

# AN1445

## Antenna design guide for MFRC52x, PN51x and PN53x

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### Document information

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| <b>Keywords</b> | NFC, MFRC522, MFRC523, PN511, PN512, PN531, PN532, Antenna Design, RF Design, constant current design                          |
| <b>Abstract</b> | 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 devices are Reader/Writer devices 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  $R_{\text{match}}$  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.

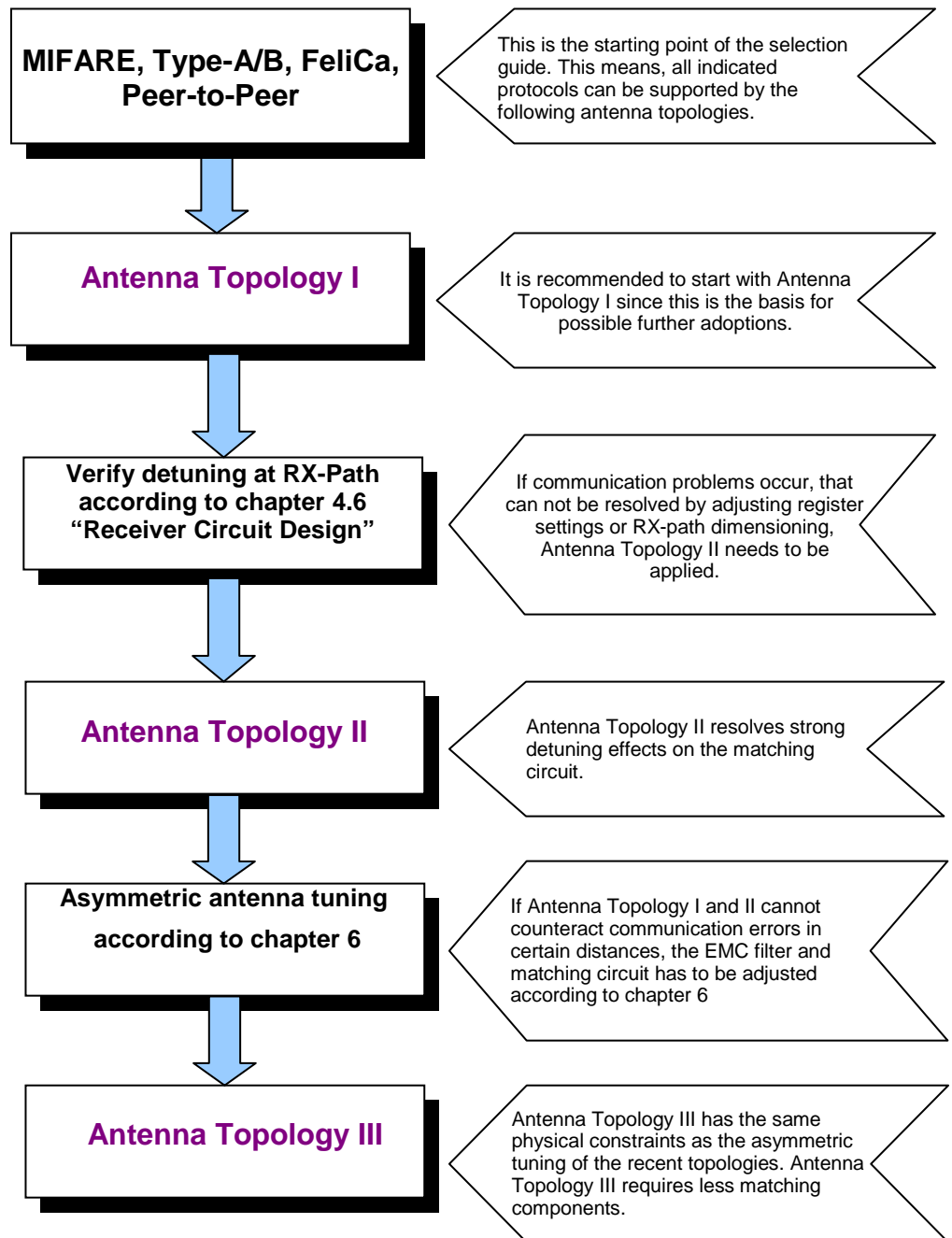
Tuning and measurement of the antenna has always to be performed at the final mounting position to consider all parasitic effects, e.g. metal influence on quality factor, inductance and additional capacitance.

**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.



## 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.

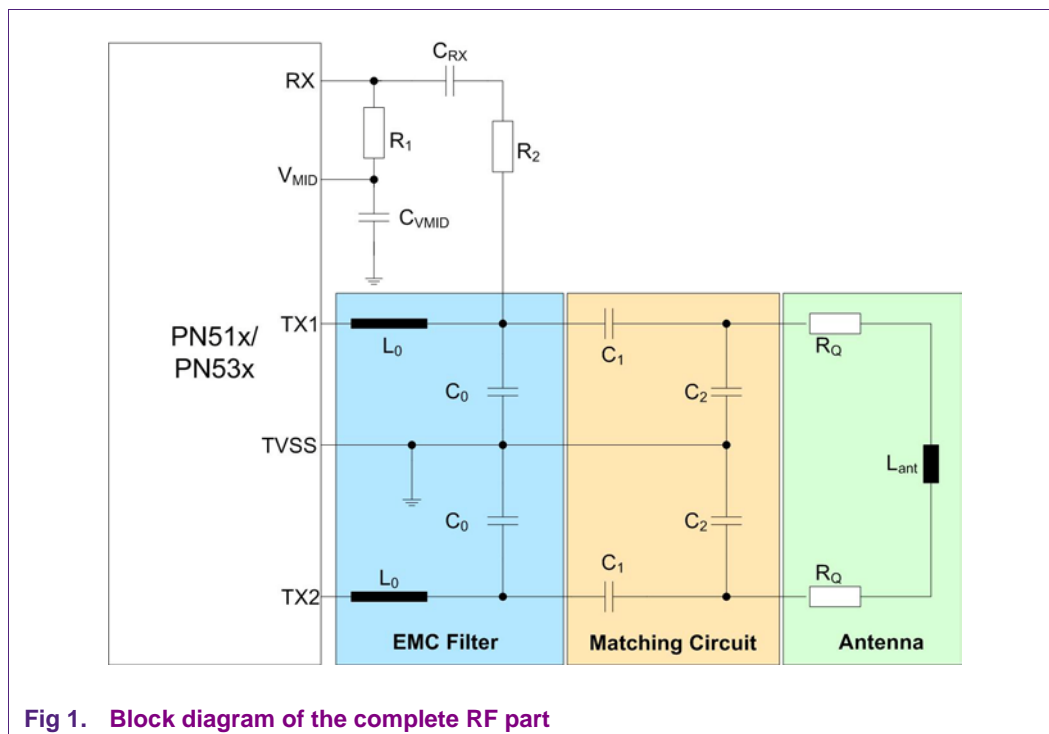


Fig 1. Block diagram of the complete RF part

**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 these 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.

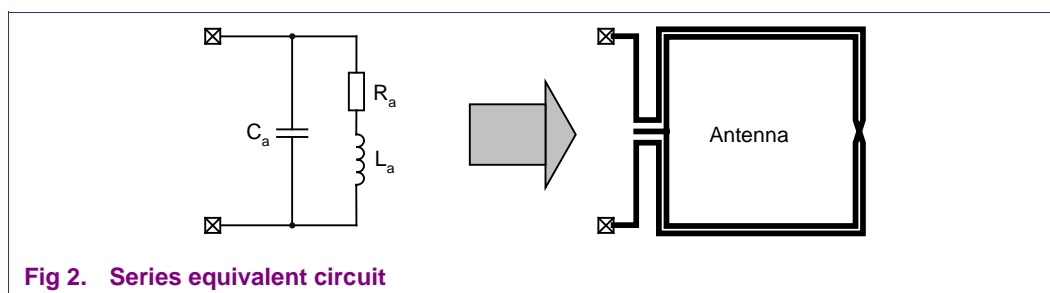


Fig 2. Series equivalent circuit

Typical values:

$$L_a = 0.3...3 \mu\text{H}$$

$$C_a = 3...30 \text{ pF}$$

$$R_a = 0.3...8 \Omega$$

### 4.1.2 Calculation of antenna quality factor damping resistor $R_Q$

The quality factor of the antenna is calculated with

$$Q_a = \frac{\omega \cdot L_a}{R_a} \quad (1)$$

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 ( $\pm 10\%$ )**.

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

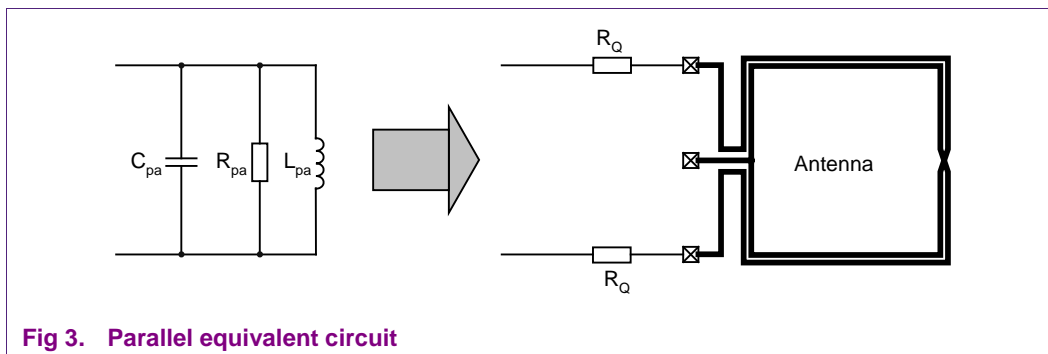
$$R_Q = 0.5 \cdot \left( \frac{\omega \cdot L_a}{35} - R_a \right) \quad (2)$$

### 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.



The following formula applies

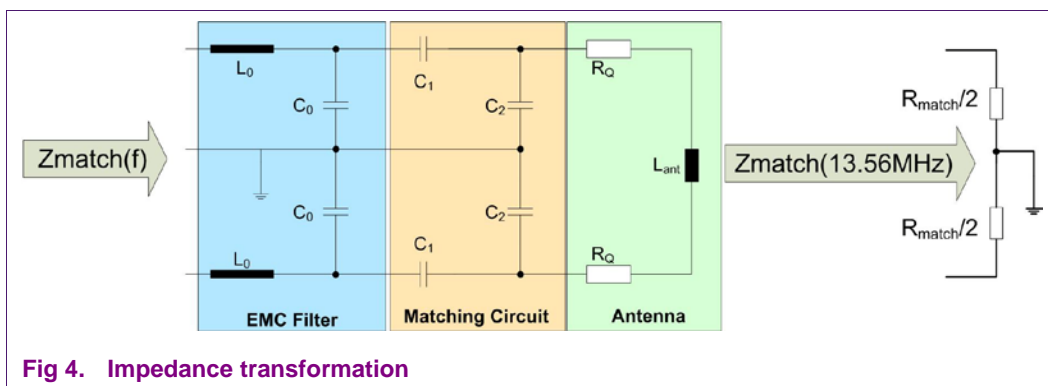
$$\begin{aligned} L_{pa} &\triangleq L_a \\ C_{pa} &\triangleq C_a \\ R_{pa} &\triangleq \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q} \end{aligned} \quad (3)$$

## 4.2 EMC filter design

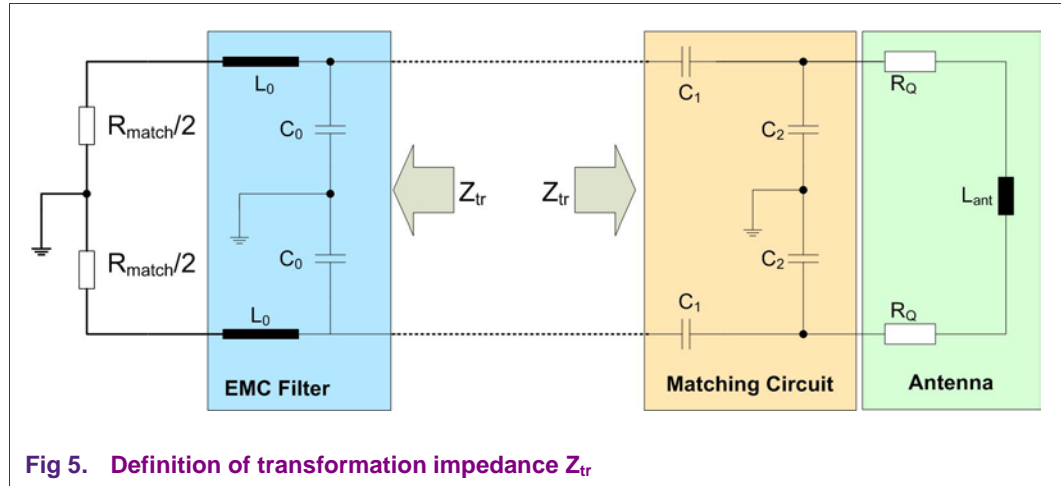
The EMC filter circuit for the MFRC522/MFRC523/PN51x/PN53x fulfills two functions: the filtering of the signal and impedance transformation block. The main properties of the impedance transformation are:

- 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  $Z_{\text{match}}(f)$  at the operating frequency of  $f = 13.56 \text{ MHz}$ .



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



$$Z_{tr} = R_{tr} + jX_{tr} \quad (4)$$

$$Z_{tr}^* = R_{tr} - jX_{tr} \quad (5)$$

EMC filter general design rules:

$$L_0 = 390 \text{ nH} - 1 \text{ } \mu\text{H}$$

Filter resonance frequency  $f_{r0} = 14.1 \text{ MHz} \dots 14.5 \text{ MHz}$ ,  $\Rightarrow C_0$

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

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:

$$L_0 = 560 \text{ nH}$$

$$f_{r0} = 14.3 \text{ MHz}$$

$$C_0 = 221.2 \text{ pF} \Rightarrow \text{chosen: } 220 \text{ pF}$$

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

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

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

### 4.3 Matching circuit design

#### 4.3.1 Component calculation

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

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

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

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.

