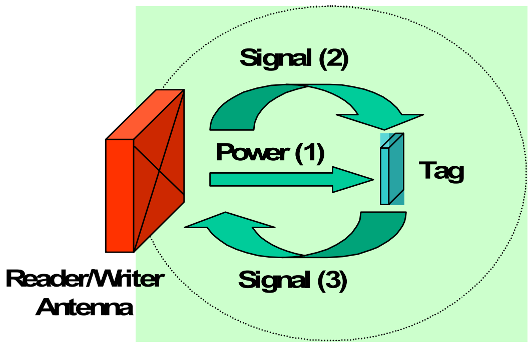
AN1806
APPLICATION NOTE

Antenna (and Associated Components) Matching-Circuit Calculation for the CRX14 Coupler

In the basic RFID system (as shown in *Figure 1*):

1. The Reader generates an electromagnetic field. This field is rectified to generate the supply voltage inside the Tag.
2. The Reader transmits information to the Tag by modulating the carrier wave.
3. The Tag back-scatters the carrier wave, by modifying its own impedance thereby perturbing the field, in order to transmit back information to the Reader.

Figure 1. Basic RFID System



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1 CRX14 Contactless Coupler Chip from ST

ST has designed the CRX14, a short range contactless coupler chip, compliant with the ISO14443 type B proximity standard. The CRX14 generates a 13.56MHz signal. Designed to deliver an RF power of 100mW, it operates in the Short Range on contactless memory tags (provided that they, too, are compliant with ISO14443 type B).

The CRX14 features the ST anti-collision mechanism, which allows the reader to detect and identify all the tags that are present in the operating range, and to access them individually. Because the CRX14 implements the France Telecom-proprietary anti-clone function, the reader can also perform authentication of tags that are equipped with the France Telecom anti-clone capability.

The CRX14 coupler interfaces between:

- the memory tags, on one side, through input/output buffers and the ISO14443 type B radio frequency protocol, and
- the system master processor, on the other side, through a 400kHz I^2C bus.

Operating from a 5V power supply, and delivered in a SO16N package, the CRX14 coupler chip is an excellent solution for building contactless readers, embedded in the final equipment, and offering a good compromise between operating range and cost.

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2 Short Range Contactless Memories from ST

All devices from the ST Short Range Contactless series are compliant with the ISO14443 type B standard. They are accessible via a 13.56MHz carrier frequency, and support a data transfer rate between tag and reader of 106kbit/s in both directions. All of them are totally compatible with each other, in terms of tag protocol access. The series is sub-divided into two families:

- Low-end SR Family
- Secure SRIX Family (equipped with anti-clone and anti-collision capabilities).

2.1 Low-end SR Family

SR176 is the first member of ST low-end short range family. It contains:

- 176 bits of EEPROM, organized as eleven 16-bit blocks, that can be write-protected
- a 64-bit UID, and
- a fixed 8-bit chip identifier.

2.2 Secure SRIX Family

SRIX is a family of highly secure devices that support the anti-clone capability, allowing tag authentication. The system master processor sends an authentication request to each of the tags present in the CRX14's field. Each tag runs its anti-clone algorithm to compute a signature, and sends it back to the reader for an authentication check. The anti-clone function helps fight against fraud, since any tag that does not belong to the system will answer with a wrong signature.

The first member of the SRIX family is the SRIX4K, featuring 4096 bits of EEPROM organized as 128 words of 32 bits. These are, in turn, organized in five main areas:

- One 5-word OTP zone, accessible in user mode, whose bits can only be switched from 1 to 0
- Two 32-bit binary counters that can only be decremented
- 121 words of user EEPROM, of which 9 can be individually write protected
- One 8-bit chip identifier that allows a reader to identify uniquely each tag present in its field during the anti-collision operation
- One 64-bit read-only unique identifier (UID), programmed on the manufacturing line.

The family will be later extended to include a lower density, 512-bit, device.

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3 Basic concepts and fundamental equations

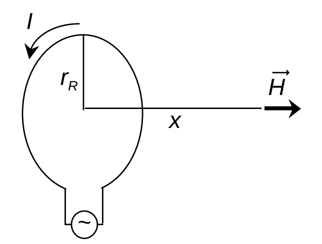
To calculate the characteristics of a RFID system, we need some definitions and assumptions:

- The reader generates a tension
- This tension supplies the inductive **antenna L_R** by the **tuning circuit**.
- A **current I_R** flows through the antenna and creates a **magnetic field** defined at **distance x**.
- This field is transformed into a supply voltage in the tag.
- When the tag is near the reader antenna, it modifies the antenna tuning.
- To calculate the real current, we need to calculate the **mutual inductance M** and the **coupling factor** between the reader antenna L_R and the tag antenna L_T.
- We can also calculate the range within which the tag receives enough magnetic flux to work well.

3.1 Electromagnetic Field

To generate an electromagnetic field, we can assume a circular loop antenna (*Figure 2.*)

Figure 2. Circular Loop Antenna



The Electromagnetic field is given by *Equation 1*.

Equation 1

$$H_r(x) = \frac{I_R \times N_R \times r_R^2}{2 \times (r_R^2 + x^2)^{3/2}}$$

Where:

- I_R is the current in the loop antenna
- N_R is the number of turns of the loop antenna
- r_R is the coil radius
- $H_r(x)$ is measured in A/m

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An inductive coupling is possible in the near field, the limit between a near field and a far field is given by *Equation 2*.

Equation 2

$$x \leq \frac{\lambda}{2 \times \pi}$$

Where:

- $\lambda = c/f$

In this application note, we use only Tags with a working frequency of 13.56MHz. So, the limit between a near field and a far field is:

- $x \leq 3.52m$

Figure 3 illustrates the magnetic field as a function of the distance of the tag from the reader, for given values of the number of turns, *N*, the current, *I*, and the antenna radius, *r*.

