AN145715

PN544 Antenna Design Guide

Rev. 1.5 — 28th August 2009 Application Note

Document information

Info	Content
Keywords	NFC, PN544, Antenna Design, RF Design
Abstract	This application notes provides guidance on antenna and RF design for NFC device PN544.

founded by Philips

Revision history

Rev	Date	Description
1.0	18/02/2008	Initial Release
1.1	14/05/2008	Updates on demo board antenna default matching
1.2	27/02/2009	Update on antenna topology
1.3	12/03/2009	Minor Updates
1.4	30/06/2009	Appendix B added
1.5	28/08/2009	U_{RX} max changed to 1.7V

Contact information

For additional information, please visit: http://www.nxp.com

For sales office addresses, please send an email to: salesaddresses@nxp.com

1. Introduction

1.1 Purpose and scope

This application draft is intended to give a practical guide to estimate and tune antenna components for the PN544 antenna topology. The PN544 is capable of performing Reader/Writer (R/W) as well as target mode functionalities. This guide is not primarily based on a strong mathematical background but on a practical approach towards PN544 antenna tuning. Therefore it is recommended to read and use this document as described in the chapter 3 “Tuning Procedure”.

To get hands-on experience it is recommended to use an antenna which has approximately the same outlines as the one used throughout this document.

This document will be adapted for upcoming versions and may contain a modification of the following topology or even contain further antenna topologies.

2. PN544 Topology

The PN544 topology is outlined in Fig 1. It can be seen that only one antenna (Z_{ant}) is used for Reader/Writer-and Card mode. The number of turns for this antenna topology using the PN544 demo board is six.

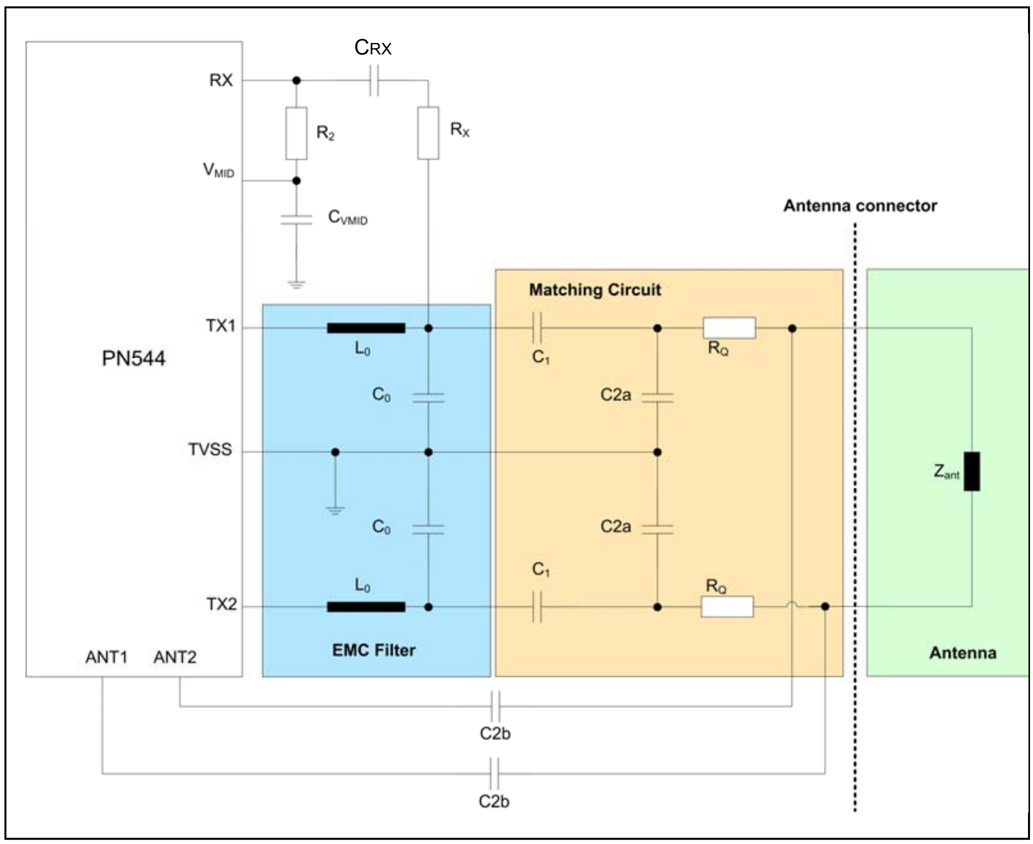


Fig. 1 PN544 antenna topology

The following component tolerances (maximum values) are required for an appropriate tuning:

Component	Maximum tolerance	Component	Maximum tolerance
L0	5%	RQ	5%
C0	5%	Rx	5%
C1	2%	R2	5%
C2a	2%	CRX	5%
C2b	2%	CVMID	5%

The antenna size used throughout this document is 3 cm x 5 cm. Refer also to Table 1 for more details. Fig 2 shows the PCB-schematic of the antenna which is used in this document. The MatchTX1 and MatchTX2 points are connected to the damping resistors R_q as well as to the capacitors C2b for the ANT1 and ANT2 pins (see also Fig 1).

For the sake of simplicity Fig 2 is a sketch of a possible PN544 demo board antenna.

Connections MatchTX1, MatchTX2 and ANT1, ANT2 on the provided NXP PN544 demo board are routed differently.

This has no impact on the tuning procedure described.

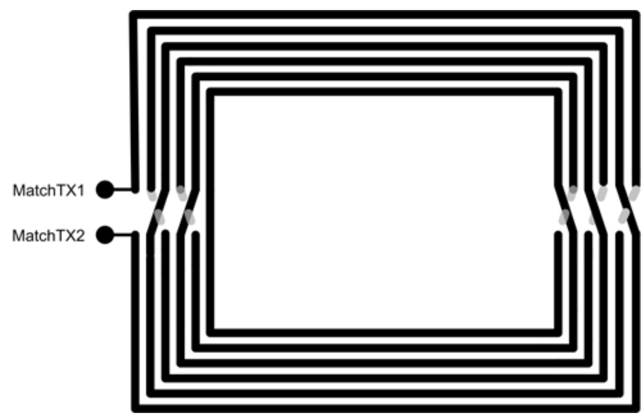


Fig. 2 6-turn demo board antenna sketch

Antenna outlines

Physical outlines of the antenna board are shown here

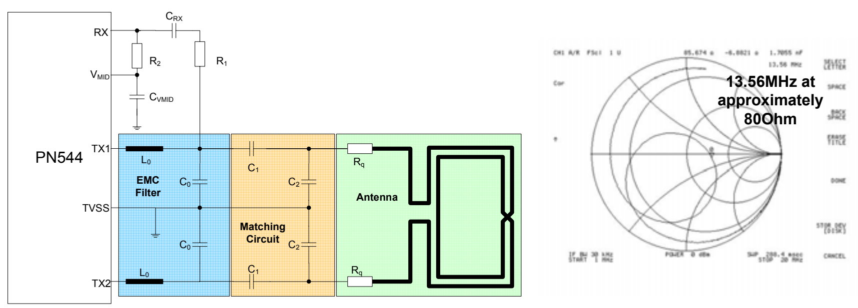
description	value	dimensions
size	**3 x 5**	**cm**
# turns R/W	**6**	
Copper width	**0.05**	**cm**
Spacing	**0.05**	**cm**
Copper height	**35**	**µm**

3. Tuning Procedure

Please follow the steps below for tuning the antenna. The antenna is matched without powering the PN544 IC. A detailed description of each step will follow after this chapter.

Step 1: At first the antenna has to be matched to the PN544 as described in chapter 4. In this phase C2b is not assembled.

Outcome: Basic tuning with resonance frequency of 13.56MHz at 80Ohm

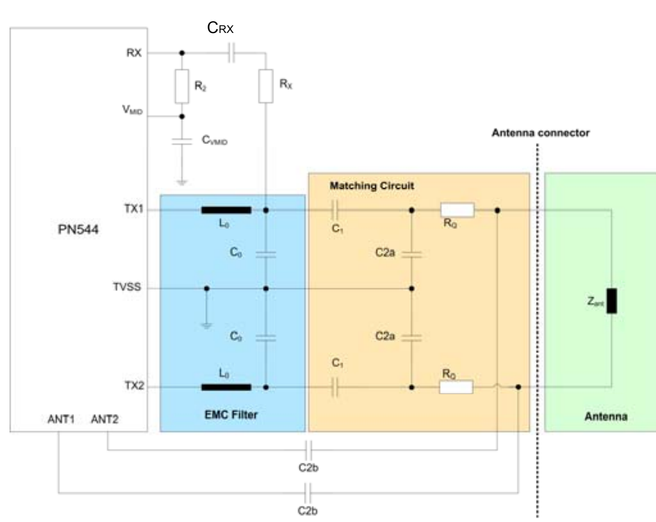


Matching circuitry and smith chart of antenna in step 1

Step 2: After tuning the antenna, C2b needs to be assembled to connect to ANT1 and ANT2 pins. The C2 value is therefore split-up. This means if C2 is calculated and assembled with 47pF in Step 1, then this values is split up into 20pF for C2a and 27pF for C2b (see chapter Step 4 – Card mode tuning).

