AN5592

Application note

ST25R single ended antenna matching

Introduction

This application note is a design guide for antennas, to be used together with the ST25R antenna matching tool.

The examples are based on ST25R3911 and ST25R3916 devices, but the document scope extends to all products listed in Table 1

Table 1. **Applicable products**

Type	Part number
ST25 NFC / RFID Tags and Readers	ST25R3911B ST25R3911 ST25R3912 ST25R3914 ST25R3915 ST25R3916 ST25R3917 ST25R3918 ST25R3920

1 Overview

ST25R antenna matching tool software supports the calculation of the matching component for differential antenna, single ended and single ended antenna with cable.

The antenna interface stage can be set up as a single ended topology or as a differential one.

Along with the tool an open source simulator is provided for basic system validation via simulation.

This document is based on the ST25R3916 device, for each device there are five different configuration files, listed in Table 2.

Table 2. Configuration files for ST25R3911/16

ST25R3911	ST25R3916
3911-differential	3916-differential
3911-differential-aat	3916-differential-aat
3911-single-ended	3916-single-ended
3911-single-ended-aat	3916-single-ended-aat
3911-single-ended-cable	3916-single-ended-cable

2 Overview matching topologies

2.1 Differential antenna

The differential antenna allows higher linearity and lower offset and makes them immune to power supply variations, temperature changes and substrate noise.

This antenna design is recommended for low power application, because gives the best range.

The entire antenna interface stage consists of EMC filter, matching network, RX voltage divider and antenna equivalent circuit together with the resistor for setting up or adjusting the Q-factor. The EMC filter is a one stage filter built up of a series inductor and a parallel capacitor to ground. The matching network consists of a series and a parallel capacitor and the resistor for the Q-factor adjustment, which can be series or parallel resistor.

The voltage divider for the receive path is capacitive and connected directly at the antenna pins.

Figure 1. ST25R3911/3916-differential

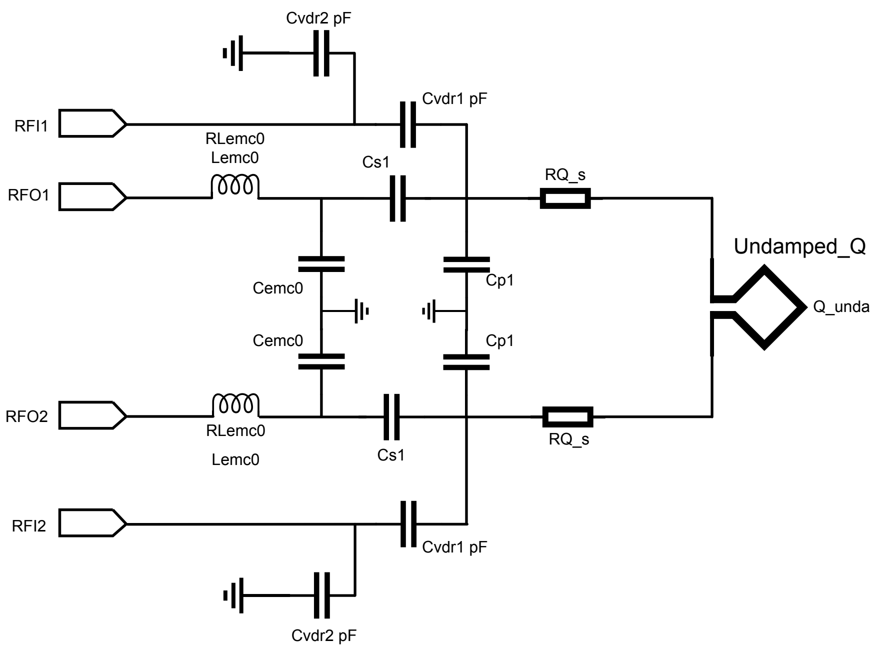


Figure 2. Device used for differential antenna

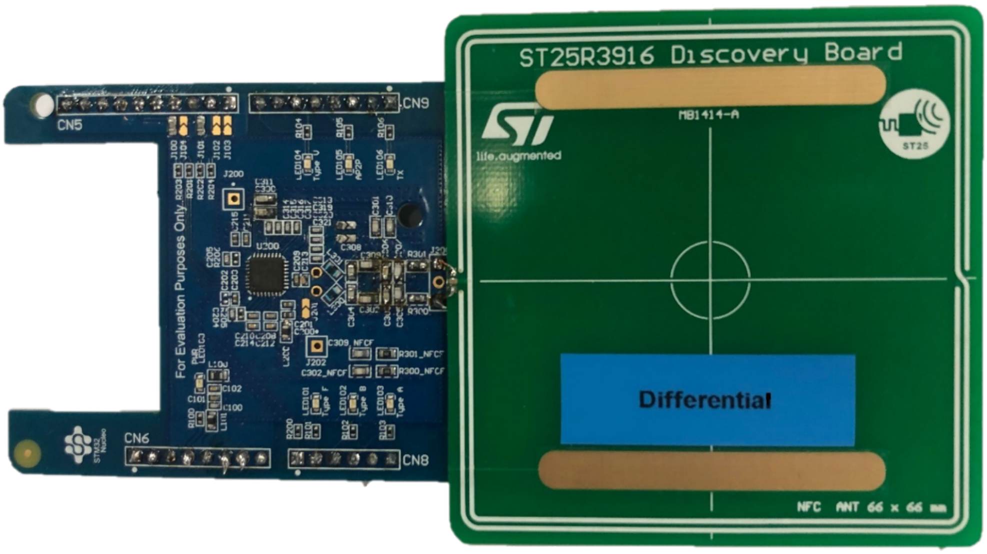


Table 3. Matching components for differential antenna

C_s [pF]	C_p [pF]	R_{q_s} [Ω]	C_{vdr1} [pF]	C_{vdr2} [pF]
52	70	0.82	10	135

2.2 Single ended antenna

Compared with differential antennas topology, single ended antennas have less components and therefore require less area.

