# AN3394
# Application note

## Antenna design and impedance matching guidelines for CR95HF multiprotocol contactless transceiver IC

### Introduction

The goal of this application note is to provide guidelines to design a CR95HF antenna which impedance matches to the CR95HF impedance. This allows to achieve the best RF communications between the CR95HF transceiver integrated circuit (IC) and ISO15693 or ISO14443 RF memory tags.

The DEMO-CR95HF-A is a demonstration board for the CR95HF 13.56 MHz contactless transceiver. It is designed as a ready-to-use circuit board to interface with the CR95HF PC host demonstration software through an USB bus. The DEMO-CR95HF-A is powered by the USB bus and no external power supply is required. It is based on the CR95HF contactless transceiver with a 47x34 mm 13.56 MHz inductive etched antenna and its associated tuning components, and on a STM32F103CB 32-bit microcontroller that communicates with the CR95HF via the USB bus.

This document is structured as follows:

- Description of the DEMO-CR95HF-A board
  - Definition of CR95HF output impedance
  - Use of inductive antenna
  - Impedance matching
- Description of equivalent circuit
  - CR95HF RF circuit modeling and description of antenna impedance matching circuit
  - Calculation of the matching circuit optimized for ISO15693 memory tags
- Read range estimate based on magnetic field calculation method for a rectangular antenna
- Main criteria for key antenna design

# Contents

# List of tables

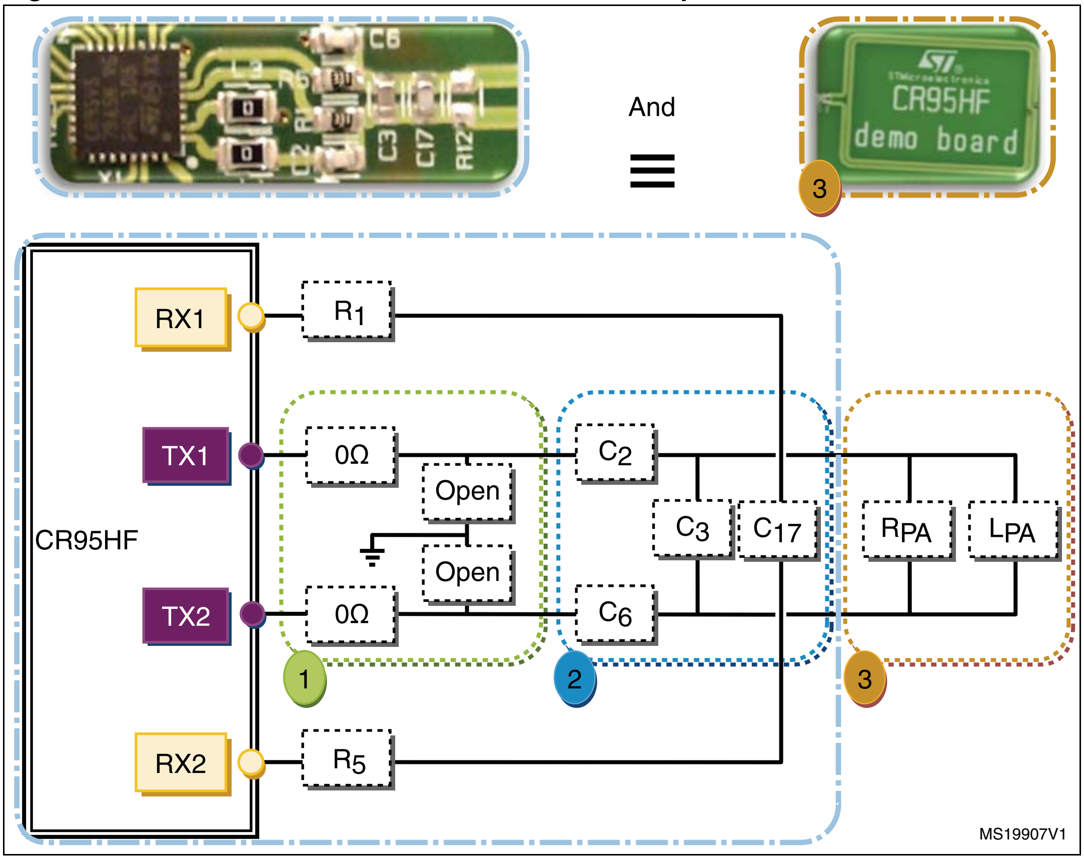
# List of figures

# 1 Description of DEMO-CR95HF-A and criteria for impedance matching

## 1.1 Overview

*Figure 1* shows the part of the circuit concerned by the impedance matching.

**Figure 1. DEMO-CR95HF-A demonstration board equivalent circuit**




**Legend and Abbreviations**

| | |
|---|---|
| 1 : | EMC Filter: For information on the EMC filter, contact your local ST sales team. |
| 2 : | Matching circuit. |
| 3 : | Inductive antenna. |
| : | Block. |
| : | Pin. |
| : | Component. |
| TX: | CR95HF output driver. |
| RX: | CR95HF receiver input stage. |
| $R_{PA}$: | Antenna equivalent parallel resistor. [Ω] |
| $L_{PA}$: | Antenna equivalent parallel inductance. [H] |
| $C_2$,$C_6$: | Serial capacitance of the matching circuit impedance. [F] |
| $C_3$,$C_{17}$: | Parallel capacitance of the matching circuit impedance. [F] |
| $R_1$,$R_5$: | 330 Ω. These resistors are used to limit the signal level on RX1-RX2. They must be considered in the calculation of the impedance matching circuit. |

## 1.2 Output impedance of the DEMO-CR95HF-A demonstration board output circuit

To generate the magnetic field, the antenna is excited by the two CR95HF differential generators (see *Figure 2: CR95HF equivalent output impedance*).

Each generator has an output impedance of 13.5 Ω.

$Z_{out}$ is the CR95HF differential output impedance between TX1 and TX2. It is a pure resistor. The resulting output impedance, $R_{out}$, can be measured as shown in *Figure 3: Chip simplified equivalent impedance*:

$$Z_{out} = R_{out} = 27\Omega \qquad (3V)$$

**Figure 2. CR95HF equivalent output impedance**

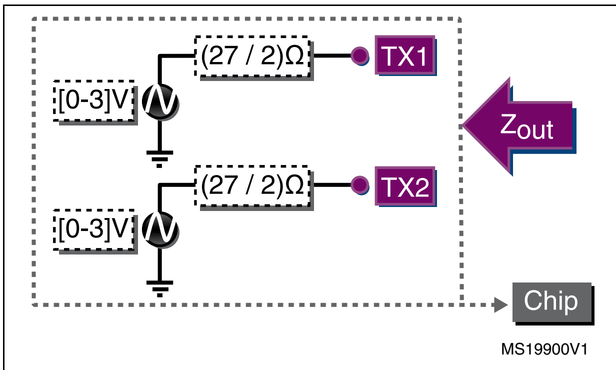
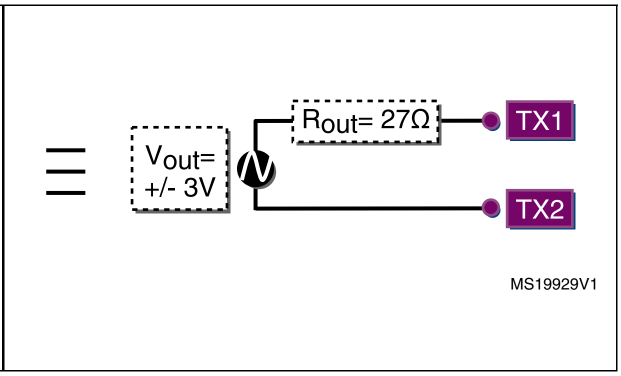