Outcome: C2 splits into C2a and C2b. (By assembling C2b, the matching circuit is now configured for card mode)

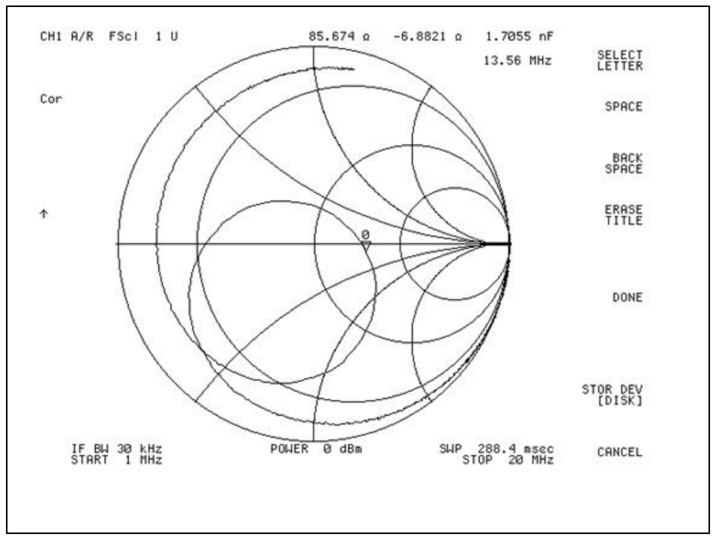
Note: The resonance frequency of the card mode is measured contactless as described in Appendix B



Block diagram with ANT1 and ANT2 connected

Step 3: This step includes the validation of the Reader/Writer matching, which is simulated by shortening the two C2b capacitors with a 10 Ohm resistor. An asymmetric impedance curve with R_{match}=80Ohm at 13.56Mhz shall be seen on the network analyzer. Further details on fine-tuning can be found in chapter 6.

Outcome: Asymmetric Reader/Writer tuning at 13.56MHz with R_{match}=80Ohm



Smith chart of the asymmetric Reader/Writer tuning

Step 4: By removing the 10Ohm resistor, the matching circuit is configured for card mode. The PN544 has to be powered and configured as card. The resonance frequency should be in the range of 14.5 to 16Mhz. Further details on tuning can be found in chapter 7.

Outcome: Card tuning in between 14.5MHz to 16MHz measured with impedance analyzer.

Attention

Step 3 and Step 4 may be repeated to find a good compromise between Reader/Writer and card mode tuning. The target of the tuning is to find component values such that in

- **Reader/Writer mode -> R_{match}=80Ohm at 13.56Mhz**
- **Card mode -> f_{res} =14.5 – 16 MHz**

4. Step 1 – Antenna Matching

The **RF block diagram** shows the circuitry design with all relevant components required to connect an antenna to the PN544. It also ensures the transmission of energy and data to the target device as well as the reception of a target device answer.

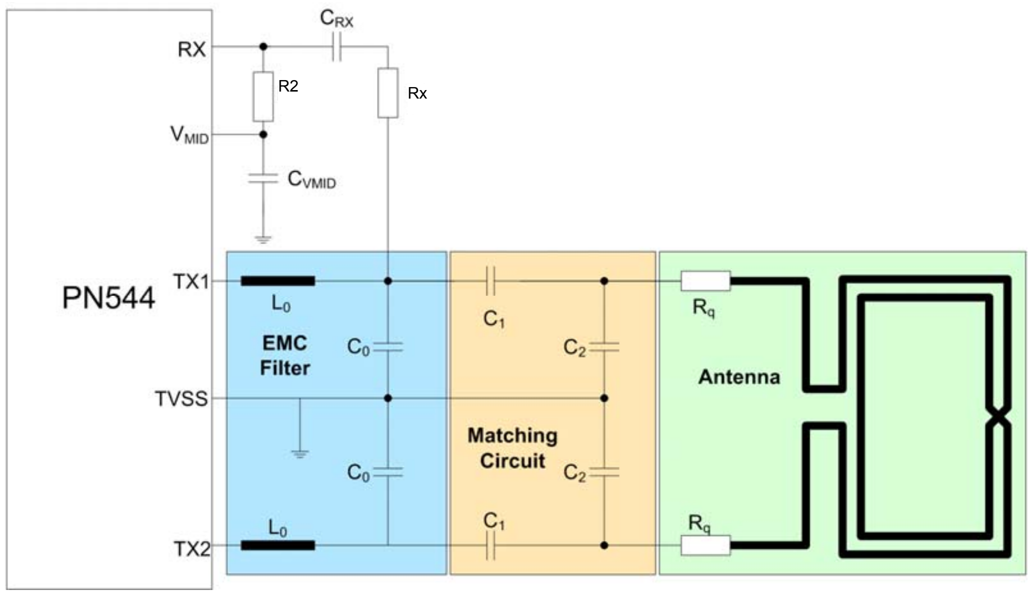


Fig. 3 Block diagram of the complete RF part

Fig 6 shows only the RF part. For a proper operation the supplies and the host interface have to be connected

The **EMC filter** reduces 13.56MHz harmonics and performs an impedance transformation.

The **Matching Circuit** acts as an impedance transformation block and joins the antenna to the EMC-filter.

The **Antenna** coil itself generates the magnetic field.

The **RX path** provides the signal to the PN544 internal receiving stage.

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.

The equivalent circuit (see Fig 7) 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.

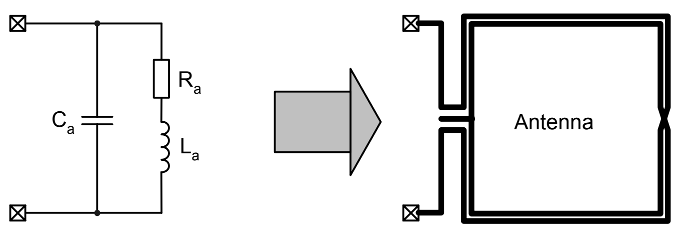


Fig. 4 Series equivalent circuit

Typical values:

L_a = 0.3...3µH

C_a = 3...30pF

R_a = 0.3...8Ω

f_{ra} = self-resonance frequency of the antenna

The antenna capacitance C_a can be calculated with:

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

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

4.1.2 Calculation of damping resistor RQ

The quality factor of the antenna is calculated with

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

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) is calculated by

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

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.

The equivalent circuit (Fig 8) 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.

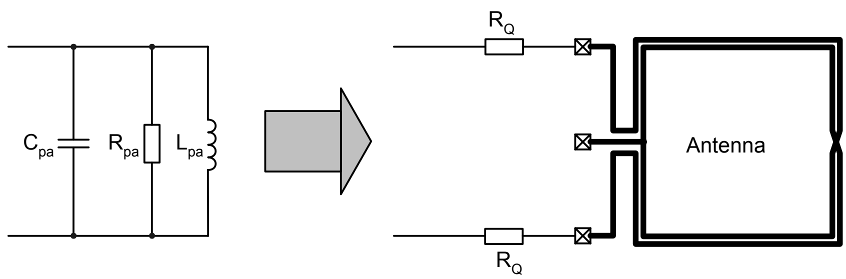


Fig. 5 Parallel equivalent circuit

The following formula applies

$$L_{pa} \triangleq L_a$$

$$C_{pa} \triangleq C_a$$

$$R_{pa} \triangleq \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q}$$

4.2 EMC filter design

The EMC filter circuit for the PN544 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.

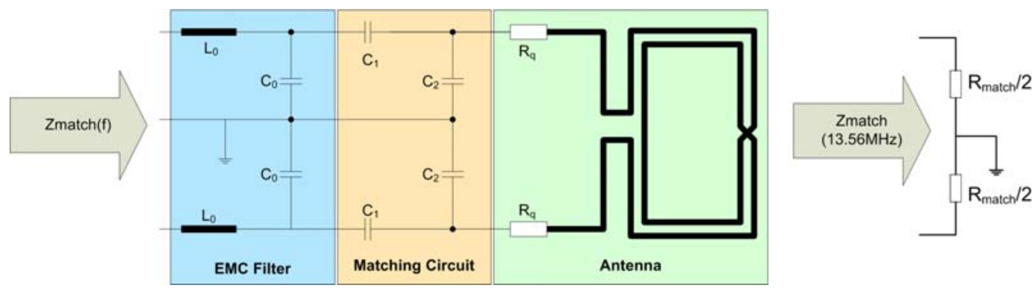


Fig. 6 Impedance transformation

The measured $Z_{match(f)}$ can be remodeled in an equivalent circuit loading each TX pin with $R_{match/2}$.

