AN4327
Application note

CR95HF transceiver antenna tuning circuit with EMI filter

Introduction

The purpose of this document is to describe the antenna tuning circuit of the CR95HF RF transceiver board embedding the EMI filter and delivered with the M24LR-DISCOVERY kit.

It explains how to use the CR95HF EMI FILTER CALCULATION.xlsm tool (STSW-95HF003), a separate Excel sheet available on *www.st.com*.

The different impedance matching calculation steps are presented.

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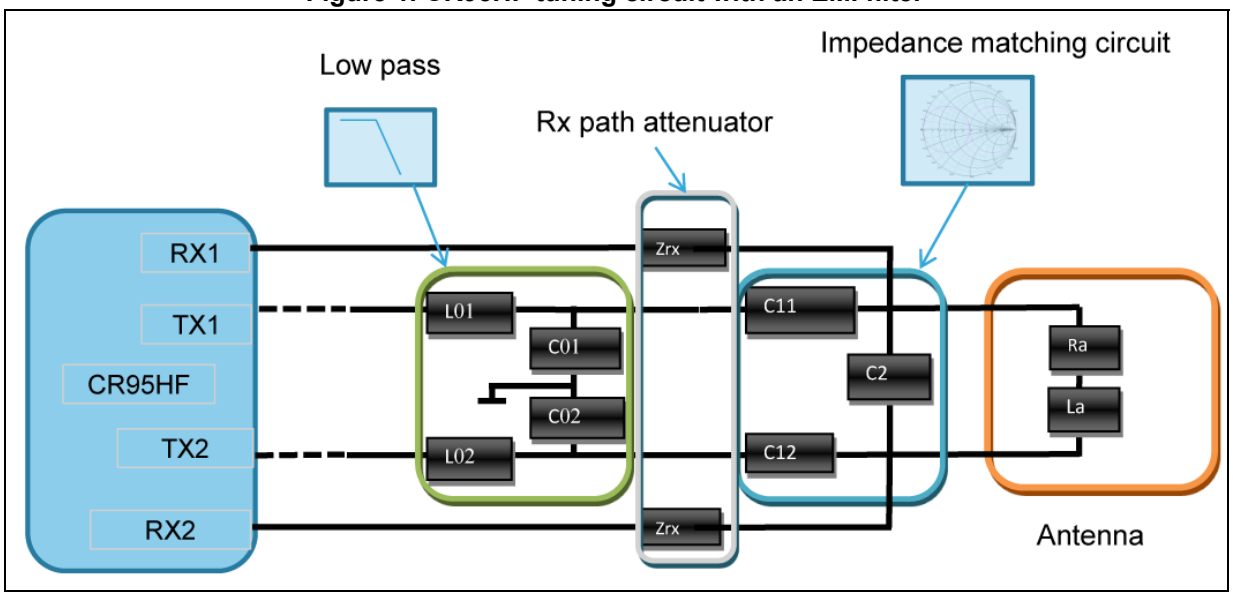
1.1 Description

To limit the spurious emission at high frequencies, the CR95HF RF transceiver board embeds a second order low-pass filter (so called EMI filter).

This filter is placed between the CR95HF and the antenna tuning circuit, as shown in *Figure 1*. Its goal is to attenuate the frequencies above 13.56 MHz, effectively reducing interferences.