**Figure 3. Chip simplified equivalent impedance**




**Where**

$Z_{out}$: Matching impedance. [Ω]

$R_{out}$: Matching resistor. [Ω]

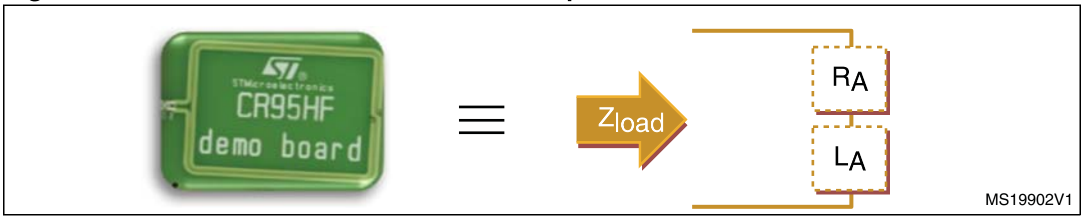
$V_{out}$: Supply voltage of the chip. [V]

## 1.3 Inductive antenna impedance

The CR95HF requires an inductive antenna to communicate at a frequency of 13,56 MHz. The equivalent impedance ($Z_{load}$) of the inductive loop antenna is shown in *Figure 7: Equivalent circuit of the CR95HF and associated matching circuit*.

DEMO-CR95HF-A antenna dimensions are 47 mm x 34 mm.

**Figure 4. Antenna demonstration board equivalent circuit**




**Where**

$Z_{load}$: Antenna equivalent parallel impedance. [Ω]

$R_A$: Antenna equivalent series resistor. [Ω]

$L_A$: Antenna equivalent series inductance. [H]

## 1.4 Need for impedance matching

The maximum power transfer between the CR95HF and the load is obtained when the condition $Z_{out} = Z_{load}^*$ is satisfied. $Z_{load}^*$ is the complex conjugate of $Z_{load}$.

The antenna equivalent impedance described in *Section 1.3: Inductive antenna impedance* does not meet this condition.

The measure of $Z_{load}$ gives:

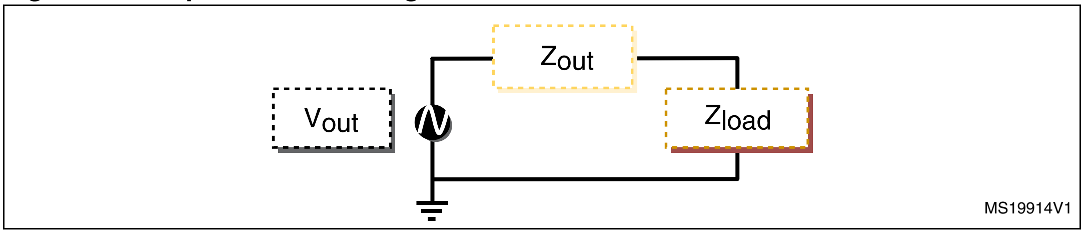
### Equation (I.4)

$$Z_{load} = (0.6 + j \times 36.6)\Omega$$

To achieve the maximum power transfer between the CR95HF and its inductive antenna, impedance matching must therefore be performed between $Z_{out}$ and $Z_{load}$. It allows to:

- Optimize the read range
- Transmit the maximum power
- Optimize the chip consumption
- Maximize the radiated magnetic field

**Figure 5. Impedance matching**



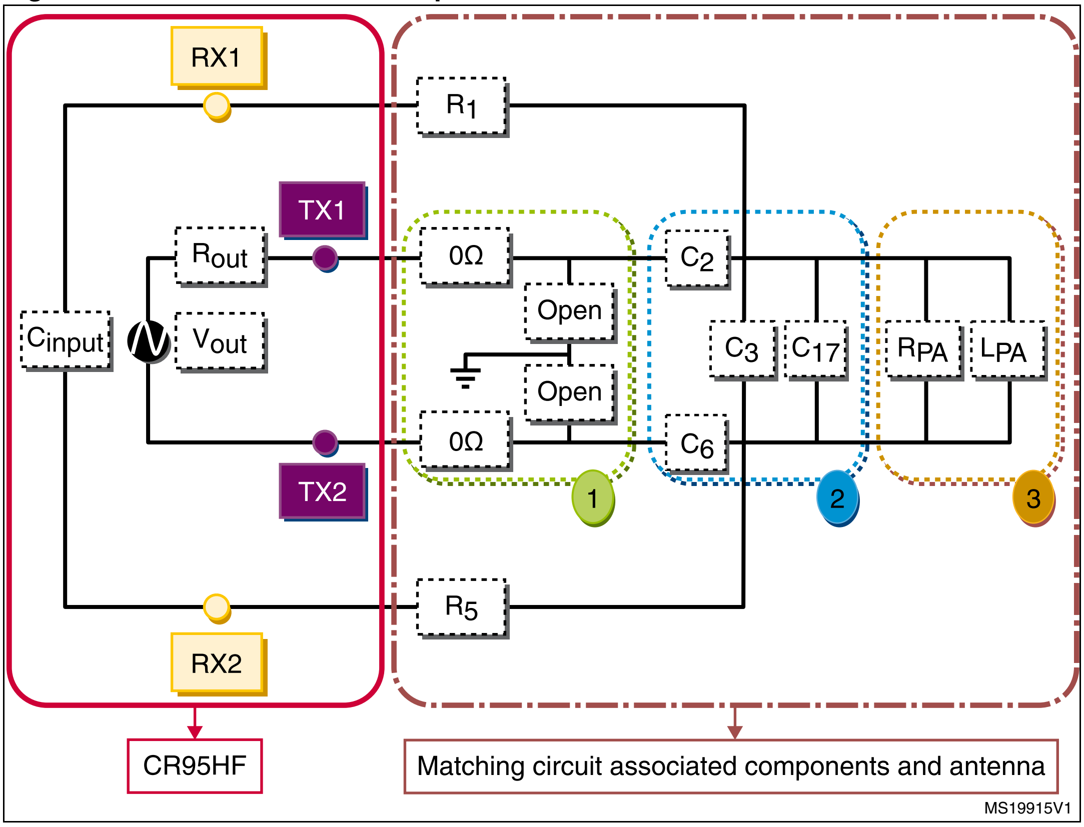
## 1.5 Impedance matching circuit

### 1.5.1 Antenna circuit description

The impedance matching circuit is composed of a serial capacitance circuit ($C_2$and $C_6$) and a parallel capacitance circuit ($C_3$and $C_{17}$).

Successive impedance transformation allows to simplify the antenna equivalent circuit and to calculate $C_2$, $C_6$, $C_3$ and $C_{17}$ capacitances easily.