By definition, single ended signal is unbalanced and is measured by the difference between the signal and a constant reference point, ground. Single ended or unbalanced signals are more prone to noise and interference.

Single ended antenna consists of EMC filter, matching network, RX voltage divider and antenna equivalent circuit together with the resistor for the Q-factor. The EMC filter is a one stage filter built up of a series inductor and a parallel capacitor to ground. The matching network consists of a series and a parallel capacitor and the resistor for the Q-factor adjustment, which can be series or parallel resistor.

For single ended antenna it is necessary to remove the EXT_LM circuit for ST25R3916 devices.

Figure 3. ST25R3911/3916-single ended

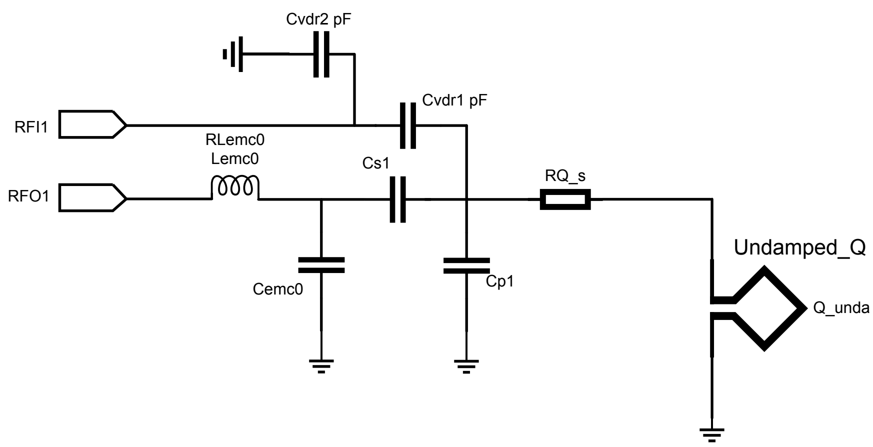


Figure 4. Device used for single ended antenna

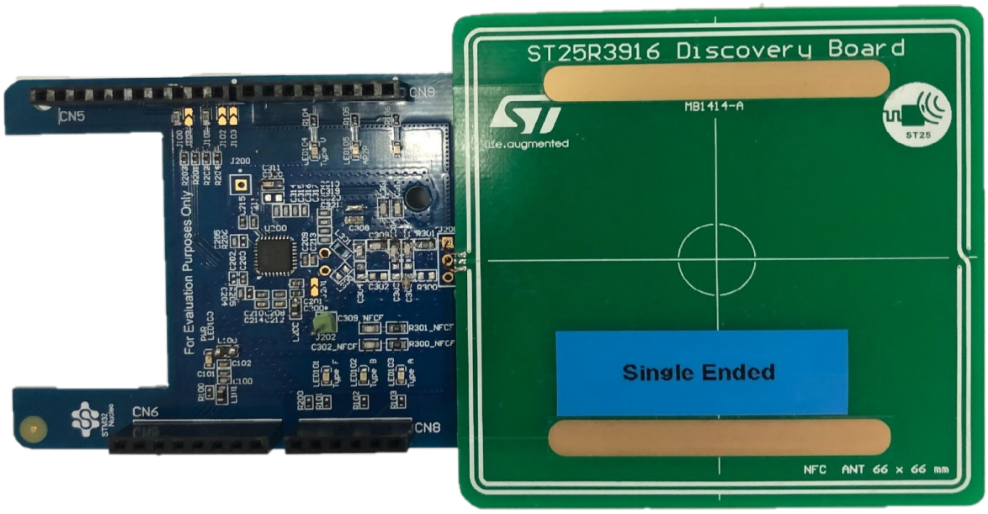


Table 4. Matching components for single ended antenna

C_s [pF]	C_p [pF]	R_{q_s} [Ω]	C_{vdr1} [pF]	C_{vdr2} [pF]
78	220	1.6	10	212

2.3 Single ended antenna with cable

Single ended antenna with cable consists of EMC filter, matching network, cable, RX voltage divider and antenna equivalent circuit together with the resistor for the Q-factor. The EMC filter is a one stage filter built up of a series inductor and a parallel capacitor to ground. The matching network consists of a series and a parallel capacitor and the resistor for the Q-factor adjustment, which can be series or parallel resistor. The two important cable parameters are: cable length and characteristic impedance (Z0).

It is possible to connect a dedicated antenna to an NFC reader. The used cable has a specific characteristic impedance. It is required to first transform from the target matching impedance to the characteristic impedance of the cable. The antenna itself also requires a matching network, which tunes the antenna to the same characteristic impedance.

This antenna interface stage can be set up only for a limited number of target matching Z (for example 4 Ohm, 8 Ohm and 16 Ohm). Compared to the conventional inductive antenna, the characteristic impedance of a cable is a real number without imaginary part. In this case, there are less mathematical solutions leading to a less possible target matching impedances. The variation of EMC inductor value and cut-off frequency as well as the characteristic impedance of the cable can have great influence on the possible solutions.

