AN4974
Application note

Antenna matching for ST25R3911B/ST25R391x devices

Introduction

One of the challenges in NFC technology is the design and matching of a proximity antenna according to a specific 13.56 MHz application. Very often, magnetic loop antennas are exposed to environmental conditions that degrade the system performance.

This application note is a design guide for magnetic loop antennas connected directly to the devices listed in *Table 1*. Beyond the antenna design it describes the antenna parameter measurement and matching, as well as the design verification.

The examples in this document are based on the ST25R3911B device, but the techniques and tools can be used for other products of the same family.

The ST25R3911B is a highly integrated NFC Initiator / HF Reader IC including an analog front end and data framing system supporting ISO 14443 A and B reader (106, 212, 424 and 848 Kbit/s), ISO 15693 reader, FeliCa™ reader (212 and 424 Kbit/s), ISO 18092 (NFCIP-1) Initiator and Active Target Mode. Thanks to its automatic antenna tuning feature and high output power the ST25R3911B prevents time-consuming re-tuning and makes NFC design user-friendly.

This document is intended to be used with the ST25R Antenna Matching Tool software (STSW-ST25R004), which supports the calculation of the matching components and reduces the tuning iteration effort to a minimum. Along with the tool an open source simulator is provided for basic system validation via simulation.

The following documents are considered as reference:

- ST25R3911B datasheet, available on *www.st.com*
- AN4914, available on *www.st.com*
- DB3051 “Discovery kit for the ST25R3911B high performance HF reader / NFC initiator”, available on *www.st.com*
- ISO/IEC 14443 and ISO/IEC 10373-6:2011, from www.iso.org
- EMVCo® specifications, from www.emvco.com

Table 1. Applicable devices

Type	Part numbers
ST25 NFC / RFID Tags and Readers	ST25R3911B ST25R3912 ST25R3914 ST25R3915
Software	STSW-ST25R004

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1 List of acronyms and notational conventions

1.1 Acronyms

RFO1,2: ST25R3911B antenna driver output pins

RFI1,2: ST25R3911B receiver input pins

Tx: Transmit signal (from RFO to antenna)

Rx: Receive signal (from antenna to RFI)

$L_{EMC1,2}$: Inductor of the EMC filter

$C_{EMC1,2}$: Capacitor of the EMC filter

$C_{S1,2}$: Series capacitor of the matching network

C_P: Parallel capacitor of the matching network

R_Q: Parallel resistor used for the Q factor adjustment (calculated)

L_{ANT}: Antenna inductance (measured)

C_{ANT}: Parasitic antenna parallel capacitance (calculated)

R_{PANT}: Total antenna parallel resistance (calculated)

f_{work}: NFC operating frequency (13.56 MHz)

f_{res}: Antenna self-resonance frequency (measured)

R_{SDC}: Antenna series resistance (measured)

$R_{P@fres}$: Antenna parallel resistance at self-resonance (measured)

K: Skin effect correction factor (calculated)

$R_{P@work}$: Antenna parallel resistance at operating frequency (calculated)

R_{PDC}: Antenna parallel resistance converted from measured series resistance (calculated)

R_T: Parallel resistance for target Q factor (calculated)

Q: Antenna Q factor (calculated)

1.2 Representation of numbers

The following conventions and notations apply in this document unless otherwise stated:

- **Binary numbers** are represented by strings of 0 and 1 digits shown with the most significant bit (MSB) on the left, the least significant bit (LSB) on the right, and "0b" added at the beginning. Example: 0b11110101.
- **Hexadecimal numbers** are represented by using numbers 0 to 9 and characters A to F, and adding "0x" at the beginning. The Most Significant Byte (MSB) is shown on the left and the Least Significant Byte (LSB) on the right. Example: 0xF5.
- **Decimal numbers** are represented without any trailing character. Example: 245.

2 HW and SW requirements

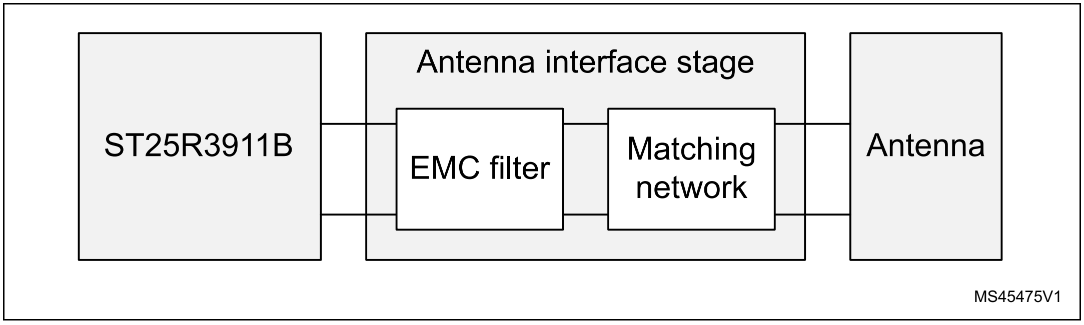
To use the ST25R Antenna Matching Tool, perform antenna measurements and verify the design, the following hardware and software resources are required:

- Network analyzer
- Oscilloscope (capable of pulse triggering)
- SMA cable
- ISO10373-6 calibration coil 1
- ST25R3911B-DISCO demonstration board
- Windows® OS
- ST25R Antenna Matching Tool

3 Antenna interface stage

As shown in *Figure 1*, the ST25R3911B, together with an antenna interface stage (consisting of an EMC filter and a matching network) and a magnetic loop antenna makes up a wireless system operating at 13.56 MHz, compliant with NFC standards.

Figure 1. Antenna interface stage



From the ST25R3911B antenna driver output pins RFO1 and RFO2, the TX signal goes through the EMC filter into the matching network and to the antenna. The RX signal coming from the antenna is lead through the capacitive voltage divider back into the ST25R3911B receiver input pins RFI1 and RFI2. The antenna interface stage can be set up as single ended or as differential topology, this document focuses on the latter configuration.

A typical differential matching network is shown in *Figure 2*.

Figure 2. Antenna interface stage (differential matching network)

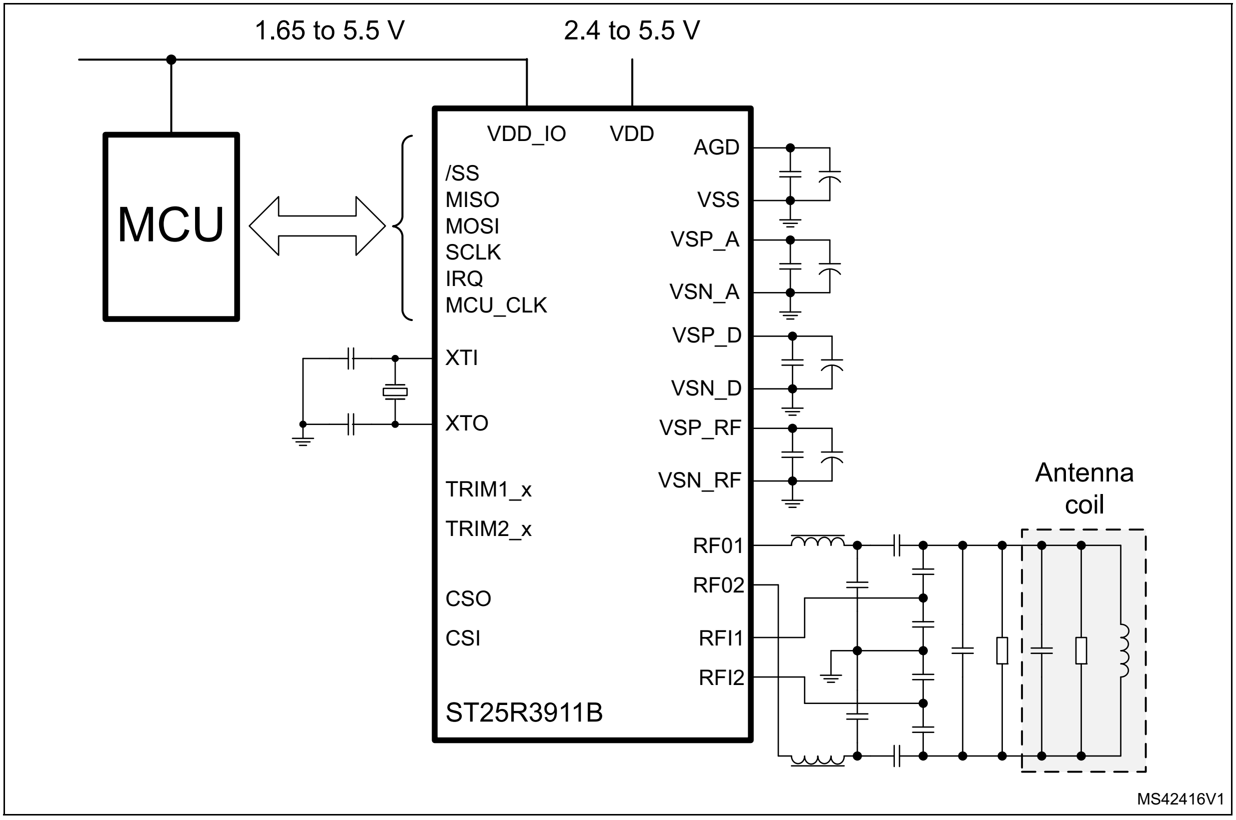
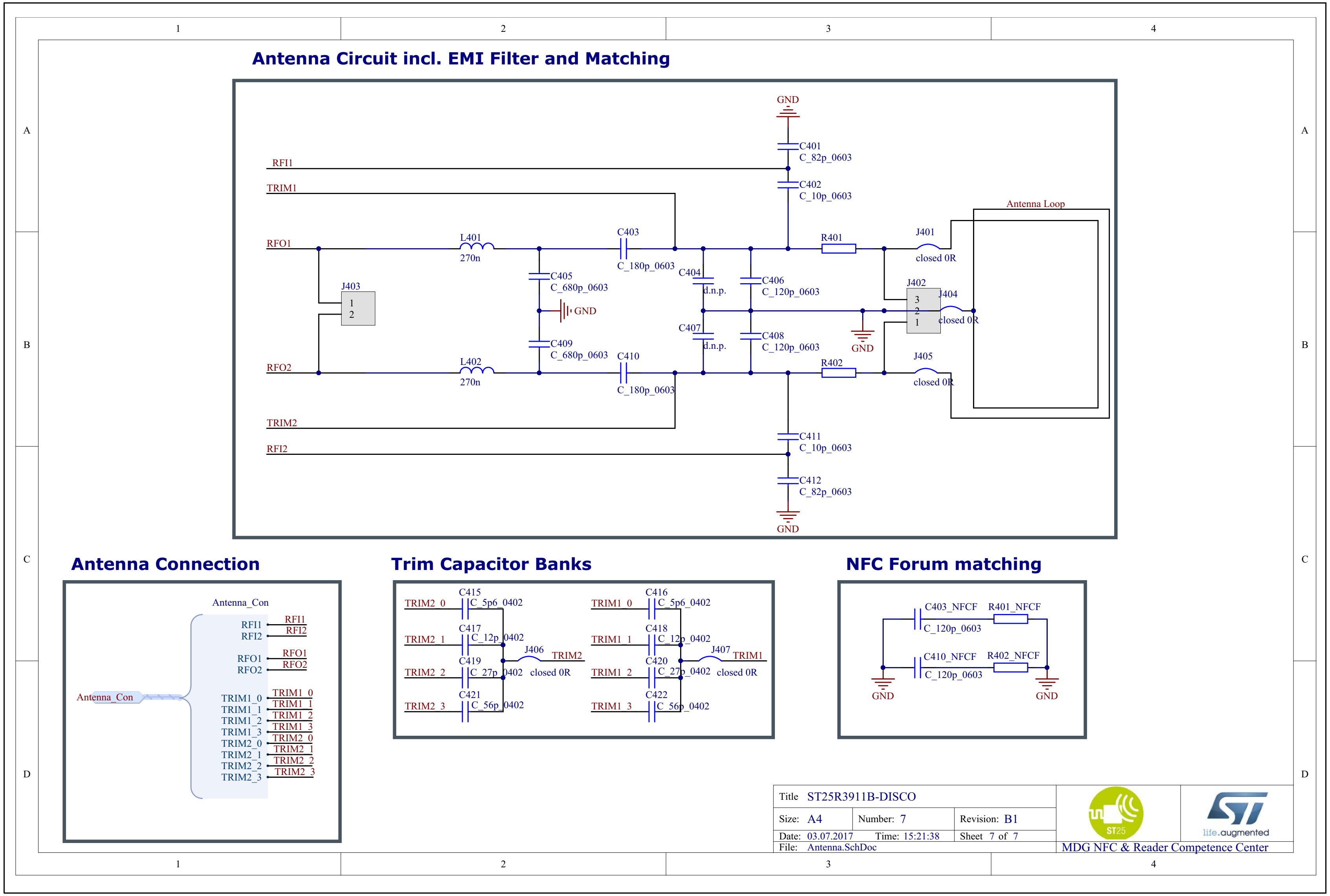


Figure 3. Antenna interface stage, alternative topologies



The parallel capacitor C_P can either be connected in differential mode (as in *Figure 2*) or similar to C_{EMC1} in single ended mode. From the functional point of view, there is no difference between these two modes. Also the damping resistor R_Q can be in parallel to the antenna, or in series between the matching network and the antenna.

Figure 3 shows these alternative connection topologies.

3.1 Reader output power

During the NFC/RFID reader design process a lot of different requirements have to be considered, a key one is the output power.

Several methods (among them capacitive or inductive wake-up) can be used to reduce the power consumption of the complete system. Besides using these power saving functions or reducing the power consumption by optimizing the polling cycle one very essential criterion is the power consumption during field on.

There are three steps to adjust the power consumption:

1. impedance matching
2. antenna driver output resistance (register 0x27)
3. V_{SP_RF} regulator setting

The impedance matching is the most important criterion to determine the ST25R3911B power consumption. When designing the matching circuitry and defining the target matching impedance, attention must be paid to *Figure 4*, showing that with higher target matching impedance less power is transferred forward to the antenna, and therefore the power consumption of the whole reader unit is reduced.

Together with matching impedance the ST25R3911B output driver resistance has to be adjusted. If there is a big mismatch between matching impedance and driver stage resistance (for example low power designs with target impedance around 30 Ω or higher) the driver resistance must be increased. It is likely that overshoots appear with large mismatches, they disappear without significant power loss on the antenna when increasing the output resistance.

The last point to adjust the output power is the supply voltage of the driver stage. The V_{SP_RF} driver supply can be automatically set to V_{DD} minus the regulator dropout voltage. This is the optimal value for operation and noise rejection. It is also possible to manually overwrite the regulator setting and set V_{SP_RF} to a value specified in the datasheet.

To determine the behavior of current as a function of the transferred power, investigations have been carried out with different matching impedances. The results are summarized in *Figure 4* and *Figure 5*, showing, respectively, the output power / power efficiency and the current consumption as a function of the matching impedance. The current has been measured differentially at the RFO1 and RFO2 pin with a V_{DD} supply voltage of 5 Volts.

The input power is calculated by using a solid 5 V supply and measuring the DC supply current with an ammeter. To measure the output power, the matching components and antenna has been replaced by a pure ohmic resistance. The voltage on this resistance has been measured with an oscilloscope. The output power has then been calculated.

Figure 4. Output power and efficiency vs. matching impedance (Ω)

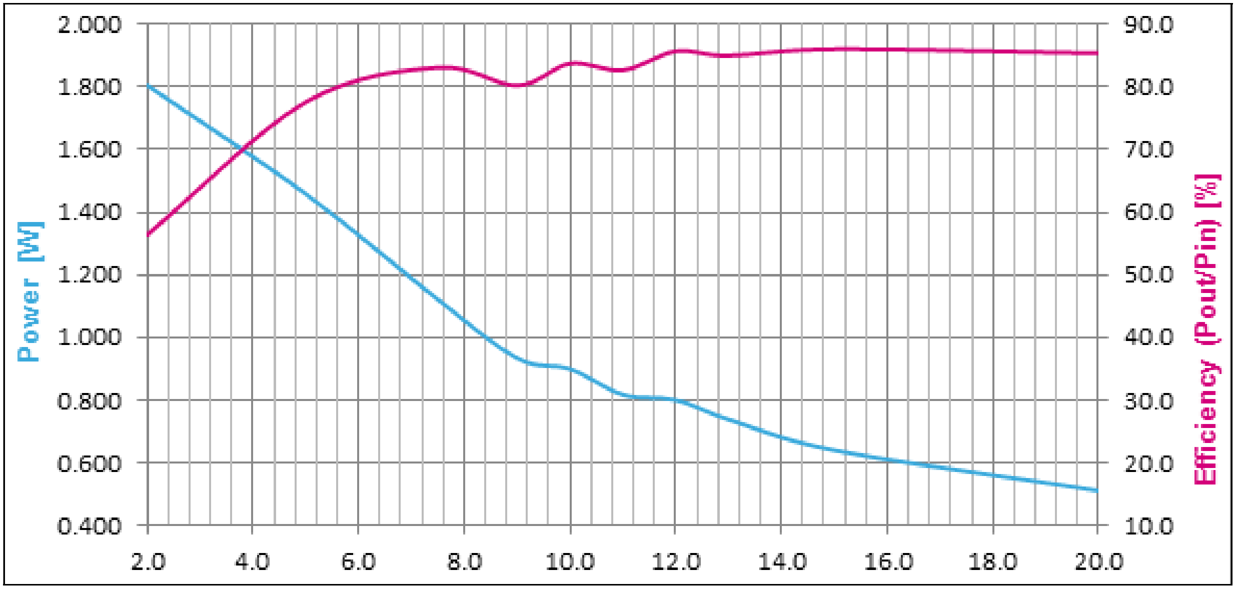
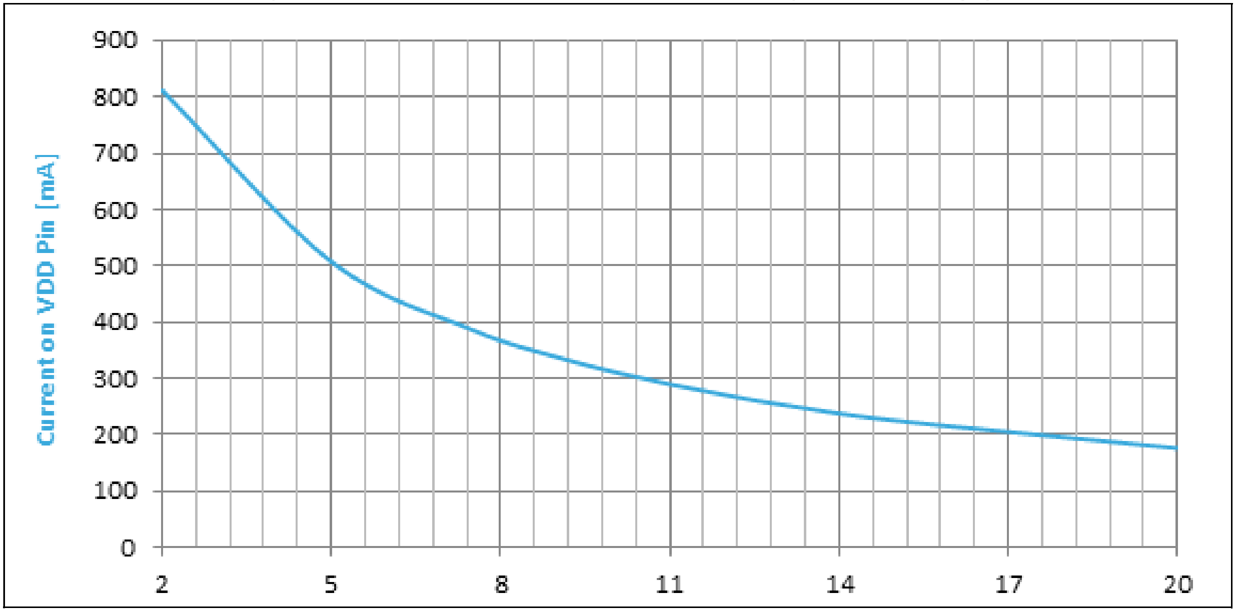


Figure 5. Current consumption vs. matching impedance (Ω)



3.2 EMC filter

The EMC filter is implemented as a single stage low pass filter consisting of a serial inductor and a parallel capacitor. The purpose of the EMC filter is to filter out higher harmonics caused by the rectangular output signal of the push-pull driver. The filter cutoff frequency should be between 8 and 17 MHz, the actual value depends on the application and the required behavior. The ST25R3911B-DISCO and X-NUCLEO-NFC05A1 are equipped with an 11.75 MHz EMC filter.

