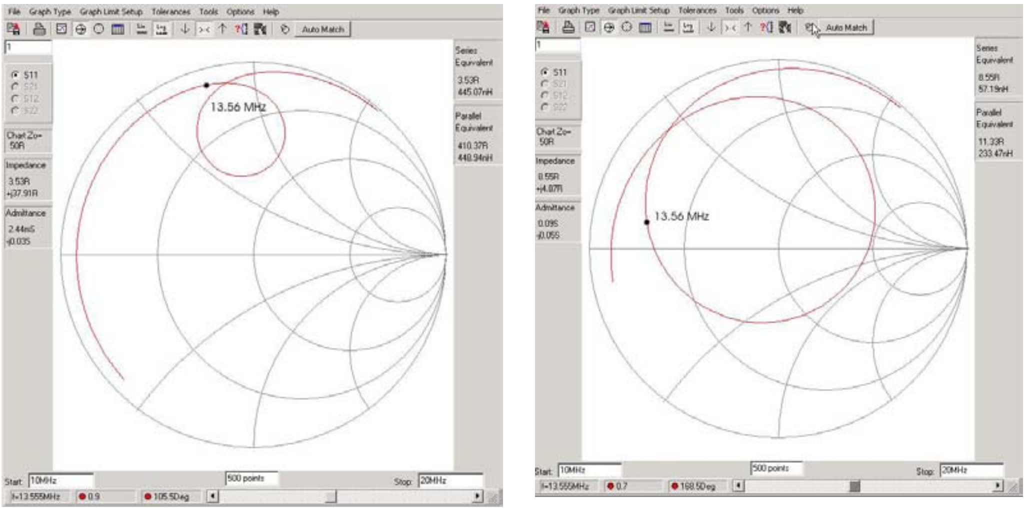
Series Equivalent 67.12R 11.14nH

Parallel Equivalent 67.13R 55.6uH

Start: 11MHz 500 points Stop: 17MHz

f=13.574MHz ● 0.15 ● 2.71Deg

Optimum C1



1

● S11
○ S21
○ S12
○ S22

Chart Zo= 50R

Impedance 3.53R +j37.91R

Admittance 2.44mS -j0.035

Series Equivalent 3.53R 445.07nH

Parallel Equivalent 410.37R 448.94nH

Start: 10MHz 500 points Stop: 20MHz

f=13.555MHz ● 0.9 ● 105.5Deg

1

● S11
○ S21
○ S12
○ S22

Chart Zo= 50R

Impedance 8.55R +j4.07R

Admittance 0.09S -j0.05S

Series Equivalent 8.55R 57.19nH

Parallel Equivalent 11.33R 233.47nH

Start: 10MHz 500 points Stop: 20MHz

f=13.555MHz ● 0.7 ● 168.5Deg

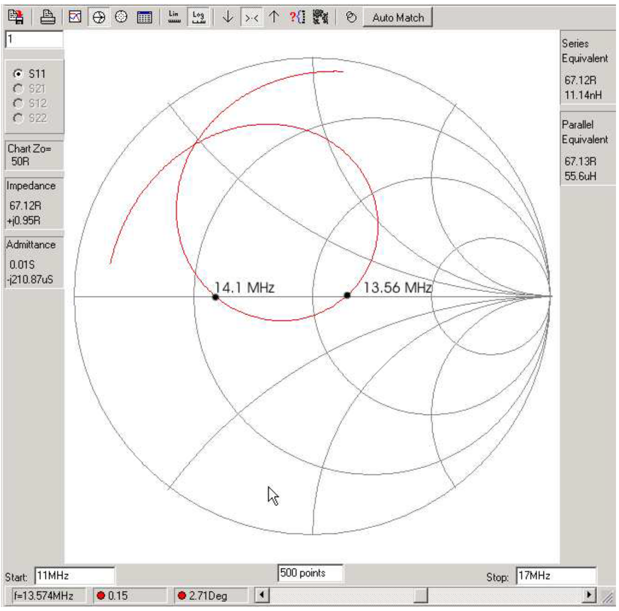
C_1 too low

C_1 too high

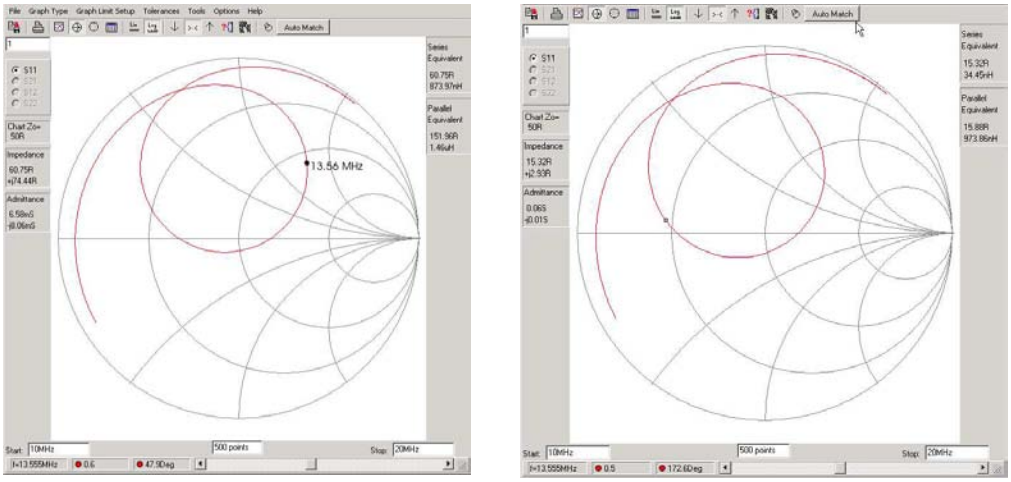
Fig 22. Smith charts for C_1 tuning

6.2 Tuning of parallel matching capacitance C_2

The smith charts in Fig 23 shows the tuning effect on the impedance curve by adjusting C2.



Optimum C2



C_1 too low

C_1 too high

Fig 23. Smith charts for C_2 tuning

7. Antenna Topology III

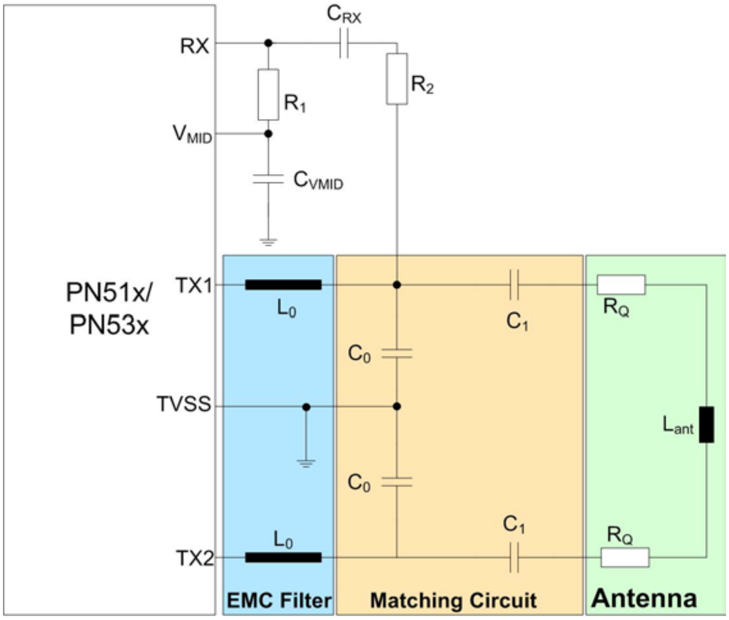


Fig 24. Block diagram of the complete RF part

Note: Fig 24 shows only the RF part and the related power supply (TVDD and TVSS). For a proper operation the analog and digital supplies and the host interface have to be connected too.

Although some of theses blocks may contain only a few passive components, it is important to consider all these blocks and all their functionality to guarantee the proper working of the complete device.

The **EMC filter** reduces 13.56 MHz harmonics and performs an impedance transformation.
The **matching circuit** acts as an impedance transformation block.
The antenna coil itself generates the magnetic field.
The receiving part provides the received signal to the PN51x/PN53x internal receiving stage.

The complete RF circuitry consists of at least 6 capacitors (max. voltage ~ 50V types), 2 inductors, 4 resistors (the part size determines the maximum power which the resistor can withstand) and the symmetrical antenna coil.

Table 2. Component list for a basic RF Design

Abbreviation	Explanation
R_Q	External damping resistors to adjust the quality factor. The power dissipation has to be considered.
C_0, C_1	Typically 0402, 0603 or 0805 SMD parts with low tolerance (< ±2%). NP0 dielectric is required for temperature stability reasons. The voltage limits has to be considered as well.
C_{vmid}, C_{RX}	X7R capacitor (< ±10%)
L_0	Typically a small inductance with high Q factor for general applications. The frequency range and the maximum allowed current have to be considered. This inductance may be magnetically shielded.
R_1, R_2	0402, 0603 or 0805 SMD parts

7.1 Features and hints of antenna topology III

The antenna topology in this document introduces some major advantages w.r.t. to power consumption, detuning effects on the RX-path and the type and amount of targets in the RF field.

The power consumption within the antenna topology described in chapter 4 "Antenna Topology I" is around 60 mA at TX-path. By changing to antenna topology III and tuning the resonance point around 70 Ω the power consumption becomes lower. The real and imaginary part of Z_{match} change from symmetric to asymmetric around the operating frequency. The asymmetric impedance anticipates the detuning effect such that the magnitude of Z_{match} stays closely constant when tags are in the field.

The detuning effect of the antenna topology III is shown in Fig 25. The figure contains the voltage at the RX-path (U_ANT) and the EMC-Filter (U_EMC) with and without a target load. The voltage at the RX-path decreases with the number of targets in the field. This can cause communication errors when the specified voltage limits at the RX-path are exceeded. The antenna topology III introduces a matching circuit to reduce the voltage peaks shown in Fig 25.

