MAX32570 EV Kit PCD Antenna Matching Design Guide

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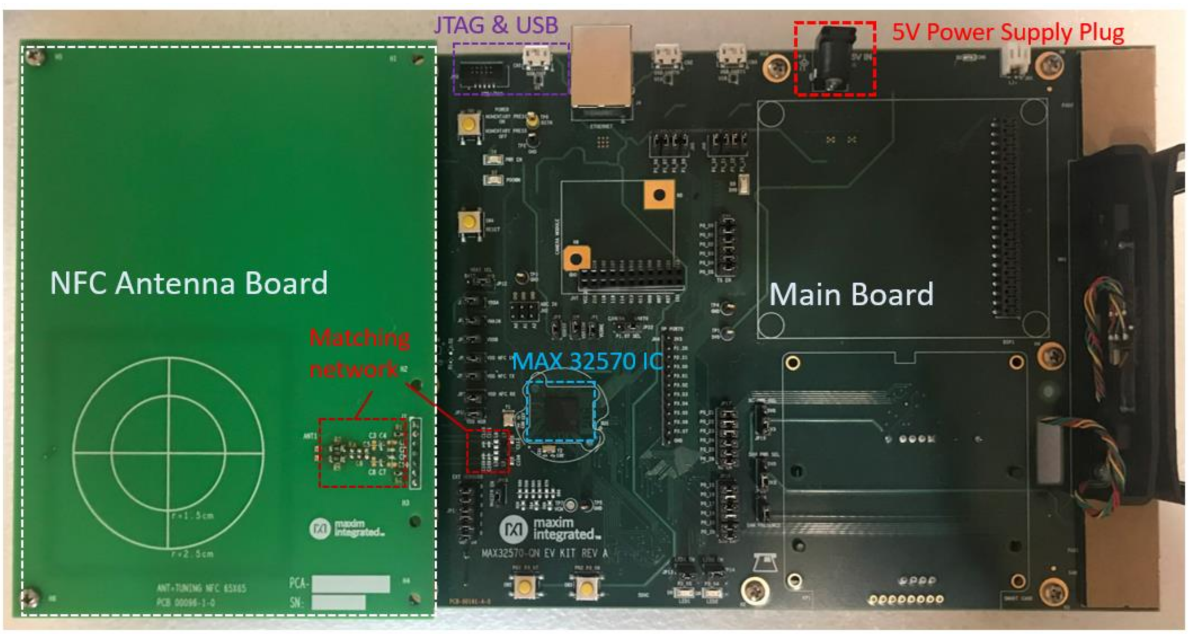
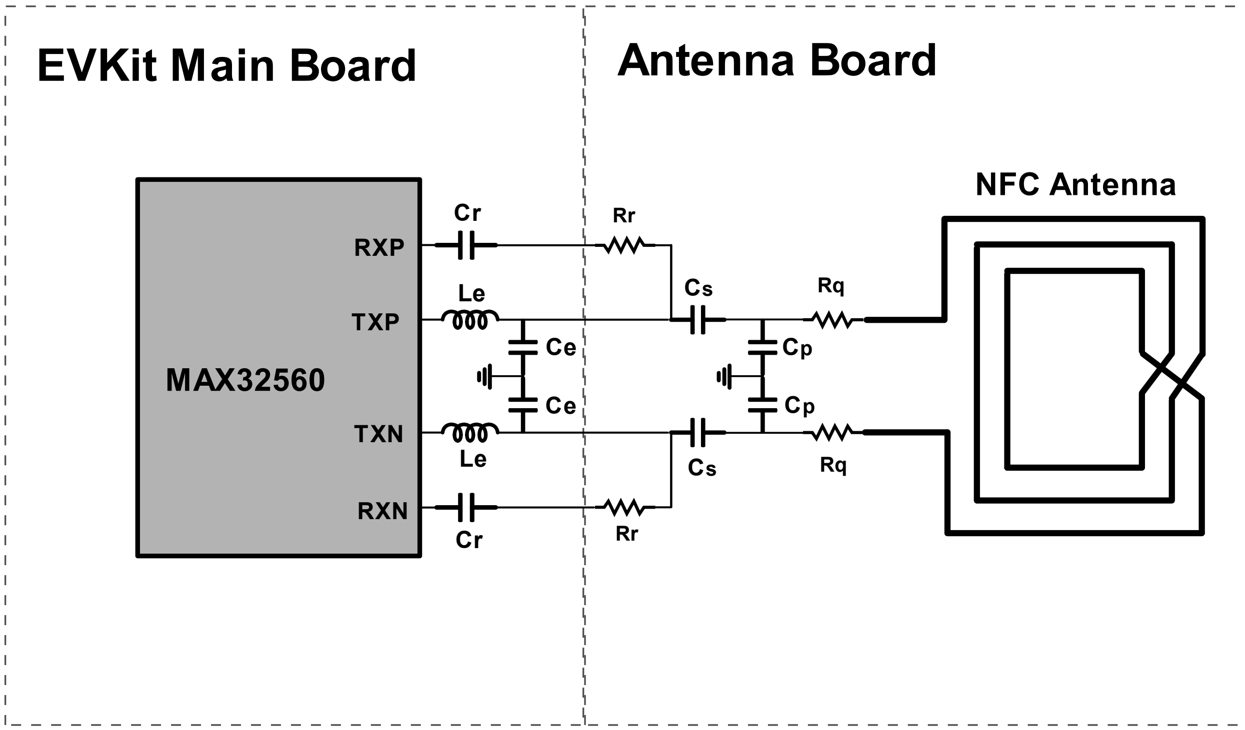
Overview

