

Document information

Info	Content
Keywords	Mifare, ICode, Micore, RC400, RC500, RC530, RC531, RC632, RFID-Reader, Directly Matched Antenna Design
Abstract	This application note describes how to design an antenna for the MICORE contactless reader IC family.
BL-ID Doc Number	M077925 update

Revision history

Rev	Date	Description
01.01	20040501	Initial version of Application Note; Directly Matched Antenna Design for Micore Reader ICs
02.05	20060510	Change of layout, general update on the content, correction in formula for C2, Add the changes of the EMC filter, and the antenna example, correction of table 4

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

This document describes the Micore antenna design for applications where the antenna is directly connected to the reader board (without any cable in between the reader and the antenna).

The MIFORE reader IC family includes the MF RC500, MF RC530, MF RC531, SL RC 400 and the CL RC 632. The antenna design and matching is the same for all of these ICs.

1.1 How to use this document

For a good overview the **Micore Antenna Principle** section shows the blocks of each reader antenna design, how these blocks fit to Micore, and also the complete schematic of a Micore Antenna.

Because there are many parameters that influence the overall performance of an antenna, a basic RF knowledge is needed to design an antenna that takes **all** these parameters into account. Although this (specific) knowledge is important for understanding the background, a **complete antenna design** (as shown in [Fig 1](#) and [Fig 2](#)) **can be done without RF-specific knowledge**. Therefore the complete design of a directly matched antenna is divided into two design levels:

1. The **basic parameter design** is dedicated to those, who are not really familiar with RF design and its tools. Although a certain number of requirements and parameters are frozen, the design will yield an optimized antenna. A guideline, the required formulas, and a tool to support the design is described and provided. Depending on some simplifications this design might not be *completely* compliant to the ISO/IEC14443, even though it fully satisfies the Mifare and I-Code requirements.
2. The **full parameter design** is dedicated to those, who want to cover all the specific cases of various design requirements to make a perfect design for the application. This design describes how to build an antenna, which is fully ISO/IEC14443 compliant (including the higher bit rates). The complete antenna design covers all the open parameters, some background information for the design, and the general behaviour of such an antenna.

In [section 5](#) some useful antenna design hints are given.

Appendix [6.1](#) contains a checklist to help optimizing and finishing an antenna design for a proximity reader based on the Micore. It also contains a collection of relevant formulas and an antenna design example.

“Card” in this document means a contactless smart card according to the ISO14443 (or MIFARE[®]) or a contactless tag / label according to the ISO15693 (or I-Code[®]).

Please be aware: This application note cannot and does not replace any of the relevant datasheets.

It is required to have some general knowledge about RFID proximity antennas as given by the application note in [ref. \[1\]](#).

For higher bit rates refer to the application note in [ref. \[2\]](#).

2. Micore antenna principle

The Micore is a single reader IC family designed to achieve operating distances up to 100mm without external amplifiers. The design rules and parameters are basically the same for ISO14443, Mifare®, ISO15693 and I-Code®, i.e. the same antenna can be used to communicate with all products mentioned.

A complete antenna design always includes the antenna coil and resonance circuit design, the matching of the antenna circuit, the receiving circuitry and the EMC filtering (see [Fig.1](#))

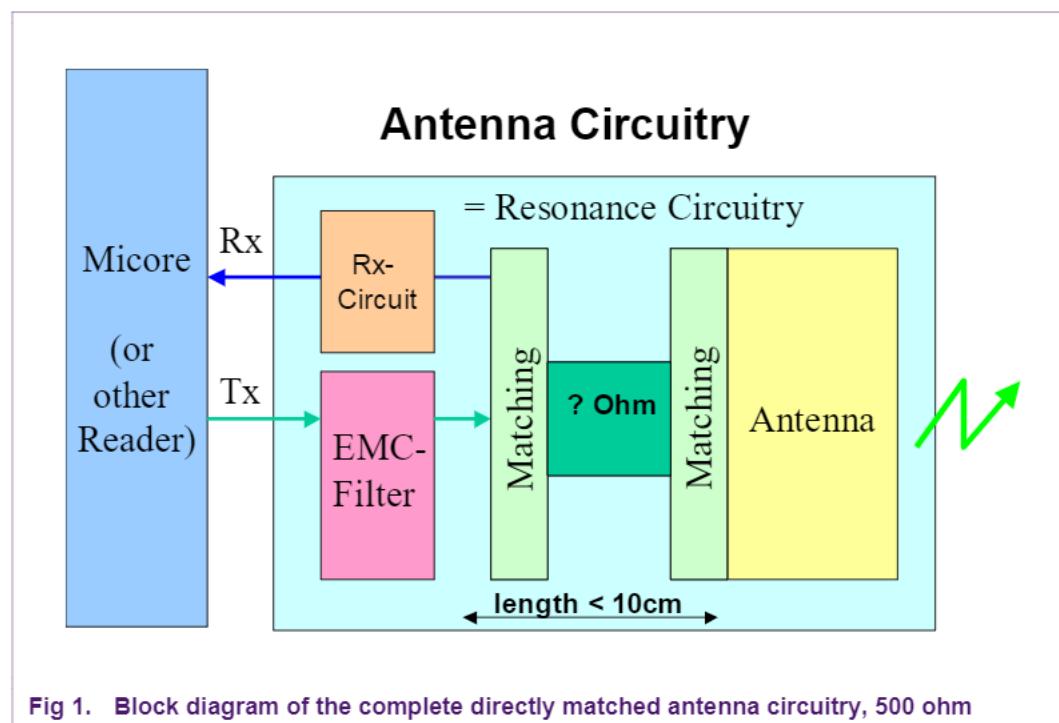


Fig 1. Block diagram of the complete directly matched antenna circuitry, 500 ohm

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 antenna.

The overall functionality can be separated into three basic functions:

1. **Transmit power:** The radiated magnetic field has to be maximized considering the radiation and datasheet limits, especially the limits for the radiation of the harmonics (up to 1GHz).
2. **Transmit data:** The 10% or 100% ASK modulated data signal has to be transmitted in such way, that every card is able to receive it. The signal shape and timing (i.e. the Q-factor) has to be considered.
3. **Receive data:** The card's answer has to be delivered to the receive input of the Micore considering the datasheet limits.

Basically this complete antenna circuitry consists of 8 capacitors, 2 inductors, 2 or 4 resistors and the symmetrical antenna coil ($L_a + L_b$) as shown in [Fig 2](#).

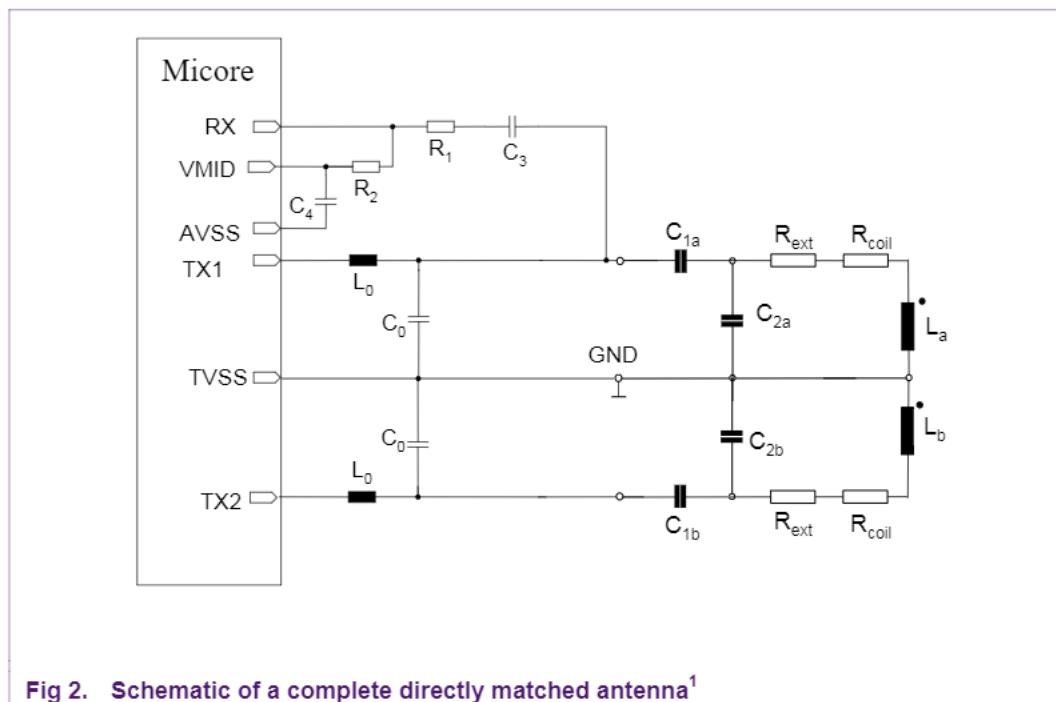


Fig 2. Schematic of a complete directly matched antenna¹

Table 1: Components for directly matched antenna

Abbreviation	Explanation
L_a , L_b and R_{coil}	Antenna coil components according to section 3.2 .
R_{ext}	External resistor to adjust the quality factor. Please also consider the power consumption.
C_0 , C_1 ... C_3	Typically 0402, 0603 or 0805 SMD parts with low tolerance ($<\pm 2\%$). NPO is required. The voltage limit has to be considered.
C_4	X7R capacitor.
L_0	Typically a small inductance with high Q for general applications. The frequency range and the maximum allowed current have to be considered. This inductance should be magnetically shielded.
R_1 and R_2	Small 0402, 0603 or 0805 SMD parts.

Remark: Plan on placing two capacitors, C_{1a} and C_{2a} in parallel to achieve the required matching values. The tuning procedure most likely will return matching values, which cannot be realized with a single capacitor.

1. The GND connection of the antenna coil (center tapping) is not required.

3. Basic parameter design for 106kbit/s

A complete Micore reader antenna design can be done in steps based on the certain number of given parameters given below (see [section 3.1](#)). Every step is described in one of the following sections . The best way to design antenna is to follow the steps given below:

1. Design a coil, measure L and R or L and Q (see [section 3.2](#)).
2. Calculate the resonance capacitors to design a resonance circuitry together with the coil (see [section 3.3](#) to [3.5](#)).
3. Tune this resonance circuitry to the required impedance (see [section 3.6](#)).
4. Connect the resonance circuitry to the EMC low pass filter output, check the I_{TVDD} and if necessary retune the components for optimum performance.
5. Check & adjust the Q-factor (see [section 3.7](#)).
6. Check & adjust the receive circuitry (see [section 3.8](#)).

Remark: *This design might not be completely compliant to the ISO/IEC 14443 (with higher bit rates) due to some simplification in the design steps. For an ISO/IEC 14443 compliant design the complete design steps need to be taken into account (see section 4).*

3.1 Given parameters

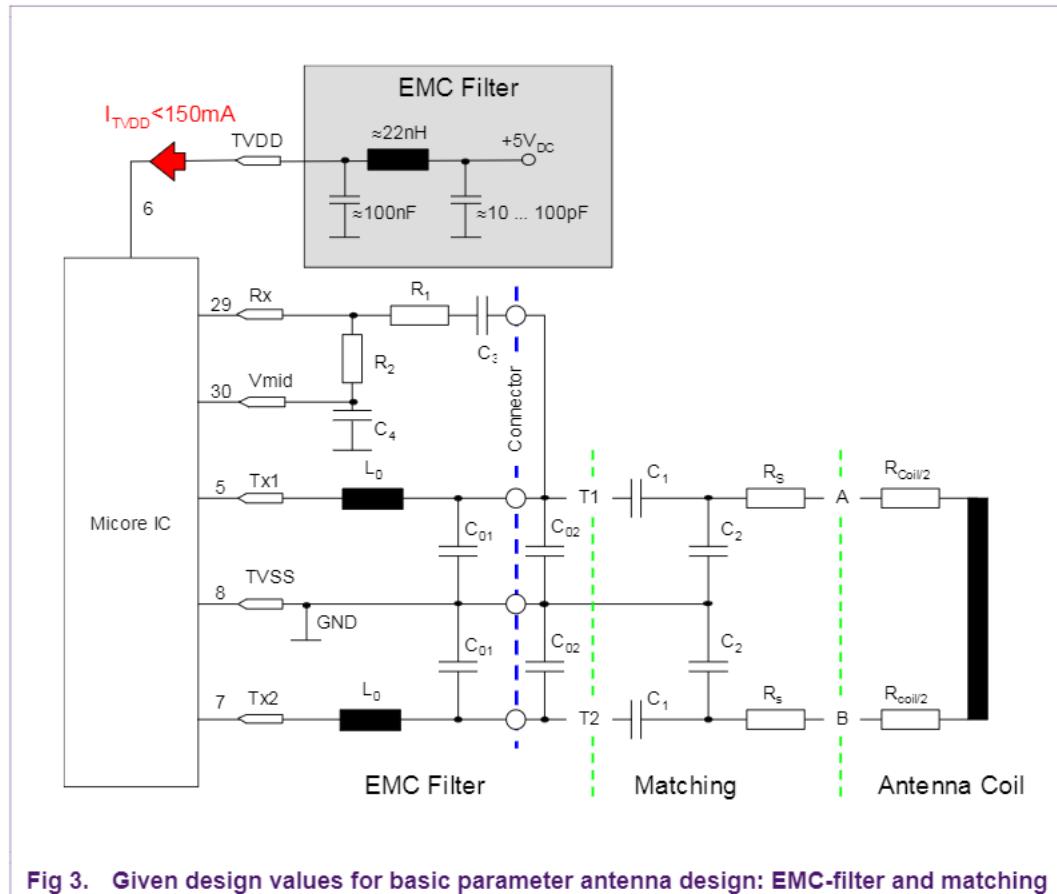


Fig 3. Given design values for basic parameter antenna design: EMC-filter and matching