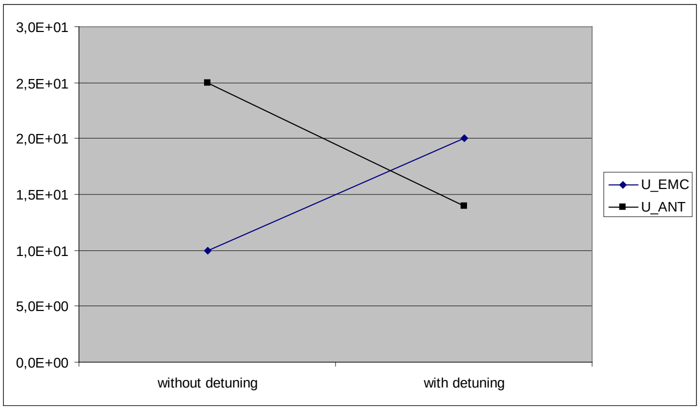


Fig 25. Detuning effects of old antenna topology

The presented topology suggests slightly lower field strengths where the performance in short reading distances increases with certain type of cards.

Note: The modulation index may be adapted in the register settings of the device. Refer to the data sheet of the device for further information.

Please also refer to the excel worksheet "Antenna Topology II" in ANxxx for further component calculations.

7.2 Transmitter matching resistance R_{match}

The transmitter (TX) matching resistance R_{match} defines the equivalent resistance at the operating frequency present between the transmitter output pins TX1 and TX2 of the PN51x/PN53x. Different equivalent resistive loads lead to different transmitter current consumption.

7.2.1 Test circuit

The following schematic in Fig 26 shows a possible configuration to investigate the optimum transmitter matching resistance R_{match}. The setup measures the available RF power P_{ant} and the TX supply current I_{TVDD} at different matching resistance values.

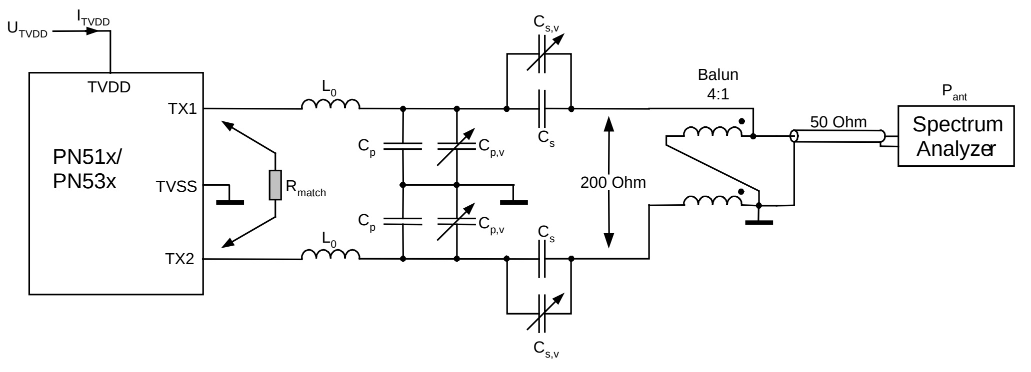


Fig 26. Test circuit for R_{match}

TX supply current vs. matching resistance

Fig 27 shows the TX supply current on the y-axis vs. the matching resistance on the x-axis in dependency on different supply voltages TVDD. An increase in R_{match} results in a lower current flow from TX and thus leads to a lower magnetical field generated by the antenna.

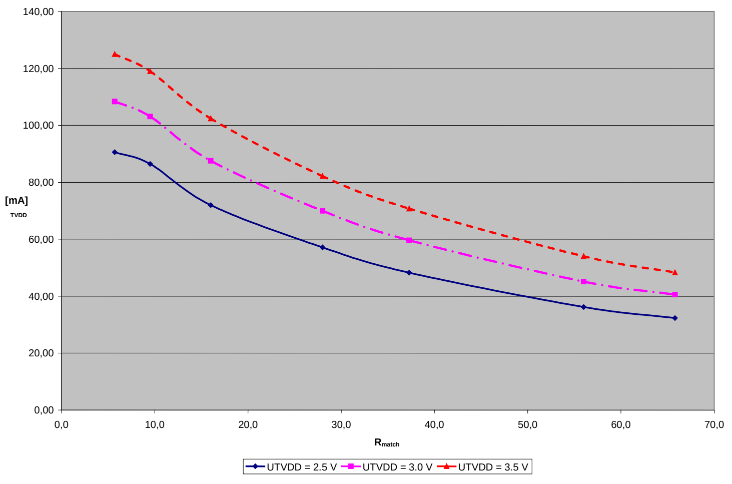


Fig 27. Transmitter supply current vs. matching resistance

RF power vs. matching resistance

Fig 28 shows antenna power (H-field) dissipation in relation to the matching resistance.

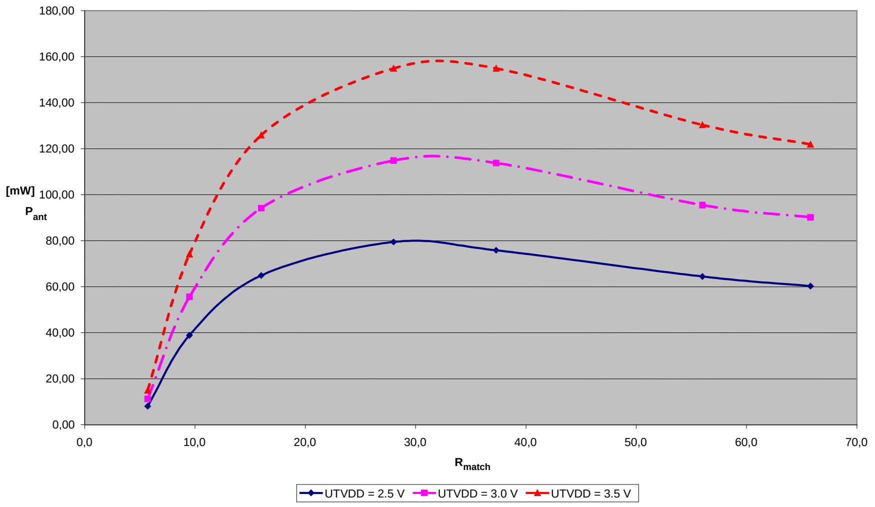


Fig 28. RF power vs. matching resistance

Power added efficiency @ 3V

Fig 29 shows the power added efficiency curve at different matching resistances of the antenna circuit.

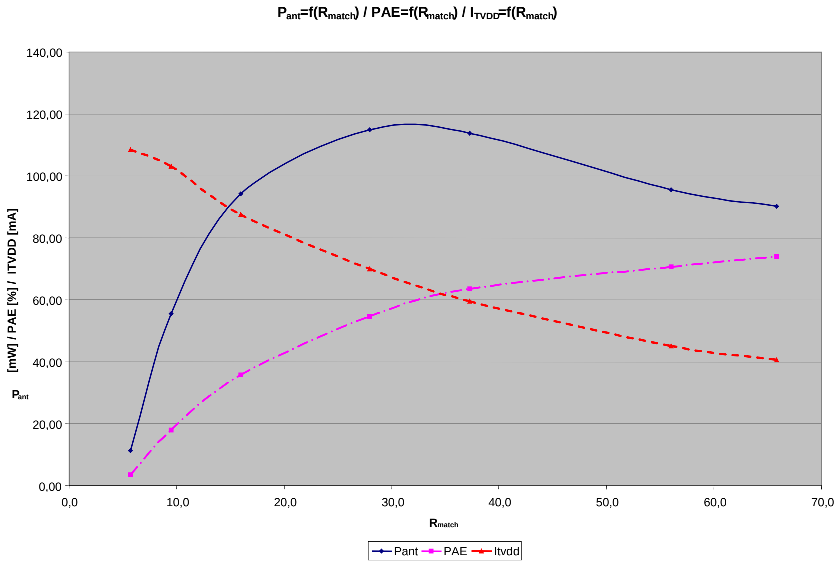


Fig 29. Power added efficiency @ 3V

Conclusion

A higher matching resistance results in less power consumption but only slightly less available RF power output compared to the maximum available RF power output. A good compromise between available RF power and TX power consumption can be reached by a matching resistance R_{match} between 60 and 80 Ohm. The example matching circuit in chapter 7.7 has been tuned to 73 Ohm.

Optimal R_{match} = 60 - 80 Ohm

7.3 Matching circuit design

7.3.1 Calculation of matching components

The impedance $Z_{match}/2$ of the matching network in Fig 29 is given by:

$$Z_{match}/2 = j\cdot\omega\cdot L_0 + \cfrac{1}{j\cdot\omega\cdot C_0 + \cfrac{1}{\cfrac{1}{\cfrac{1}{R_p} + \cfrac{1}{j\cdot\omega\cdot L_A} + j\cdot\omega\cdot C_A} + \cfrac{1}{j\cdot\omega\cdot C_1}}} \qquad (17)$$

Note: The calculation for the remaining matching components requires only half of the antenna. This means that the series equivalent parameters are obtained by first measuring at both ends of the antenna. These values have then to be divided by two for inductances and resistances and doubled by two for capacitances for equation (17).

