AN11019

CLRC663 Antenna Design Guide

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Application note
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Document information

Info	Content
Keywords	CLRC663, antenna tuning, directly matched antenna design, reader tuning, matching procedure
Abstract	This document describes the principles of antenna tuning for the contactless reader IC CLRC663. A practical example is given to tune an ID2±10 antenna for all baudrates according to ISO14443.

Revision history

Rev	Date	Description
0.2	20110601	Fig 1, Fig 11 and Section 7.3 Licenses updated
0.1	20110315	Initial Draft

Contact information

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1. Introduction

This application note is intended to give a practical guide to match an application specific antenna coil to the output driver of the RC663. The antenna is directly connected to the reader board without any cable in between the reader and the antenna.

2. How to use this document

The application note is intended to give a practical guide to design antennas and calculate the matching components for the CLRC663 RF part.

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

1. RF field generation and data transmission part
    a. The **RF part block diagram** in Fig. 5 shows a recommended circuitry design with all relevant components required to connect an antenna to the CLRC663. It also ensures the transmission of energy and data to the target device as well as the reception of a target device answer.
    b. The TX matching resistance R_{match} is explained which is required to calculate the remaining components and to optimize the RF system properties.
    c. Formulas to calculate the EMC filter and the matching circuit
    d. Antenna tuning procedure
2. Receiver part
    a. Design and calculation of the receiver part
3. Example calculations

Note: This application note does not replace the relevant specifications for the different operating modes.

"Card" or "Target device" in this document means a contactless smart card according to the ISO14443A (or MIFARE) scheme. Design hints on how to place the components on a PCB are not included.

Tuning and measurement of the reader 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.

3. General aspects

The RC663 device is designed to communicate in the following operation modes:

1. read/write mode supporting ISO/IEC 14443A/MIFARE
2. read/write mode supporting ISO/IEC 14443B
3. read/write mode supporting FeliCa scheme
4. read/write mode supporting ISO/IEC 15693
5. read/write mode supporting I ICODE EPC UID/ EPC OTP
6. read/write mode supporting ISO/IEC 18000-3 Mode 3

The communication distance is dependent on different factors including primarily

- the reader and card antenna size
- antenna area
- coupling between antennas
- generated Reader HF field
- minimum H-Field required by card
- environmental influences and other aspects.

The RC663's overall functionality can be separated into three functions:

1. **Generate the RF field**: The generated magnetic field has to be maximized within the limits of the transmitter supply current, general emission limits and requirements to protocol standards.
2. **Transmit data**: The coded and modulated data signal has to be transmitted in a way, that all supported card standards are able to receive it. The signal shape and timing according to relevant standards has to be considered.
3. **Receive data**: The response of a card or NFC passive device has to be transferred to the differential or single sided receive input of the RC663 considering various limits, e.g. maximum voltage and receiver sensitivity.

4. Matching the RC663

The **RF block diagram** shows the circuitry design with all relevant components required to connect an antenna to the CLRC663. It also ensures the transmission of energy and data to the target device as well as the reception of a target device answer.