To optimize the EMC behavior of the reader board some considerations must be made:

- Filter coils:
  - Self-resonance frequency of the inductance: it can boost unwanted emissions in the investigated frequency range, must be chosen carefully, hence the EMC inductor for the ST25R3911B-DISCO and X-NUCLEO-NFC05A1 boards has been chosen with a SFR higher than 1 GHz.
  - Equivalent serial resistance: influences the system Q factor of the reader, and can lower the conducted output power. EMC inductors with a higher ESR (>1 Ω) can only be used for mid and low power matchings. The ESR is put in series to the RFO output resistance. Higher ESR lower system Q factor, and more power is lost in the EMC inductors.
  - Rated current of the chosen filter coils must be higher than the current in the matching network.
- Filter cut off frequency (filter resonance frequency):
  - If the filter cut of frequency is too close to the carrier frequency (13.56 MHz), the system Q factor is strongly decreased. The reason is the combination of the antenna and the filter Q factor. For this reason the EMC cutoff frequency should not be between 13 and 14 MHz.
  - If the phase difference between RFO and RFI signals is smaller than 30° or bigger than 150° it cannot be measured anymore. The automatic antenna tuning cannot be used in this case.
- Antenna design
  - The electrical length must not be too long to avoid additional self-resonances that could boost unwanted emissions.

3.3 Matching network

The matching network in L topology follows the EMC filter and consists of one series and two parallel capacitors, in differential topology.

The purpose of the matching network is to match the antenna interface stage to a desired impedance value so that, depending on the application, either a maximum power transfer from the ST25R3911B to the antenna or a certain current consumption is achieved.

Figure 3 shows a typical antenna interface stage.

3.4 Capacitive voltage divider

As the voltage on the antenna can be high, a capacitive voltage divider is needed in the receive path at the antenna terminals to limit the signal strength going back to the RFI pins. This voltage divider is connected to the antenna and consists of two capacitors.

In *Figure 3* capacitor pairs C401, C402 and C411, C412 form the capacitive voltage divider.

The voltage at the receive pins must not exceed 3 V_{pp}. In HF reader mode and NFC transmit mode the recommended signal level is 2.5 V_{pp}.

3.5 Trim capacitors

The ST25R3911B supports an antenna auto tuning function that adjusts the antenna resonance frequency if required. This feature helps to compensate environmental influences, and filter as well as matching component tolerances.

The tuning network consists of chip internal switches and external capacitors connected at the antenna terminals. During the auto tuning process the internal switches are adjusted to connect the appropriate capacitors to the antenna.

The ST25R3911B can sustain voltages up to 25 V on its antenna tuning pins. In some high power applications the voltage at the antenna may exceed this value. In that case additional capacitors for voltage limitation need to be applied.

In *Figure 3* the capacitors C415 to C422 represent the trim capacitors. Additional capacitors can be placed for voltage limitation (voltage divider), they must be placed between the trim capacitor and the ST25R3911B trim input to GND, similarly to the RFI capacitive voltage divider. *Figure 6* is an example of how to enable the AAT based on a ST25R3911B-DISCO board high antenna voltage. The capacitors connected to GND are the added ones.

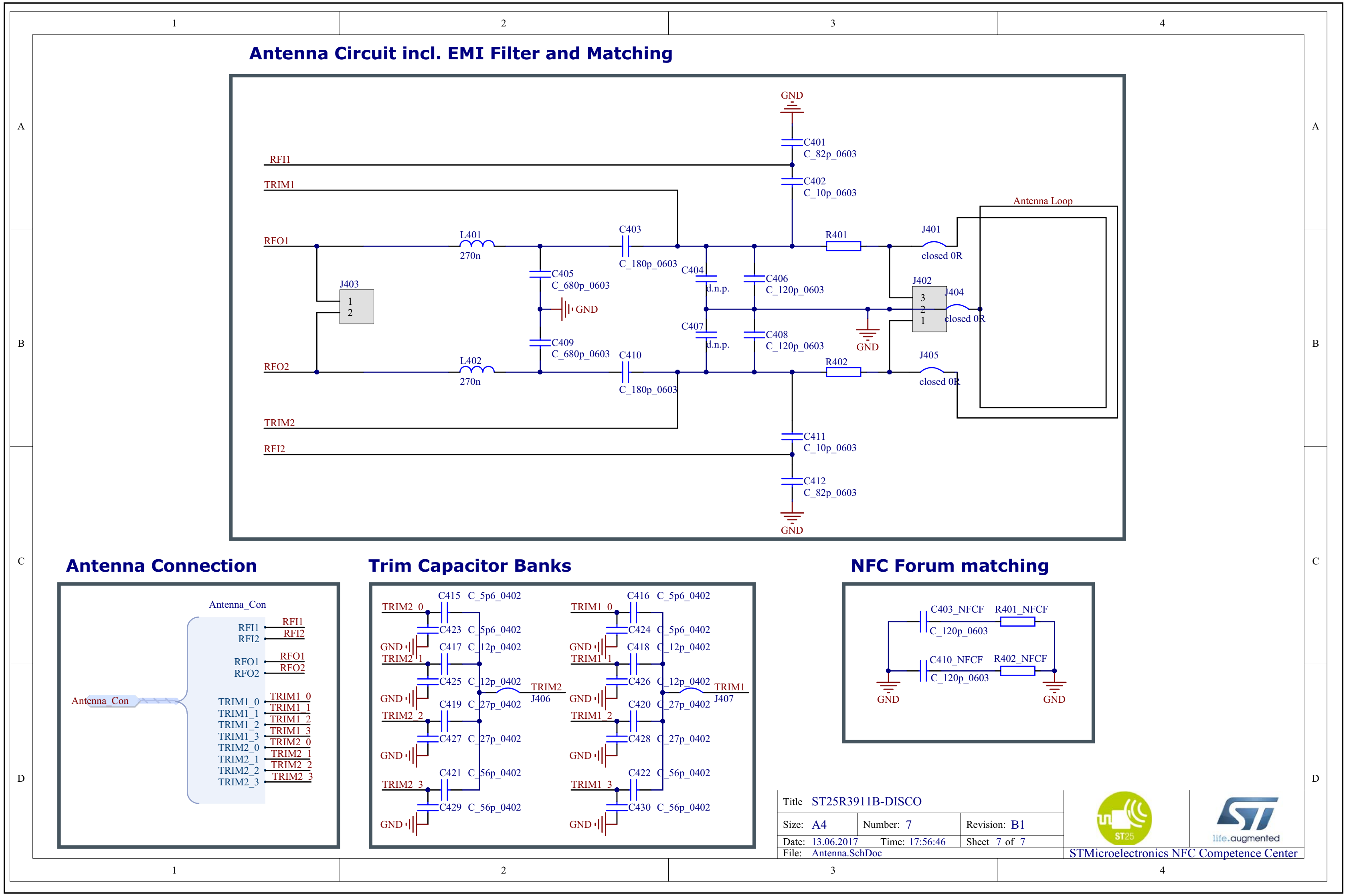
3.6 Antenna

The antenna of the HF reader is a magnetic loop antenna, typically implemented as a printed coil, Flex-PCB or wire wound antennas, or metal casing are other possible approaches.

Factors like size, number of tracks, track and gap width determine the electrical parameters of the antenna: inductance, series and parallel resistance, self-resonance frequency, and, most important of all, the Q factor.

The antenna must be designed with a Q factor higher than the target system Q factor. This is because the antenna Q factor can only be decreased by damping resistors afterwards, and not increased anymore.

Figure 6. Schematic of high voltage capacitors



4 Antenna parameters

Every antenna is composed of inductance, resistance and capacitance. These values and the self-resonance frequency of the antenna must be determined first to calculate the antenna equivalent circuit and its Q factor, and then determine the matching components.

4.1 Network analyzer preparation

In order to measure the antenna parameters use a network or impedance analyzer, and set it up according to the procedure detailed below:

1. Set the measurement mode of the network analyzer to S11 reflection measurement
2. Use the Smith chart format (R + jX) to display the impedance curve
3. Set the start frequency at 1 MHz and the stop frequency at 300 MHz

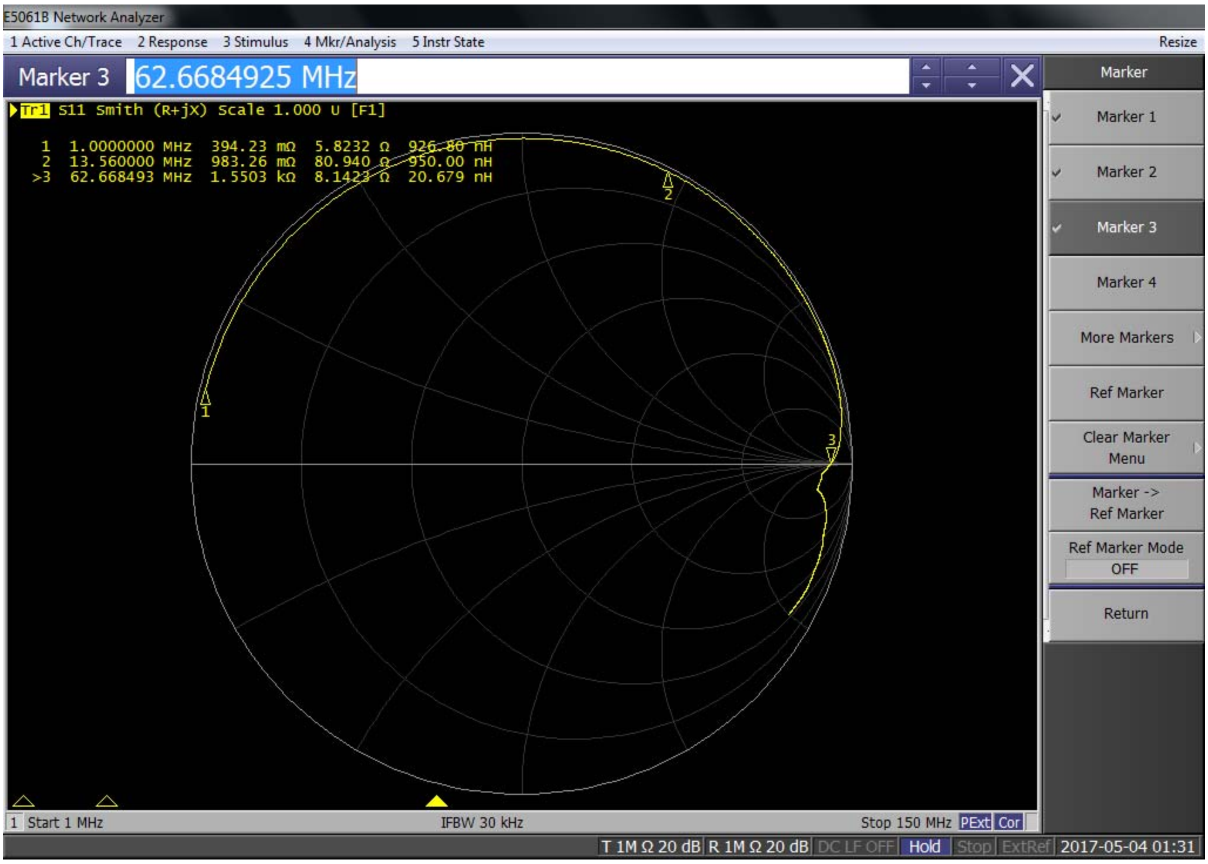
Note: Some of the antenna parameters are measured at 1 MHz, which is far off the self-resonance frequency of the antenna to minimize the skin effects measured at higher frequencies. The stop frequency must be higher than the first self-resonance frequency (usually between 50 and 250 MHz) of the reader antenna.

4. Set the network analyzer resolution (number of points) to the maximum to ensure accurate measurements
5. Connect a short SMA cable (<50 cm) to the RF port of the network analyzer and start the calibration using OPEN, SHORT and LOAD from a calibration kit or auto-calibration. If no calibration kit is available, a workaround with a 50 Ω resistance as load, as well as an open and short connection on the cable can be used. With the calibration the SMA cable length is accounted for.
6. In order to connect the SMA cable to the antenna to be measured, make a probe connection from pins (one pin soldered to the signal connection of the SMA connector, the other one soldered to one of its ground connections).
7. The added pins can be taken into account for calibration with the auto port extension function of the VNA.

4.2 Parameter measurement

1. Connect the cable of the network analyzer at the antenna ends. The antenna has to be disconnected from the reader / matching network and the reader has not to be powered. Connecting a powered reader to a VNA can cause damage to the VNA.
2. The impedance curve from 1 to 300 MHz is displayed in the Smith chart, as shown in *Figure 7*
3. Set a marker to 1 MHz and read the series inductance and the DC series resistance values (in *Figure 7* they are displayed in the upper part of the network analyzer screen):
   - L_{ANT} = 926 nH
   - R_{SDC} = 394 mΩ
4. Set another marker to the real axis of the Smith chart, where the inductive and the capacitive part of the impedance cancel each other. At this point, the parallel resistance and the self-resonance frequency of the antenna are measured:
   - $R_{P@fres}$ = 1.55 kΩ
   - f_{res} = 62.67 MHz

Figure 7. Antenna parameter measurement at 1 MHz



Marker 3 62.6684925 MHz

```
Tr1 S11 Smith (R+jX) Scale 1.000 U [F1]

  1  1.0000000 MHz  394.23 mΩ  5.8232 Ω  926.80 nH
  2  13.560000 MHz  983.26 mΩ  80.940 Ω  950.00 nH
 >3  62.668493 MHz  1.5503 kΩ  8.1423 Ω  20.679 nH
```

1 Start 1 MHz IFBW 30 kHz Stop 150 MHz

The antenna parameters have now been measured, and the equivalent circuit can be determined, this is described in *Section 4.3*.

4.3 Antenna equivalent circuit

Using the antenna inductance measured at 1 MHz, the parasitic capacitance at self-resonance-frequency can be calculated as follows:

$$C_{ANT} = 1 / (\omega^2 * L) = 1 / [(2\pi * f_{res})^2 * L_{ANT}] = 1 / [(2\pi * 62.7\text{ MHz})^2 * 926\text{ nH}] = 6.96\text{ pF}$$

The measured value of the parallel resistance has to be converted from the self-resonance to the operating frequency (f_{work} = 13.56 MHz). The reason for this conversion is the correction for the frequency dependent change due to the skin effect. To convert the parallel resistance at the self-resonance frequency, a correction factor has to be calculated:

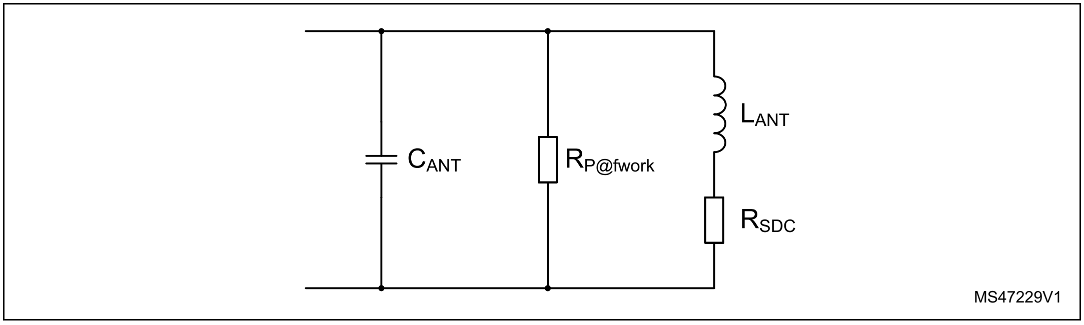
$$K = \sqrt{\frac{f_{res}}{f_{work}}} = \sqrt{\frac{62{,}7\text{MHz}}{13.56\text{MHz}}} = 2.15$$

The parallel resistance at the operating frequency is calculated as

$$R_{P@fwork} = K * R_{P@fres} = 2.15 * 1.55\text{ k}\Omega = 3.33\text{ k}\Omega$$

All antenna components are now known, so the equivalent circuit can be determined (see *Figure 8*).