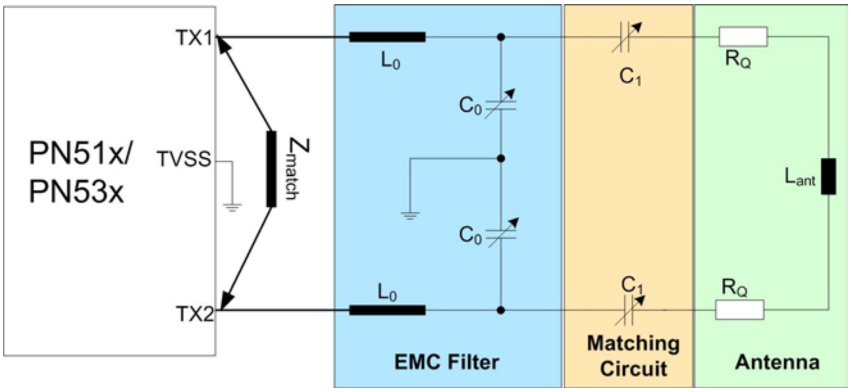


Fig 30. Measurement of matching impedance

The EMC filter circuit for the PN51x/PN53x fulfills two functions: the filtering of the signal and impedance transformation block. The main properties of the impedance transformation are:

- Decreasing the amplitude rise time after a modulation phase
- Increasing the receiving bandwidth

The EMC filter and the matching circuit must transform the antenna impedance to the required TX matching resistance Z_{match} at the operating frequency of f = 13.56 MHz.

The matching components C_0 and C_1 are determined by first measuring and then calculating the antenna impedance Z_{ant}.

The following formulas apply for $Z_{ant} = \mathrm{Re}(Z_{ant}) + \mathrm{Im}(Z_{ant})$:

$$\mathrm{Re}(Z_{ant}) = \frac{\frac{1}{R_p}}{\left(\frac{1}{R_p}\right)^2 + \left(\omega \cdot C_A - \frac{1}{\omega \cdot L_A}\right)^2} \tag{18}$$

$$\mathrm{Im}(Z_{ant}) = \frac{\frac{1}{\omega \cdot L_A} - \omega \cdot C_A}{\left(\frac{1}{R_p}\right)^2 + \left(\omega \cdot C_A - \frac{1}{\omega \cdot L_A}\right)^2}$$

In order to solve the two unknown variables C_0 and C_1 in equation (17), the real part of the impedance network Z_{match} is set to the matching resistance R_{match} = 73 Ohm and the imaginary part of Z_{match} is set to 0. This is accomplished by extending the fraction in (17) with its complex conjugate, which is due to simplification reasons not carried out in this document.

$$C_0 = \frac{\dfrac{\omega \cdot L_0}{73^2 + (\omega \cdot L_0)^2} \pm \dfrac{\sqrt{73 \cdot \mathrm{Re}(Z_{ant}) + \dfrac{\mathrm{Re}(Z_{ant}) \cdot (\omega \cdot L_0)^2}{73} - \mathrm{Re}(Z_{ant})^2}}{73 \cdot \mathrm{Re}(Z_{ant}) + \dfrac{\mathrm{Re}(Z_{ant}) \cdot (\omega \cdot L_0)^2}{73}}}{\omega \cdot} \tag{19}$$

$$C_1 = \frac{1}{\omega \cdot \mathrm{Im}(Z_{ant}) \pm \omega \cdot \sqrt{73 \cdot \mathrm{Re}(Z_{ant}) + \dfrac{\mathrm{Re}(Z_{ant}) \cdot (\omega \cdot L_0)^2}{73} - \mathrm{Re}(Z_{ant})^2}} \tag{20}$$

Note: Due to simplification of the formulas and tolerances of the measured equivalent antenna circuit values, a final tuning of the matching circuit is necessary to achieve the required matching resistance at the transmitter output pins.

7.4 Tuning procedure

The matching circuit elements C_0 and C_1 must be tuned to get the required matching resistance R_{match} ($X_{match} = 0$) at the PN51x/PN53x TX pins. The matching impedance $Z_{match} = R_{match} + jX_{match}$ is measured with an impedance analyzer or network analyzer.

The following Fig 31 shows a simulation of the matching impedance Z_{match}.

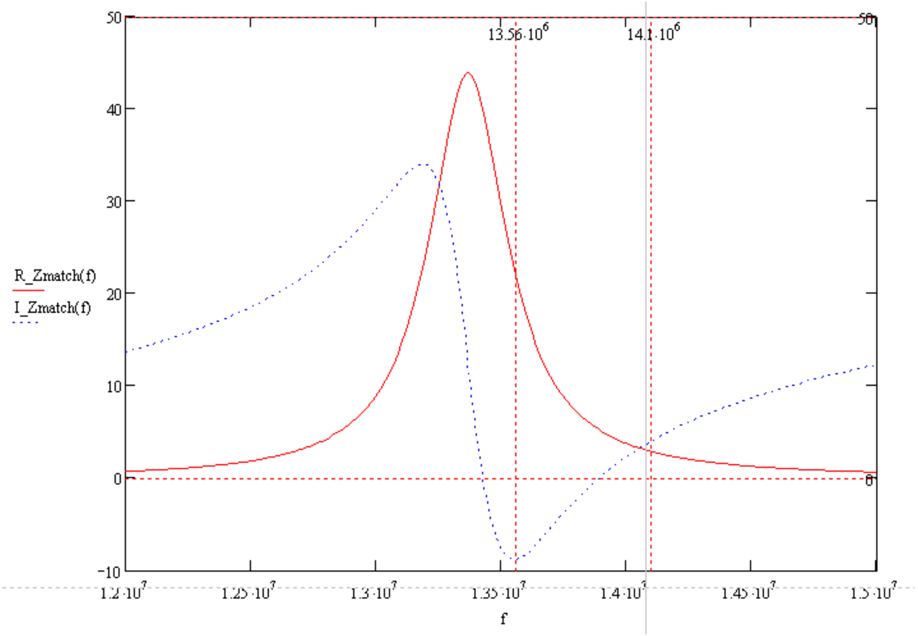


Fig 31. Simulation of matching impedance

Note: All tuning and measurement of the antenna has always to be performed at the final mounting position to consider all parasitic effects like metal influence on quality factor, inductance and additional capacitance.

The smith chart in Fig 32 shows the antenna simulation based on the example values used in chapter 7.7.