Figure 5. ST25R3911/3916-single-ended with cable

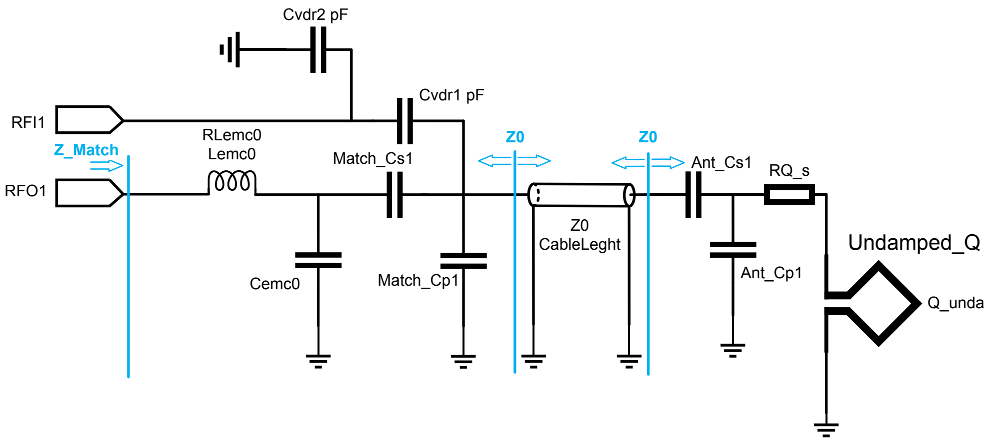


Figure 6. Device used for single ended antenna with cable

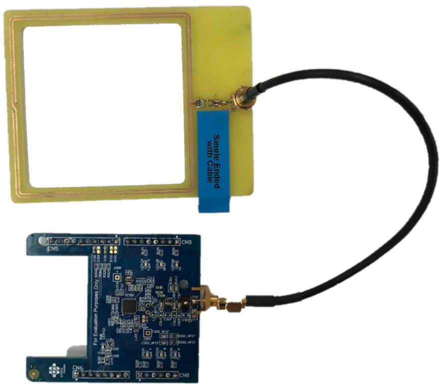


Table 5. Matching components for single ended antenna with cable

C_s [pF]	C_p [pF]	R_{q_s} [Ω]	C_{vdr1} [pF]	C_{vdr2} [pF]
584	39	0	10	15

Table 6. **Matching components for 50 Ω antenna**

Ant_Cs [pF]	Ant_Cp [pF]	R [Ω]
36	104	2.7

2.4 Automatic antenna tuning (AAT)

AAT configuration is used only for differential and single ended antenna, not possible for single ended antenna with cable due to the presence of the coaxial cable. Any change in cable parameters results to de-tuning reader.

Typical tuning component values (C_{Max} to C_{Min}) are in the range of 200 pF to 100 pF, 100 pF to 50 pF and 50 pF to 25 pF.

The ideal tuning range depends on the chosen antenna SRF (self resonant frequency) and application. An higher antenna SRF requires a bigger parallel capacitor to tune the antenna to 13.56 MHz. The EMC filter inductance value can be used to change the series capacitance value by keeping the same EMC cut-off filter frequency. This change influences the required series capacitance value to achieve the same matching impedance.

Table 7. **AAT**

C_P (device as V_{CC})	C_S (device as V_{CC})
STPTIC-0N050 (17.5 pF…50 pF)	STPTIC-0N0200 (>67.5 pF)
STPTIC-0N100 (35 pF…100 pF)	STPTIC-0N0200 (>67.5 pF)
STPTIC-0N0200 (75 pF…200 pF)	STPTIC-0N0200 (>67.5 pF)

The entire antenna interface stage consists of EMC filter, AAT, matching network, RX voltage divider and antenna equivalent circuit together with the resistor for the Q-factor. The EMC filter is a one stage filter built up of a series inductor and a parallel capacitor to ground. The matching network consists of a series and a parallel capacitor and the resistor for the Q-factor adjustment, which can be series or parallel resistor.