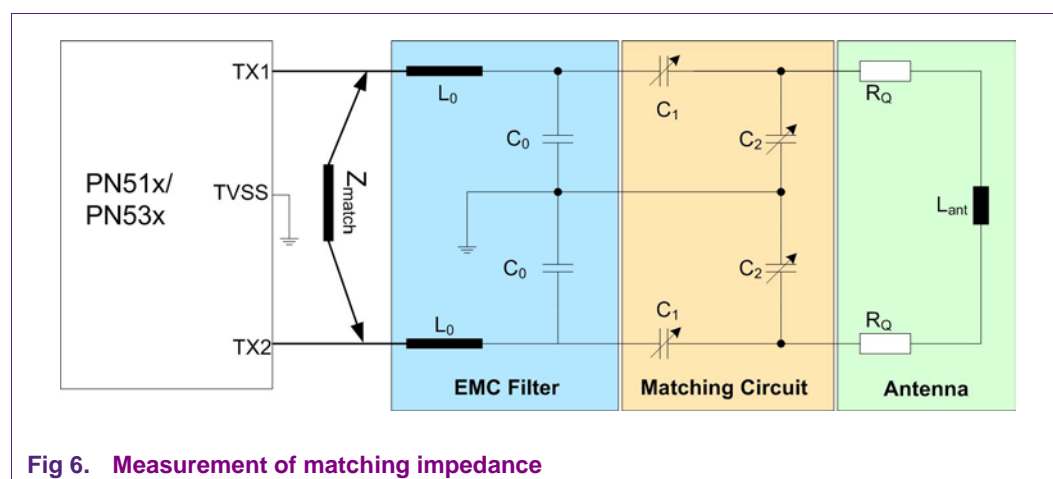


Fig 6. Measurement of matching impedance

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

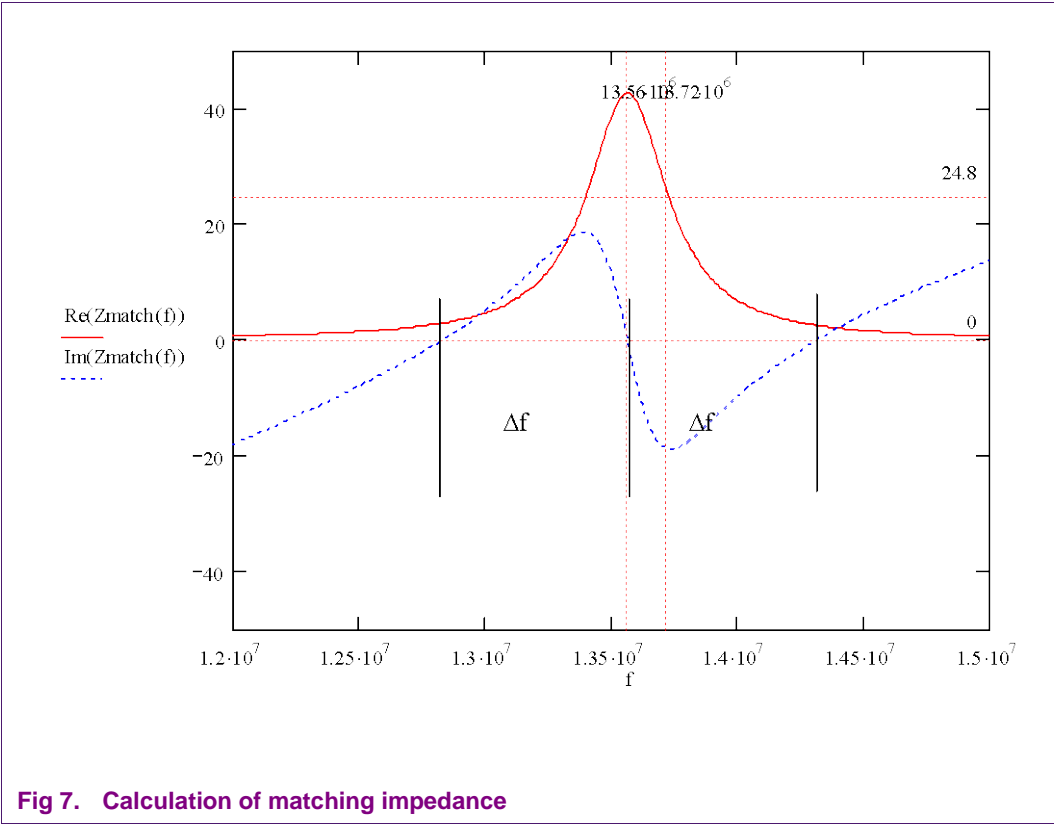
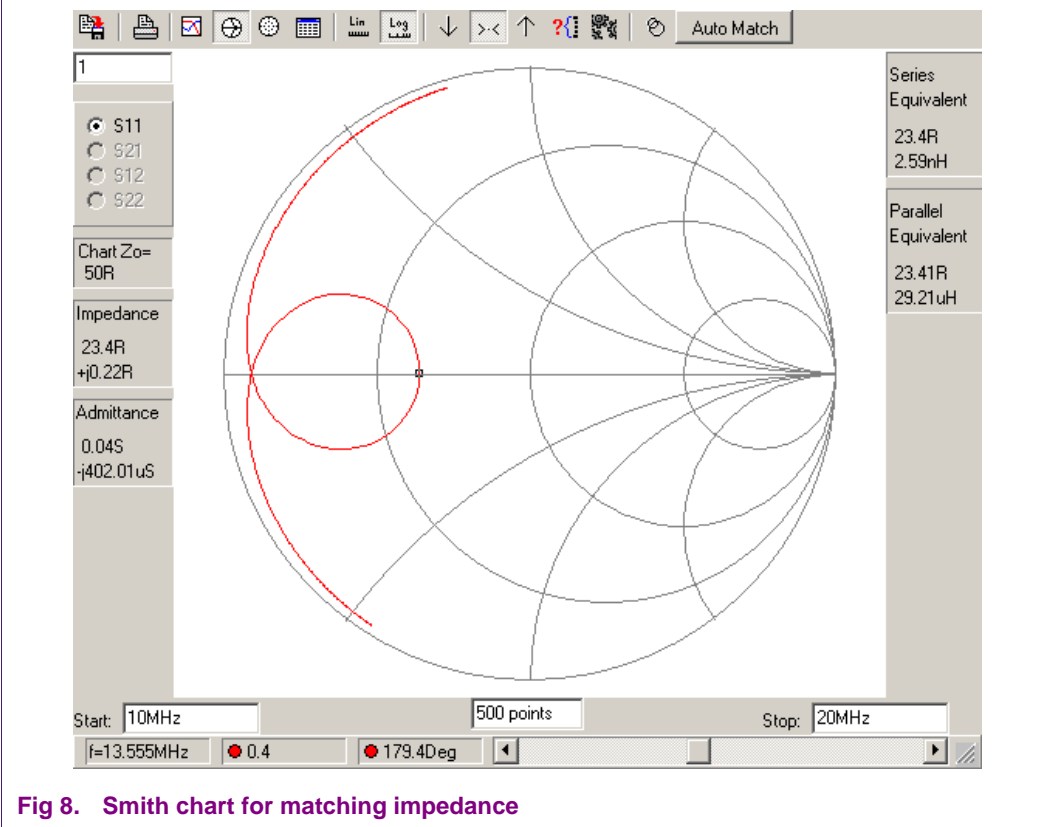


Fig 8 shows the smith chart simulation for  $Z_{\text{match}} / 2$ :



Conditions for the tuning:

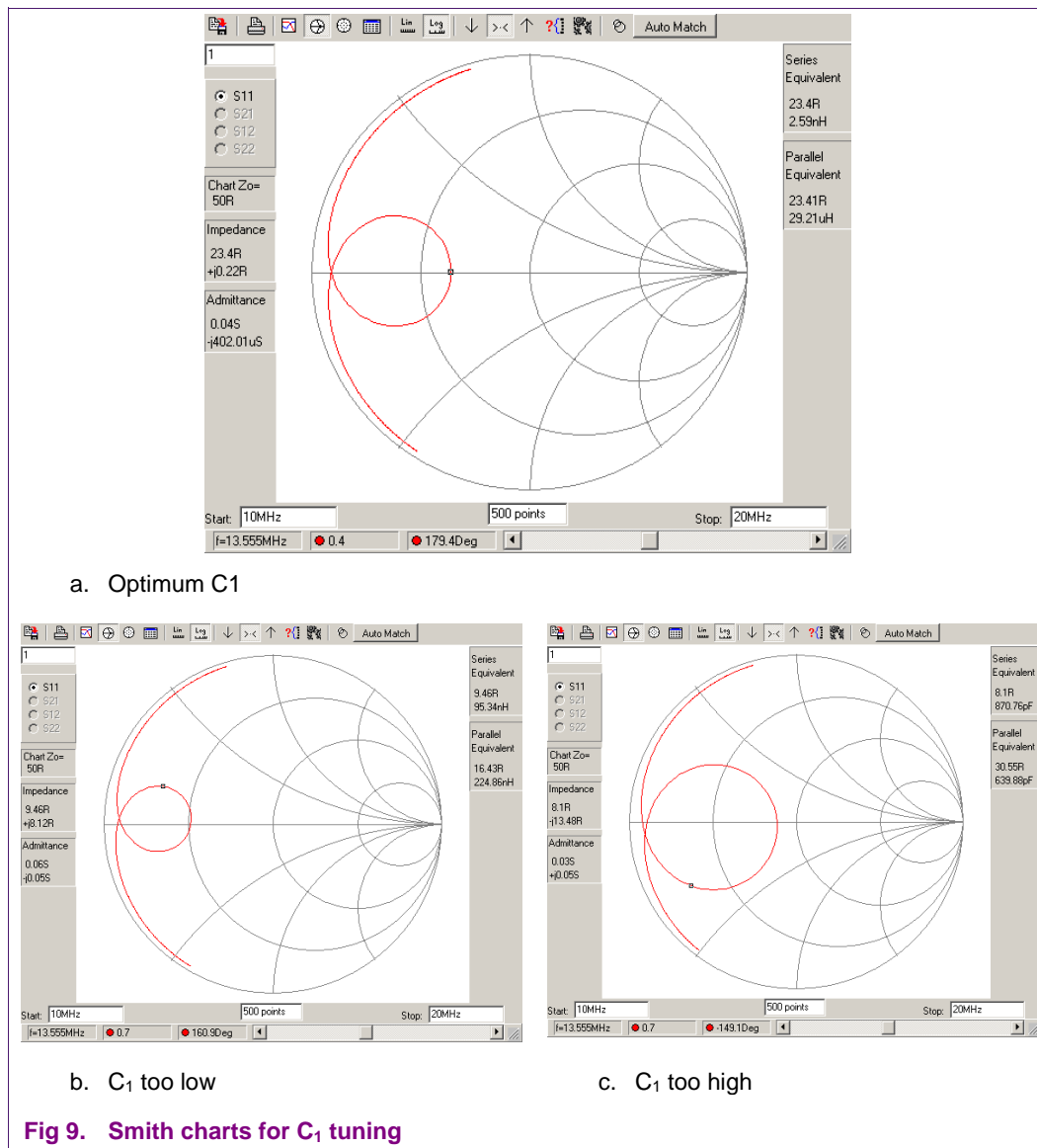
→  $R_{\text{match}}$  curve symmetric around the operating frequency

→  $X_{\text{match}}$  **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  $Z_{\text{match}} / 2$  vs. frequency.



**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  $Z_{\text{match}}$  must be compensated by adjusting  $C_2$ .

4.5 Tuning of parallel matching capacitance C<sub>2</sub>

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

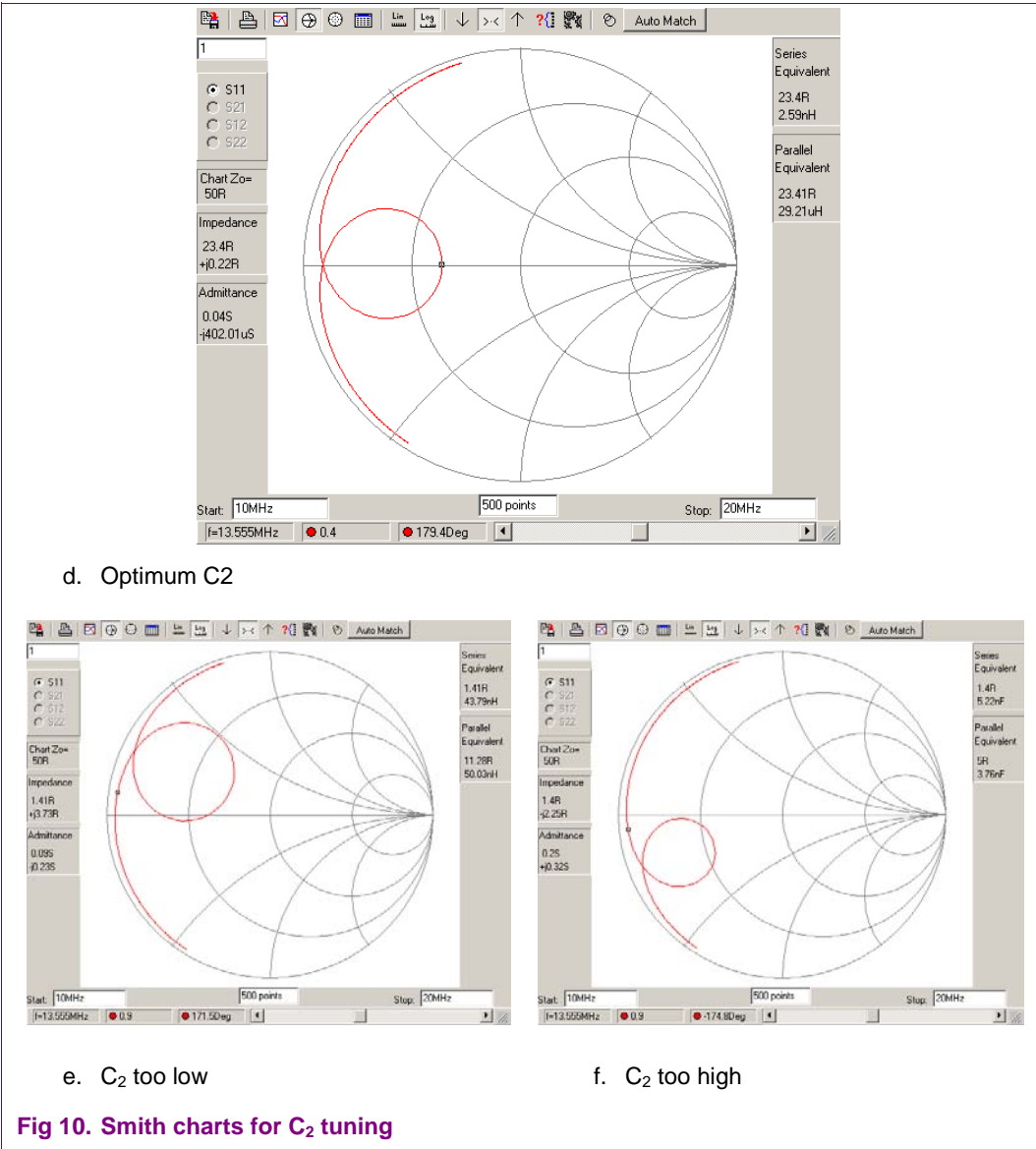
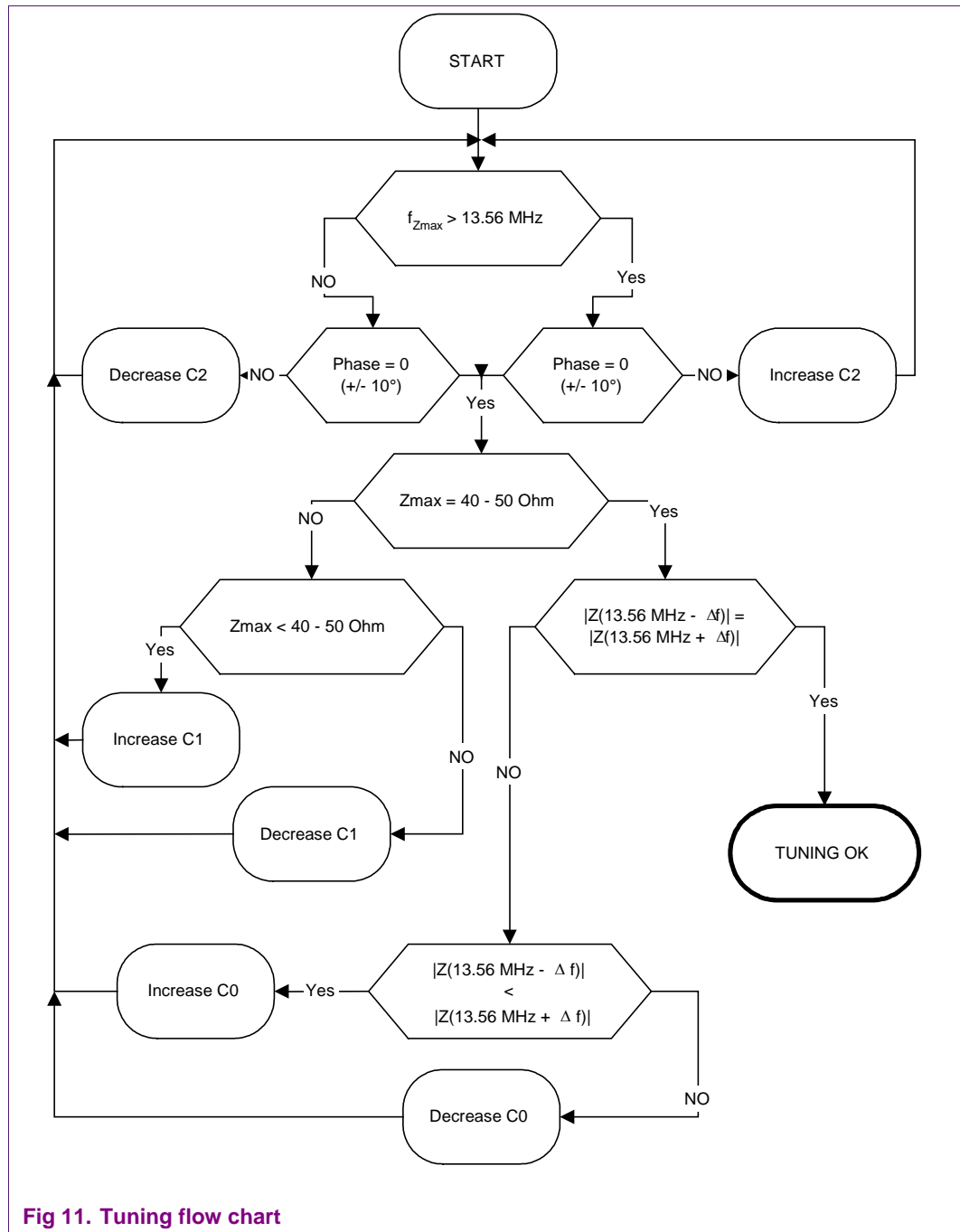


Fig 10. Smith charts for  $C_2$  tuning

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



## 4.5.1 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.

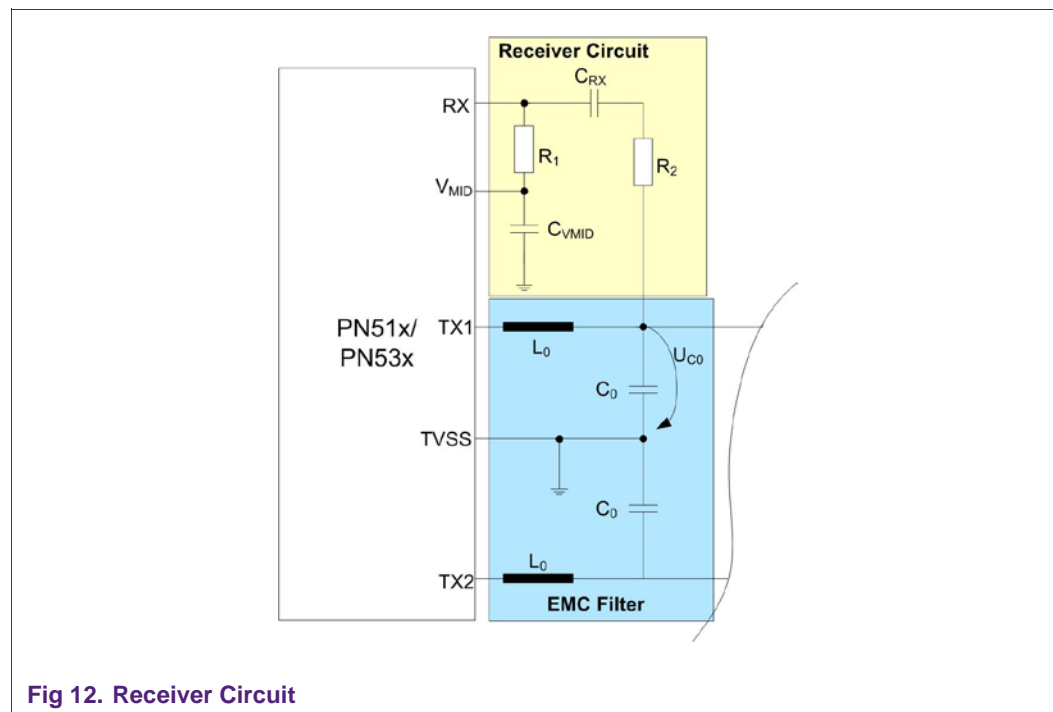


Fig 12. Receiver Circuit

### 4.6.1 Initiator mode

#### Step 1:

Predefined components:

$C_{RX} = 1 \text{ nF}$ : DC blocking capacitor

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

$R_1 = 1 \text{ k}\Omega$ : 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 ( $< 2 \text{ pF}$ ). Typically low capacitance probes are terminated with  $50 \text{ Ohm}$ , thus the scope configuration has to be set correctly!