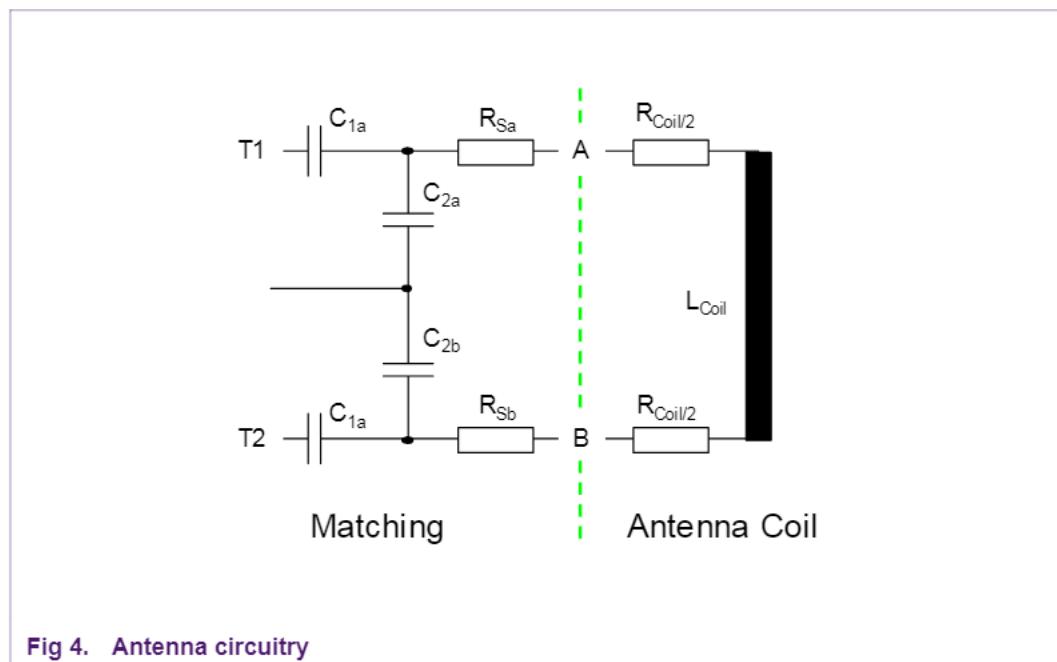
To reduce the number of parameters for the basic parameter antenna design, the following fixed component values shall be used:

Table 2: Fixed value of components of directly matched antenna

Component	Value
L_0	1uH (e.g. TDK NL322522T-1R0J)
C_{01}, C_{02}	68pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_3	1nF (Ceramic NP0, tolerance $\leq \pm 10\%$)
C_4	100nF (Ceramic X7R, tolerance $\leq \pm 10\%$)
R_1	$470\Omega \dots 4.7k\Omega^2$
R_1	820 Ω

Remark: GND should be one GND-plane for the Micore circuitry itself, and should be directly connected to the center pin of the shielding, if shielding is applicable. It is not required to connect the center tapping of the antenna coil.

² The exact value has to be chosen according to the value of the antenna coil ([section 3.8](#)).

**Fig 4.** Antenna circuitry

The complete directly matched antenna consists of the parts as shown in [Fig 4³](#).

Table 3: Components of antenna circuitry

Component	Value
L_{Coil}	Antenna coil (see section 3.2)
R_{coil}	Internal resistor of the antenna coil (see section 3.2)
R_{Sa}, R_{Sb}	External resistor (see section 3.7)
$C_{1a}, C_{1b}, C_{2a}, C_{2b}$	Capacitors to match impedance and resonance (see section 3.5)

3. It is not required to connect a center tapping of the coil to GND.

3.2 The antenna coil

As a start the required antenna coil shall be designed within the mechanical application requirements and according to the general antenna design rules ([see \[1\]](#)).

The inductance $L = L_a + L_b$ and series resistor $R_L = 2 \cdot R_{coil}$ shall be measured between A and B in [Fig 5](#). This measurement could be done with an impedance analyzer or an LCR meter at a frequency of $f = 13.56\text{ MHz}$.

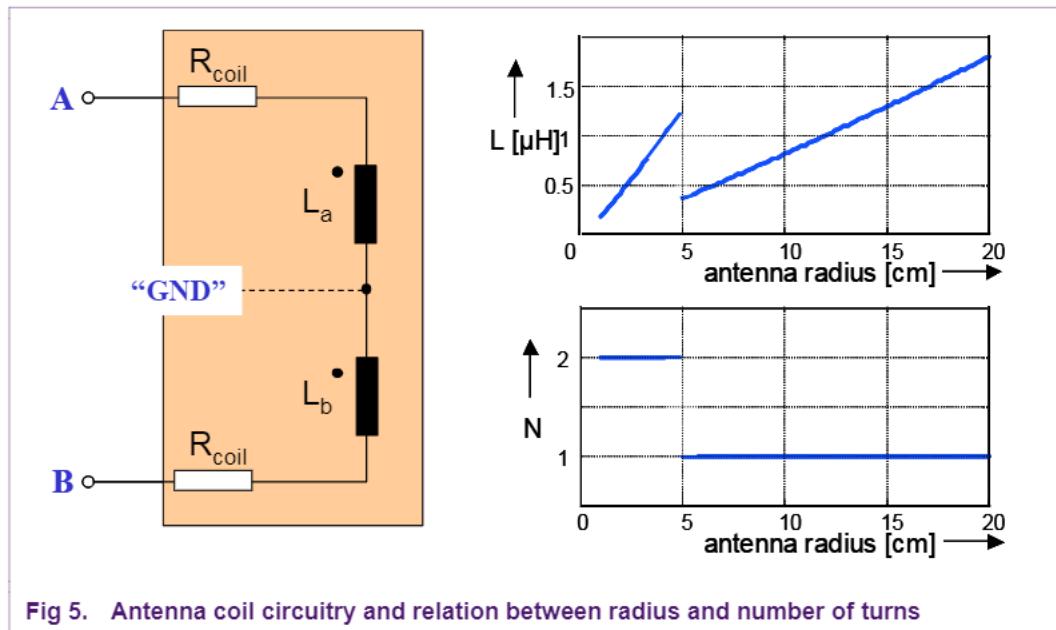


Fig 5. Antenna coil circuitry and relation between radius and number of turns

Depending on the antenna radius use either a single turn coil ($r \geq 5\text{ cm}$) or a double turn coil ($r < 5\text{ cm}$) for each coil L_a and L_b .

The antenna coil shall be symmetrical.

The (electrical) center point can be connected to GND. If this center point is connected to GND, it is suggested to use the same number of complete turns for both L_a and L_b (even number of turns for L), to keep this center point as near as possible to the antenna coil connector. If one and a half turns are used, no center tapping shall be used. The shielding (if applicable) shall be connected to GND directly at the antenna connector (center tapped). Two layout examples based on a 2-layer board are shown in [Fig 6](#).

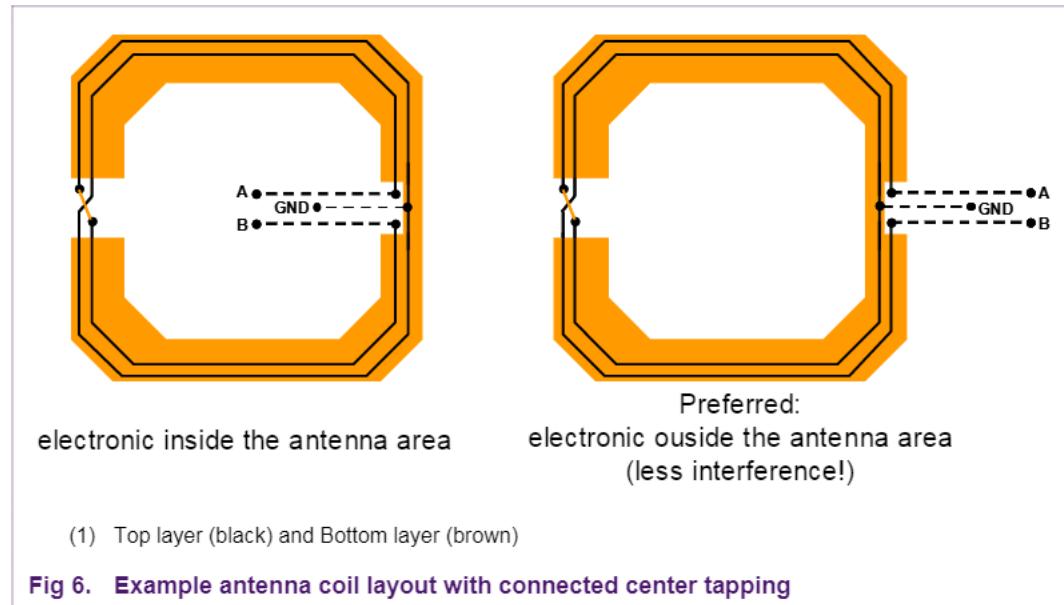


Fig 6. Example antenna coil layout with connected center tapping

According to the given design rules (coil radius \approx operating distance, and number of turns as shown in [Fig 5](#)) the inductance of the antenna coil usually is between

$$L = L_a + L_b = 300nH \dots 2\mu H$$

$$R_L = 2 \cdot R_{coil} = 0.5\Omega \dots 5\Omega$$

Remark: These values are only typical values.

The turn direction of the two parts of the coil (L_a and L_b) should be considered!

The antenna shall be measured completely ($L_a + L_b$ between A and B) because of the coupling between the two parts of the antenna coil (L_a and L_b).

The measured value of R_L is usually too high due to the high Q-factor of the coil. This has to be considered as follows. The effect is really low, as on one hand the influence of a slight change of R_L on the matching is not high, and on the other hand the Q-factor has to be checked later anyway.

To be measured at 13.56 MHz.

It is not required to connect the center tapping of the coil, but it is required to connect the shielding (if applicable) to GND.

3.3 Simplification due to symmetry

Due to the symmetrical circuitry of the whole antenna for one coil it is required that:

$$L_a = L_b$$

$$Z_a = Z_b = \frac{Z_{ant}}{2} \text{ (as shown in Fig 7).}$$

As this symmetry is a general requirement for the proper function of the antenna, it can be used to simplify the whole circuitry. In the following only the upper half of the complete antenna circuit is used to calculate the matching network and the external resistor(s). The lower half looks and behaves exactly the same.