Figure 8. Antenna equivalent circuit



The equivalent circuit can be simplified by recalculating the series resistance into a parallel resistance (see *Figure 9*) at the operating frequency, with the formula

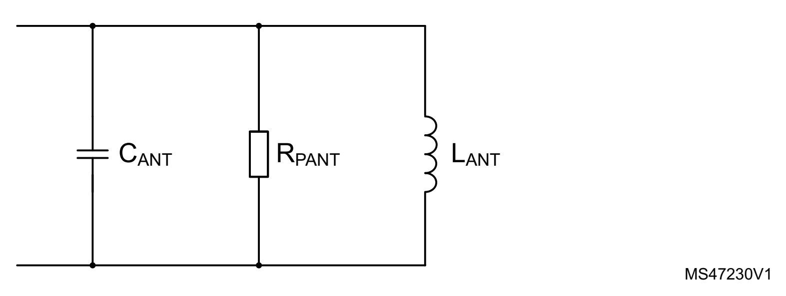
$$Q = \frac{\omega L_{ANT}}{R_{SDC}} \approx \frac{R_{PDC}}{\omega L_{ANT}} \Rightarrow R_{PDC} = \frac{(2 \cdot \pi \cdot f_{res} \cdot L_{ANT})^2}{R_{SDC}} = \frac{(2 \cdot \pi \cdot 13{,}56\text{MHz} \cdot 926\text{nH})^2}{394\text{m}\Omega} = 15.9\text{k}\Omega$$

The total resistance for the antenna equivalent circuit is represented by a parallel resistance consisting only of the DC series resistance (recalculated into a parallel one), and the parallel resistance converted to the operating frequency.

Adding the two parallel resistances leads to the total parallel resistance

$$R_{PANT} = \frac{R_{PDC} \cdot R_{P@fwork}}{R_{PDC} + R_{P@fwork}} = \frac{15.9\Omega \cdot 3.33\text{k}\Omega}{15.9\text{k}\Omega + 3.33\text{k}\Omega} = 2.76\text{k}\Omega$$

Figure 9. Antenna equivalent circuit (final)



The values for the final and simplified antenna equivalent resonance circuit are:

- R_{PANT} = 2.76 kΩ
- C_{ANT} = 6.96 pF
- L_{ANT} = 926 nH

The maximum achievable Q factor for this antenna can now be calculated:

$$Q = R_{PANT} / (\omega * L_{ANT}) = 2.76\ k\Omega / (2\ \pi * 13.56\ MHz * 926\ nH) = 34.8$$

This Q factor is valid for the freely oscillating unconnected antenna.

The Q factor has a direct influence on the rise and fall times of the modulated signal.

Figure 10 and *Table 2* show the definition of rise and fall times for a Type-A signal modulated with 100% ASK and a data rate of 106 kbit/s (f_{work} / 128), while *Figure 11* is an example of their dependence on the Q factor.

Figure 10. Definition of timing parameters for Type-A with 106 kbit/s

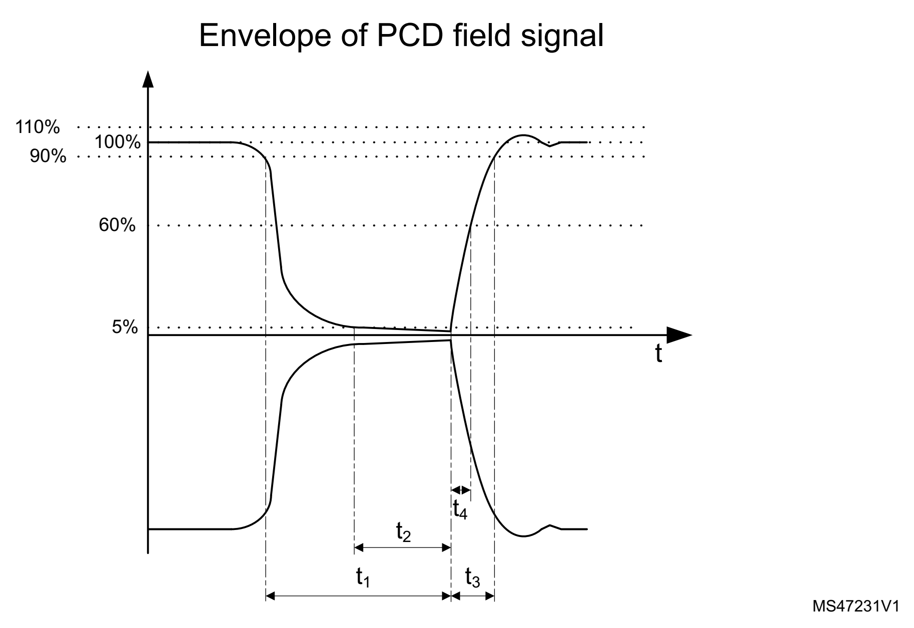
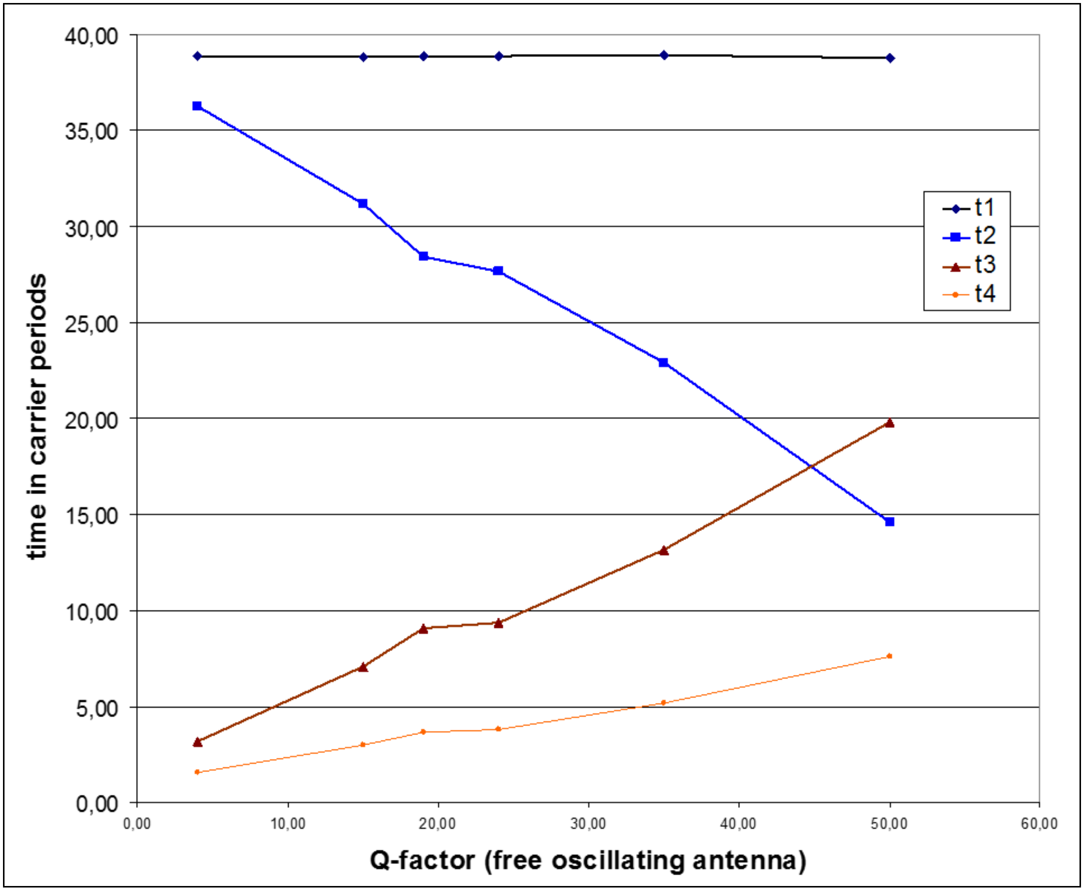


Table 2. Timing parameters for Type-A with 106 kbit/s

Parameter	Condition	Min	Max
t_1	-	6 / fc	40.5 / fc
t_2	t_1 > 34 / fc	7 / fc	t_1
	t_1 ≤ 34 / fc	10 / fc	
t_3	-	1.5 t_4	16 / fc
t_4	-	0	6 / fc

Figure 11. Timing parameters vs. Q factor



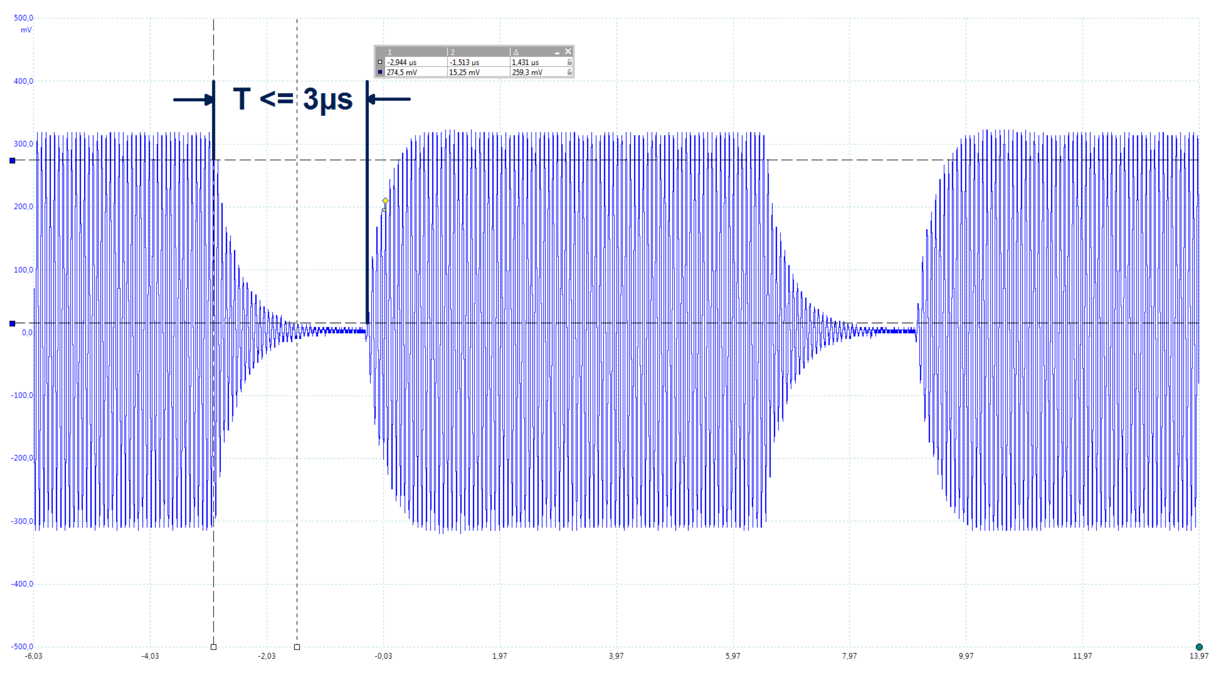
For each protocol (Type-A, Type-B) and data rate a maximum allowable Q factor can be determined, which must not be exceeded to get a modulated signal compliant with ISO waveforms.

The calculation of the maximum allowable Q factor for Type-A with a data rate of 106 kbit/s is based on the bandwidth - time product and a on definition of the Q factor resulting in the following equation:

$$B * T \geq 1; Q = f_{work} / B \rightarrow Q \leq f_{work} * T \rightarrow Q \leq 13.56\ \text{MHz} * 3\ \mu\text{s} = 41$$

In the above calculation the time T, represented in *Figure 12*, is the highest possible value of the timing parameter t_1 according to the ISO 14443 standard.

Figure 12. Definition of t_1 for Type-A with a data rate of 106 kbit/s



	1	2	Δ
☐	-2,944 µs	-1,513 µs	1,431 µs
■	274,5 mV	15,25 mV	259,3 mV

The desired Q factor for the application has to be below 41 (for Type-A and 106 kbit/s) to achieve standard-compliant rise and fall times.

Hence the previously calculated Q factor is too high and has to be lowered. This is achieved by connecting an external parallel resistor (R_Q) at the antenna pins. The resistor value depends on the targeted Q factor, which shall be 8, and is determined as follows:

$$R_T = Q * \omega * L_{ANT} = 8 * 2\,\pi * 13.56\ \text{MHz} * 926\ \text{nH} = 631\ \Omega$$

Taking the parasitic resistor R_{PANT} from the antenna equivalent circuit into account, the effective resistor R_Q to adjust the Q factor to 20 is calculated by the formula below

$$R_Q = (R_{PANT} * R_T) / (R_{PANT} - R_T) = (2.76\ \text{k}\Omega * 631\ \Omega) / (2.76\ \text{k}\Omega - 631\ \Omega) = 818\ \Omega$$

The closest available component value is 820 Ω.

The explanation of how to determine the antenna equivalent circuit and the resistor for the Q factor adjustment shall be seen as the theoretical background on which the ST25R Antenna Matching Tool is based on.

5 Antenna design

5.1 Boundary conditions and simulation model

The design of a proximity reader system requires a knowledge of the end user application. This includes the environmental conditions when placing the reader or type of cards to be used.

Some basic boundary conditions should be considered in advance:

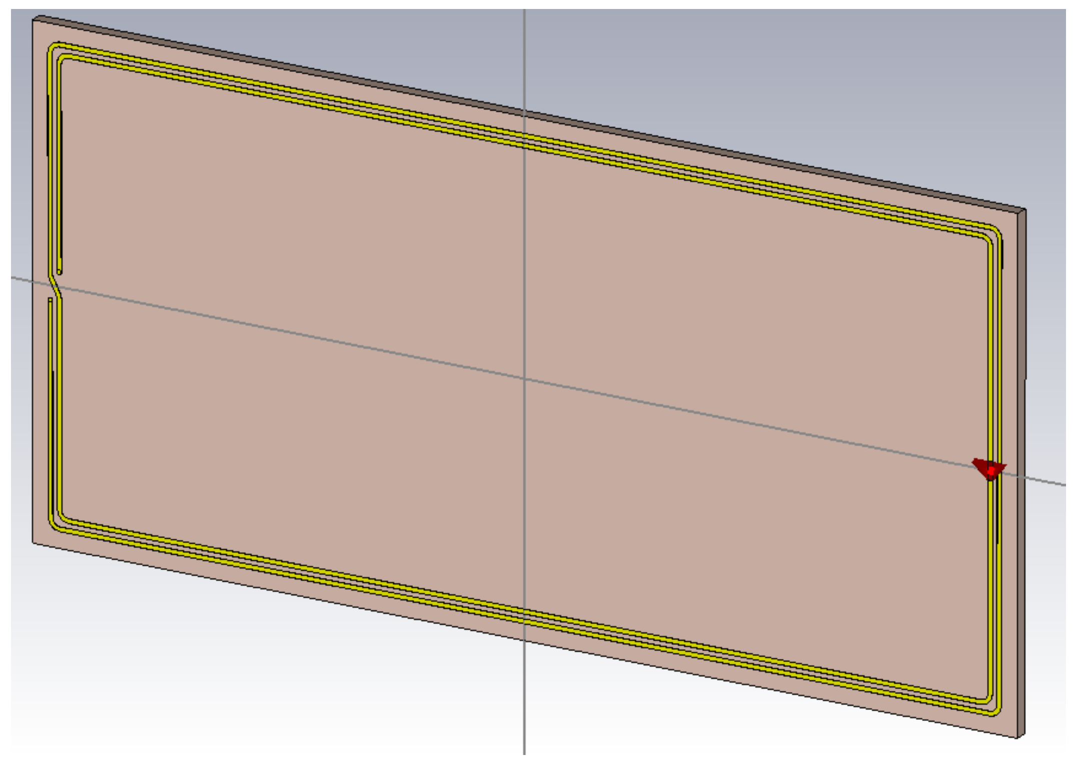
- Target reading distance
- Tag / card type
- Output power
- EMC regulations
- Industrial design
- Antenna placement
- Environmental influences
- Supported NFC technologies and standards, and data rates

The design of an antenna must fit the industrial design of the application, and there is not always a large degree of freedom on where to place the magnetic loop. The best case of an antenna placement would be far away from electronics or other components like batteries, displays or large ground planes that harm the effective radiated RF field.

As guidelines for the antenna design three antennas of different, but no specific size have been simulated. All of them have a constant number of tracks (two) with a copper thickness of 35 µm on an FR4 plate, with a thickness of 1.5 mm.

Figure 13 shows the EM - simulation model with the biggest size. The simulations were carried out in the frequency domain.

Figure 13. Simulation model of the coil antenna



To find the dependency of the antenna Q factor and of its other parameters upon the geometry, the trace width and the gap width between traces, as well as the antenna size, have been varied in the simulation.

5.2 Simulation results

Figure 15, *Figure 16*, *Figure 18* and *Figure 17* show the main antenna electrical parameters as a function of antenna size, trace and gap width. *Table 3* summarizes their behavior.

The Q factor depends also upon the antenna size, but the relation is more complex and a more detailed analysis is needed. Additional antenna parameters like inductance, series DC resistance, parallel resistance and self-resonance frequency influence the Q factor, too.

The Q factor of a parallel resonance circuit is:

$$Q = R_{PANT} / (2 \pi f_{carrier} L)$$

where

- R_{PANT} is the total parallel resistance, see *Section 4.3* for details
- L is the antenna inductance
- $f_{carrier}$ is the carrier frequency

The resonance frequency depends on the electrical length of the antenna. The shorter the electrical length, the higher this frequency.