When cutting the circuitry after the EMC filter the precondition Rmatch/2 needs to be introduced to calculate the remaining components.

Note, that $R_{match/2}$ does not reflect the driver resistance!

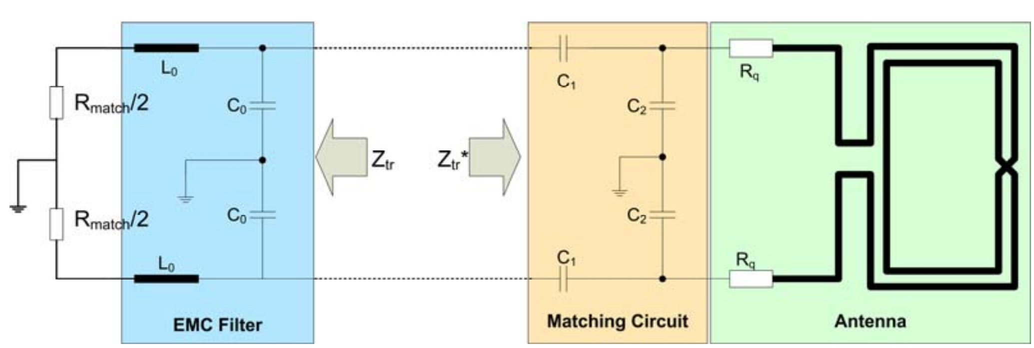


Fig. 7 Definition of transformation impedance Ztr

$$Z_{tr} = R_{tr} + jX_{tr}$$

$$Z_{tr}^{*} = R_{tr} - jX_{tr}$$

EMC filter general design rules:

L_0 = 390nH - 1µH

Filter resonance frequency f_{r0} = 15.5MHz ...16MHz, => C_0

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

The EMC filter resonance frequency f_{r0} has to be higher than the upper sideband frequency determined by the highest data rate (848 kHz sub carrier) in the system.

Example:

L_0 = 560nH

f_{r0} = 15.5MHz

C_0 = 188.3pF → chosen: 180pF

A recommended value of 560nH 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.

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

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

4.2.1 Capacitive tuning of antenna

Due to detuning effects in close distance between reader and card antennas a capacitive tuning is recommended.

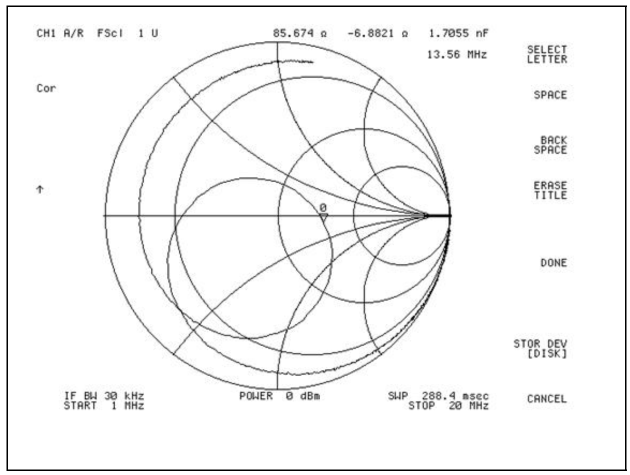


Fig. 8 Smith diagram for capacitive antenna tuning

It is accomplished by lowering C0 compared to the design guidelines given for the first generation NFC devices.

The reason for the higher cut-off frequency is a higher stability with close coupling devices in reader mode: less detuning effect. Minimum field strength of 1.5A/m can be provided also with close coupling devices.

4.3 Matching circuit design

4.3.1 Component calculation

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

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

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

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 contain some errors as well.

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 PN544 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 12 is the probing point for the network/impedance analyzer.

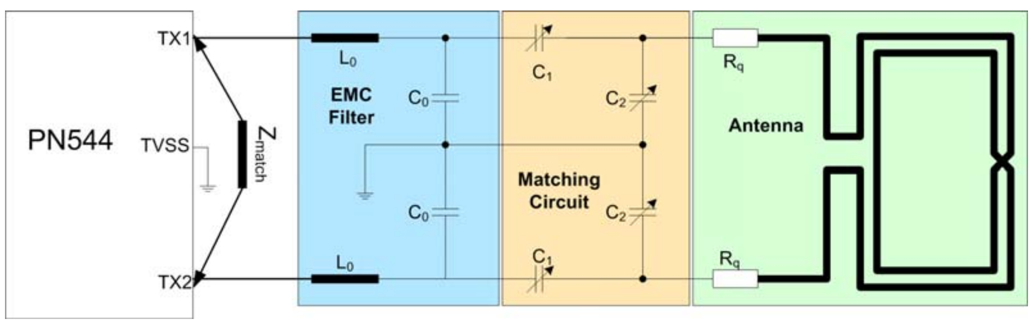


Fig. 9 Measurement of matching impedance

Fig 13 shows the smith chart simulation for Z_{match} / 2:

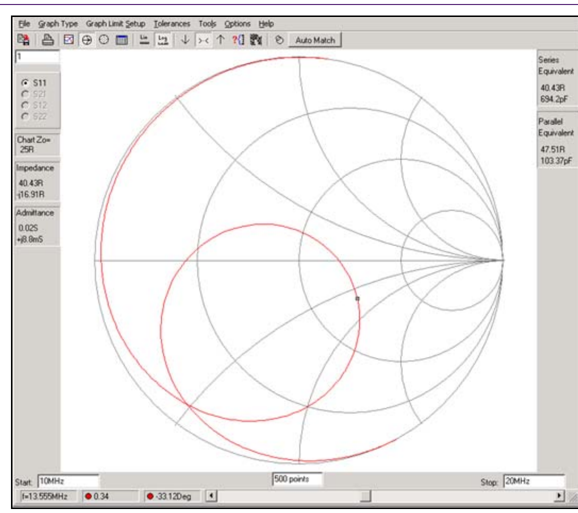


Fig. 10 Smith chart for matching impedance

All tuning and measurement of the NFC antenna has to be performed at the final mounting position to consider all parasitic effects like metal which influences the quality factor, the inductance and parasitic capacitance.

4.4.1 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 PN544. Different equivalent resistive loads lead to different transmitter supply currents.

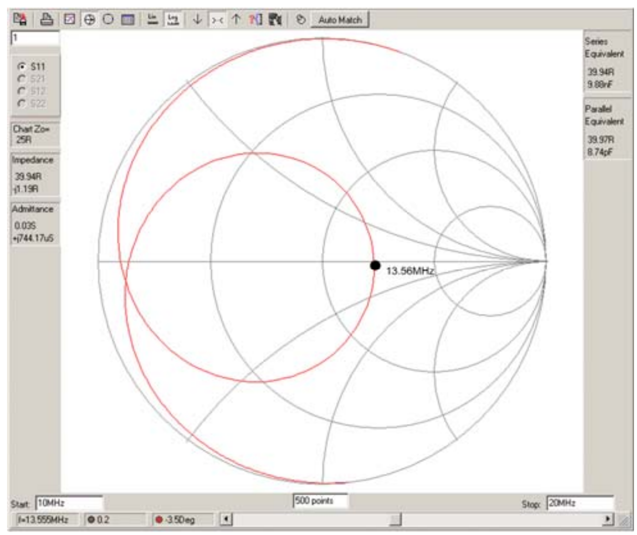
An optimum tuning R_{match} for PN544 is 80Ohm

4.5 Impact of the tuning capacitors visualized on Smith chart

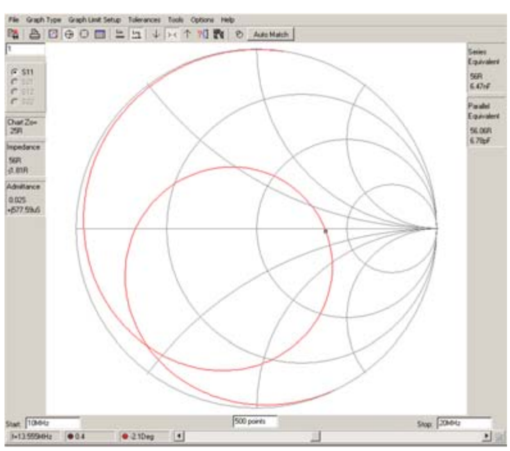
4.5.1 EMC capacitance C0

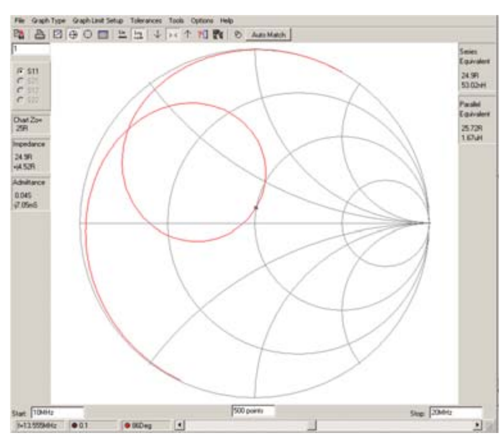
The following diagrams show the effect to the impedance curve by changing C0.