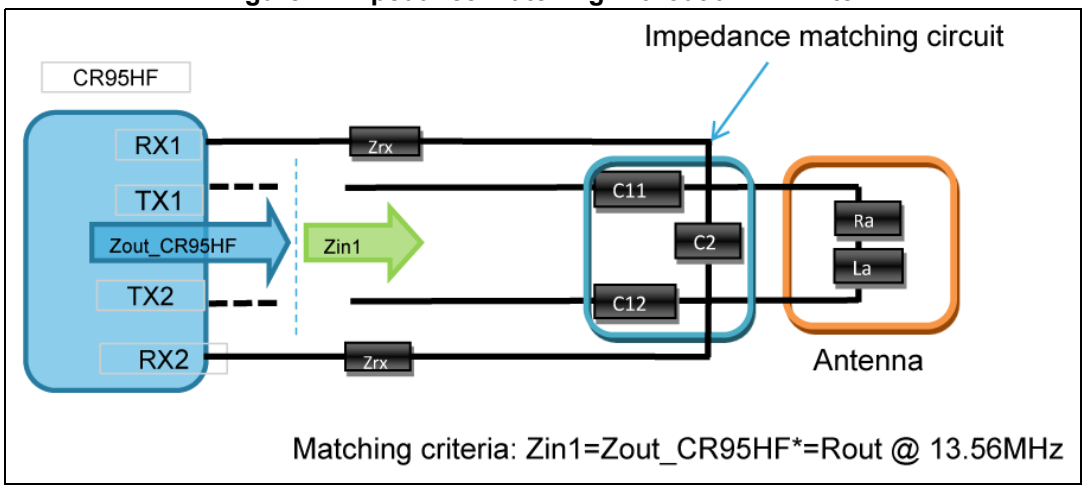
Figure 1. CR95HF tuning circuit with an EMI filter



1.2 Designing a tuning circuit without an EMI filter

Designing a tuning circuit without an EMI filter for the CR95HF consists in calculating the C11, C12 and C2 capacitor values, so that the input impedance (Zin1) of the circuit, seen from TX1 and TX2, matches the complex conjugate of the CR95HF output impedance.

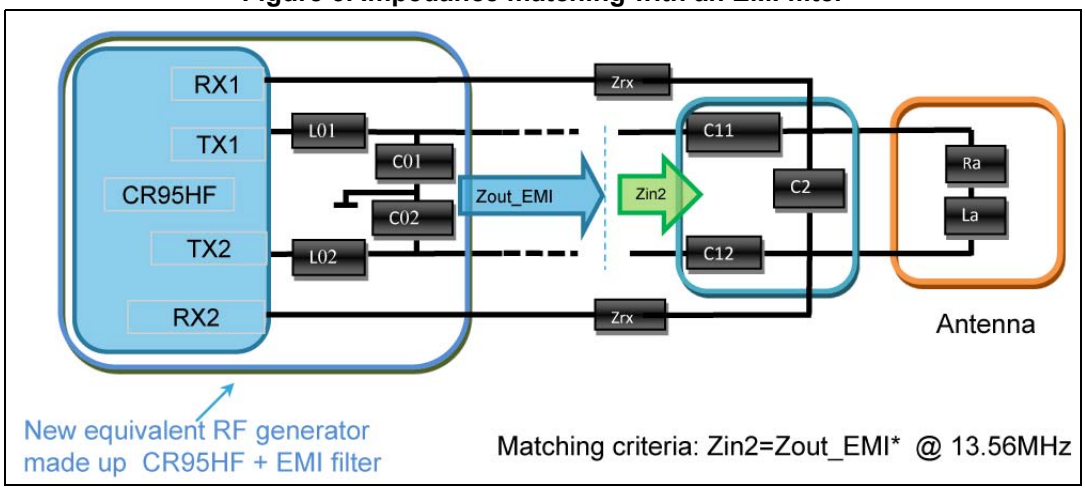
Figure 2. Impedance matching without an EMI filter



1.3 Designing a tuning circuit with an EMI filter

Designing a tuning circuit with an EMI filter for the CR95HF follows the same procedure described in *Section 1.2*, except that C11, C12 and C2 are calculated so that the tuning circuit input impedance (Zin2) matches the complex conjugate output impedance of the new RF generator, which is made of the CR95HF and its EMI filter (see *Figure 3*).