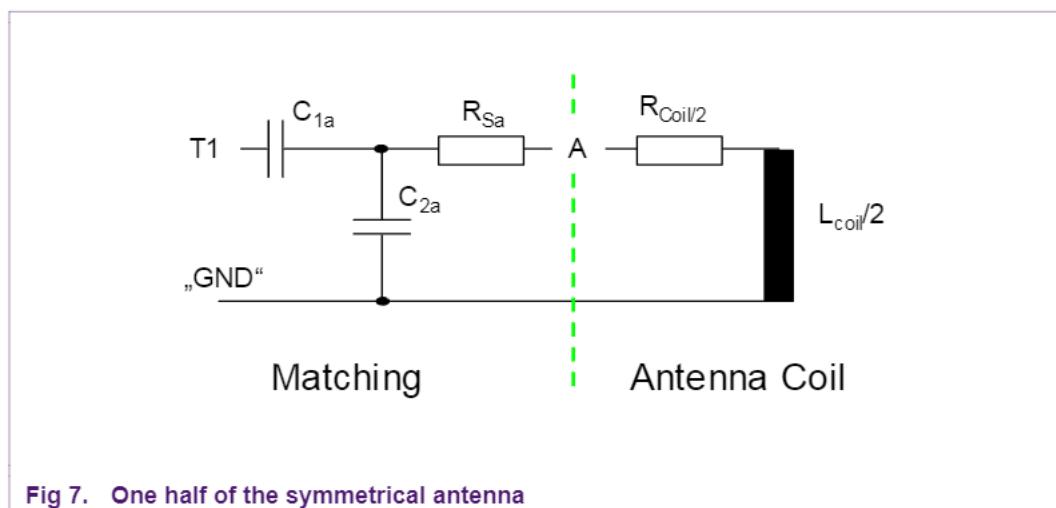


Fig 7. One half of the symmetrical antenna

Although this simplification can be done in theory, the practical measurement cannot be done with this simplified model, because of the coupling between L_a and L_b . So all the impedance *measurements* have to be done with the complete antenna circuit with both sides (between T1 and T2 or A and B) and NOT between T1(or A) and GND or T2 (or B) and GND.

3.4 The external resistor

Together with the general definition of the Q-factor of the coil

$$Q = \frac{\omega L}{R_{Coil}} \quad \text{or} \quad R_{Coil} = \frac{\omega L}{Q}$$

the overall resistor (that specifies the overall Q)

$$R = 2 \cdot R_S + R_{Coil} = R_{Sa} + R_{Sb} + 2 \cdot \frac{R_{Coil}}{2}$$

and the requirements for

$$Q = 30^4$$

the external resistor R_{Sa} and R_{Sb} can be estimated:

$$R_{Sa} = R_{Sb} = \frac{1}{2} \cdot (R - R_{Coil}) = \frac{\omega L}{2 \cdot Q} - \frac{R_{Coil}}{2} \quad \text{with } \omega = 2\pi \cdot 13.56 \text{ MHz}$$

Neglecting the influence of all the other components on the Q-factor, this calculation only gives an estimation of the later used value of R_S , but this estimation is necessary to do the calculation of the matching capacitors in the next step.

The Q-factor has to be checked and adjusted later on as described in [section 3.7](#) to get an exact value for the external resistor.

⁴ Although I-Code basically uses a higher Q-factor, the Micore requires a Q < 40. Micore is limited to the proximity range. For ISO/IEC 14443 higher bit rates even a lower Q is required.

3.5 The parallel and serial capacitors

With these values of the coil L_a , R (including the external resistor) and the required impedance Z_{ant} , now the parallel capacitor C_2 and serial capacitor C_1 can be calculated:

$$C_{2a} = C_{2b} = \frac{1}{\omega \cdot \sqrt{\left(\frac{\omega L}{1 - R/Z_a} \right)^2 - \frac{R^2 + \omega^2 L^2}{1 - R/Z_a} + \frac{\omega^2 L}{1 - R/Z_a}}}$$

$$C_{1a} = C_{1b} = \frac{R^2 + \left(\omega L - \frac{1}{\omega C_2} \right)^2}{\frac{\omega L}{C_2} \left(\frac{1}{\omega C_2} - \omega L \right) - \frac{R^2}{C_2}} \quad \text{with } Z_a = 250\Omega$$

Although the estimated external resistor may vary from the really needed one, the calculated capacitor values should be taken as start values for the following tuning procedure.

Remark: There is an Excel-Sheet available that performs this calculation.

Designing based on the given parameters, the value of $Z = 2 \cdot Z_{ant} = 500\Omega \cdot e^{0^\circ}$ may be increased up to $Z = 2 \cdot Z_{ant} = 800\Omega \cdot e^{0^\circ}$ to increase the output power (details see section 4), but of course the limit of the output current of Micore must not be exceeded!

3.6 Tuning procedure

With the given and calculated values for L , R_{Sa} , R_{Sb} , C_{1a} , C_{1b} , C_{2a} and C_{2b} the complete antenna circuit has to be tuned to equalize measurement and calculation uncertainty and tolerances. Fig 8 shows the tuning procedure. C1 and C2 each mean both the corresponding symmetrical values. The use of an impedance analyzer is recommended, but there is also an easy method described in the [appendix 6.2](#) to tune the antenna circuit (without impedance analyzer) using only an oscilloscope and a signal generator.

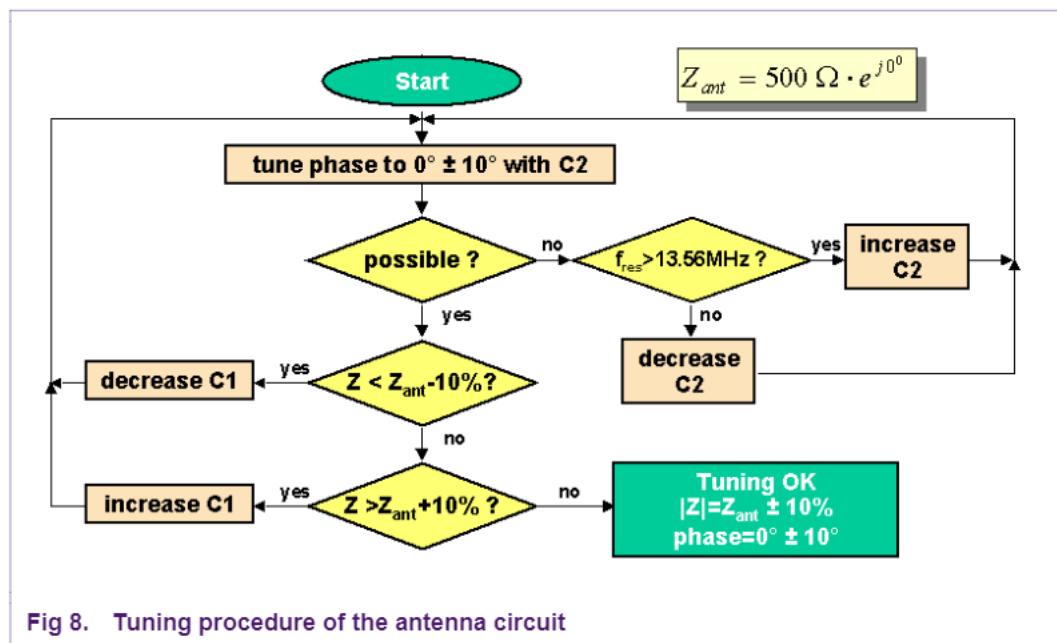


Fig 8. Tuning procedure of the antenna circuit

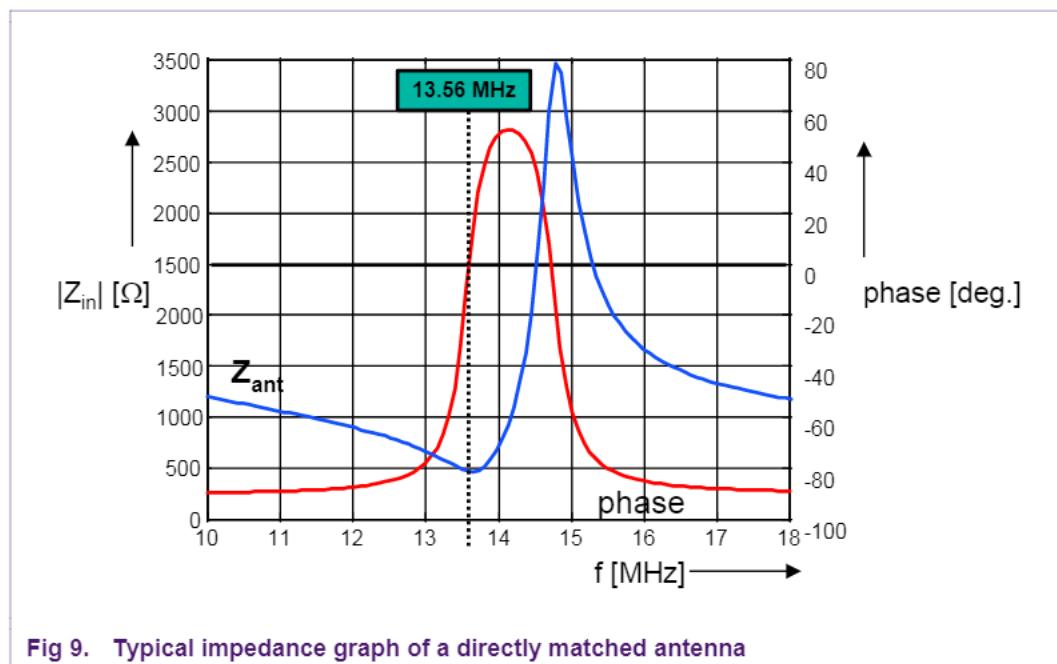


Fig 9. Typical impedance graph of a directly matched antenna

Remark: It is useful to start the tuning procedure with smaller capacitance values than calculated. On one hand measuring the antenna coil disregards stray capacitance also influencing the tuning. On the other hand it is much easier to increase capacitance (by adding extra capacitors) during the tuning procedure than reducing the capacitance.

The Excel sheet can also be used to check and “get a feeling” for the relation between capacitor value changes and the impedance changes. A few pF may change the whole matching!

3.7 Checking the Q-factor and output current

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

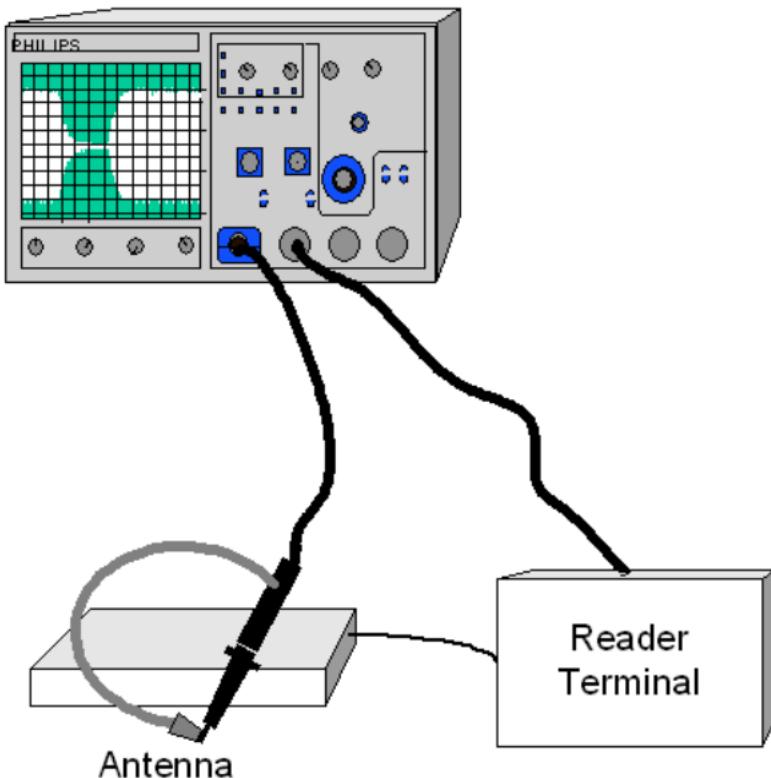


Fig 10. Setup to check the Q-factor

An oscilloscope with a bandwidth of at least 50 MHz shall be used and two probes shall be connected as shown in [Fig 10](#):

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: Connect probe to the MFout signal at Pin 4 of the reader IC, Trigger source = CH2.
The MFoutSelect register (26h) has to be set to
“2” (Modulation Signal (envelope) from internal coder, Miller coded)
or “3” (Serial data stream, not Miller coded)

For further details see the related Micore datasheets.

An example of these test signals is shown in [Fig 11](#).