Figure 7. **ST25R3911-differential-aat**

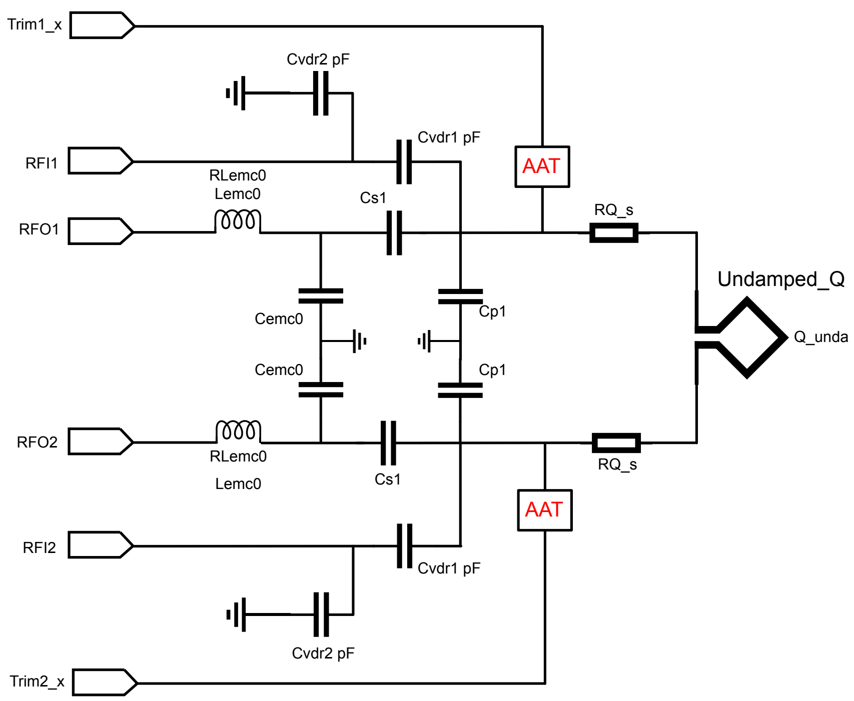


Figure 8. ST25R3916-differential-aat

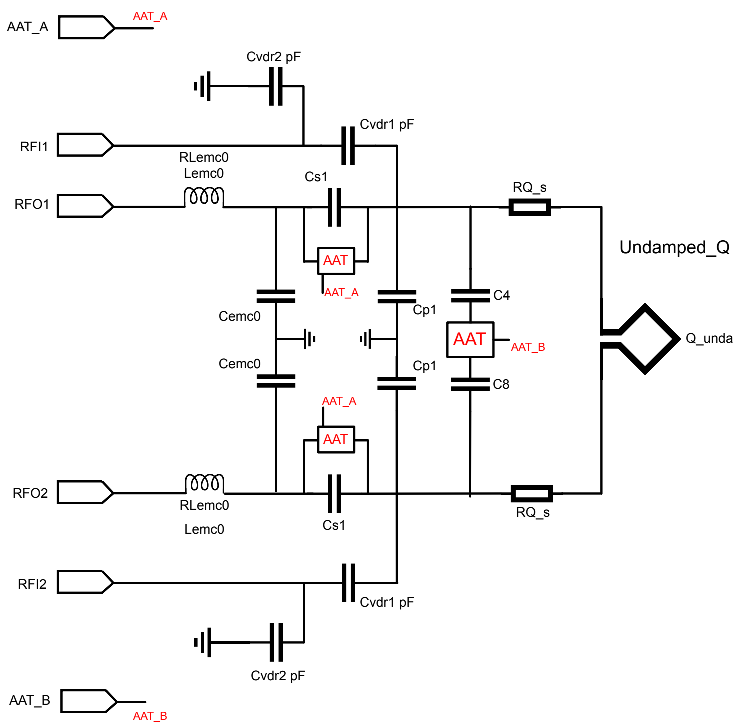
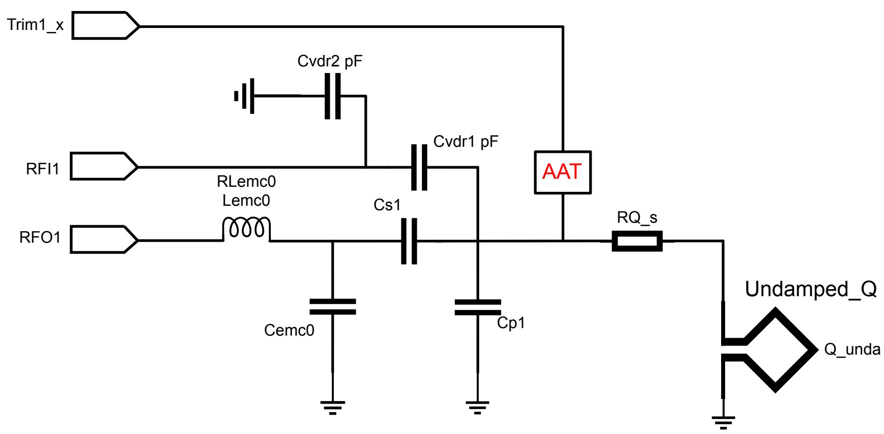


Figure 9. ST25R3911-single-ended-aat



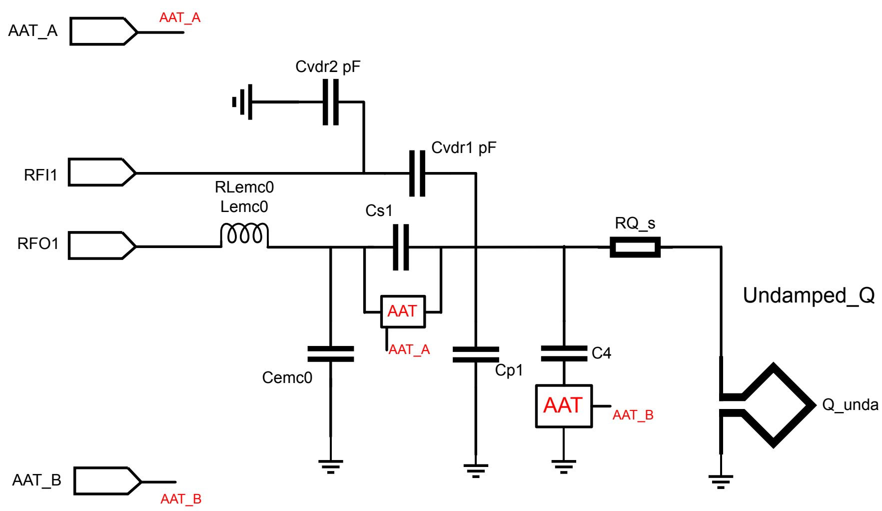


Figure 10. **ST25R3916-single-ended-aat**

3 Antenna matching

3.1 Differential antenna

ST25R antenna matching tool software for each type of antenna uses different formula for calculation. To get formula for matching components it is necessary to analyse the whole circuit (circuit for differential antenna, circuit for single ended antenna and circuit for single ended antenna with cable).

The formulas used for calculation are:

$$R_{match} = \text{"Target matching Z"} - 2 \cdot \text{DC Resistance}$$

$$R_{total} = Q_{chosen} \cdot 2 \cdot \pi \cdot f_{work} \cdot L_{ant}$$

$$R_{TR} = \frac{\mathrm{R_{match}}}{\left(1 - \omega^2 \mathrm{L_{emc}} \mathrm{C_{emc}}\right)^2 + \left(\omega \cdot \frac{\mathrm{R_{match}}}{2} \cdot \mathrm{C_{emc}}\right)^2}$$

$$X_{TR} = 2 \cdot \omega \cdot \frac{\mathrm{L_{emc}}\left(1 - \omega^2 \mathrm{L_{emc}} \mathrm{C_{emc}}\right) - \frac{\mathrm{R_{match}}}{4} \cdot \mathrm{C_{emc}}}{\left(1 - \omega^2 \mathrm{L_{emc}} \mathrm{C_{emc}}\right)^2 + \left(\omega \cdot \frac{\mathrm{R_{match}}}{2} \cdot \mathrm{C_{emc}}\right)^2}$$