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



a. C0 reference value





b. C_0 lower than reference value

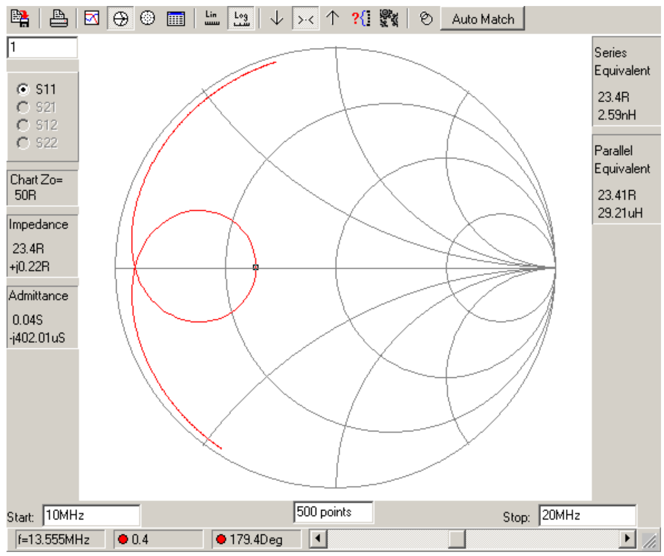
c. C_0 higher than reference value

Fig. 11 Smith charts for C0 tuning

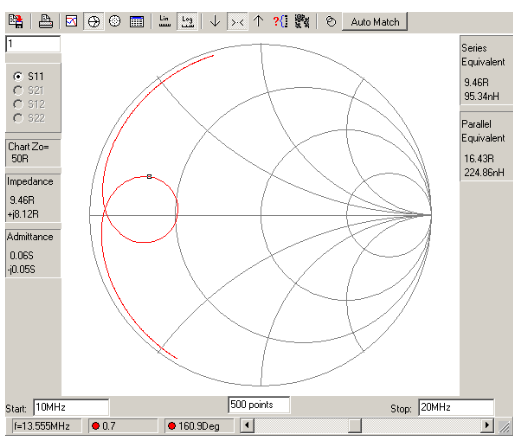
4.5.2 Series capacitance C1

The following diagrams show the effect to the impedance curve by changing C1.

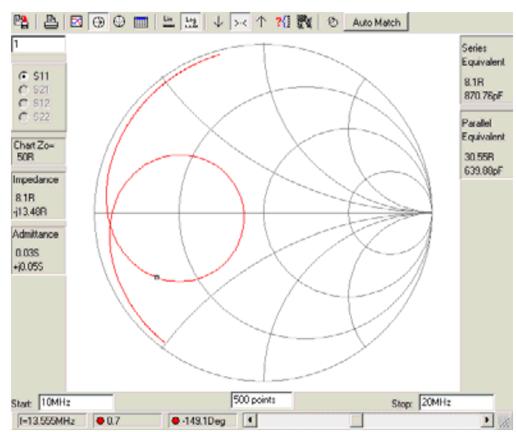
The smith charts in Fig 15 show the matching impedance Z_{match}/ 2 vs. frequency.



d. C_1 reference value



e. C_1 lower than reference value



f. C_1 higher than reference value

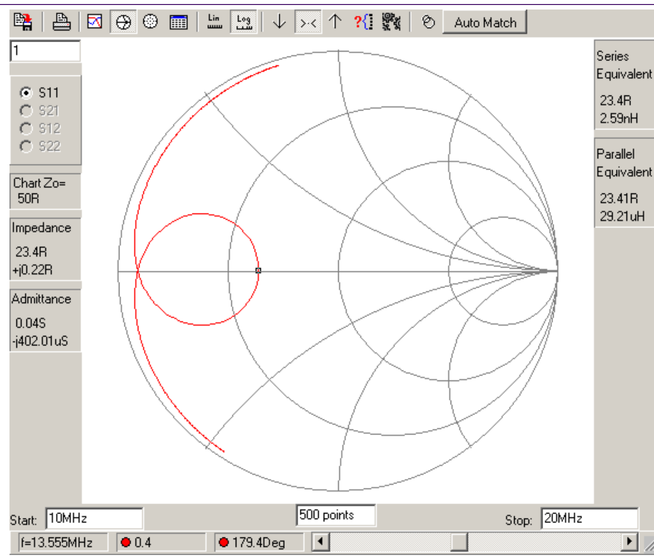
Fig. 12 Smith charts for C1 tuning

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

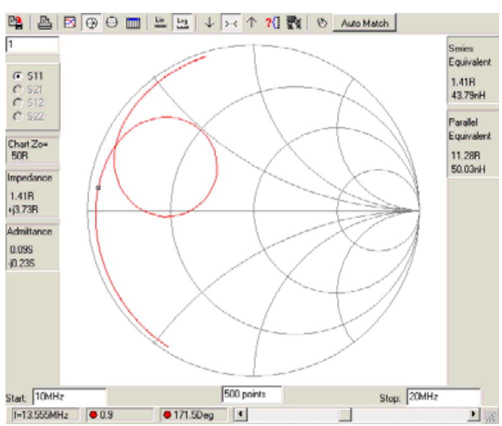
4.5.3 Parallel matching capacitance C2

The following diagrams show the effect to the impedance curve by changing C2.

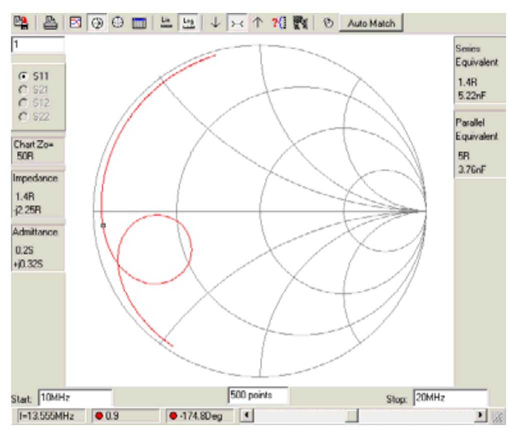
The smith charts show the matching impedance Z_{match} / 2 vs. frequency.



g. C2 reference value



h. C_2 lower than reference value



i. C_2 higher than reference value

Fig. 13 Smith charts for C2 tuning

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

4.6 Receiver circuit design

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

Fig 17 shows the relevant components for the receiver circuit. R_X and R_2 form a voltage divider which has to be adjusted according to the incoming voltage levels at U_{RX} and U_{C0}. Both, Initiator and Target mode of the NFC device have to be investigated, since detuning effects on the RX path behave differently.

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}=1.7V even when the antenna is detuned by a target or passive card

Hence, the RX-point must be checked under following conditions:

1. **PN544 antenna not detuned**
2. **PN544 antenna detuned with a card**
3. **PN544 in card/target mode and U_{RX} < U_{RXmax} for H <= 7.5 A/m**
4.

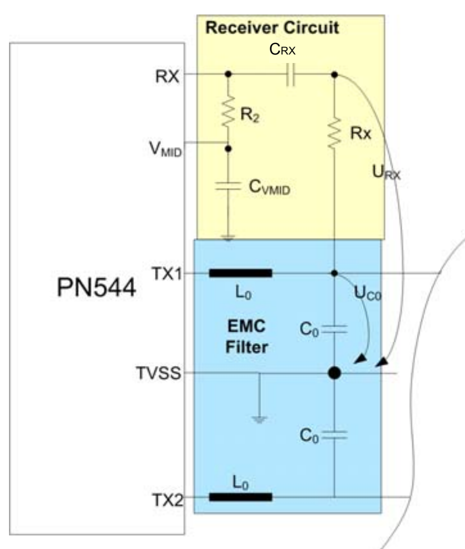


Fig. 14 RX-path

4.7 Example

The antenna of the PN544 evaluation board will be matched to the PN544 transmitter output.

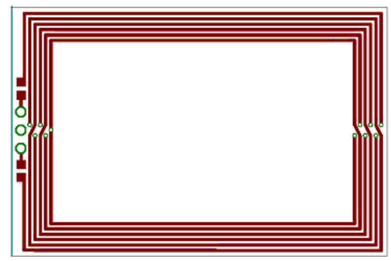


Fig. 15 PN544 evaluation board antenna

Recommended $R_{match} \approx$ 80Ohm

The series equivalent circuit of the antenna results to:

R_a = 1.3Ohm

C_a = 11pF

L_a= 3.09µH

The calculation for the external damping resistor results to R_Q = 2.5Ohm. The chosen value for R_Q is 2.2Ohm and results in a Q-factor of about 30.

