Semiconductors

AN100720

NFC Transmission Module Antenna and RF Design Guide

Rev. 2.0 — 12 April 2005 **Application note**

[1] Document information

[2] Info	[3] Content
[4] Keywords	[5] NFC, PN511, PN531, Antenna Design, RF Design
[6] Abstract	[7] This application notes provides guidance on antenna and RF design for NFC devices PN511 and PN531

PHILIPS

[8] Revision history

[9] Rev	[10] Date	[11] Description
[12] 2.0	[13] 20050412	[14] Extend to product PN531 Insert PAE Diagram (§ 4.3) Update on Centre tap connection of Antenna (Note: in § 4) Update Antenna recommendation (§ 5.2) New Template
[15] 1.0	[16] 20040601	[17] Initial first version

Contact information

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

For sales office addresses, please send an email to: sales.addresses@www.semiconductors.philips.com

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 the PN511/PN531. The aim is to 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 PN511/PN531 ICs.

The RF part covers the required matching circuit to match an application specific antenna coil to the output driver of the PN511/PN531 as well as the receiving circuit in order to detect a received RF signal.

- As a basic knowledge it is assumed that the reader has a basic knowledge on RFID technology as well as a basic understanding how to use the PN511/PN531.

1.2 Reference documents

1) Data sheet: PN 511 Transmission Module, rev 1.6
2) Application note: How to use PN 511, rev. 0.8
3) Ecma 340 NFCIP-1 Interface and protocol
4) ISO/IEC 18092: Near Field Communication – Interface and Protocol (NFCIP-1)

1.3 Reference Simulation Tools

1) MathCAD 11
2) RFSim99

1.4 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

2. How to use this document

The application note is intended to give a practical guide to design antennas and calculate the matching components for the PN511/PN531's RF part. It gives a guideline starting with the complete RF part circuit description followed by an introduction in the overall antenna design theory for the NFC system as well as a description of the transmitter matching resistance and finally the matching procedure is described using a reference antenna coil.

The user can follow the guideline to design an antenna and the RF circuitry by him self and will find a tuning procedure described as well. The guideline covers the following items:

1. RF field generation and data transmission par
   a. The **RF part block diagram** shows as a recommended circuit with all relevant components required to connect an antenna to the PN511/PN531 and to ensure that energy and data can be transmitted to the target device as well as the required components to receive a target device answer.
   b. The TX matching resistance R_{match} is described to find an optimum starting point for the following component calculation from the PN511/PN531 power consumption perspective.
   c. The antenna design part describes how to calculate the inductance of an NFC antenna coil and gives basics hints on symmetry and environmental influences to be taken into consideration. As a preparation for the calculation the equivalent circuits and the relevant formulas are given.
   d. Formulas to calculate the EMC filter and the matching circuit
   e. Antenna tuning procedure
2. Receiving part
   a. Design and calculation of the receiving part
3. Examples on how to calculate the RF parts for a given antenna design and given current targets for the PN511/PN531.
4. Hints for checking the antenna and RF part design.

As there are many parameters influencing the overall performance of the PN511/PN531, a basic RF knowledge is needed to design and match an antenna.

Note: This application note cannot and does not replace any of the relevant datasheets. "Card" in this document means a contact less smart card according to the ISO14443A (or MIFARE®) or a contact less card according to the FeliCa scheme. Design hints on how to place the components on a PCB are not included.

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

3. Block Diagram

The PN511/PN531 NFC IC is designed to communicate in 3 different operation modes:

- Reader/Writer mode for communication to a ISO14443A/MIFARE® or FeliCa card up to 50 mm depending on the antenna size and tuning
- NFCIP-1 mode for communication to further NFC devices up to 50 mm depending on the antenna sizes and tuning
- ISO14443A / MIFARE® card or FeliCa card mode for communication to ISO14443A / MIFARE® or FeliCa Reader up to 10 cm depending on the generated external field strength.

The PN511/PN531's overall functionality can be separated into three functions:

- **Generate the RF field**: The generated magnetic field has to be maximized considering the limits of the transmitter supply current and general emission limits.
- **Transmit data**: The coded and modulated data signal has to be transmitted in a way, that every card and NFC device is able to receive it. The signal shape and timing has to be considered.
- **Receive data**: The response of a card or NFC device has to be transferred to the receive input of the PN511/PN531 considering the datasheet limits like maximum voltage and receiver sensitivity.

The operating distance for the PN511/PN531 depend besides the matching of the antenna and the sensitivity of the receiving part especially on the antenna size of the NFC device, the antenna size of the communication partner and external parameters such as metallic environment and noise.

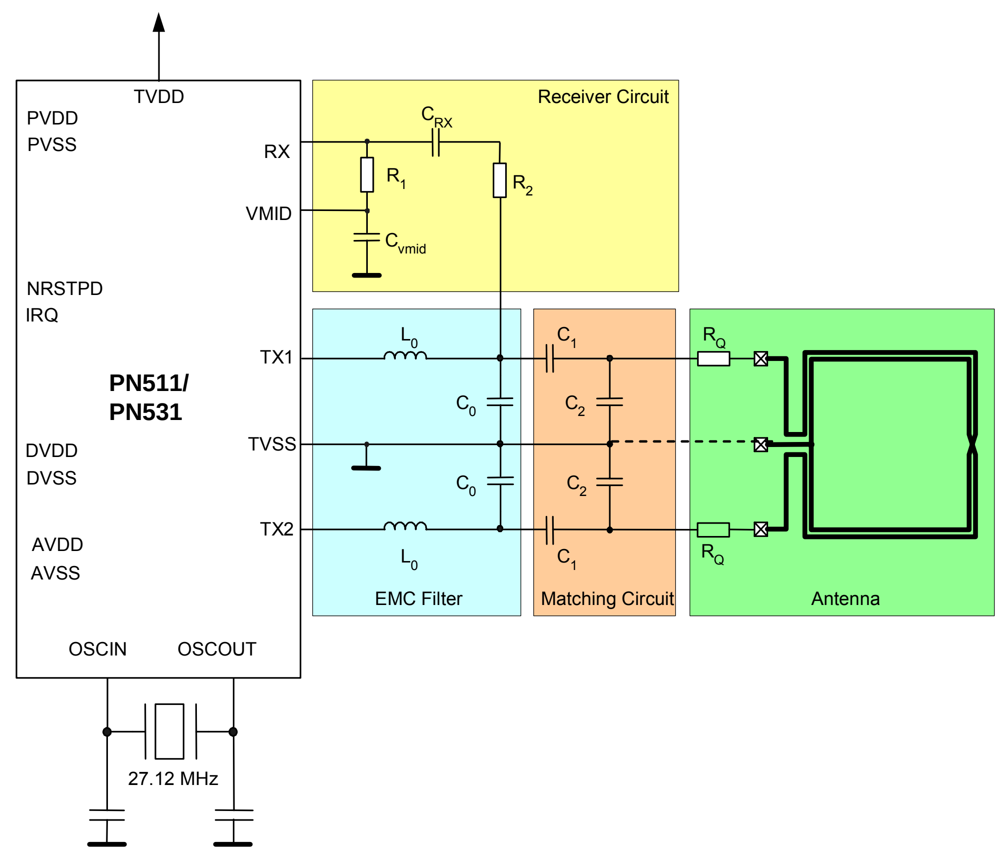


Fig 1. Block diagram of the complete RF part

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.

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 PN511/PN531 internal receiving stage.

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

Table 1. Component list for a basic RF Design

[18]	Abbreviation	[19]	Explanation
[20]	**R_Q**	[21]	External damping resistors to adjust the quality factor. The power dissipation has to be considered.
[22]	**C_0, C_1, C_2**	[23]	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.
[24]	**C_{vmid}, C_{RX}**	[25]	X7R capacitor (< ±10%)
[26]	**L_0**	[27]	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.
[28]	**R_1, R_2**	[29]	0402, 0603 or 0805 SMD parts

Note: The center tap connection of the antenna (dotted line) may be neglected without negative influence on the EMC performance of the circuitry.

4. 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 PN511/PN531. Different equivalent resistive loads lead to different transmitter supply currents.

4.1 Test Circuit

The following schematic shows one possible configuration for investigations on optimum transmitter matching resistance R_{match}.