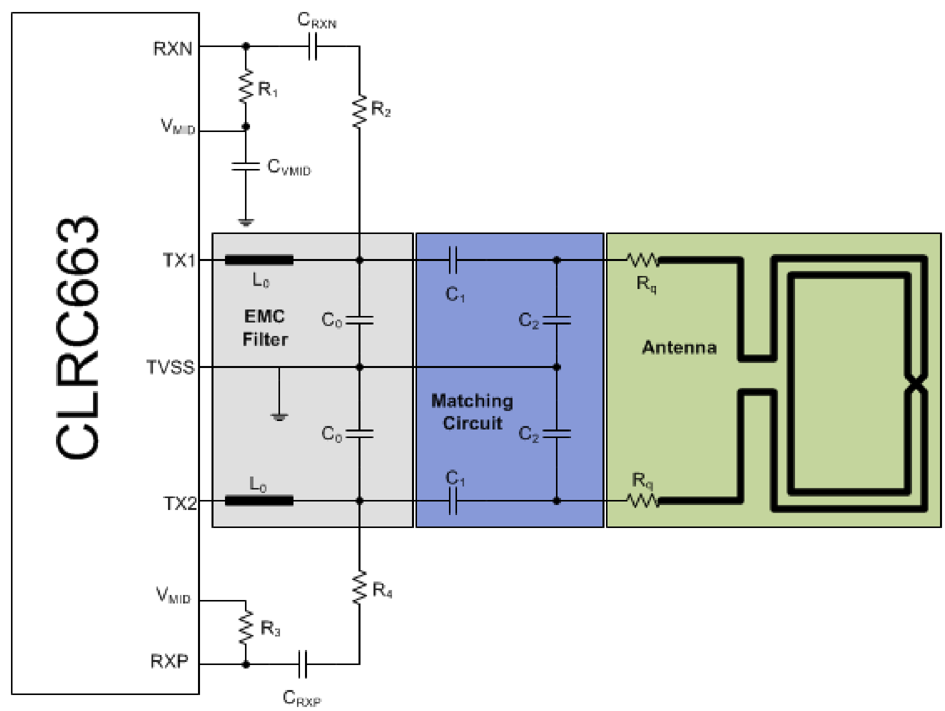


Fig 1. Antenna matching block diagram

The following blocks and their functionality have to be considered to guarantee the proper working of the complete device:

- The EMC filter reduces 13.56 MHz harmonics and performs an impedance transformation.
- The EMC filter coil has to be chosen according to Table 1
- 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 RC663 internal receiving stage.

Table 1. Component list and requirements 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, C_2	Typically 0603 or 0805 SMD parts with low tolerance (< ±2%). NP0 dielectric is required for temperature stability reasons. Voltage ratings must be higher than 200V.
C_{vmid}, C_{RX}	X7R capacitor (< ±10%)
L_0	The EMC inductance must have a Q<20 at 13.56Mhz. Current rating for the coil must be higher than 400mA.
R_1, R_2, R_3,R_4	0603 or 0805 SMD parts

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

5. Step 1 – Antenna Matching

The antenna is matched without powering the CLRC663. The basic transmitter matching can be also done without assembly of the IC.

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.

The antenna equivalent circuit (inductance, capacitance and resistance) and quality factor have to be determined first.

5.1.1 Determination of series equivalent circuit

The antenna loop has to be connected to an impedance or network analyzer to measure the series equivalent components. The analyzer has to be calibrated accordingly before measurements are done.

Note: The equivalent circuit (see Fig 7) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

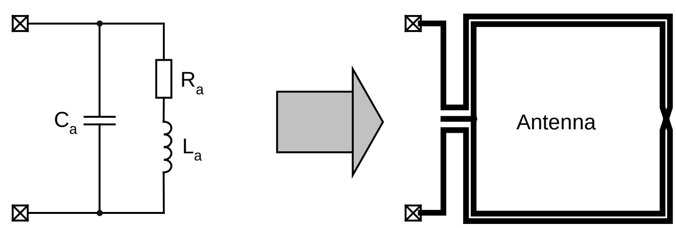


Fig 2. Series equivalent circuit

It is recommended to measure the inductance as well as the series resistance value at 1Mhz. The self resonance frequency and the parallel resistance can be obtained at the resonant point of the system where the imaginary part is zero.

Typical values:

L_a = 0.3...4µH

C_a = 3...30pF

R_a = 0.3...8Ω

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

The antenna capacitance C_a can be calculated with:

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

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

5.1.2 Calculation of damping resistor R_Q

The quality factor of the antenna is calculated with

$$Q_a = \frac{\omega \cdot L_a}{R_a} \quad (2)$$

If the calculated value of Q_a is higher than the target value of 30, an external damping resistor R_Q has to be inserted on each antenna side to reduce the Q-factor to a value of **30 (±10%)**.

The value of R_Q (each side of the antenna) is calculated by

$$R_Q = 0.5 \cdot \left(\frac{\omega \cdot L_a}{30} - R_a \right) \quad (3)$$

5.1.3 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=30.