Figure 3. Magnetic Field as a Function of the Distance of the Tag from the Reader

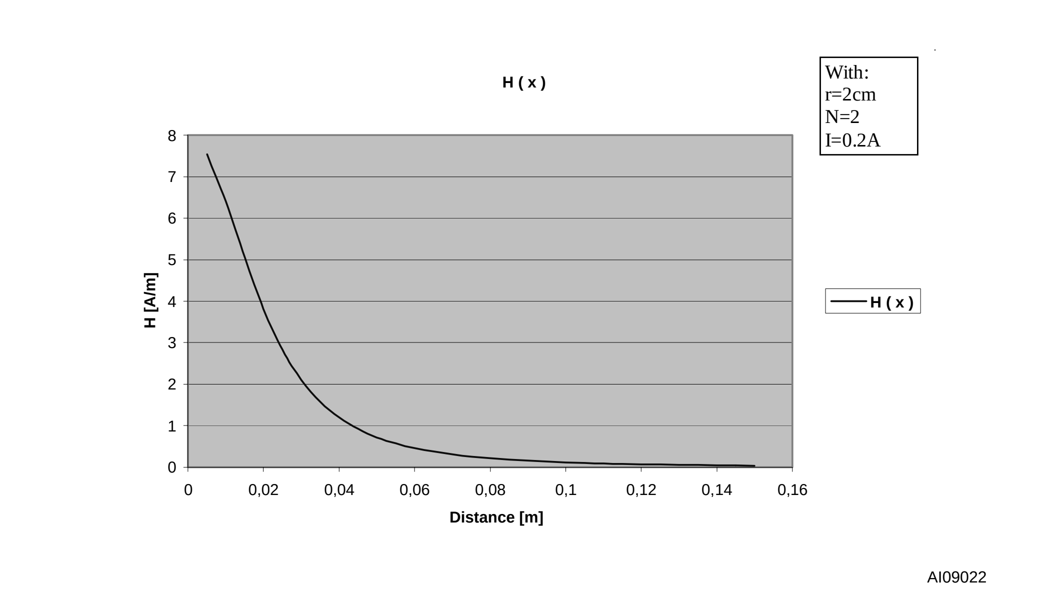

Figure 4 illustrates the magnetic field as a function of the antenna radius, *r*, for given values of the number of turns, *N*, the current, *I*, of reader antenna, and the distance between tag and antenna reader, *x*.

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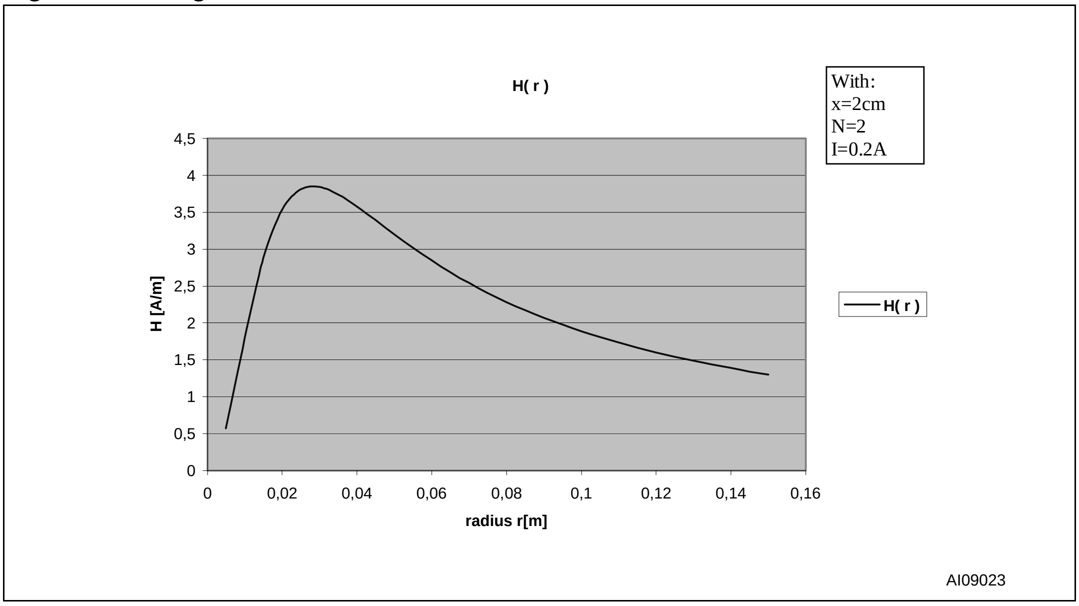
Figure 4. Magnetic Field as a Function of the Antenna Radius



In this example we can see that the field decrease when the radius goes beyond an optimal value.

3.2 Inductance, *L*, and the Antenna

To tune the reader antenna, we need to be able to calculate its inductance.

Equation 3: Inductance of a Circular Loop

$$L = \mu_0 \times N^{1.9} \times r \times \ln\left(\frac{r}{r_0}\right)$$

Where:

- r is the mean coil radius
- r_0 is the wire diameter
- N is the number of turns
- $\mu_0 = 4\pi 10^{-7}$ H/m
- L is measured in H

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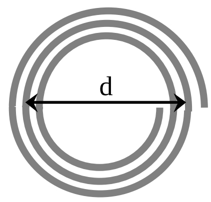
Figure 5. Round Planar Spiral Coils



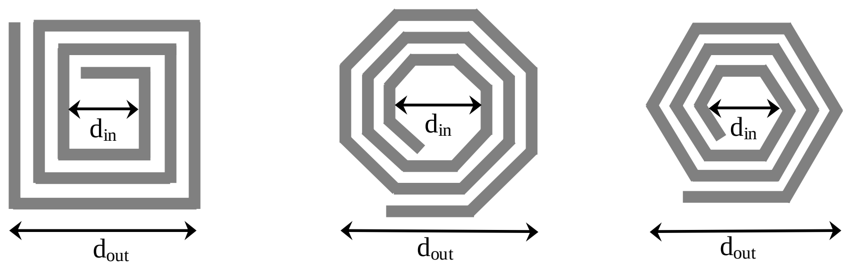
Equation 4: Inductance of Round Planar Spirals

$$L = 31.33 \times \mu_0 \times N^2 \times \frac{d}{8 \cdot d + 11 \cdot c}$$

Where:

- *d* is the mean coil diameter
- *c* is the thickness of the winding
- *N* is the number of turns
- $\mu_0 = 4\pi 10^{-7}$ H/m
- *L* is measured in H

Figure 6. Planar Square, Hexagonal and Octagonal Spiral Coils



Equation 5: Inductance of Planar Square, Hexagonal and Octagonal Coil

$$L = K_1 \times \mu_0 \times N^2 \times \frac{d}{1 + K_2 \cdot \rho}$$

Where:

- *d* is the mean coil diameter: $(d_{out}+d_{in})/2$
  - d_{out} is the outer diameter
  - d_{in} is the inner diameter
- $\rho = (d_{out}-d_{in})/(d_{out}+d_{in})$
- K_1 and K_2 depend on the layout (as summarized in *Table 1*.)