Figure 14. Antenna Q factor vs. antenna size, trace and gap width

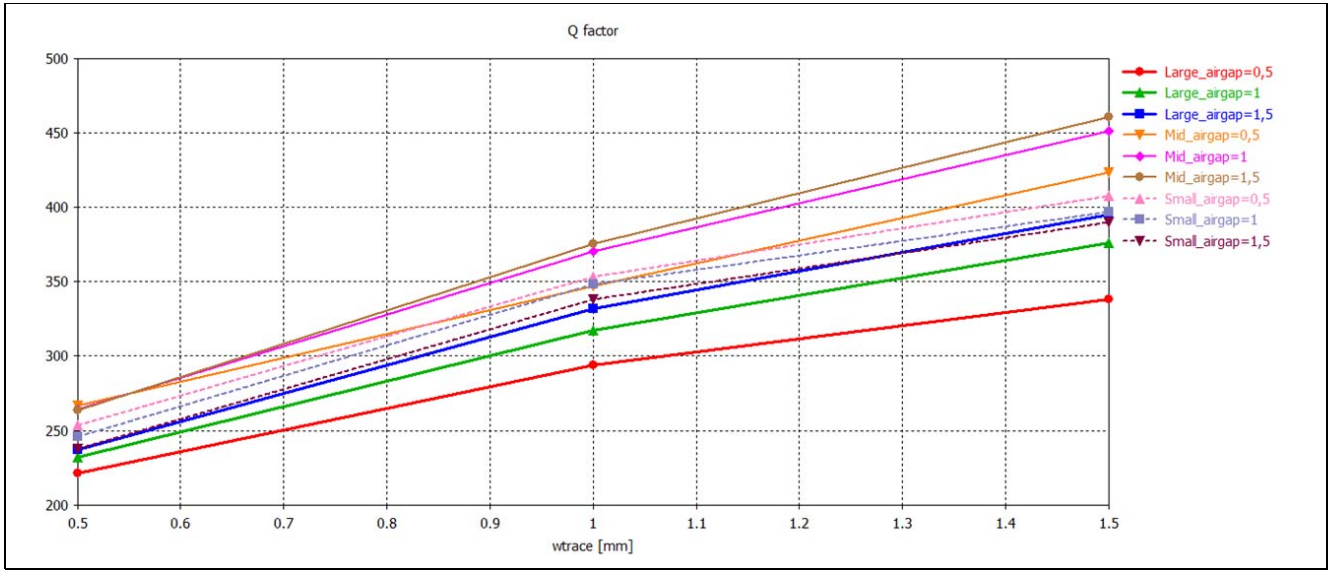


Figure 15. Inductance vs. antenna size, trace and gap width

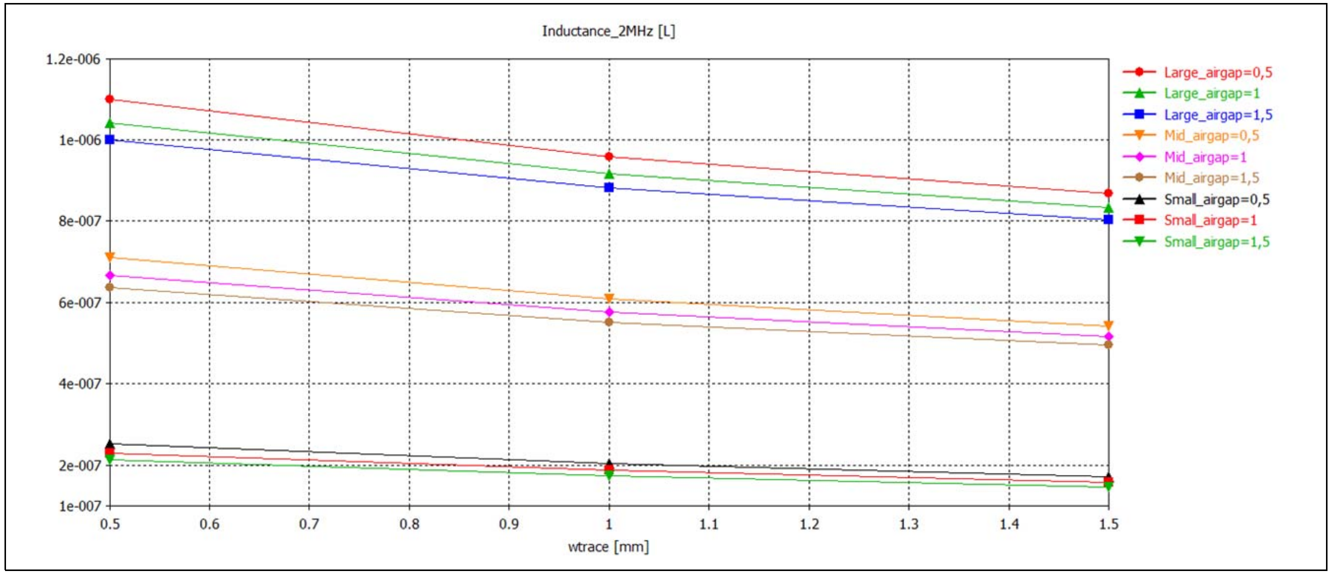


Figure 16. Series DC resistance vs. antenna size, trace and gap width

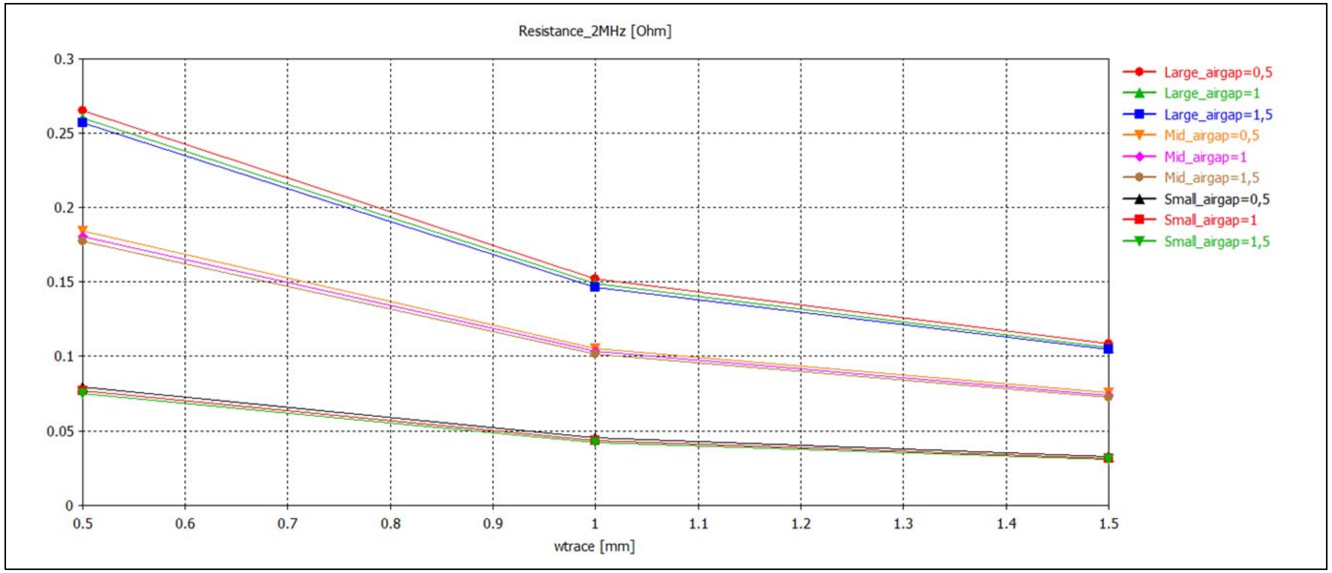


Figure 17. Parallel resistance vs. antenna size, trace and gap width

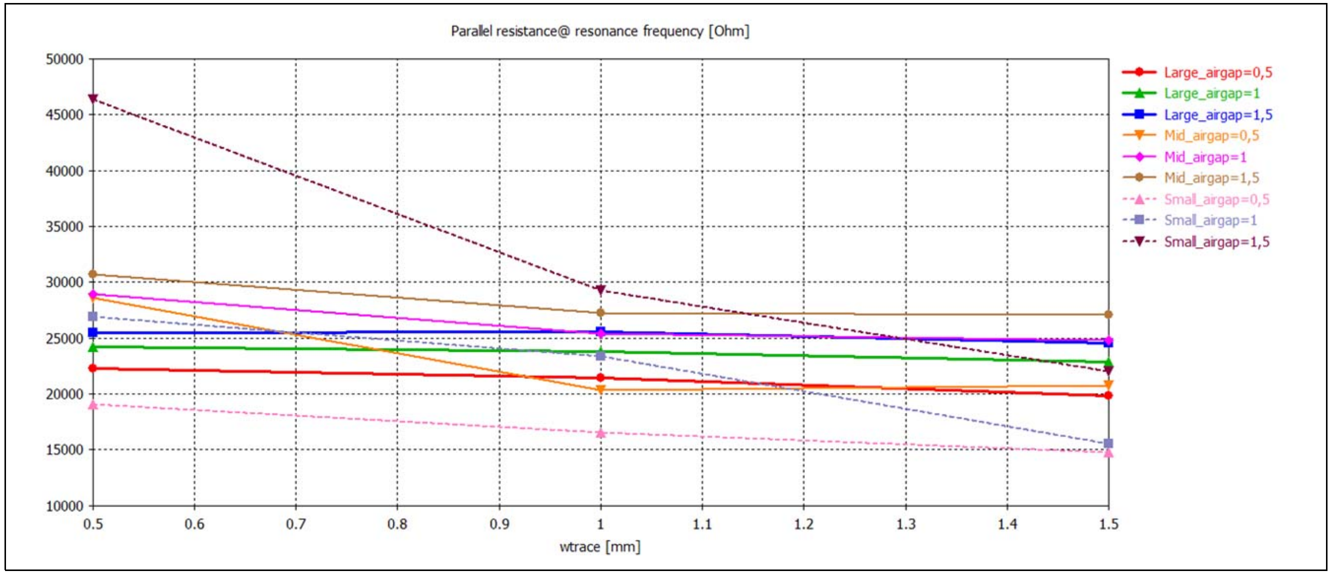


Figure 18. Resonance frequency vs. antenna size, trace and gap width

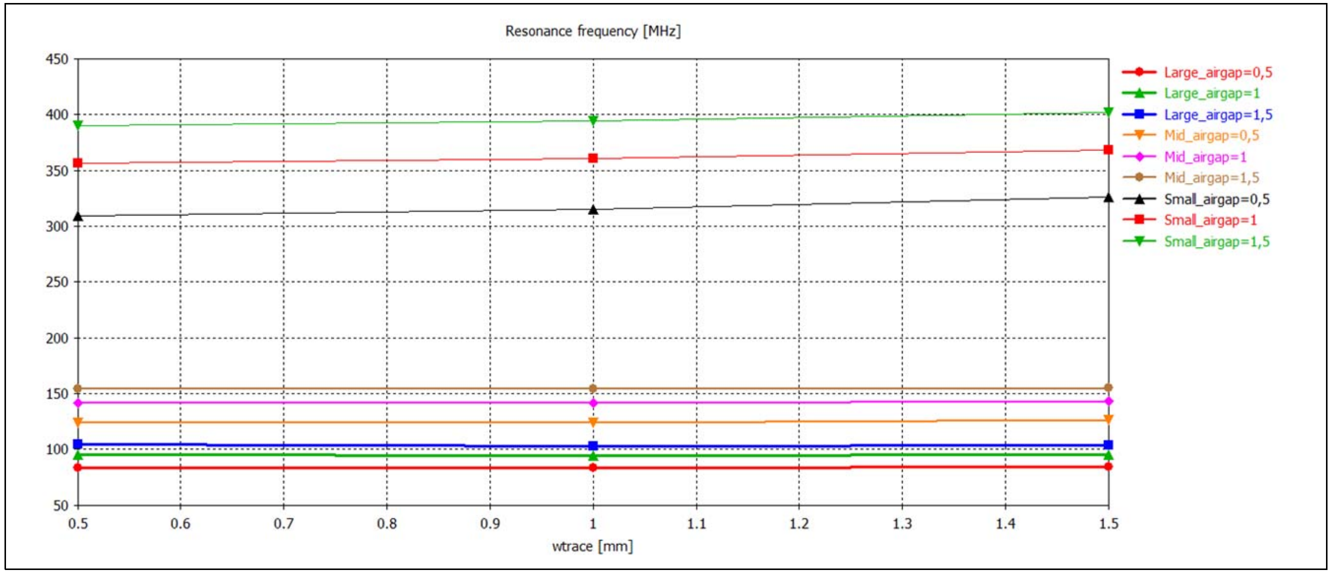


Table 3. Behavior of antenna parameters vs. geometrical parameters

Parameter	Action	Effect on parameter	Q factor
Q factor	Increase trace width	-	Increases
	Increase gap width		
Inductance	Larger antenna	Increases	Decreases
	Decrease trace width		
	Decrease gap width		
Series DC resistance	Larger antenna	Increases	Decreases
	Decrease trace width		
	Decrease gap width		
Parallel resistance	Decrease trace width	Increases	Increases
	Increase gap width		
Resonance frequency	Smaller antenna	Increases	Increases
	increase gap width		

Note: The separated view of each antenna parameter is a theoretical one to understand the basic behavior. In reality all parameter are linked together, e.g. if the inductance is increased by a larger antenna (lower Q), the electrical length increases, which in turn lowers the resonance frequency (Q increases) and the series DC resistance increases (lowering Q).

The inductance of magnetic loop antennas is defined by the electrical length of the conductor. A longer and thinner path for the signal (more electrical length) result in a higher coil inductance. On the other hand, the wider and shorter a transmission line is. the more capacitive is its behavior. Changing the inductance of a loop antenna may thus be realized by altering the thickness of the turns, the gap width or the size of the antenna.

A desired value to be targeted in loop antenna design for NFC reader applications should be between 200 and 1000 nH. Depending on the application higher inductance values can be chosen and are supported by the chip.

In direct relation to the change of the inductance stands the series resistance of the loop antenna, which increases with longer and thinner turns. The antenna self-resonance frequency shows the tendency to increase with larger gap widths between the antenna tracks and also with decreasing size of the antenna.

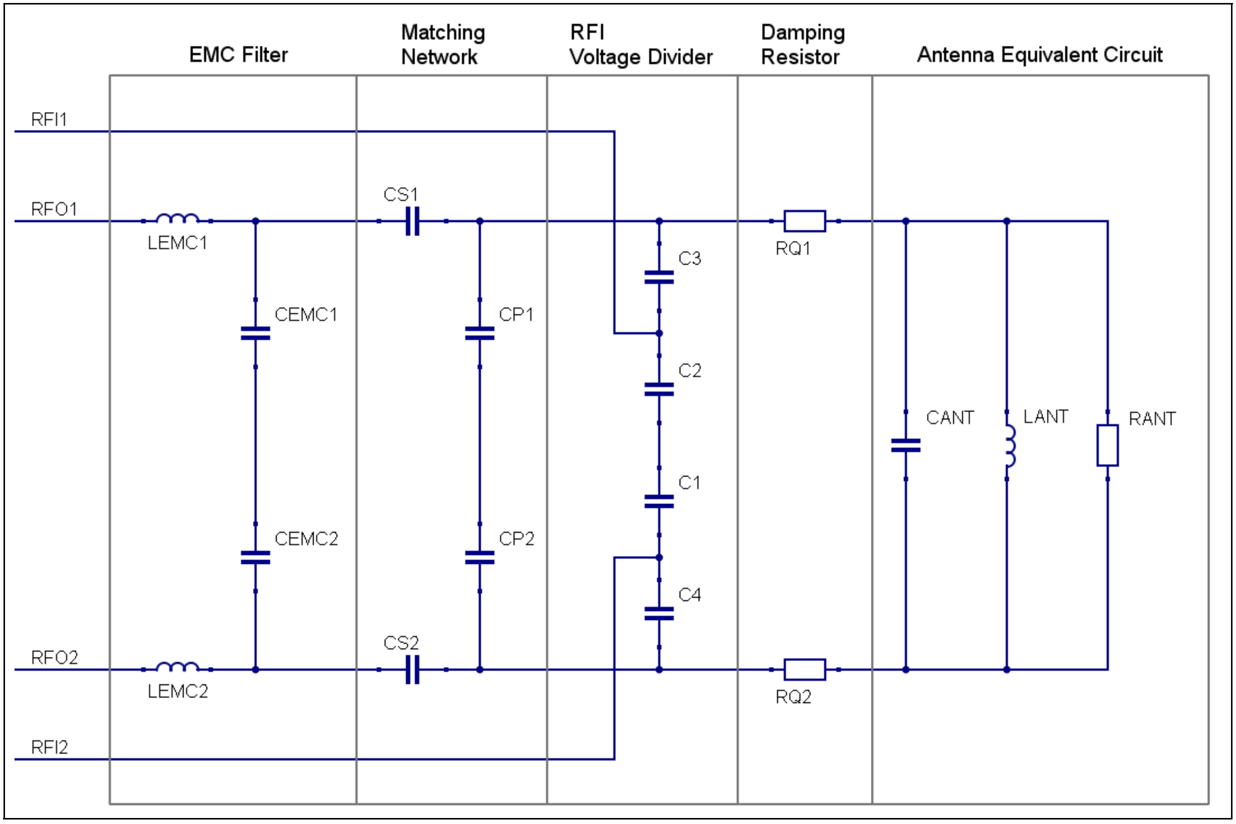
As mentioned in *Section 5* the antenna has to be designed with a Q factor higher than the one needed for the application. The reason is that the Q factor can be decreased by a damping resistor connected at the antenna pins, but it cannot be increased anymore, except with a redesign of the antenna.

6 Antenna matching

The whole antenna interface stage consisting of EMC filter, matching network, RFI voltage divider and antenna equivalent circuit together with the resistor for the Q factor adjustment is represented in *Figure 19* as a differential topology.

The EMC filter is a one stage filter made up of a series inductor and a parallel capacitor to ground. The matching network consists of a series and a parallel capacitor, whereas just one parallel component is used in this topology. The resistor for the Q factor adjustment is a series resistor. The antenna is shown as an equivalent circuit consisting of a series inductor, a parallel resistor and a parallel capacitor. The voltage divider for the receive path is capacitive and connected directly at the antenna pins.