Figure 3. Impedance matching with an EMI filter

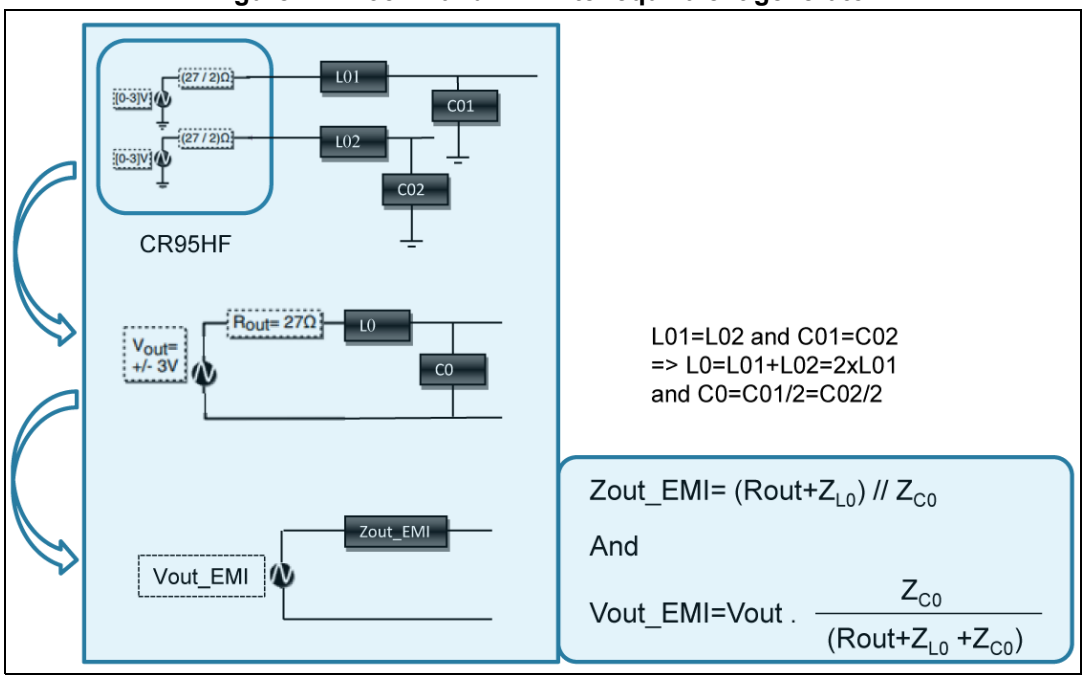


When the matching criteria is satisfied, the input impedance (Zin) of the circuit seen from TX1-TX2 also satisfies the condition Zin = Rout, and the maximum power transfer occurs between the CR95HF and the antenna.

2 Calculation explanations

The equivalent circuit of the CR95HF with the EMI filter is derived with some simple transformations, as indicated in *Figure 4*.

Figure 4. CR95HF and EMI filter equivalent generator



The cut-off frequency of the EMI filter defined by $fc = \frac{1}{2\pi\sqrt{(L0 \times C0)}}$ is chosen above 14 MHz.

It is recommended to use an inductance wired on a ferrite core. However, to maximize the EMI performance of the circuit on the CR95HF RF transceiver board, the wired inductance has been replaced by a Wurth Elektronik ferrite bead EMI suppressor (ref. 742792042). Its impedance at 13.56 MHz is 653 nH in series with 2 Ω. Above 200 MHz, it behaves as a pure resistor to suppress spurious emission.