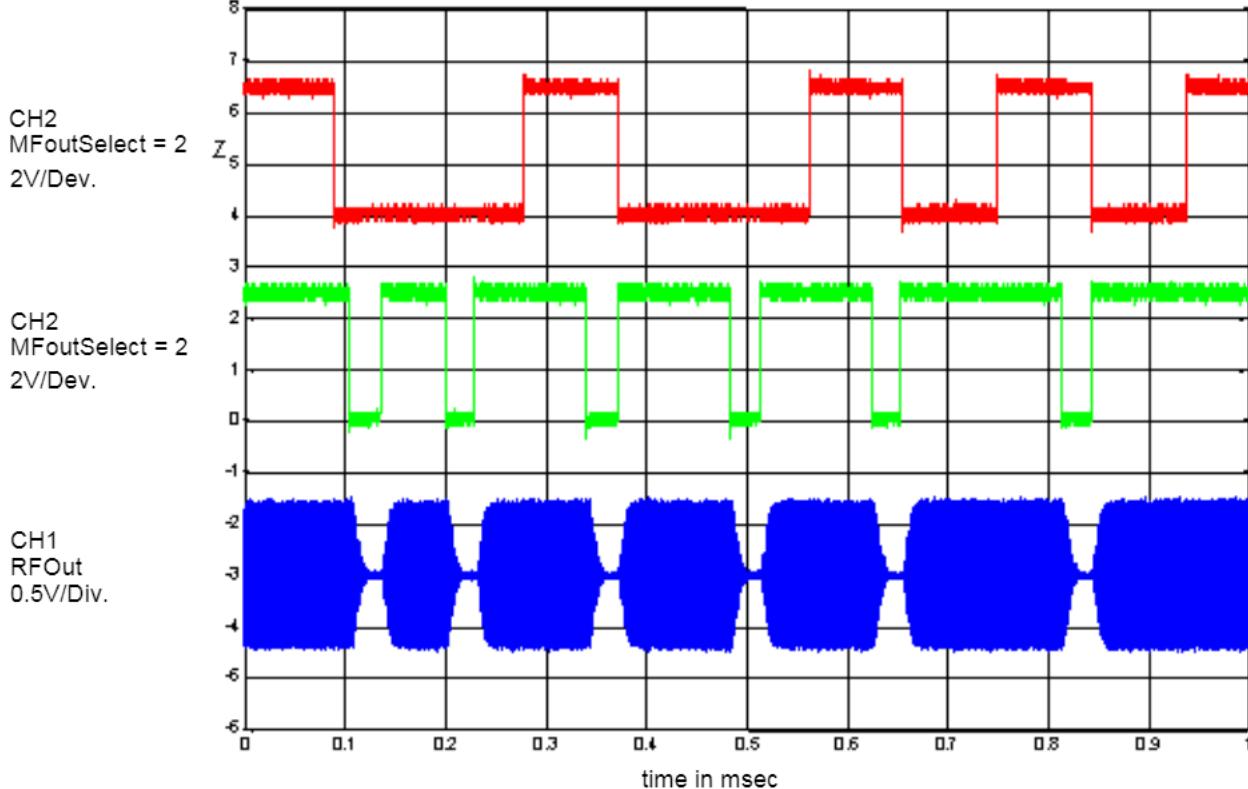


Fig 11. Test Signals of the Micore Antenna

It is recommended to check the pulse shape and compare the scope plot to [Fig 12](#). The related values are given in [Table 4](#):

Remark:

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 (unloaded). However, the complete PCD has to be checked against the ISO/IEC14443 (see ref [8]) using the reference PICCs acc. ISO10373-6 (see ref [9]). That requires e.g. to check the pulse shapes unloaded and under load conditions (using the reference PICC as defined in ref [9]).

3.7.1 Pulse shape according to ISO14443A

For the antenna design for the MF RC500, the MF RC530, the MF RC531 and the CL RC632 the pulse shape (Q-Factor) shall be checked according to the ISO14443A. For the SL RC400 the shape is described in [section 3.7.2](#)

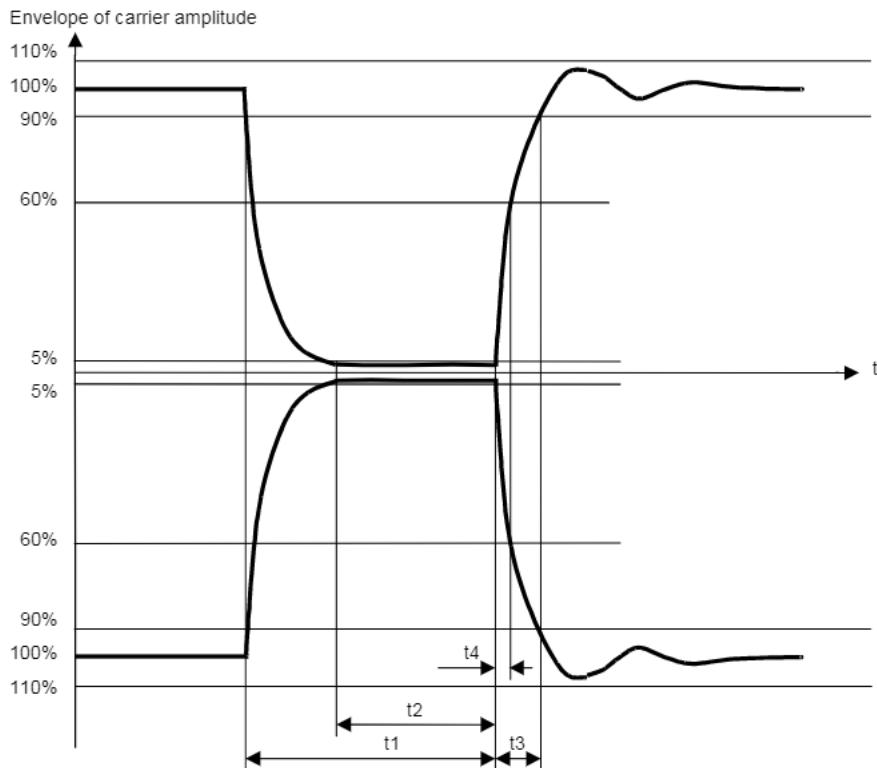


Fig 12. Pulse shape according to ISO/IEC 14443A

Table 4: Pulse duration in [μ s] compliant with ISO/IEC 14443A

Pulses length	t1	t2 min	t3 max	t4 max
T1 MAX	3.0	0.7	1.0	0.4
T1 MIN	2.0	0.7	1.0	0.4

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 Micore is accurate enough, only the times t_2 and t_4 have to be checked: the signal has to remain below 5% for the time t_2 .

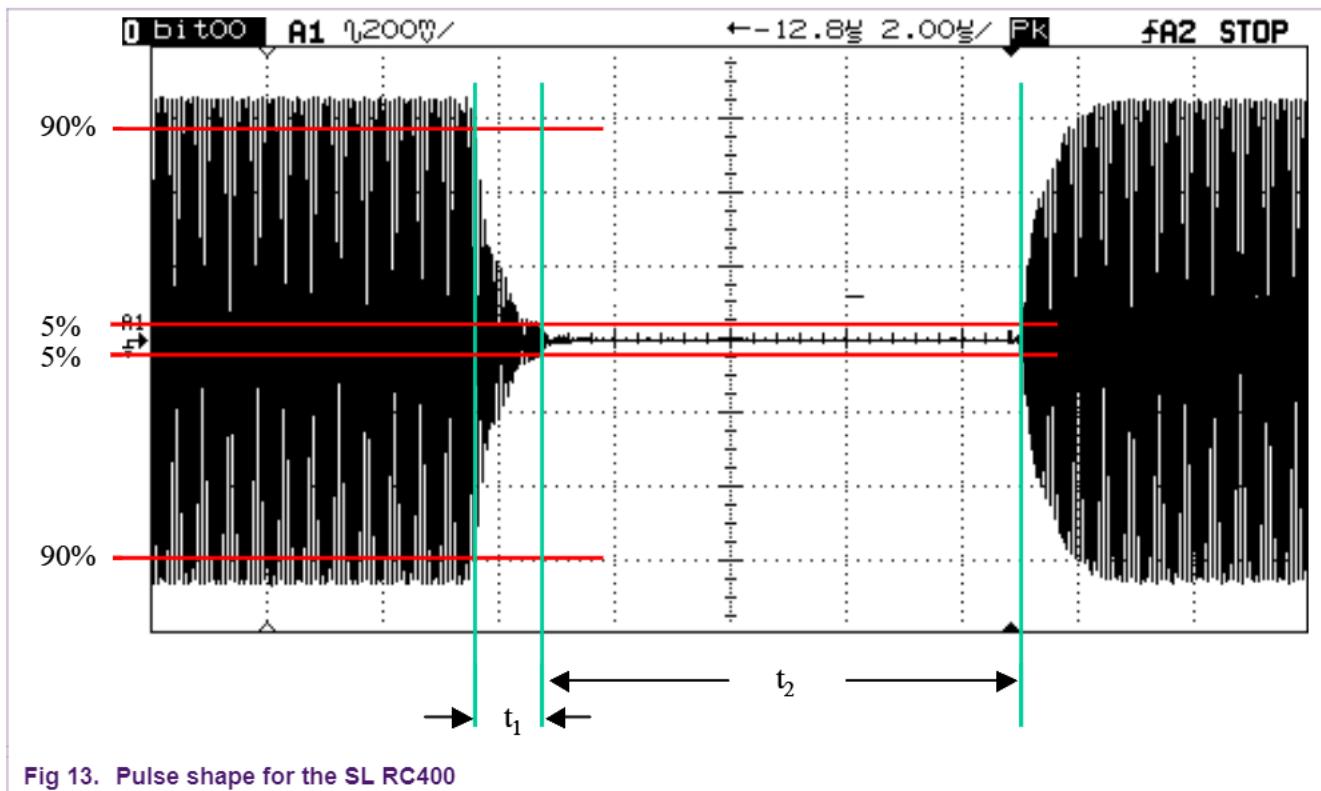
To guarantee a correct antenna tuning and Q-factor the following shall be checked:

- I) The signal has to fall below the 5 % value.
- II) The time t_2 shall be in the limit: $0.7 \mu\text{s} < t_2 < 1.4 \mu\text{s}$

If $t_2 < 0.7 \mu\text{s}$, the Q-factor is too high ($Q > 35$). R_{ext} has to be increased.

If $t_2 > 1.4 \mu\text{s}$, the Q-factor is too low and the operating distance will be dissatisfying. R_{ext} has to be decreased.

3.7.2 Pulse shape for the SL RC400 design



The I-Code pulse shall be switched to 100% ASK to check the Q-factor as shown in Fig 13. The time t_1 describes the time span, in which the signal falls from 90% down below 5 % of the signal amplitude. As the pulse length of Micore is accurate enough, only the time t_2 has to be checked: the signal has to remain below 5% for the time t_2 .

Table 5: Pulse duration for the SL RC400

Pulses length	t_2 [μs]
T MAX	8.7
T MIN	7.2

To guarantee a correct antenna tuning and Q-factor the following shall be checked:

- I) The signal has to fall below the 5 % value.
- II) The time t_2 shall be in the limit: $7.2 \mu s < t_2 < 8.7 \mu s$

If $t_2 < 7.2 \mu s$, the Q-factor is too high ($Q > 35$). R_{ext} has to be increased.

If $t_2 > 8.7 \mu s$, the Q-factor is too low and the operating distance will be dissatisfying. R_{ext} has to be decreased.

3.8 Receiving circuitry

When all the transmit design issues ([sections 3.2 to 3.7](#)) have been taken care of, the reader antenna radiates the maximum possible magnetic field and correctly transmits the TX-data according to the specified protocol and coding. Now the receive circuitry has to be connected and adjusted.

The antenna circuitry should be assembled with the components as given in [section 3.1](#):

$$C_3 = 1nF \quad (\text{Ceramic NP0, tolerance} \leq \pm 10\%)$$

$$C_4 = 100nF \quad (\text{Ceramic X7R, tolerance} \leq \pm 10\%)$$

$$R_1 = 470\Omega \dots 4.7k\Omega \quad (\text{For determining the exact value: see below})$$

$$R_2 = 820\Omega$$

As the matching of the antenna (TX-way) provides a maximum of power coupled into the antenna depending on its impedance, the voltage at the antenna (at node T1 as given in [Fig 3](#)) is slightly different from antenna coil to antenna coil. The Rx input pin (PIN29) of the Micore is high-impedance, so a voltage is coupled back into the Rx-input of the Micore.

So two rules have to be fulfilled:

- I) DC-voltage level at the Rx input pin has to be kept at Vmid.
(That is why R2 and C4 are required.)
- II) AC-voltage level at the Rx input pin has to be kept within the following limit:
 $1.5 \text{ Vpp} < V_{Rx} < 3 \text{ Vpp}$

If $V_{Rx} > 3 \text{ Vpp}$, R_1 has to be increased.

If $V_{Rx} < 1.5 \text{ Vpp}$, R_1 has to be decreased.