Note: The equivalent circuit (Fig 8) must be determined under final environmental conditions especially if the antenna will be operated in metal environment or a ferrite will be used for shielding.

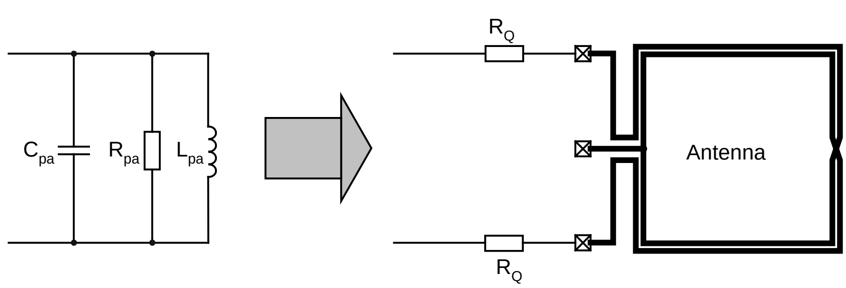


Fig 3. Parallel equivalent circuit

The following formula applies

$$L_{pa} \mathrel{\hat{=}} L_a$$
$$C_{pa} \mathrel{\hat{=}} C_a$$
$$R_{pa} \mathrel{\hat{=}} \frac{(\omega \cdot L_a)^2}{R_a + 2 \cdot R_Q} \quad (4)$$

5.2 EMC filter design

The EMC filter circuit for the PN544 fulfills two functions: the filtering of the signal and impedance transformation block. The main properties of the impedance transformation are:

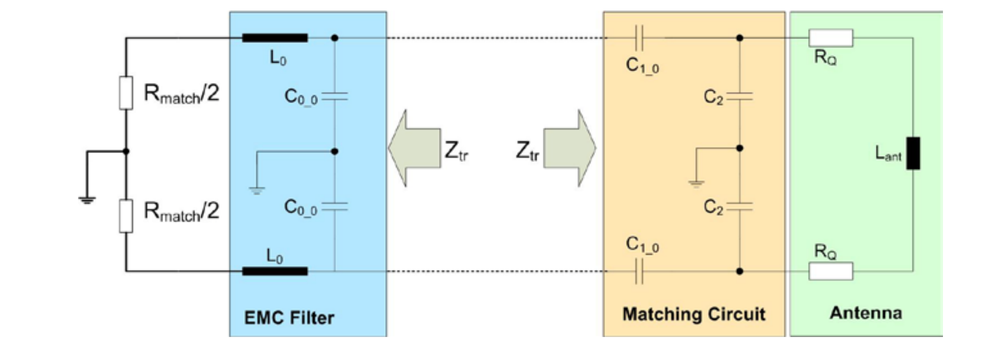


Fig 4. Impedance Transformation

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

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

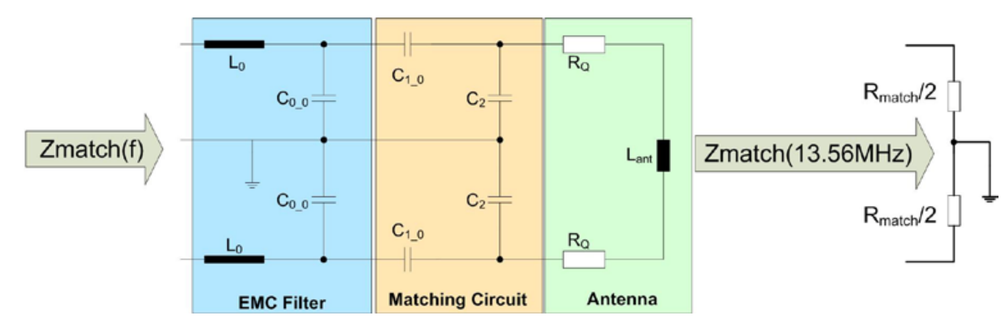


Fig 5. Definition of transformation impedance Ztr

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

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

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

$$Z_{tr} = R_{tr} + jX_{tr} \quad (5)$$

$$Z_{tr}^{*} = R_{tr} - jX_{tr} \quad (6)$$

EMC filter general design rules:

L_0 = 390nH - 1µH

Filter resonance frequency f_{r0} = 21 MHz, => C_0

$$C_0 = \frac{1}{(2 \cdot \pi \cdot f_{r0})^2 L_0} \quad (7)$$

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

Example:

L_0 = 470nH

f_{r0} = 21MHz

C_0 = 122.2pF → chosen: 120pF

A recommended value of 470nH for L_0 is chosen to calculate the capacitance C_0. The following formulas apply for Z_{ant} = Re(Z_{ant})+Im(Z_{ant}) and are needed to calculate the matching components.

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

$$X_{tr} = 2 \cdot \omega \cdot \frac{L_0 \cdot (1 - \omega^2 \cdot L_0 \cdot C_0) - \frac{R_{match}^{\;2}}{4} \cdot C_0}{(1 - \omega^2 \cdot L_0 \cdot C_0)^2 + \left(\omega \cdot \frac{R_{match}}{2} \cdot C_0\right)^2} \quad (9)$$

5.3 Matching circuit design

5.3.1 Component calculation

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

$$C_1 \approx \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{tr} \cdot R_{pa}}{4}} + \frac{X_{tr}}{2} \right)} \quad (10)$$

$$C_2 \approx \frac{1}{\omega^2 \cdot \frac{L_{pa}}{2}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{tr} \cdot R_{pa}}{4}}} - 2 \cdot C_{pa} \quad (11)$$

Finally, a fine tuning of the matching circuit is often necessary, since the calculated values are based on simplified equations and the equivalent circuit values contain some errors as well.

5.4 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 CLRC663 TX pins. The matching impedance $Z_{match} = R_{match} + jX_{match}$ is measured with an impedance or network analyzer. The Z_{match} point between TX1 and TX2 as shown in Fig 12 is the probing point for the network/impedance analyzer.

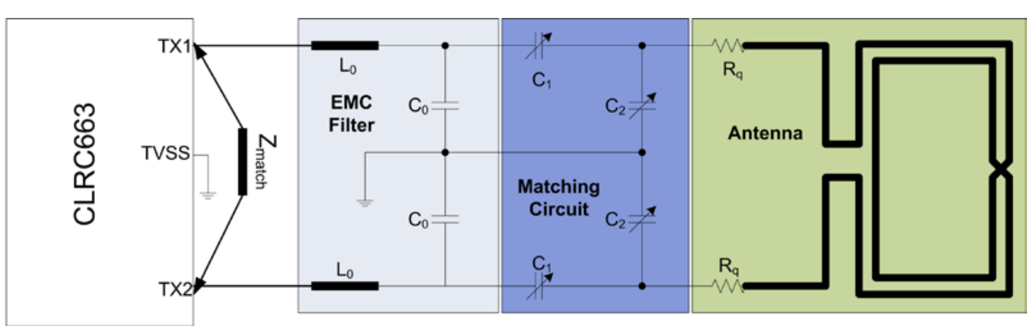


Fig 6. Measurement of matching impedance

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

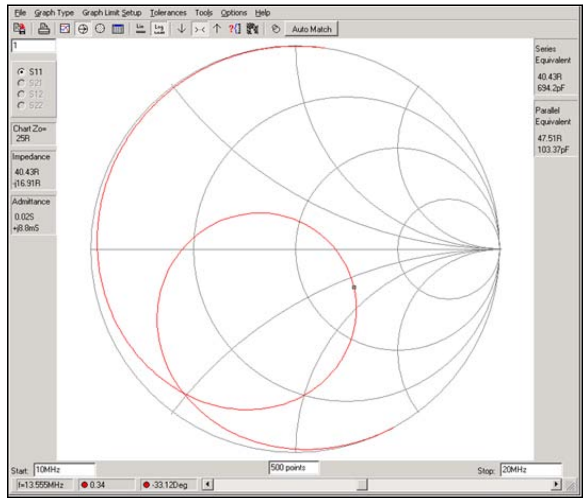


Fig 7. Smith chart for matching impedance

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

5.4.1 Transmitter matching resistance R_{match}

The transmitter (TX) matching resistance R_{match} defines the equivalent resistance at the operating frequency present between the transmitter output pins TX1 and TX2 of the CLRC663. Different equivalent resistive loads lead to different transmitter supply currents.