Figure 19. Differential matching topology



6.1 Matching tool

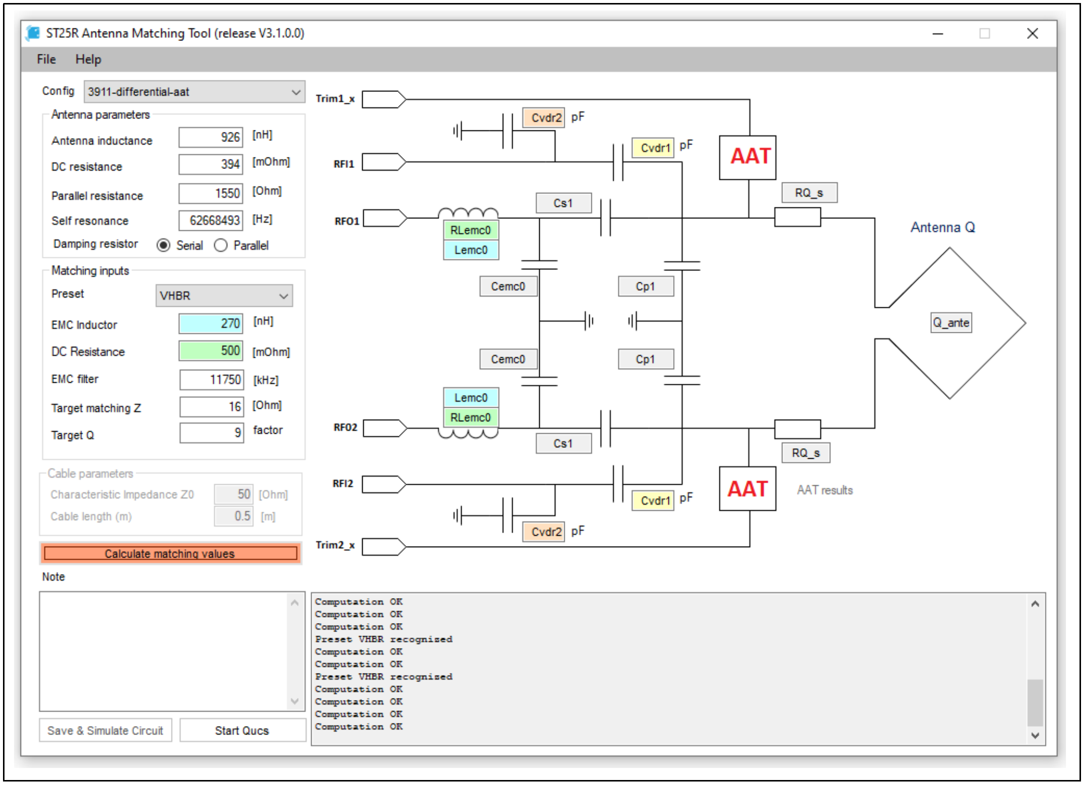
The STMicroelectronics ST25R Antenna Matching Tool is a straightforward tool to determine the matching for the antenna once the electrical antenna parameters have been measured. The tool comes with an intuitive GUI to guide the user through the process of finding the component values. Additionally, a program called Qucs (Quite Universal Circuit Simulator) can be started directly from the GUI. The Qucs simulation tool can be used to perform AC, S-Parameter and Transient simulations to verify the component values.

Qucs is integrated into the ST25R Antenna Matching Tool installer, and can also be freely downloaded at http://sourceforge.net (it is recommended to use version number 0.0.18, the one embedded into the ST25R Antenna Matching Tool). As for the installation path, do not use the default Windows directory, but rather a path like C:\Tools\Qucs.To open the matching tool, download the executable (STSW-ST25R004) from *www.st.com*. The main window is shown in *Figure 20*.

The process flow is from top to bottom, made up of five basic steps

1. Insert the measured antenna input parameters at 1 MHz and SRF
2. Select a precondition, or define your own condition
3. Define EMC filter coil inductance and DC resistance
4. Enter the target matching impedance and target Q factor
5. Calculate and simulate the computed values

Figure 20. ST25R Antenna Matching Tool - Main window



Config 3911-differential-aat

Antenna parameters

Antenna inductance 926 [nH]

DC resistance 394 [mOhm]

Parallel resistance 1550 [Ohm]

Self resonance 62668493 [Hz]

Damping resistor ● Serial ○ Parallel

Matching inputs

Preset VHBR

EMC Inductor 270 [nH]

DC Resistance 500 [mOhm]

EMC filter 11750 [kHz]

Target matching Z 16 [Ohm]

Target Q 9 factor

Cable parameters

Characteristic Impedance Z0 50 [Ohm]

Cable length (m) 0.5 [m]

```
Computation OK
Computation OK
Computation OK
Preset VHBR recognised
Computation OK
Computation OK
Preset VHBR recognised
Computation OK
Computation OK
Computation OK
Computation OK
```

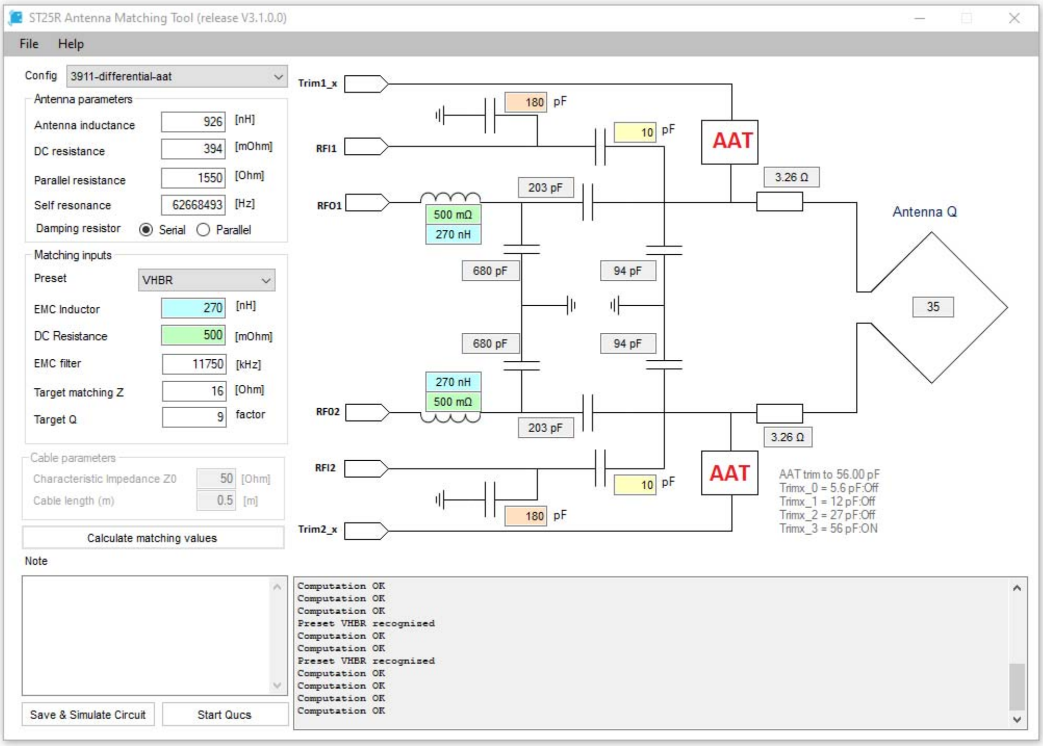
The first step is already completed in *Figure 20*: as described in *Section 4.2: Parameter measurement* the antenna parameter have already been entered in the input parameter fields.

In the precondition tab enter the desired EMC filter cutoff frequency, the target matching impedance and the desired antenna Q factor. There are three preconditions defined, either select one of them or define your own condition, depending on the application.

The third step is to choose a value for the inductance of the EMC filter. The selected EMC filter frequency and inductance are dependent on each other and may have to be adapted. The EMC filter capacitor value is calculated from these two inputs. Depending on the chosen EMC inductors, a proper inductor DC resistance has to be entered. This value can be found in the datasheet of the inductor. The antenna Q factor is shown after the computation in the schematic area. If the desired Q factor is higher than the calculated antenna Q factor, a negative damping resistor value is displayed.

By clicking the calculate button all the component values are calculated and shown in the schematic part (*Figure 21*).

Figure 21. ST25R Antenna Matching Tool - Calculated matching components



ST25R Antenna Matching Tool (release V3.1.0.0)

Config: 3911-differential-aat

Antenna parameters
Antenna inductance: 926 [nH]
DC resistance: 394 [mOhm]
Parallel resistance: 1550 [Ohm]
Self resonance: 62668493 [Hz]
Damping resistor: ● Serial ○ Parallel

Matching inputs
Preset: VHBR
EMC Inductor: 270 [nH]
DC Resistance: 500 [mOhm]
EMC filter: 11750 [kHz]
Target matching Z: 16 [Ohm]
Target Q: 9 factor

Cable parameters
Characteristic Impedance Z0: 50 [Ohm]
Cable length (m): 0.5 [m]

AAT trim to 56.00 pF
Trimx_0 = 5.6 pF:Off
Trimx_1 = 12 pF:Off
Trimx_2 = 27 pF:Off
Trimx_3 = 56 pF:ON

```
Computation OK
Computation OK
Computation OK
Preset VHBR recognised
Computation OK
Computation OK
Preset VHBR recognised
Computation OK
Computation OK
Computation OK
Computation OK
```

Parasitic (like ESR of the capacitors) and special component parameters are not taken into account.

With all values calculated the results can now be simulated: click on Simulate Circuit, a save dialog pops up asking to save the schematic file. Carefully choose the data destination (depending on the r/w permissions), the suggested location being

`%userprofile%\.qucs\PROJECT_prj (PROJECT = Project Name; _prj = QUCS suffix)`

If the schematic files need to be loaded to continue the simulations, Qucs can be started by pressing the “Start Qucs” button. If the files are saved in above mentioned location, Qucs automatically finds and displays them in the projects panel.

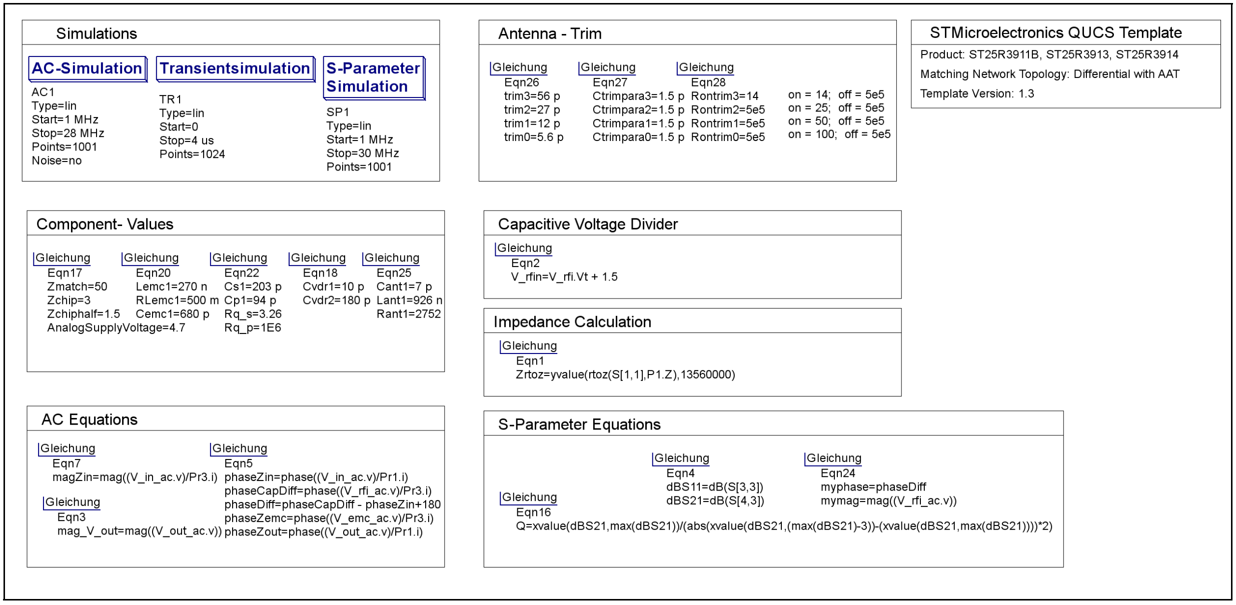
6.2 Simulation

If Qucs has been started via the “Simulate Circuit” button and the schematic files have been saved accordingly, Qucs automatically loads the schematics. If this is not happening, use the file-open dialog to load the schematics.

Qucs uses a schematic file to setup the simulation and a display file to view the simulation results. The before calculated values are automatically inserted in a Qucs schematic template, displayed while saving.

The component values and simulation parameters are found in the top section of the sheet, it also contains formulas required for the display file/view. It is strongly recommended to change component values only in the section “Component-Values” and not in the simulation model itself. *Figure 22* shows the antenna parameters, very similar to the before-calculated values.

Figure 22. Simulation parameters



```
Simulations

AC-Simulation         Transientsimulation    S-Parameter
AC1                                          Simulation
Type=lin              TR1
Start=1 MHz           Type=lin               SP1
Stop=28 MHz           Start=0                Type=lin
Points=1001           Stop=4 us              Start=1 MHz
Noise=no              Points=1024            Stop=30 MHz
                                             Points=1001
```

```
Antenna - Trim

Gleichung      Gleichung          Gleichung
  Eqn26          Eqn27              Eqn28
  trim3=56 p     Ctrimpara3=1.5 p  Rontrim3=14      on = 14;  off = 5e5
  trim2=27 p     Ctrimpara2=1.5 p  Rontrim2=5e5     on = 25;  off = 5e5
  trim1=12 p     Ctrimpara1=1.5 p  Rontrim1=5e5     on = 50;  off = 5e5
  trim0=5.6 p    Ctrimpara0=1.5 p  Rontrim0=5e5     on = 100;  off = 5e5
```

```
STMicroelectronics QUCS Template
Product: ST25R3911B, ST25R3913, ST25R3914
Matching Network Topology: Differential with AAT
Template Version: 1.3
```

```
Component- Values

Gleichung         Gleichung         Gleichung      Gleichung       Gleichung
  Eqn17             Eqn20             Eqn22          Eqn18           Eqn25
  Zmatch=50         Lemc1=270 n       Cs1=203 p      Cvdr1=10 p      Cant1=7 p
  Zchip=3           RLemc1=500 m      Cp1=94 p       Cvdr2=180 p     Lant1=926 n
  Zchiphalf=1.5     Cemc1=680 p       Rq_s=3.26                      Rant1=2752
  AnalogSupplyVoltage=4.7             Rq_p=1E6
```

```
Capacitive Voltage Divider

Gleichung
  Eqn2
  V_rfin=V_rfi.Vt + 1.5
```

```
Impedance Calculation

Gleichung
  Eqn1
  Zrtoz=yvalue(rtoz(S[1,1],P1.Z),13560000)
```

```
AC Equations

Gleichung                             Gleichung
  Eqn7                                  Eqn5
  magZin=mag((V_in_ac.v)/Pr3.i)         phaseZin=phase((V_in_ac.v)/Pr1.i)
                                        phaseCapDiff=phase((V_rfi_ac.v)/Pr3.i)
 Gleichung                              phaseDiff=phaseCapDiff - phaseZin+180
   Eqn3                                 phaseZemc=phase((V_emc_ac.v)/Pr3.i)
   mag_V_out=mag((V_out_ac.v))          phaseZout=phase((V_out_ac.v)/Pr1.i)
```

```
S-Parameter Equations

                        Gleichung                Gleichung
                          Eqn4                     Eqn24
                          dBS11=dB(S[3,3])         myphase=phaseDiff
Gleichung                 dBS21=dB(S[4,3])         mymag=mag((V_rfi_ac.v))
  Eqn16
  Q=xvalue(dBS21,max(dBS21))/(abs(xvalue(dBS21,(max(dBS21)-3))-(xvalue(dBS21,max(dBS21))))*2)
```

6.2.1 Models

Three models are used to perform simulations:

1. S-parameter model (*Figure 23*) is used to calculate the target matching impedance in the Smith chart. 50 Ω is used as source impedance to compare the results with the VNA. The results are shown in *Figure 27*.
2. Transient simulation (*Figure 24*) checks the waveform of the OOK and calculates the RFI Voltage to define the capacitive voltage divider values. The estimated IC output driver impedance of 3 Ω is used. The results are shown in *Figure 29*.
3. AC simulation (*Figure 25*) calculates the reflection and transmission coefficients (S11 and S21) with the IC output driver impedance of 3 Ω. This is used to calculate the Q factor, the phase differences between RFO and RFI and to monitor the relation between the resonance frequencies of the antenna and EMC filter stages. The results are shown in *Figure 27* and *Figure 29*.

Figure 23 shows the S-Parameter model, while “Component-Values” and “Antenna-Trim” areas are shown in *Figure 22*. The values assigned here are automatically linked to all three models. In the “Antenna-Trim” area the antenna can be tuned by switching the four binary weighted trim capacitors put in parallel to CP1.

The trim pin 3 is enabled by setting Rontrim3 to the ON value (14 Ω). The other three trim pins are disabled (Rontrim[0, 1, 2] = 500 MΩ). By enabling trim pin 3 the parallel capacitor of the matching network changes to C_P = (56 pF * 56 pF) / (56 pF + 56 pF) + 68 pF = 96 pF.

The difference between S-parameter and AC model is the impedance of the power source. While measuring the impedance (S-parameter measurement) the matching network and antenna is powered by this VNA. The impedance of the VNA is in most cases 50 Ω, therefore the source impedance of the S-parameter model has to be 50 Ω.