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Table 1. K_1 and K_2 values according to layout

Layout	K_1	K_2
Square	2.34	2.75
Hexagonal	2.33	3.82
Octagonal	2.25	3.55

3.3 Inductance of a Planar Rectangular Coil

We have developed a convenient software tool, using the Grover method (*Equation 6*) for calculating the inductance of rectangular planar antenna. The user interface is shown in *Figure 7*.

We have found that the software gives a good approximation of the inductance *L*, in comparison to measurements of the inductance of a real antenna on an impedance meter.

Equation 6: Grover Method

$$L = L_0 + \sum M$$

Where:

- M is the mutual inductance between each of the segments of the antenna
- L_0 is as defined in *Equation 7*

Equation 7

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

Where:

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

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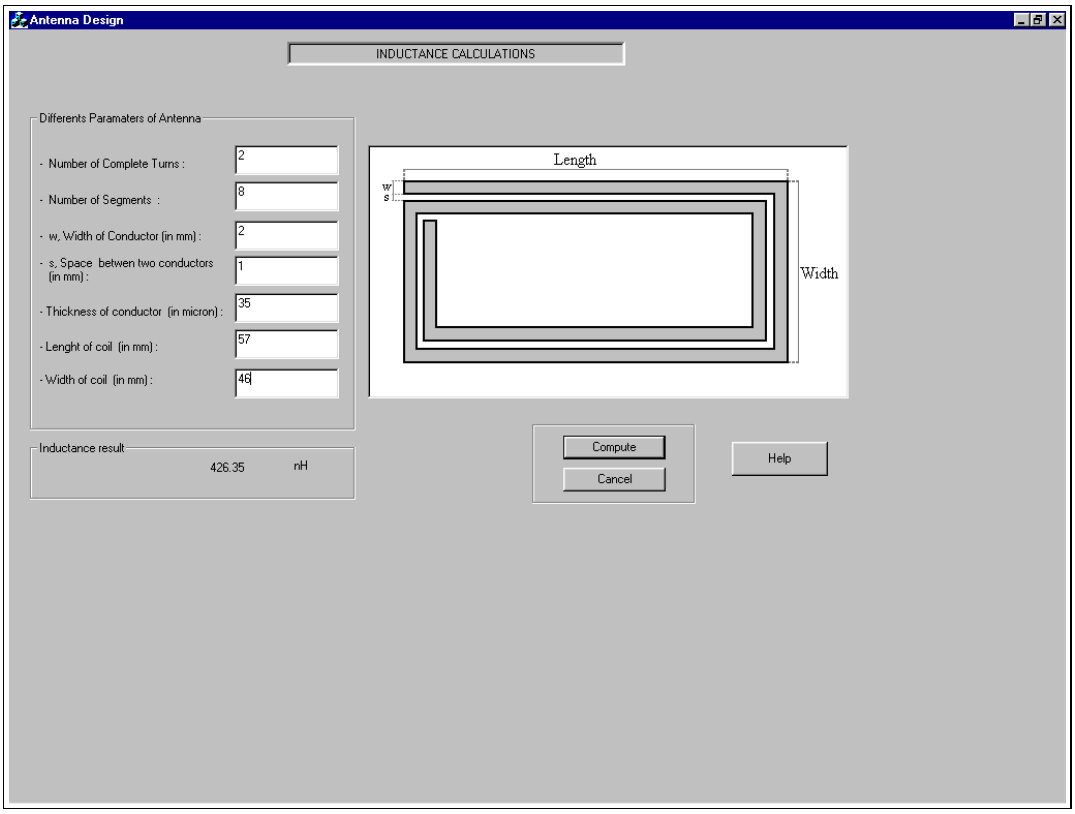
Figure 7. User Interface Screen of the Planar Rectangular Coil Inductance Calculator



3.4 Magnetic Coupling Factor

To have a good model of the system, we need to calculate the mutual inductance and coupling factor of the system.

Equation 8: Magnetic Flux

$$\Phi = \oint_{S} \vec{B} d\vec{S}$$

Where:

- $\overline{B}$ is the magnetic induction
- $d\overline{S}$ is the surface cross by the magnetic induction

Equation 9

$$\Phi = B \times S \times \cos\alpha$$

If $\alpha = 0$:

- $\Phi = B.S$

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Equation 10: Mutual Inductance between Reader and Tag Antenna

$$M = \frac{N_T \times \Phi_R}{I_R}$$

Equation 11

$$M(x) = \frac{\mu_0 \times r_R^2}{2 \times (r_R^2 + x^2)^{3/2}} \times S_T \times N_R \times N_T$$

Where:
- N_R is the number of turns on the reader antenna
- N_T is the number of turns on the tag antenna
- S_T is the area of the tag antenna
- r_R is the coil radius of the reader antenna
- x is the distance between the reader antenna and the tag antenna

Equation 12: Magnetic Coupling Factor between Reader and Tag Antenna

$$k(x) = \frac{M(x)}{\sqrt{L_T \times L_R}}$$

Where:
- L_R is the inductance of reader antenna
- L_T is the inductance of tag antenna

Therefore:

Equation 13

$$k(x) = \frac{\mu_0 \times r_R^2}{2 \times (r_R^2 + x^2)^{3/2}} \times \frac{S_T \times N_R \times N_T}{\sqrt{L_T \times L_R}}$$

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4 Antenna

The quality factor is a characteristic of the antenna performance. This parameter is used when tuning the reader antenna.