The optimum matching resistance is dependent on antenna shape, size and end application

An optimum tuning R_{match} for RC663 is between 40-80Ohm

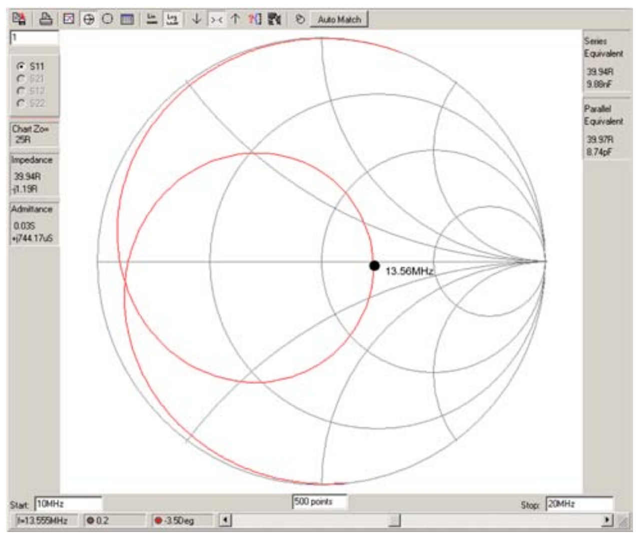
This tuning is measured in an unloaded condition

5.5 Impact of the tuning capacitors visualized on Smith chart

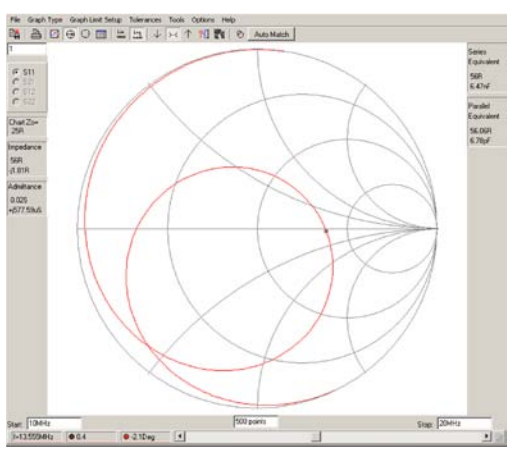
5.5.1 EMC capacitance C0

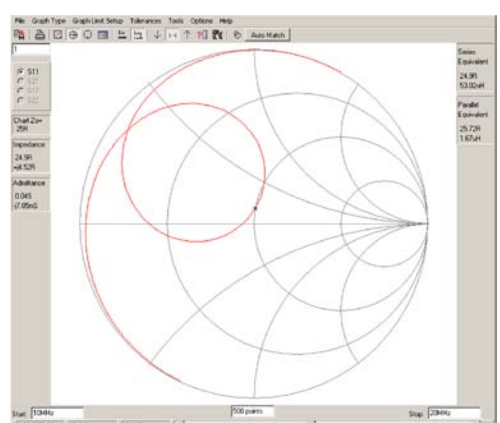
The following diagrams show the effect to the impedance curve by changing C0.