#### Step 3:

The voltage divider resistor  $R_2$  can be calculated by:

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

with the target value of  $U_{RX} = 1 \text{ V}_{pp}$  (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 ( $< 2 \text{ pF}$ ) 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  $H \leq 7.5 \text{ A/m}$

If the voltage level on RX gets higher than the maximum value for field strength below  $7.5 \text{ A/m}$ , 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  $I_{TVDD} \approx 50 \text{ mA}$ .

Recommended  $R_{match} \approx 50 \text{ Ohm}$

The series equivalent circuit of the antenna results to:

$R_a = 1.9 \text{ Ohm}$

$C_a = 11 \text{ pF}$

$L_a = 2.9 \text{ } \mu\text{H}$

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

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

$$R_{pa} = 7148 \text{ Ohm}$$

$$C_{pa} = 11 \text{ pF}$$

$$L_{pa} = 2.9 \text{ }\mu\text{H}$$

The EMC filter is determined with:

$$L_0 = 560 \text{ nH}$$

$$C_0 = 220 \text{ pF}$$

Calculation of  $Z_{tr}$ :

$$R_{tr} = 217 \text{ Ohm}$$

$$X_{tr} = -58 \text{ Ohm}$$

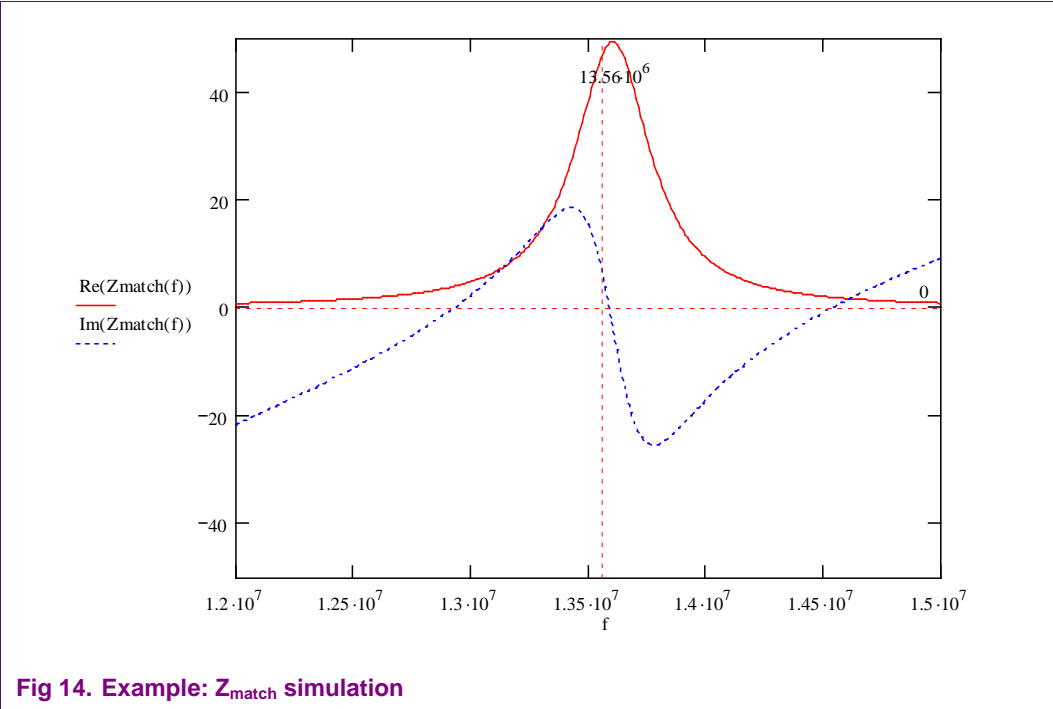
**Calculation of the matching parts  $C_1$ ,  $C_2$ :**

$$C_1 = 19.8 \text{ pF} \rightarrow 18 \text{ pF}$$

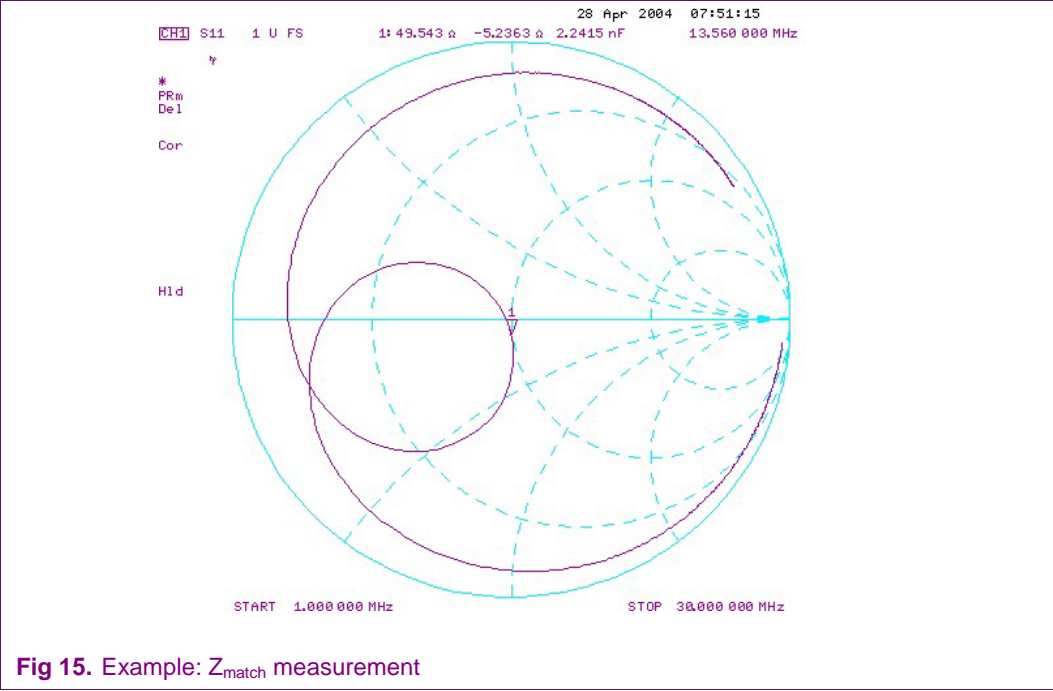
$$C_2 = 54.1 \text{ pF} \rightarrow 56 \text{ pF}$$

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

Simulation result:



Measurement result:

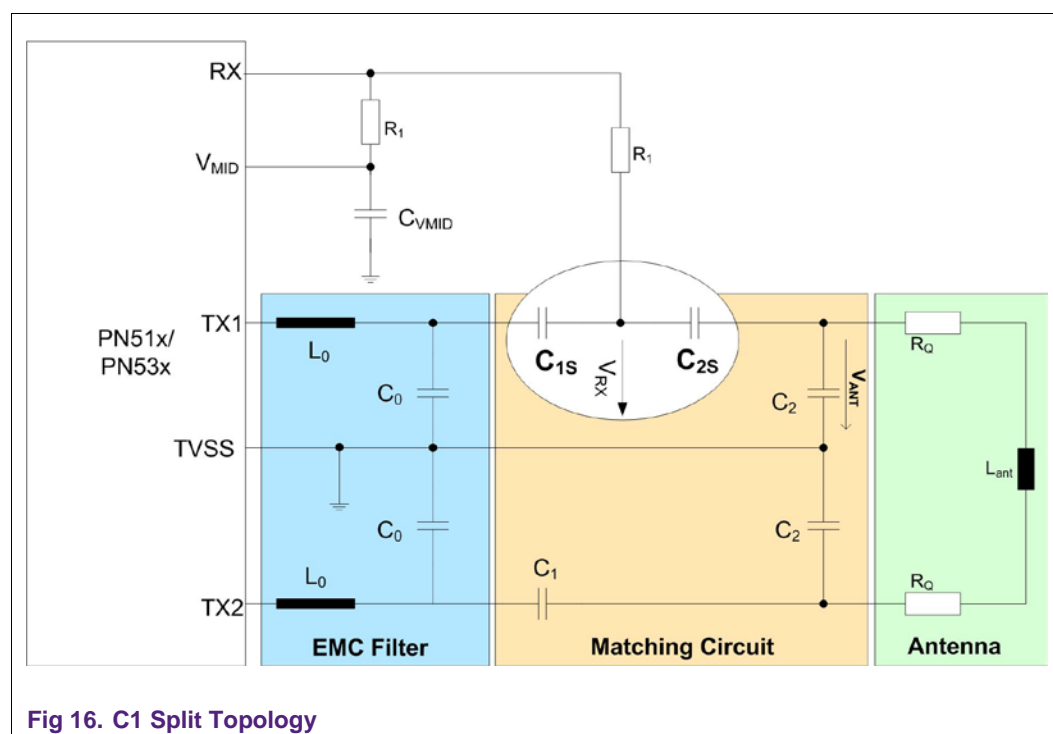


## 5. Antenna Topology II

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 shown 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  $C_1$  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  $C_1$ .



**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.

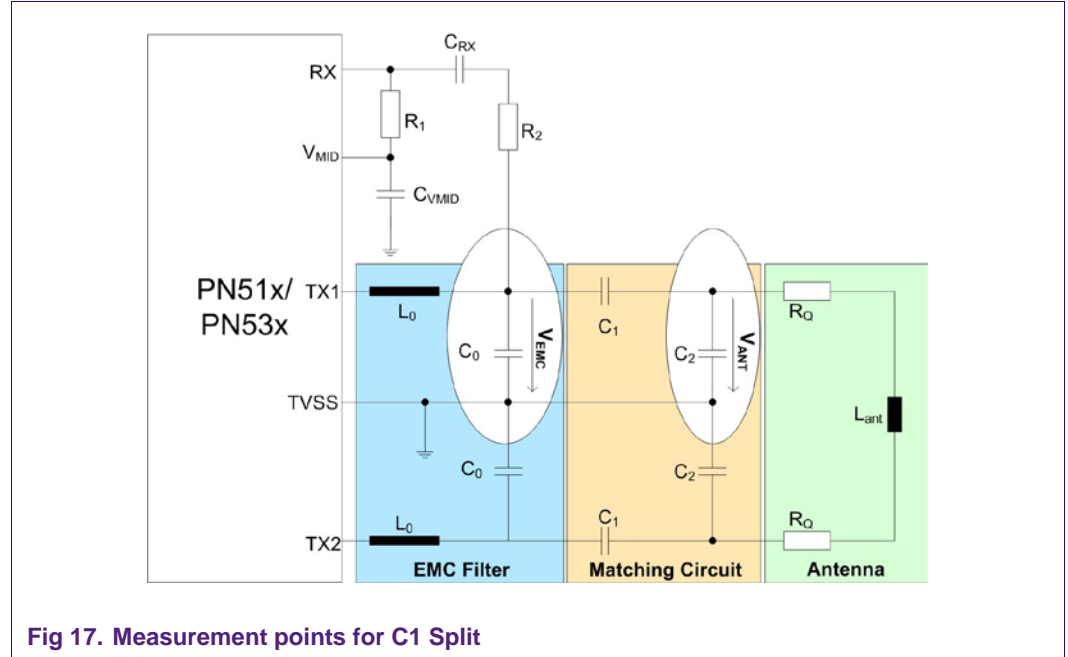


Fig 17. Measurement points for C1 Split

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.

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

with

$V_{ANT}$  ... Voltage at antenna **without** target

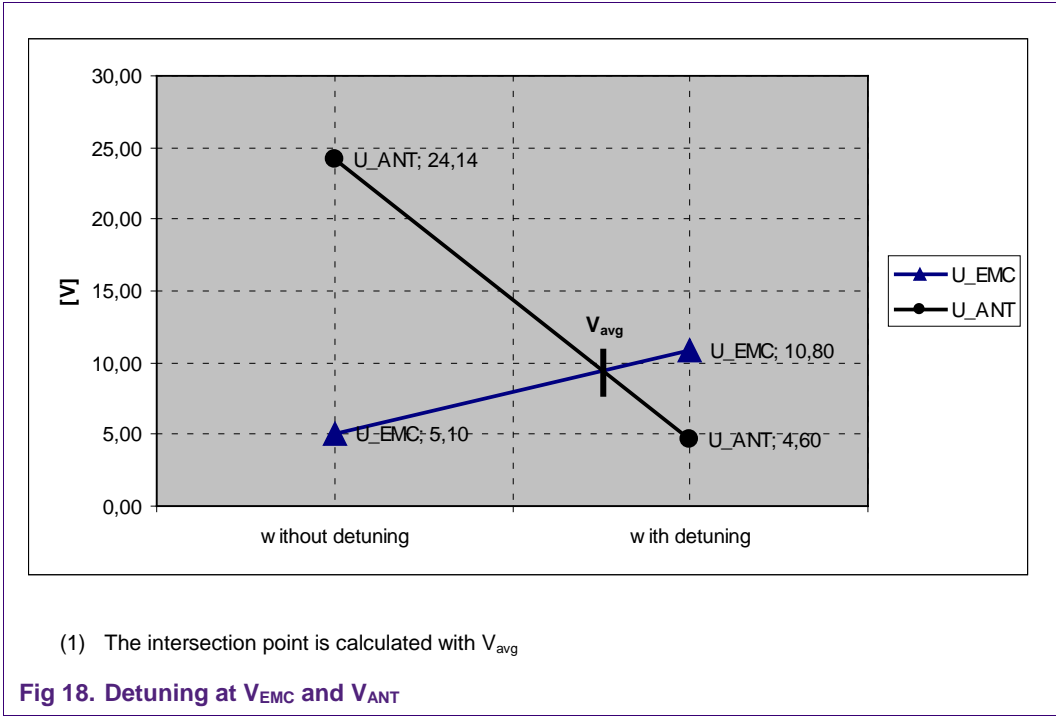
$V_{ANT\_D}$  ... Voltage at antenna **with** target

$V_{EMC}$  ... 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:

$$S_{C1} = \frac{V_{avg} - V_{EMC}}{V_{ANT} - V_{EMC}} \quad S_{C1} \dots \text{Percentage Separation of } C1 \quad (13)$$



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

$$C_{1S} = \frac{C1}{S_{C1}} \tag{14}$$

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

$$C_{2S} = \frac{C1}{1 - S_{C1}} \tag{15}$$

**Table 1. Example of C1-Split**

| Measurements                      | Values   |
|-----------------------------------|----------|
| U <sub>EMC</sub> without detuning | 5,10 V   |
| U <sub>EMC</sub> with detuning    | 10,80 V  |
| U <sub>ANT</sub> without detuning | 24,14 V  |
| U <sub>ANT</sub> with detuning    | 4,60 V   |
| V <sub>avg</sub>                  | 9,39 V   |
| Percentage seperation of C1       | 22,58 %  |
| C <sub>1S</sub>                   | 79,71 pF |
| C <sub>2S</sub>                   | 23,25 pF |



Now choose appropriate values for  $C_{1S}$  and  $C_{2S}$ , such that the back transformation to a series capacitance gives  $C_1$  again. Thus, always check if

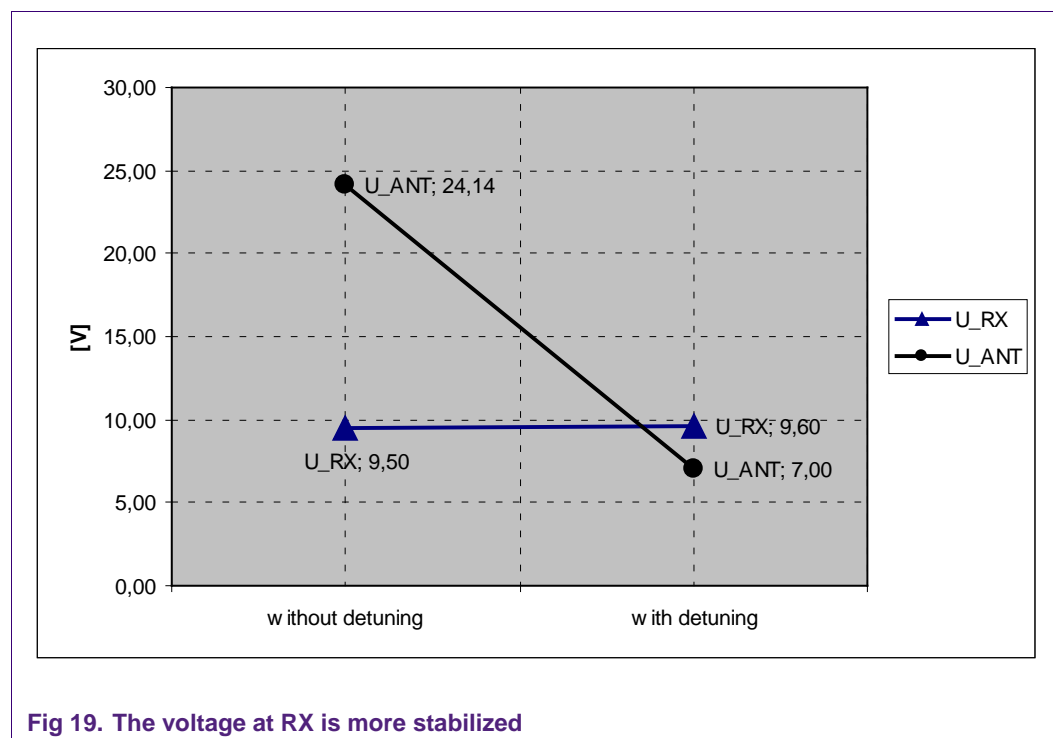
$$C_1 \cong \frac{C_{1S} \cdot C_{2S}}{C_{1S} + C_{2S}} \quad (16)$$

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  $C_1$ .