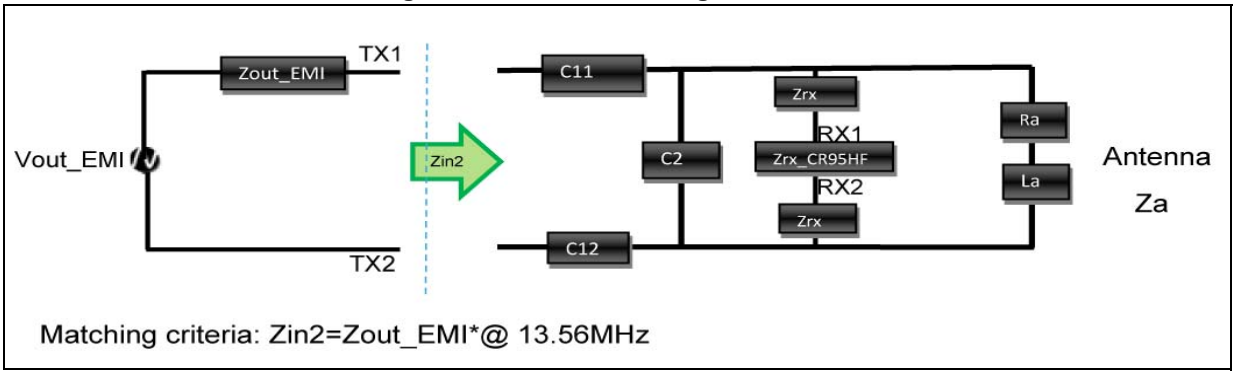
Among the available standard SMD ceramic capacitor values, C01 and C02 have been chosen to 180 pF, hence the EMI filter cut-off frequency is:

$$fc = \frac{1}{2\pi\sqrt{(L0 \times C0)}} = \frac{1}{2\pi\sqrt{(2 \times 653nH) \times \left(\frac{180pF}{2}\right)}} = 14.6MHz$$

The CR95HF receiving path RX1-RX2 input impedance ZRX_CR95HF = 22 pF // 80 kΩ.

After replacing the RX path by its impedance, the circuit becomes the one shown in *Figure 5*.

Figure 5. Circuit for tuning calculation



Assuming C11 = C12 = C1, the resulting equation is:

$$Zin2 = \frac{C1}{2} + (C2 \,||\, (2Zrx + Zrx_{CR95HF}) \,||\, Za)$$

The values for C11 = C12 and C2 are found by solving the impedance matching criteria Zin2 = Zout_EMI*.

This calculation is done using the CR95HF EMI FILTER CALCULATION.xlsm spreadsheet, available for download on *www.st.com*.

3 Calculation tool

The CR95HF EMI FILTER CALCULATION.xlsm spreadsheet includes four tabs:

1. Tuning circuit calculation
2. Input impedance curves
3. Circuit voltages
4. Magnetic fields vs. distance

This tool allows the user to:

- Calculate the ideal tuning capacitance C11, C12 and C2 based on the system components (select the first tab).
- Calculate the theoretical circuit input impedance according to the system parameters and custom tuning capacitance values (select the first tab)
  - This feature lets you use tuning capacitance values different from the ideal values, and check the impact on the input impedance.
  - In combination with the impedance curve given in the second tab, this feature lets you adjust the tuning capacitance values on the Printed circuit board (PCB).
- Trace the theoretical circuit input impedance curve (magnitude and phase) vs. the frequency, according to the custom tuning capacitance values defined in the first tab.
- Trace the voltage amplitude at different points of the circuit according to the custom tuning capacitance value (select the third tab).
- Estimate the magnetic field strength generated by the reader according to the system parameters of the system (select the fourth tab).