The MAX32570 is an integrated payment system IC with magnetic strip reader, smart card reader, and contactless (or NFC) reader. The IC supports different contactless protocols at 13.56 MHz. Typically an external loop coil, or NFC antenna is connected to the MAX32570 through a specifically designed direct matching network. This document provides guidelines for the design of this antenna matching network.

Using the MAX32570 EV Kit as an example, Figure 1.(a) shows the location of the NFC antenna, Matching Network and the MAX32570 IC. Figure 1.(b) shows the high-level matching network schematic between MAX32570 IC and the NFC antenna. The dashed line in Figure 1.(b) shows the boundary between the EVKit main board and Antenna board. When designing the matching network for an NFC antenna, the high-level circuit schematic in Figure *1*.(b) shall be followed. Typically, the antenna side components must be selected via tuning for different antennas, while the components on the main board remain fixed. This document demonstrates how to design the matching network to properly connect an NFC antenna the MAX32570. Without proper matching, the contactless performance will be poor.



(a)



(b)

Figure 1. Overview of NFC antenna connected with MAX32570 through matching network: (a) Picture of MAX32570 EVKit showing the location of the NFC antenna, Matching Network and MAX32570 IC; (b) High level schematic of the matching network for NFC antenna.

Antenna Design and Selection

Unlike far field antennas that care about radiation properties, NFC antennas are not really antennas. The radiation efficiency of an NFC antenna is almost 0 at the frequency of interest (13.56 MHz). The usual antenna design discipline regarding parameters such as radiation patterns and gain cannot be applied here.

The general operation of NFC antennas can be considered as mutual coupling between two inductors. The principle of inductive coupling dictates magnetic field strength generated from a circular coil ***H***, with number of turns ***N***, radius ***r*** and current strength ***I*** can be estimated by the following equation:

$$H = N \frac{Ir^2}{2\sqrt{(r^2 + z^2)^3}}$$

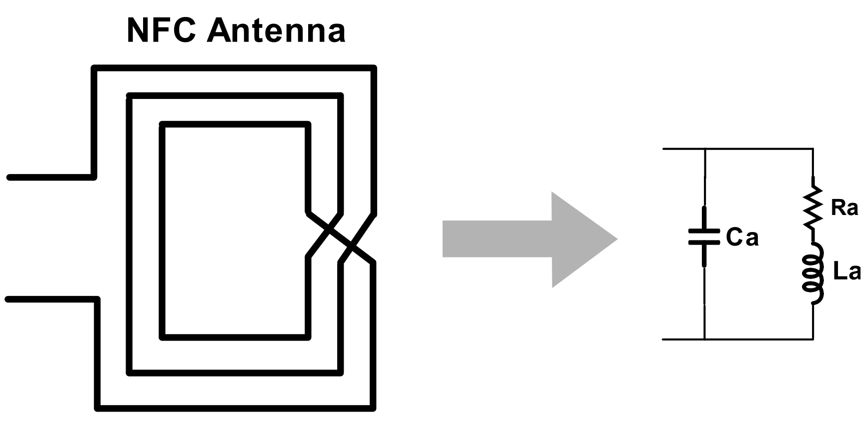
Where *z* is the distance from the center of the antenna coil along the axis crossing the center of the coil and is perpendicular to the antenna plane. Similarly, the magnetic field strength generated from a rectangular coil with number of turns ***N*** and length ***a*** x ***b*** can be estimated by the following equation:

$$H = N \frac{Iab}{4\pi\sqrt{z^2 + \left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2}} \left(\frac{1}{z^2 + \left(\frac{a}{2}\right)^2} + \frac{1}{z^2 + \left(\frac{b}{2}\right)^2}\right)$$

The above equations are a starting point to design the geometrical parameters of an NFC antenna. However, to accurately calculate the field strength and other performance metrics, practical factors such as the width and thickness of the metal trace that forms the coil, the gap between adjacent turns and the effect from substrate materials must all be taken into consideration. In NFC applications, the magnetic field distribution is also influenced by the secondary loop (i.e. the target such as NFC card or card emulation mobile device) as well as the shielding/cover materials especially when they are in close proximity to the antenna. Therefore, an electromagnetic simulation tool can be used if an accurate estimation of the performance metrics is required during the design phase. A full analysis of the impact from those practical factors is beyond the scope of this document.

In practice, for an NFC contactless solution, the prototype of an antenna design or a standard antenna selected from the market may be connected to the MAX32570 EVKit Antenna board for rapid performance evaluation. The original antenna on the PCB can be removed by peeling off the metal traces and the new antenna can be connected to the corresponding pins. Antenna equivalent circuit parameters at the operating frequency can be measured with tools such as impedance analyzer and network analyzer. Figure *2*.(a) shows the inductance and the resistance at 13.56 MHz of a rectangular coil NFC antenna measured by a network analyzer and shown on a Smith Chart. An equivalent RLC resonating circuit for the antenna is shown in Figure *2*.(b); because what is considered here is narrow band matching, ***La*** and ***Ra*** can directly use the values measured at 13.56 MHz, and ***Ca*** can be assigned a very small capacitance value (below 1 pF). Other equivalent circuit topologies, for example, parallel ***Ra***, can also be used here for matching calculation purpose.

(a)



(b)

Figure 2. Antenna parameter extraction: (a) Measurement of antenna parameters using a network analyzer; (b) Equivalent circuit of an NFC antenna.

Design of Matching Network

Once the NFC antenna is selected and the antenna parameters are extracted, the performance of the system can be optimized with proper design and tuning of the matching network. The optimization of RF power delivered from the MAX32570 NFC transmitter to the field through the antenna is the primary target of matching network design. Figure 3.(a) shows the whole matching network with antenna equivalent circuit for the transmitter path. The whole network can be divided in three stages: EMC filter, Impedance matching and antenna quality factor (Q) detuning, as shown in Figure 3.(b).