The Rx input voltage shall be checked with and without a card in the field with minimum and maximum operating distance.

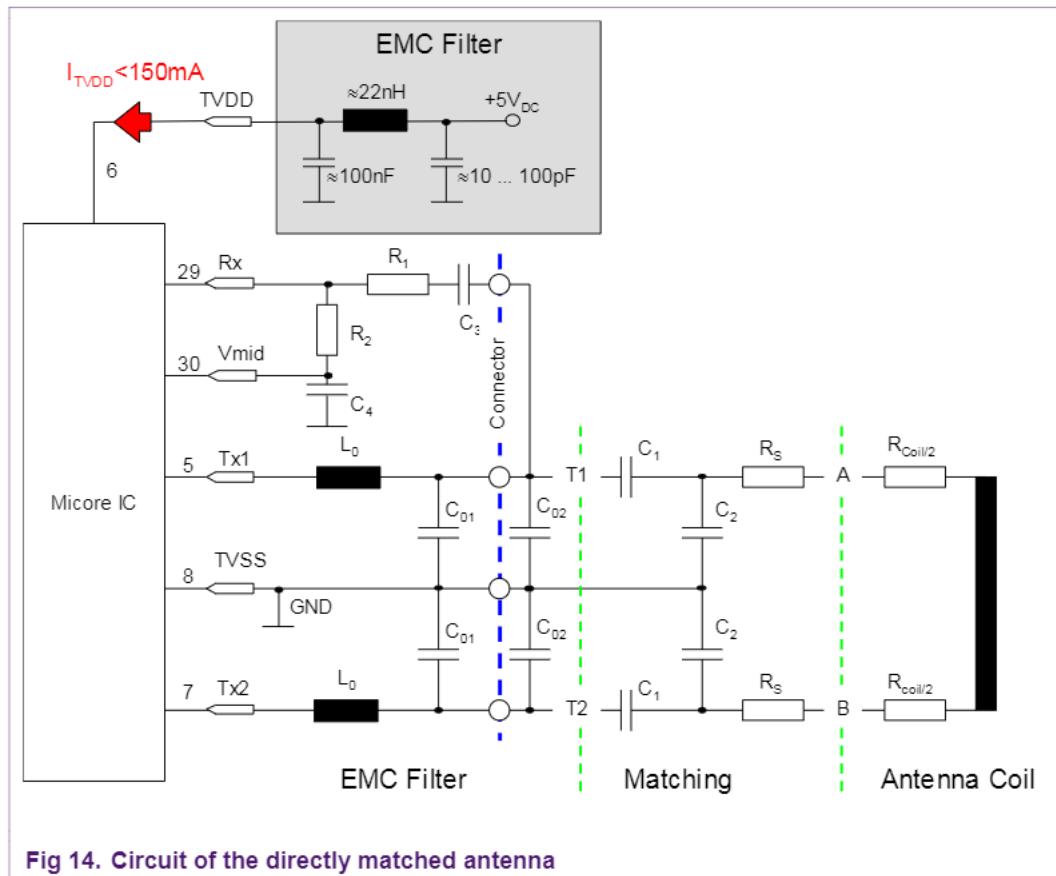
Remarks: *Do not exceed the limit of $V_{Rx} = 3Vpp$ AC at the Rx-input pin!!
A higher input voltage may not destroy the chip, but results in a receiving failure.*

The RX-Input may either be connected to node T1 or T2.

4. Full parameter design

The full parameter design needs some basic knowledge about RF design. Some parameters, that are fixed in [section 3](#), here are free to be changed or adapted to special requirements to achieve more flexibility, but of course the design needs some more design steps and detailed design work. The complete Micore reader antenna design principle is discussed with the same reference hardware as shown in [Fig 2](#).

So the antenna design principle is the same as given in [section 3](#), and the circuit (see [Fig 14](#)) itself is the same as above (compare with [Fig 3](#)). To get improve performance the EMC low pass filter is included into the matching.



4.1 Design requirements

4.1.1 Filtering the supply voltage

Even though it is not required, an EMC filter connected to the TVDD pin as shown in [Fig 14](#) might help to improve the overall performance:

- a) It suppresses noise coming from the supply voltage coupling into the analog part of the antenna circuit, and
- b) it suppresses harmonics coming from the transmitter to be radiated into the environment (and the rest of the circuit).

A similar filter might be used for the AVDD and even DVDD.

4.1.2 Resonance frequency of the EMC filter

In the basic design the resonance frequency of the given EMC low pass filter is approximately 13.56 MHz to make the design easy.

To get a better performance the resonance frequency of the EMC filter itself should be around 14.4MHz (= $f_c + 847.5\text{kHz}$). Proposed values for this EMC filter can be found in [Table 6](#): This should be for two reasons:

- a) It increases the signal to noise ratio for the receive signal, and improves the receive performance.
- b) It decreases the overshoots of the transmit pulses, and improves the signal quality of the transmit signal.

Table 6: Proposed value of EMC low pass filter components

Component	Value
L_0	1 μH (e.g. TDK NL322522T-1R0J)
C_{01}	68pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_{02}	56pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)

Of course this resonance frequency requires the EMC low pass filter to be considered in the matching of the antenna.

4.1.3 Matching requirement

In addition to the general design rules based on the Mifare interface principle, as given in the application note in [ref. \[1\]](#), the basic requirement for the antenna design is reduced to the minimum requirement of the Micore.

The Micore delivers a square signal of

$U_{\text{TxAC}} \approx \pm 2.5 \text{ V pp (square)}^5$ with $f_0 = 13.56 \text{ MHz}$ and a maximum output current of $I_{\text{TVDD}} \leq 150\text{mA}$

That means, the TX output toggles between $V_L = 0\text{V}$ and $V_H \approx 5\text{V}$ at a frequency of 13.56 MHz. Tx1 and Tx2 usually have a 180 degrees phase shift, depending on the setting of

⁵ Additionally there is a mean DC voltage of $U_{\text{TxDC}} = 2.5 \text{ V}$!

TX2Inv (bit 3 of the Tx-Control Register). Please refer also to the related Micore datasheet.

Therefore four main requirements can be specified:

- I) The TX-output current must not exceed the given limit: $I_{TVDD} \leq 150mA$
- II) The harmonics have to be suppressed to meet the regulation rules.⁶
- III) The receive signal has to be coupled back into Rx input of the Micore.

Limiting the radiation of harmonics is not the specific goal of this application note. However, the basic guidance provided herein shows, that an easy design is possible that also meets the general EMC rules. The use of a low pass filter directly connected to the TX outputs is recommended.

Remark: As mentioned in the beginning of the full parameter design, some knowledge is required to design a Micore reader antenna different from the recommendation in section 3. This includes the knowledge of the EMC behavior at RF outputs. Usually highly efficient RF outputs generate a great number of harmonics, which have to be suppressed sufficiently to meet government restrictions. Due to the limited Q-factor and some parasitic effects of the passive components the whole antenna circuitry might resonate at some frequencies above 100MHz, or behave like a second (unwanted) antenna at a certain frequency above 13.56 MHz. This has to be checked very carefully during the design.

Layout hint: The most critical part of the antenna circuit is the EMC low pass filter, so the component area of this filter shall be as small as possible, and a proper GND connection of this filter shall be directly connected to the TVSS pin.

⁶ EN (Europe) or FCC (USA) EMC regulations, mainly the radiation of electro-magnetic field <1GHz

With the given voltage and current, the first requirement can be formed into the following (see [Fig 15](#)):

- la) The minimum load impedance connected to a TX-output, shall be at least
 $Z = Z_{\text{loadTx}} = 20 \Omega$.⁷

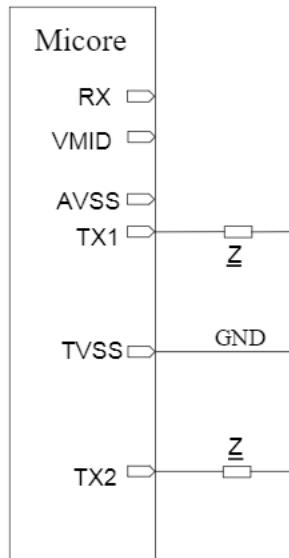


Fig 15. Micore minimum load requirement

Remark: Of course all the general rules, like maximum power, a correct Q-factor, resonance, antenna size, receive circuit, etc. have to be considered, too.

The mean DC voltage at each TX pin has to be considered, too, but usually a matching capacitor decouples the DC voltage anyway.

Although the TX-output current basically is AC (@13.56 MHz), the specified supply current I_{TVDD} is DC that easily can be measured and checked at the TVDD pin of the Micore continuously during the whole design.

\underline{Z} always means a complex impedance, consisting of resistance and reactance:
 $\underline{Z} = R + jX = Z \cdot e^{j\varphi}$

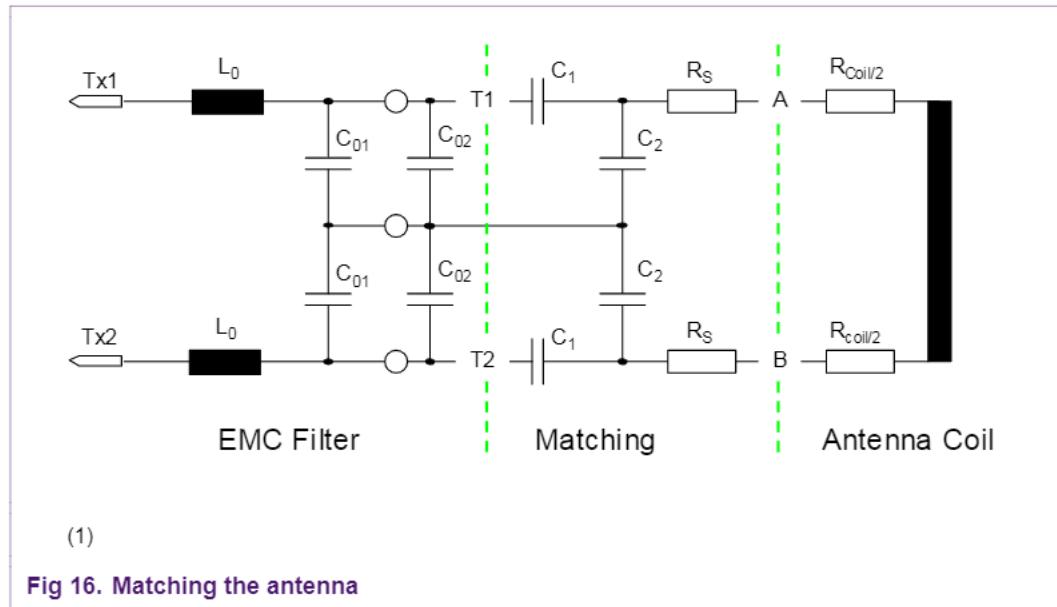
⁷ The impedance and the voltage are referred to GND. Phase = 0, if not specified.

4.2 Required design steps

1. Design a coil, measure L and R or L and Q (see [section 3.2](#)).
2. Calculate the resonance capacitors to design a resonance circuitry together with the coil (see [section 3.3](#) to [3.5](#)).
3. Tune this resonance circuitry together with the EMC low pass filter to the required impedance (see [section 4.3](#))
4. Connect the resonance circuitry to the Micore output, check the I_{TVDD} and if necessary retune the components for optimum performance.
5. Check & adjust the Q-factor (see [section 4.3.1](#)).
6. Check & adjust the receive circuitry (see [section 3.8](#)).

4.3 Impedance Matching & Resonance

The principle of the antenna matching is the same as shown before in [section 3.6](#), but now the EMC low pass filter has to be included into the matching and tuning procedure.



So based on the same design the whole circuit as shown in [Fig 16](#) has to be matched to an impedance of approximately 40Ω between Tx1 and Tx2, using the following values as proposed in [Table 6](#):

4.3.1 Q-factor

In any case of designing a Micore reader antenna, the Q-factor has to be checked. The overall Q-factor of a Micore antenna – supporting higher bit rates – is limited to

$$Q \leq 22$$

and shall be checked in principle as given in [section 3.7](#). This value is valid for mifare® and I-Code® (proximity) designs.

The lower Q factor compared to a standard mifare reader design is related to the pulse shape requirements of higher bit rates according to [8]. In addition to that the lower Q-factor increases the overall stability and the robustness against environmental changes.

So in addition to [section 3.7](#) for higher bit rates the relevant pulse shapes shall be checked, too. Refer to the application note [2] for details.