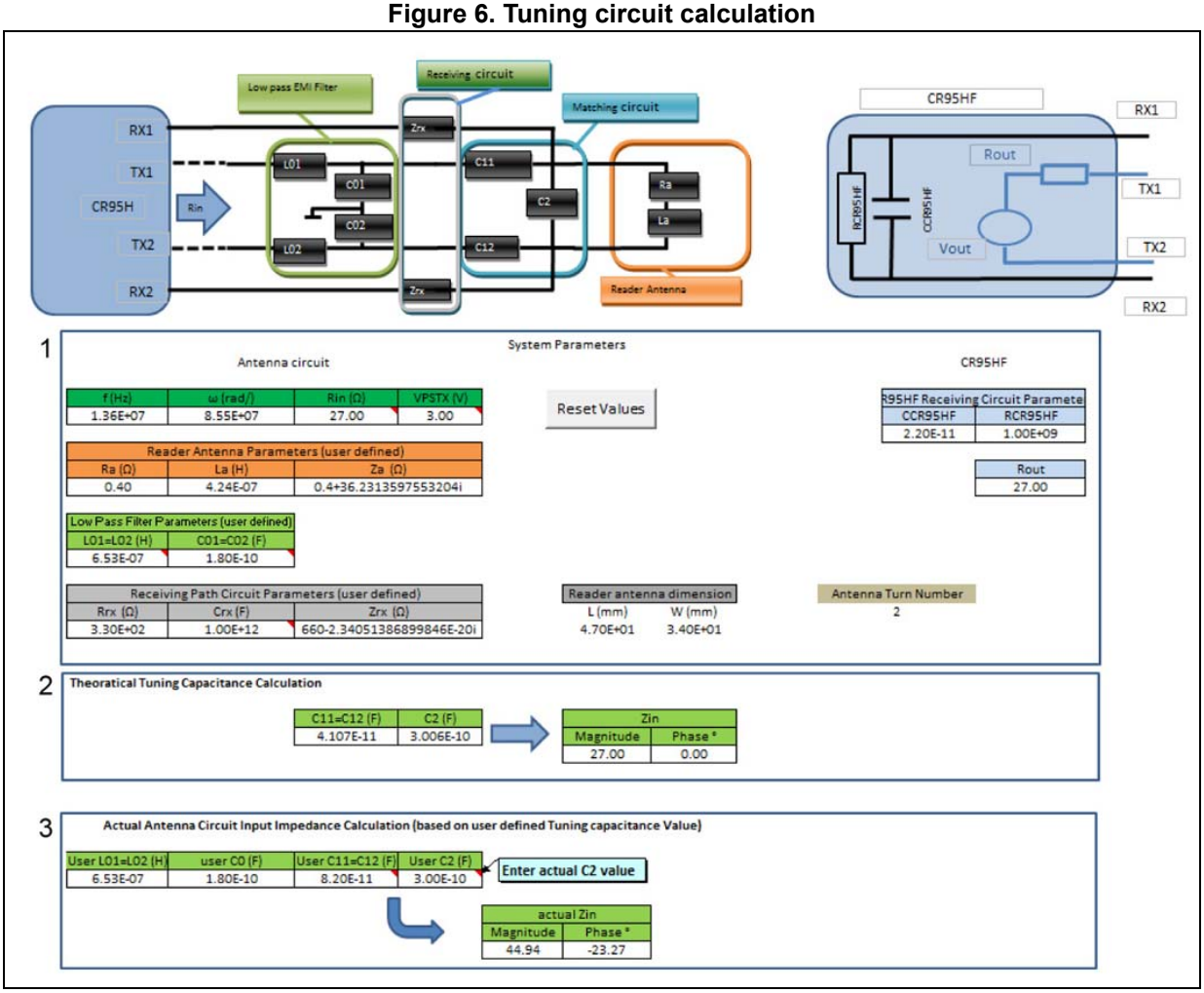
3.1 Tuning circuit calculation

Select the first tab of CR95HF EMI FILTER CALCULATION.xlsm spreadsheet:

- Tuning circuit calculation

Several configurations can be calculated, as shown in *Figure 6*.

Figure 6. Tuning circuit calculation



1. CR95HF and user defined system parameters.
2. Ideal tuning capacitance calculation.
3. Input impedance calculation based on user defined tuning capacitances.

EMI filter

It is possible to calculate the tuning circuit without the EMI filter by simply choosing L01 = L02 = 0 and C01 = C02 = 10^{-40} (simulating an open circuit).