In order to minimize the noise and interference generated at other frequency bands, an Electromagnetic Compatibility (EMC) filter is required to modify the signal directly transmitted from the MAX32570. The EMC filter is a second order LC filter, with a resonant frequency at f_{emc}:

$$f_{emc} = \frac{1}{2\pi\sqrt{L_e C_e}}$$

Considering the bandwidth requirement for typical NFC applications with 848 kHz subcarrier, the filter resonant frequency is usually set at least 1 MHz higher than the carrier frequency of 13.56 MHz, but lower than the second harmonic of the carrier frequency. The selection of ***Le*** value is flexible, but needs to consider the power handling ability of the inductor component. For example, we can choose ***Le*** = 470nH and ***Ce*** = 124pF, in this case F_{cutoff} is about 20.85MHz.

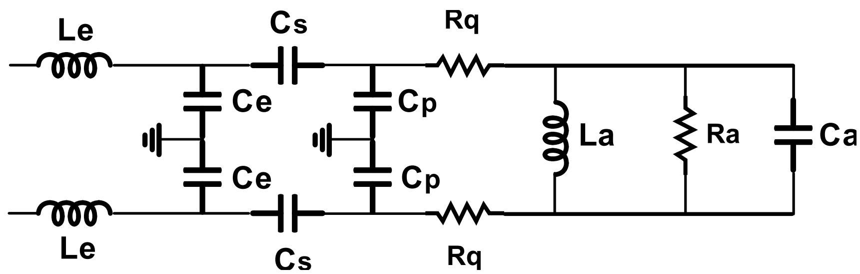
Antenna quality factor has major impact on the NFC reader system performance. The selection of quality factor involves a tradeoff between transmitting power, transmitted signal integrity and bandwidth for received signal. The intrinsic quality factor of an antenna is:

$$Q_{ant} = \frac{2\pi f L_a}{R_a}$$

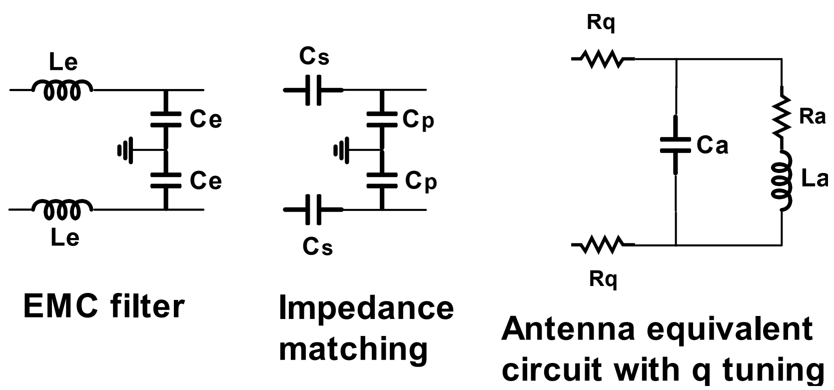
To reduce the quality factor of the antenna, a pair of detuning resistor ***Rq*** can be connected to the antenna, and the reduced quality factor now becomes:

$$Q_{det} = \frac{2\pi f L_a}{(R_a + 2R_q)}$$

The higher the quality factor is, the higher power the transmitter delivers to the field at carrier frequency, while narrowing the bandwidth. The signal integrity requirement for ISO14443 type A and type B in contactless applications restricts the slew rate of the signal, which in turn restricts the quality factor. Typical quality factors for NFC applications with the MAX32570 range from 18 to 30.



(a)



(b)

Figure 3. NFC Antenna matching network with antenna equivalent circuit: (a) the whole matching network; (b) matching network divided into three major stages.

With the EMC filter and Antenna quality factor (Q) detuning stage fixed, the component parameters in the impedance matching stage can be calculated following the standard lumped component matching design techniques used in microwave engineering. The value of C_p and C_s can be either calculated through closed form equations or found through impedance matching analysis on a Smith Chart. The target is to match the network to a R_{match} looking from the port connect to TXP and TXN pins of MAX32570. The value of R_{match} depends on the transmitter IC properties. For MAX32570, R_{match} with value from 3 Ω to 10 Ω are normally acceptable for NFC applications. The selection of R_{match} is a trade-off between power delivery and power efficiency. Along with this document, Maxim Integrated provides an easy-to-use matching calculation spreadsheet to rapidly design the impedance matching. Appendix A provides a practical example of this antenna matching design procedure.