Figure 23. S-parameter model

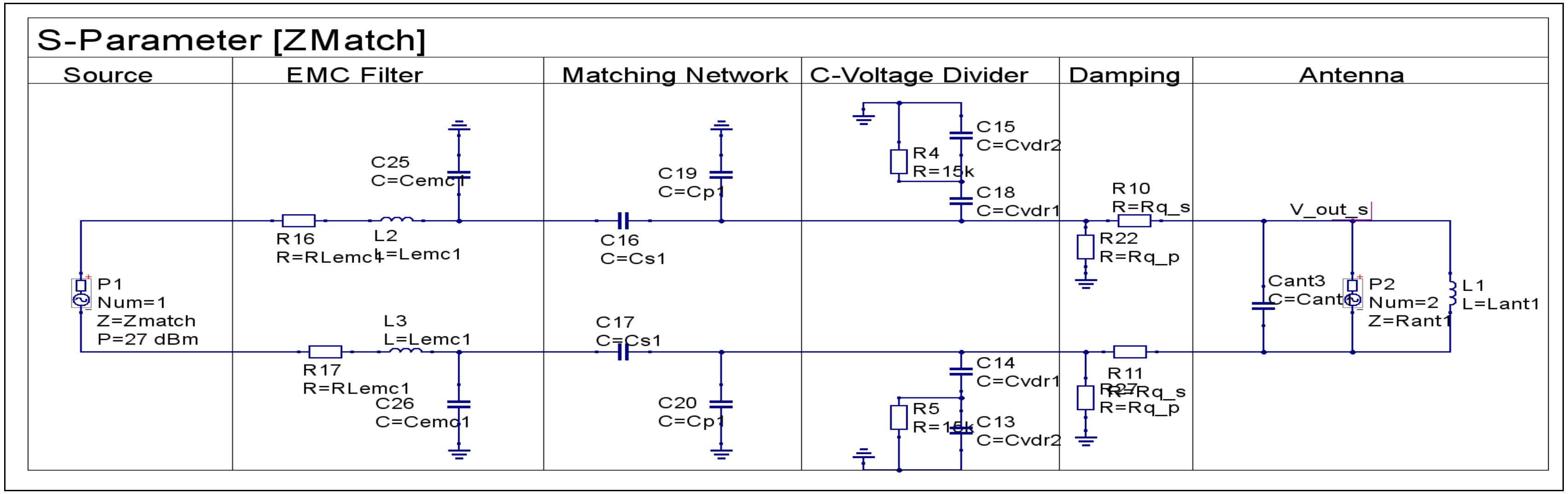


Figure 24. Transient simulation

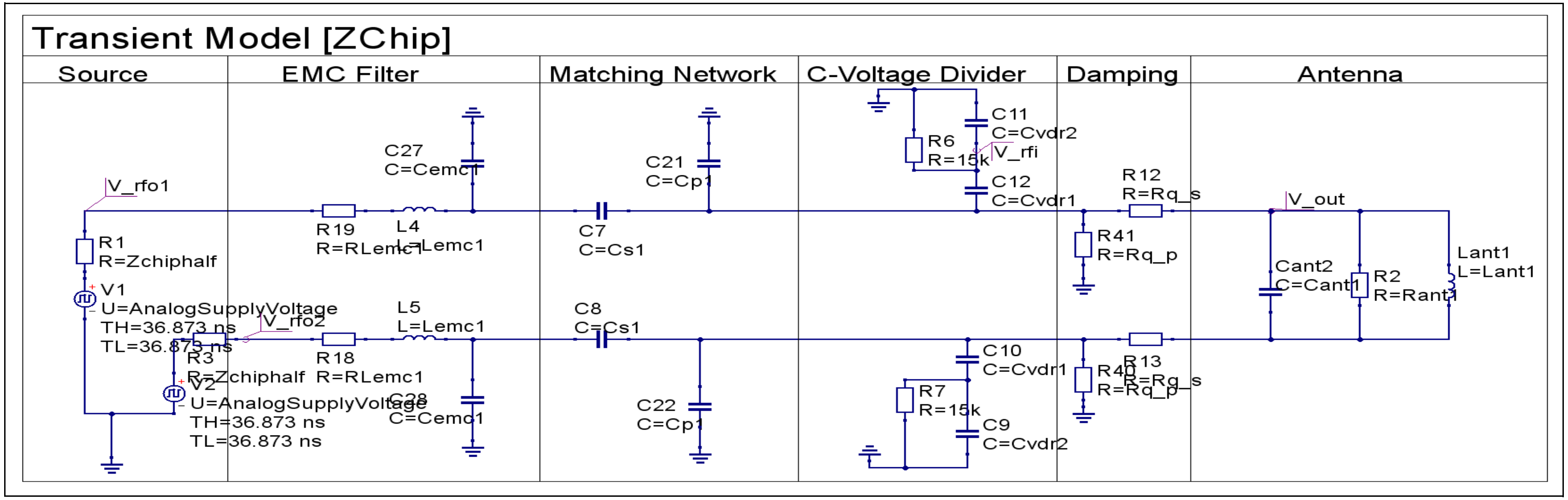
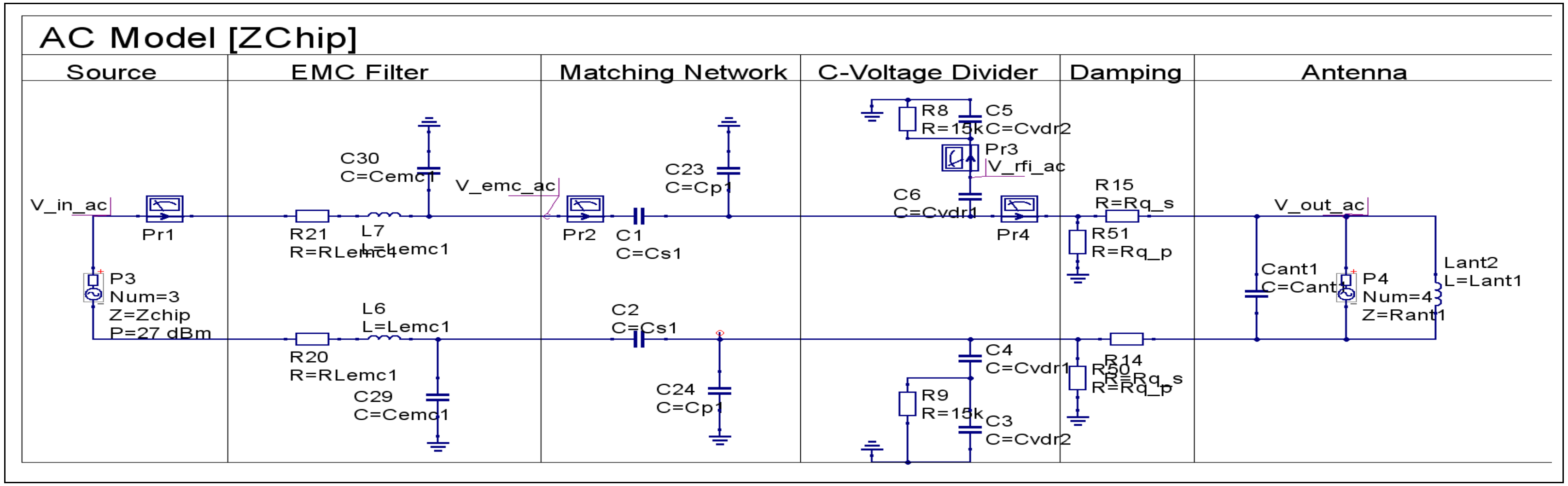


Figure 25. AC simulation



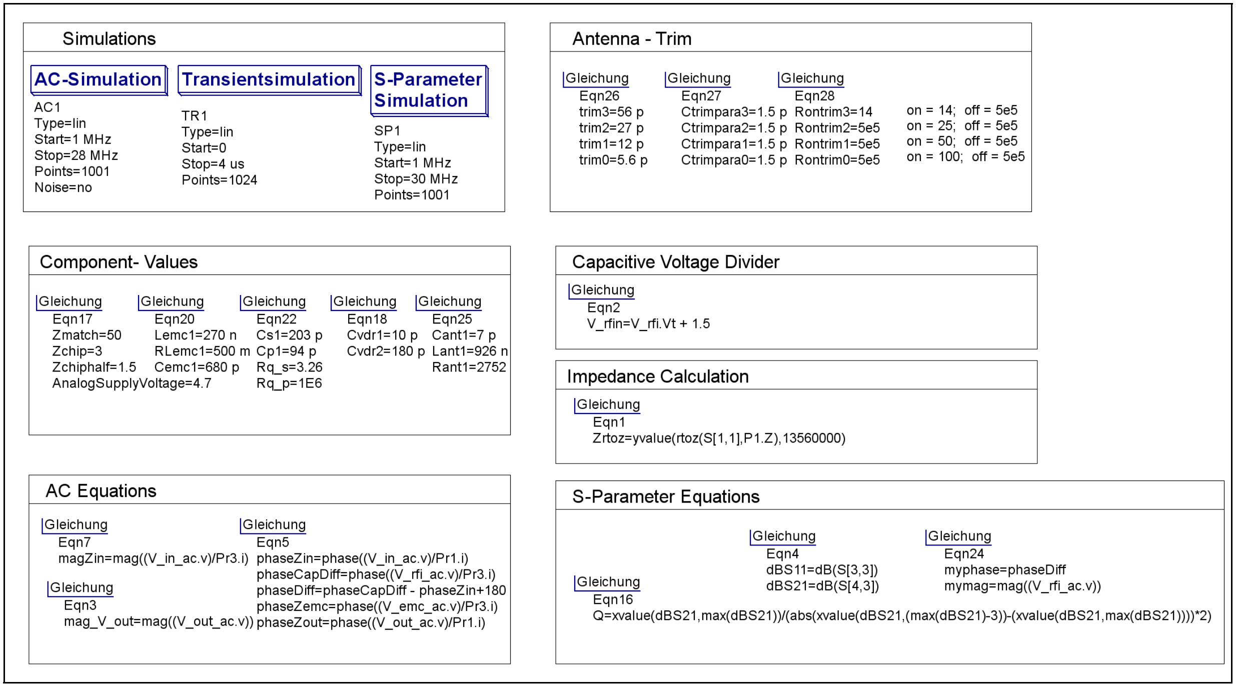
The transient model is powered by two periodic rectangular voltage pulse sources. Every source represents one single ended driver stage. The output resistance of the driver stage can be defined by setting R88 and R89 (differential output resistance = 2 * R88 = 2 * R89).

The AC model is used to simulate the matching network during normal operation, hence the source impedance of the AC power source must correlate with the chip impedance. The forward reflection (S11) and forward transmission coefficients (S21), as well as the phase and magnitude characteristics can calculated with this simulation. At the end, the results are displayed in a new tab. It is also possible to include further simulations like parameter sweep.

6.2.2 Results

The transfer functions dB [S11] and dB [S21] are calculated in Eqn4 (S-Parameter Equations box in *Figure 26*). This equation uses port 3 and 4 of the AC simulation model. dB [S11] represents the reflected power on the RFOx pins. With better matching between ST25R3911B driver stages and matching network, less power is reflected. In our case the output resistance is set to 3 Ω differential and the matching network is tuned to (16.83 + j 1.484) Ω.

Figure 26. Definition of simulations and equations



```
Simulations

AC-Simulation        Transientsimulation     S-Parameter
                                             Simulation
AC1
Type=lin             TR1
Start=1 MHz          Type=lin                SP1
Stop=28 MHz          Start=0                 Type=lin
Points=1001          Stop=4 us               Start=1 MHz
Noise=no             Points=1024             Stop=30 MHz
                                             Points=1001
```

```
Antenna - Trim

Gleichung        Gleichung             Gleichung
  Eqn26            Eqn27                 Eqn28
  trim3=56 p       Ctrimpara3=1.5 p      Rontrim3=14       on = 14;  off = 5e5
  trim2=27 p       Ctrimpara2=1.5 p      Rontrim2=5e5      on = 25;  off = 5e5
  trim1=12 p       Ctrimpara1=1.5 p      Rontrim1=5e5      on = 50;  off = 5e5
  trim0=5.6 p      Ctrimpara0=1.5 p      Rontrim0=5e5      on = 100;  off = 5e5
```

```
Component- Values

Gleichung          Gleichung        Gleichung      Gleichung      Gleichung
  Eqn17              Eqn20            Eqn22          Eqn18          Eqn25
  Zmatch=50          Lemc1=270 n      Cs1=203 p      Cvdr1=10 p     Cant1=7 p
  Zchip=3            RLemc1=500 m     Cp1=94 p       Cvdr2=180 p    Lant1=926 n
  Zchiphalf=1.5      Cemc1=680 p      Rq_s=3.26                     Rant1=2752
  AnalogSupplyVoltage=4.7             Rq_p=1E6
```

```
Capacitive Voltage Divider

Gleichung
  Eqn2
  V_rfin=V_rfi.Vt + 1.5
```

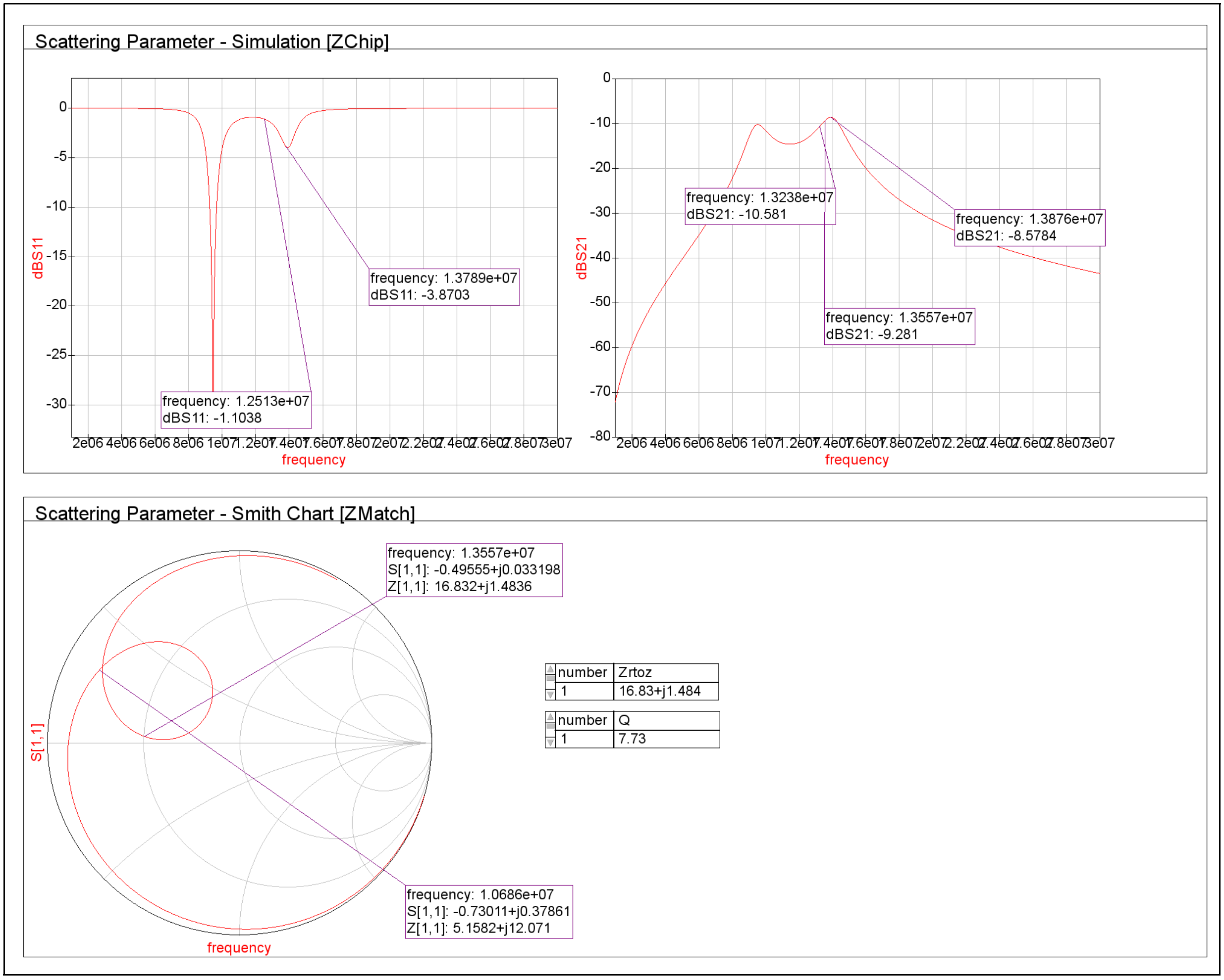
```
Impedance Calculation

Gleichung
  Eqn1
  Zrtoz=yvalue(rtoz(S[1,1],P1.Z),13560000)
```

```
AC Equations

Gleichung                          Gleichung
  Eqn7                               Eqn5
  magZin=mag((V_in_ac.v)/Pr3.i)      phaseZin=phase((V_in_ac.v)/Pr1.i)
                                     phaseCapDiff=phase((V_rfi_ac.v)/Pr3.i)
 Gleichung                           phaseDiff=phaseCapDiff - phaseZin+180
   Eqn3                              phaseZemc=phase((V_emc_ac.v)/Pr3.i)
   mag_V_out=mag((V_out_ac.v))       phaseZout=phase((V_out_ac.v)/Pr1.i)
```

```
S-Parameter Equations

                       Gleichung                  Gleichung
                         Eqn4                       Eqn24
                         dBS11=dB(S[3,3])           myphase=phaseDiff
Gleichung                dBS21=dB(S[4,3])           mymag=mag((V_rfi_ac.v))
  Eqn16
  Q=xvalue(dBS21,max(dBS21))/(abs(xvalue(dBS21,(max(dBS21)-3))-(xvalue(dBS21,max(dBS21))))*2)
```

Figure 27 shows the forward transmission, which shows the damping over frequency. The Smith chart displays the nominal resistance of the matching network plus antenna over frequency. If the curve cuts the real axis, the imaginary part is zero and the circuit is in resonance. In our case one resonance frequency of the matching network is at 13.57 MHz. The complex resistance of the circuit at this frequency is (16.83 + j 1.484) Ω. Because the nominal resistance is 50 Ω, this graph should match with the measurement of the VNA.