Equation 14: Quality Factor

$$Q_R = \frac{2 \times \pi \times f_0 \times L_R}{r_{LR}}$$

Where:

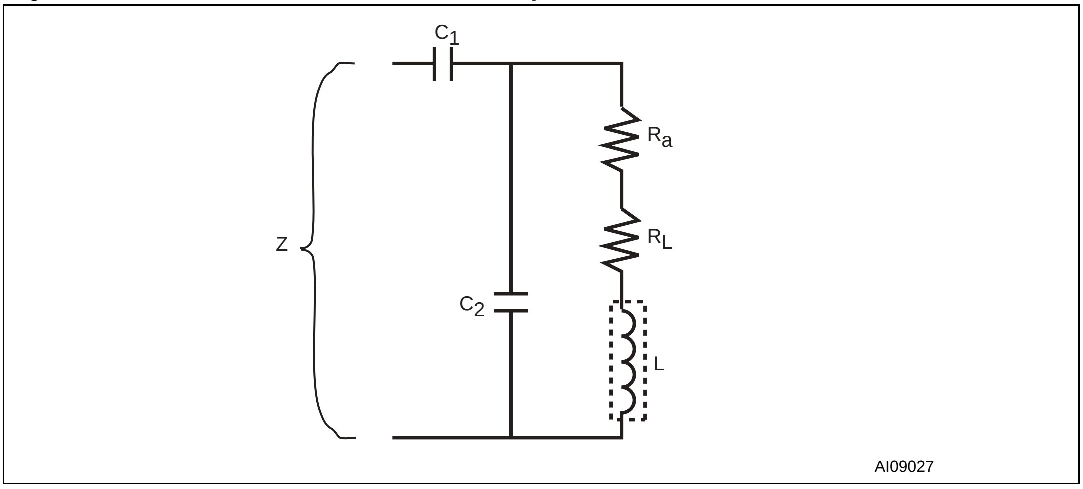
- L_R is the inductance of reader antenna
- r_{LR} is the resistance of reader antenna
- R_{LR} is the natural resistance of the reader antenna
- f_0 is the resonance frequency

4.1 Matching Circuit

To tune an antenna at the specific frequency, we performed the following analysis.

First, we started with the equivalent circuit for the antenna system on the board.

Figure 8. Real Circuit for the Antenna System on the Board



Where:

- C_1 and C_2 are calculated later
- R_L is the natural resistance of the loop antenna
- L is the inductance value of the loop antenna
- R_a is an additional resistor to have the good value of antenna parameters.

Then we made use of the following series-to-parallel circuit equivalence.

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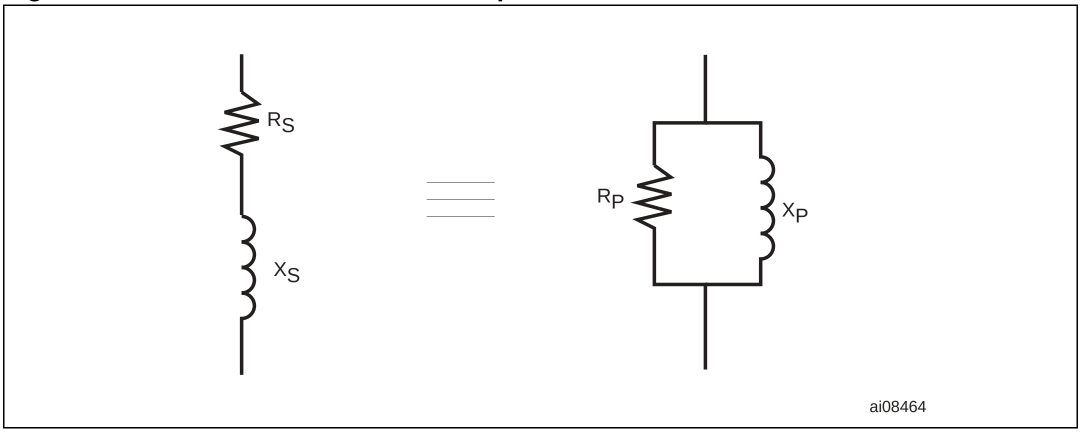
Figure 9. Series-to-Parallel Circuit Equivalence



Where:

$$R_P = \frac{X_S^2}{R_S}$$

and:

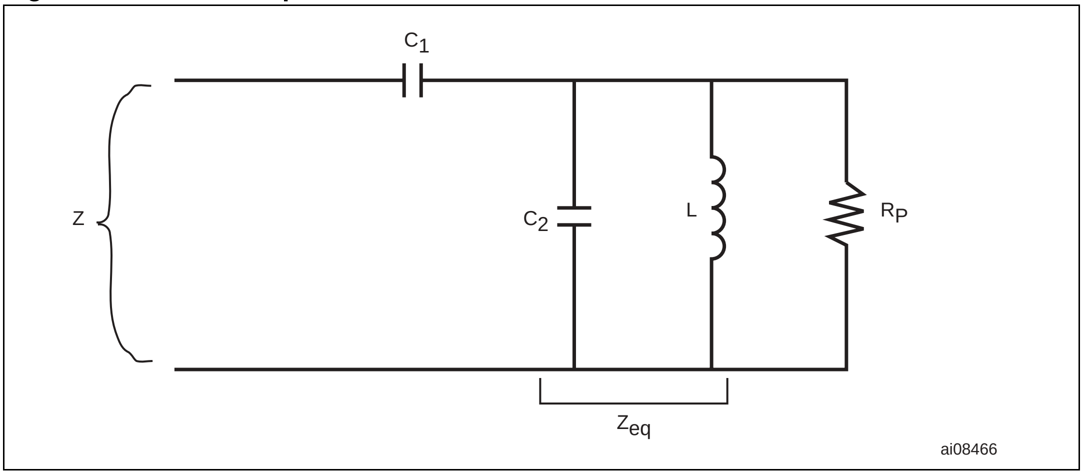
$$X_P = X_S$$

If we assume that:

$$R_S << X_S^2$$

This gives a new equivalent circuit, as shown in *Figure 10*.