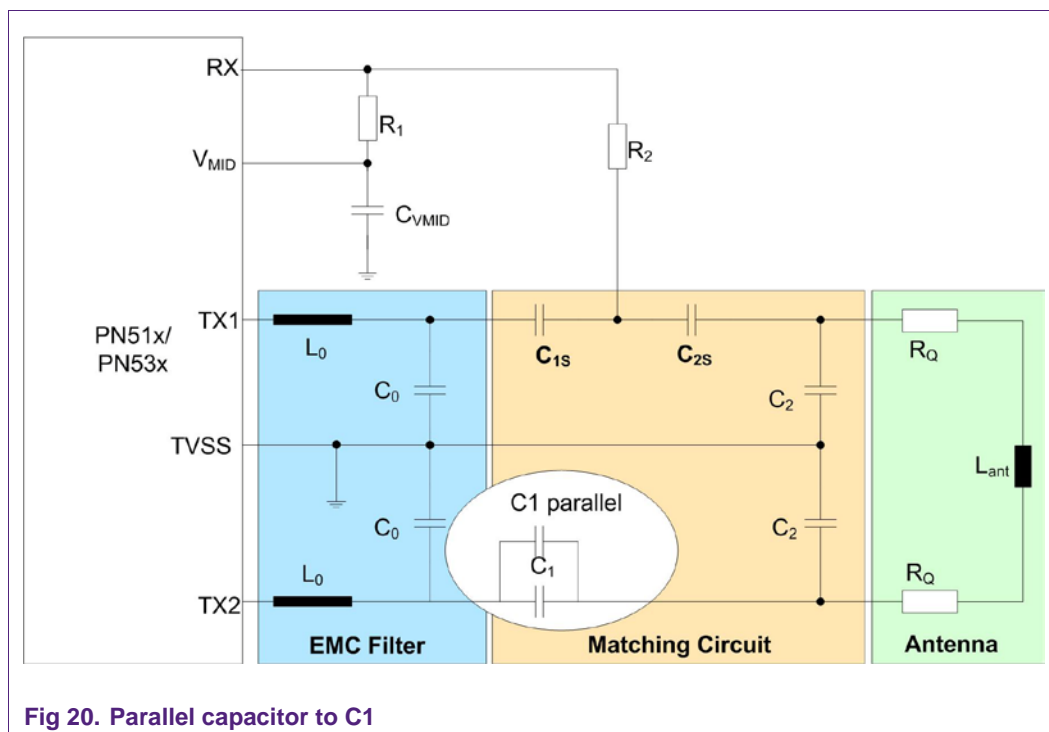
Note that the decoupling capacitor  $C_{RX}$  was removed in the  $C_1$ -split topology. See also Fig 17 on how to setup the  $C_1$ -split.

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  $C_1$  topology.



## 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.



## 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  $Z_{\text{match}}$  vs. frequency of Antenna Topology I or II

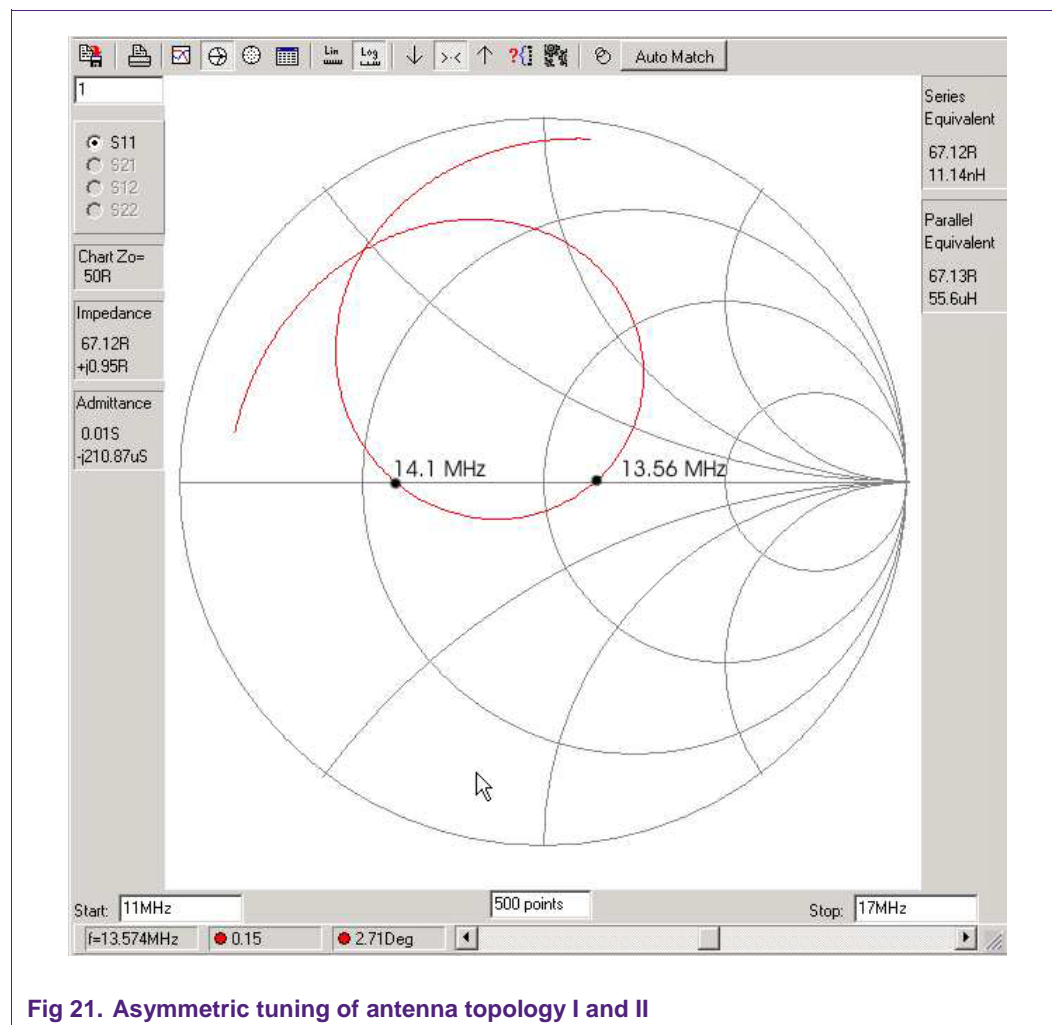


Fig 21. Asymmetric tuning of antenna topology I and II

6.1 Tuning of series matching capacitance C<sub>1</sub>

The smith charts in Fig 22 shows the tuning effect on the impedance curve by adjusting C<sub>1</sub>.

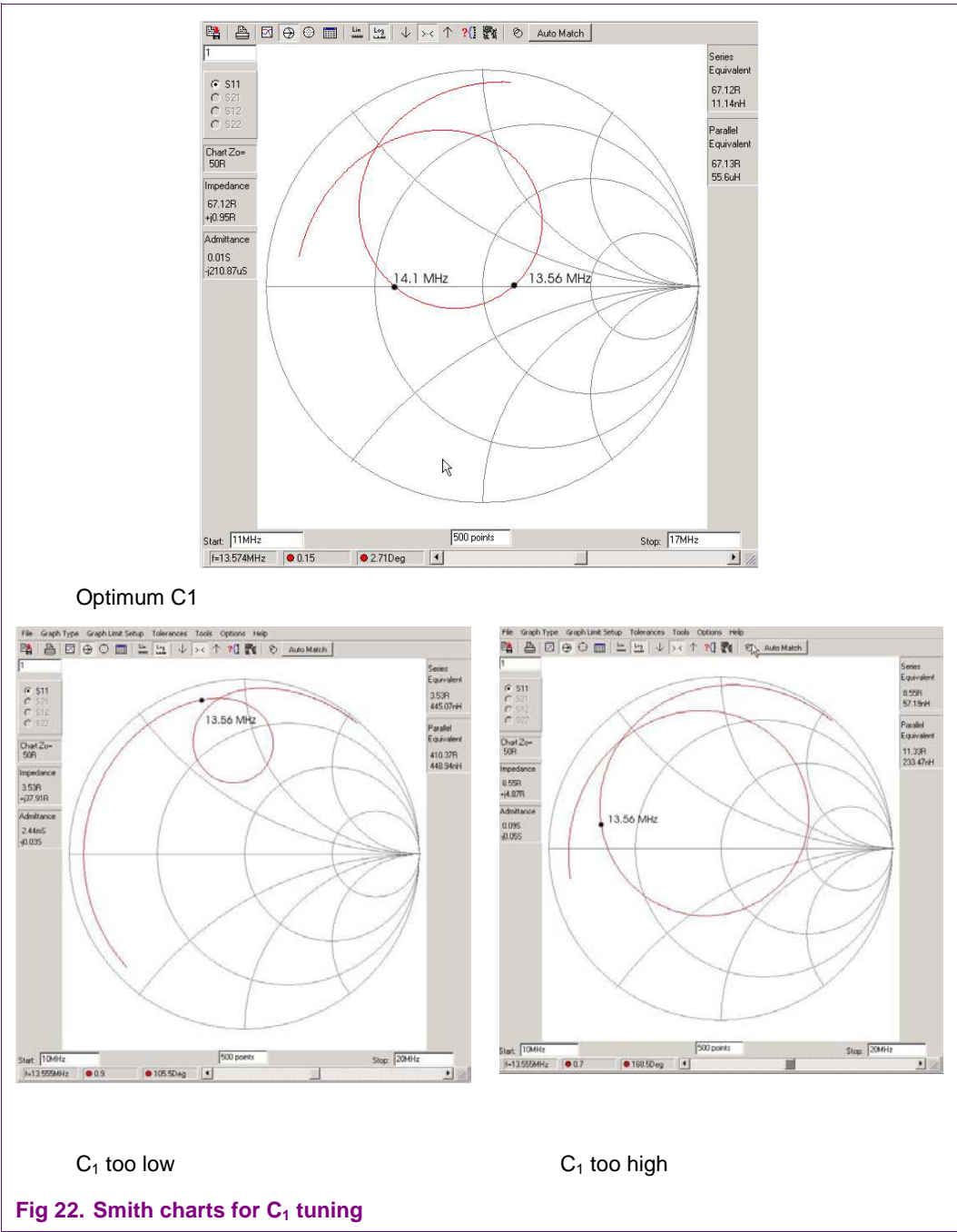
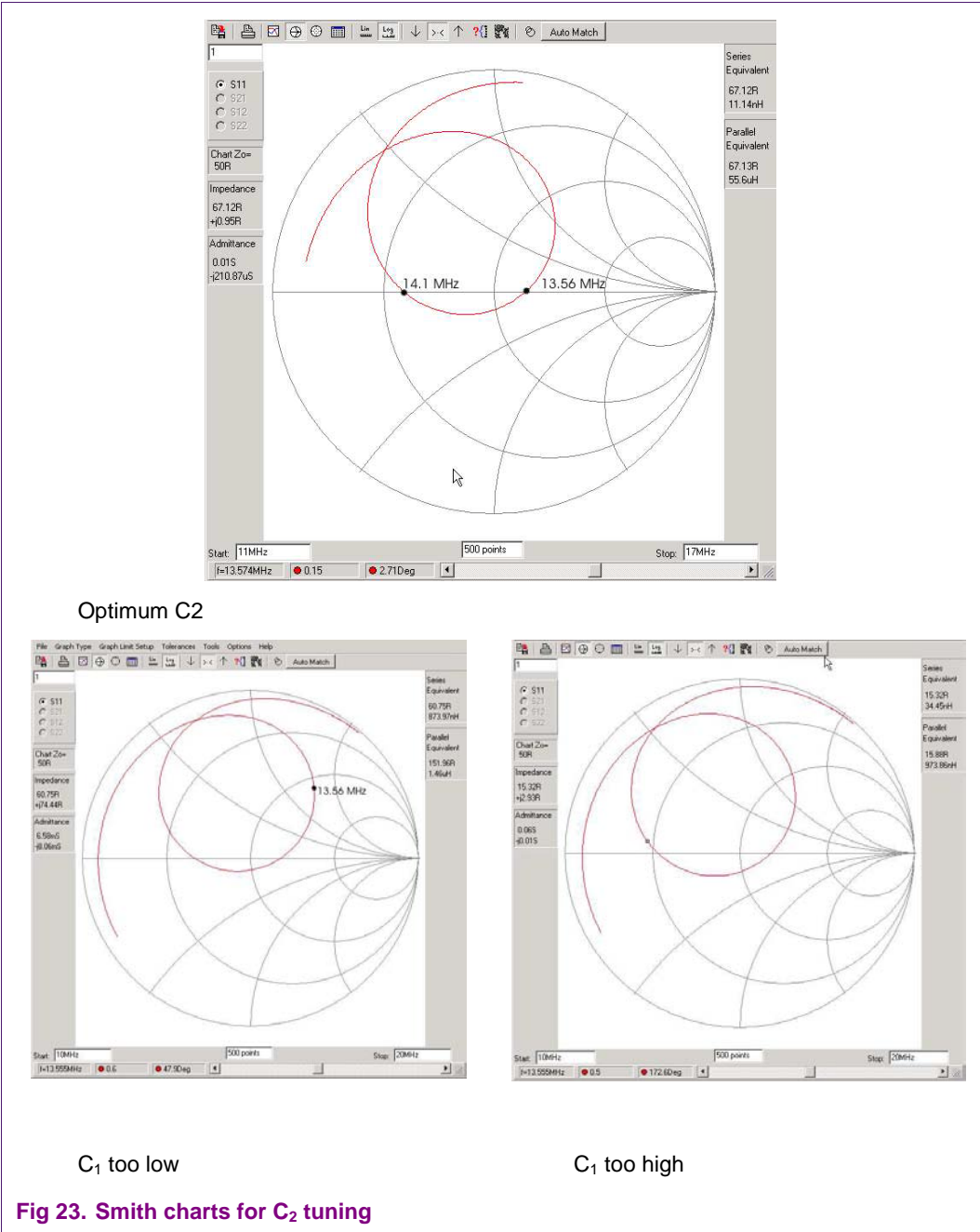


Fig 22. Smith charts for C<sub>1</sub> tuning

6.2 Tuning of parallel matching capacitance C<sub>2</sub>

The smith charts in Fig 23 shows the tuning effect on the impedance curve by adjusting C<sub>2</sub>.