Receiving path

The calculation tool allows the user to put a resistor in series with a capacitor in the receiving path, by choosing:

- Crx = 10^{12} (the calculation is made with a resistor only in the receiving path)
- Rrx = 0 (the calculation is made with a series capacitor only in the receiving path).

3.2 Input impedance curves

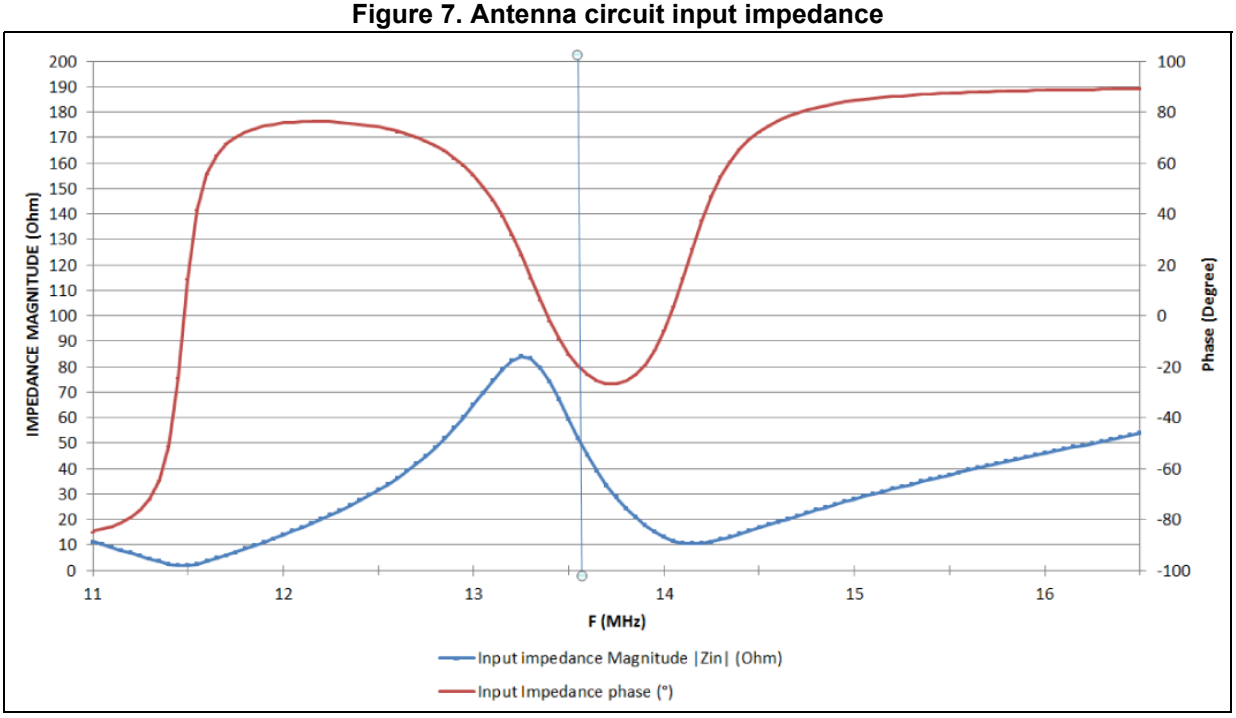
Select the second tab of CR95HF EMI FILTER CALCULATION.xlsm spreadsheet:

- Input impedance curves

Based on the chosen tuning capacitance values (see *Figure 6*), the circuit input impedance is calculated over the frequency (F).

The example in *Figure 7* shows the input impedance calculated with the CR95HF RF transceiver board tuning capacitances.