Figure 10. Parallel Equivalent Circuit



Where:

$$R_P = \frac{(L \times \omega_0)^2}{R_a + R_L}$$

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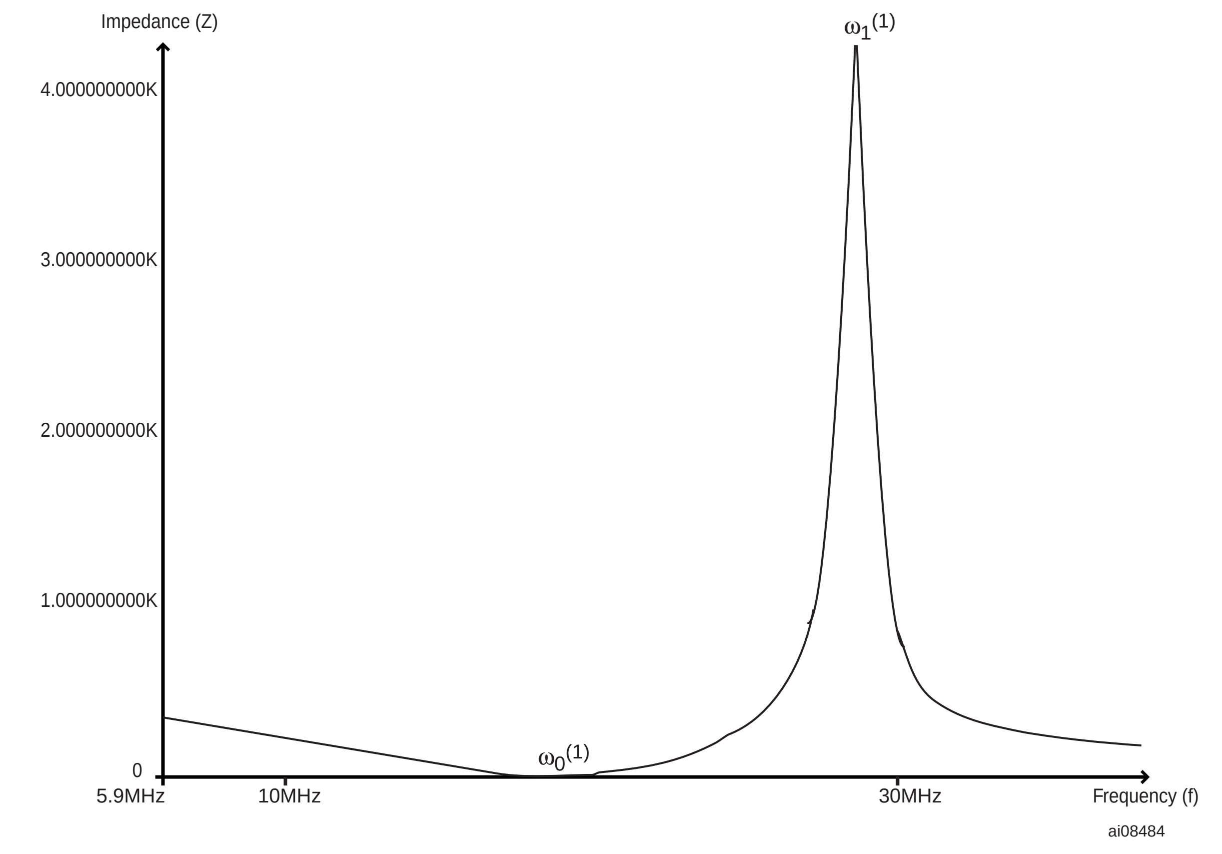
Figure 11. Equivalent Impedance (Z) Plotted against Frequency (f)



1. See resonance frequency in *Table 2*.

Table 2. Main Results

Resonance frequency	Equivalent impedance of the circuit
$\omega_0 = \frac{1}{\sqrt{L(C_1 + C_2)}}$	$\Re[Z] = \frac{RpL(C_1 + C_2)}{C_1^2 Rp^2 + L(C_1 + C_2)}$
$\omega_1 = \frac{1}{\sqrt{LC_2}}$	$\Re[Z] = Rp$

Table 3. Values of Capacitors

C1	C2
$C_1 = \frac{1}{\sqrt{Z \cdot Rp} \times \omega_0}$	$C_2 = \frac{1}{L\omega_0^2} - C_1$

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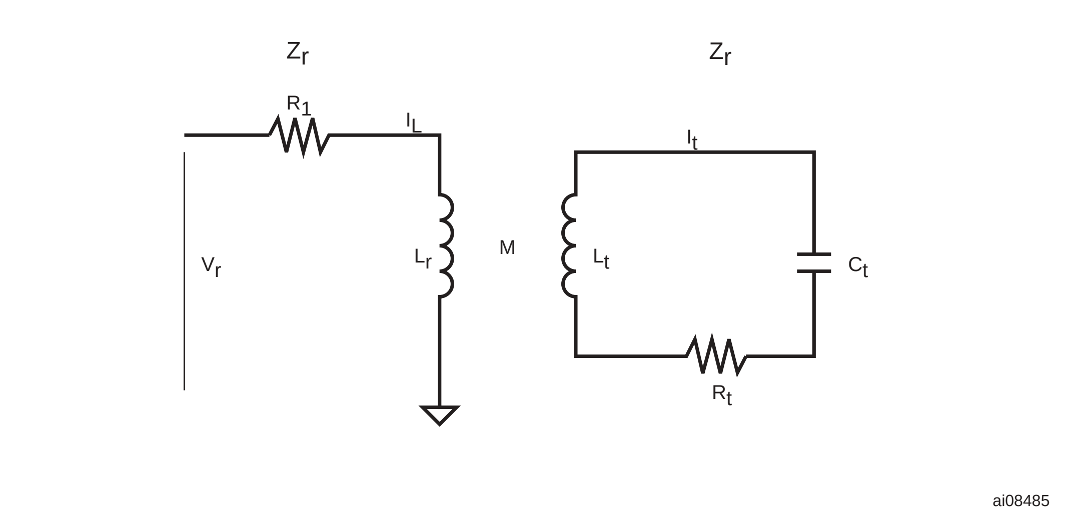
4.2 Current Calculation

To calculate the current, we use the complete system with tuning circuit and the influence of the tag when it is near the reader antenna. For this, we need to know the mutual inductance between the reader antenna and the Tag.