## 7. Antenna Topology III

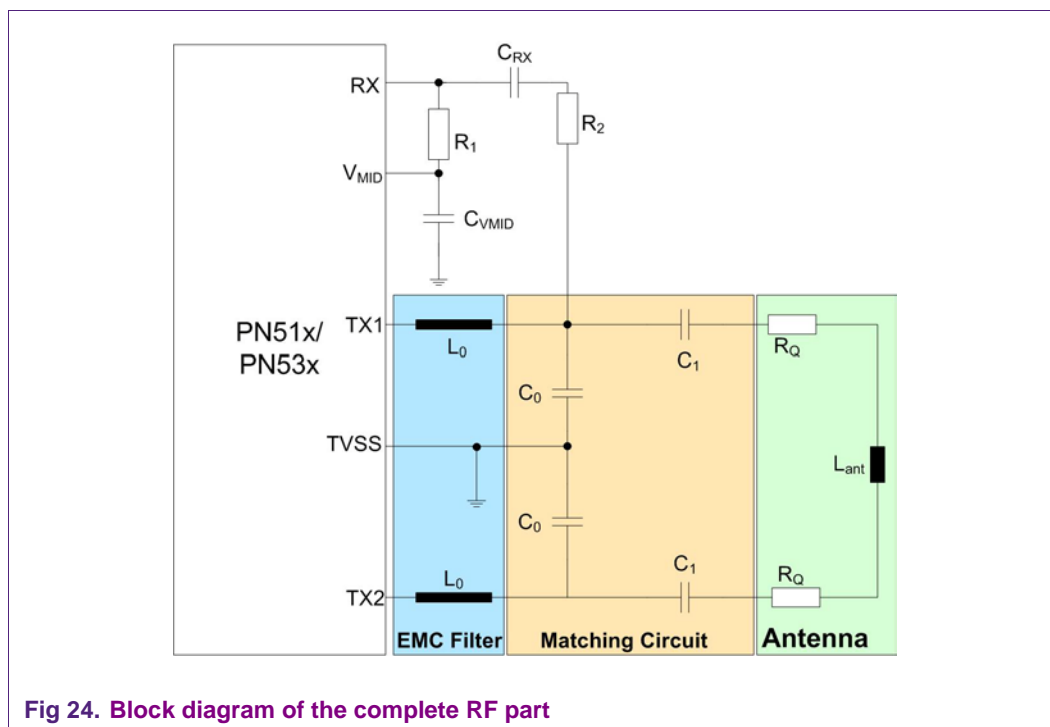


Fig 24. Block diagram of the complete RF part

**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 these 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 ( $< \pm 2\%$ ). NP0 dielectric is required for temperature stability reasons. The voltage limits has to be considered as well.          |
| $C_{vmid}, C_{RX}$ | X7R capacitor ( $< \pm 10\%$ )   |
| $L_0$              | 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  $\Omega$  the power consumption becomes lower. The real and imaginary part of  $Z_{\text{match}}$  change from symmetric to asymmetric around the operating frequency. The asymmetric impedance anticipates the detuning effect such that the magnitude of  $Z_{\text{match}}$  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.

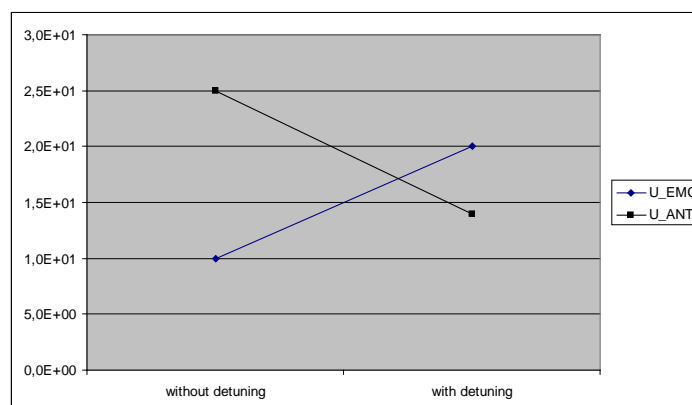


Fig 25. Detuning effects of old antenna topology

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 $R_{\text{match}}$

The transmitter (TX) matching resistance  $R_{\text{match}}$  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  $R_{\text{match}}$ . The setup measures the available RF power  $P_{\text{ant}}$  and the TX supply current  $I_{\text{TVDD}}$  at different matching resistance values.

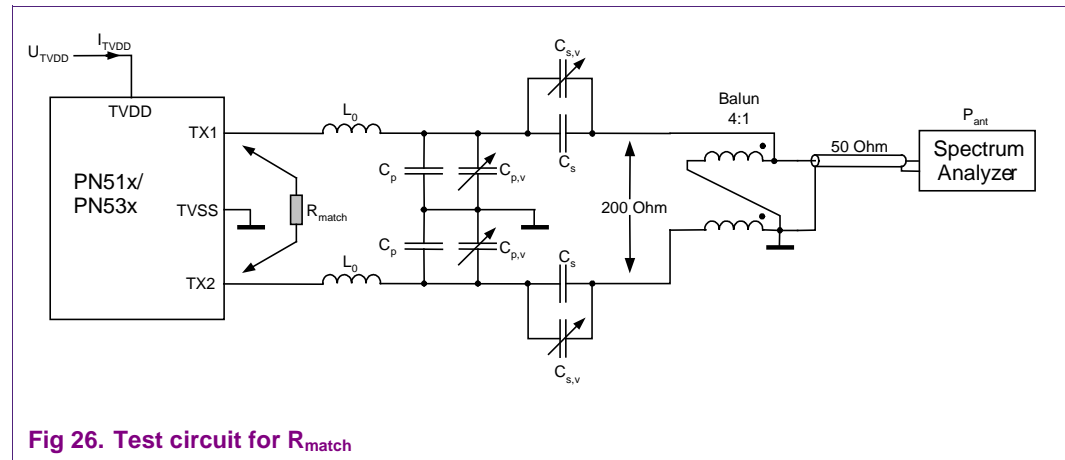


Fig 26. Test circuit for  $R_{\text{match}}$

### 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  $U_{\text{TVDD}}$ . An increase in  $R_{\text{match}}$  results in a lower current flow from TX and thus leads to a lower magnetical field generated by the antenna.

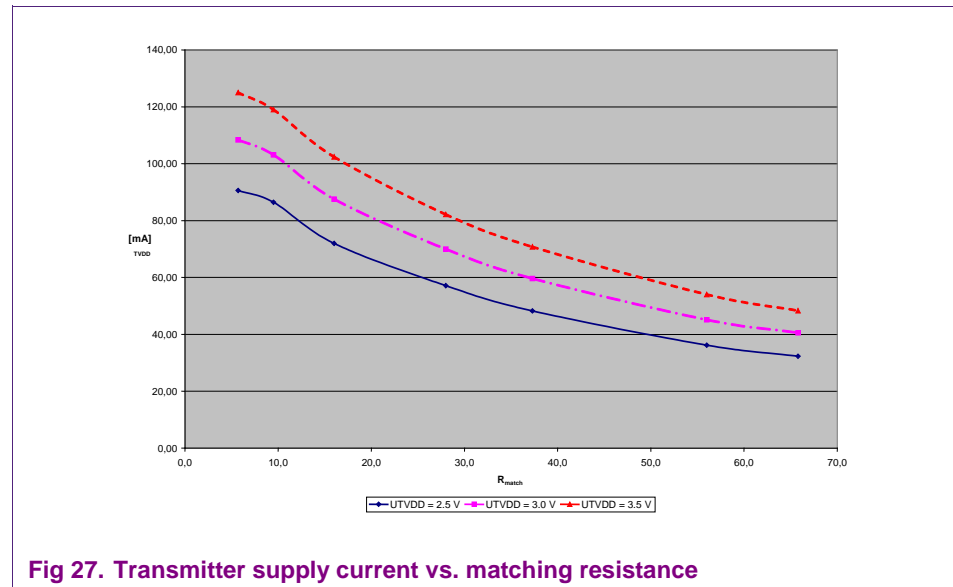
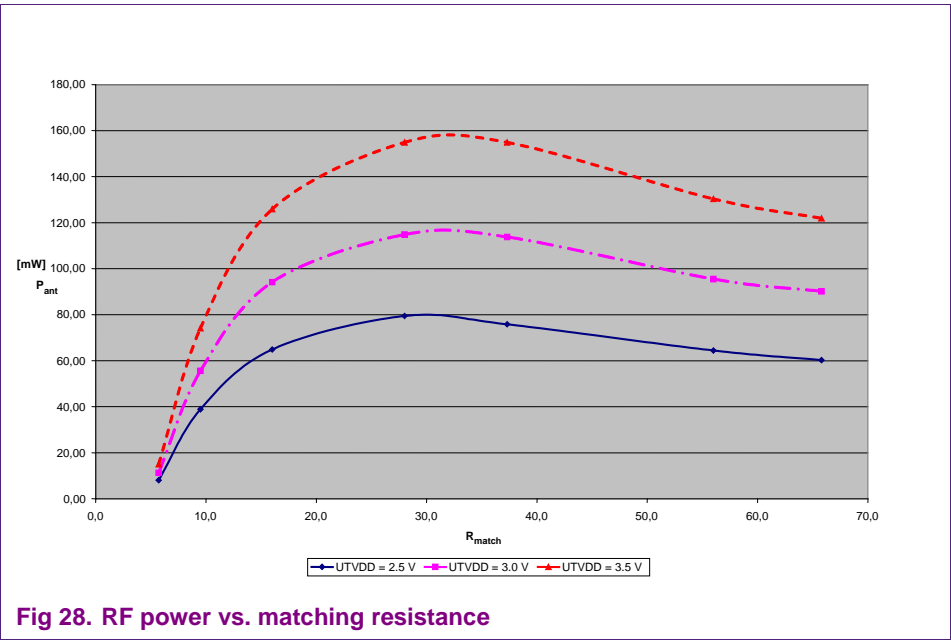


Fig 27. Transmitter supply current vs. matching resistance

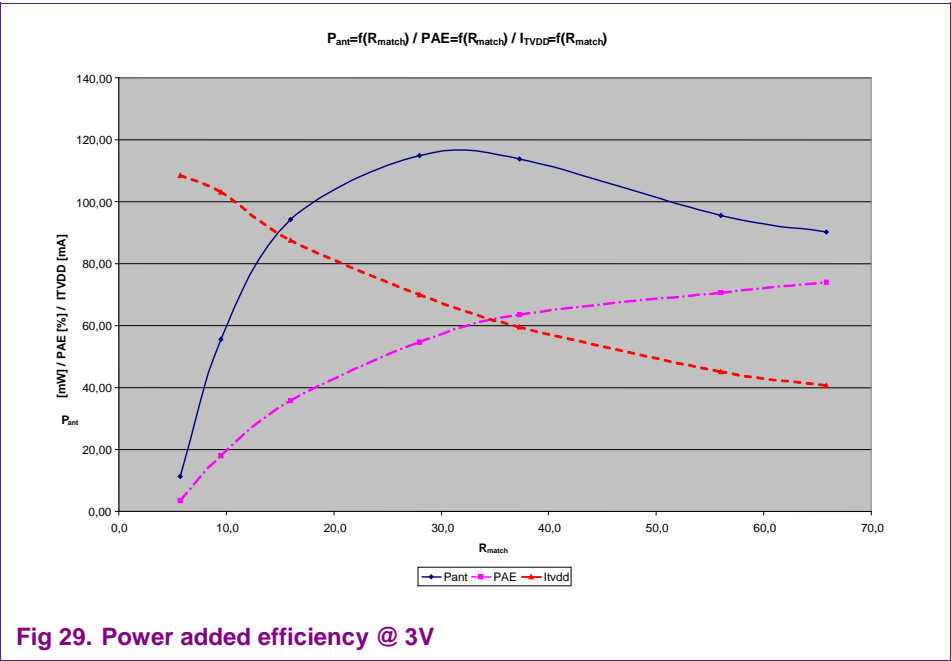
### RF power vs. matching resistance

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



Power added efficiency @ 3V

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



## 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  $R_{\text{match}}$  between 60 and 80 Ohm. The example matching circuit in chapter 7.7 has been tuned to 73 Ohm.

**Optimal  $R_{\text{match}} = 60 - 80 \text{ Ohm}$**

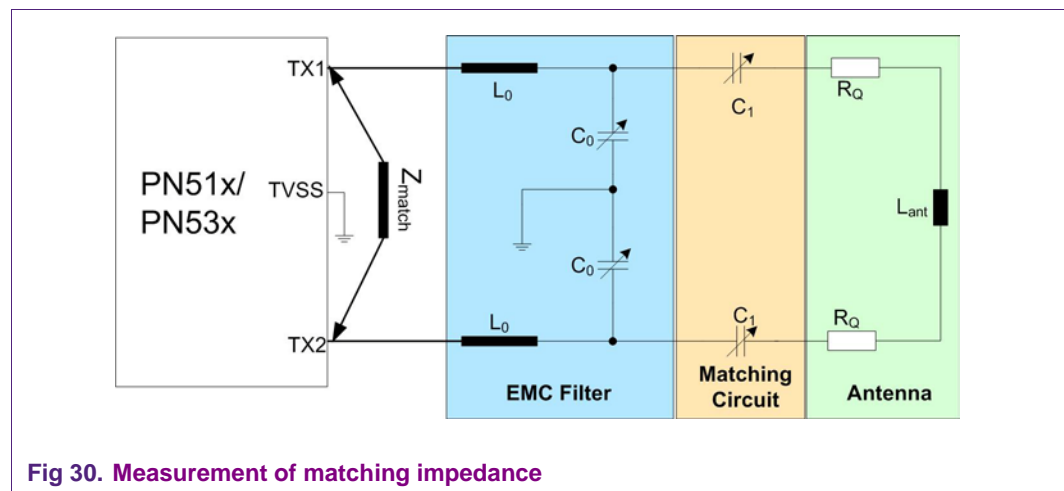
## 7.3 Matching circuit design

### 7.3.1 Calculation of matching components

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

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

**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).



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  $Z_{\text{match}}$  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  $Z_{\text{ant}}$ .

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

$$\begin{aligned} \text{Re}(Z_{\text{ant}}) &= \frac{\frac{1}{R_p}}{\left(\frac{1}{R_p}\right)^2 + \left(\omega \cdot C_A - \frac{1}{\omega \cdot L_A}\right)^2} \\ \text{Im}(Z_{\text{ant}}) &= \frac{\frac{1}{\omega \cdot L_A} - \omega \cdot C_A}{\left(\frac{1}{R_p}\right)^2 + \left(\omega \cdot C_A - \frac{1}{\omega \cdot L_A}\right)^2} \end{aligned} \quad (18)$$

In order to solve the two unknown variables  $C_0$  and  $C_1$  in equation (17), the real part of the impedance network  $Z_{\text{match}}$  is set to the matching resistance  $R_{\text{match}} = 73$  Ohm and the imaginary part of  $Z_{\text{match}}$  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.

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

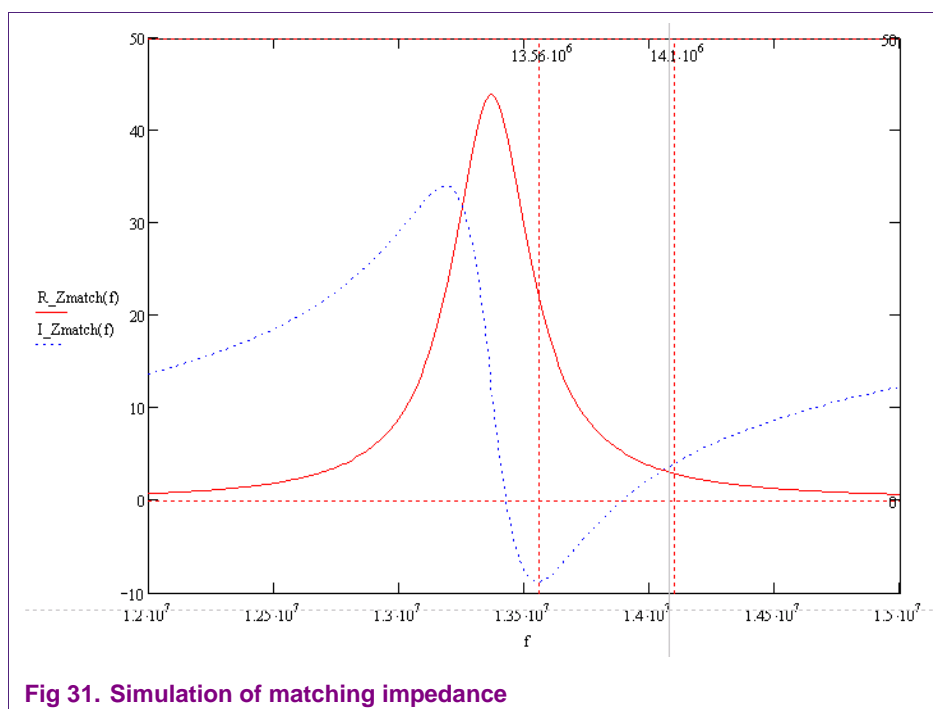
$$C_1 = \frac{1}{\omega \cdot \text{Im}(Z_{\text{ant}}) \pm \omega \cdot \sqrt{73 \cdot \text{Re}(Z_{\text{ant}}) + \frac{\text{Re}(Z_{\text{ant}}) \cdot (\omega \cdot L_0)^2}{73} - \text{Re}(Z_{\text{ant}})^2}} \quad (20)$$

**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  $R_{\text{match}}$  ( $X_{\text{match}} = 0$ ) at the PN51x/PN53x TX pins. The matching impedance  $Z_{\text{match}} = R_{\text{match}} + jX_{\text{match}}$  is measured with an impedance analyzer or network analyzer.