Figure 7. Antenna circuit input impedance



3.3 Circuit voltages

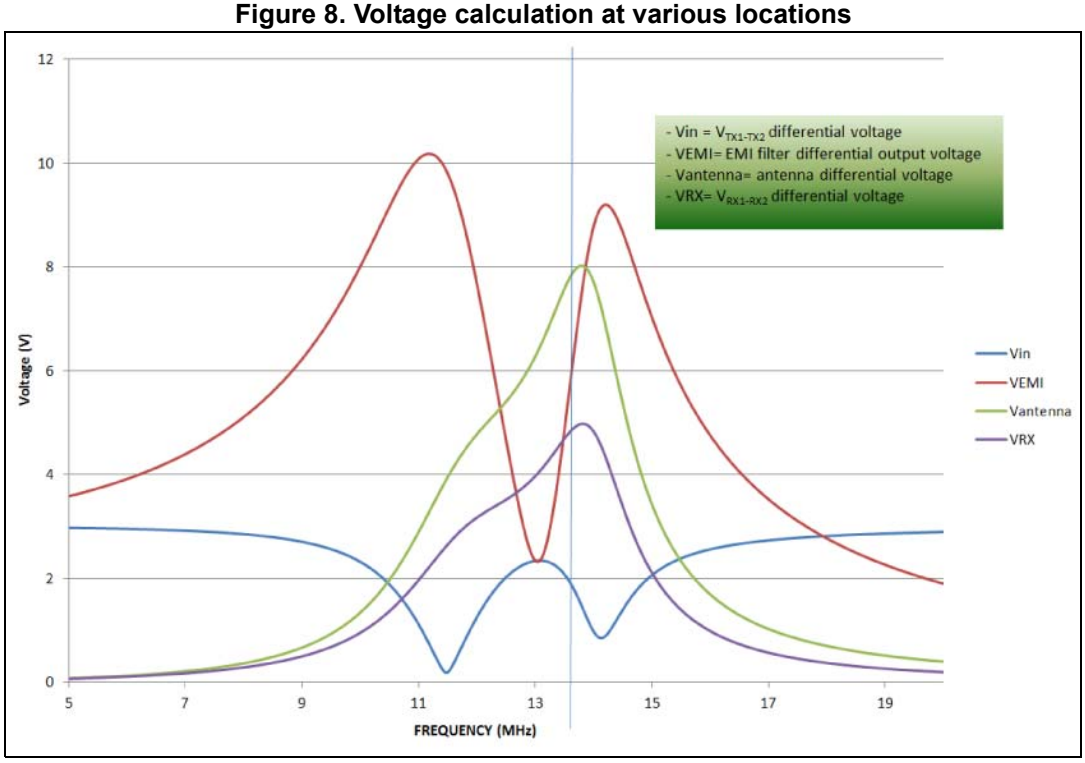
Select the third tab of CR95HF EMI FILTER CALCULATION.xlsm spreadsheet:

- Circuit voltages

Based on the tuning capacitance values chosen of the calculation tool, voltages at various locations in the circuit are calculated (see *Figure 8*).

This feature is useful to estimate the RX path attenuation needed to limit VRX1-RX2 below 7 V.