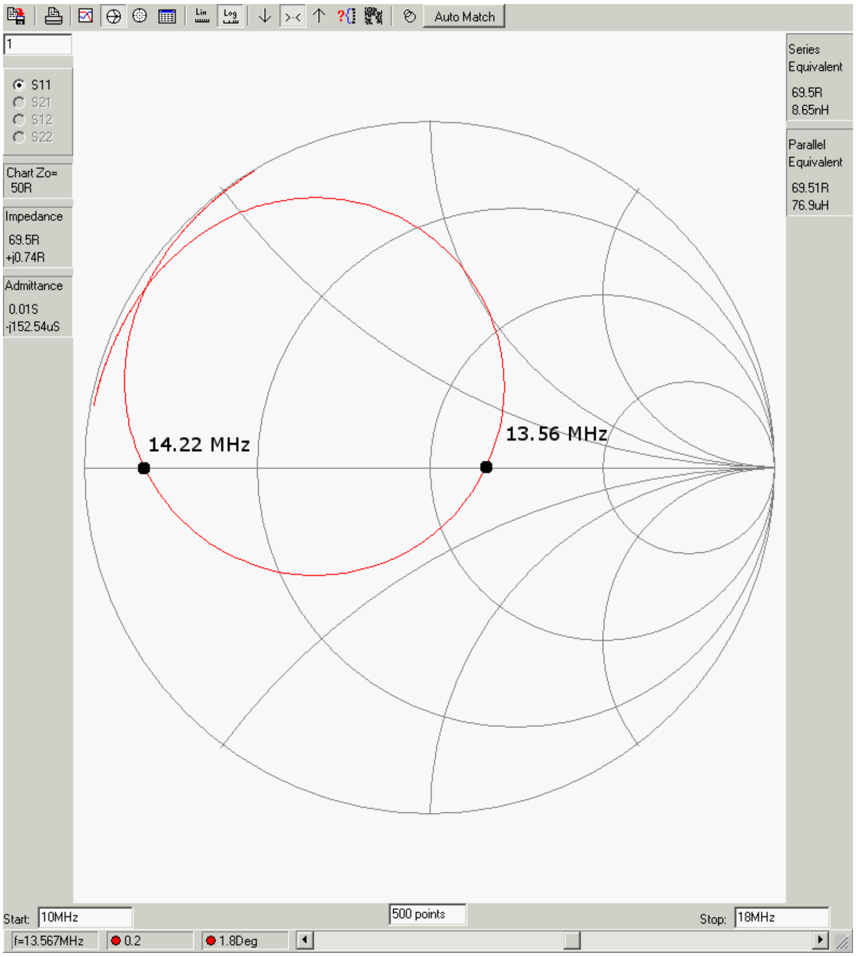


Chart Zo=
50R

Impedance
69.5R
+j0.74R

Admittance
0.01S
-j152.54uS

Series Equivalent
69.5R
8.65nH

Parallel Equivalent
69.51R
76.9uH

Start: 10MHz

500 points

Stop: 18MHz

f=13.567MHz

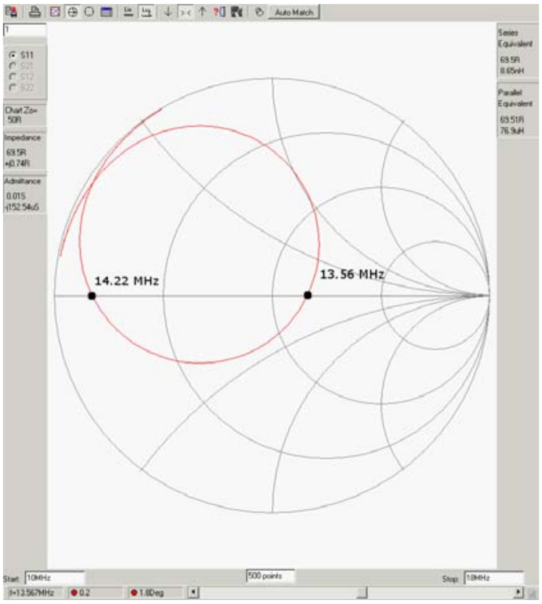
● 0.2

● 1.8Deg

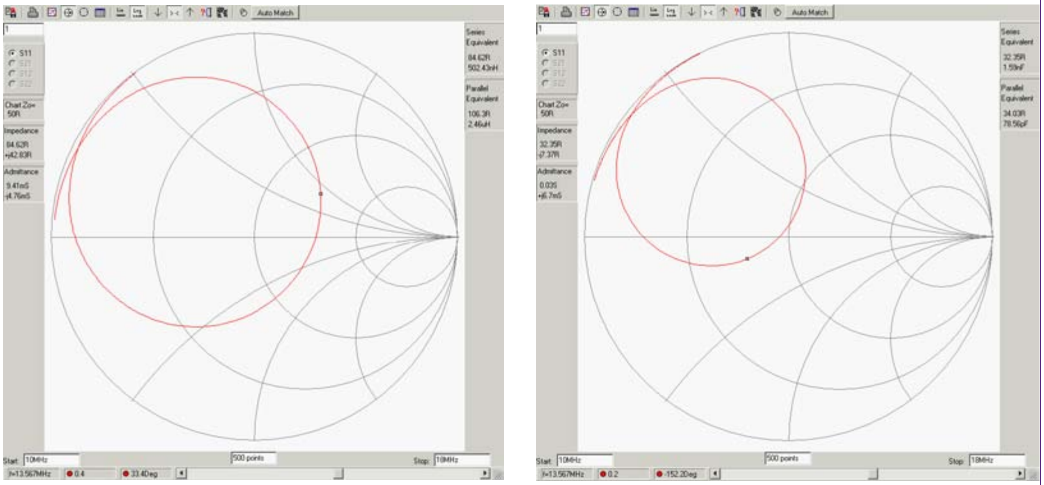
Fig 32. Smith chart for matching impedance

7.4.1 Tuning of EMC matching capacitance C_0

The smith charts in Fig 33 show the matching impedance Z_{match} vs. frequency.



Optimum C0



C_0 too low

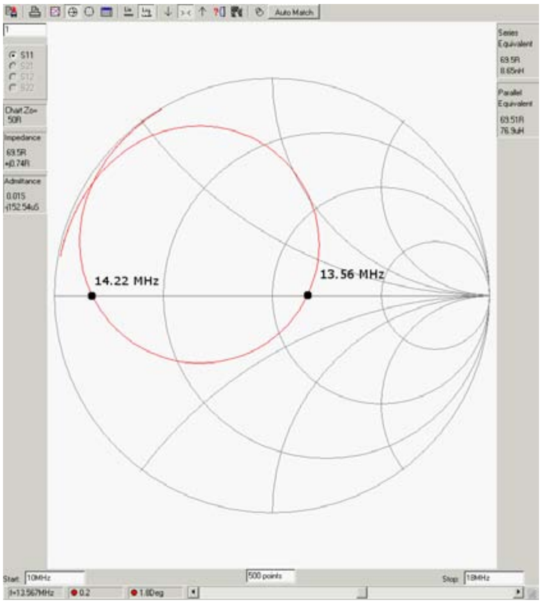
C_0 too high

Fig 33. Smith charts for C_0 tuning

C_0 changes the magnitude of the matching impedance. After a change of C_0 the imaginary part of Z_{match} needs to be compensated by adjusting C_1.

7.4.2 Tuning of series matching capacitance C_1

The smith charts in Fig 34 show the matching impedance Z_{match} 2 vs. frequency.



1

Chart Zo= 50R

Impedance 69.5R +j0.74R

Admittance 0.01S -j152.54uS

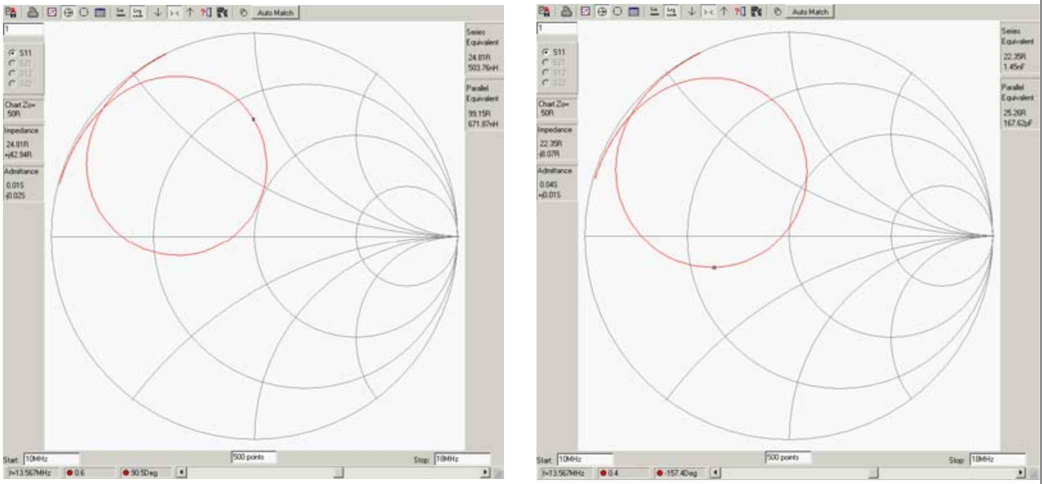
Series Equivalent 69.5R 11.65nH

Parallel Equivalent 69.51R 76.9uH

Start: 10MHz 500 points Stop: 18MHz

f=13.567MHz ● 0.2 ● 1.8Deg

Optimum C1



1

Chart Zo= 50R

Impedance 24.01R +j42.94R

Admittance 0.01S -j0.02S

Series Equivalent 24.01R 503.76nH

Parallel Equivalent 99.15R 671.87nH

Start: 10MHz 500 points Stop: 18MHz

f=13.567MHz ● 0.6 ● 90.5Deg

1

Chart Zo= 50R

Impedance 22.35R -j8.07R

Admittance 0.04S +j0.01S

Series Equivalent 22.35R 1.45nF

Parallel Equivalent 25.26R 167.62pF

Start: 10MHz 500 points Stop: 18MHz

f=13.567MHz ● 0.4 ● -157.4Deg

C_1 too low

C_1 too high

Fig 34. Smith charts for C_1 tuning

C_1 changes mainly the imaginary part of Z_{match}.

7.4.3 Tuning flow chart

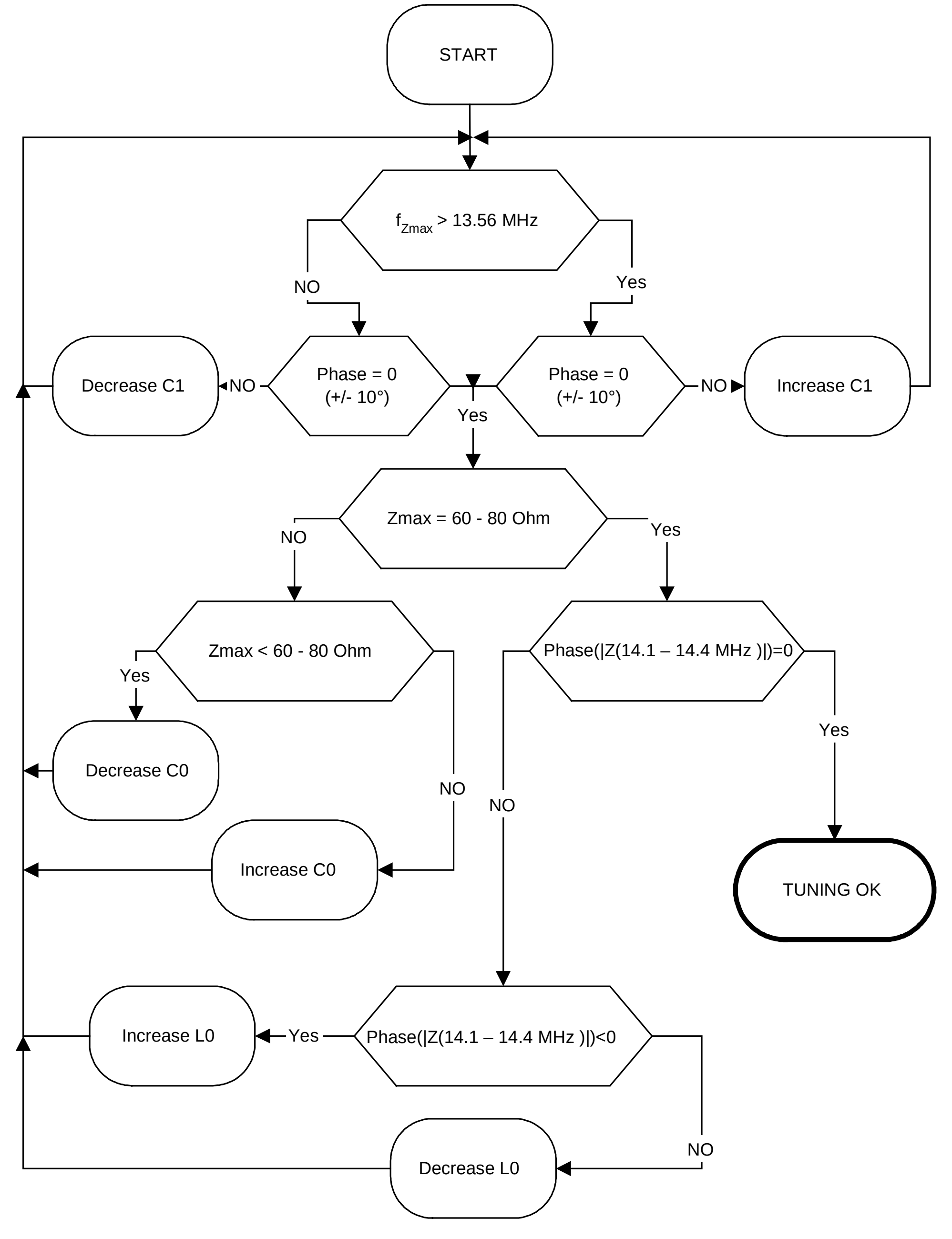


Fig 35. Tuning flow chart

Note: The initial value of L_0 has been set to 0.33 µH.