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



**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.

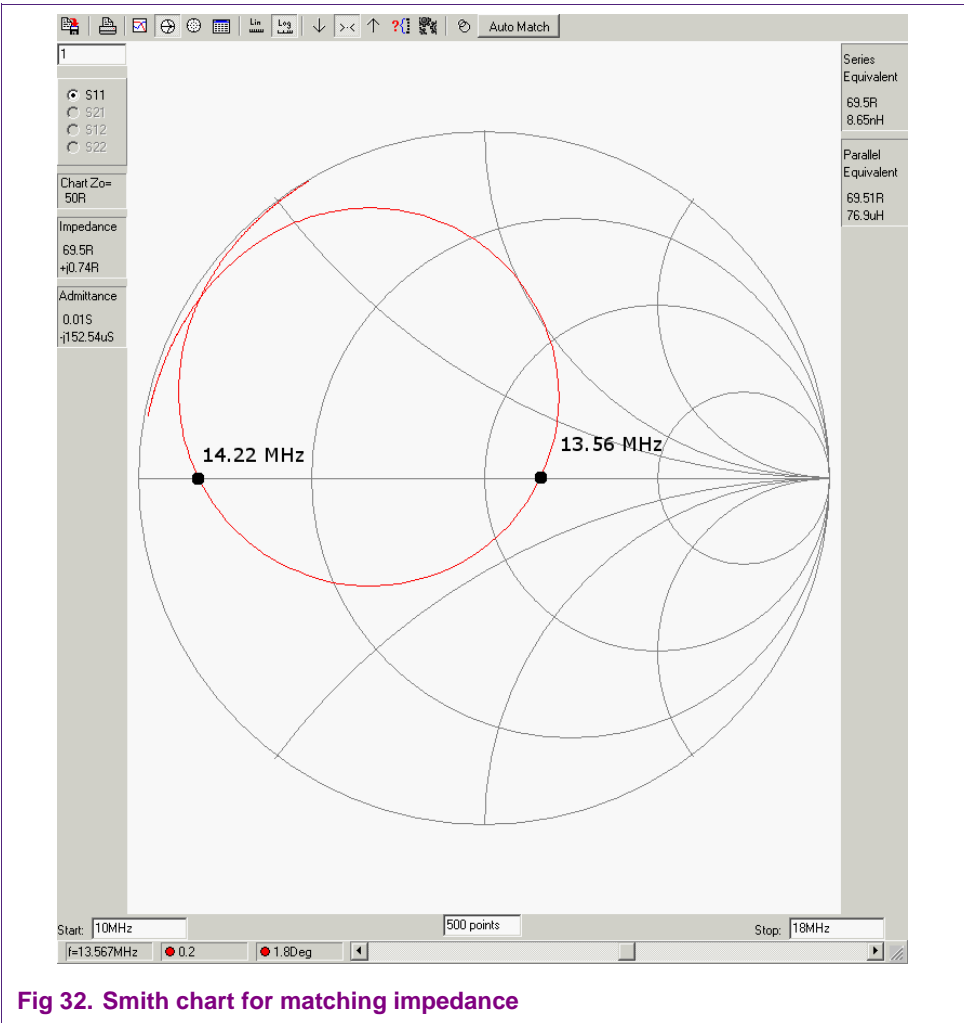
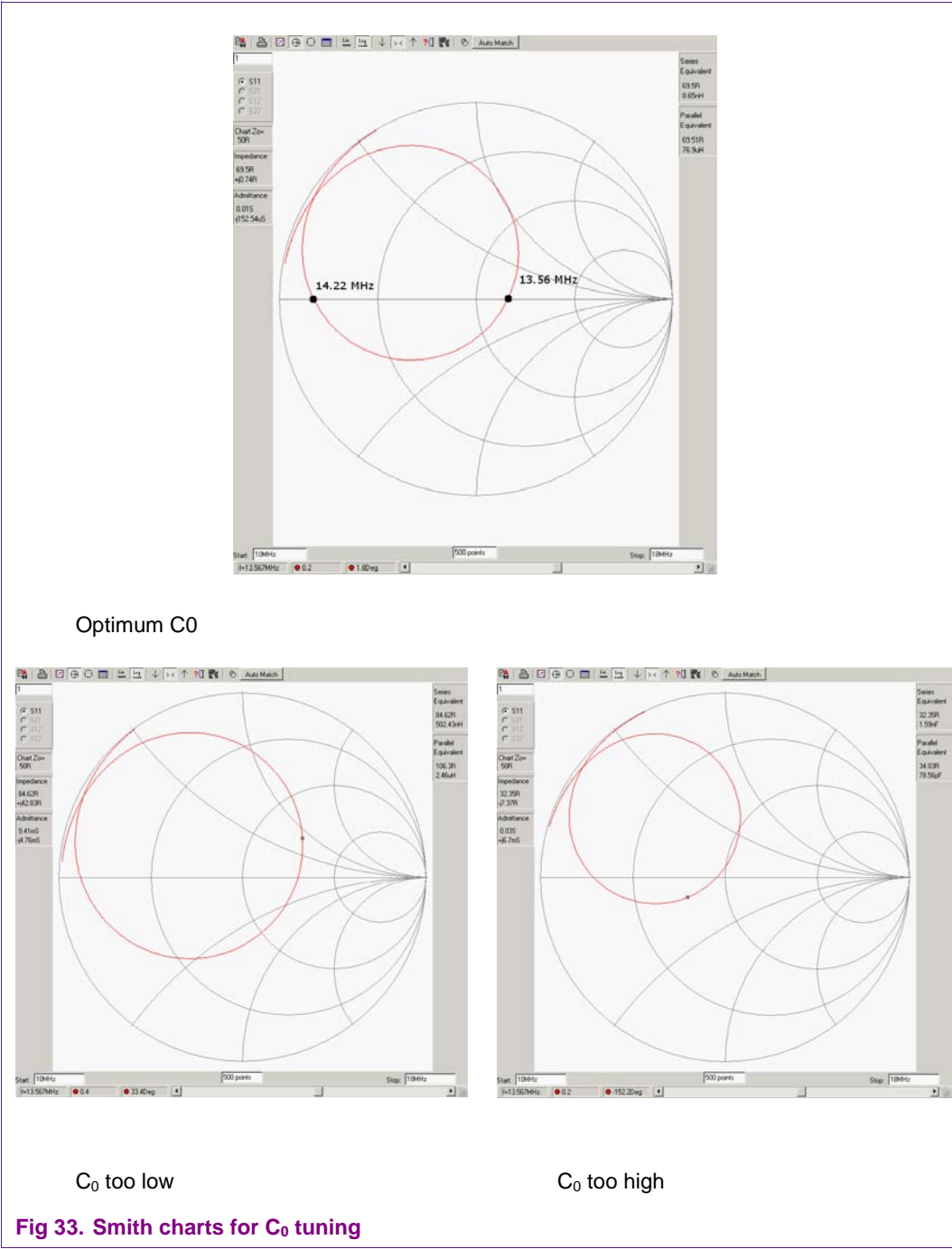


Fig 32. Smith chart for matching impedance

7.4.1 Tuning of EMC matching capacitance  $C_0$

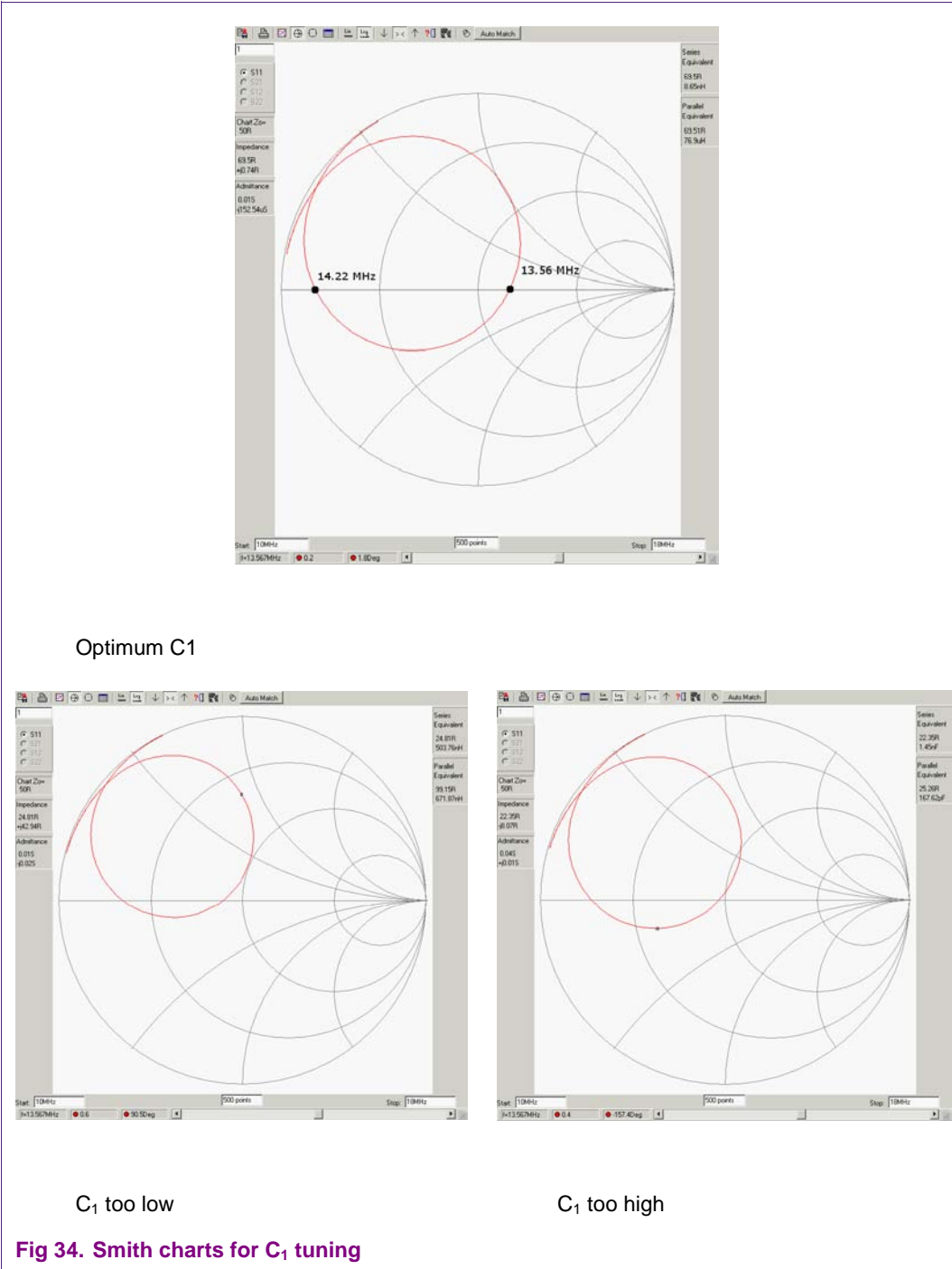
The smith charts in Fig 33 show the matching impedance  $Z_{\text{match}}$  vs. frequency.



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

7.4.2 Tuning of series matching capacitance  $C_1$

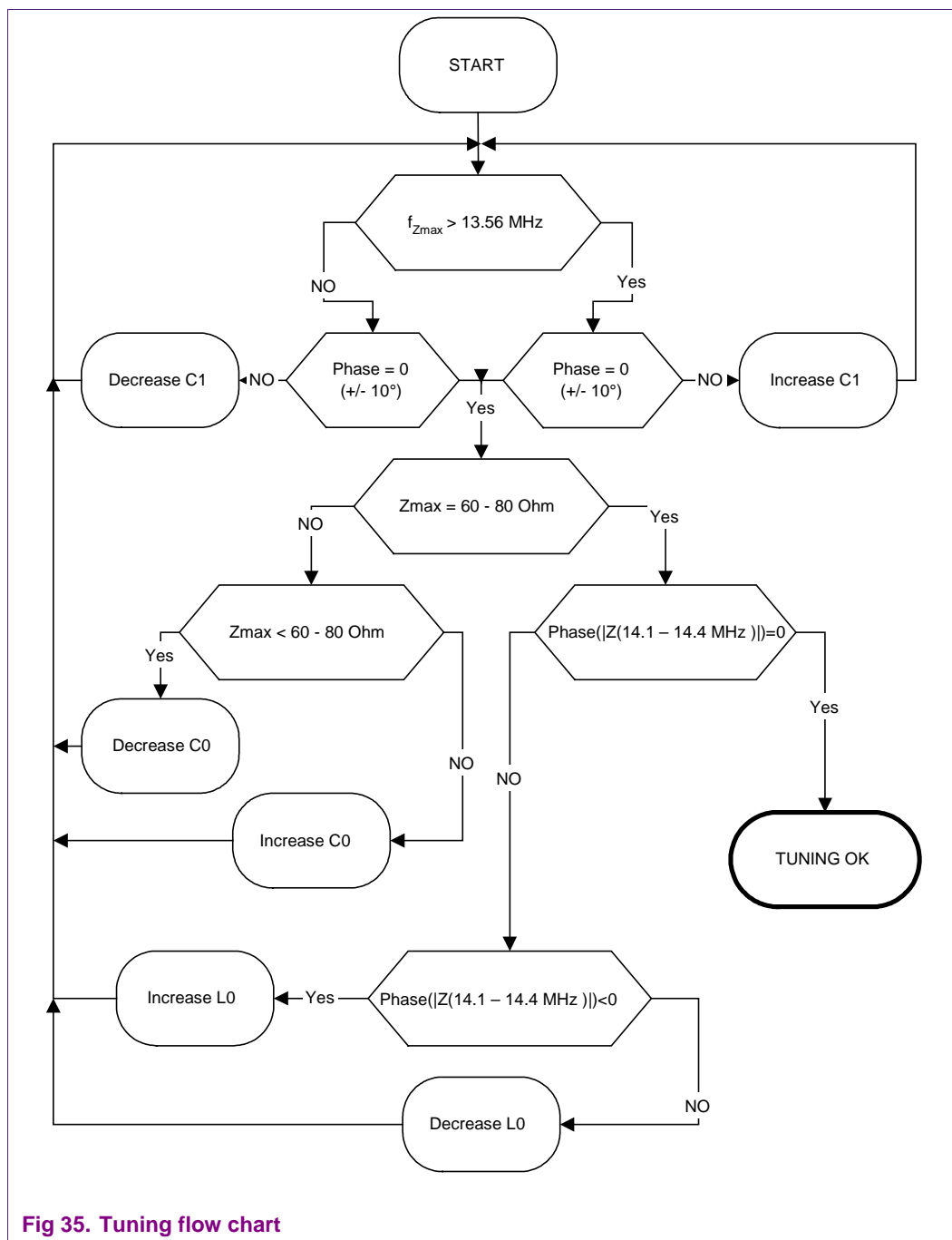
The smith charts in Fig 34 show the matching impedance  $Z_{match}$  2 vs. frequency.



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



## 7.4.3 Tuning flow chart



**Note:** The initial value of  $L_0$  has been set to 0.33  $\mu\text{H}$ .

## 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.

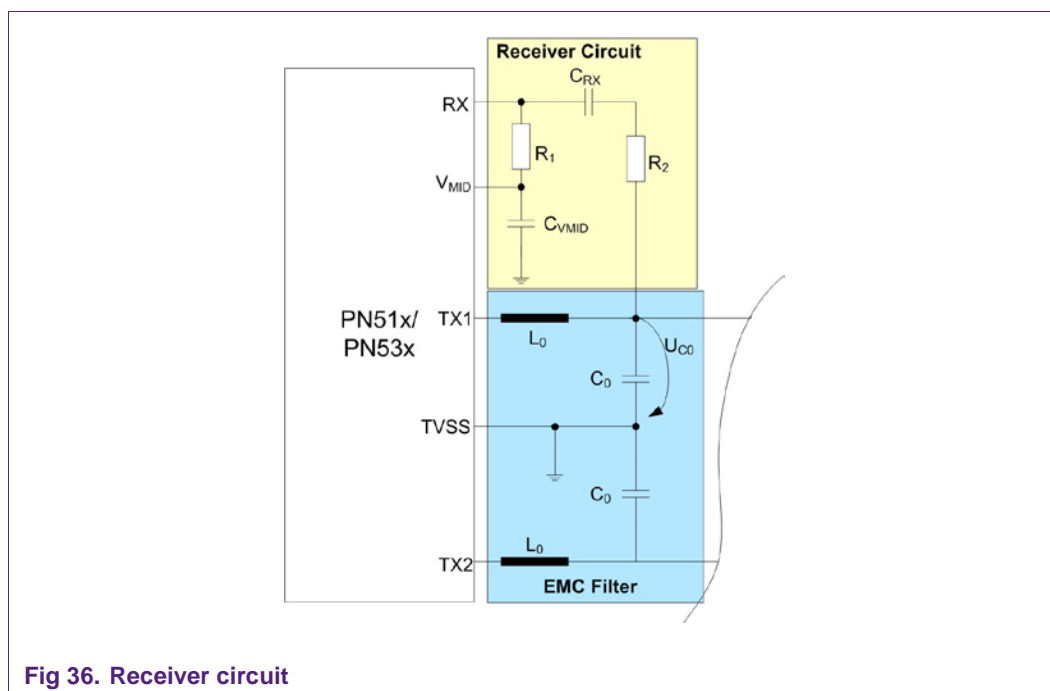


Fig 36. Receiver circuit

### 7.5.1 Initiator mode

#### Step 1:

Predefined components:

$C_{RX} = 1 \text{ nF}$ : DC blocking capacitor

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

$R1 = 1 \text{ k}\Omega$ : 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 ( $< 2 \text{ pF}$ ).