5. Additional design hints

5.1 Antenna functionality

In each of the design steps the three functions of a reader antenna should be considered:

1. **Transmit power:** The radiated magnetic field has to be maximized considering the radiation and datasheet limits, especially the limits for the radiation of the harmonics (up to 1GHz).
2. **Transmit data:** The coded and 10% or 100% ASK modulated data signal has to be transmitted in a way, that every card is able to receive it. The signal shape and timing (i.e. the Q-factor) has to be considered.
3. **Receive data:** The card's answer has to be delivered to the receive input of the Micore considering the datasheet limits.

If one of these functions is not completely provided, the overall function of the antenna is disturbed or at least the performance is reduced. So if a supposed overall performance is not achieved with a specific design, each of these 3 functions shall be checked separately.

5.2 Layout

Even though this document does not replace any relevant RF design documents and it does not cover EMC related topics in detail, some general recommendations can be given to simplify a proper design.

The Micore IC itself drives the 13.56 MHz carrier with a signal, which is almost a square signal. This leads to many harmonics up to the GHz range, which have to be suppressed sufficiently to meet all the relevant EMC regulations⁸. The most critical part of the overall analog layout is the circuits directly connected to the Micore IC: the EMC low pass filter as well as the connection of the supply voltage pin TVDD.

So on one hand an additional EMC filter for the supply voltage might be usefull.

On the other hand the layout of L_0 and C_0 shall be considered carefully. The overall layout and placement area of TX1, TX2, L_0 , C_0 and TVSS shall be kept as small as possible. A proper and short GND connection is required! One proper GND plane is recommended!

A 2-layer board reference layout is shown in [Fig 17](#) and [Fig 18](#) with the corresponding schematic in [Fig 20](#) and [Table 7](#):

8. Like FCC in the USA an CE in Europe.

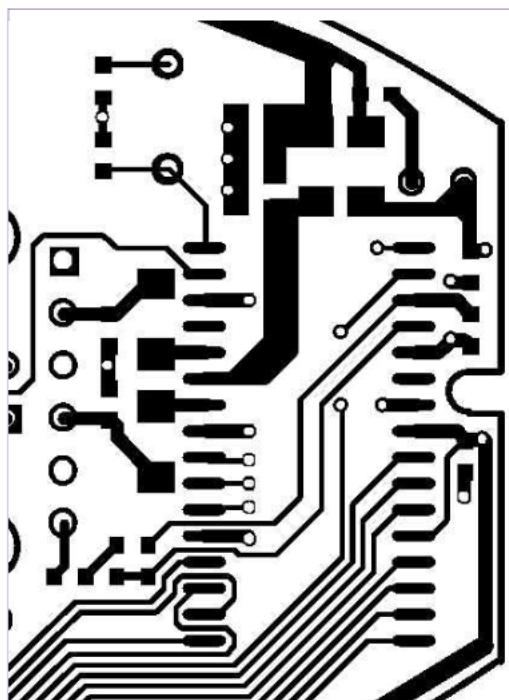


Fig 17. Example layout, top layer

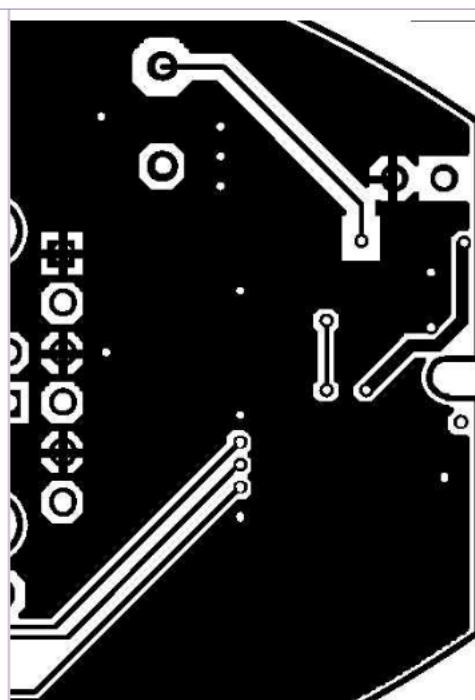


Fig 18. Example layout, bottom layer (mirror view)

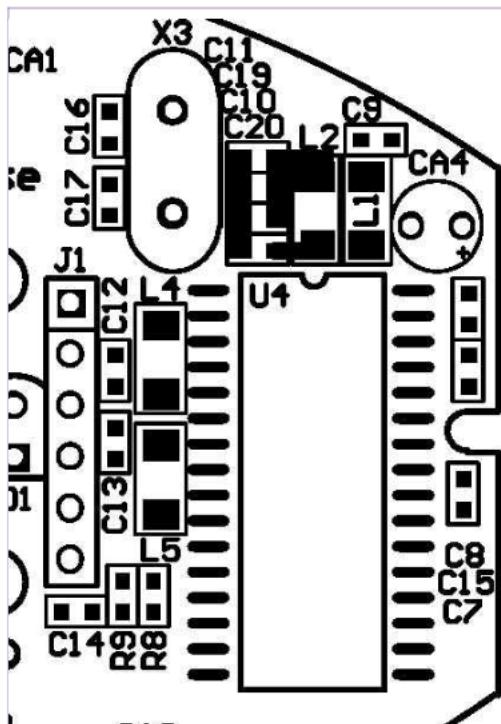


Fig 19. Example layout, placement

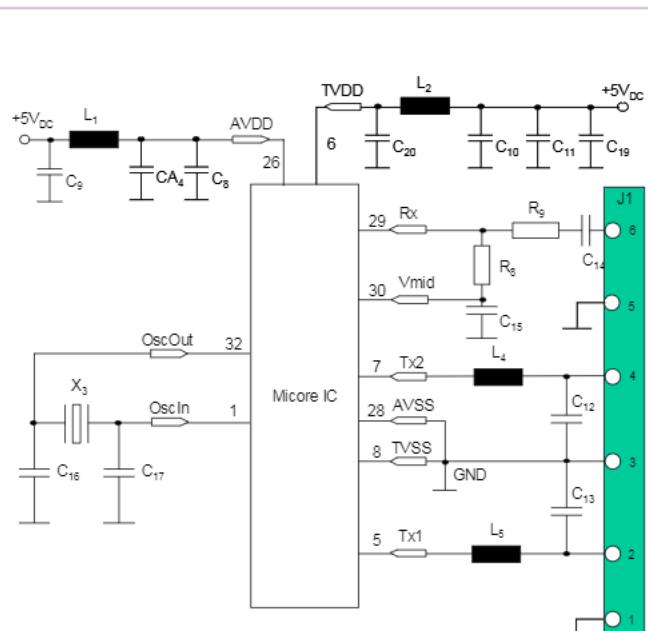


Fig 20. Example schematic

Table 7: Bill of Material

Part	Value	Remark
X ₃	13.56MHz	X-Tal
L ₁ , L ₂	22nH	Or 0Ω Jumper
L ₄ , L ₅	1 μH	Shielded, +/-5% tolerance
C ₁₂ , C ₁₃	68pF	NPO, +/-2% tolerance
C ₈ , C ₉ , C ₁₅ , C ₁₉	100nF	X7R
C ₁₄	1nF	NPO
C ₂₀	10pF	NPO
C ₁₀	100pF	NPO
C ₁₁	n.a.	
C ₁₆ , C ₁₇	15pF	NPO
CA4	10μF	
R ₈	820Ω	
R ₉	2.2kΩ	

6. Appendices

6.1 General Checklist for Micore antenna design

Table 8: Checklist

Parameter	Requirement	Comment	Check
Power	maximum	maximum operating distance	
I_{TVDD}	$I_{TVDD} < 150\text{mA DC}$	detuning has to be considered!	
U_{rxpin}	$1.5V_{pp} < U_{rxpin} < 3V_{pp}$	measured at pin 29	
Quality factor	$Q < 30$	check with oscilloscope	
Temperature influence	operating range	Min & max operating distance	
Temperature influence	$I_{TVDD} < 150\text{mA DC}$		
Environmental changes	operating range	Min & max operating distance	
Environmental changes	$I_{TVDD} < 150\text{mA DC}$		

6.2 Simple method for impedance measurement

If no impedance analyzer is available, the impedance measurement and tuning could be done with the following simple method.

The test setup consists of:

1. Signal generator (13.56 MHz)
2. Oscilloscope with low impedance probe
3. Measurement circuit as shown in [Fig 21](#)

The two probes of the oscilloscope ($C_{x\text{probe}}$ $C_{y\text{probe}}$) are connected to the function generator output and in parallel to the reference resistor. The oscilloscope displays a Lissajous figure, allowing us to derive the absolute magnitude and the phase. The magnitude is given by the angle of the Lissajous figure and the area as depicted in the figure below gives the phase.

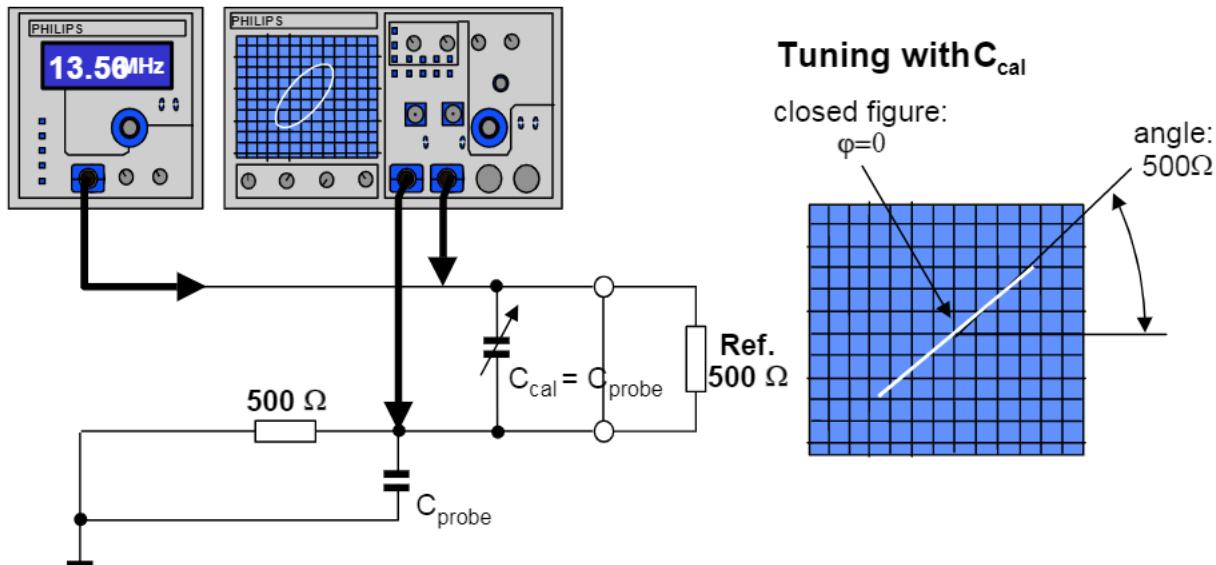


Fig 21. Simple impedance measurement, calibration

The x-probe capacitance $C_{x\text{probe}}$ only reduces the amplitude at the function generator output. This has no influence on the tuning results.

The y-probe capacitance $C_{y\text{probe}}$ affects a phase shift, which changes the area of the Lissajous figure. To compensate this effect, the capacitor C_{cal} is connected in parallel to the matching network.

The tuning procedure has to be done in two steps:

Step 1: Calibration

For the calibration a reference resistor of 500Ω has to be inserted instead of the antenna.