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



a. C0 reference value





b. C_0 lower than reference value

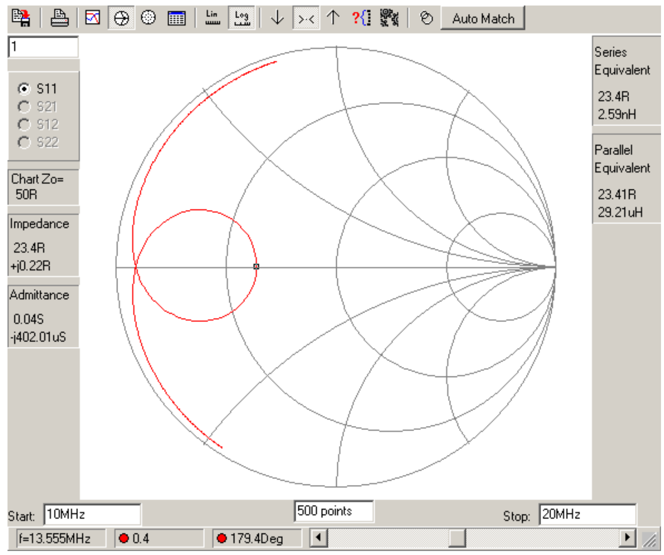
c. C_0 higher than reference value

Fig 8. Smith charts for C0 tuning

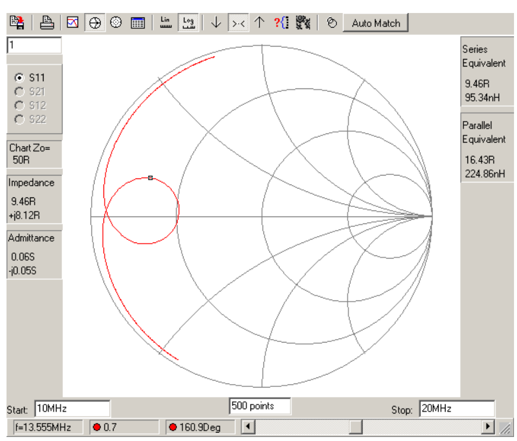
5.5.2 Series capacitance C1

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

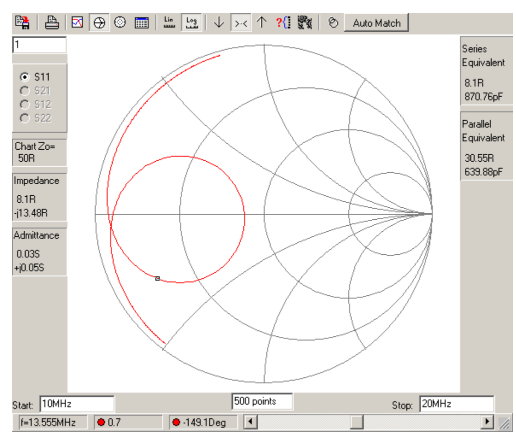
The smith charts in Fig 15 show the matching impedance Z_{match}/ 2 vs. frequency.