The parallel equivalent circuit of the antenna including quality factor damping resistors R_Q = 2.2Ohm is determined with the following values:

R_{pa} = 20kOhm

C_{pa} = 11pF

L_{pa}= 3.09µH

The EMC filter is determined with:

L_0 = 560nH

C_0 = 180pF

Calculation of Z_{tr}:

R_{tr} = 112Ohm

X_{tr} = -95Ohm

Calculation of the matching parts C_1, C_2

C_1 = 19.73pF → 18pF normalized value

C_2 = 52.55pF → 47pF normalized value

Simulation result:

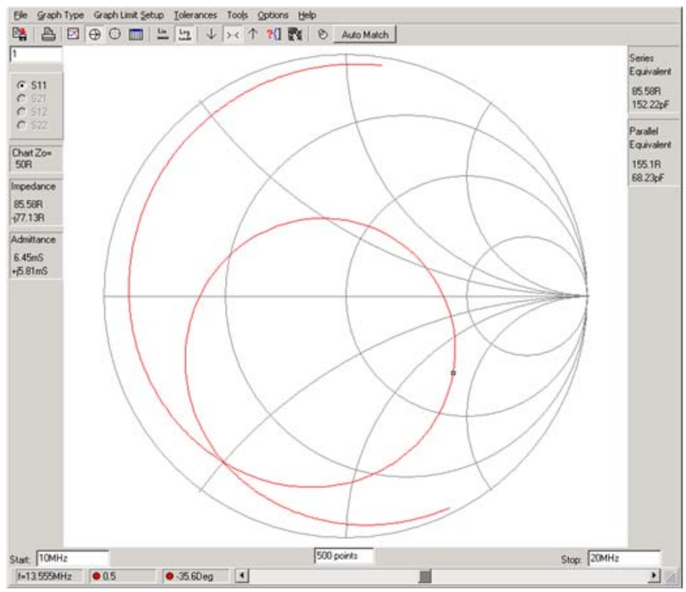


Fig. 16 Example: Z_{match} Smith chart

It can be seen from Fig 19 that the resonance point (13.56MHz) is in the capacitive part and would need a fine-tuning of the circuit to bring it to R_{match}=80Ohm.

5. Step 2 – Connecting ANT1 and ANT2 pins

In step 1 we successfully tuned the matching circuit to a resonance frequency at 13.56 MHz at around 80Ohm. The circuit of step one is again outlined in Fig 20.

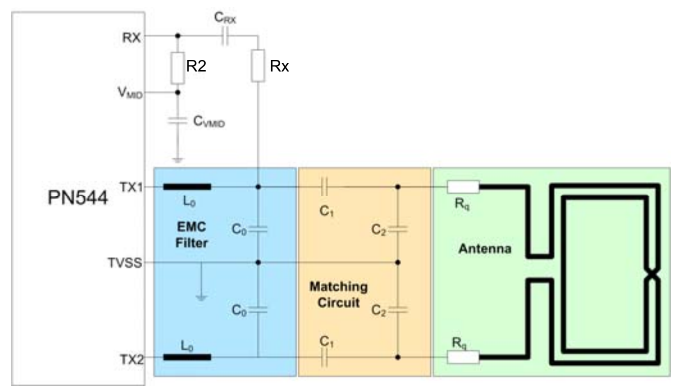


Fig. 17 Block diagram for Step 1

The goal in step 2 is now to connect the ANT1 and ANT2 pins to the matching circuit. Therefore, we decouple the signal after the damping resistors R_q with two additional capacitances. Refer also to Fig 21 for connection details.

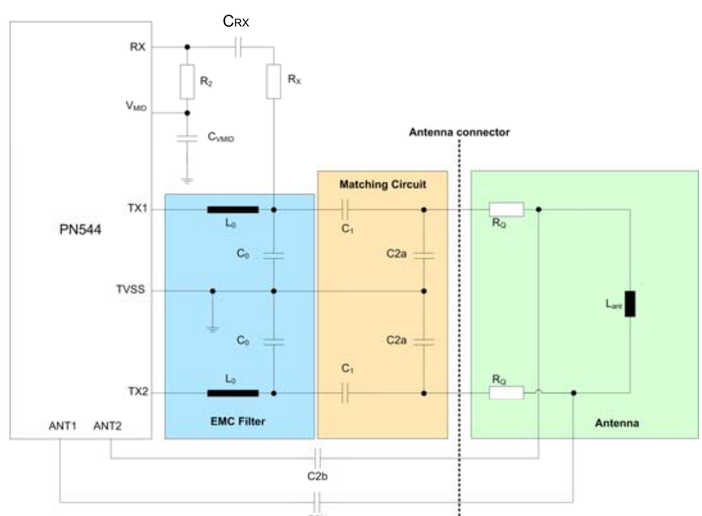


Fig. 18 Antenna topology with connection to ANT1 and ANT2 by assembling C2b

C2a and C2b are derived from the capacitor C2. The splitting ratio must be calculated.

Therefore, the resonance formula (11) is used to calculate the required capacitance for 13.56MHz in Reader/Writer and 14.5-16MHz in card mode. The inductance of the antenna has already been measured in a previous step.

$$f_{res} = \frac{1}{2 \cdot \pi \sqrt{L \cdot C}}$$

$$C_{fres} = \frac{1}{\frac{(2 \cdot \pi \cdot f_{res})^2}{L}}$$

Example for a given inductance value L=3.09uH:

$C_{13.56MHz}$=44.66pF

C_{16MHz}=32pF

$C_{13.56MHz}$ - C_{16MHz} = 12.66pF

C_{shift} = 12.66pF

In other words, the total parallel capacitance for the reader mode needs to be 12.66pF higher than in card mode.

With this information, C2a and C2b can be calculated.

C2 is already given from the previous steps and reflects the $C_{13.56MHz}$ capacitance.

C2 = C2a + C2b

C2b = 2. C_{shift}

C_{shift} = 12.66pF

C2b=25.32pF → 27pF normalized value

C2a = C2 – C2b = 47pF – 27pF = 20pF

In Step 3 and 4 the values/circuitry have to be fine-tuned, because different resonance frequencies are required in Reader/Writer and card mode and available discrete components.

6. Step 3 – Reader/Writer fine-tuning

All tuning steps for the PN544 need to be done without powering the chip.

Precondition to start measurements

In order to simulate the Reader/Writer behavior of the antenna, C2b capacitors need to be shortcut with a 10 Ohm resistor. In the final application this will be taken over by PN544 so do not forget to remove the part after finishing the tuning.

What is the effect?

When shortening C2b with 10Ohm resistance C2b acts as additional capacitance parallel to C2a and causes a frequency shift.

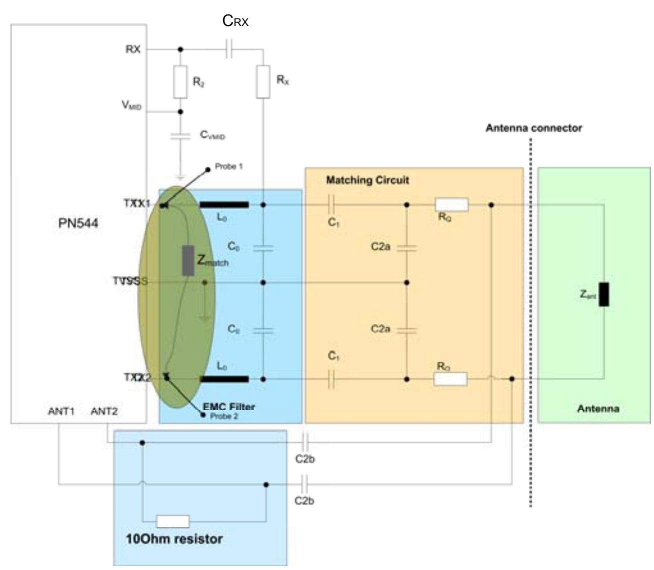


Fig. 19 Block diagram for Reader/Writer tuning with 10Ohm short

Measurement of antenna tuning

The probes of the network analyzer are connected to Probe 1 and Probe 2 as indicated in Fig 23 to verify the matching (Z_{match}).