Figure 12. Coupling between One Tag and One Reader Antenna



Equation 15

$$\begin{cases} Z_R = R + jL_R\omega \\ Z_T = R_T + jL_T\omega + \dfrac{1}{jL_T\omega} = R_T + j\left(L_T\omega - \dfrac{1}{C_T\omega}\right) \end{cases}$$

Equation 16

$$\begin{cases} V_R = Z_R \cdot I_R + jM\omega I_R \\ 0 = Z_T + jM\omega I_R \end{cases}$$

Equation 17

$$V_R = \left(Z_R + \frac{M^2\omega^2}{Z_T}\right) \cdot I_R$$

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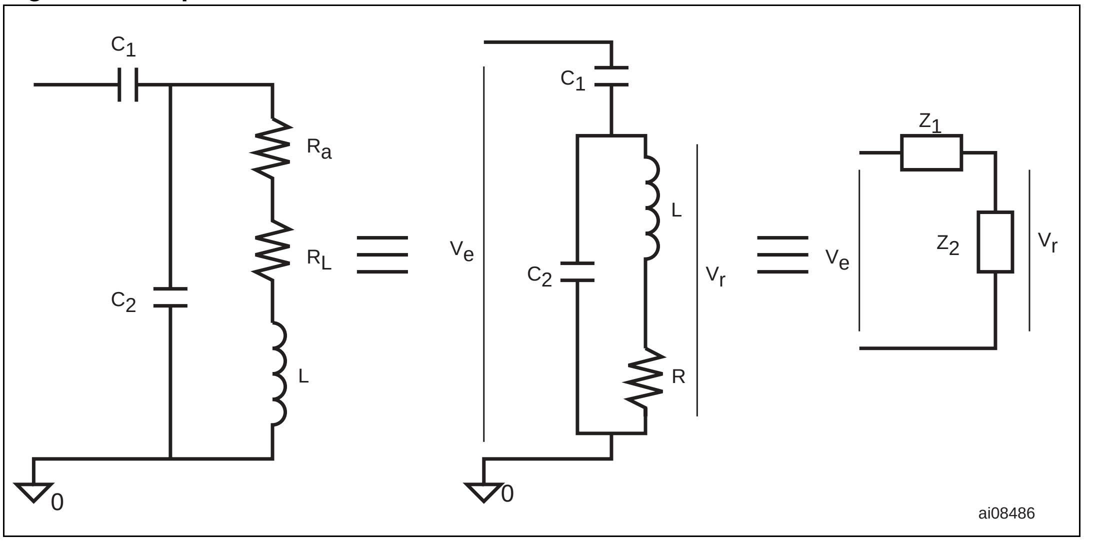
Equation 18

$$I_R = \frac{V_R \cdot Z_T}{Z_T \cdot Z_R + M^2 \omega^2}$$

This equation allows the current I_R in reader antenna to be calculated.

4.3 V_R Calculation

Figure 13. Equivalent Circuits



Equation 19

$$R = R_a + R_L$$

Equation 20

$$V_R = \frac{V_e \times Z_2}{Z_1 + Z_2}$$

Equation 21

$$V_R = \frac{(R + jL\omega) \cdot jC_1\omega}{(R + jL\omega) \cdot jC_1\omega + jRC_2\omega - LC_2\omega^2 + 1} \times V_e$$

4.4 Current Calculation

Combining *Equation 18* and *Equation 21* we get *Equation 22*.

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Equation 22

$$I_R = \frac{\dfrac{jRC_1\omega - LC_1\omega^2}{jR(C_1 + C_2)\omega - L(C_1 + C_2)\omega + 1} \times \left(R_T + \dfrac{1 - L_T C_T \omega^2}{jC_T\omega}\right)}{\left(R_T + \dfrac{1 - L_T C_T \omega^2}{jC_T\omega}\right) \times (R + jL_R\omega) + M^2\omega^2} \times V_e$$

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5 Designing an RFID application

It is not easy to calculate directly the optimal antenna to have specific reading distance. Here is a suggested method:

- Choose a Tag
- Start with an approximate antenna size
- Calculate the real reading range with these parameter
- Adjust the antenna size appropriately, to get the desired reading range.

Table 4 summarizes the different steps to calculate the additional components and reading range.

Table 4. Calculation steps

Step	Action	Input Parameters	Output parameters
1	Choose Tag package	A3,A4,A5	H_{min}[A/m]
2	Choose reading range and select first reader antenna size	X_{Tag} d_{out} Nr Wc Sc Tc	L_R[H] R_L [Ω]
3	Calculate C_1, C_2 Current in Antenna reader	f_{tune}	r_a[Ω] C_1 [F] C_2 [F] I_r [A]
4	Calculate Reading distance min/max Coupling coefficient		X_{max} [m] X_{min} [m] K_{min}

- N_R: Number of turns for the reader antenna
- W_C: conductor width of reader antenna
- L_R: Inductance of reader antenna
- R_L: Resistance of reader antenna
- f_{tune}: Tuning frequency of reader antenna
- C_1, C_2: Tuning capacitance
- R_a: Additional resistance of reader antenna
- I_r: Current in reader antenna

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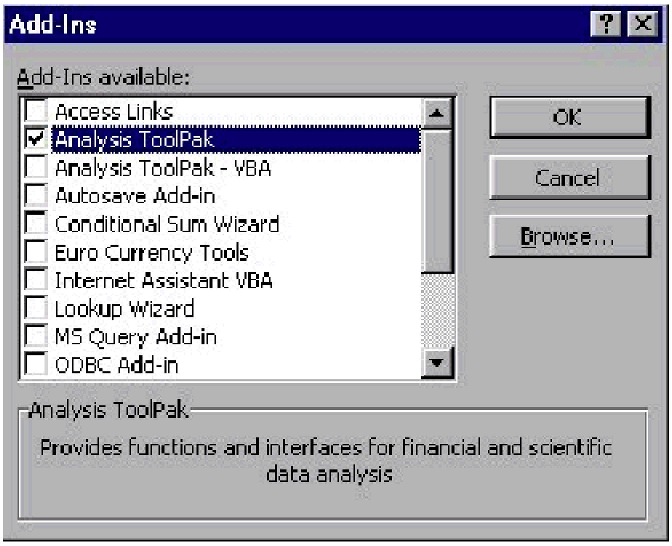
5.1 Using the Excel Spreadsheet

Before using the Excel spreadsheet, you must to configure it:

- In **Tools** menu, click on sub menu **Add-Ins**
- Select the **Analysis ToolPak** check box, then click **OK**

Figure 14. Excel Configuration



5.2 Step 1

Choose the Tag package according to your application:

- A3: size 38mm x 38mm
- A4: size 15mm x 15mm
- A5: size 65mm x 42mm

If you have no constrains on the size tag, select the maximum size (A5) to start.