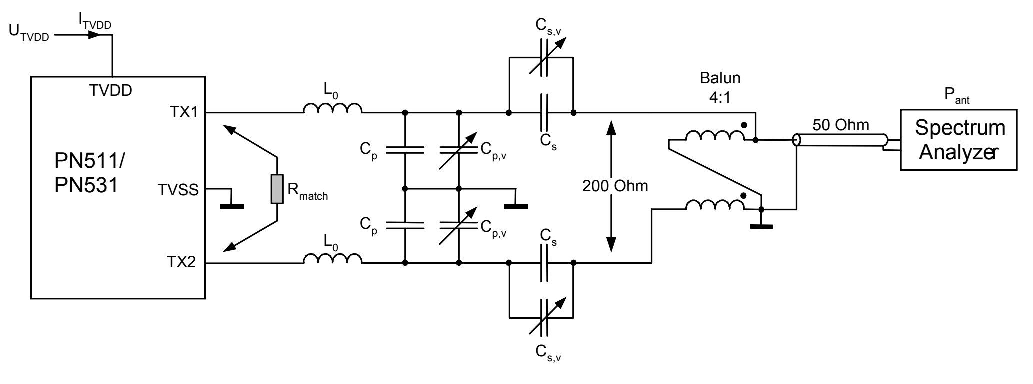


Fig 2. Test circuit for R_{match}

For different matching resistance values the available RF power P_{ant} and the TX supply current I_{TVDD} are recorded.

4.2 TX supply current vs. matching resistance

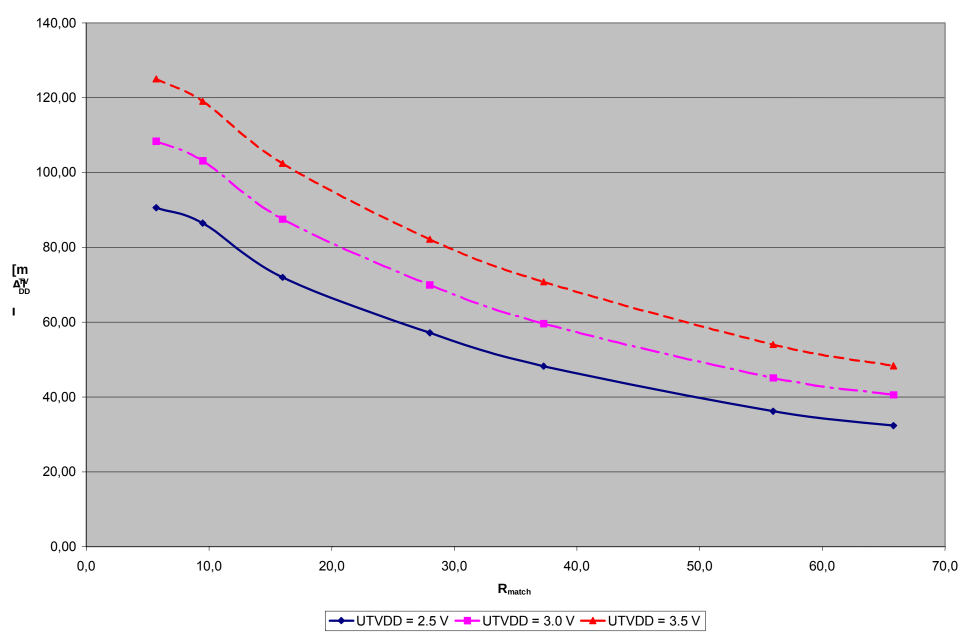


Fig 3. Transmitter supply current vs. matching resistance

4.3 RF power vs. matching resistance

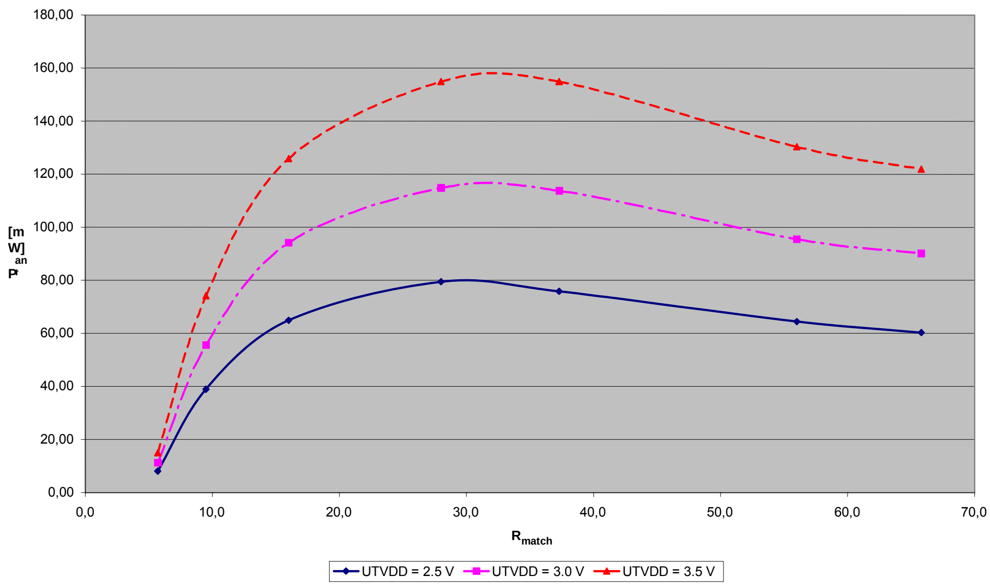


Fig 4. RF power vs. matching resistance

4.4 Power Added Efficiency @ 3V

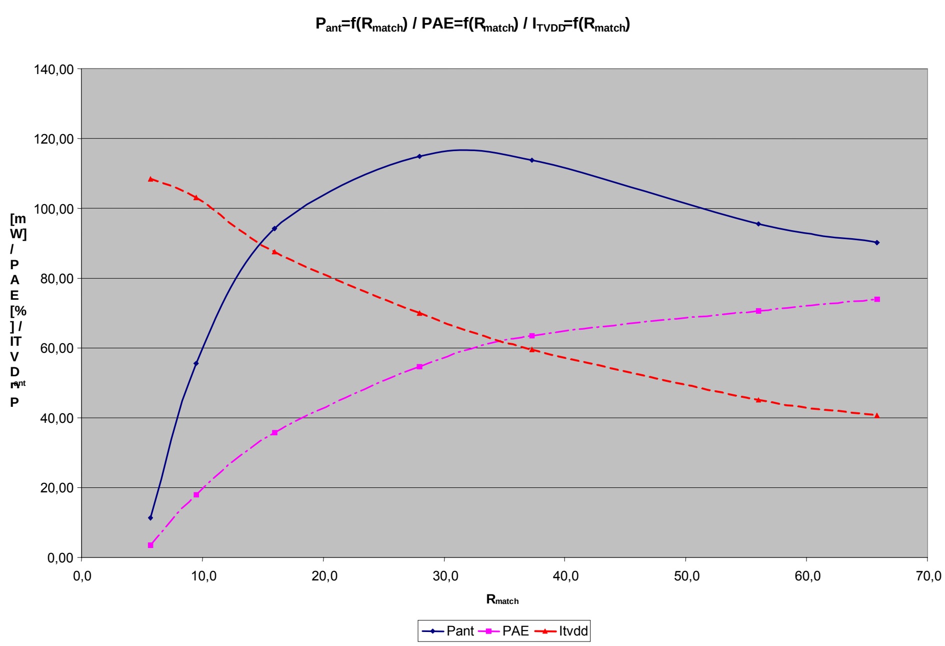


Fig 5. Power Added Efficiency @ 3V

4.5 Conclusion

- The maximum RF power can be obtained when transforming to an R_{match} of approx. 30 Ohm.
- A higher matching resistance means less power consumption with only slightly less available RF power compared to the maximum available RF power. A good compromise between available RF power and TX power consumption can be found for a matching resistance R_{match} between 40 and 50 Ohm.

R_{match} = 40 - 50 Ohm

5. Antenna design

5.1 Antenna Inductance

The following two sections list formulas to estimate the antenna inductance in free air.

To estimate antenna values under influence of metal (such as shielding planes or batteries in devices) simulation software would be needed to calculate the antennas parameters in this environment.