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  $U_{RX} = 1 \text{ V}_{pp}$  (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 ( $< 2 \text{ pF}$ ) 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  $U_{RXmax}$ .

$$U_{RX} < U_{RXmax} \text{ for } H \leq 7.5 \text{ A/m}$$

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).

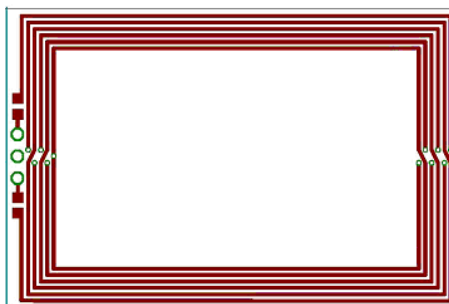


Fig 37. MFRC52x/PN51x/PN53x evaluation board antenna

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

$$R_{\text{match}} \approx 70 \text{ Ohm}$$

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

$$R_a = 1.1 \text{ Ohm}$$

$$C_a = 9.8 \text{ pF}$$

$$L_a = 3.1 \text{ }\mu\text{H}$$

The calculation for the external damping resistor results to  $R_Q = 3.668 \text{ Ohm}$ . 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  $R_Q = 3.3 \text{ Ohm}$  - is determined with the following values:

$$R_{\text{pa}} = 9650 \text{ Ohm}$$

$$C_{\text{pa}} = 9.7 \text{ pF}$$

$$L_{\text{pa}} = 3.3 \text{ }\mu\text{H}$$

The EMC coil  $L_0$  is chosen with an initial value of 0.33  $\mu\text{H}$ .

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

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

$$\text{Re}(Z_{\text{ant}}) = 6.977 \text{ }\Omega$$

$$\text{Im}(Z_{\text{ant}}) = 183.387 \text{ j}\Omega$$

The series capacitance  $C_1$  calculates from the solution from the quadratic equation (19) and (20) of the EMC capacitance  $C_0$ .

$$C_{1\_1} = 57.63 \text{ pF}$$

$$C_{1,2} = 71.95 \text{ pF}$$

The EMC capacitances  $C_{0,1}$  and  $C_{0,2}$  are determined for the values of  $C_{1,1}$  and  $C_{1,2}$ :

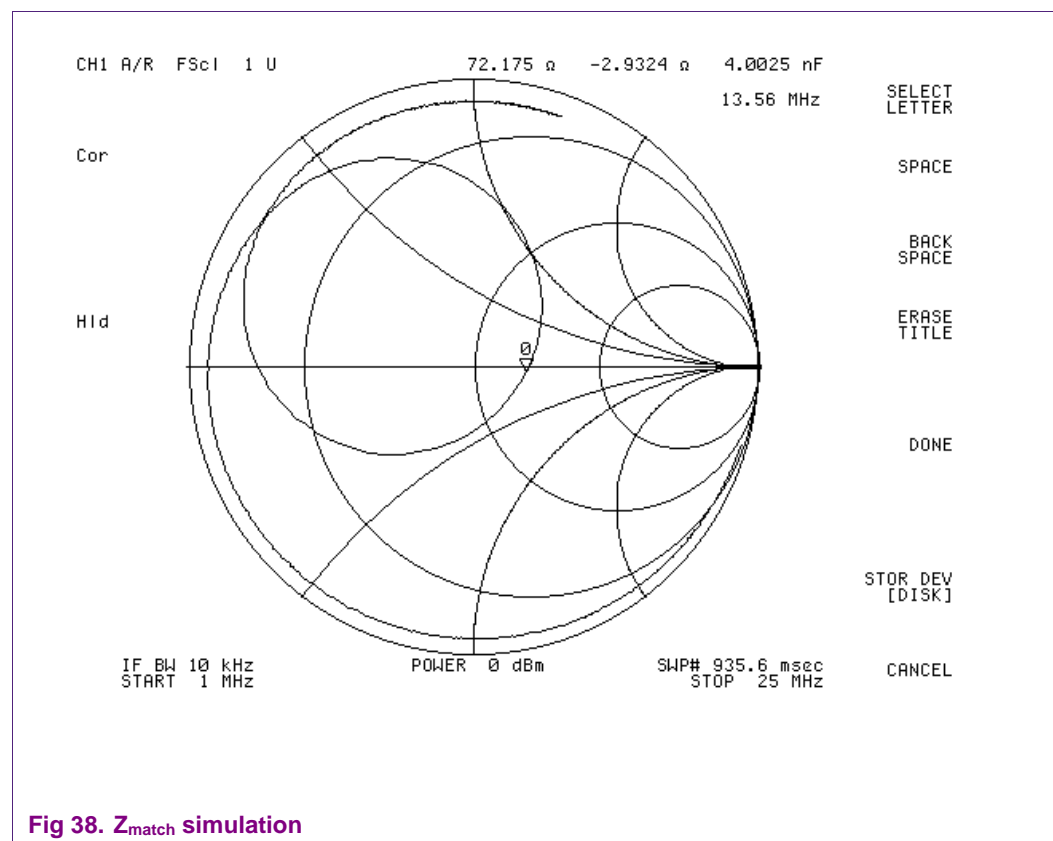
$$C_{0,1} = -417.62 \text{ pF}$$

$$C_{0,2} = 618.20 \text{ pF}$$

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.



## 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.

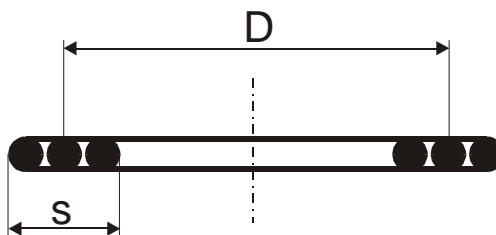


Fig 39. Circular antenna

The inductance can be estimated using the following formula:

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

D Average antenna diameter

s Antenna width

N<sub>a</sub> Number of turns

### 8.1.3 Rectangular antennas

Fig 40 shows a typical rectangular antenna.

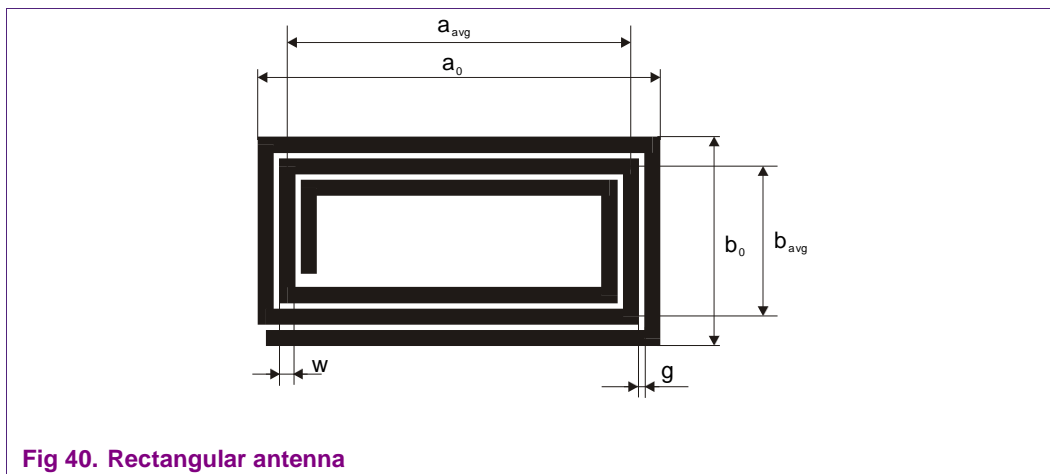


Fig 40. Rectangular antenna

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:

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

With:

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

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

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

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

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

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

### 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. 2<sup>nd</sup> NFC device, Card, Reader) to the 1<sup>st</sup> device. This also means that the detuning effect on the 1<sup>st</sup> 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

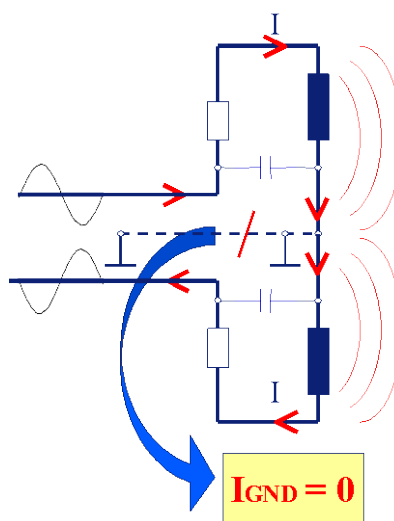


Fig 41. Ground current compensation

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.

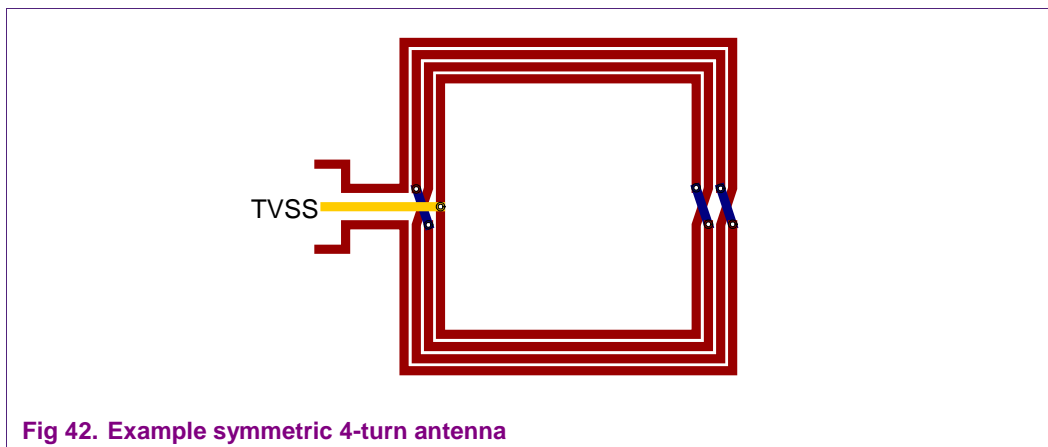


Fig 42. Example symmetric 4-turn antenna

### 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  $H_{\text{MIN}} = 1.5 \text{ A/m}$  defined by ISO/IEC 14443 is marked with dotted 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  $\mu_R < 10$ ).

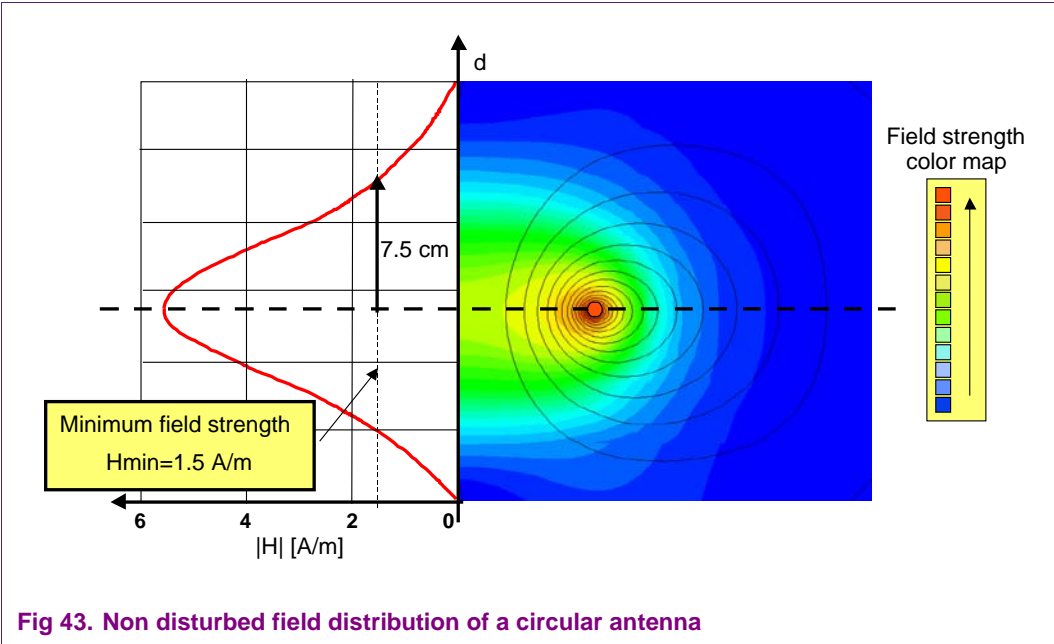


Fig 44 shows the field distribution of the defined antenna but a metal plane near to the antenna. The magnitude of the field strength has decreased compared to the disturbed field which leads to a decreased operating distance.

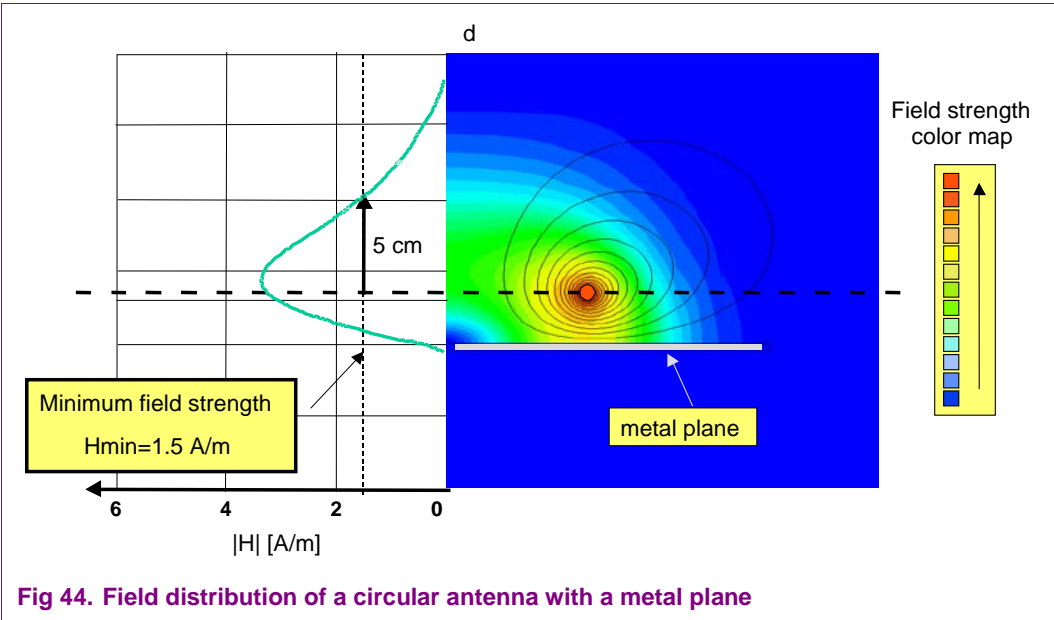


Fig 45 shows a ferrite plane ( $\mu_R=40$ ) which is positioned between the metal plane and the antenna coil itself. The field strength very near to the ferrite increases, but the increasing magnitude does not necessarily result in an increase of the operating distance at  $H_{MIN}$  value (vertical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

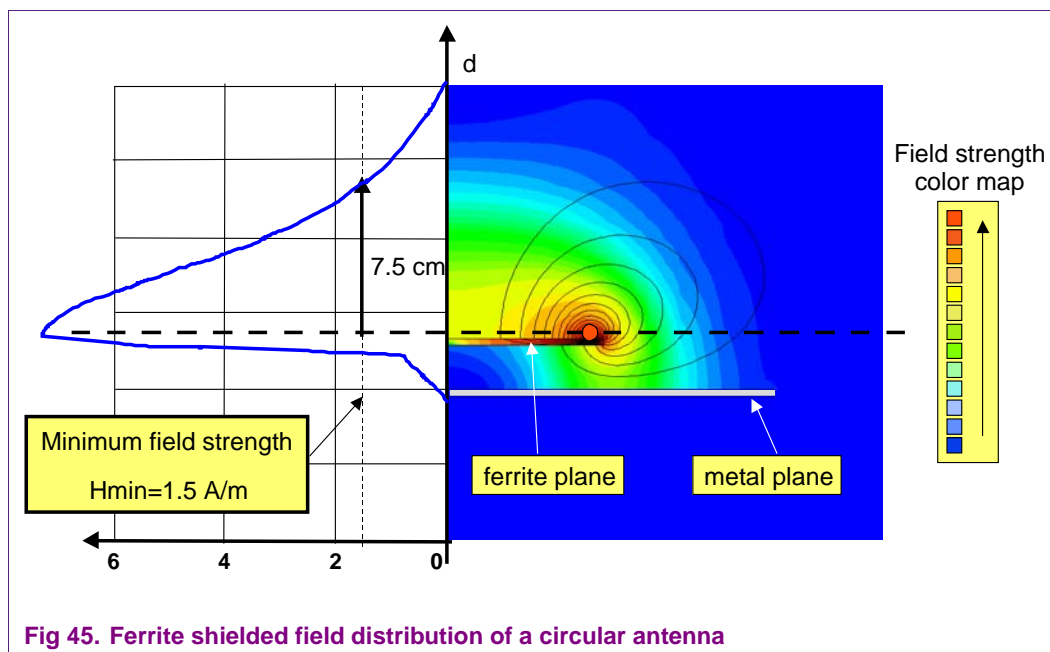


Fig 45. Ferrite shielded field distribution of a circular antenna

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 3 $\mu$ s (as defined in the ISO/IEC14443) for a modulation pause is taken to calculate the quality factor.