The calibration procedure is depicted in [Fig 21](#). The function generator shall be set to:

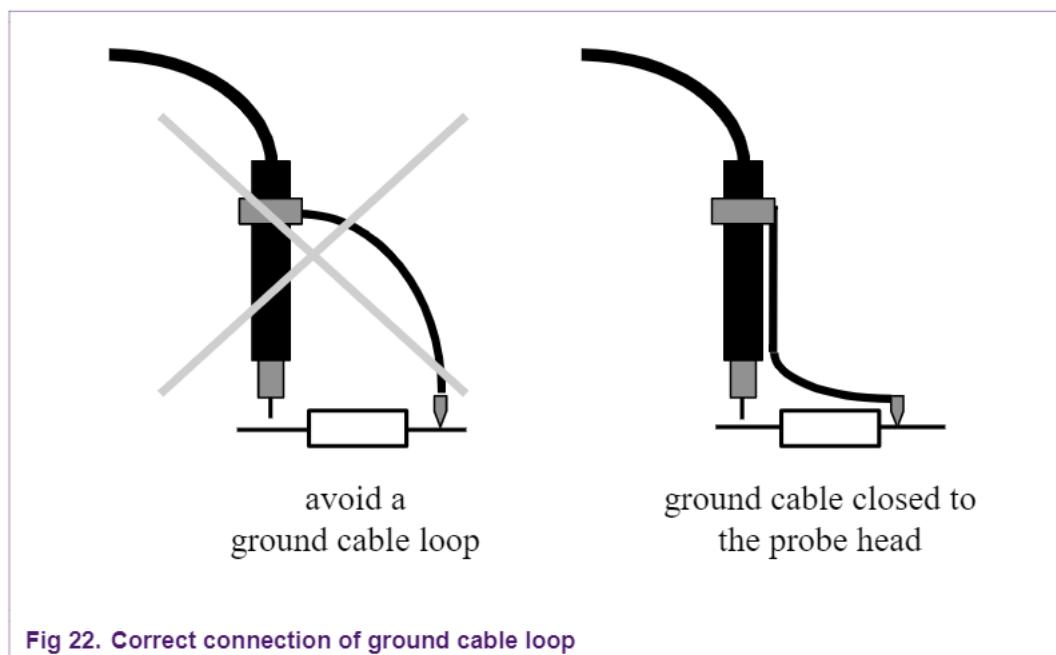
Table 9: Settings of function generator for calibration

Parameter	Value
Wave form:	Sinusoidal
Frequency:	13.56 MHz
Amplitude:	2V - 5V

The calibration capacitor has to be adjusted until the Lissajous figure is completely closed (phase = 0°). Then the calibration capacitance C_{cal} is equal to the capacitance C_y -probe. The y-probe voltage is in phase and the amplitude is exactly half of the function generator voltage (x-probe).

Remark: If the scale for the x-probe is chosen twice the scale for the y-probe (e.g. x-scale: 2V/DIV and y-scale: 1V/DIV) the Lissajous figure angle shall be 45 degree.

A loop of the ground cable of the probe shall be avoided to minimize inductive coupling from the antenna. The use of a low capacitance, high frequency probe is recommended.



Step 2: Tuning procedure:

After the calibration, the reference resistor has to be replaced by the antenna circuit (Z) as shown in [Fig 23](#). The matching network shall be tuned by the (variable) capacitors C_1 and C_2 until the Lissajou figure is completely closed. Now the Lissajou figure angle has to equal to the angle of the calibration step. In this case the impedance of the tuned antenna has $Z = 2 \cdot Z_{ant} = 500\Omega \cdot e^{0^\circ}$.

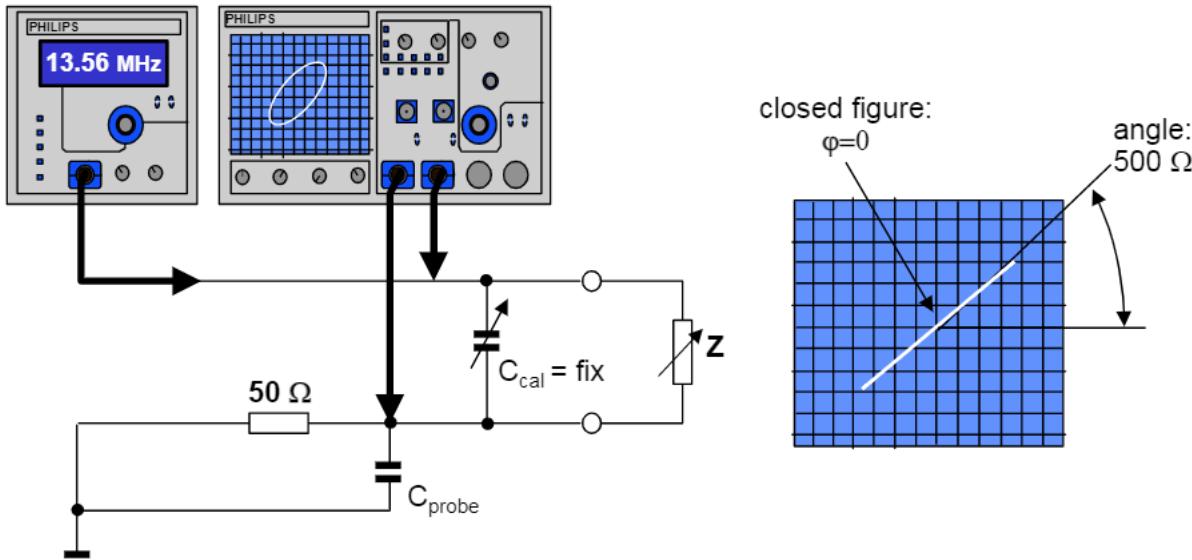


Fig 23. Simple impedance measurement, tuning procedure

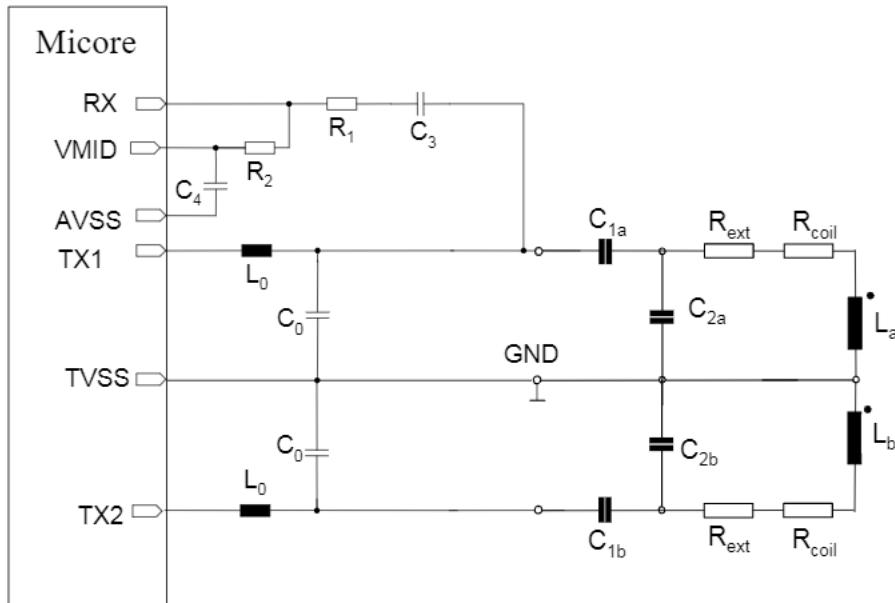
Notes to interpret the Lissajou figures:

- If the figure is not closed the phase between x and y is unequal to zero.
- If the angle $\phi=0^\circ$, the Lissajou figure is closed completely.
- If the angle is greater than 45° , Z is greater than 500Ω .
- If the angle is smaller than 45° , Z is greater than 500Ω

Remark: This calibration and tuning procedure principally may be done with any required impedance value. In praxis the environmental influences have to be considered. Therefore this method typically is limited to impedance values $< 1k\Omega$.

The impedance curve of an antenna (as shown in [Fig 9](#)) has two points of resonance, where the phase is 0° . It is only possible to tune the lower one of both these resonance frequencies (f_{LOW}) to the required $Z = 2 \cdot Z_{ant} = 500\Omega \cdot e^{0^\circ}$. To be sure that the tuning is done to the lower resonance frequency, it is recommended to reduce the calculated value for C_1 and C_2 by 40% and add tuning capacitors in that range: Start the tuning with the lowest values for the tuning capacitors.

6.3 All formulas on one page



$$L_0 = 1 \mu H$$

$$C_3 = 15 \text{ pF}$$

$$C_4 = 100 \text{ nF}$$

$$R_1 = 470 \Omega \dots 2.7 k\Omega$$

$$R_2 = 820 \Omega$$

$$Z_{ant} = Z = 500 \Omega = (500 + j0) \Omega = 500 \Omega \cdot e^{j0^\circ}$$

Fig 24. Schematic diagram and component values

Measured Coil: $L = L_a + L_b \quad R_L = 2 \cdot R_{coil}$

Symmetry: $L_a = L_b \quad Z_a = Z_b = \frac{Z_{ant}}{2}$

External resistor: $R_{ext} = \frac{1}{2} \cdot (R_L - R) = \frac{\omega L}{2 \cdot Q} - R_{coil} \quad \text{with } \omega = 2\pi \cdot 13.56 \text{ MHz}$

Parallel capacitor: $C_{2a} = C_{2b} = \frac{1}{\omega \cdot \sqrt{\left(\frac{\omega L}{1 - R/Z_a} \right)^2 - \frac{R^2 + \omega^2 L^2}{1 - R/Z_a} + \frac{\omega^2 L}{1 - R/Z_a}}}$

Serial capacitor: $C_{1a} = C_{1b} = \frac{R^2 + \left(\omega L - \frac{1}{\omega C_2} \right)^2}{\omega L \left(\frac{1}{\omega C_2} - \omega L \right) - \frac{R^2}{C_2}} \quad \text{with } Z_a = 250 \Omega$

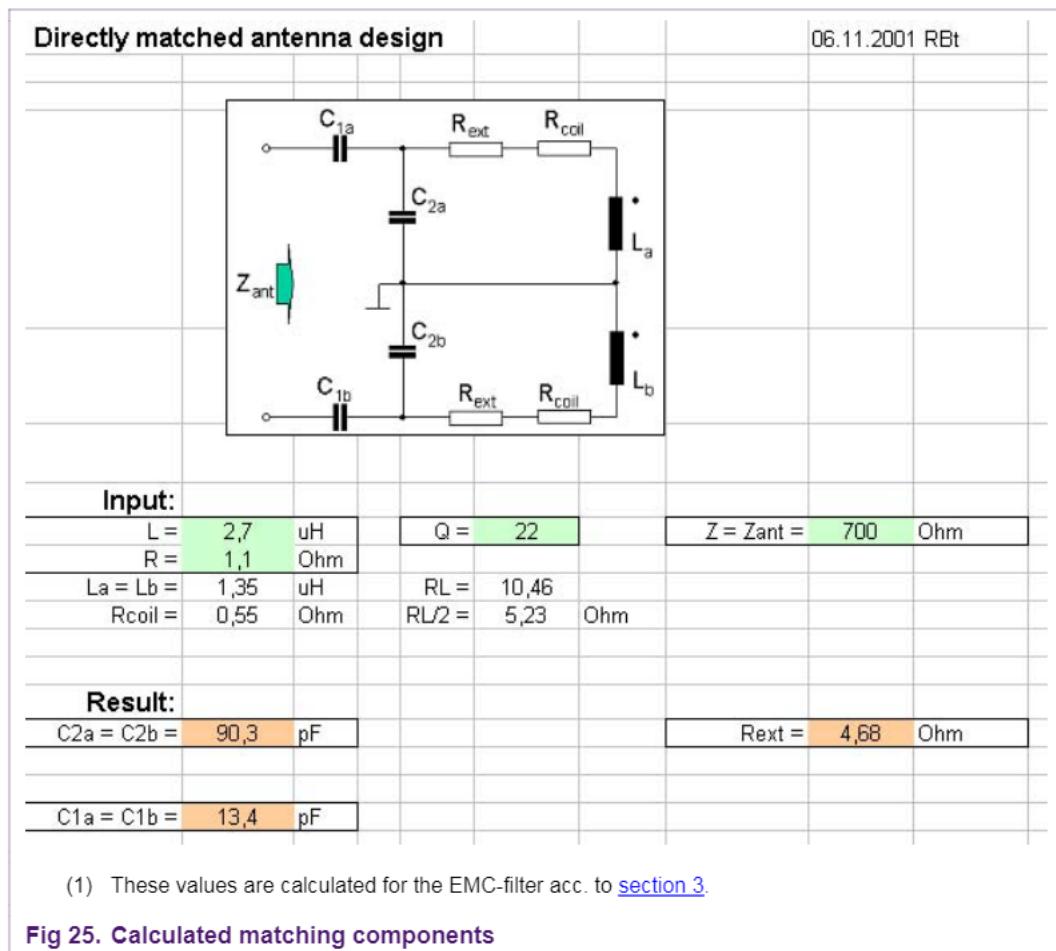
6.4 Antenna design example

In the following pages an antenna examples is shown. First of all the antenna coil is designed. In this example a two turns antenna with a rectangular size of 160mm x 180mm is used (one turn per each L_a and L_b). This coil is measured with an impedance analyzer.