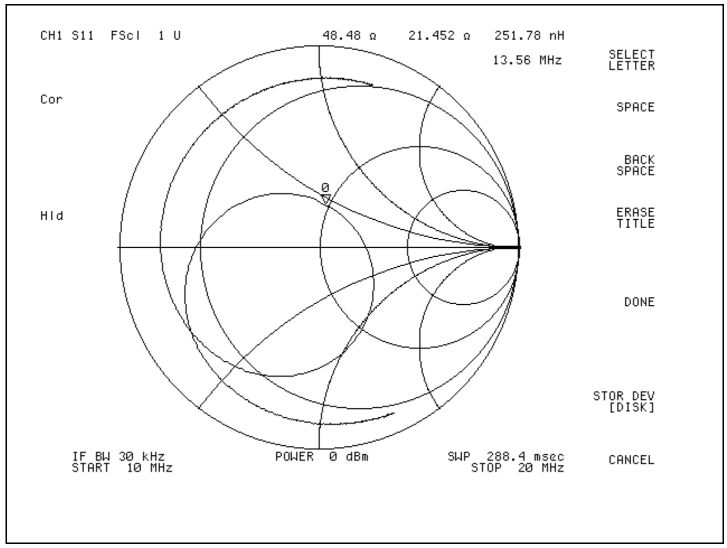


Fig. 20 Smith chart Reader/Writer mode

Adjustments on antenna

According to the results of the measurement slight modifications on C2a/C2b and C1 are needed to finally meet the Z_{match} requirements.

See section 4.5 for the impact of the antenna matching components.

7. Step 4 – Card mode tuning

The tuning steps of PN544 circuitry needs to be done without powering the chip.

After accomplishing “Step 3” we need to verify the card mode.

The 10Ohm resistor has to be removed now!

Card mode tuning is measured with the PN544 being not powered and configured as card.

5.

The resonance frequency of the card mode is measured contactless as described in Appendix B

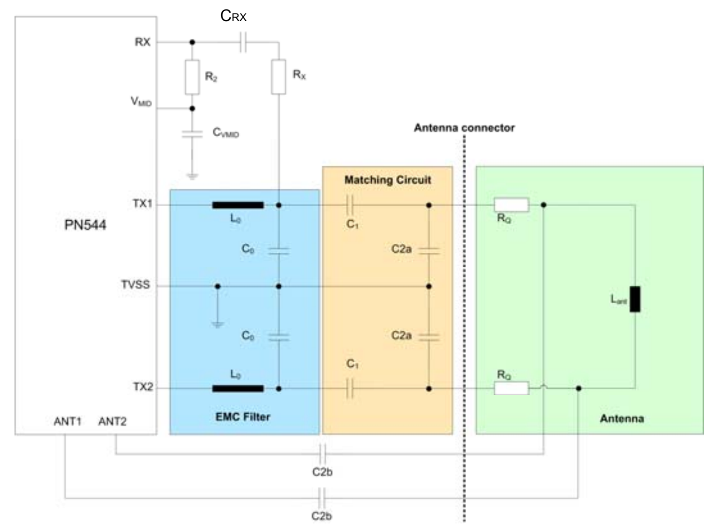


Fig. 21 Block diagram for card mode tuning with removed 10Ohm resistor

The measurement shall show a resonance in the range of 14.5MHz to 16Mhz.

Modifications if resonance frequency does not meet the requirements

1. Resonance frequency too low:

Change the split ratio of C2a and C2b. Reducing C2a by the same amount of capacitance which is added to C2b.

Explanation: C2b is not working in parallel to C2a in card mode. A lower value for C2a means a higher resonance frequency in card mode. Only C2a is working as parallel capacitance towards the antenna.

2. Resonance frequency too high:

Decrease the split ratio C2b/C2a by reducing C2b and increasing C2a by the same capacitance value.

C2a+C2b=constant!

Perform a final check: check Reader/Write and card mode tuning again

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.

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 27 shows the profile a typical circular antenna.

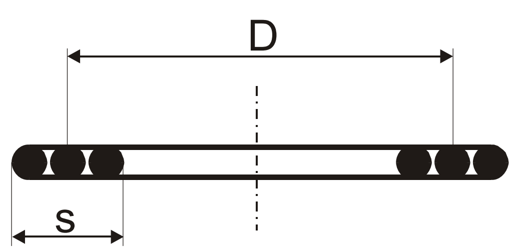


Fig. 22 Circular Antenna

The inductance can be estimated using the following formula:

$$L_a[nH] = \frac{24.6 \cdot N_a^{\ 2} \cdot D[cm]}{1 + 2.75 \cdot \frac{s[cm]}{D[cm]}}$$

D Average antenna diameter

s Antenna width

N_a Number of turns

8.1.3 Rectangular antennas

Fig 28 shows a typical rectangular antenna.

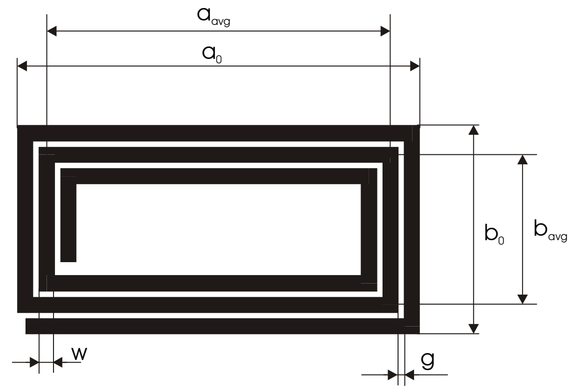


Fig. 23 Rectangular antenna

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:

$$L_a = \frac{\mu_0}{\pi} \cdot [x_1 + x_2 - x_3 + x_4] \cdot N_a^{1.8}$$

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 is 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 29). 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

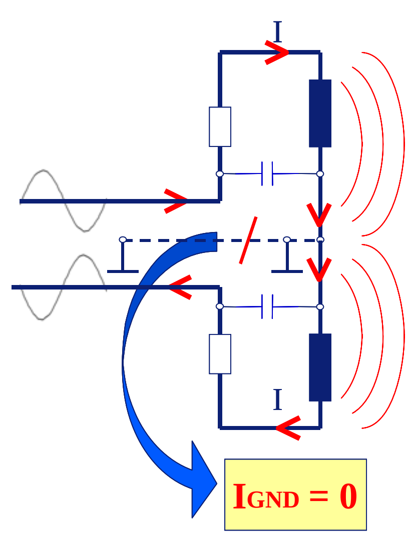


Fig. 24 Ground current compensation

Fig 30 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 29 where center tap is not connected.

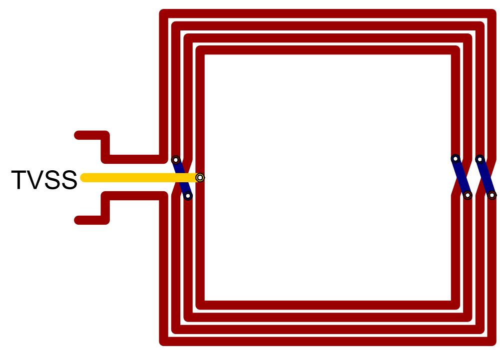


Fig. 25 Example symmetric 4-turn antenna

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 NFC device or a ground plane of the NFC 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 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 31 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 14443 is marked with doted vertical line.

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).

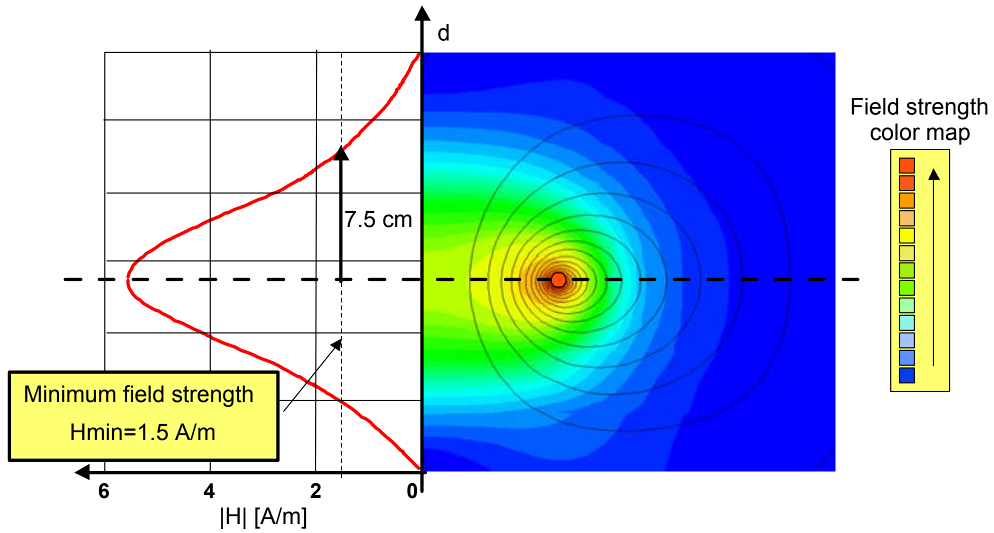


Fig. 26 Field distribution of a circular antenna

Fig 32 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.