d. C_1 reference value



e. C_1 lower than reference value



f. C_1 higher than reference value

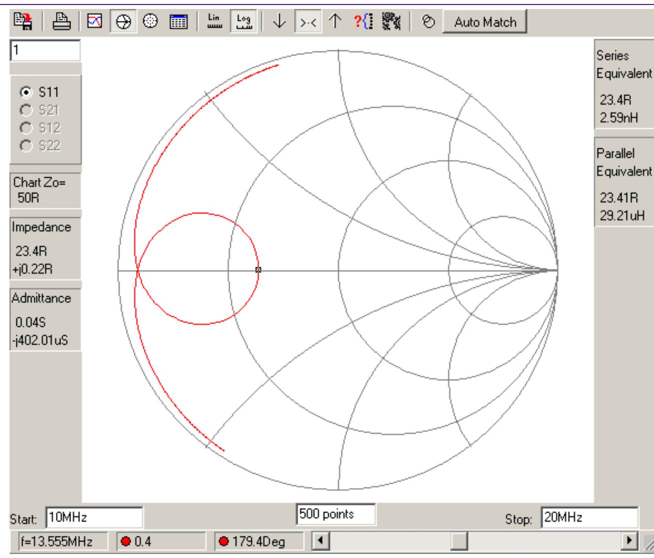
Fig 9. Smith charts for C1 tuning

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

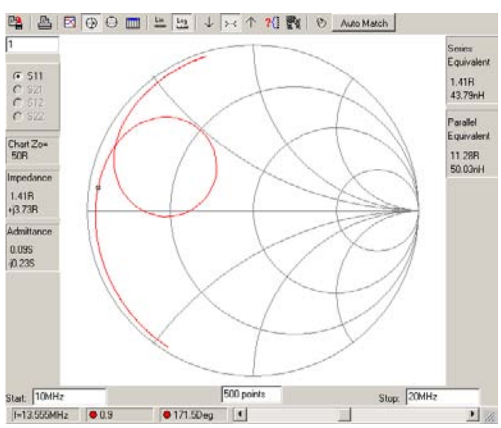
5.5.3 Parallel matching capacitance C2

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

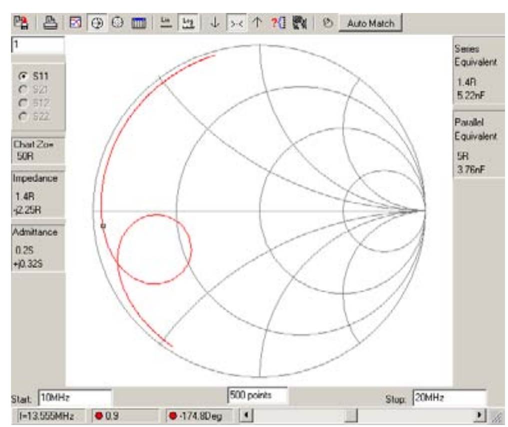
The smith charts show the matching impedance Z_{match} / 2 vs. frequency.



g. C2 reference value



h. C_2 lower than reference value



i. C_2 higher than reference value

Fig 10. Smith charts for C2 tuning

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

5.6 Receiver circuit design

Next step, after matching and tuning the Reader/Writer antenna, is the design and tuning of the receiver circuit. The investigations need to be carried out under various antenna loading effects like presenting different cards, mobile phones, etc.

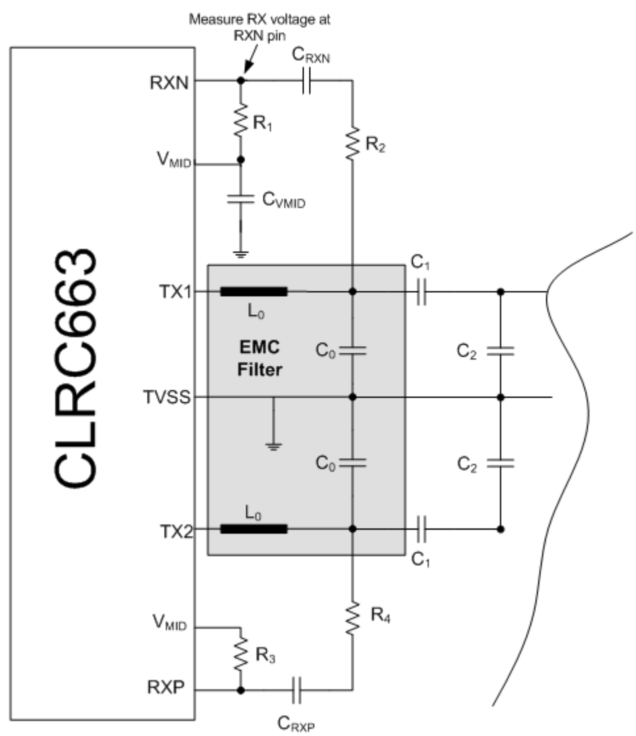


Fig 11. Receiver Circuit

Fig 11 shows the relevant components for the receiver circuit.

The internal receiving concept of the CLRC663 makes use both side-bands of the sub-carrier load modulation of the card response via a differential receiving concept (RXP,RXN). No external filtering is required. It is recommended to use the internally generated VMID DC potential as the input potential of pin RXN and RXP. This DC voltage level of VMID has to be coupled to the RX-pins via R1 and R3. To provide a stable DC reference voltage, capacitances C_{VMID} has to be connected between VMID and ground.

Considering the (AC) voltage limits at the Rx-pins the AC voltage divider of R1 and R2 as well as R3 and R4 has to be designed. Depending on the antenna coil design and the impedance matching the voltage at the antenna coil varies from antenna to antenna. Therefore, the recommended way to design the receiving circuit is to use the given starting values for R1 (=R3) and R2(=R4) and adjust the voltage at the RX-pins by varying R2(=R4) in respect to the RX input limits.