5.1.1 Circular Antennas

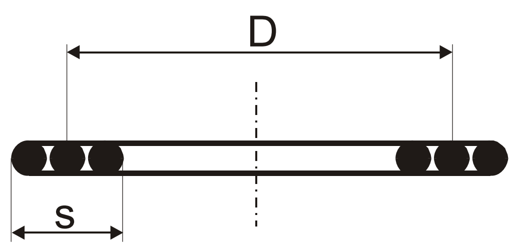


Fig 6. Circular Antenna

The inductance can be estimated using the following formula:

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

D Average antenna diameter

s Antenna width

N_a Number of turns

5.1.2 Rectangular Antennas

The inductance can be calculated by:

$$L_a = \frac{\mu_0}{\pi} \cdot \left[x_1 + x_2 - x_3 + x_4 \right] \cdot N_a^{1.8} \quad (2)$$

With:

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

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

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

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

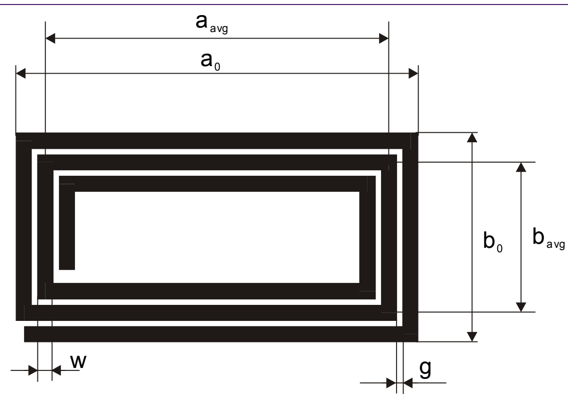


Fig 7. Rectangular antenna

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

5.2 Number of Turns

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

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

For many applications and antenna sizes, the number of turns will be in the range $\mathbf{N_a=1-6}$.

Due to the coupling coefficient, low numbers of turns are preferred. The lower the numbers of turns are used; the lower is the influence of coupled devices (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.

5.3 Antenna Symmetry

The symmetry in antenna design is absolutely necessary with respect to tuning and EMC behavior.

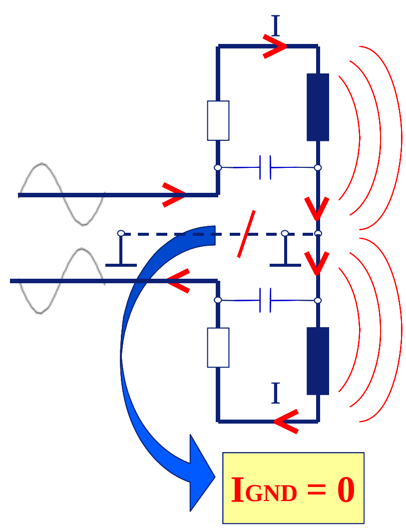


Fig 8. Ground current compensation

The following drawing shows an example of a symmetric 4-turn antenna design.

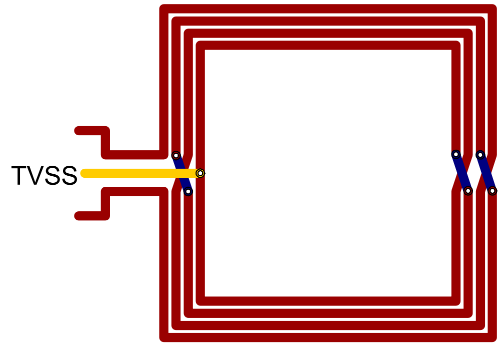


Fig 9. Symmetric 4-turn antenna

5.4 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, for operation of an antenna in close metallic environment, it is necessary to shield the antenna with ferrite.

The following examples should give an impression on the influence of ferrite for the distribution of a magnetic field.

For easy simulation a circular antenna has been used in every case. A circular antenna is rotation symmetrical to the x-axis. Therefore the simulation can be reduced to a two dimensional mathematical problem. The simulation shows on the one hand the field distribution of a non-disturbed antenna. Common for all examples: Radius of the antenna 7.5 cm, 1 turn, wire width 1mm copper.

Fig 10 shows the two-dimensional 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 line of a minimal field strength of H_{MIN} = 1.5 A/m is marked.

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

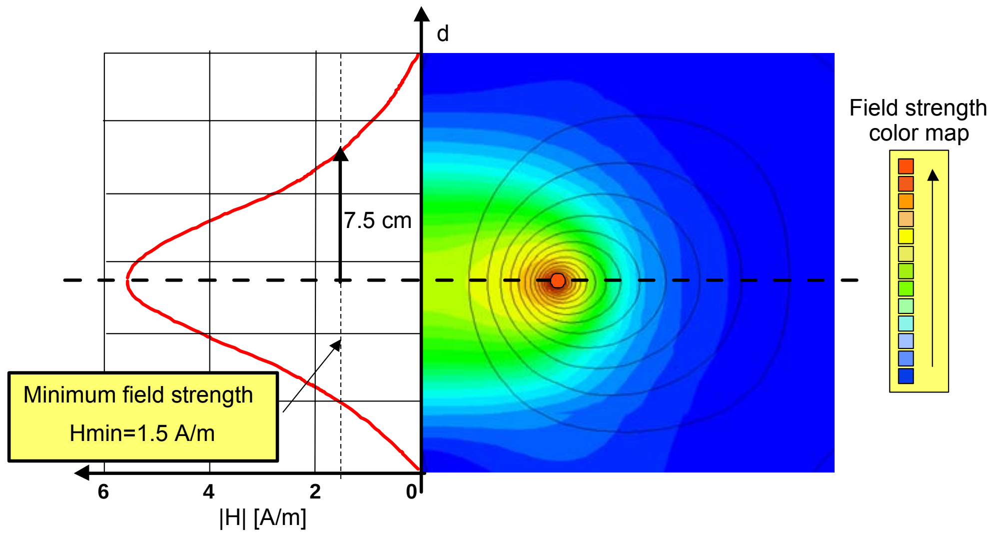


Fig 10. Non disturbed field distribution of a circular antenna

Fig 11 shows the field distribution of the same antenna with a metal plane near to the antenna. Compared to the disturbed field it is obvious that the magnitude of the field strength has decreased leading to a decreased operating distance.

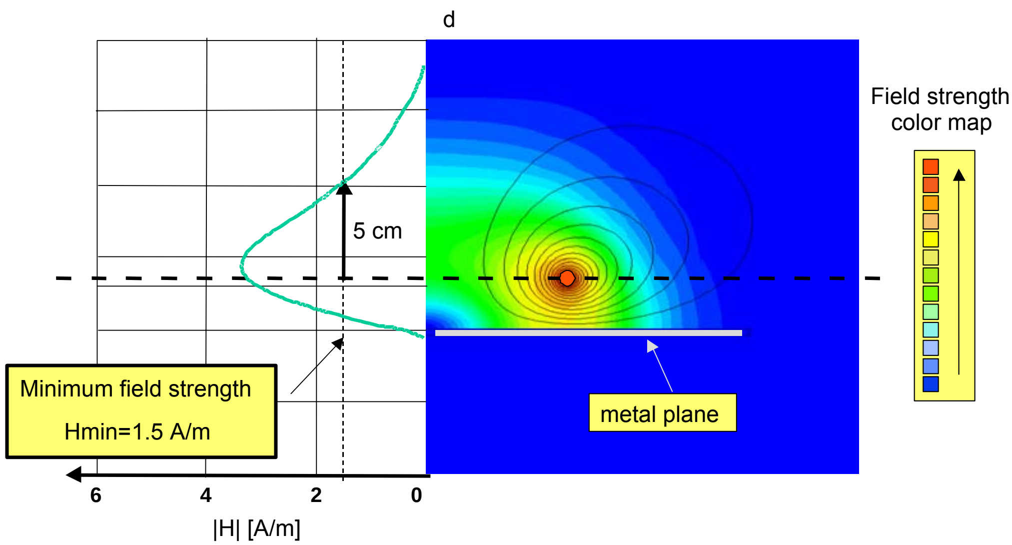


Fig 11. Field distribution of a circular antenna with a metal plane

Now, as shown in Fig 12 a ferrite plane (μ_R=40) is positioned in between the metal plane and the antenna coil itself. The field strength very near to the ferrite increases, but this increasing of the magnitude is not combined with an increase of the operating distance. This is marked once again with the H_{MIN} value.

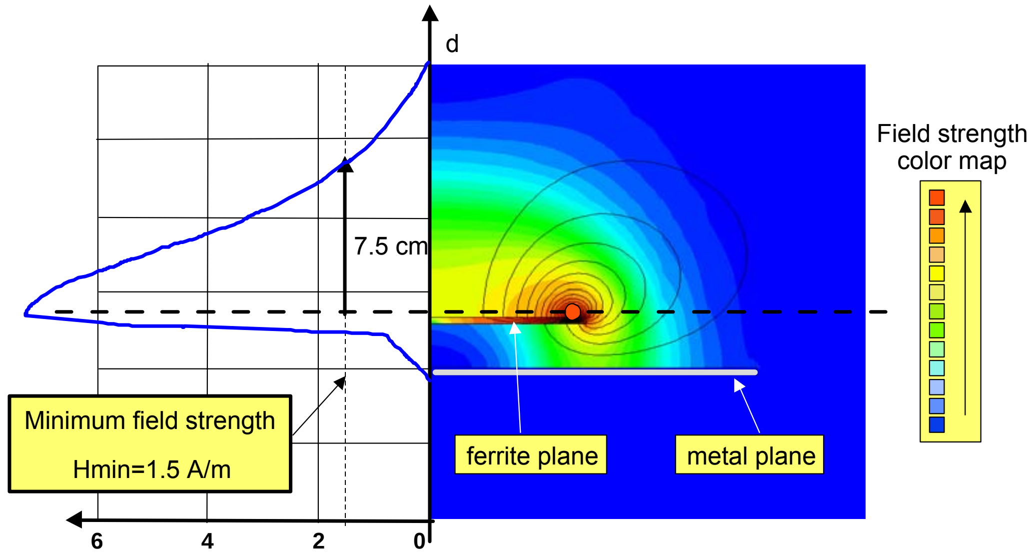


Fig 12. Ferrite shielded field distribution of a circular antenna

These simulations show how the use of ferrite reduces the generated eddy currents in a metal plane. The ferrite generates an additional field component and the effect for the design of the antenna is a fixed detuning of the antenna itself.