**Figure 6. Antenna circuit description**




**Where**

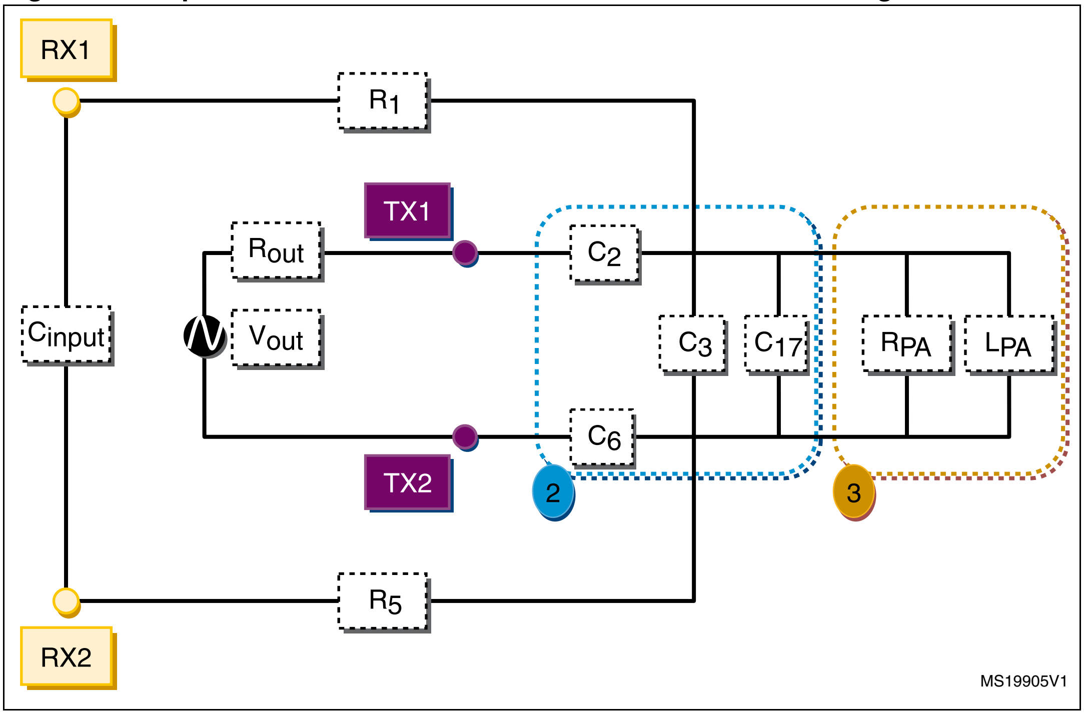
$R_1$,$R_5$: 330 Ω. These resistors are used to limit the signal level on RX1-RX2. They must be considered in the calculation of the impedance matching circuit.

$C_{input}$: 22 pF. $C_{input}$ is the integrated capacitor between RX1-RX2. As $R_1$,$R_5$, it must be considered for the impedance matching circuit.

### 1.5.2 Entire equivalent circuit

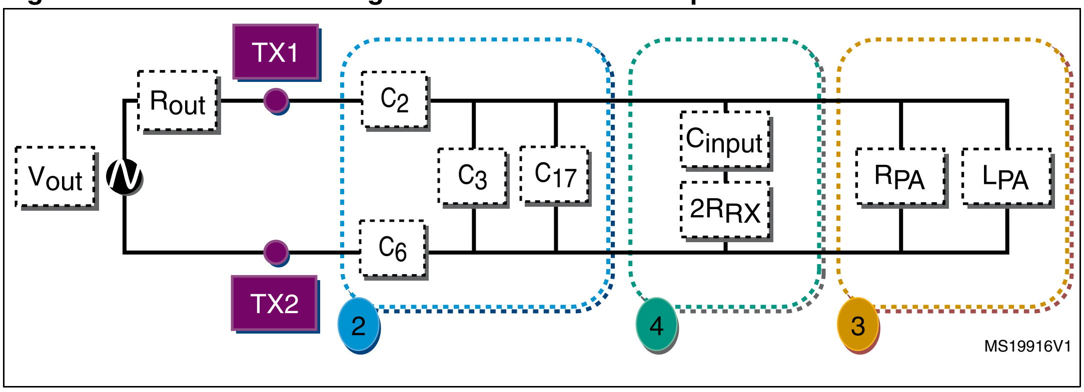
Without the EMI filter, the circuit is reduced as shown in *Figure 7: Equivalent circuit of the CR95HF and associated matching circuit*.

**Figure 7. Equivalent circuit of the CR95HF and associated matching circuit**




From antenna point of view, the CR95HF receiving circuit impedance ($R_1$, $R_5$ and $C_{input}$) is in parallel of $C_3$,$C_{17}$ as described in the equivalent circuit shown in *Figure 8: CR95HF matching circuit intermediate simplification*. $R_1$ and $R_5$ are equal and can be replaced by $R_{RX}$.

**Figure 8. CR95HF matching circuit intermediate simplification**

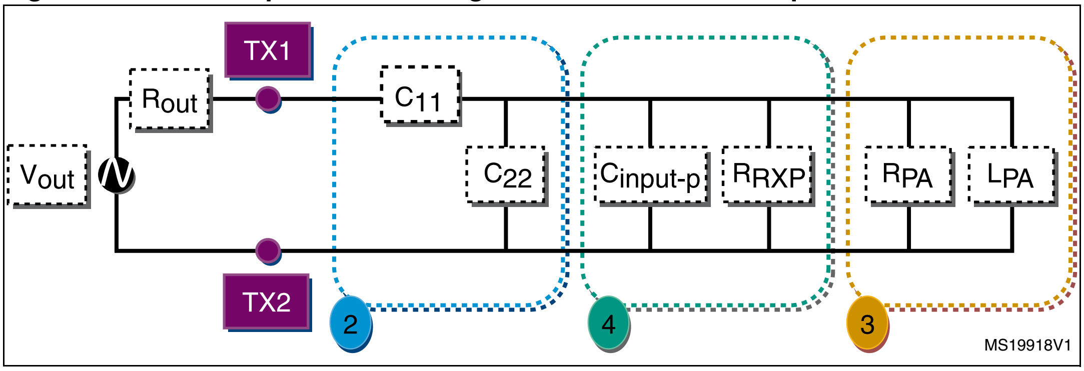



**Where**

4 : input impedance of the CR95HF reception circuit

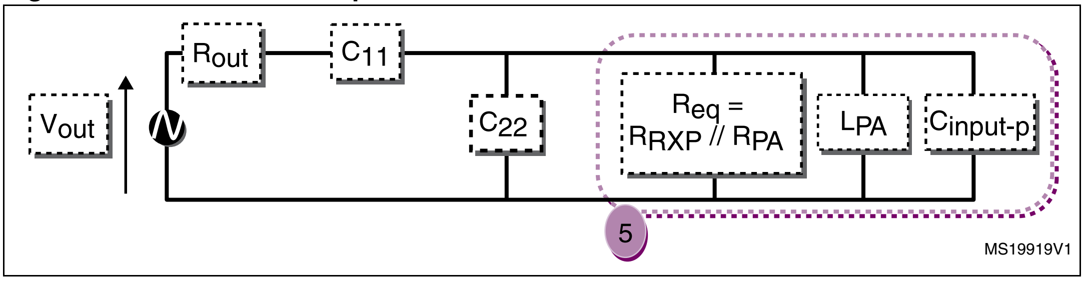
Both serial capacitances ($C_2$and $C_6$) are equivalent to a serial capacitance $C_{11}$ = $C_2/2 = C_6/2$. Both parallel capacitances ($C_3$ and $C_{17}$) are equivalent to a parallel capacitance $C_{22} = (C_3 + C_{17}).C_{input}$, and $R_{RX}$ can be transformed in a parallel equivalent circuit (see *Figure 9: CR95HF parallel matching circuit intermediate simplification*).