7.5 Receiver circuit design

Next step, after matching and tuning the transmitting antenna, is the design and tuning of the receiver circuit. The investigations need to be carried out for initiator and target mode.

Fig 36 shows the relevant components for the receiver circuit. R_1 and R_2 form a voltage divider which has to be adjusted according to the incoming voltage levels at U_{C0}. Both, Initiator and Target mode of the device have to be investigated, since detuning effects on the RX path behave differently.

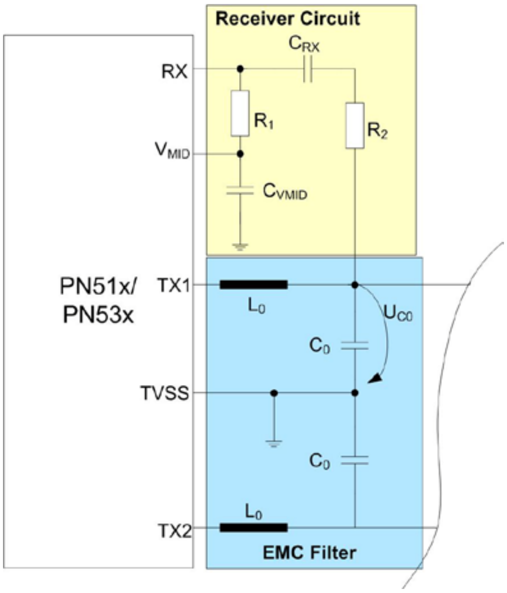


Fig 36. Receiver circuit

7.5.1 Initiator mode

Step 1:

Predefined components:

C_{RX} = 1 nF: DC blocking capacitor

C_{vmid} = 100 nF: V_{mid} decoupling capacitance

R1 = 1 kΩ: Predefined part of the voltage divider

Step 2:

The transmitter must be switched on in continuous wave mode and the voltage on the EMC filter capacitance U_{C0} has to be measured with a low capacitance probe (< 2 pF).

Typically low capacitance probes are terminated with 50 Ohm, thus the scope configuration has to be set correctly!

Step 3:

The voltage divider resistor R_2 can be calculated by:

$$R_2 = R_1 \cdot \left(\frac{U_{C0}}{U_{RX}} - 1 \right) \quad (21)$$

with the target value of U_{RX} = 1 V_{pp} (antenna not detuned)

Step 4:

After inserting the determined resistor R_2 the voltage on RX pin U_{RX} must be measured with a low capacitance probe (< 2 pF) for continuous transmitting mode.

The voltage U_{RX} **must not** exceed the maximum value U_{RXmax} even when the antenna is detuned by a target or passive card.

7.6 Target mode

Step 5:

The device must be placed in the test setup according to NFCIP1 test method standard. The magnetic field has to be increased continuously and the voltage on RX checked against the level U_{RXmax}.

$U_{RX} < U_{RXmax}$ for H <= 7.5 A/m

If the voltage level on RX gets higher than the maximum value for field strength below 7.5 A/m, the resistor R_2 must be increased to a value that meets the specification.

7.7 Example

As an example the antenna of the MFRC52x/PN51x/PN53x evaluation board Rev. 1.1 will be matched to the transmitter output (see Fig 37).

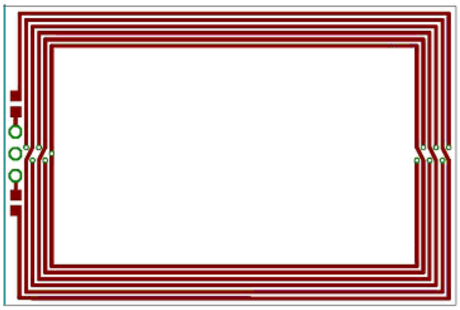


Fig 37. MFRC52x/PN51x/PN53x evaluation board antenna

The external RF components should be tuned to a value $I_{TVDD} \approx 50mA$. The matching resistance has been set around 70 Ohm.

$R_{match} \approx 70$ Ohm

The series equivalent circuit of the antenna results to (see chapter 8.2.1):

$R_a = 1.1$ Ohm

$C_a = 9.8$ pF

$L_a = 3.1$ µH

The calculation for the external damping resistor results to $R_Q = 3.668$ Ohm. The value for R_Q is 3.3 Ohm, which results in a Q-factor of approximately 35.

The parallel equivalent circuit of the antenna - including quality factor damping resistors $R_Q = 3.3$ Ohm - is determined with the following values:

$R_{pa} = 9650$ Ohm

$C_{pa} = 9.7$ pF

$L_{pa} = 3.3$ µH

The EMC coil L_0 is chosen with an initial value of 0.33 µH.

Note: The following calculation requires only half the values R_{pa}, C_{pa}, L_{pa} since only $Z_{match}/2$ of the matching circuit is calculated.

With equation (18) the antenna impedance is given with:

$Re(Zant) = 6.977\ \Omega$

$Im(Zant) = 183.387\ j\Omega$

The series capacitance C1 calculates from the solution from the quadratic equation (19) and (20) of the EMC capacitance C0.

$C_{1\_1} = 57.63$ pF

C_{1_2} = 71.95 pF

The EMC capacitances C_{0_1} and C_{0_2} are determined for the values of C_{1_1} and C_{1_2}:

C_{0_1} = -417.62 pF

C_{0_2} = 618.20 pF

The correct values for the matching components are C_{1_2} and C_{0_2}.

Refer to Fig 31 for a simulation of the magnitude and phase of the final antenna circuit.

The smith chart in Fig 38 was captured with a network analyzer showing a matching at 72 Ohm with the given values above.

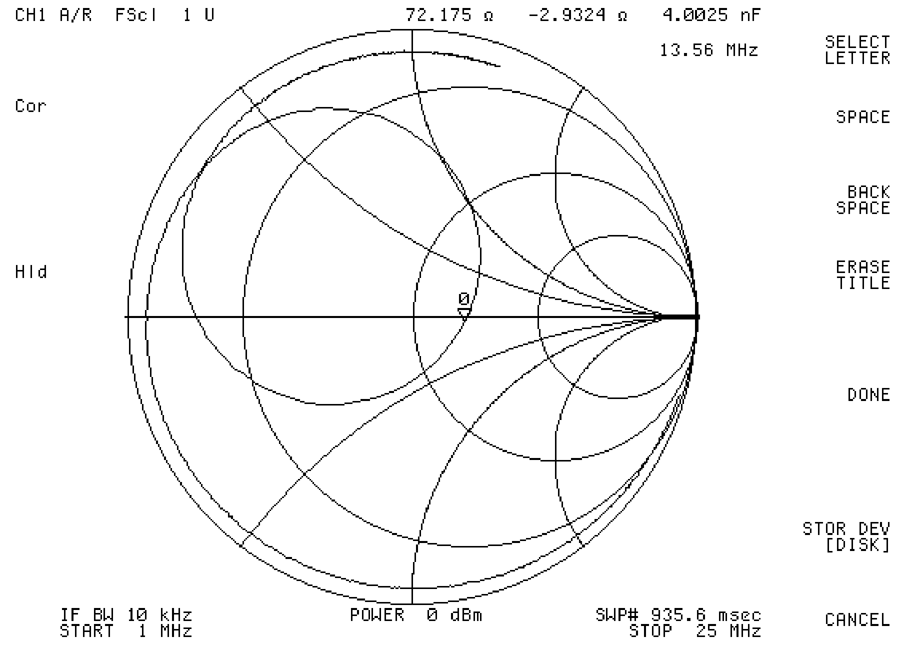


Fig 38. Z_{match} simulation

8. Appendix

8.1 Antenna design

8.1.1 Antenna inductance

The following two sub-chapters 8.1.2 and 8.1.3 show required formulas to estimate the antenna inductance in free air.

Note: Sophisticated simulation software is required to calculate the antennas parameters to estimate antenna values in environments containing metal (such as shielding planes or batteries in devices).

8.1.2 Circular antennas

Fig 39 shows the profile a typical circular antenna.

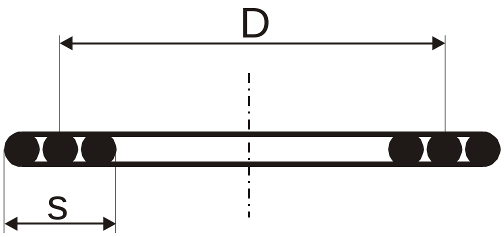


Fig 39. Circular antenna

The inductance can be estimated using the following formula:

$$L_a[nH] = \frac{24.6 \cdot N_a^{\;2} \cdot D[cm]}{1 + 2.75 \cdot \dfrac{s[cm]}{D[cm]}} \qquad (22)$$

D Average antenna diameter

s Antenna width

N_a Number of turns

8.1.3 Rectangular antennas

Fig 40 shows a typical rectangular antenna.