5.5 Antenna quality factor

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

$$B \cdot T \geq 1 \tag{3}$$

With the bandwidth definition

$$B = \frac{f}{Q} \tag{4}$$

the B-T product results to

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

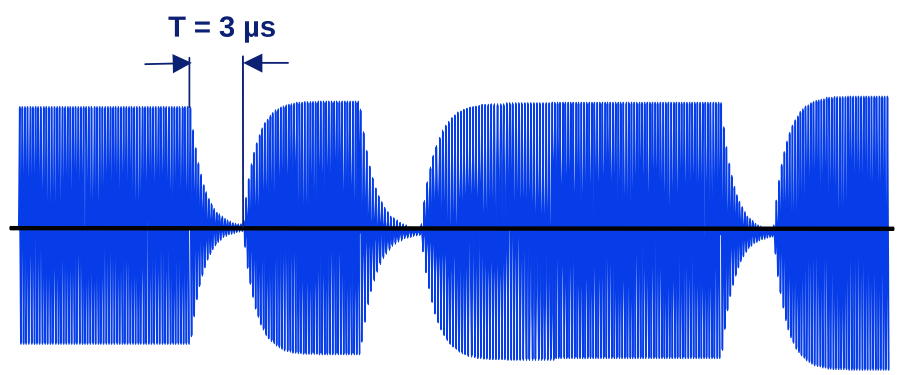


Fig 13. Pulse width definition

The recommended antenna quality factor to be used is defined to be **Q_a = 35.**

5.6 Equivalent Circuit

5.6.1 Determination of series equivalent circuit

The antenna loop has to be connected to an impedance analyser and the series equivalent circuit determined.

If the antenna will be operated in metal environment or ferrite will be used for shielding, the equivalent circuit must be determined under final environmental conditions!

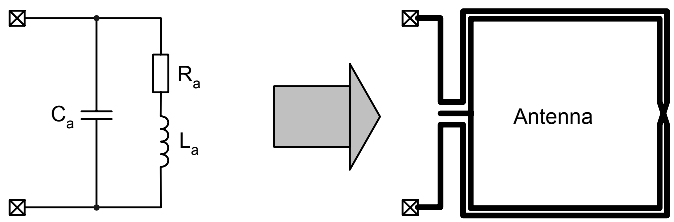


Fig 14. Series equivalent circuit

Typical values:

L_a = 0.3...3 µH

C_a = 3...30 pF

R_a = 0.3...8 Ω

5.6.2 Determination of antenna quality factor damping resistor R_Q

The quality factor of the antenna is

$$Q_a = \frac{\omega \cdot L_a}{R_a} \quad (5)$$

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 diminish the Q-factor to a value of **35 (±10%)**.

The value of R_Q calculates as:

$$R_Q = 0.5 \cdot \left(\frac{\omega \cdot L_a}{35} - R_a \right) \quad (6)$$

5.6.3 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.

If the antenna will be operated in metal environment or ferrite will be used for shielding, the equivalent circuit must be again determined under final environmental conditions!

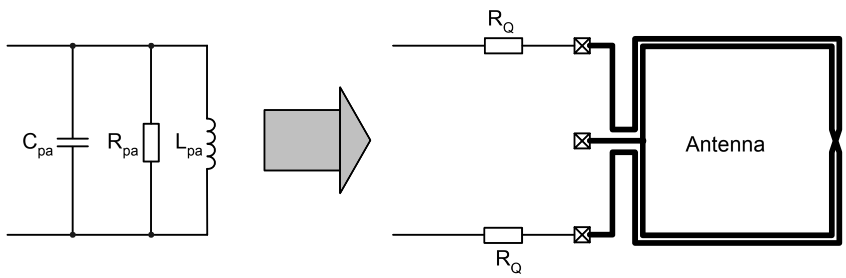


Fig 15. Parallel equivalent circuit

The following applies:

$$L_{pa} \mathrel{\hat{=}} L_a$$
$$C_{pa} \mathrel{\hat{=}} C_a$$
$$R_{pa} \mathrel{\hat{=}} \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q} \tag{7}$$

6. EMC Filter Design

The EMC filter circuit for the PN511/PN531 acts besides the filtering properties also as an impedance transformation block. The main functions of this 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 R_{match} at the operating frequency of f = 13.56 MHz.

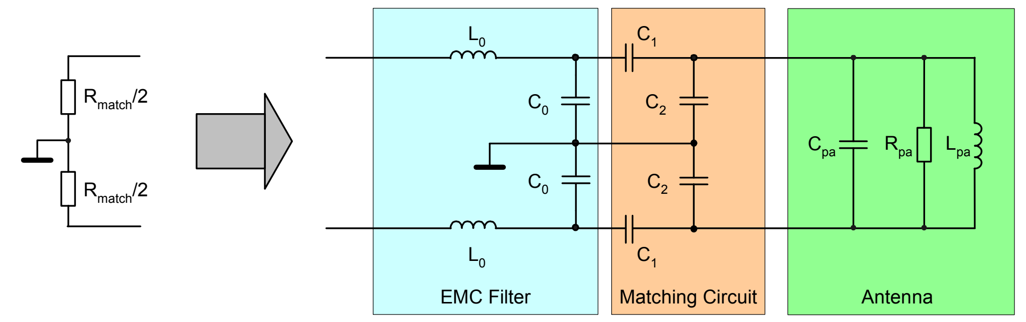


Fig 16. Impedance transformation

When splitting the circuit between EMC Filter and Matching Circuit the following applies:

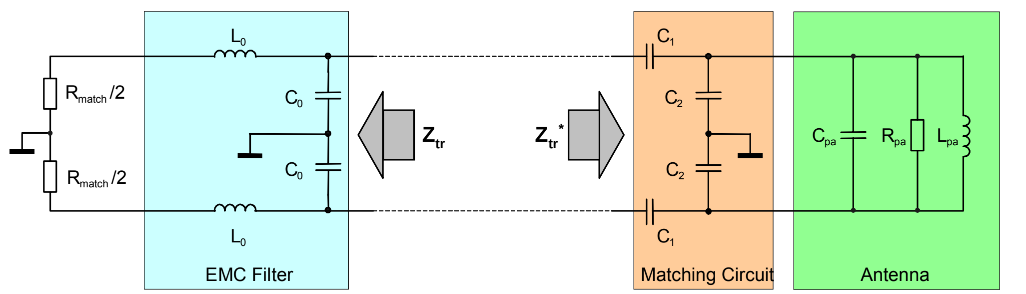


Fig 17. Definition of transformation impedance Z_{tr}

$$Z_{tr} = R_{tr} + jX_{tr} \tag{8}$$

$$Z_{tr}^{*} = R_{tr} - jX_{tr} \tag{9}$$

EMC filter general design rules:

L_0 = 390 nH - 1 µH

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

(10)

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

The EMC filter resonance frequency f_{r0} hast 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

With these EMC filter values found by applying the general design rules, the real and imaginary part of the transformation impedance R_{tr} and X_{tr} can be calculated. These values are needed to calculate the matching circuit components.

$$R_{tr} = \frac{R_{match}}{(1 - \omega^2 \cdot L_0 \cdot C_0)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2} \quad (11)$$

$$X_{tr} = 2 \cdot \omega \cdot \frac{L_0 \cdot (1 - \omega^2 \cdot L_0 \cdot C_0) - \frac{R_{match}^2}{4} \cdot C_0}{(1 - \omega^2 \cdot L_0 \cdot C_0)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2} \quad (12)$$

7. Matching Circuit Design

7.1 Component calculation

With the following formulas the series and parallel matching capacitances can be calculated:

$$C_1 \approx \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{tr} \cdot R_{pa}}{4}} + \frac{X_{tr}}{2} \right)} \tag{13}$$

$$C_2 \approx \frac{1}{\omega^2 \cdot \frac{L_{pa}}{2}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{tr} \cdot R_{pa}}{4}}} - 2 \cdot C_{pa} \tag{14}$$

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.