Performance Verification and Matching Network Tuning

Due to the parasitics from the board such as trace impedance, the calculated values for the matching network usually cannot guarantee a perfect matching, a fine tuning of the impedance matching is required when a matching network is populated for the first time. The fine tuning normally only involves the adjustment of Cp to achieve a pure resistive impedance. Figure 4 shows an example matched to 6.37+0.35j Ω after the fine tuning. The variation of the component affects the condition of the matching circuit. To avoid the need of fine tuning for each board, in mass production, it is recommended to have components with the tolerance of ± 1% or better.

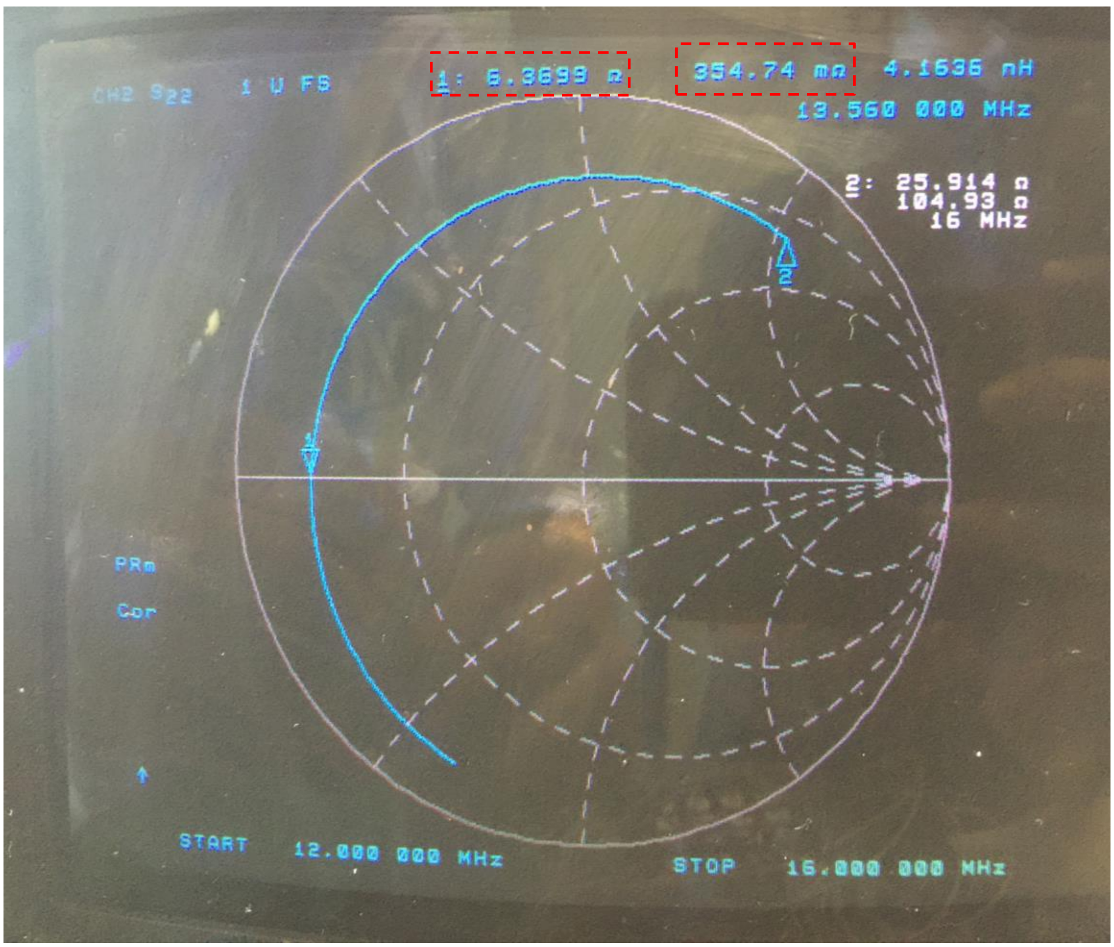


Figure 4. An example when a network matches to 6.37+0.35j Ω after fine tuning.