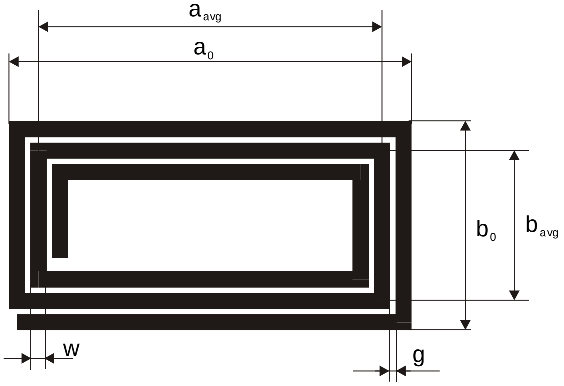


Fig 40. Rectangular antenna

Variables:

a_o, b_o	Overall dimensions of the coil
a_{avg}, b_{avg}	Average dimensions of the coil
t	Track thickness
w	Track width
g	Gap between tracks
N_a	Number of turns
d	Equivalent diameter of the track

The inductance can be calculated by:

$$L_a = \frac{\mu_0}{\pi} \cdot \left[x_1 + x_2 - x_3 + x_4\right] \cdot N_a^{1.8} \qquad (23)$$

With:

$$d = \frac{2 \cdot (t + w)}{\pi}$$

$$a_{avg} = a_o - N_a \cdot (g + w) \qquad b_{avg} = b_o - N_a \cdot (g + w)$$

$$x_1 = a_{avg} \cdot \ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(a_{avg} + \sqrt{a_{avg}^{\ 2} + b_{avg}^{\ 2}}\right)}\right] \qquad x_2 = b_{avg} \cdot \ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(b_{avg} + \sqrt{a_{avg}^{\ 2} + b_{avg}^{\ 2}}\right)}\right]$$

$$x_3 = 2\cdot\left[a_{avg} + b_{avg} - \sqrt{a_{avg}{}^2 + b_{avg}{}^2}\right] \qquad x_4 = \frac{a_{avg} + b_{avg}}{4}$$

8.1.4 Number of turns

Depending on the antenna size, the number of turns has to be chosen in a way to achieve an antenna inductance between 300 nH and 3 µH.

The parasitic capacitance should be kept as low as possible to achieve a self-resonance frequency > 35 MHz.

A typical the number of turns will be in the range

N_a=1 – 6,

which is suitable for various applications and antenna sizes.

Due to the coupling coefficient, a low number of turns are preferred. The lower the numbers of turns, the lower is the influence of coupled devices (e.g. 2nd NFC device, Card, Reader) to the 1st device. This also means that the detuning effect on the 1st device is minimized when reducing the distance between the two devices. The overall performance loss due to low number of turns is negligible.

8.1.5 Antenna symmetry

The symmetry in antenna design is absolutely necessary with respect to tuning and EMC behavior (see Fig 41). Otherwise common mode currents are generated due to parasitic capacitances from the antenna to ground. These currents can cause emissions that hurt the EMV regulations

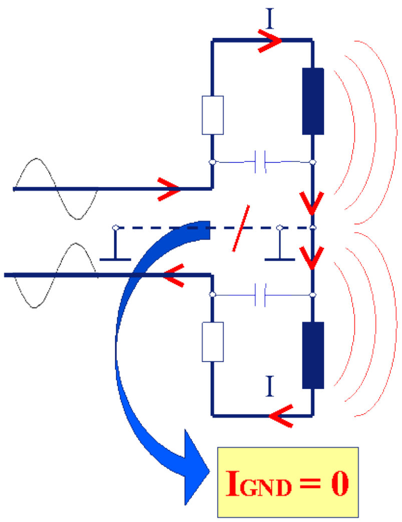


Fig 41. Ground current compensation

The following Fig 42 shows an example of a symmetric 4-turn antenna design. It can be seen that the center tap of the antenna is connected to ground. Basically, we do not recommend grounding the center tap, but leaving it floating. This has the advantage of a virtual ground point which is floating to achieve symmetry of the antenna. Refer also to Fig 41 where center tap is not connected.

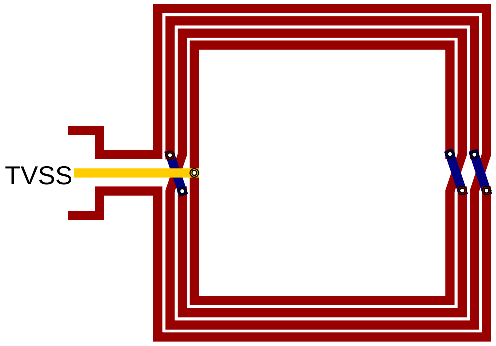


Fig 42. Example symmetric 4-turn antenna

8.1.6 Ferrite shielding

The benefit of a ferrite is to shield an antenna against the influence of metal. A metal plane could be part of the housing of the device or a ground plane of the device PCB itself, which has to be connected very near to the antenna. If metal is placed very near to the antenna the alternating magnetic field generates eddy currents in the metal. These eddy currents absorb power, and lead to detuning of the antenna due to a decreased inductance and quality factor. Therefore, it is necessary to shield the antenna with ferrite for proper operation in close metallic environment.

The following examples should give an estimation about the influence of ferrite to the distribution of the magnetic field.

A circular antenna has been used to simplify the simulation. A circular antenna is rotational symmetric to the x-axis. Therefore, the simulation can be reduced to a two dimensional mathematical problem. The simulation estimates the field distribution of a non-disturbed antenna. It has been assumed an antenna radius of 7.5 cm with 1 turn and a copper wire of 1mm thickness.

Fig 43 shows the two-dimensional magnetic field of the circular antenna.

The right part shows the field distribution. The highest field strength is generated in the area of the coil.

The left part shows the magnitude of the field strength H over the distance d. The minimal field strength of H_{MIN} = 1.5 A/m defined by ISO/IEC 14443 is marked with doted vertical line.

Note: The shielding effect of the ferrite strongly depends on the ferrite material and the distance between antenna and influencing material. The shielding effect may be negligible if the antenna is very near to interfering material (metal, battery) and the ferrite has low permeability (foils usually μ_R<10).

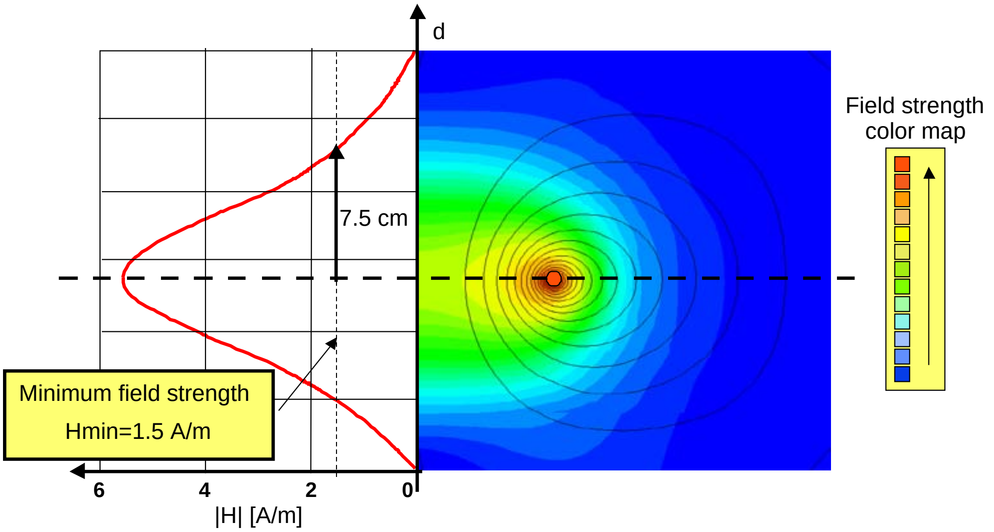


Fig 43. Non disturbed field distribution of a circular antenna

Fig 44 shows the field distribution of the defined antenna but a metal plane near to the antenna. The magnitude of the field strength has decreased compared to the disturbed field which leads to a decreased operating distance.

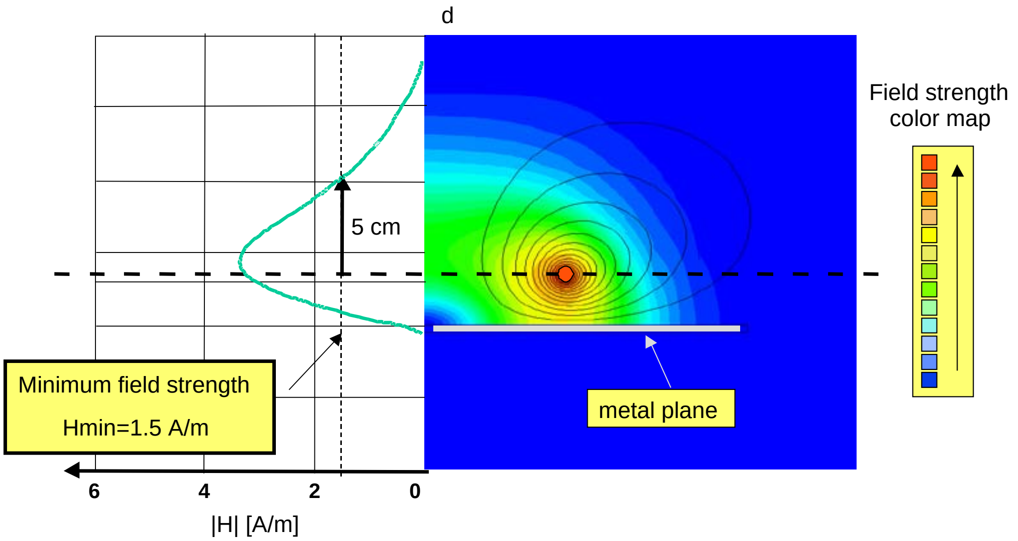


Fig 44. Field distribution of a circular antenna with a metal plane

Fig 45 shows a ferrite plane (μ_R=40) which is positioned between the metal plane and the antenna coil itself. The field strength very near to the ferrite increases, but the increasing magnitude does not necessarily result in an increase of the operating distance at H_{MIN} value (vertical doted line).