8. 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 PN511/PN531 TX pins. The matching impedance $Z_{match} = R_{match} + jX_{match}$ is measured with an impedance analyser or network analyser as shown in next figure.

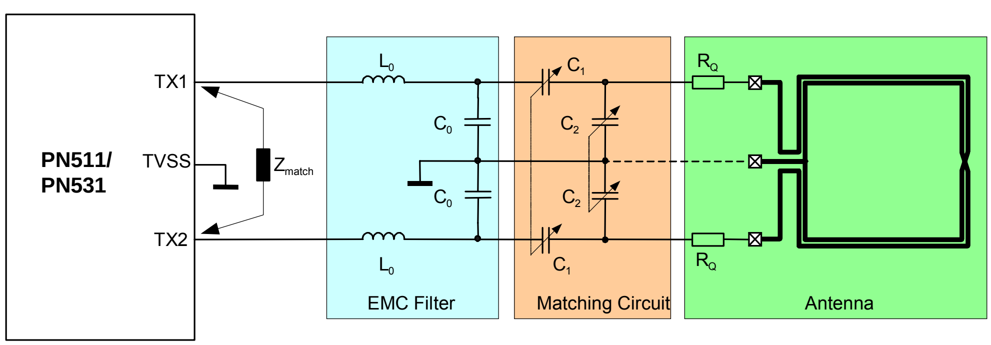


Fig 18. Measurement of matching impedance

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

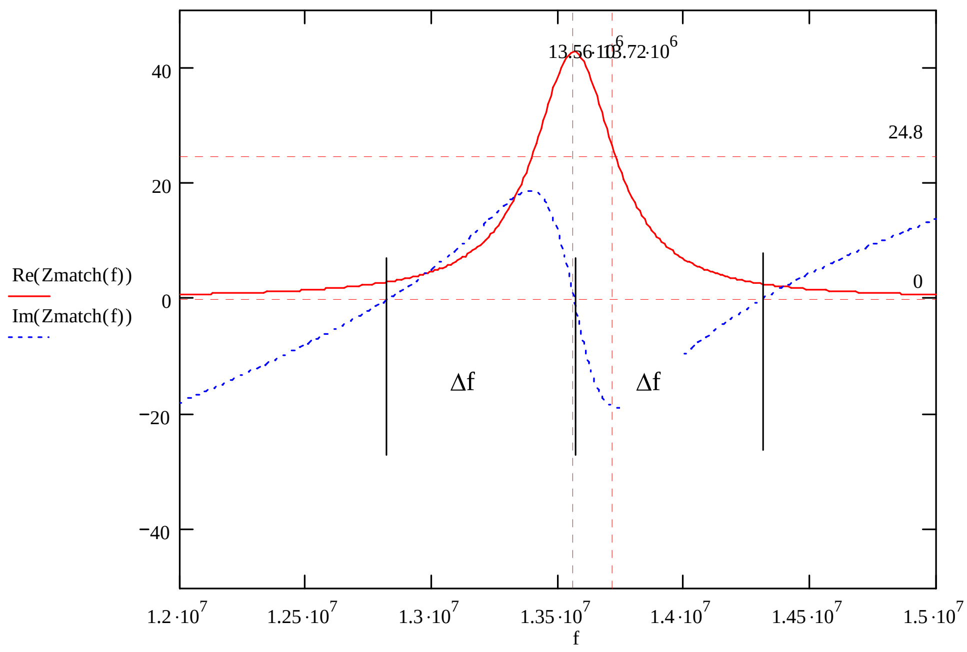


Fig 19. Calculation of matching impedance

Conditions for the tuning:

→ R_{match} curve symmetric around the operating frequency

→ **X_{match} curve hermitic symmetric around the operating frequency**

Smith chart simulation for Z_{match} / 2 :

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

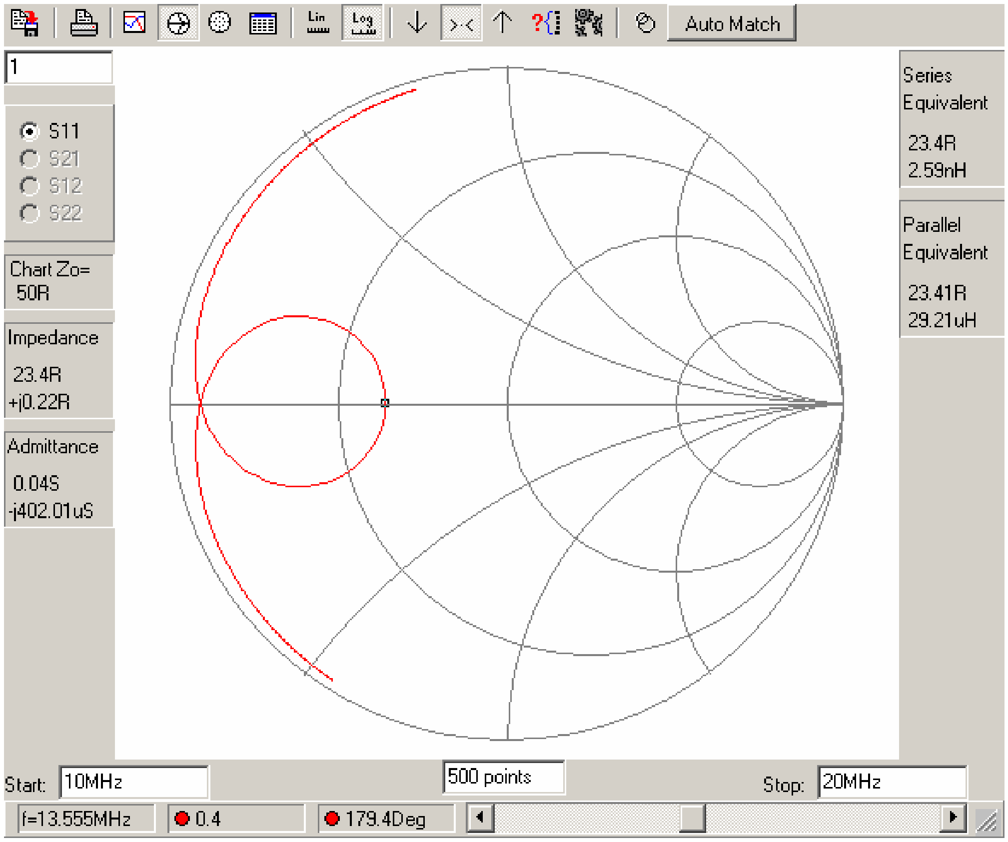
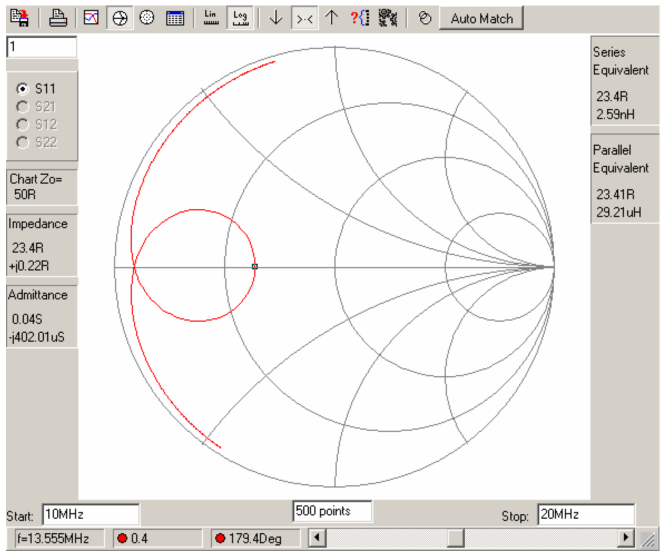


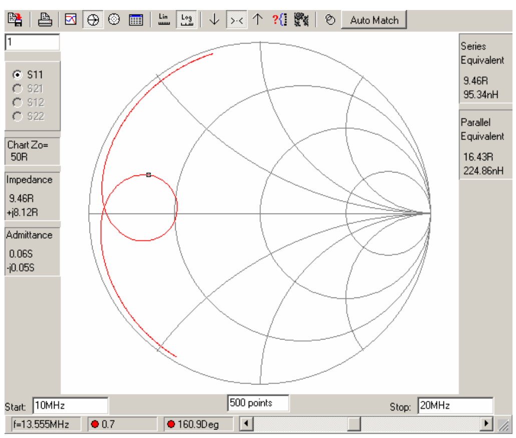
Fig 20. Smith chart for matching impedance