**Figure 9. CR95HF parallel matching circuit intermediate simplification**




The resulting equivalent circuit allows to calculate the matching circuit composed of $C_{11}$ and $C_{22}$ that satisfies the condition $Z_{out} = Z_{eq}^*$ where $Z_{eq}^*$ is the complex conjugate of $Z_{eq}$.

**Figure 10. CR95HF final equivalent circuit**




**Where**

5 : Equivalent circuit.

The calculation described in *Equation (A.I.7)* and *Equation (A.I.9)* leads to:

$$C_{11} = \frac{1}{R_{eq} \times \omega} \times \sqrt{\left(\frac{R_{eq}}{R_{out}} - 1\right)}$$

$$C_{22} = \frac{1}{L_{eq} \times \omega^2} - C_{11} - C_{input-p}$$

Where

$R_{RXP}$: Equivalent parallel resistor of $R_{RX}$. [Ω]

$R_{eq}$: Equivalent parallel resistor of $R_{RX}$ and $R_{PA}$. [Ω]

$C_{input\text{-}p}$: Equivalent parallel capacitance of $C_{input}$. [F]

$C_{11}$: Equivalent serial capacitance of $C_2$ and $C_6$ capacitances. [F]

$C_{22}$: Equivalent serial capacitance of $C_3$ and $C_{17}$ capacitances. [F]

Zeq: Equivalent impedance of circuits 2, 3 and 4.

# 2 Application to DEMO-CR95HF-A demonstration board

This section describes in detail the numerical application corresponding to the DEMO-CR95HF-A demonstration board.

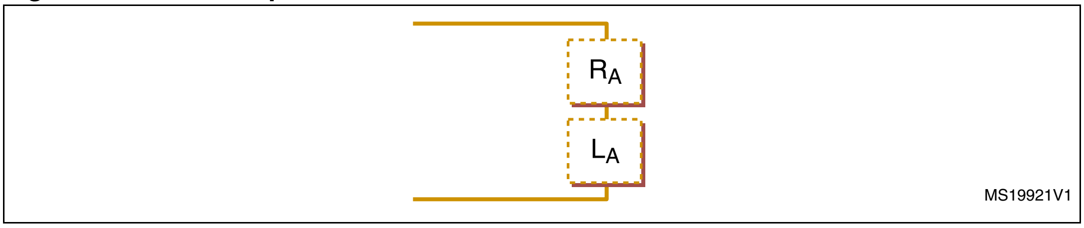
If your application requires a different antenna, use the DEMO-CR95HF-A Gerber files available for http://ww.st.com to design your own antenna. Guidelines on how to design an antenna can be found in *Section 4: Main criteria for key antenna design*.

## 2.1 Antenna parameters

This section describes part 3 of circuit shown in *Figure 9: CR95HF parallel matching circuit intermediate simplification*.

### 2.1.1 Antenna serial equivalent model

**Figure 11. Antenna parameters without EMI filter**




Where values from *Equation (I.4)* give:

$R_A$ = O.6 Ω and $L_A$ = 36.6* ω.

As a result, $L_A$ = 430 nH.

The capacitance is included in the inductance presented above. As a result:

**Equation (II.1)**

$$Q_A = \frac{|[IM(Z_{load})]|}{RE(Z_{load})} = \frac{\omega \times L_A}{R_A} = 61,1$$

Where

$Q_A$: Antenna quality factor, defined with antenna parameter.

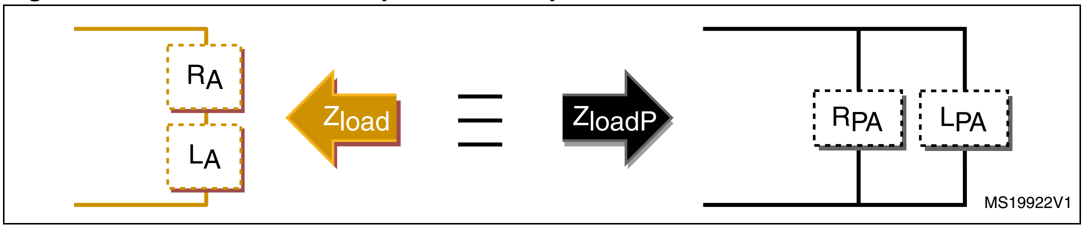
IM(x): Imaginary part of the complex number x.

RE(x): Real part of the complex number x.

ω: Resonance pulsation [rad/s]. ω = 2π f with f = 13.56 MHz.

### 2.1.2 Antenna parallel equivalent model

**Figure 12. Antenna serial-to-parallel RL equivalent circuit**




The values given hereafter are the numerical application of *Equation (A.II.5)* and *Equation (A.II.6)*:

$R_{PA}$ = 2238 Ω

$L_{PA}$ = 430,1 nH

**Where**

$Z_{load}$: Antenna equivalent series impedance. [Ω]

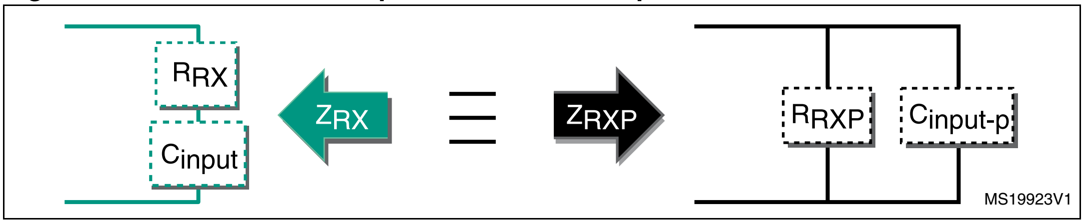
$Z_{loadP}$: Antenna equivalent parallel impedance. [Ω]

## 2.2 CR95HF receiving circuit equivalent models

### 2.2.1 CR95HF receiving circuit parallel equivalent model

This section describes part 4 of the circuit shown in *Figure 9: CR95HF parallel matching circuit intermediate simplification*.

**Figure 13. CR95HF serial-to-parallel RC circuit equivalence**



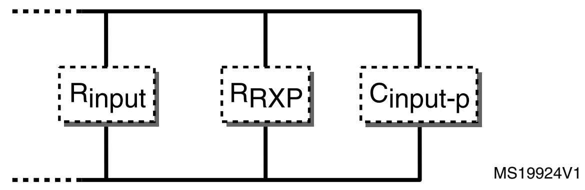

The values hereafter are the numerical application of *Equation (A.III.5)* and *Equation (A.III.6)*:

$R_{RXP}$ = 1091 Ω

$C_{input-p}$ = 8.69 pF

The circuit includes a 80 kΩ $R_{input}$ in parallel with $Z_{RXP}$, as shown in *Figure 14: Circuit including Rinput internal resistor*. For more details, refer to the CR95HF datasheet. $R_{input}$ resistance should be neglected as demonstrated below.