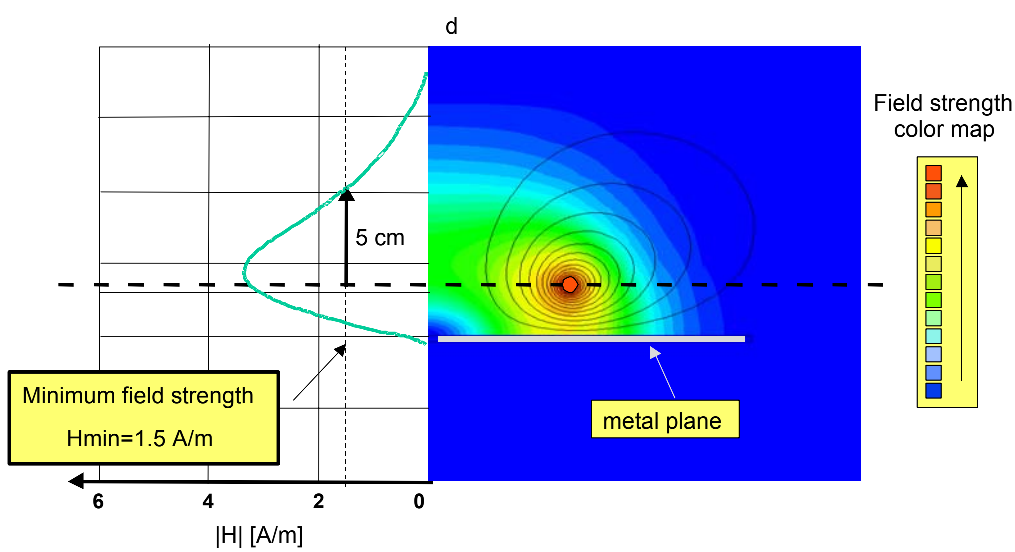


Fig. 27 Field distribution of a circular antenna with a metal plane

Fig 33 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).

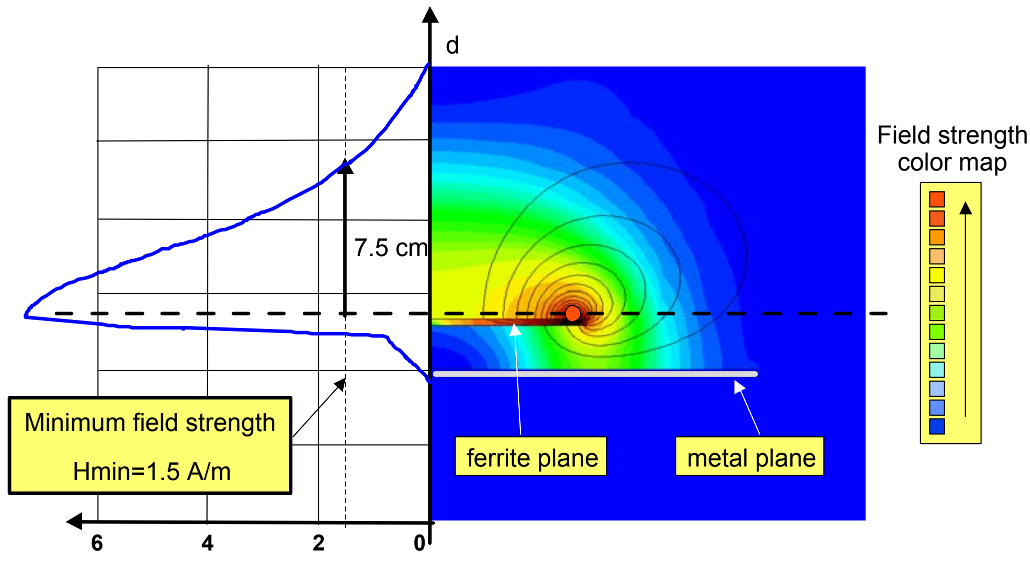


Fig. 28 Ferrite shielded field distribution of a circular antenna

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 34 shows an excerpt of a typical 100% ASK modulation. The maximum timing limit of 3us (as defined in the ISO14443) for a modulation pause is taken to calculate the quality factor.

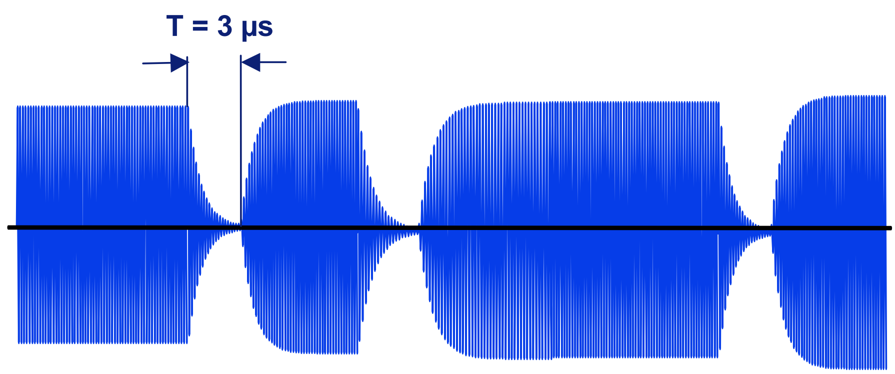


Fig. 29 Pulse width definition

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

$$B \cdot T \geq 1$$

With the bandwidth definition

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

the B-T product results to

$$Q \leq f \cdot T$$
$$Q \leq 13.56 MHz \cdot 3 \mu s$$
$$Q \leq 40.68$$

The recommended antenna quality factor is $\mathbf{Q_a = 35}$

8.2 Equivalent circuit measurement

8.2.1 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.

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: $|Z|$, Θ

Start frequency: 1 MHz

Stop frequency: above self-resonance frequency of the antenna (point where antenna impedance is real: pure resistance)

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).

8.2.2 Network analyzer

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

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

8.2.3 Series equivalent circuit

The following characteristic circuit elements can be determined by measurements at characteristic points (see also Fig 35 for series equivalent circuit).

R_s Equivalent resistance at f = 1MHz

L_a Equivalent inductance at f = 1MHz

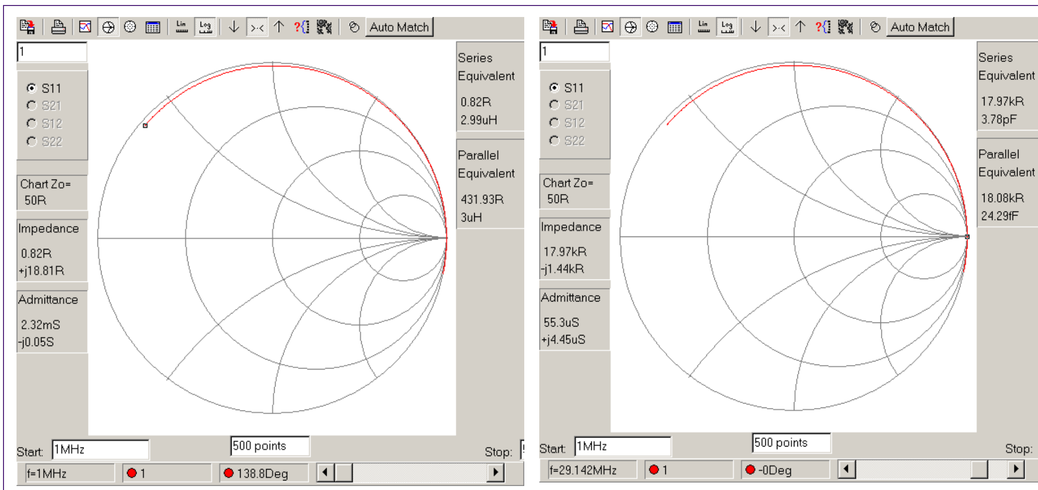
R_p Equivalent resistance at the self-resonance frequency

f_{ra} Self-resonance frequency of the antenna

The antenna capacitance C_a can be calculated with:

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

The following Fig 37 shows simulation results to determine the characteristic circuit.



a. R_s = 0.82Ohm, L_a = 2.99 µH

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

Fig. 30 Simulation results for characteristic circuit

The series equivalent resistance of the antenna at the operating frequency f_{op} = 13.56MHz can be calculated out of the characteristic circuit.