8.1 Tuning of series matching capacitance C_1

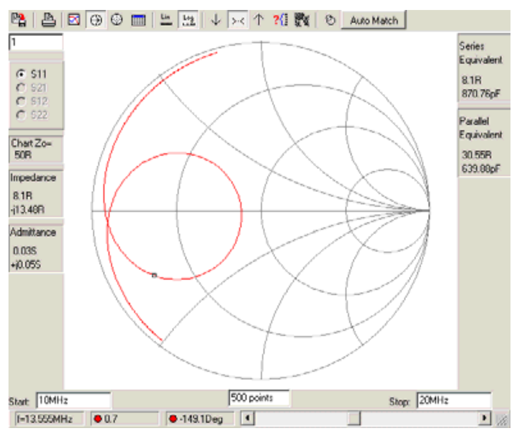
The Smith charts show the matching impedance Z_{match} / 2 vs. frequency.



a. Optimum C1



b. C_1 too low



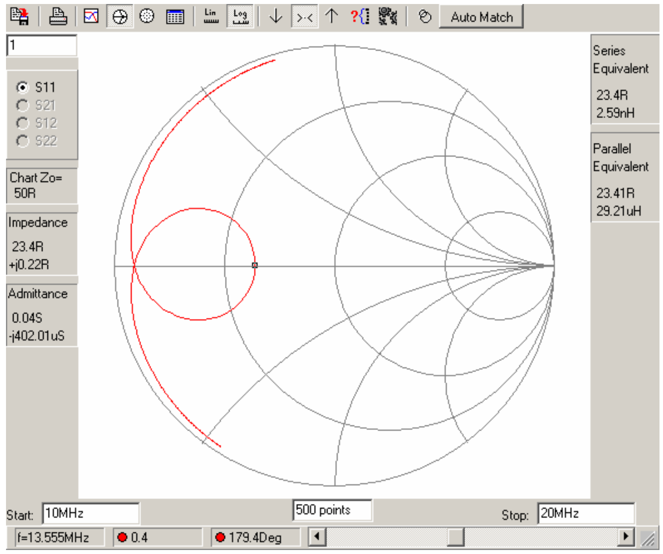
c. C_1 too high

Fig 21. Smith charts for C_1 tuning

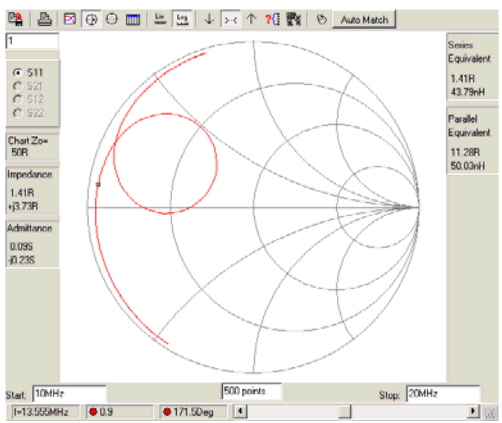
C_1 changes the magnitude of the matching impedance. After a change of C_1 the imaginary part of Z_{match} must be compensated by adjusting C_2.

8.2 Tuning of parallel matching capacitance C_2

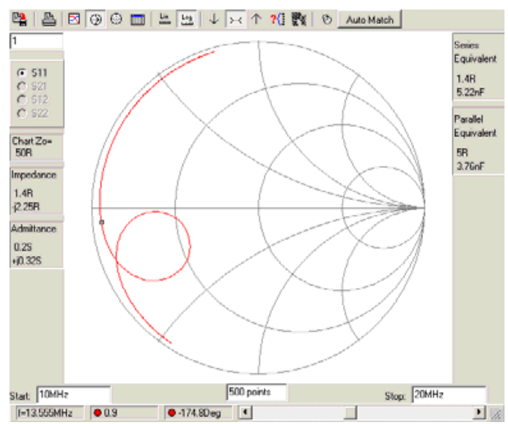
The smith charts show the matching impedance Z_{match} / 2 vs. frequency.



d. Optimum C2



e. C_2 too low



f. C_2 too high

Fig 22. Smith charts for C_2 tuning

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

8.3 Tuning Flow-Chart

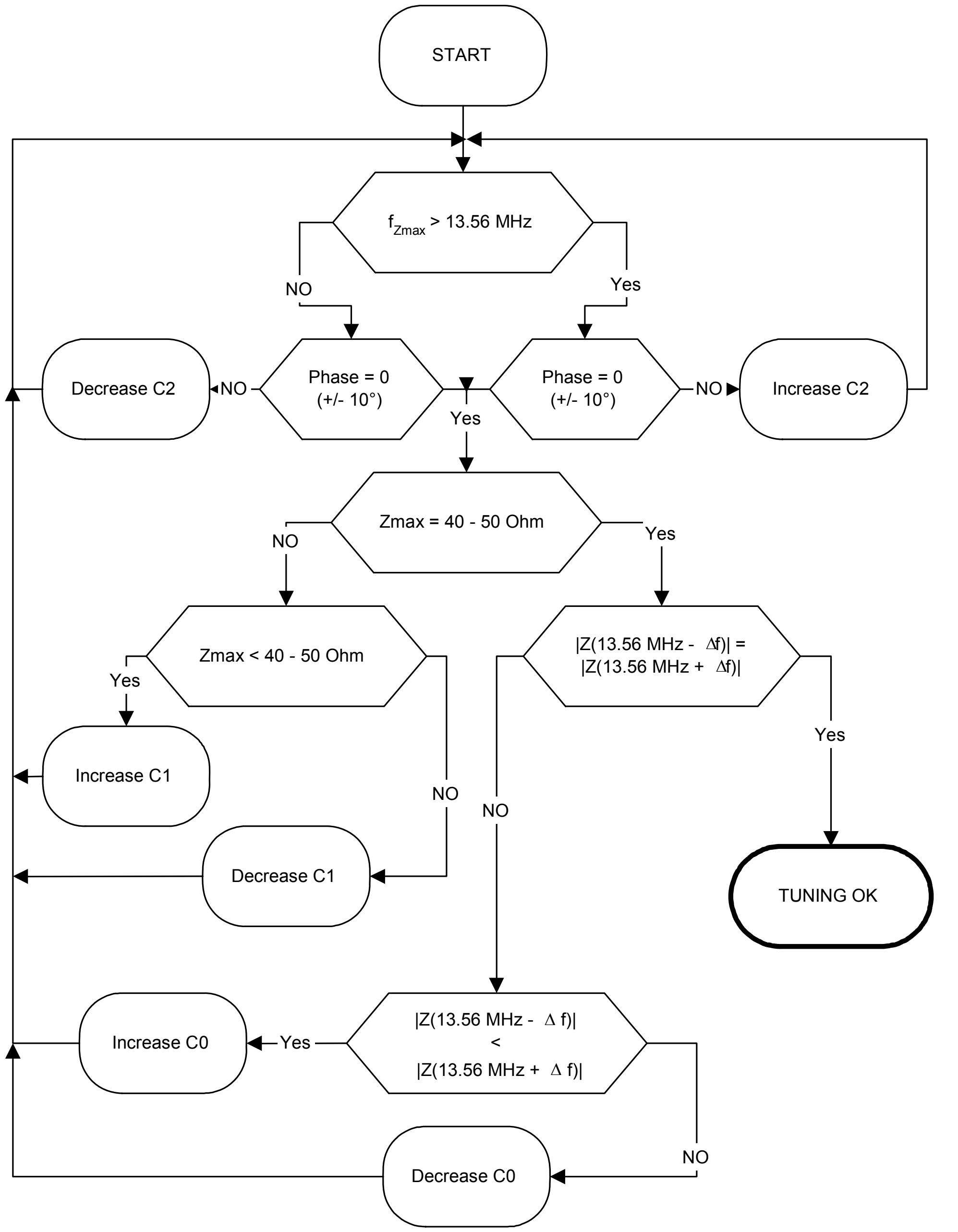


Fig 23. Tuning flow chart

9. Receiver circuit Design

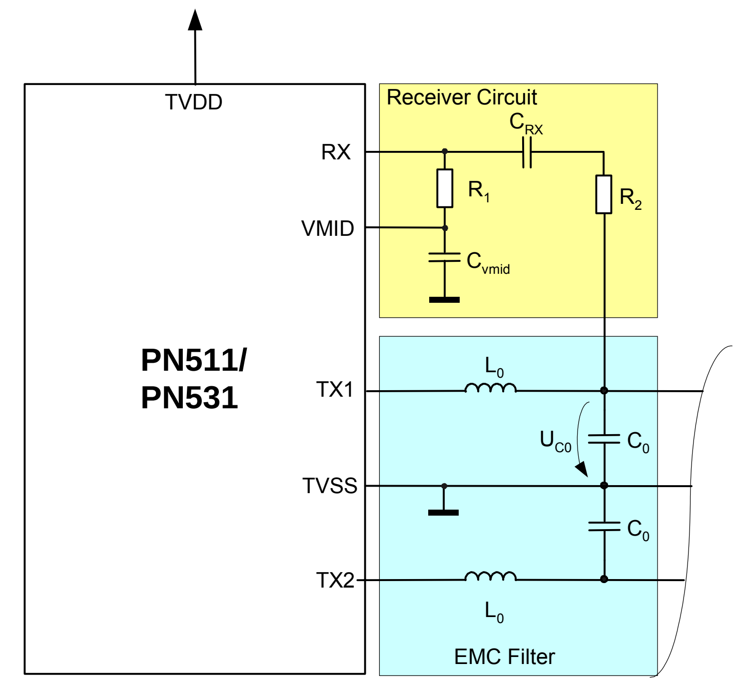


Fig 24. Receiver circuit

9.1 Initiator mode

After matching and tuning the transmitting antenna, the receiver circuit must be designed. The investigations on that design starts with the 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).