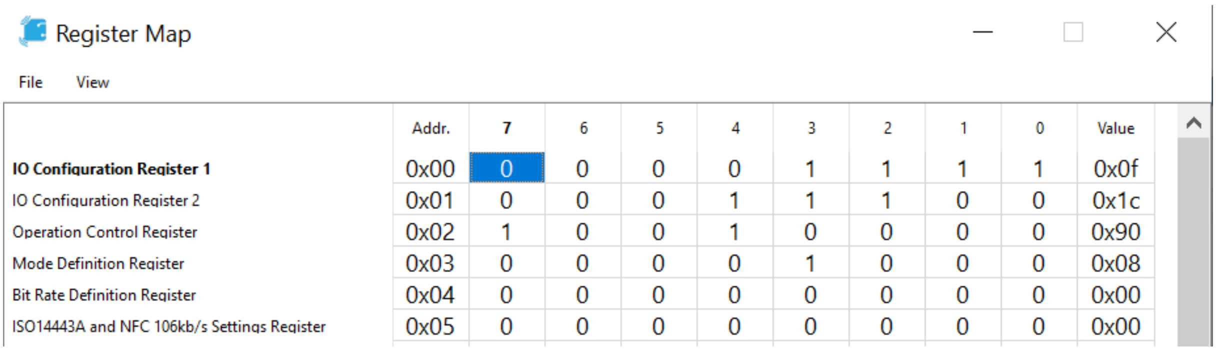
In this case, the values of matching components for C_S and C_P are calculated using these two formulas:

$$C_S = \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{TR} \cdot R_{total}}{4}} + \frac{X_{TR}}{2}\right)}$$

$$C_P = \frac{1}{\omega^2 \cdot \frac{L_{ant}}{2}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{TR} \cdot R_{total}}{4}}} - 2 \cdot C_{ant} - \frac{CVDR_1 \cdot CVDR_2}{CVDR_1 + CVDR_2}$$

Register map: IO configuration register 1

Figure 11. Register setting



	Addr.	7	6	5	4	3	2	1	0	Value
IO Configuration Register 1	0x00	0	0	0	0	1	1	1	1	0x0f
IO Configuration Register 2	0x01	0	0	0	1	1	1	0	0	0x1c
Operation Control Register	0x02	1	0	0	1	0	0	0	0	0x90
Mode Definition Register	0x03	0	0	0	0	1	0	0	0	0x08
Bit Rate Definition Register	0x04	0	0	0	0	0	0	0	0	0x00
ISO14443A and NFC 106kb/s Settings Register	0x05	0	0	0	0	0	0	0	0	0x00

3.2 Single ended antenna

The same method of calculation is used for the single ended circuit to get value for matching components for single ended antenna.

The formulas used for calculation are:

$$R_{match} = \text{"Target matching Z"} - \text{DC Resistance}$$

$$R_{total} = Q_{chosen} \cdot 2 \cdot \pi \cdot f_{work} \cdot L_{ant}$$

$$R_{TR} = \frac{2 \cdot \mathrm{R_{match}}}{\left(1 - \omega^2 \mathrm{L_{emc}} \mathrm{C_{emc}}\right)^2 + \left(\omega \cdot \frac{\mathrm{R_{match}}}{2} \cdot \mathrm{C_{emc}}\right)^2}$$

$$X_{TR} = 2 \cdot \omega \cdot \frac{\mathrm{L_{emc}}\left(1 - \omega^2 \mathrm{L_{emc}} \mathrm{C_{emc}}\right) - \frac{4 \cdot \mathrm{R_{match}^2}}{4} \cdot \mathrm{C_{emc}}}{\left(1 - \omega^2 \mathrm{L_0} \mathrm{C_0}\right)^2 + \left(\omega \cdot \frac{2 \cdot \mathrm{R_{match}}}{2} \cdot \mathrm{C_0}\right)^2}$$

Matching C_S and C_P calculation:

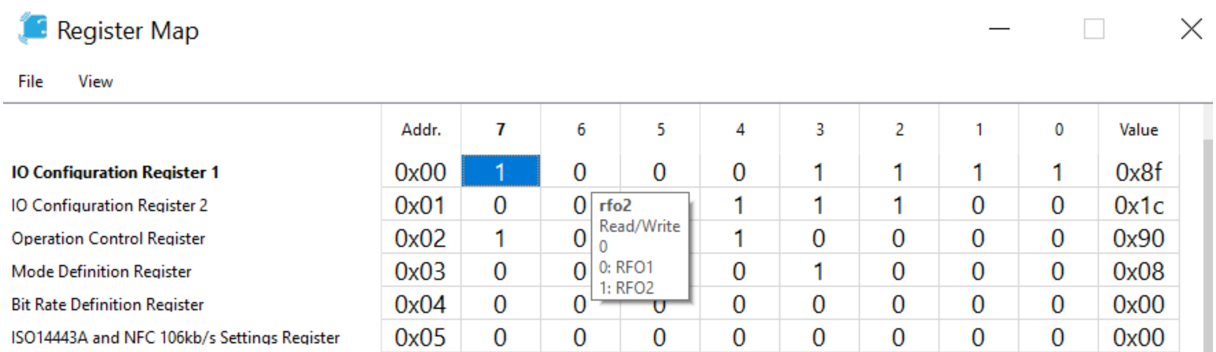
$$C_S = \frac{1}{\omega \cdot \left(\sqrt{\frac{R_{TR} \cdot 2 \cdot R_{total}}{4}} + \frac{X_{TR}}{2}\right)}$$

$$C_P = \frac{1}{\omega^2 \cdot L_{ant}} - \frac{1}{\omega \cdot \sqrt{\frac{R_{TR} \cdot 2 \cdot R_{total}}{4}}} - C_{ant} - \frac{CVDR_1 \cdot CVDR_2}{CVDR_1 + CVDR_2}$$

Register map: IO configuration register 1

The IO configuration register 1 is set according to RFO for the single ended antenna.