Layout, Quality Factor and Other Considerations

During the layout design, the overall trace on the PCB for the matching network is recommended to be as short as possible. The distance between transmitter output and EMC filter is the most critical. If the product has a metal structure in proximity of the NFC antenna, it will have observable loading effect to the antenna. In this case the evaluation of antenna impedance must take the static loading effect into account. Dynamic loading effect from target cards or smartphones, usually are not taken into consideration when evaluating antenna impedance as such loading effect varies when the target moves. For most targets, obvious impedance change for the antenna is only observed when the distance between target and antenna is less than 2cm. A lower quality factor for the antenna reduces the severity of dynamic loading at close distances, but can also reduce performance at longer distances. With MAX32570, dynamic power control is possible without the need of “symmetric matching”; details of dynamic power control will be included in a separate document.

The impact of the quality factor of the EMC filter inductors ***Le*** sometimes is significant, in practice the lower cost inductor components tend to have lower quality factor. If the parasitic resistance of the inductor is comparably high, a significant portion of the power delivered out from the NFC IC TX ports will be lost in terms of heat in those inductors before able to reach the NFC reader antenna and transfer to the target. Therefore, it is very important to choose high Q inductor if possible. Also, for the same quality factor, the lower the inductance the better in terms of minimizing the loss, as the parasitic resistance is proportional to the value of inductance. Moreover, the inductor is in the TX circuit, current handling is a big concern, 1 A current tolerance would be recommended for the safety consideration. If there’s further EMC requirement, a shielded inductor should be a good candidate.

Apendix A. Design Example

The following example demonstrates the antenna matching design procedure. The MAX32570 Antenna Matching Network Design spread sheet is also provided to assist with the design. In this example, the MAX32570 EVKit schematic as shown in Figure 5 is used for showing the finalized component values. The detailed consideration of defining the corresponding parameters and antenna impedance measurement process are already described in the main sections. All the calculations in the following example were done through the Matching Network Design spread sheet.

1. **Define targets of the matching network**

   Define R_{match} = 7 Ω;

   Define Q = 20;

   Define cut off frequency of EMC filter F_{cutoff} = 21MHz;

2. **Measure the antenna impedance**

   Measure La = 1265 nH;

   Measure Ra = 1.3 Ω;

   Assign Ca = 0.1 pF;

3. **EMC filter design**

   Select Le = 470 nH;

   Calculate Ce based on the values of <Le, F_{cutoff}> --> Ce = 122.2 pF;

   Rounded to standard component values --> Ce can be realized by $Ce1$ = 68 pF and $Ce2$ =56 pF;

4. **Q-tuning resistor**

   Calculate Rq based on the values of <Q, La, Ra> --> Rq = 2.04 Ω;

   Rounded value, component selection consideration, and overall trace loss compensation --> Choose Rq = 1.5 Ω; R_{loss} is estimated to be 0.5 Ω;