**Figure 14. Circuit including $R_{input}$ internal resistor**




### Equation (II.2)

$$R_{RXP}{}^{1} = \frac{R_{RXP} \times R_{input}}{R_{RXP} + R_{input}}$$

Numerical application of *Equation (II.2)*:

$$R_{RXP}{}^{1} = 1077\Omega$$

The coefficient error is: $\frac{\Delta R_{RXP}}{R_{RXP}{}^{1}} = \frac{1091 - 1077}{1091 + 1077} = 0,67$ % of error.

$R_{input}$ is equivalent to an open circuit, and can be neglected.

**Where**

$Z_{RX}$: Antenna equivalent series impedance. [Ω]

$Z_{RXP}$: Antenna equivalent parallel impedance. [Ω]

$R_{input}$: Differential input resistor between RX1/RX2 inputs. [Ω]

## 2.3 Numerical application of $C_2$, $C_6$, $C_3$ and $C_{17}$

This section gives the numerical application of part 2 of the circuit shown in *Figure 9: CR95HF parallel matching circuit intermediate simplification*.

The numerical application for *Equation (A.I.7)* is:

$C_{11}$ = 82,2 pF

$C_2 = C_6 = 2.C_{11}$ = 164,4 pF

The numerical application for *Equation (A.I.9)* is:

$C_{22} = C_3 + C_{17}$ = 229,4 pF

To keep the most possible C11 and C22 values and to optimize the performance, the following values have been chosen for $C_2$, $C_6$, $C_3$ and $C_{17}$:

- $C_2 = C_6$ = 150 pF
- $C_3$ = 220 pF
- $C_{17}$ = 15 pF

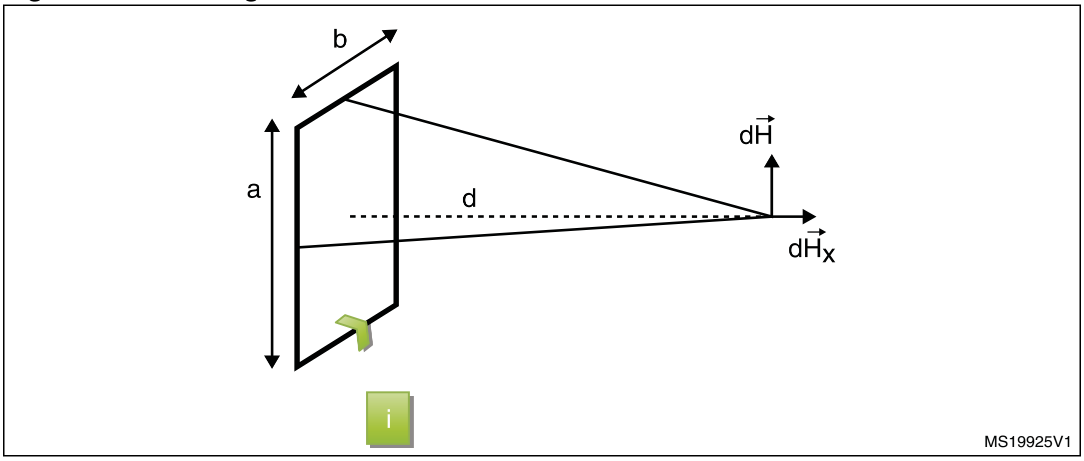
# 3 Read range estimate

This section explains how to obtain the maximum read range between tag and CR95HF.

## 3.1 Magnetic field calculation

For a rectangular antenna, the radiated magnetic field can be estimated using the following formula:

**Figure 15. Rectangular antenna**




### Equation (III.1)

$$H_x(d,r) = \frac{2 \times N \times i \times a \times b}{\pi \times \sqrt{(a^2 + b^2 + 4 \times d^2)}} \times \left(\frac{1}{a^2 + 4 \times d^2} + \frac{1}{b^2 + 4 \times d^2}\right)$$

Where

a: Antenna length. [m]

b: Antenna width. [m]

d: Distance from tag to antenna. [m]

N: Number of turns

i: Current in the antenna. [A rms]

$H_x$: Magnetic field. [A/m rms]

rms: Root mean square.

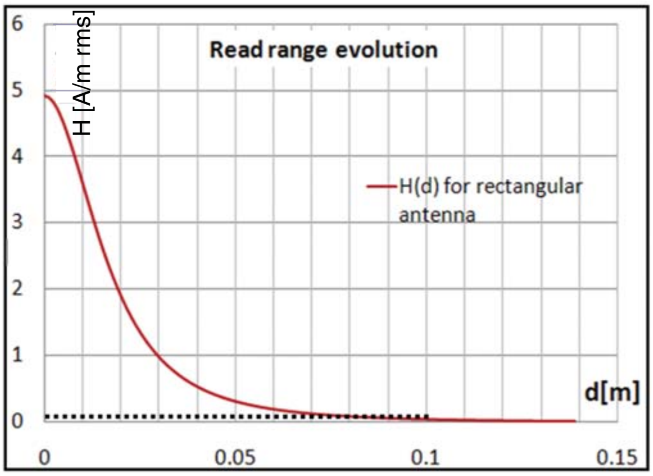
## 3.2 Read range calculation

*Figure 16: Read range evolution* shows the magnetic field strength radiated by the DEMO-CR95HF-A demonstration board. Neglecting the effect of mutual coupling between the CR95HF antenna and tag, it is possible to estimate the read range for a given tag.

As an example, the minimum operating fields for a M24LR64-R dual mode memory mounted on the ANT1-M24LR-A reference board is around 50 mA/m.

Reporting this value on *Figure 16: Read range evolution* gives an estimated read range of 10 cm.

**Figure 16. Read range evolution**



# 4 Main criteria for key antenna design

The following sections explain how to determine the antenna dimensions for a given value of antenna inductance (L).

## 4.1 Inductance of a circular antenna

### Equation 1

$L_{ant} = \mu_0 \times N^{1.9} \times r \times \ln\left(\frac{r}{r_0}\right)$, where:

- r is the radius in millimeters
- $r_0$ is the wire diameter in millimeters
- N is the number of turns
- $\mu_0 = 4\pi \cdot 10^{-7}$ H/m
- $L_{ant}$ is expressed in Henry

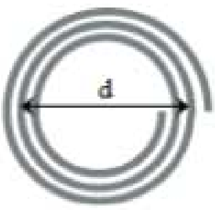
## 4.2 Inductance of a spiral antenna

### Equation 2

$L_{ant} = 31.33 \times \mu_0 \times N^2 \times \frac{d_{ant}}{8d_{ant} + 11c}$, where:

- $d_{ant}$ is the mean antenna diameter in millimeters
- c is the thickness of the winding in micrometers
- N is the number of turns
- $\mu_0 = 4\pi \cdot 10^{-7}$ H/m
- $L_{ant}$ is expressed in Henry

**Figure 17. Spiral antenna**




ai15812

## 4.3 Inductance of a square antenna

### Equation 3

$L_{ant} = K1 \times \mu_0 \times N^2 \times \frac{d_{ant}}{1 + K2 \cdot p}$, where:

- $d_{ant} = (d_{out} + d_{in})/2$ in millimeters, where: $d_{out}$ = outer diameter
  $d_{in}$ = inner diameter
- $p = (d_{out} - d_{in})/(d_{out} + d_{in})$ in millimeters
- K1 and K2 depend on the layout (refer to *Table 1* for values)