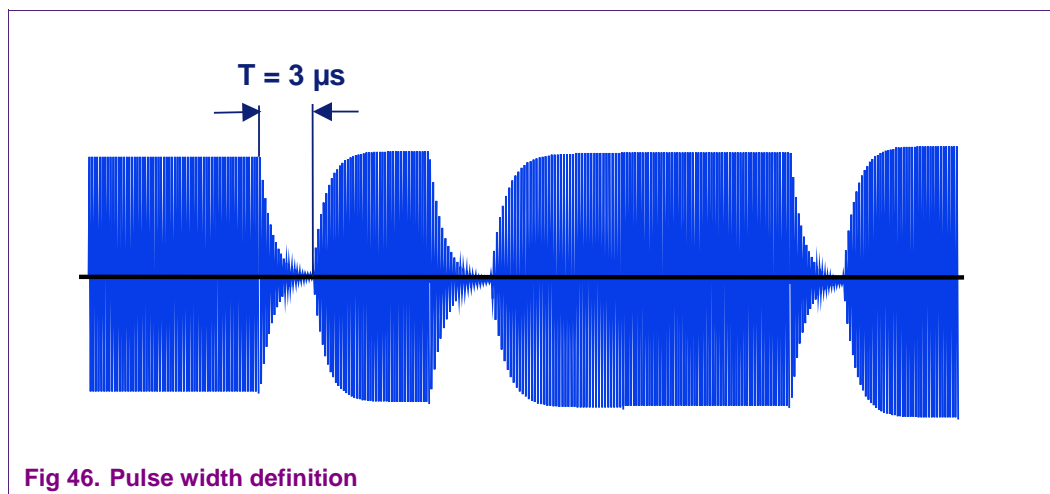


Fig 46. Pulse width definition

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

$$B \cdot T \geq 1 \quad (24)$$

With the bandwidth definition

$$B = \frac{f}{Q} \quad (25)$$

the B-T product results to

$$Q \leq f \cdot T$$

$$Q \leq 13.56 \text{ MHz} \cdot 3 \mu\text{s}$$

$$Q \leq 40.68$$

**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.

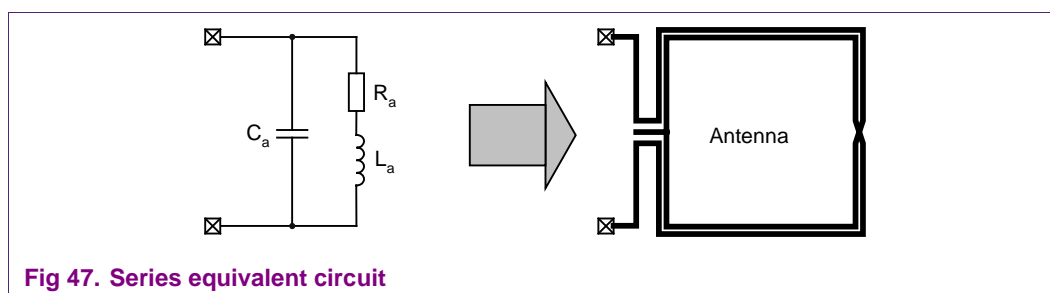


Fig 47. Series equivalent circuit

Typical values:

$$L_a = 0.3...3 \mu\text{H}$$

$$C_a = 3...30 \text{ pF}$$

$$R_a = 0.3...8 \Omega$$

### 8.2.2 Calculation of antenna quality factor damping resistor $R_Q$

The quality factor of the antenna is

$$Q_a = \frac{\omega \cdot L_a}{R_a} \quad (26)$$

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 ( $\pm 10\%$ )**.

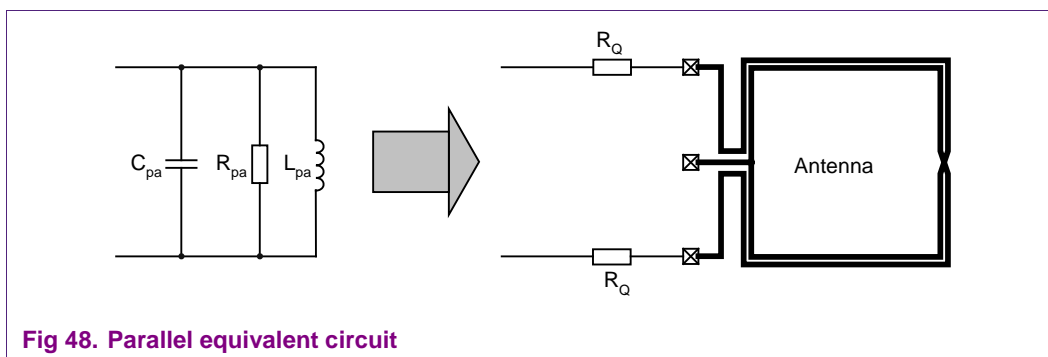
The value of  $R_Q$  calculates as:

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

### 8.2.3 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 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.



The following formula applies:

$$\begin{aligned}
 L_{pa} &\triangleq L_a \\
 C_{pa} &\triangleq C_a \\
 R_{pa} &\triangleq \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q}
 \end{aligned}
 \tag{28}$$

## 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

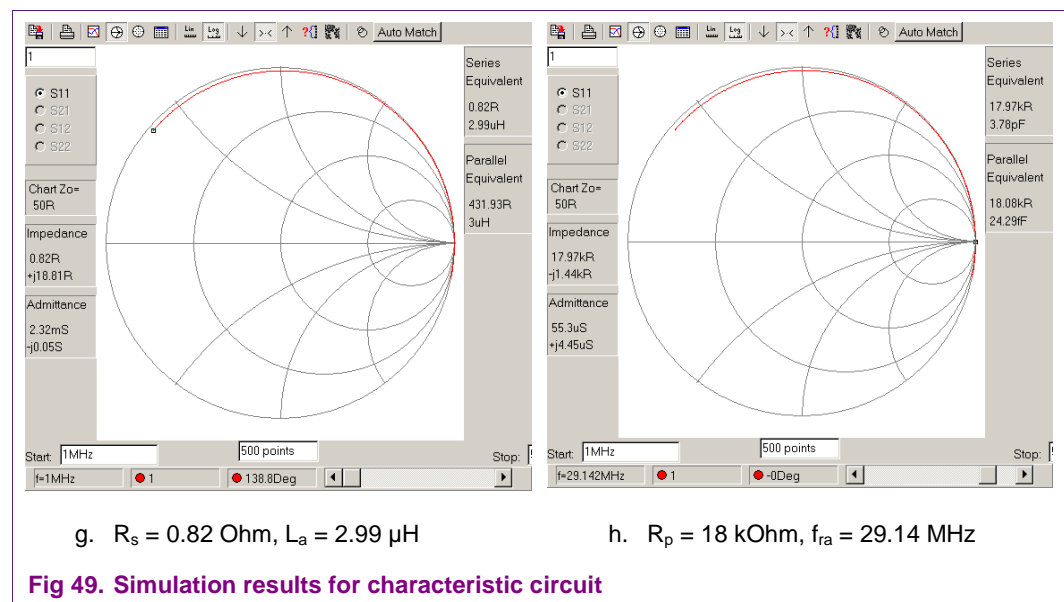
$R_p$  Equivalent resistance at the self-resonance frequency

$f_{ra}$  Self-resonance frequency of the antenna

The antenna capacitance  $C_a$  can be calculated with:

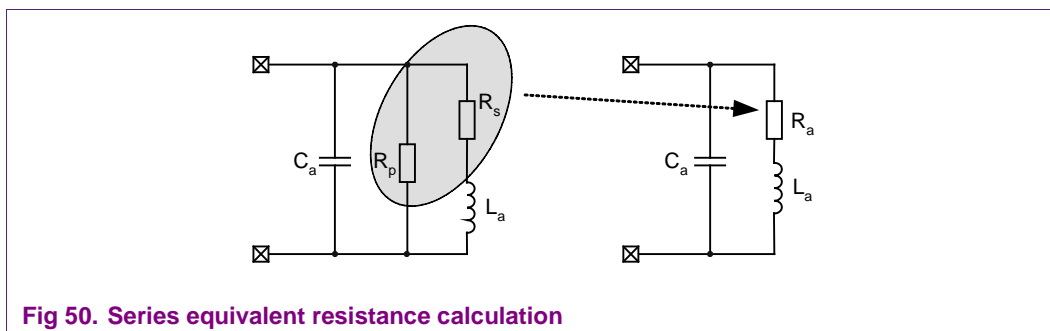
$$C_a = \frac{1}{(2 \cdot \pi \cdot f_{ra})^2 L_a} \quad (29)$$

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



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





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

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

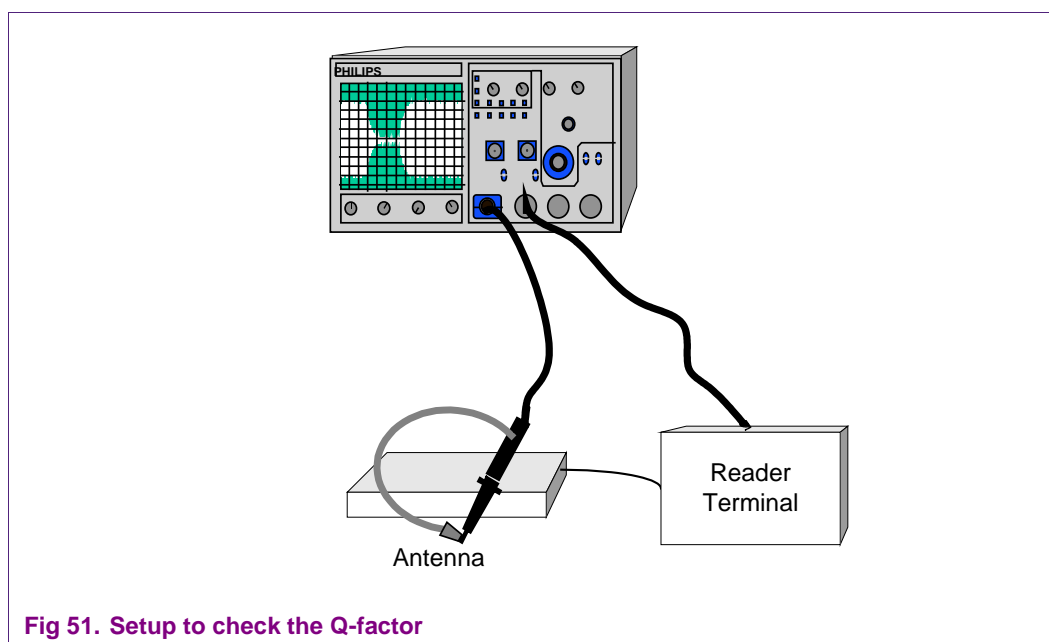
## 8.4 Pulse shape check

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.

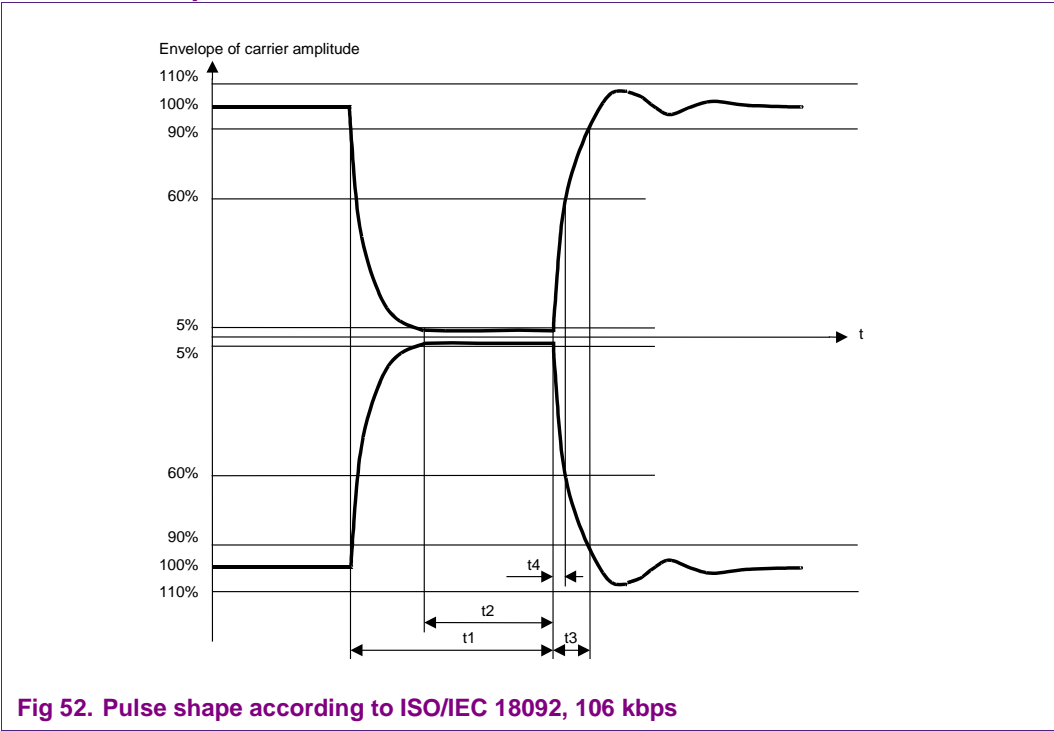
**Note:** The absolute measured voltage in CH1 depends on the coupling (= distance) between the probe loop and the reader antenna.

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

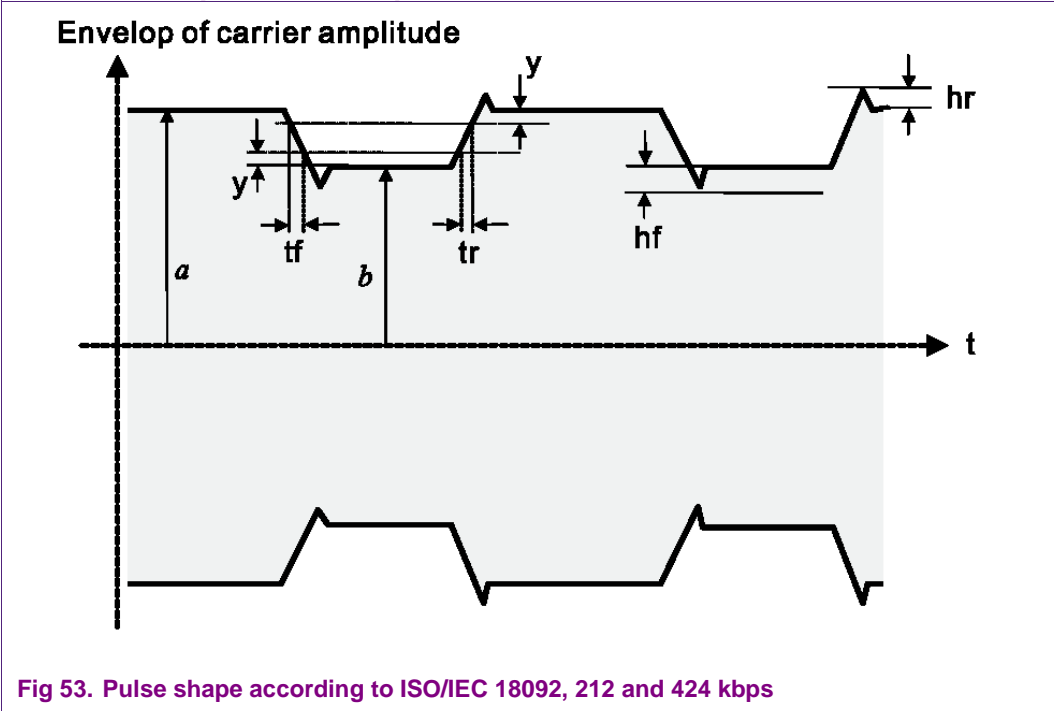


The time  $t_1$ - $t_2$  describes the time span, in which the signal falls from 90% down below 5% of the signal amplitude. As the pulse length of PN51x/PN53x is accurate enough, only the time  $t_2$  has to be checked: the signal has to remain below 5% for the time  $t_2$ . The most critical time concerning rising carrier envelope is  $t_4$ . It must be checked that the carrier envelope at the end of the pause reaches 60% of the continuous wave amplitude within 0.4  $\mu$ s.

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

| Pulse length<br>(Condition) | t1 [ $\mu$ s] | t2 [ $\mu$ s]   |            | t3 [ $\mu$ s] | t4 [ $\mu$ s] |
|-----------------------------|---------------|-----------------|------------|---------------|---------------|
|                             |               | (t1 $\leq$ 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



|        | 212 kbps        | 424 kbps        |
|--------|-----------------|-----------------|
| tf     | 2,0 $\mu$ s max | 1,0 $\mu$ s max |
| tr     | 2,0 $\mu$ s max | 1,0 $\mu$ s max |
| y      | 0,1 (a-b)       | 0,1 (a-b)       |
| hf, hr | 0,1 (a-b) max   | 0,1 (a-b) max   |

## 9. References

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- [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           |
| $R_{\text{match}}$ | Transmitter matching resistance |
| RF                 | Radio frequency                 |
| RFID               | Radio frequency identification  |
| RX                 | Receiver                        |
| TX                 | Transmitter                     |
| $Z_{\text{match}}$ | Transmitter matching impedance  |

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