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5.3 Step 2

Choose reading distance and select first size antenna reader.

Select the diameter d_{out} equal to the reading distance you wish. Start with:

- $d_{out} = X_{Tag}$
- Nr=2
- W_c=0.002 [m]
- S_c=0.0005 [m]
- T_c function of board specifications (Standard $35x10^{-6}$ [m])
- L and R_L are the electrical characteristics of your antenna.

Table 5. Parameter values

d_{out} [m]	Nr	W_C [m] (width of conductor)	S_C [m] (space between conductor)	L [H]	T_C [m] Thickness of conductor	R_L [ohm]
0.055	2	0.002	0.0005	4.77079E-07	0.000035	0.19853714

5.4 Step 3

- Keep the default parameter for the f_{tune} (tuning frequency of reader antenna)
- Ra, C1 and C2 are the additional components to tune the reader antenna.

Table 6. Parameter values for tuning

f_{tune} Tunning Frequency [Hz]	Ra [ohm]	C1s [pF]	C2p [pF]
1.42E+07	0.33353276	1.1089E-10	1.5242E-10

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5.5 Step 4

The last table gives three pieces of information (the green background, not shown in *Table 7*, indicates those values that are OK, and the red background, shown shaded in *Table 7*, indicates those that are not OK):

- The self supply distance available
- The coupling coefficient between reader and Tag available for each reading distance.
- The magnetic field value for each reading distance.

Table 7. Computed read range as a function of K and the H field

Distance Between Tag and Reader [m]	K	H(x) [A/m]
0	0.29747676	4.09952789
0.005	0.28079988	4.07239802
0.01	0.23907764	3.92851237
0.015	0.18903897	3.57250903
0.02	0.14328997	3.02781035
0.025	0.10674754	2.42659743
0.03	0.07943063	1.88468486
0.035	0.05957594	1.44786262
0.04	0.0452454	1.11426535
0.045	0.0348568	0.86480968
0.05	0.02724888	0.67892022
0.055	0.02160527	0.53964094
0.06	0.01736053	0.43426455
0.065	0.0141234	0.35361388
0.07	0.01162142	0.29113953
0.075	0.00966294	0.24216658
0.08	0.00811155	0.20333723
0.085	0.00686896	0.1722174
0.09	0.00586343	0.14702389
0.095	0.00504195	0.12643577

In this example the maximum reading distance is 4.5cm.

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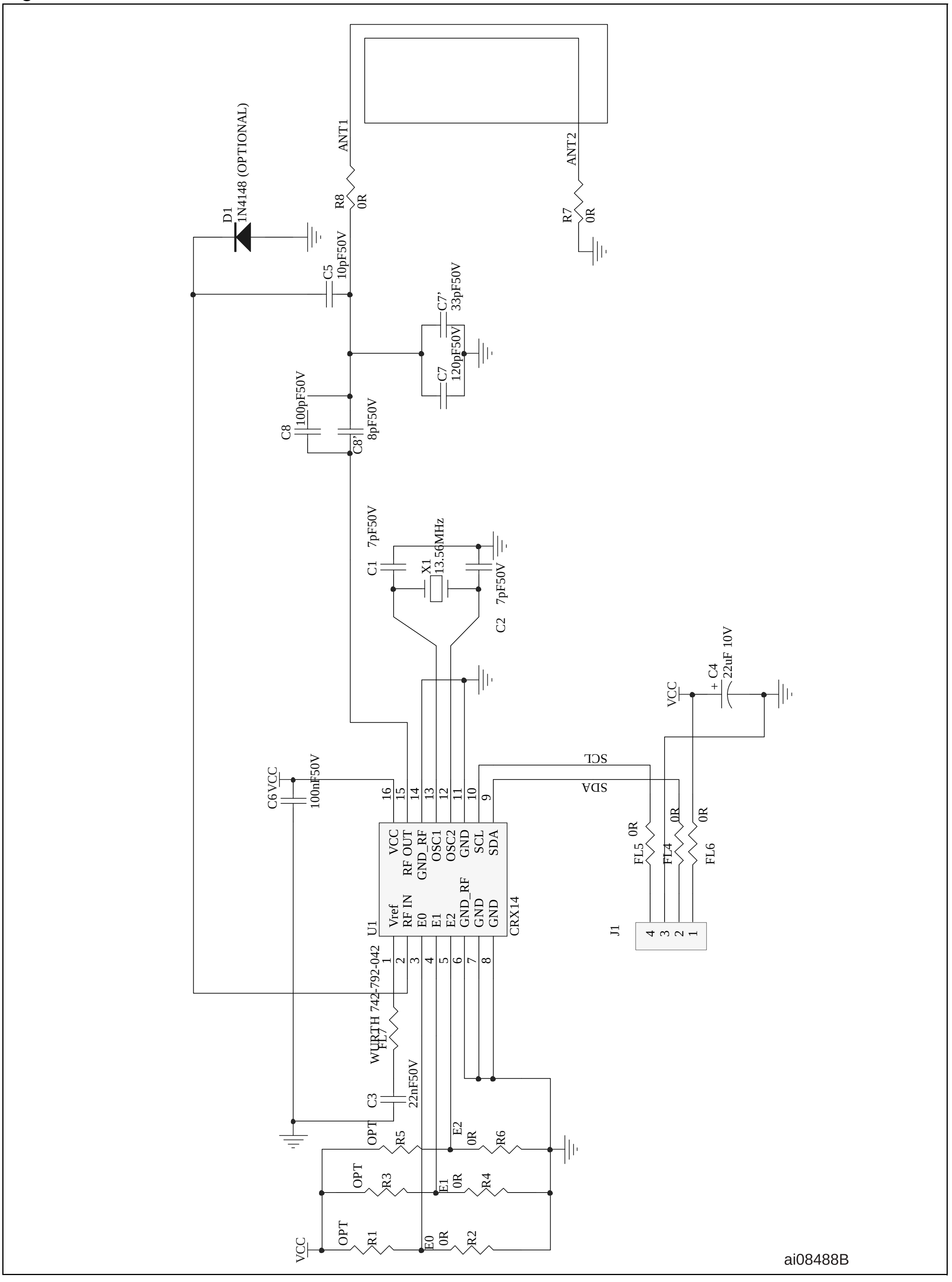
Figure 15. Basic Schematic