Figure 27. Simulation results of the S-parameter and the AC model



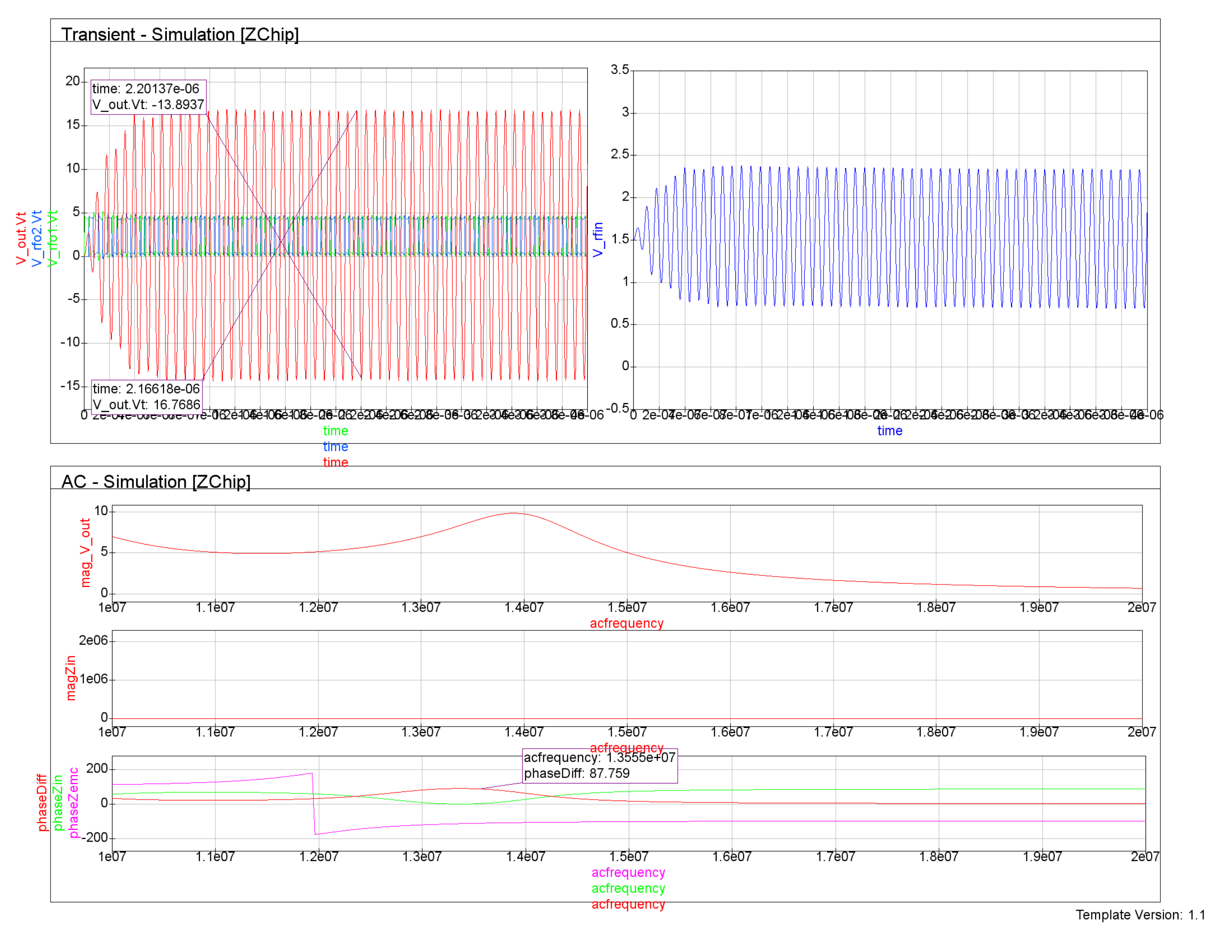
number	Zrtoz
1	16.83+j1.484

number	Q
1	7.73

The result of the Q factor simulation is calculated from the dB[S21] result.

As result of the transient simulation, it is worth looking at the shape of the antenna voltage and at the voltage at the RFIx pins. Eqn2 (Capacitive Voltage Divider box in *Figure 26*).describes how the voltage at RFIx pins gets biased to the level of AGD (the analog reference voltage). The input voltage must not exceed 3 V_{PP}. In the lower section of *Figure 28* the magnitude of the antenna voltage, the matching impedance and the phase difference (phasediff) between RF0x and RFIx pins are displayed.

Figure 28. Simulation results of the transient and of the AC model



6.3 Matching network behavior

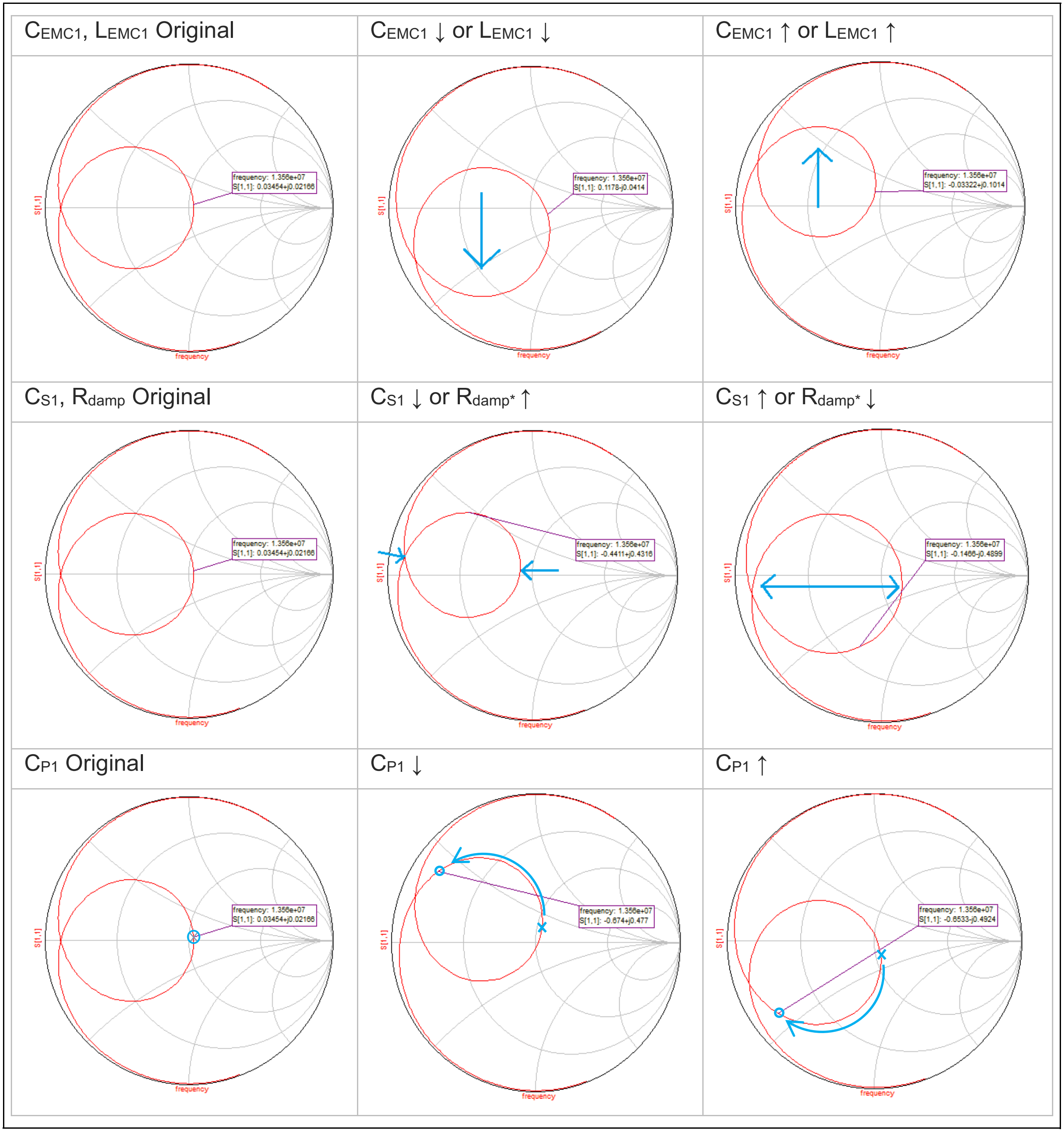
Since the simulation does not always match to the reality, some fine tuning may be needed.

Figure 29 shows how the matching network behaves when some components are changed.

Note that the behavior of R_{damp} is valid only for the series resistor configuration, for the parallel damping resistor the behavior is the opposite.

When changing one component other effects may appear. As an example, changing the serial capacitor changes the diameter of the resonance cycle, but also shifts the resonance frequency, as when changing the parallel capacitor.

Figure 29. Fine tuning of the matching circuit



C_{EMC1}, L_{EMC1} Original

C_{EMC1} ↓ or L_{EMC1} ↓

C_{EMC1} ↑ or L_{EMC1} ↑

C_{S1}, R_{damp} Original

C_{S1} ↓ or R_{damp^*} ↑

C_{S1} ↑ or R_{damp^*} ↓

C_{P1} Original

C_{P1} ↓

C_{P1} ↑

7 Design verification

This section discusses the verification of the designed antenna and explains the measurement of timing parameters, Q factor, and target matching impedance.

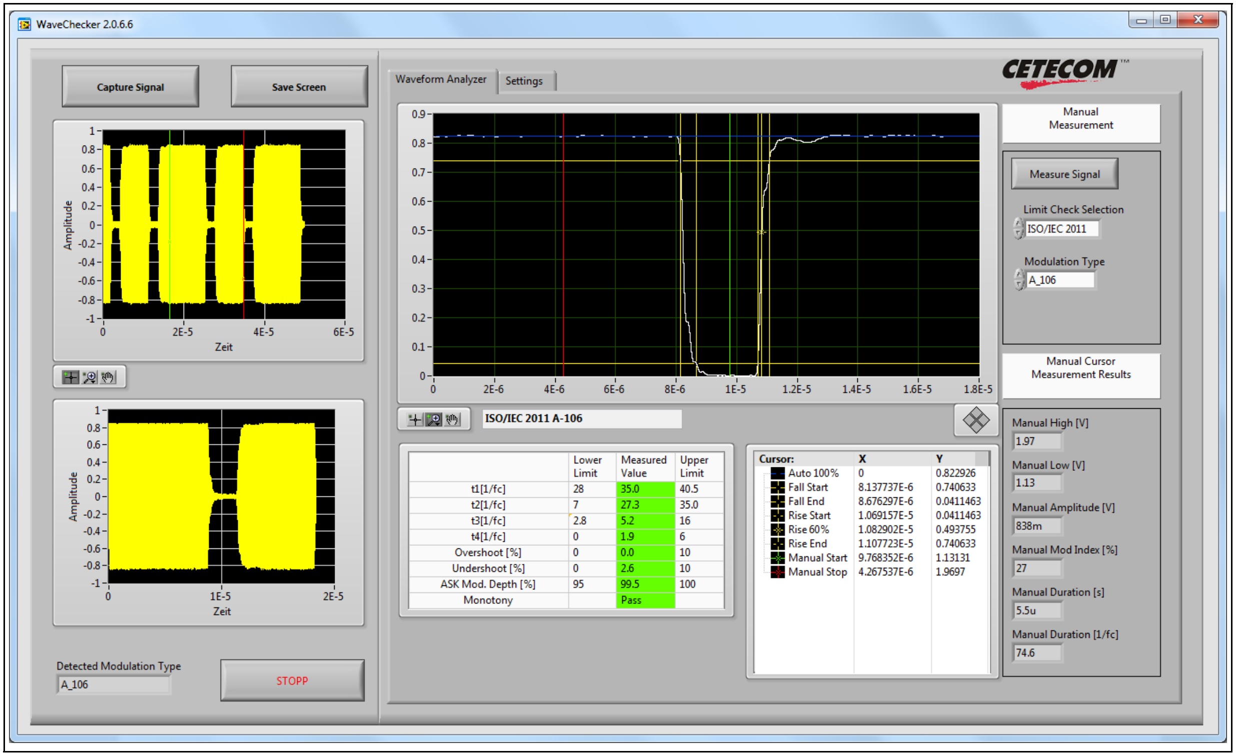
7.1 Measurement of PCD RF analog parameters

To ensure correct operation and interoperability of a reader system, all measurements must be performed according to the required standard (e.g. ISO14443, or EMV contactless). As an example, to test against ISO14443 contactless standard it is necessary to use the ISO reference PICC defined in ISO/IEC10373-6.

Verifying the RF signaling parameters with an oscilloscope loop only gives a first indication on signal forms, but does not produce any meaningful or comparable measurement result.

Figure 30, *Figure 31*, and *Figure 32* show, respectively, snapshots of Type A 106 kbit/s, Type B 106 kbit/s and Felica™ measurements with a reference PICC.

Figure 30. ISO 14443 Type A wave shape measurement



Limit Check Selection: ISO/IEC 2011

Modulation Type: A_106

ISO/IEC 2011 A-106

	Lower Limit	Measured Value	Upper Limit
t1[1/fc]	28	35.0	40.5
t2[1/fc]	7	27.3	35.0
t3[1/fc]	2.8	5.2	16
t4[1/fc]	0	1.9	6
Overshoot [%]	0	0.0	10
Undershoot [%]	0	2.6	10
ASK Mod. Depth [%]	95	99.5	100
Monotony		Pass	

Cursor:	X	Y
Auto 100%	0	0.822926
Fall Start	8.137737E-6	0.740633
Fall End	8.676297E-6	0.0411463
Rise Start	1.069157E-5	0.0411463
Rise 60%	1.082902E-5	0.493755
Rise End	1.107723E-5	0.740633
Manual Start	9.768352E-6	1.13131
Manual Stop	4.267537E-6	1.9697

Manual High [V]: 1.97

Manual Low [V]: 1.13

Manual Amplitude [V]: 838m

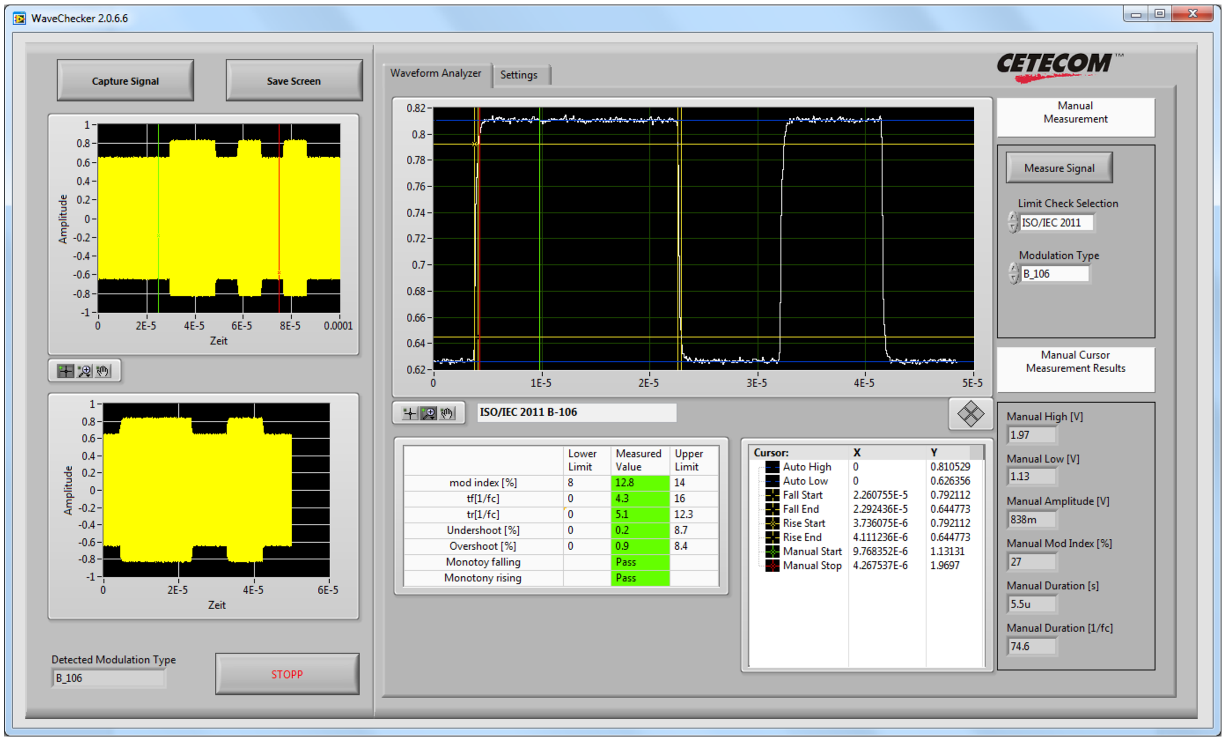
Manual Mod Index [%]: 27

Manual Duration [s]: 5.5u

Manual Duration [1/fc]: 74.6

Detected Modulation Type: A_106

Figure 31. ISO 14443 Type B wave shape measurement



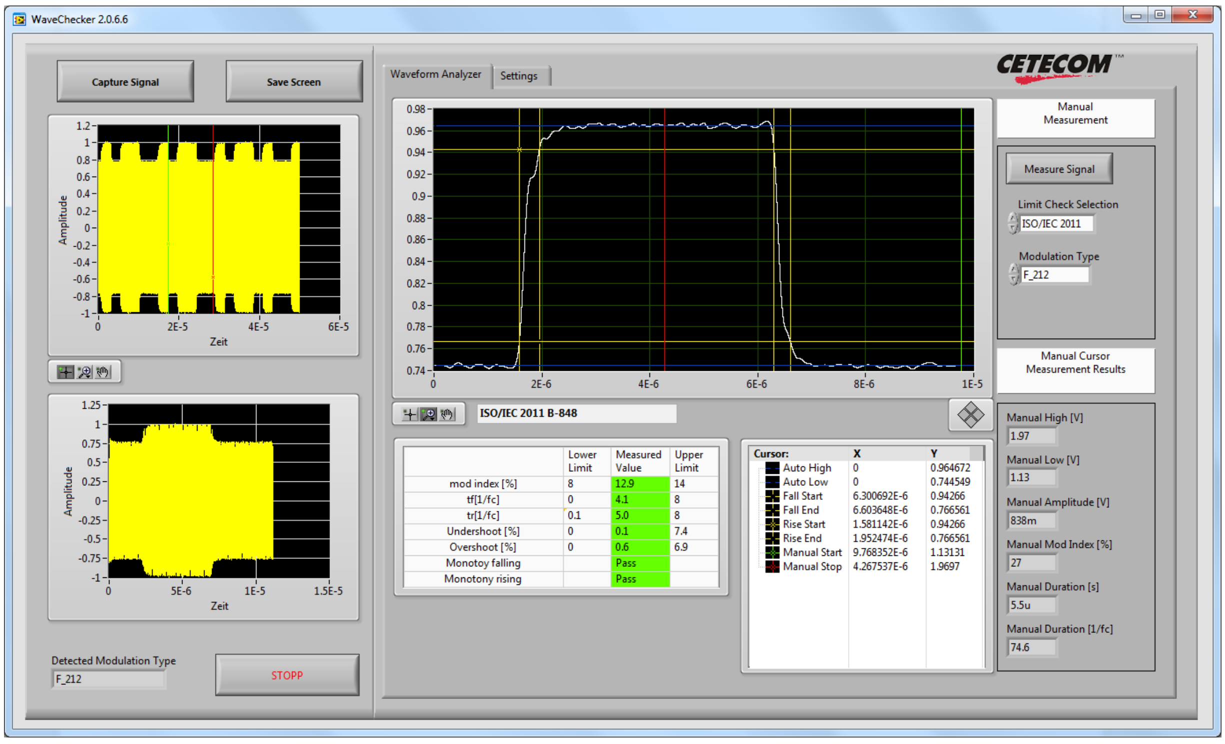
ISO/IEC 2011 B-106

	Lower Limit	Measured Value	Upper Limit
mod index [%]	8	12.8	14
tf[1/fc]	0	4.3	16
tr[1/fc]	0	5.1	12.3
Undershoot [%]	0	0.2	8.7
Overshoot [%]	0	0.9	8.4
Monotoy falling		Pass	
Monotony rising		Pass	

Cursor:	X	Y
Auto High	0	0.810529
Auto Low	0	0.626356
Fall Start	2.260755E-5	0.792112
Fall End	2.292436E-5	0.644773
Rise Start	3.736075E-6	0.792112
Rise End	4.111236E-6	0.644773
Manual Start	9.768352E-6	1.13131
Manual Stop	4.267537E-6	1.9697

Limit Check Selection: ISO/IEC 2011
Modulation Type: B_106
Manual High [V]: 1.97
Manual Low [V]: 1.13
Manual Amplitude [V]: 838m
Manual Mod Index [%]: 27
Manual Duration [s]: 5.5u
Manual Duration [1/fc]: 74.6
Detected Modulation Type: B_106

Figure 32. FeliCa™ wave shape measurement



ISO/IEC 2011 B-848

	Lower Limit	Measured Value	Upper Limit
mod index [%]	8	12.9	14
tf[1/fc]	0	4.1	8
tr[1/fc]	0.1	5.0	8
Undershoot [%]	0	0.1	7.4
Overshoot [%]	0	0.6	6.9
Monotoy falling		Pass	
Monotony rising		Pass	

Cursor:	X	Y
Auto High	0	0.964672
Auto Low	0	0.744549
Fall Start	6.300692E-6	0.94266
Fall End	6.603648E-6	0.766561
Rise Start	1.581142E-6	0.94266
Rise End	1.952474E-6	0.766561
Manual Start	9.768352E-6	1.13131
Manual Stop	4.267537E-6	1.9697

Limit Check Selection: ISO/IEC 2011
Modulation Type: F_212
Manual High [V]: 1.97
Manual Low [V]: 1.13
Manual Amplitude [V]: 838m
Manual Mod Index [%]: 27
Manual Duration [s]: 5.5u
Manual Duration [1/fc]: 74.6
Detected Modulation Type: F_212

7.2 Verification of the Q factor in the time domain

The resonance circuit envelope can be calculated for falling and rising edges with exponential functions:

$$Q_f = 2 \pi f_{work} [(t_1 - t_2) / (\ln 0.9 - \ln 0.05)]$$

$$Q_r = 2 \pi f_{work} [t_3 / (\ln 0.9 - \ln 0.05)]$$

The overall Q is determined averaging Q_f and Q_r, that is $Q = (Q_f + Q_r) / 2$

7.3 Verification of the Q factor in the frequency domain

The Q factor can be measured using a vector network analyzer and an ISO10373-6 Class 1-3 calibration coil.