Figure 12. Register setting for single ended antenna



	Addr.	7	6	5	4	3	2	1	0	Value
IO Configuration Register 1	0x00	1	0	0	0	1	1	1	1	0x8f
IO Configuration Register 2	0x01	0	0		1	1	1	0	0	0x1c
Operation Control Register	0x02	1	0		1	0	0	0	0	0x90
Mode Definition Register	0x03	0	0		0	1	0	0	0	0x08
Bit Rate Definition Register	0x04	0	0	0	0	0	0	0	0	0x00
ISO14443A and NFC 106kb/s Settings Register	0x05	0	0	0	0	0	0	0	0	0x00

3.3 Single ended antenna with cable

Single ended antenna with cable had additional matching components formulas for 50 Ω antenna.

$$R_{match} = \text{"Target matching Z"} - \text{DC Resistance}$$

50 Ω antenna:

$$C_{p1(1)} = \frac{L_{ant} \cdot \sqrt{2 \cdot (R_{total} - CHI)} * \omega + 10 \cdot R_{total}}{10 \cdot R_{total} \cdot L_{ant} \cdot \omega^2} - C_{ant}$$

$$C_{s1(1)} = \frac{-\left(R_{total}^2 \cdot ((C_{p1} + C_{ant})^2 \cdot L_{ant}^2 \cdot \omega^4 - 2 \cdot (C_{p1(1)} + C_{ant}) \cdot L_{ant} \cdot \omega^2 + 1\right) + L_{ant}^2 \cdot \omega^2)}{L_{ant} \cdot R_{total}^2 \cdot \omega^2 \cdot ((C_{p1(1)} + C_{ant}) \cdot L_{ant} \cdot \omega^2 - 1)}$$

$$C_{p1(2)} = -\frac{L_{ant} \cdot \sqrt{2 \cdot (R_{total} - CHI)} * \omega + 10 \cdot R_{total}}{10 \cdot R_{total} \cdot L_{ant} \cdot \omega^2} - C_{ant}$$

$$C_{s1(2)} = \frac{-\left(R_{total}^2 \cdot ((C_{p1} + C_{ant})^2 \cdot L_{ant}^2 \cdot \omega^4 - 2 \cdot (C_{p1(2)} + C_{ant}) \cdot L_{ant} \cdot \omega^2 + 1\right) + L_{ant}^2 \cdot \omega^2)}{L_{ant} \cdot R_{total}^2 \cdot \omega^2 \cdot ((C_{p1(2)} + C_{ant}) \cdot L_{ant} \cdot \omega^2 - 1)}$$

Note: C_P is quadratic equation, which give us two possible solution ($C_{P1(1)}$, $C_{P1(2)}$). In this case only the positive result is valid.

50 Ω matching:

$$C_{s2} = \frac{L_{emc} \cdot \omega + R_{match}^2 \cdot \sqrt{\frac{CHI \cdot C_{emc}^2 \cdot L_{emc}^2 \cdot \omega^4 + CHI \cdot C_{emc}^2 \cdot \omega^2 \cdot R_{match}^2 - 2 * CHI \cdot C_{emc} \cdot L_{emc} \cdot \omega^2 - R_{match} + CHI}{R_{match}^3}} - C_{emc} \cdot L_{emc}^2 \cdot \omega^3 - C_{emc} \cdot \omega + R_{match}^2}{L_{emc}^2 \cdot \omega^3 + \omega \cdot R_{match}^2 - CHI \cdot \omega \cdot R_{match}}$$

For C_{S2} there are two possible solutions ($C_{P2(1)}$, $C_{P2(2)}$), only positive result is valid.

$$C_{p2(1)} = \frac{\sqrt{CHI^2 \cdot C_{s2}{}^4 \cdot \omega^4 - 4 \cdot (C_{s2} + C_{emc})^2 \cdot (L_{emc} \cdot C_{s2} \cdot \omega^2 + C_{emc} \cdot L_{emc} \cdot \omega^2 - 1)^2} - CHI \cdot C_{s2} \cdot \left(C_{s2} \cdot (2 \cdot C_{emc} \cdot L_{emc} \cdot \omega^2 - 1) + 2 \cdot C_{emc} \cdot (C_{emc} \cdot L_{emc} \cdot \omega^2 - 1)\right) \cdot \omega}{2 \cdot CHI \cdot (C_{s2} + C_{emc}) \cdot (L_{emc} \cdot C_{s2} \cdot \omega^2 + C_{emc} \cdot L_{emc} \cdot \omega^2 - 1) \cdot \omega}$$

$$C_{p2(2)} = \frac{-(\sqrt{CHI^2 \cdot C_{s2}{}^4 \cdot \omega^4 - 4 \cdot (C_{s2} + C_{emc})^2 \cdot (L_{emc} \cdot C_{s2} \cdot \omega^2 + C_{emc} \cdot L_{emc} \cdot \omega^2 - 1)^2} + CHI \cdot C_{s2} \cdot \left(C_{s2} \cdot (2 \cdot C_{emc} \cdot L_{emc} \cdot \omega^2 - 1) + 2 \cdot C_{emc} \cdot (C_{emc} \cdot L_{emc} \cdot \omega^2 - 1)\right) \cdot \omega)}{2 \cdot CHI \cdot (C_{s2} + C_{emc}) \cdot (L_{emc} \cdot C_{s2} \cdot \omega^2 + C_{emc} \cdot L_{emv} \cdot \omega^2 - 1) \cdot \omega}$$

Register map: IO configuration register 1

Depending on which RFO for the single ended antenna is used, it is required to set IO configuration register 1. See Figure 11

4 Benchmarking

4.1 Power consumption

4.1.1 Measurement setup and settings (board configuration, schematic)

To measure the impedance, the antenna ends need to be connected to the cable of the network analyser.