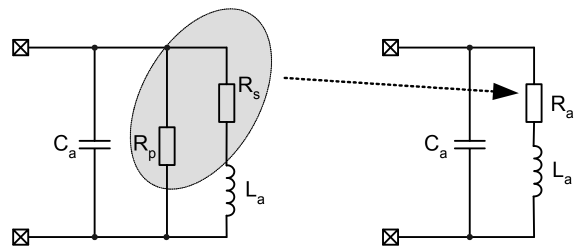


Fig. 31 Series equivalent resistance calculation

$$R_p(13.56MHz) = \frac{R_p(fres)}{\sqrt{\frac{13.56}{fres}}}$$

$$R_a = R_s + \frac{(2 \cdot \pi \cdot f_{op} \cdot L_a)^2}{R_p(13.56MHz)}$$

The parallel equivalent circuit always has to be calculated by means of the series equivalent circuit using equation (19).

The parallel resistance R_p(fres) obtained by measurements has to be calculated to the parallel equivalent value at 13.56MHz. This is accomplished in equation (21).

R_a in equation (22) is then calculated by using R_p(13.56Mhz).

8.3 PULSE shape check

The following pulse shape checks are a quick way for investigating the shaping of the generated RF-field. Chapter 8.5 points out the pulse shape timings according to ISO/IEC18092:2004. Please note that always to the latest version of ISO/IEC18902 is referenced.

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 50MHz has to be used to carry out the module shape measurements (Fig 39).

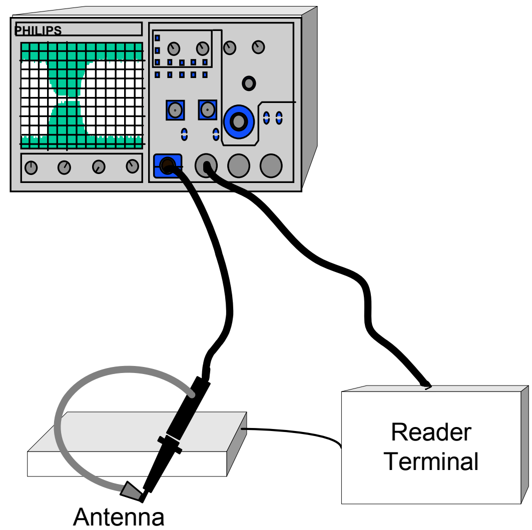


Fig. 32 Setup to check the Q-factor

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 if possible

It is recommended to check the pulse shape according to the values given in Fig 40.

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.

8.4 Pulse shape according to ISO 18092

8.4.1 Bit rate 106kbps

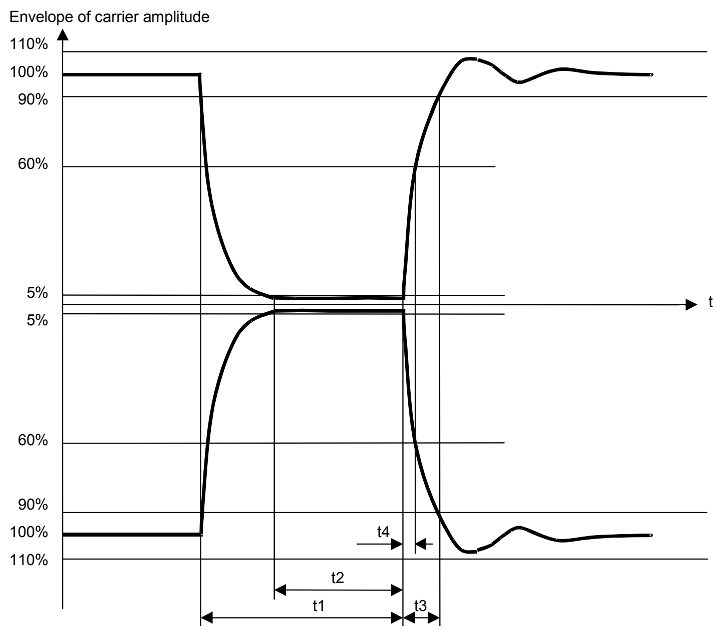


Fig. 33 Pulse shape according to ISO 18092, 106 kbps

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 PN544 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 0.4µs.

Pulse shape definitions according to ISO18092, 106 kbps

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

8.4.2 Bit rate 212 kbps and 424 kbps

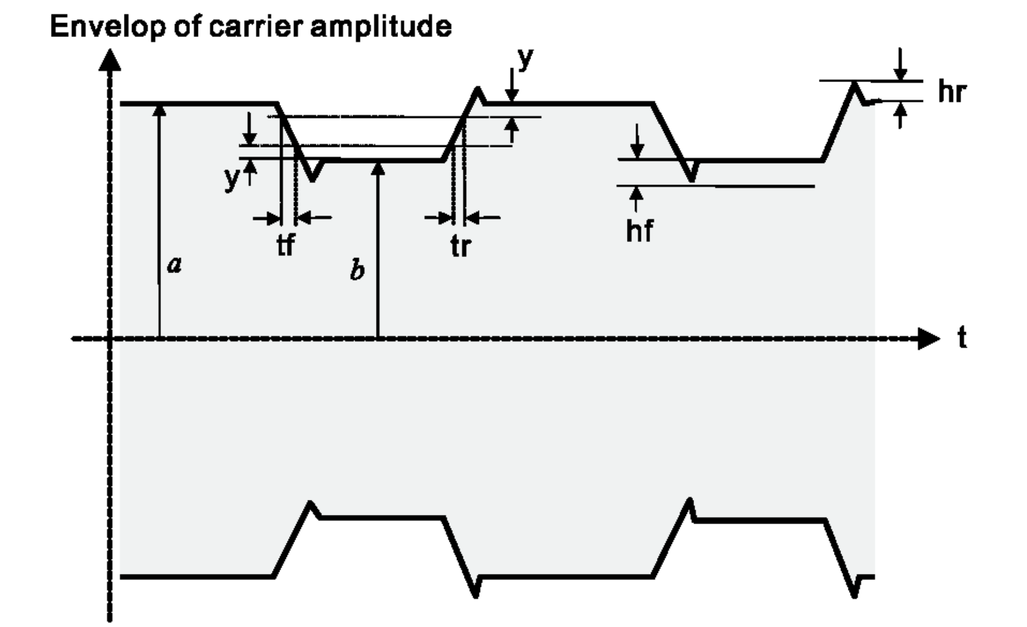


Fig. 34 Pulse shape according to ISO 18092, 212 and 424 kbps

Table 8-1: Pulse shape definitions according to ISO18092, 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. Appendix B

9.1 How to measure card mode resonance frequency

The card-mode resonance frequency and quality factor depends on the H-field strength. As a matter of fact, the chip input resistance and capacitance have a dependency on the antenna voltage. It is recommended to measure the resonance frequency of the DUT in an unloaded condition, keeping the applied field strength very low, so that the chip can not power up. Below an antenna voltage of ~ 0.3Vpp the chip input impedance stays constant over a wide range and the Q-factor has the highest value allowing accurate resonance frequency measurements.

Basically, the resonance frequency is measured contact less on an impedance analyzer with a pickup coil defined in the ISO10373-6. A non-conductive distance holder of 1cm thickness shall be put in-between DUT and pickup coil.

9.2 Calibration and measurement procedure

The following steps guide through the configuration and calibration setup for the Agilent 4395A:

1. Switch on Agilent 4395A and configure as Impedance Analyzer
2. Choose frequency range from 10MHz to 20MHz
    a. Start → 10MHz
    b. Stop → 20MHz
    c. Number of points → 801
3. Calibrate the instrument
    a. Cal → Cal Kit → 3.5mm → Return
    b. Cal → Calibrate Menu
    c. Connect the calibration kit and calibrate to Open, Short and Load → Done
    d. Connect the calibration kit with the 50Ohm Load and check the calibration
    e. Scale Ref → Autoscale
    f. A horizontal run of the curve should be seen now, otherwise repeat the calibration procedure
4. Fixture compensation
    a. Cal → Fixture Compen → Compen Menu
    b. Connect pickup coil
    c. → Short
    d. Control the horizontal run of the curve again
5. → Source → Power → -10dbm
6. *Place DUT on top of pickup coil, search for maximum peak and read resonance frequency*

10. Abbreviations

EMC	Electromagnetic compatibility
R/W	Reader/Writer
RX	Receiver
PCB	Printed Circuit Board
R_{match}	Transmitter matching resistance
TX	Transmitter
Z_{match}	Transmitter matching impedance

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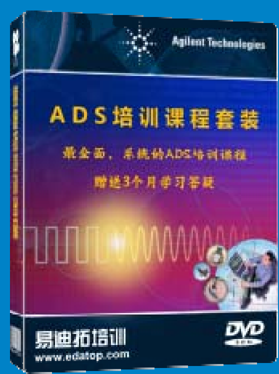

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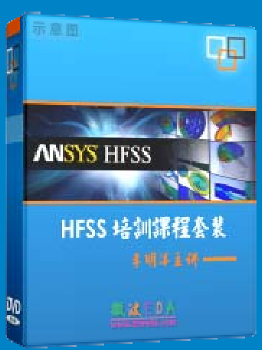

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※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

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