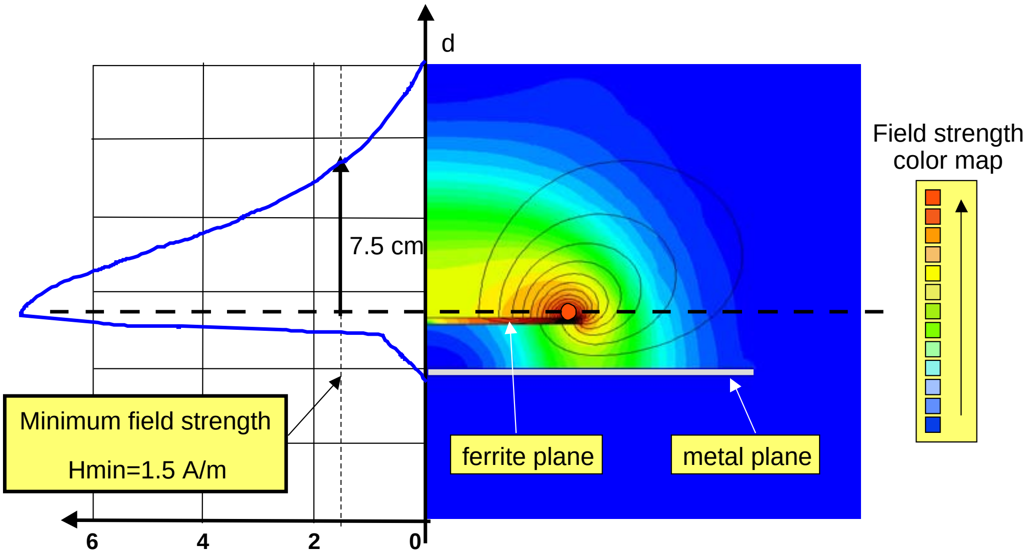


Fig 45. Ferrite shielded field distribution of a circular antenna

The simulation shows that the use of a ferrite reduces the generated eddy currents in a metal plane. The ferrite generates an additional field component, which results in a fixed detuning of the antenna itself.

8.1.7 Antenna quality factor

The quality factor is a determining constraint to design and tune an antenna. Fig 46 shows an excerpt of a typical 100% ASK modulation. The maximum timing limit of 3us (as defined in the ISO/IEC14443) for a modulation pause is taken to calculate the quality factor.

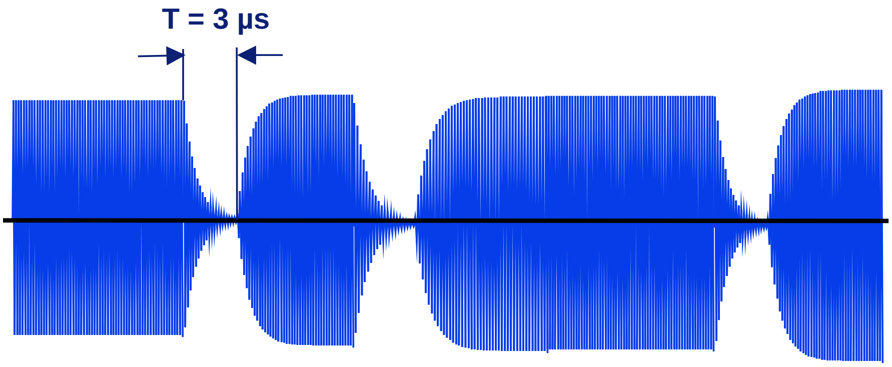


Fig 46. Pulse width definition

The bandwidth B –pulse width T product is defined as:

$$B \cdot T \geq 1 \tag{24}$$

With the bandwidth definition

$$B = \frac{f}{Q} \tag{25}$$

the B-T product results to

$$Q \leq f \cdot T$$

$$Q \leq 13.56MHz \cdot 3\mu s$$

$$Q \leq 40.68$$

Note: The recommended antenna quality factor is **Q_a = 35.**

8.2 Equivalent circuit

8.2.1 Determination of series equivalent circuit

The antenna loop has to be connected to an impedance analyzer to measure the series equivalent components.

Note: The equivalent circuit (see Fig 47) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

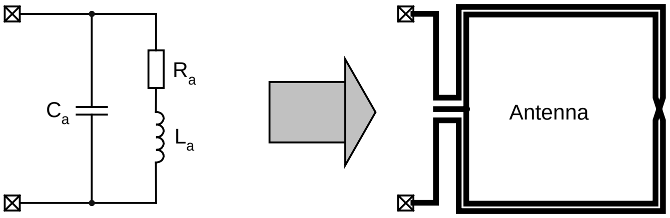


Fig 47. Series equivalent circuit

Typical values:

L_a = 0.3...3 µH

C_a = 3...30 pF

R_a = 0.3...8 Ω

8.2.2 Calculation of antenna quality factor damping resistor R_Q

The quality factor of the antenna is

$$Q_a = \frac{\omega \cdot L_a}{R_a} \tag{26}$$

If the calculated value of Q_a is higher than the target value of 35, an external damping resistor R_Q has to be inserted on each antenna side to reduce the Q-factor to a value of **35 (±10%)**.

The value of R_Q calculates as:

$$R_Q = 0.5 \cdot \left(\frac{\omega \cdot L_a}{35} - R_a \right) \tag{27}$$

8.2.3 Determination of parallel equivalent circuit

The parallel equivalent circuit of the **antenna together with the added external damping resistor** $\mathbf{R_Q}$ has to be measured. The quality factor should be checked again to be sure to achieve the required value of Q=35.

Note: The equivalent circuit (Fig 48) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

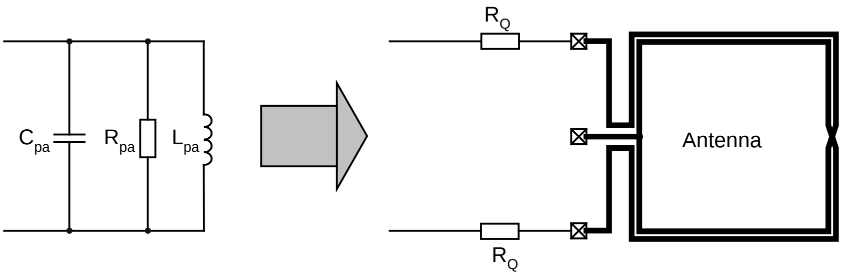


Fig 48. Parallel equivalent circuit

The following formula applies:

$$L_{pa} \hat{=} L_a$$
$$C_{pa} \hat{=} C_a \qquad (28)$$
$$R_{pa} \hat{=} \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q}$$

8.3 Equivalent circuit measurement

8.3.1 Impedance analyzer with equivalent circuit calculation

Impedance analyzers like Agilent 4294A or 4395A can determine directly the series or parallel equivalent circuit by measuring the magnitude and the phase of the impedance of the connected antenna.

Note: The antenna has to be at the final mounting position to consider all parasitic effects like metal influence on quality factor, inductance and additional capacitance.

The antenna needs to be connected to the analyzer by using an appropriate test fixture that does not influence any antenna parameters.

The analyzer has to be calibrated (open, short and load compensation at the calibration plane) and the test fixture needs to be compensated (open, short compensation at the connection points) before each measurement. Please refer to device manual on how to carry out these steps.

Settings: $|Z|, \Theta$

Start frequency: 1 MHz

Stop frequency: above self-resonance frequency of the antenna

Advantage:

- Fast and simple method

Disadvantages:

- Additional equipment required
- Low accuracy of the measurement which especially results from the loss resistance for high quality factor coils ($Q_{pc} > 60$).

8.3.2 Network analyzer

This section briefly describes the determination of the antenna equivalent circuit using a network analyzer without any equivalent circuit functionality.

Note: The antenna has to be at the final mounting position to consider all parasitic effects like metal influence on quality factor, inductance and additional capacitance.

The antenna needs to be connected to the analyzer by using an appropriate test fixture that does not influence the antenna parameters.

The analyzer has to be calibrated (open, short and load compensation at the calibration plane) and the test fixture needs to be compensated (open, short compensation at the connection points) before each measurement. Please refer to device manual on how to carry out these steps.

Settings:S11,

Chart: Smith Z

Start frequency: 1 MHz

Stop frequency: above self-resonance frequency of the antenna

8.3.3 Series equivalent circuit

The following characteristic circuit elements can be determined by measurements at characteristic points (see also Fig 47 for series equivalent circuit).

R_s Equivalent resistance at f = 1 MHz

L_a Equivalent inductance at f = 1 MHz

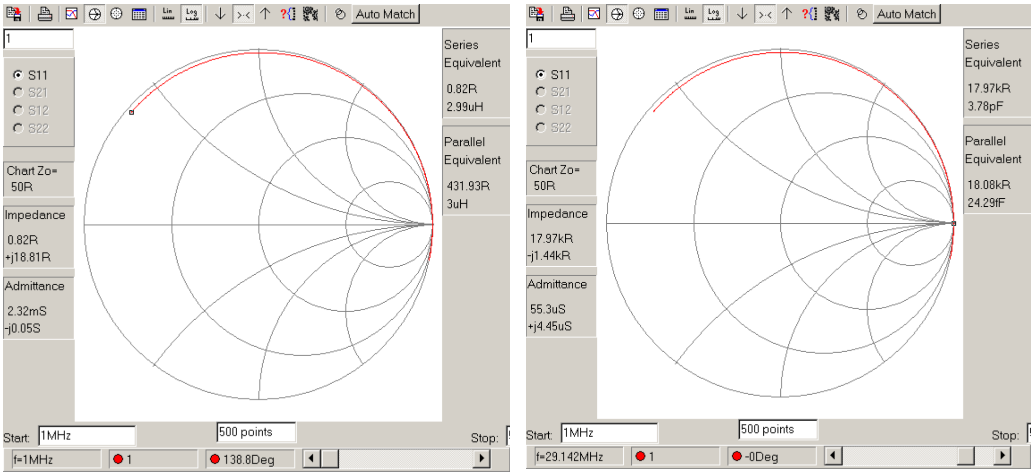
R_p Equivalent resistance at the self-resonance frequency

f_{ra} Self-resonance frequency of the antenna

The antenna capacitance C_a can be calculated with:

$$C_a = \frac{1}{(2 \cdot \pi \cdot f_{ra})^2 L_a} \tag{29}$$

The following Fig 49 shows simulation results to determine the characteristic circuit.