The voltage U_{RX} on RXN pin must be measured with a low capacitance probe (< 2 pF) for continuous transmitting mode

The voltage U_{RX} must not exceed the maximum value U_{RXmax}=1.7Vpp even when the antenna is detuned by a target or passive card

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

1. **CLRC663 antenna not detuned**
2. **CLRC663 antenna loaded under various conditions**

6. Matching Recommendations

Antennas of different shapes must be individually matched to the CLRC663. The tuning is dependent on the requirements (e.g. baud rates, protocols, environment, etc.) of the end application. The following subchapters explain matching recommendations for antennas with form factors of ID2 +10%.

6.1 Matching Recommendations for Antenna Size ID2

This chapter explains the matching procedure of a 2turn ID2 (+10%) antenna for the ISO14443 protocol for all baud rates.

The recommended matching impedance at 13.56Mhz is $R_{match} \approx$ 50Ohm + j0.

The EMC filter resonance frequency recommendation is $f_{res\ EMC} \approx$ 21Mhz

The following Fig shows the target matching for this antenna size. The matching steps are described below.

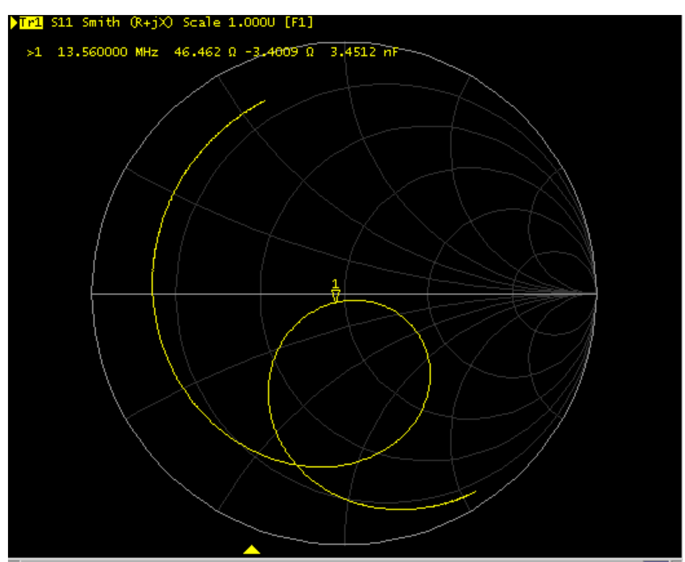


Fig 12. Matching impedance diagram for ID1 antenna

At first, the series equivalent parameters of the antenna have to be determined using a network analyzer. Details can be found in chapter 5.

Measurement results:

R_a = 0.33Ohm

$C_a \approx$ 7pF

L_a= 1.2µH

$R_p \approx$ 3,8kOhm

The calculation for the external damping resistor for a quality factor of 10 results to R_Q = 4.3Ohm. The chosen value for R_Q is 4.7Ohm; the high damping resistor and low Q factor is required for realizing the tight modulation requirements for higher baudrates.

The provided excel sheet for matching calculation will help to determine the remaining components.

The parallel equivalent circuit (calculated at a frequency of 13.56Mhz) of the antenna including quality factor damping resistors R_Q = 4.7Ohm is determined with the following values:

R_{pa} = 7.7kOhm

C_{pa} = 6,7pF

L_{pa}= 1.2µH

The EMC filter is determined with:

$R_{res\ EMC} \approx$ 21Mhz

L_0 = 470nH

C_0 = 56pF+68pF

Calculation of Z_{tr}:

R_{tr} = 155Ohm

X_{tr} = 28.9Ohm

Calculation of the matching parts C_1, C_2

C_1 = 57.10pF → 50pF normalized value

C_2 = 154.9pF → 162pF normalized value

The receiver path has been assembled with R2=22 kOhm and R1=1kOhm

The receiver is connected at the antenna between the points of C1 and C2.

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10. Contents

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