5. **Impedance matching design**

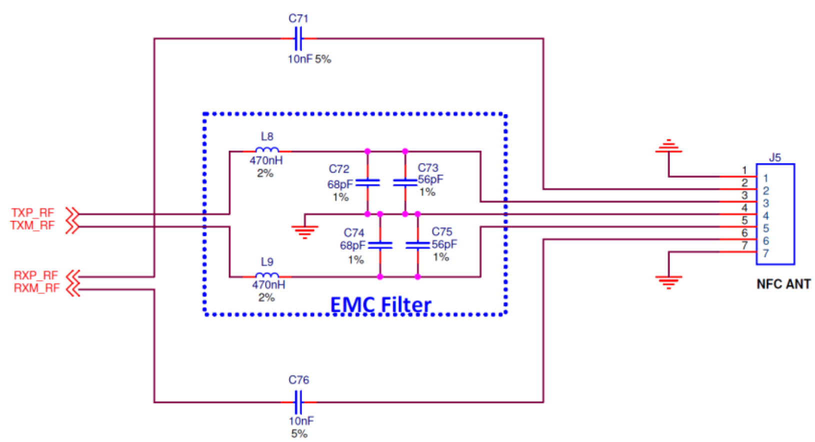
   Matching Calculation of Cs and Cp are based on the values of $<\boldsymbol{La}, \boldsymbol{Ca}, \boldsymbol{Ra}, \boldsymbol{Rq} + \boldsymbol{R_{loss}}, \boldsymbol{Le}, \boldsymbol{Ce}, \boldsymbol{R_{match}}>$ --> $\boldsymbol{Cs}$ = 67.1 pF; $\boldsymbol{Cp}$ = 107.1 pF;

   Rounded value, component selection consideration --> $\boldsymbol{Cs}$ is realized by $\boldsymbol{C1}$ = 24pF, $\boldsymbol{C2}$ = 43pF;

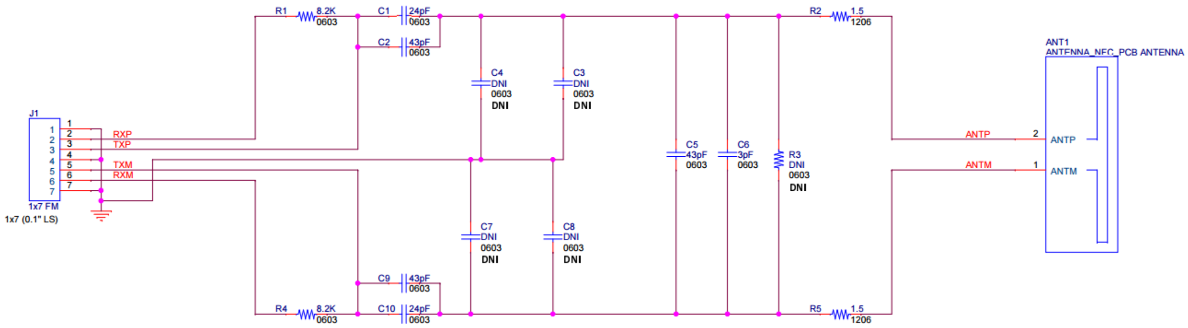
   Rounded value, component selection and board layout consideration --> $\boldsymbol{Cp}$ is realized by two parallel capacitors $\boldsymbol{C5}$ = 43pF and $\boldsymbol{C6}$ = 10 pF; After empirical matching tuning, $\boldsymbol{C6}$ is adjusted to 3pF, and the overall impedance looking at TXp, TXn pin measures 7.2- 0.3j Ω.

6. **Receiver Dividing Resistor Tuning**

   $\boldsymbol{Rr}$ ($\boldsymbol{R1}$ and $\boldsymbol{R4}$ in the board schematic) is determined after the transmitter path components have been populated. Some initial values of $\boldsymbol{R1}$ and $\boldsymbol{R4}$, e.g. 10k Ω can be applied at first, and the carrier amplitude looking at Rxp, Rxn should be measured. If the amplitude is within the range of 2.6 ~ 3.1 V, it should be acceptable, otherwise it can be tuned by adjusting the value of $\boldsymbol{R1}$ and $\boldsymbol{R4}$. Here in the example, $\boldsymbol{R1}$ and $\boldsymbol{R4}$ is adjusted to 8.2 kΩ to ensure proper carrier amplitude feeding into the receiver.



(a)



(b)

Figure 5. Schematic view of MAX32570 EVKit, only NFC antenna and matching related parts are shown. (a) The EMC filter on the main board; (b) the Antenna board.