Series Equivalent 0.82R 2.99uH
Parallel Equivalent 431.93R 3uH
Chart Zo= 50R
Impedance 0.82R +j18.81R
Admittance 2.32mS -j0.05S
Start: 1MHz
500 points
f=1MHz
1
138.8Deg

Series Equivalent 17.97kR 3.78pF
Parallel Equivalent 18.08kR 24.29fF
Chart Zo= 50R
Impedance 17.97kR -j1.44kR
Admittance 55.3uS +j4.45uS
Start: 1MHz
500 points
f=29.142MHz
1
-0Deg

g. R_s = 0.82 Ohm, L_a = 2.99 µH

h. R_p = 18 kOhm, f_{ra} = 29.14 MHz

Fig 49. Simulation results for characteristic circuit

The series equivalent resistance of the antenna (see Fig 50) at the operating frequency f_{op} = 13.56 MHz can be calculated out of the characteristic circuit with:

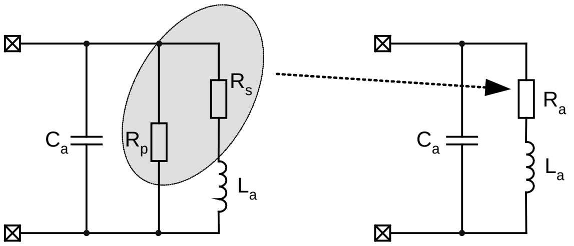


Fig 50. Series equivalent resistance calculation

$$R_a = R_s + \frac{(2 \cdot \pi \cdot f_{op} \cdot L_a)^2}{R_p} \quad (30)$$

The parallel equivalent circuit always has to be calculated by means of the series equivalent circuit using equation (28).

8.4 Pulse shape check

The following pulse shape checks are a quick way for investigating the shaping of the generated RF-field. The figures in 8.5 always relates to the latest ISO/IEC18092 specification.

The correct measurement techniques needs to be carried out in ISO/IEC 22536 (NFCIP – RF Interface Test methods) and/or ISO/IEC 10373-6 (Identification cards – Test methods) and ISO/IEC14443!

The Q-factor can be checked by using the fact that the Q-factor has a direct influence on the edges of the modulation shape.

An oscilloscope with a bandwidth of at least 50 MHz has to be used to carry out the module shape measurements (Fig 51).

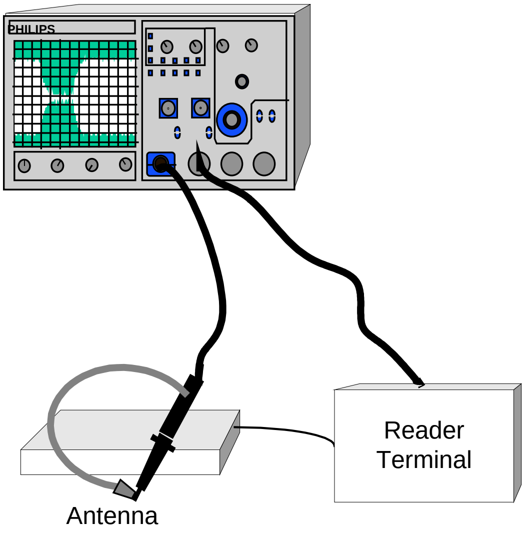


Fig 51. Setup to check the Q-factor

CH1: Use a loop with the ground line shortcut at the probe to enable inductive signal coupling. Hold the probe loop closely above the antenna.

CH2: Used as trigger signal by using Sigout (See [1]-[4] for reference documents)

It is recommended to check the pulse shape according to the values given in Fig 52 and Fig 52.

Note: The absolute measured voltage in CH1 depends on the coupling (= distance) between the probe loop and the reader antenna.

The influence of the coupling on the shape can be neglected.

The complete antenna tuning and Q-checking is done without any card.

8.5 Pulse shape according to ISO/IEC 18092

8.5.1 Bit rate 106kbps

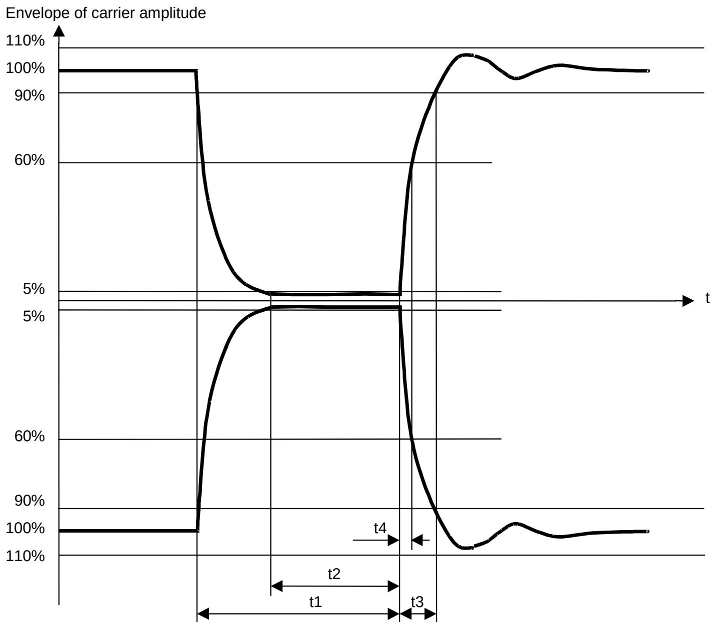


Fig 52. Pulse shape according to ISO/IEC 18092, 106 kbps

The time t1-t2 describes the time span, in which the signal falls from 90% down below 5% of the signal amplitude. As the pulse length of PN51x/PN53x is accurate enough, only the time t2 has to be checked: the signal has to remain below 5% for the time t2. The most critical time concerning rising carrier envelope is t4. It must be checked that the carrier envelope at the end of the pause reaches 60% of the continuous wave amplitude within 0.4 µs.

Table 3. Pulse shape definitions according to ISO/IEC18092, 106 kbps

Pulse length (Condition)	t1 [µs]	t2 [µs]		t3 [µs]	t4 [µs]
		(t1 ≤ 0,5)	(t1 > 2,5)		
Maximum	3,0	t1		1,5	0,4
Minimum	2,0	0,7	0,5	0,0	0,0

8.5.2 Bit rate 212 kbps and 424 kbps

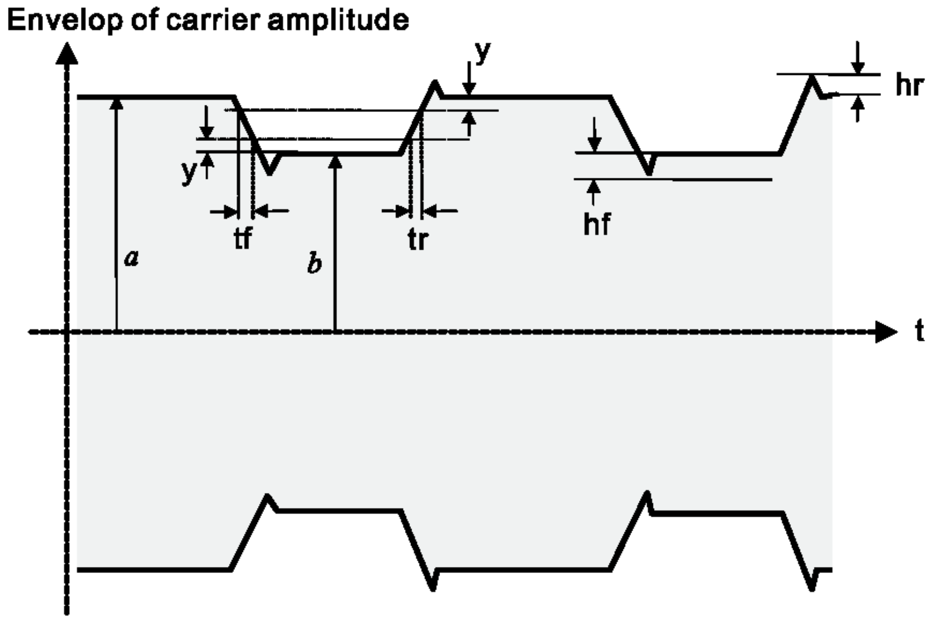


Fig 53. Pulse shape according to ISO/IEC 18092, 212 and 424 kbps

Table 4. Table 8-1: Pulse shape definitions according to ISO/IEC18092, 212 and 424 kbps

	212 kbps	424 kbps
tf	2,0 µs max	1,0 µs max
tr	2,0 µs max	1,0 µs max
y	0,1 (a-b)	0,1 (a-b)
hf, hr	0,1 (a-b) max	0,1 (a-b) max

9. References

[1] Data sheet: PN511 Transmission Module (Doc. No.: 0797xx)

[2] Data sheet: PN512 Transmission Module (Doc. No.: 1113xx)

[3] Data sheet: PN531 Transmission Module (Doc. No.: 1119xx)

[4] Data sheet: PN532 Transmission Module (Doc. No.:1154xx)

[5] Ecma 340 NFCIP-1 Interface and protocol

[6] ISO/IEC 18092: Near Field Communication – Interface and Protocol (NFCIP-1)

[7] MathCAD 13

[8] RFSim99

[9] NFC Transmission Module Antenna and RF Design Guide - Addon - Excel Calculation (Doc. No.: 1444xx)

[10] ISO/IEC 10373-6

[11] ISO/IEC 22536

[12] ISO/IEC 14443

[13] RF amplifier for NXP’s contactless NFC Reader IC’s (Doc. No.: 1425xx)

[14] Datasheet MFRC523, Contactless Reader IC

[15] Datasheet MFRC522, Contactless Reader IC

10. Abbreviations

EMC	Electromagnetic compatibility
IC	Integrated circuit
NFC	Near field communication
PCB	Printed circuit board
R_{match}	Transmitter matching resistance
RF	Radio frequency
RFID	Radio frequency identification
RX	Receiver
TX	Transmitter
Z_{match}	Transmitter matching impedance

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