Figure 8. Voltage calculation at various locations



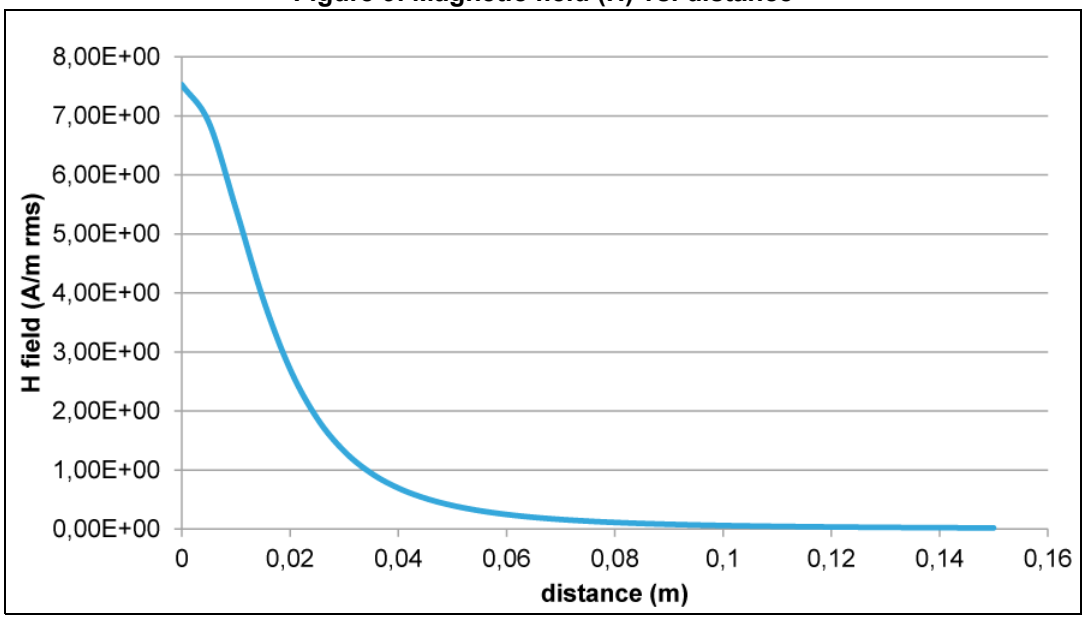
3.4 Magnetic field vs. distance

Select the fourth tab of CR95HF EMI FILTER CALCULATION.xlsm spreadsheet:

- Magnetic field vs. distance.

Based on the differential antenna voltage Vantenna from the third tab and the antenna parameters (dimensions and number of turns) chosen in the first tab, an estimation of the generated magnetic field is calculated in the fourth tab (see *Figure 9*).

Figure 9. Magnetic field (H) vs. distance



Note: For information only.

4 Practical tuning circuit design

4.1 Step by step procedure

Step 1

Measure the CR95HF antenna impedance on the PCB.

Step 2

Estimate the C11, C12, C2 and ZRX impedance values using the CR95HF EMI filter calculation tool. Mount the component values from step 2 on the PCB.

Step 3

a) Without powering the board, measure the circuit input impedance between TX1 and TX2 using a network analyzer or an impedance analyzer. Tune the C11, C12 and C2 capacitance values, if necessary.

b) As a design trick, the tuning frequency can be adjusted using C2, and the impedance magnitude can be adjusted using C11/C12. This can be verified using the impedance curve feature of the CR95HF EMI filter calculation tool.

c) Power up the board and activate the RF generation (this can be achieved by sending a Protocol_Select command to the CR95HF).

d) Measure the DC voltage in the ST_R0 pin: adjust the ZRX component value to limit the voltage measured on ST_R0 below 7 V.

e) After powering down the PCB, check the input impedance and adjust it with C11, C12 and C2, if necessary.

Step 4

Check the RF performance with a tag.

4.2 Input impedance choice

Because of the reader antenna detuning occurring when the tag is very close to the reader, some communication holes can appear at very short distance.

To overcome this, it is appropriate to choose an input impedance higher than the CR95HF output impedance: for instance, to maintain the energy harvesting capability of the C95HF RF transceiver board, the input impedance of the antenna circuit is set to 50 Ω.

This value has a minor impact on the CR95HF to power up the tag at a long distance from the reader antenna, maintaining a magnetic field strength level sufficient to guarantee the energy harvesting function of the M24LRXXE-R and of ST25DV-I2C tags at a short distance from the reader antenna.

5 Revision history

Table 1. Document revision history

Date	Revision	Changes
29-Aug-2013	1	Initial release.
12-Feb-2019	2	Updated document title, *Introduction*, *Section 1.2: Designing a tuning circuit without an EMI filter* and *Section 4.2: Input impedance choice*. Removed former *Table 1: Applicable tool and software*. Minor text edits across the whole document.