Figure 13. Measurement setup for impedance-Differential antenna

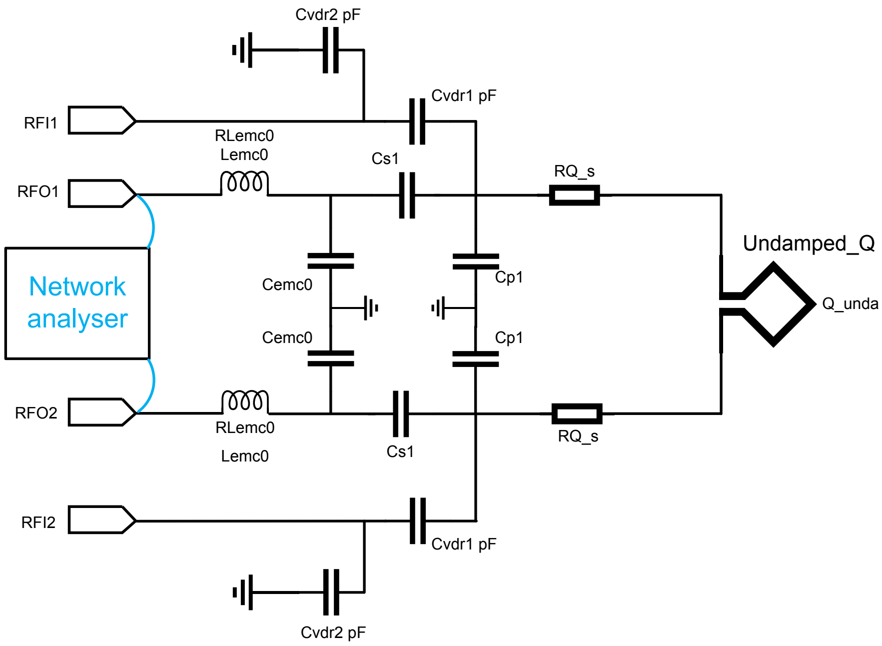
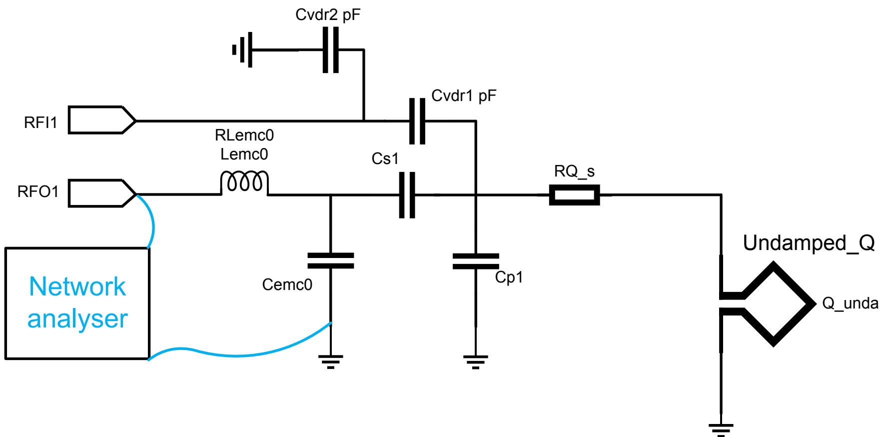


Figure 14. Measurement setup for impedance-Single ended antenna



The measure value of the impedance can be determined setting the frequency of resonance to 13.56 MHz.

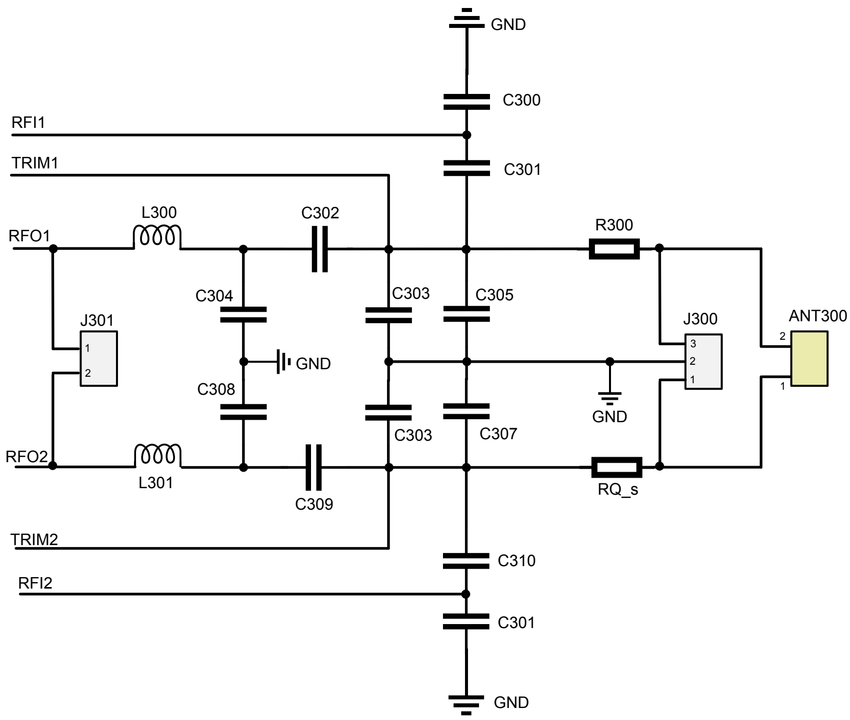
The goal is to get impedance of 20 Ω for the differential antenna and 10 Ω for single ended and single ended antenna with cable. To be able to get these values of impedance it is necessary to adjust the matching network components:

- Measuring the RFI voltage with ST25R3911B Discovery GUI
- Adjusting the capacitive voltage divider (C300, C301) on the board so that approximately 2.7 V is present on the differential and the single ended boards

The RFI voltage can be measured by using the direct command “Measure Amplitude”.