**Figure 18. Square antennas**

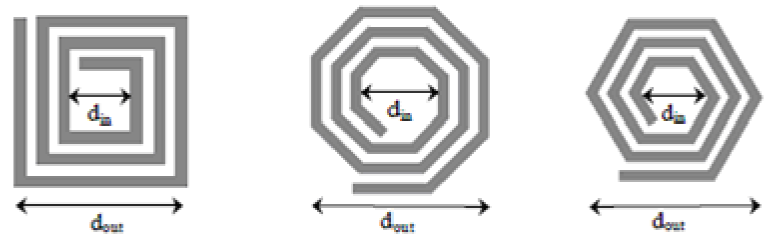



**Table 1. K1 and K2 values depending on layout**

| Layout | K1 | K2 |
|---|---|---|
| Square | 2.34 | 2.75 |
| Hexagonal | 2.33 | 3.82 |
| Octagonal | 2.25 | 3.55 |

## 4.4 ST antenna calculation tool

ST provides a simplified software tool (**antenne.exe**) to compute rectangular planar antenna inductances. This tool gives good approximations of the inductance value. It is recommended to verify the obtained results.

ST tool is based on the Grover method (see *Equation 4.1: Grover method*).

### Equation 4.1: Grover method

$L_{ant} = L_0 + \sum M$ , where:

- M is the mutual inductance between each of the antenna segments
- $L_0$ is as given by

### Equation 4.2

$L_0 = \sum_{j=1}^{s} L_j$ , where:

- s is the number of segments
- $L_j$ is the self inductance of each segment

A user interface allows to enter the antenna parameters which will be used to compute the antenna coil inductance:

- The number of turns
- The number of segments
- w: the conductor width in millimeters
- s: the conductor spacing in millimeters
- the conductor thickness in micrometers)
- Length in millimeters
- Width in millimeters

The number of turns is incremented each time a segment is added to a complete turn.

*Figure 19* shows the user interface corresponding to the DEMO-CR95HF-A antenna and *Figure 20* the characteristics of the rectangular planar antenna etched on the DEMO-CR95HF-A PCB.

The resulting impedance, $L_{ant}$, is 423.07 nH instead of 430 nH, knowing that this value includes the parasitic capacitance. Without the parasitic capacitance, the measured value of $L_{ant}$ is 420.2 nH.

**Figure 19. User interface for planar rectangular coil inductance calculation**

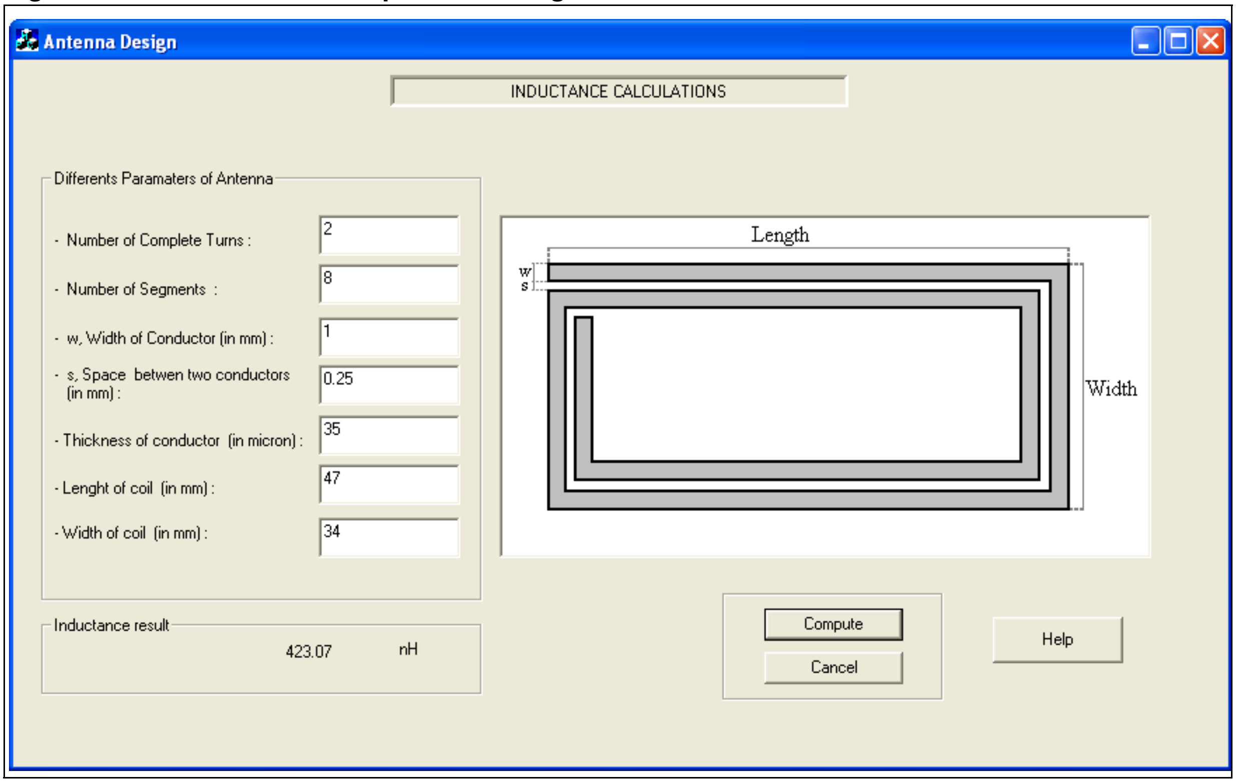
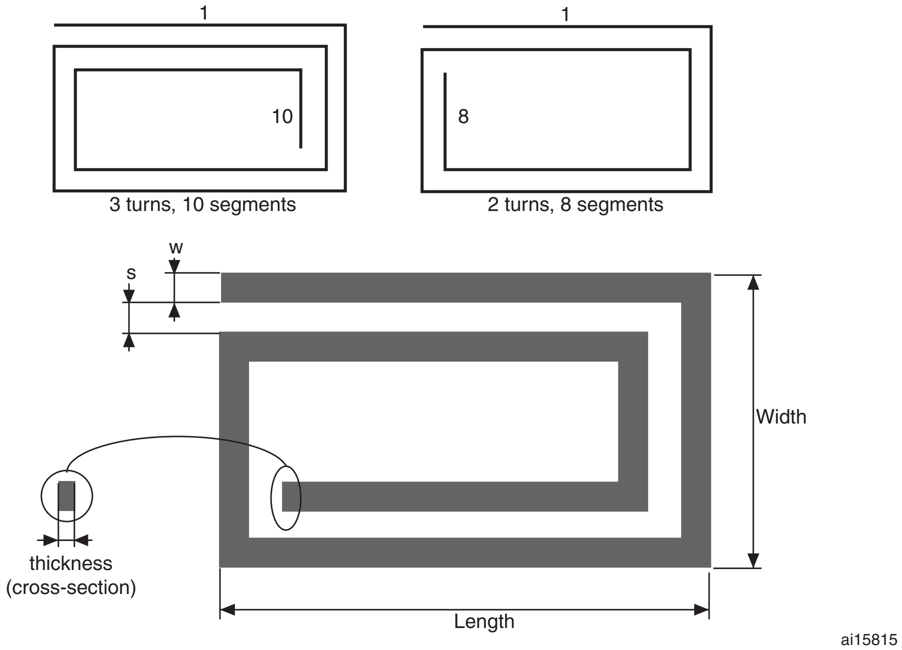