Table 10: Example antenna coil
Inductance and resistance measurement, using an impedance analyzer

	L_s and R_s	L_s , R_s , and C_p (resonance equivalent circuit)
L	2.7 μH	2.5 μH
R	1.1 Ω	0.95 Ω
C	-	4pF

With these values the matching components can be calculated, using the spreadsheet:



Based on these values the tuning procedure is started, including the EMC low pass filter as proposed in [section 4.1.2](#). The resulting circuit is shown in [Fig 26](#), the component values are shown in [Table 11](#); and the matching result is shown in [Fig 27](#).

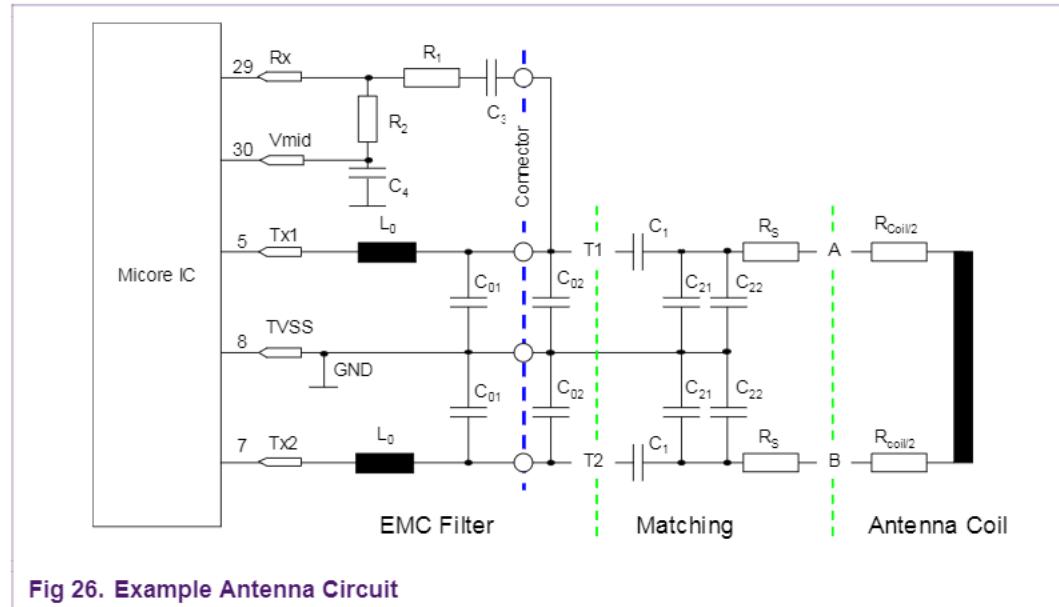
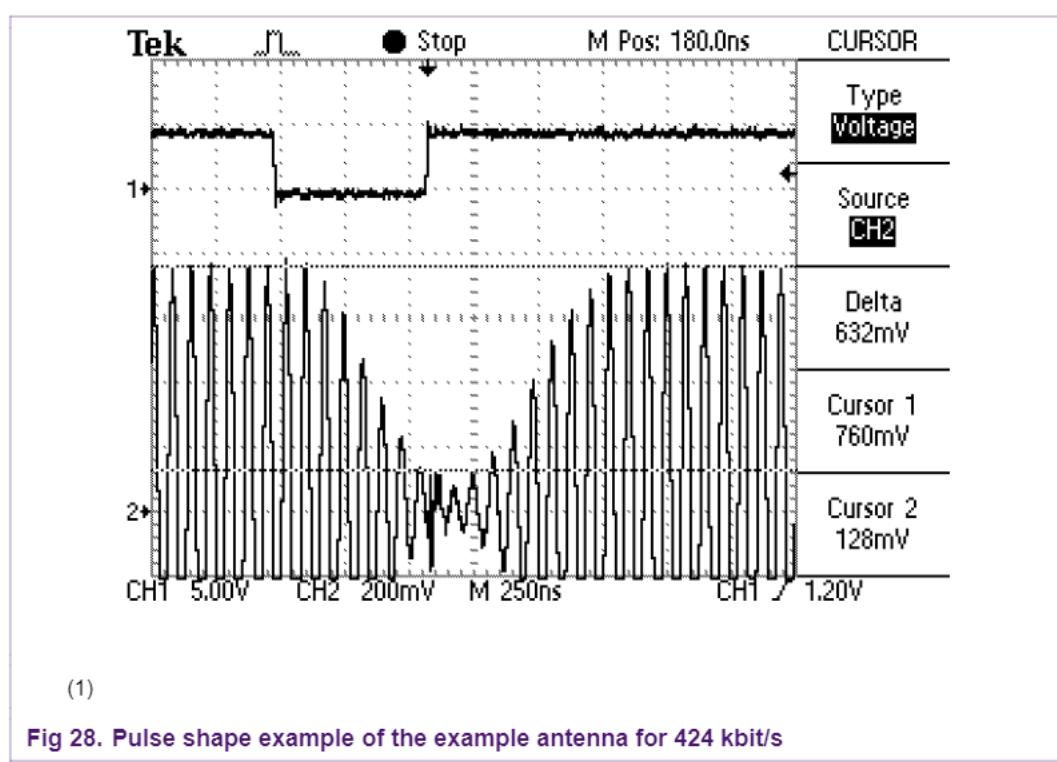
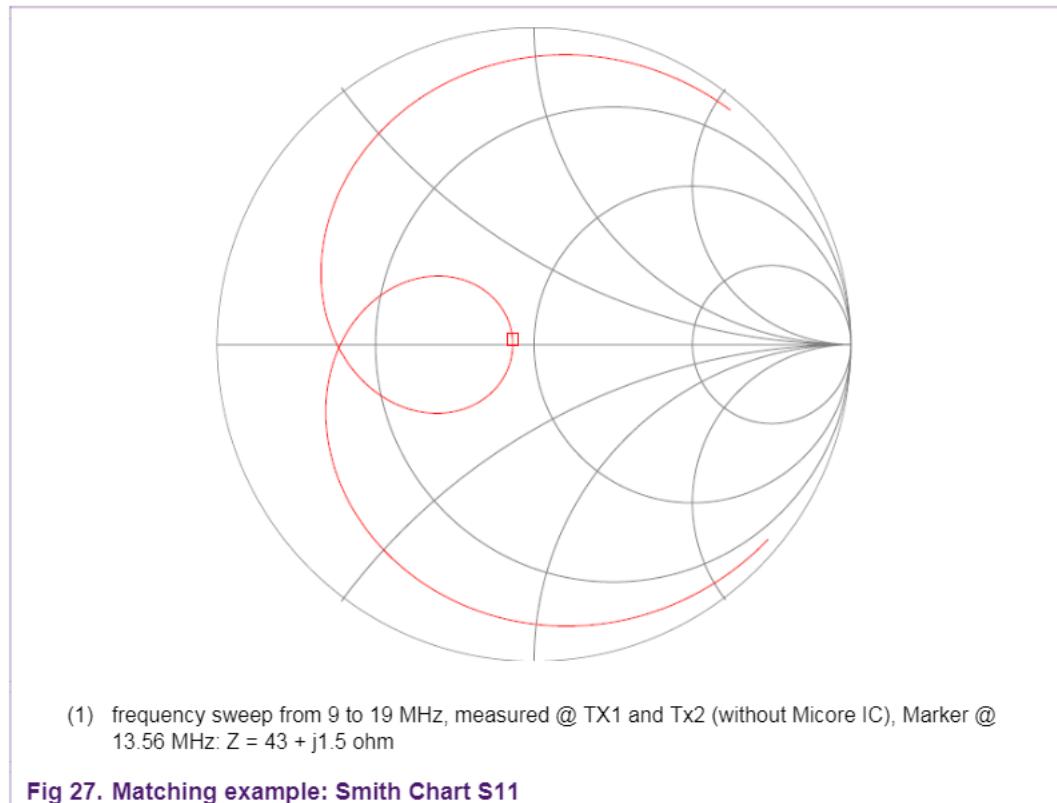


Fig 26. Example Antenna Circuit

Table 11: Resulting component values of the example antenna

Component	Value
L_0	1uH (e.g. TDK NL322522T-1R0J)
C_{01}	68pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_{02}	56pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_1	12pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_{21}	82pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_{22}	6.8pF each (Ceramic NP0, tolerance $\leq \pm 2\%$)
C_3	1nF (Ceramic NP0, tolerance $\leq \pm 10\%$)
C_4	100nF (Ceramic X7R, tolerance $\leq \pm 10\%$)
R_1	2.2 k Ω
R_1	820 Ω
R_S	4.7 Ω



This antenna meets the Q-factor requirements and fulfills the pulse shapes requirements according to [8], and with a driving current of $I_{TVDD} = 112\text{mA}$ and a receive voltage of $U_{RXAC} = 2.9\text{Vpp}$ at the receive pin an operating distance of approximately 10cm for a typical mifare card can be measured:

- >12cm (DESfire, $f_{res} = 14.6\text{MHz}$)
- >10cm (Mifare 1K, $f_{res} = 16.5 - 17\text{MHz}$)
- >10cm (2x Mifare 1K, each $f_{res} = 16.5 - 17\text{MHz}$)

7. Abbreviations

Table 12: Abbreviations

Acronym	Description
ATQA	Answer To reQuest type A
ATS	Answer To Select
BCC	Block Check Character (checksum)
CBC	Cipher-Block Chaining
f_c	Carrier frequency (13.56 MHz)
f_{res}	Resonance frequency
FSCI	Frame Size for proximity Card Integer
PCD	Proximity Coupling Device (ISO/IEC 14443 term for reader/writer unit)
PICC	Proximity Integrated Circuit Card
PPS	Protocol and Parameter Selection
RATS	Request for Answer To Select
REQA	REQuest type A
RFU	Reserved for Future Use
SAK	Select AcKnowledge
UID	Unique IDentification number

8. References

- [1] Mifare®(14443A) 13,56 MHz RFID Proximity Antennas; Application Note
- [2] ISO/IEC 14443 higher bit rates with Micore; Application Note
- [3] Data Sheet; SL RC400 I Code Reader IC
- [4] MIFARE® MF RC500; Highly Integrated ISO 14443A Reader IC
- [5] MIFARE® MF RC 530 ISO14443A reader IC
- [6] MIFARE® MF RC531; ISO 14443 Reader IC
- [7] MIFARE® and I Code CL RC632 Multiple protocol contactless reader IC
- [8] ISO/IEC14443 Identification cards - Contactless integrated circuit(s) cards - Proximity cards
- [9] ISO10373-6 Identification cards — Test methods part 6: Proximity cards

9. 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.

10. Trademarks

ICode — is a trademark of Koninklijke Philips Electronics N.V.

Mifare — is a trademark of Koninklijke Philips Electronics N.V.

11. Contents

1.	Introduction	3
1.1	How to use this document.....	3
2.	Micore antenna principle	4
3.	Basic parameter design for 106kbit/s.....	6
3.1	Given parameters	7
3.2	The antenna coil	9
3.3	Simplification due to symmetry	11
3.4	The external resistor	12
3.5	The parallel and serial capacitors	13
3.6	Tuning procedure.....	14
3.7	Checking the Q-factor and output current	16
3.7.1	Pulse shape according to ISO14443A	18
3.7.2	Pulse shape for the SL RC400 design	19
3.8	Receiving circuitry.....	20
4.	Full parameter design	21
4.1	Design requirements.....	22
4.1.1	Filtering the supply voltage	22
4.1.2	Resonance frequency of the EMC filter	22
4.1.3	Matching requirement	22
4.2	Required design steps	25
4.3	Impedance Matching & Resonance	26
4.3.1	Q-factor	26
5.	Additional design hints.....	27
5.1	Antenna functionality.....	27
5.2	Layout.....	27
6.	Appendices	30
6.1	General Checklist for Micore antenna design ...	30
6.2	Simple method for impedance measurement....	31
6.3	All formulas on one page	34
6.4	Antenna design example	35
7.	Abbreviations	39
8.	References.....	40
9.	Disclaimers	41
10.	Trademarks	41
11.	Contents.....	42



© Koninklijke Philips Electronics N.V. 2006

All rights are reserved. Reproduction in whole or in part is prohibited without the prior written consent of the copyright owner. The information presented in this document does not form part of any quotation or contract, is believed to be accurate and reliable and may be changed without notice. No liability will be accepted by the publisher for any consequence of its use. Publication thereof does not convey nor imply any license under patent- or other industrial or intellectual property rights.

Date of release: 10. May 2006
Document number:

Published in Austria