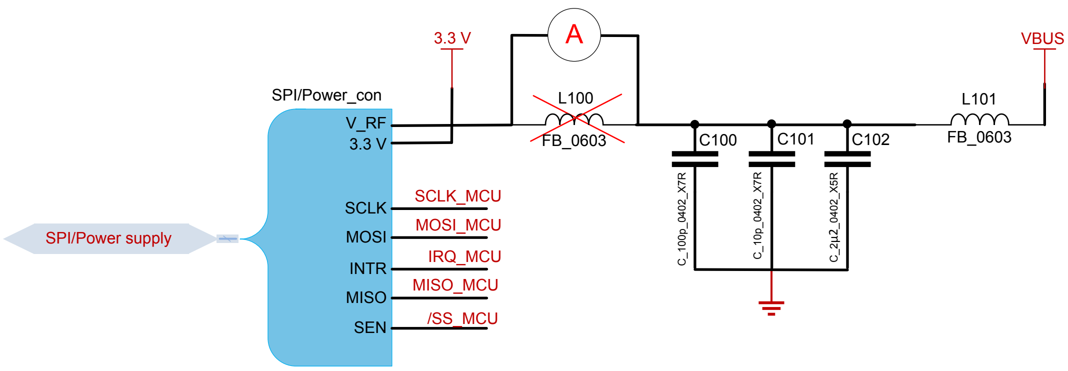
Antenna circuit included EMI filter and matching

Figure 15. **Matching circuit for capacitive voltage divider**



For current measurements, the coil (L100) is removed and replaced with current probe.

Figure 16. **Current measurements**



4.1.2 Measurement results

Table 8. Measurement results

Measurement	Differential antenna	Single ended antenna	Single ended antenna with cable	Unit
Impedance	20.017	10.077	9.772	Ω
RFI-Voltage	2.690	2.617	2.617	V
TX-Current	181.15	91.45	96.55	mA

4.2 Read range measurement

4.2.1 Measurement setup and settings

Low power card detection and card activation, normal interaction with the card, are done by testing NFC cards from a defined card stack and by placing them near an NFC reader (DUT) in different positions and angles. At each position, a defined number of tests is executed, and the test result is stored.

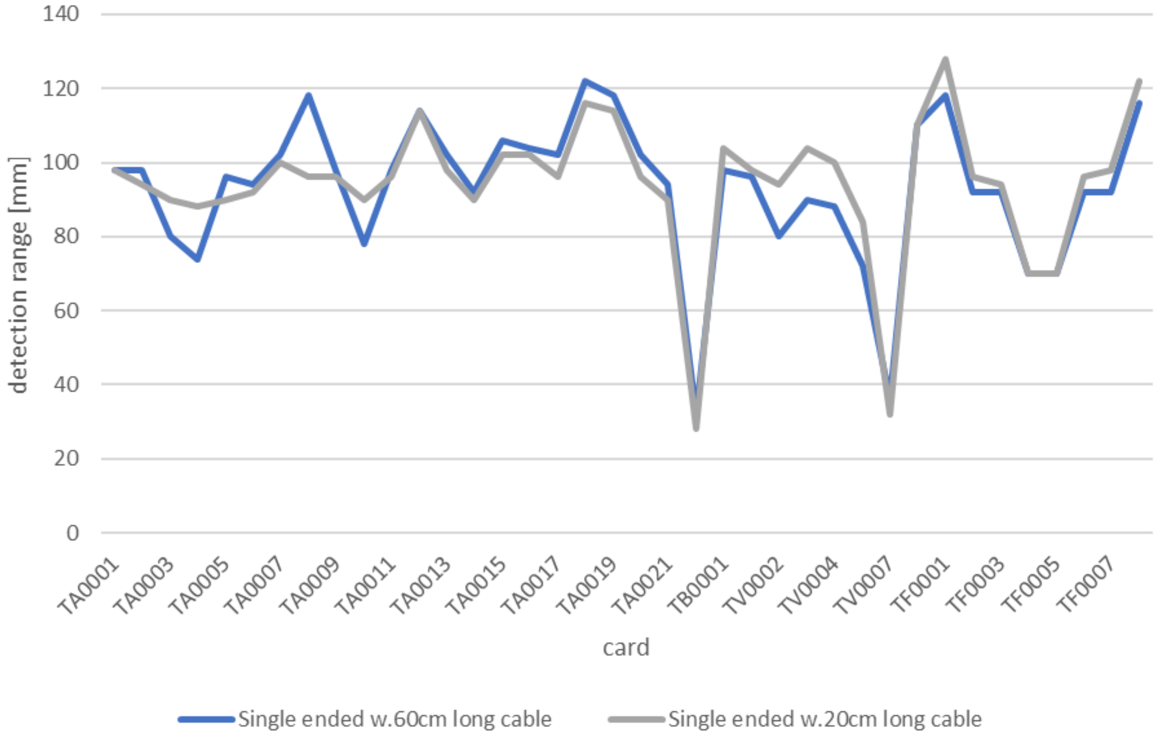
4.2.2 Read range measurement results

Figure 17. Low power card detection

Figure 18. **Card activation**

For single ended antenna with cable the read range measurements are done for two different size of cable: 60 cm long cable and 20 cm long cable to check if the size of cable have any impact in the measurements. As can be seen in Figure 13 the size of cable is not relevant for the low power card detection.

Figure 19. **Low power card detection of single ended antenna for different size of cable**



5 Conclusion

This document describes the antenna matching tool. It helps the user in the computation and simulation of the matching network for differential, single ended and single ended antenna with cable.

The matching tool calculates all required values for the EMC filter and the matching network, which is shown in the GUI, so that the desired matching impedance is achieved.

The simulation starts after the type of the configuration file is selected and all values are entered.

Revision history

Table 9. Document revision history

Date	Version	Changes
15-Mar-2021	1	Initial release.

Contents

List of tables

List of figures