Step 3:

The voltage divider resistor R_2 can be calculated by:

$$R_2 = R_1 \cdot \left(\frac{U_{C0}}{U_{RX}} - 1 \right) \tag{15}$$

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.

9.2 Target mode

Depending on antenna size and matching circuit this mode may determine the design of the RX path voltage divider with respect to the maximum voltage on the RX pin.

Step 5:

The NFC device must be placed in the test setup according to NFCIP1 test method standard. The magnetic field hast 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 fulfils the specification above.

10. Equivalent Circuit Measurement

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

The analyzer must be calibrated (open, short and load compensation at the calibration plane) and the test fixture compensated (open, short compensation at the connection points) according to the manual before each measurement.

Settings: $|Z|, \Theta$

Start frequency: 1 MHz

Stop frequency: above self-resonance frequency of the antenna

Advantage:

- Fast and simple method

Disadvantages:

- Additional instrument to network analyzer
- Low accuracy of the measurement results especially of the loss resistance for high quality factor coils (Q_{pc} > 60).

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

The analyzer must be calibrated (open, short and load calibration) and the test fixture compensated (electrical delay) according to the manual before each measurement.

Settings: S11, Chart: Smith Z

Start frequency: 1 MHz

Stop frequency: above self-resonance frequency of the antenna

10.2.1 Series Equivalent Circuit

The following characteristic circuit elements can be determined by measurements at characteristic points.

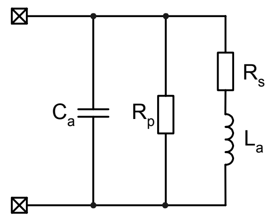


Fig 25. Characteristic circuit

R_s Equivalent resistance at f = 1 MHz

L_a Equivalent inductance at f = 1 MHz

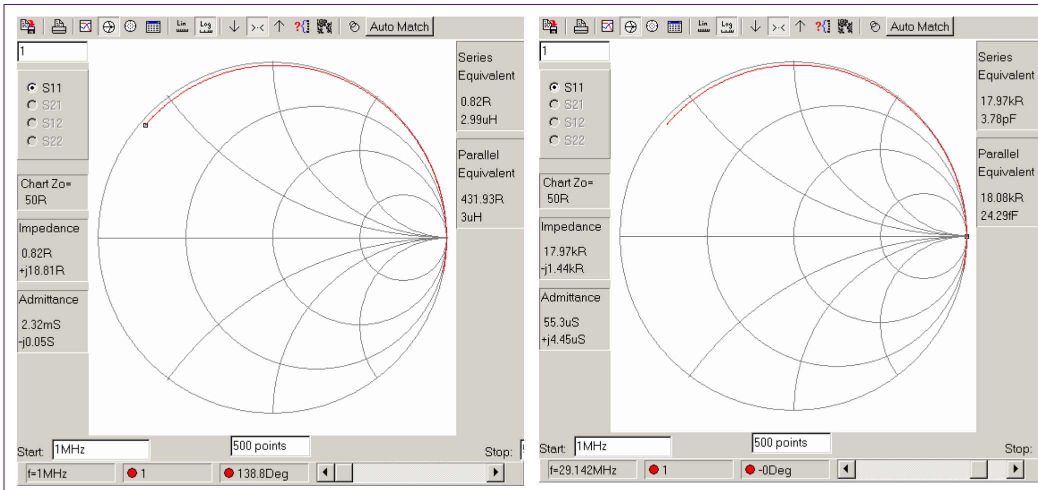
R_p Equivalent resistance at the self-resonance frequency

f_{ra} Self-resonance frequency of the antenna

The antenna capacitance C_a can be calculated with:

$$C_a = \frac{1}{(2 \cdot \pi \cdot f_{ra})^2 L_a} \tag{16}$$

The following figure shows simulation results to determine the characteristic circuit.



a. R_s = 0.82 Ohm, L_a = 2.99 µH

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

Fig 26. Simulation results for characteristic circuit

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

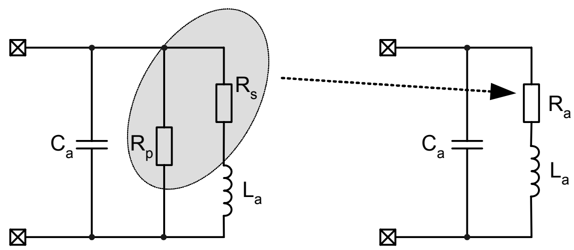


Fig 27. Series equivalent resistance calculation

$$R_a = R_s + \frac{\left(2 \cdot \pi \cdot f_{op} \cdot L_a\right)^2}{R_p} \quad (17)$$

The parallel equivalent circuit must be calculated always out of the series equivalent circuit using Equation (7).

11. EXAMPLE

As an example the antenna of the PN511/PN531 evaluation board Rev. 1.1 will be matched to the transmitter output.

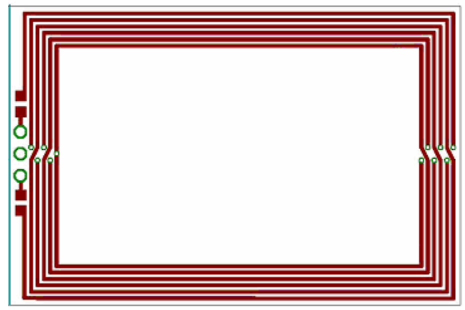


Fig 28. PN511/PN531 evaluation board antenna

The external RF components should be tuned to a value, that $I_{TVDD} \approx 50mA$. With Fig 3 the required matching resistance can be determined.

→ $R_{match} \approx 50$ 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

Simulation result:

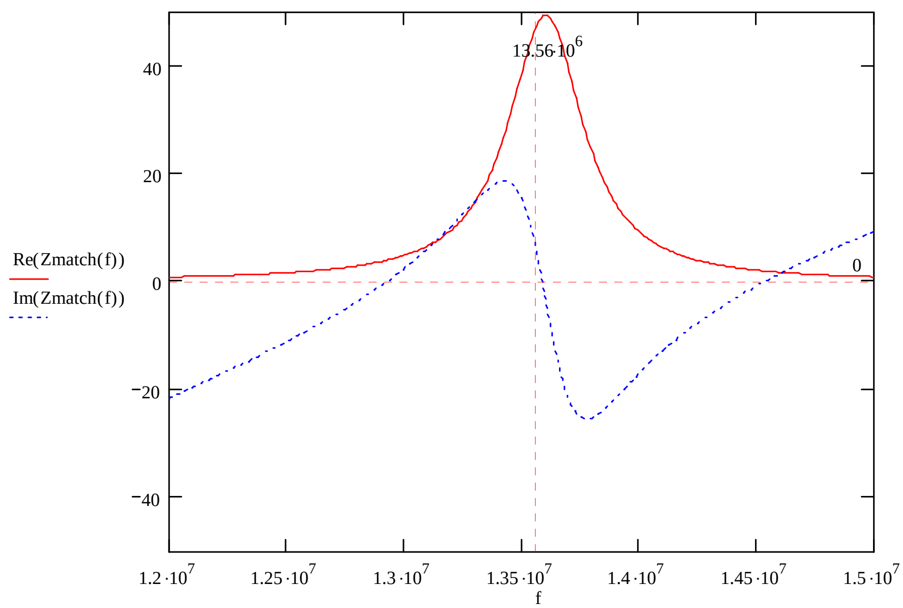


Fig 29. Example: Z_{match} simulation

Measurement result:

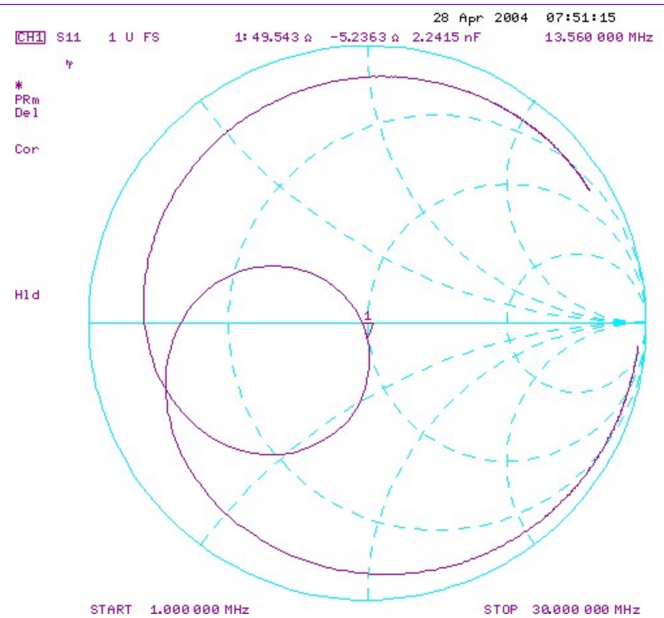


Fig 30. Example: Z_{match} measurement

12. PULSE shape CHECK

As the Q-factor has a direct influence on the edges of the modulation shape, this can be used to check the Q-factor.

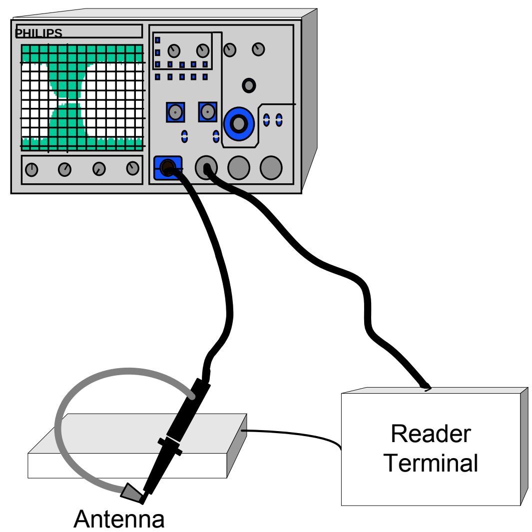


Fig 31. Setup to check the Q-factor

An oscilloscope with a bandwidth of at least 50 MHz has to be used for these measurements.

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

CH2: Can be used as trigger signal by using Sigout (See PN511/PN531 Data Sheet)

It is recommended to check the pulse shape and compare the scope plot to and the according values are given in Fig 32 Pulse shape according to ISO 18092, 106 kbps and the values are given in Table 2 Pulse shape definitions according to ISO18092, 106 kbps.

Remarks:

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.

12.1 Pulse shape according to ISO 18092

12.1.1 Bit rate 106kbps

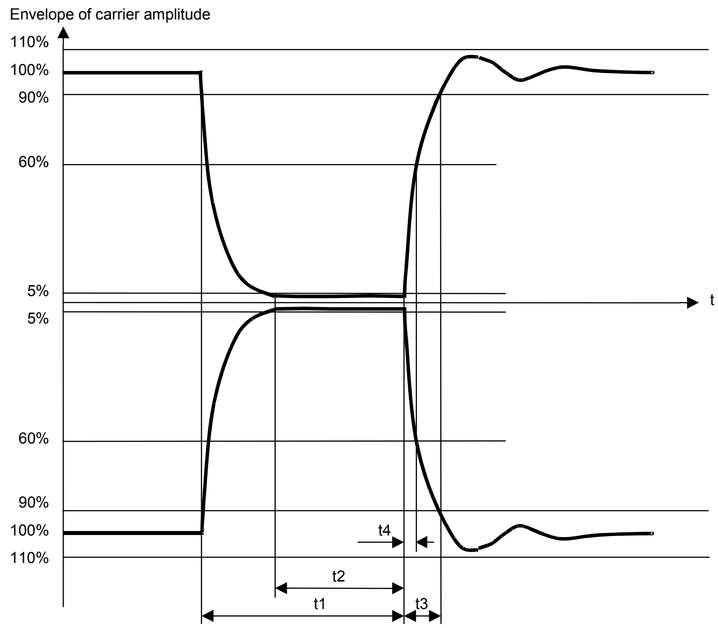


Fig 32. Pulse shape according to ISO 18092, 106 kbps

Table 2. Pulse shape definitions according to ISO18092, 106 kbps

[30] **Pulse length** [31] (Condition)	[32] **t1 [µs]**	[33] **t2 [µs]**		[34] **t3 [µs]**	[35] **t4 [µs]**
		[36] (t1 ≤ 0,5)	[37] (t1 > 2,5)		
[38] Maximum	[39] 3,0	[40] t1		[41] 1,5	[42] 0,4
[43] Minimum	[44] 2,0	[45] 0,7	[46] 0,5	[47] 0,0	[48] 0,0

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 PN511/PN531 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.

12.1.2 Bit rate 212 kbps and 424 kbps

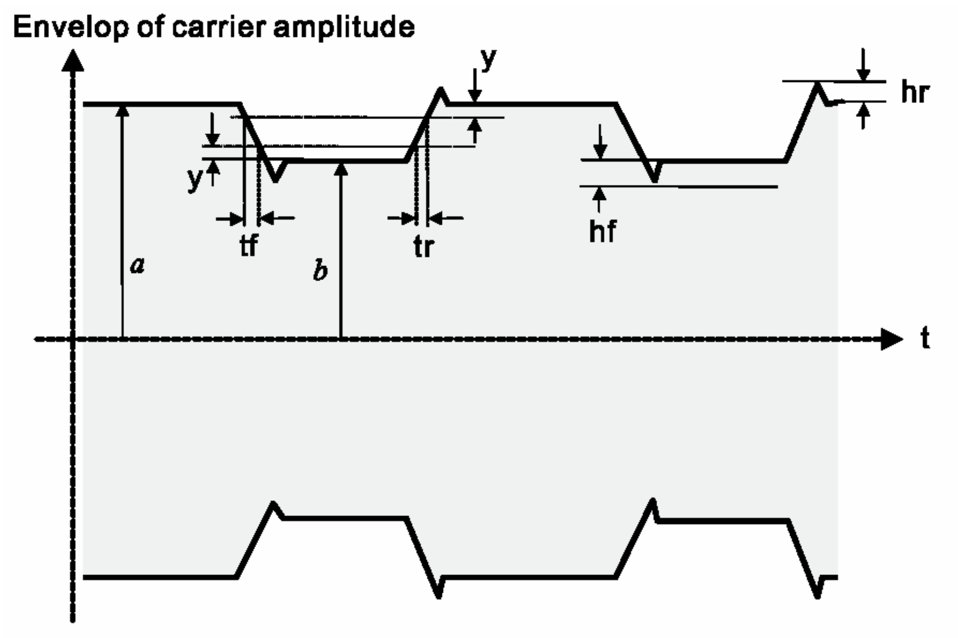


Fig 33. Pulse shape according to ISO 18092, 212 and 424 kbps

Table 3. Table 12-1: Pulse shape definitions according to ISO18092, 212 and 424 kbps

[49]	[50] 212 kbps	[51] 424 kbps
[52] tf	[53] 2,0 µs max	[54] 1,0 µs max
[55] tr	[56] 2,0 µs max	[57] 1,0 µs max
[58] y	[59] 0,1 (a-b)	[60] 0,1 (a-b)
[61] hf, hr	[62] 0,1 (a-b) max	[63] 0,1 (a-b) max

13. Disclaimers

Life support — These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips Semiconductors customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips Semiconductors for any damages resulting from such application.

Right to make changes — Philips Semiconductors reserves the right to make changes in the products - including circuits, standard cells, and/or software - described or contained herein in order to improve design and/or performance. When the product is in full production (status 'Production'), relevant changes will be communicated via a Customer Product/Process Change Notification (CPCN). Philips Semiconductors assumes no responsibility or liability for the use of any of these products, conveys no licence or title under any patent, copyright, or mask work right to these products, and makes no representations or warranties that these products are free from patent, copyright, or mask work right infringement, unless otherwise specified.

Application information — Applications that are described herein for any of these products are for illustrative purposes only. Philips Semiconductors make no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

14. Trademarks

MIFARE — is a registered trademark of Royal Philips Electronics

FeliCa — is a trademark of Sony Cooperation

15. Contents

Date of release:12 April 2005
Document number: 100720

Published in Austria