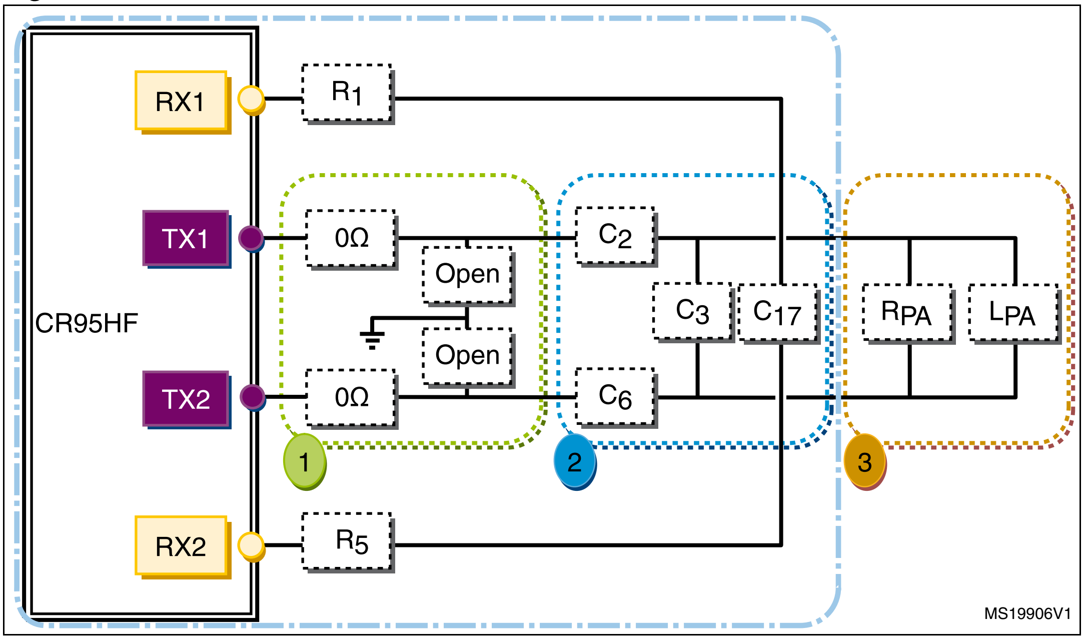
**Figure 20. Rectangular planar antennas**




Once the antenna coil inductance has been calculated, a prototype coil is realized. The value of the so-obtained prototype must then be validated by measurement. This can be done using either a contactless or a non-contactless method.

# 5 Conclusion

**Figure 21. DEMO-CR95HF-A circuit**




The following table summarizes the component values mounted on the DEMO-CR95HF-A demonstration board:

**Table 2. DEMO-CR95HF-A component commended values**

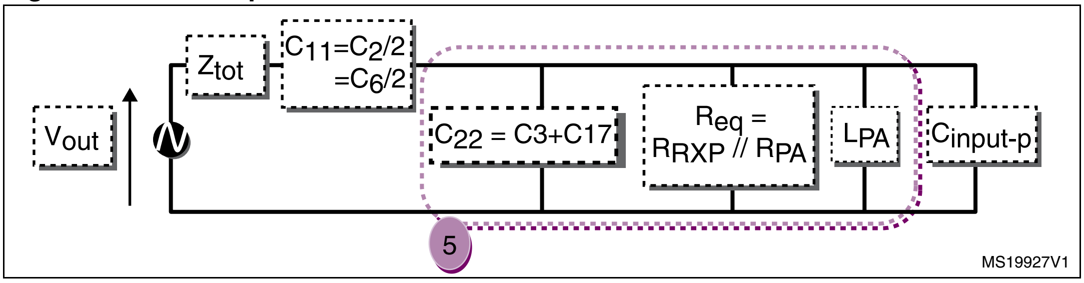
| Component | Recommended value |
|---|---|
| $C_2$ | 150 pF |
| $C_6$ | 150 pF |
| $C_3$ | 220 pF |
| $C_{17}$ | 15 pF |
| $R_{PA}$ | 2238 Ω |
| $L_{PA}$ | 430 nH |
| $R_1$ | 330 Ω |
| $R_5$ | 330 Ω |

# Appendix A Demonstration of $C_{11}$ and $C_{22}$ calculation

## A.1 Equivalent circuit

$Z_{tot}$ defines the input impedance of the matching circuit and the equivalent parallel antenna.

**Figure 22. Final equivalent circuit**




1. Calculation of $R_{eq}$:

### Equation (A.I.1)

$$R_{eq} = \frac{R_{RXP} \times R_{PA}}{R_{RXP} + R_{PA}}$$

2. Calculation of $Z_{tot}$:

### Equation (A.I.2)

$$Z_{tot} = \frac{1}{j \times C_{11} \times \omega} \times \frac{R_{eq} \times (1 - L_{PA} \times \omega^2 \times (C_{22} + C_{11})) + j \times \omega \times L_{PA}}{R_{eq}(1 - L_{PA} \times C_{22} \times \omega^2) + j \times \omega \times L_{PA}}$$

3. Resonance pulsation:

$$Z_{tot} = R_{tot} + j \times X_{tot}$$

To determine the resonance pulsation, the imaginary part of $Z_{tot}$ must be cancelled. The conditions are:

$$R_{tot} = R_{out} \quad \text{and} \quad X_{tot} = 0$$

### Equation (A.I.3)

$$R_{tot} = \frac{-R_{eq} \times L_{PA} \times C_{11} \times \omega^2 \times (1 - L_{PA} \times \omega^2 (C_{22} + C_{11})) + \omega^2 \times L_{PA} \times R_{eq} \times C_{11} \times (1 - L_{PA} \times \omega^2 \times C_{22}))}{(R_{eq} \times C_{11} \times \omega)^2 \times (1 - L_{PA} \times C_{22} \times \omega^2)^2 + (\omega^2 \times L_{PA} \times C_{11})^2}$$

**Equation (A.I.4)**

$$X_{tot} = -\omega \times C_{11} \times \frac{R_{eq}^{2} \times (1 - L_{PA} \times \omega^{2} \times C_{22})(1 - L_{PA} \times \omega^{2} \times (C_{22} + C_{11})) + \omega^{2} \times L_{PA}^{2}}{(R_{eq} \times C_{11} \times \omega)^{2} \times (1 - L_{PA} \times C_{22} \times \omega^{2})^{2} + (\omega^{2} \times L_{PA} \times C_{11})^{2}}$$

Neglecting $\omega^2$ x $L_{PA}^2$, then resolving the numerator leads to two different resonance pulsation $\omega_0$ and $\omega_1$:

**Equation (A.I.5)**

$$\omega_0 = \sqrt{\frac{1}{L_{PA} \times (C_{22} + C_{11})}}$$

**Equation (A.I.6)**

$$\omega_1 = \sqrt{\frac{1}{L_{PA} \times C_{22}}}$$

Finally inserting *Equation (A.I.5)* in *Equation (A.I.3)* leads to:

**Equation (A.I.7)**

$$C_{11} = \frac{1}{R_{eq} \times \omega_0} \times \sqrt{\left(\frac{R_{eq}}{R_{out}} - 1\right)}$$

**Equation (A.I.8)**

$$C_{22} = \frac{1}{L_{PA} \times \omega_0^{2}} - C_{11}$$

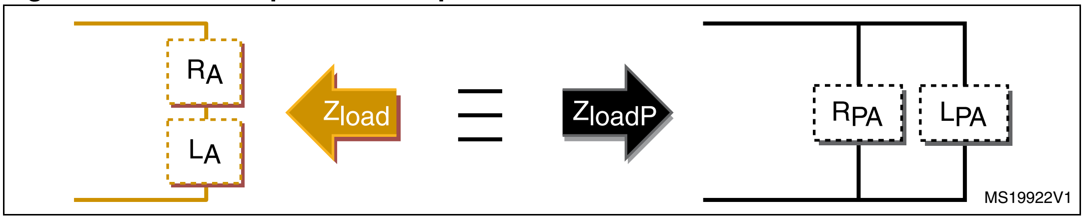
**Equation (A.I.9)**

$$C_{22} = \frac{1}{L_{PA} \times \omega_0^{2}} - C_{11} - C_{input-p}$$

In addition, $C_{input\text{-}p}$ is in parallel with $C_{22}$, and $C_{input\text{-}p}$ has to be subtracting to $C_{22}$.

## A.2 Serial to parallel equivalence RL impedance, and example of RL load

**Figure 23. Serial-to-parallel RL equivalent circuit**



$$Z_{load} = Z_{loadP}$$

$$R_A + j \times \omega \times L_A = \frac{R_{PA} \times L_{PA} \times j \times \omega}{R_{PA} + L_{PA} \times j \times \omega}$$

**Equation (A.II.1)**

$$R_A + j \times \omega \times L_A = \frac{R_{PA} \times L_{PA}^{\ 2} \times \omega^2}{R_{PA}^{\ 2} + (L_{PA} \times \omega)^2} + j \times \frac{R_{PA}^{\ 2} \times L_{PA} \times \omega}{R_{PA}^{\ 2} + (L_{PA} \times \omega)^2}$$

Consider that:

**Equation (A.II.2)**

$$Q_A = \frac{|\Im(Z_{load})|}{\Re(Z_{load})} = \frac{\omega \times L_A}{R_A} = \frac{\Re(Z_{loadP})}{|\Im(Z_{loadP})|} = \frac{R_{PA}}{L_{PA} \times \omega}$$

Equation (A.II.2) in equation (A.II.1) leads to:

$$R_A + j \times \omega \times L_A = \frac{R_{PA}}{1 + Q_A^{\ 2}} + j \times \frac{Q_A \times R_{PA}}{1 + Q_A^{\ 2}}$$

Identify the real part and the imaginary parts:

**Equation (A.II.3)**

$$R_A = \frac{R_{PA}}{1 + Q_A^{\ 2}}$$

**Equation (A.II.4)**

$$\omega \times L_A = \frac{Q_A \times R_{PA}}{1 + Q_A^{\ 2}}$$

From equation (A.II.3):

**Equation (A.II.5)**

$$R_{PA} = R_A \times (1 + Q_A^{\ 2})$$

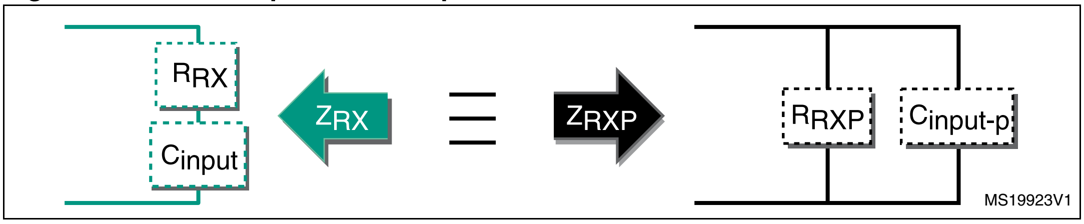
By equation (A.II.4):

**Equation (A.II.6)**

$$L_{PA} = L_A \times \frac{(1 + Q_A^{\ 2})}{Q_A^{\ 2}}$$

## A.3 Serial to parallel equivalence RC impedance, and example of RC load

**Figure 24. Serial-to-parallel RC equivalent circuit**




$$Z_{RX} = Z_{RXP}$$

$$2 \times R_{RX} + \frac{1}{j \times \omega \times C_{input}} = \frac{R_{RXP}}{j \times \omega \times R_{RXP} \times C_{input-p} + 1}$$

So:

**Equation (A.III.1)**

$$2 \times R_{RX} - j \times \frac{1}{\omega \times C_{input}} = \frac{R_{RXP}}{1 + (R_{RXP} \times C_{input-p} \times \omega)^2} - j \times \frac{R_{RXP}^2 \times C_{input-p} \times \omega}{1 + (R_{RXP} \times C_{input-p} \times \omega)^2}$$

Consider that:

**Equation (A.III.2)**

$$Q_{RX} = \frac{|IM(Z_{RX})|}{RE(Z_{RX})} = \frac{1}{2 \times \omega \times C_{input} \times R_{RX}} = \omega \times C_{input-p} \times R_{RXP}$$

Equation (A.III.2) in equation (A.III.1) leads to:

$$2 \times R_{RX} - j \times \frac{1}{\omega \times C_{input}} = \frac{R_{RXP}}{1 + Q_{RX}^2} - j \times \frac{Q_{RX}^2}{1 + Q_{RX}^2} \times \frac{1}{C_{input-p} \times \omega}$$

Identify the real and the imaginary parts:

**Equation (A.III.3)**

$$2 \times R_{RX} = \frac{R_{RXP}}{1 + Q_{RX}^2}$$

**Equation (A.III.4)**

$$\frac{1}{\omega \times C_{input}} = \frac{Q_{RX}^2}{1 + Q_{RX}^2} \times \frac{1}{C_{input-p} \times \omega}$$

By equation (A.III.3):

**Equation (A.III.5)**

$$R_{RXP} = 2 \times R_{RX} \times (1 + Q_{RX}^2)$$

By equation (A.III.4):

**Equation (A.III.6)**

$$C_{input-p} = C_{input} \times \frac{Q_{RX}^2}{1 + Q_{RX}^2}$$

Where

$Q_{RX}$ = quality coefficient.

# 6 Revision history

**Table 3. Document revision history**

| Date | Revision | Changes |
|---|---|---|
| 10-June-2011 | 1 | Initial release. |
| 12-Jul-2011 | 2 | Updated DEMO-CR95HF-A antenna dimensions *Section 1.3: Inductive antenna impedance*. |
| 25-Jul-2011 | 3 | Corrected $C_{22}$ equivalent serial capacitance name in *Section 1.5.2: Entire equivalent circuit* |
| 22-Aug-2011 | 4 | Modified document title.<br>Updated *Introduction*.<br>Updated *Section 2: Application to DEMO-CR95HF-A demonstration board* overview to add the case of user-designed antenna.<br>Added *Section 4: Main criteria for key antenna design*.<br>Updated disclaimer on last page. |
| 03-Oct-2011 | 5 | Modified $C_3$ and $C_{17}$ in *Table 2: DEMO-CR95HF-A component commended values*. |