The following steps should be carried out:

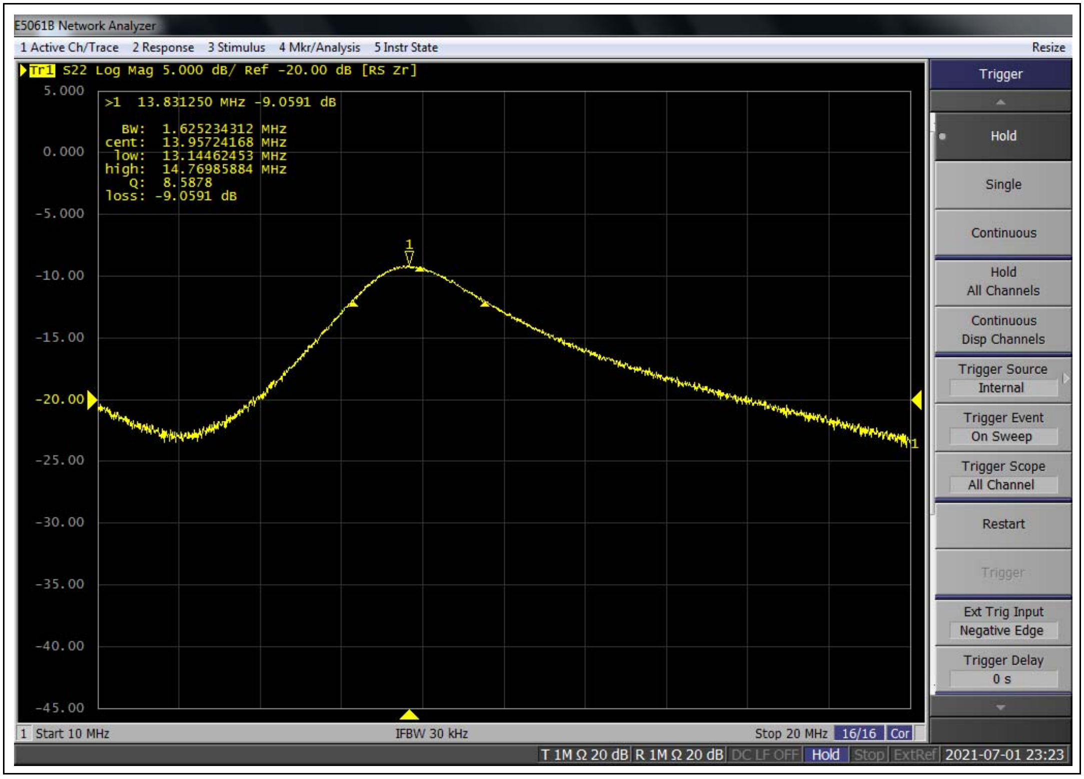
1. The network analyzer shall be calibrated for a frequency sweep from about 10 to 20 MHz
2. S11 measurement in log mag format shall be displayed.
3. The calibration coil is connected to the VNA.
4. “Short” calibration of the coil and conversion to “Z: Reflection”
5. Set marker 1 and enable the bandwidth/Q factor measurement
6. Place the PCD antenna on the measurement coil

Note: If the reader is plugged and powered, ensure that register 0x27 is set to 0xFF to avoid an high power transfer to the VNA ports, which can damage the VNA.

7. Adjust the suitable trim value via the register map (register 0x21) in the GUI of the reader
8. Place a 3 Ω resistor between the RFO pin to simulate the chip resistance during operation.
9. Press “max search” to align the marker on the resonance frequency peak of the PCD antenna

Figure 33 shows the results of such a measurement.

Figure 33. Measurement of the Q factor with the network analyzer



```
Tr1 S22 Log Mag 5.000 dB/ Ref -20.00 dB [RS Zr]

>1  13.831250 MHz -9.0591 dB

  BW:  1.625234312 MHz
cent:  13.95724168 MHz
 low:  13.14462453 MHz
high:  14.76985884 MHz
   Q:  8.5878
loss: -9.0591 dB
```

Trigger Source: Internal

Trigger Event: On Sweep

Trigger Scope: All Channel

Ext Trig Input: Negative Edge

Trigger Delay: 0 s

1 Start 10 MHz IFBW 30 kHz Stop 20 MHz 16/16 Cor

T 1M Ω 20 dB R 1M Ω 20 dB DC LF OFF Hold Stop ExtRef 2021-07-01 23:23

7.4 Measurement of the target matching impedance

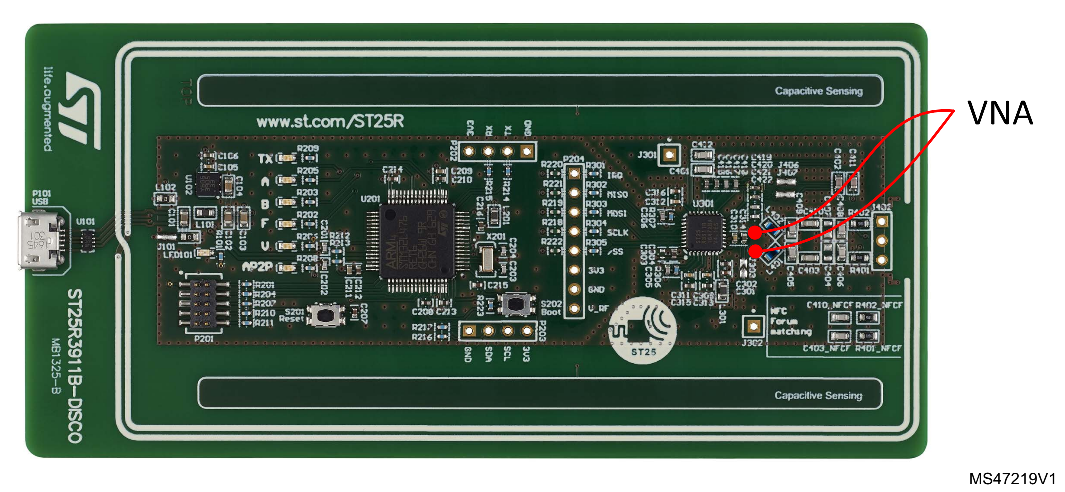
The matching impedance of a reader system must be measured with the antenna placed in its final position. A network analyzer is required and must be configured as described in *Section 4.1*.

Note: *If the reader is plugged, ensure that register 0x27 is set to 0xFF to avoid to high power transfer to the VNA ports.*

Adjust the suitable trim value via the register map (register 0x21) in the GUI of the reader

The target matching impedance is measured differentially, as shown in *Figure 34*.

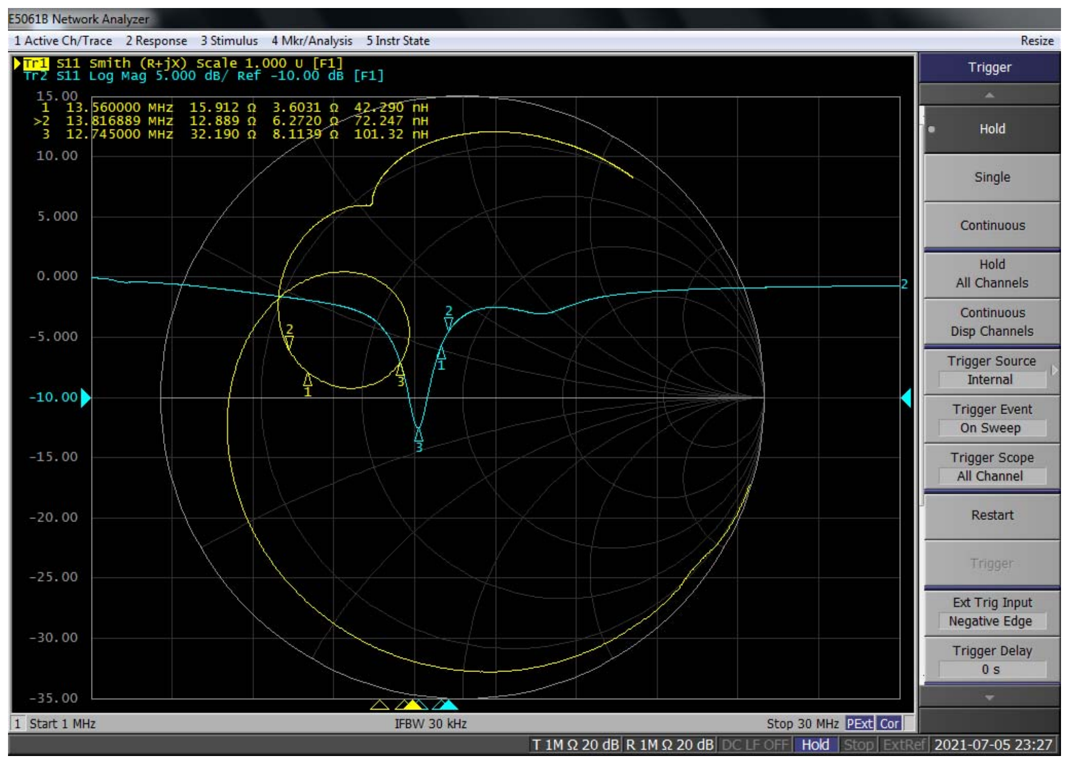
Figure 34. Network analyzer connection diagram



Note: *The VNA is configured single-ended, but the differences in comparison to a differential VNA setup are negligible for this measurement.*

Figure 35 shows the results of this measurement, which compare nicely with the simulation results.

Figure 35. Target matching impedance measured with network analyzer



```
Tr1 S11 Smith (R+jX) Scale 1.000 U [F1]
Tr2 S11 Log Mag 5.000 dB/ Ref -10.00 dB [F1]
 1   13.560000 MHz  15.912 Ω  3.6031 Ω  42.290 nH
>2   13.816889 MHz  12.889 Ω  6.2720 Ω  72.247 nH
 3   12.745000 MHz  32.190 Ω  8.1139 Ω  101.32 nH
```

7.5 NFC tuning circuit calculation

The NFC tuning circuit calculator applies to ST25R readers. It provides the component values of the matching network for a given NFC antenna.

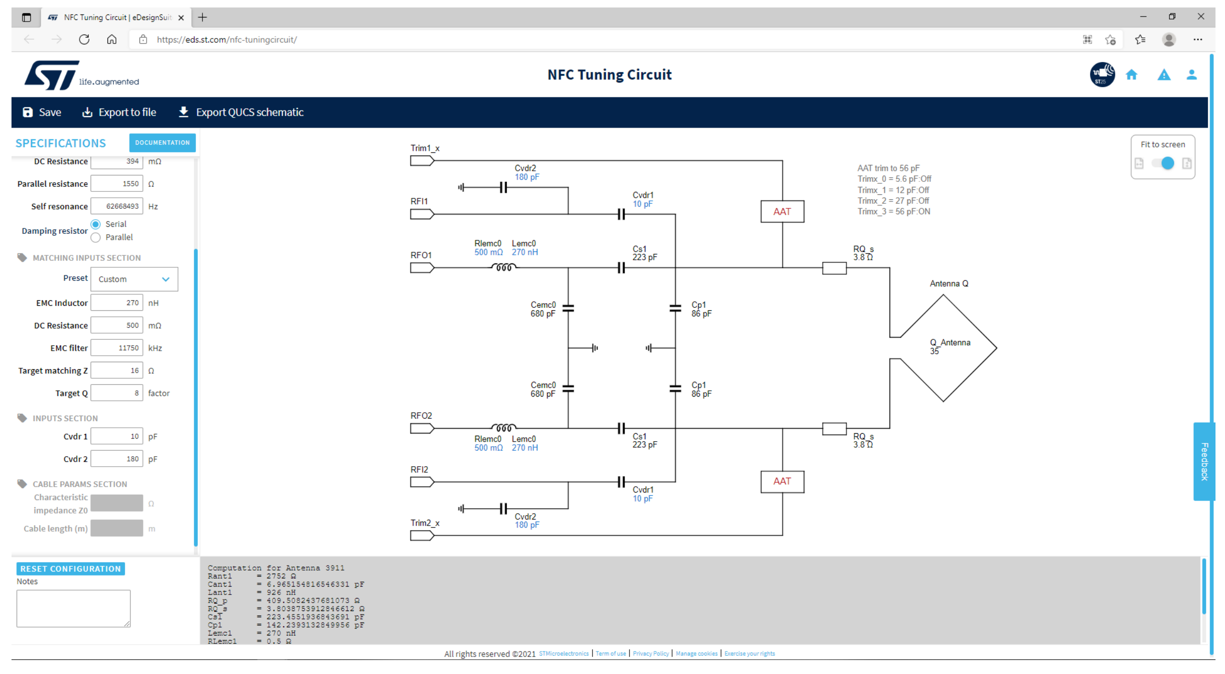
To compute the components value of the matching network located between the NFC reader and the antenna, enter the antenna electrical parameters and matching targets values, and select the topology of the matching network.

The tool returns the complete set of component values (including the capacitors in the AAT circuit) requested to achieve the desired design targets.

The circuit can then be exported as a Qucs file to further analyze and optimize the design.

An on-line version of the tool is available at https://eds.st.com.

Figure 36. NFC tuning circuit calculator



AAT trim to 56 pF
Trimx_0 = 5.6 pF:Off
Trimx_1 = 12 pF:Off
Trimx_2 = 27 pF:Off
Trimx_3 = 56 pF:ON

DC Resistance: 394 mΩ
Parallel resistance: 1550 Ω
Self resonance: 62668493 Hz
Damping resistor: ● Serial ○ Parallel

MATCHING INPUTS SECTION

Preset: Custom
EMC Inductor: 270 nH
DC Resistance: 500 mΩ
EMC filter: 11750 kHz
Target matching Z: 16 Ω
Target Q: 8 factor

INPUTS SECTION

Cvdr 1: 10 pF
Cvdr 2: 180 pF

CABLE PARAMS SECTION

Characteristic impedance Z0: Ω
Cable length (m): m

Notes

```
Computation for Antenna 3911
Rant1      = 2752 Ω
Cant1      = 6.965154816546331 pF
Lant1      = 926 nH
RQ_p       = 409.5082437681073 Ω
RQ_s       = 3.8038753912846612 Ω
Cs1        = 223.4551936843691 pF
Cp1        = 142.2393132849956 pF
Lemc1      = 270 nH
RLemc1     = 0.5 Ω
```

8 Conclusion

This document describes the basic design process of an NFC reader device, using as an example the design of the ST25R3911B-DISCO board.

It helps the user to define the output power of the reader, specifying the components like EMC inductors used for the matching network. It also guides through the measurements of the antenna parameters, and the computation and simulation of the matching network.

The last section is dedicated to basic design verification steps, to ensure that the matching network is properly defined.

9 Revision history

Table 4. Document revision history

Date	Revision	Changes
16-Aug-2017	1	Initial release.
03-Oct-2017	2	Updated document title, *Introduction* and *Section 3: Antenna interface stage*. Added *Table 1: Applicable devices*.
23-Jul-2021	3	Updated *Table 1: Applicable devices*. Updated *Figure 20: ST25R Antenna Matching Tool - Main window*, *Figure 21: ST25R Antenna Matching Tool - Calculated matching components*, *Figure 22: Simulation parameters*, *Figure 23: S-parameter model*, *Figure 24: Transient simulation*, *Figure 25: AC simulation*, *Figure 26: Definition of simulations and equations*, *Figure 27: Simulation results of the S-parameter and the AC model*, *Figure 28: Simulation results of the transient and of the AC model*, *Figure 33: Measurement of the Q factor with the network analyzer* and *Figure 35: Target matching impedance measured with network analyzer*. Updated *Section 6.2.2: Results*. Added *Section 7.5: NFC tuning circuit calculation*. Minor text edits across the whole document.

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