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Appendix A Calculation details of serial-to-Parallel Conversion

The two circuits in *Figure 9* are equivalent, where:

$$R_S + jX_S = \frac{jR_P \times X_P}{R_P + jX_P}$$

Multiplying by the complex conjugate we find:

$$R_P = \frac{R_S^2 + X_S^2}{R_S} = R_S + \frac{X_S^2}{R_S}$$

and:

$$X_P = \frac{R_P \times R_S}{X_S}$$

If:

$$R_S << X_S^{\ 2}$$

this simplifies to:

$$R_P = \frac{X_S^{\ 2}}{R_S}$$

and:

$$X_P = X_S$$

This gives the equivalent circuit shown in *Figure 10*, whose impedance (Z) versus frequency (f) is plotted in *Figure 11*, where:

$$R_P = \frac{(L\omega_0)^2}{R_a + R_L}$$

We start to calculate the equivalent impedance Z_{eq} from C_2, L and R_P in parallel:

$$\frac{1}{Z_{eq}} = \frac{1}{R_P} + \frac{1}{jL\omega} + jC^2\omega$$

and so:

$$Z_{eq} = \frac{R_P * jL\omega}{jL\omega + R_P + jC_2\omega * R_P * jL\omega}$$

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We can also calculate the equivalent impedance Z:

$$Z = \frac{1}{jC_1\omega} + Z_{eq}$$

$$Z = \frac{1}{jC_1\omega} + \frac{R_P * jL\omega}{jL\omega + R_P + jC_2\omega * R_P * jL\omega}$$

$$Z = \frac{jL\omega + R_P * \left(1 - L(C_1 + C_2) * \omega^2\right)}{jC_1\omega * \left(R_P - LC_2R_P\omega^2\right) - C_1L\omega^2}$$

The first resonant frequency occurs when:

$$1 - L(C_1 + C_2) * \omega^2 = 0$$

We define $\omega = \omega_0$ to be at this point, and hence that:

$$\omega_0 = \frac{1}{\sqrt{L(C_1 + C_2)}}$$

We find the equivalent impedance, Z, at this frequency, ω_0:

$$Z = \frac{jL\omega_0}{jC_1\omega_0 * \left(R_P - LC_2R_P\omega_0^2\right) - C_1L\omega_0^2}$$

$$Z = \frac{jL}{j * \left(C_1R_P - LC_1C_2R_P\omega_0^2\right) - C_1L\omega_0}$$

We can separate the real and imaginary parts:

$$Z = \frac{C_1R_PL - L^2C_1C_2R\omega_0^2}{C_1R_P - LC_1C_2R_P\omega_0^{2\,2} + (C_1L\omega_0)^2} - j \cdot \frac{C_1L^2\omega_0}{\left(C_1R_P - LC_1C_2R\omega_0^2\right)^2 + (C_1L\omega_0)^2}$$

Taking the real part, and substituting for ω_0 we obtain:

$$\Re[Z] = \frac{R_PL(C_1 + C_2)}{C_1^2R_P^2 + L(C_1 + C_2)}$$

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5.6 Calculation of the Impedance of Equivalent Circuit at the Second Resonance Frequency

We start with the expression of the equivalent impedance Z, calculated earlier:

$$Z = \frac{jL\omega + R_P * \left(1 - L(C_1 + C_2) * \omega^2\right)}{jC_1\omega * (R_P - LC_2R_P\omega^2) - C_1L\omega^2}$$

The second resonant frequency occurs when:

$$R_P - LC_2R_P\omega^2 = 0$$

We define $\omega = \omega_1$ to be at this point, and hence that:

$$\omega_1 = \frac{1}{\sqrt{LC_2}}$$

We find the equivalent impedance, Z, at this frequency, ω_1:

$$Z = -\frac{jL\omega_1 + R_P * \left(1 - L(C_1 + C_2) * \omega_1^{\ 2}\right)}{C_1L\omega_1^{\ 2}}$$

We can separate the real and imaginary parts, and take the real part:

$$\Re[Z] = -\frac{R_P * \left(1 - L(C_1 + C_2) * \omega_1^{\ 2}\right)}{C_1L\omega_1^{\ 2}}$$

Substituting for ω_1 we obtain:

$$\Re[Z] = R_P$$

Table 8. Summary of the Main Results

Resonance frequency	Equivalent impedance of the circuit
$\omega_0 = \frac{1}{\sqrt{L(C_1 + C_2)}}$	$\Re[Z] = \frac{RpL(C_1 + C_2)}{C_1^{\ 2}Rp^2 + L(C_1 + C_2)}$
$\omega_1 = \frac{1}{\sqrt{LC_2}}$	$\Re[Z] = Rp$

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Now we can easily calculate the value of the C1 and C2 capacitors, in terms of Z, R_p, L, ω_0:

$$\omega_0 = \frac{1}{\sqrt{LC_1 + C_2}} \Rightarrow LC_1\omega_0^2 + LC_2\omega_0^2 = 1 \Rightarrow C_2 = \frac{1}{L\omega_0^2} - C_1$$

We can substitute for ω_0:

$$C_1 = \sqrt{\frac{R_P - Z}{R_P^2\omega_0^2 Z}}$$

and:

$$C_2 = \frac{\sqrt{R_P^2\omega_0^2 Z} - \sqrt{R_P - Z}}{L\omega_0^2\sqrt{R_P^2\omega_0^2 Z}}$$

Table 9. Values of the Capacitors

C1	C2
$C_1 = \frac{1}{\sqrt{Z \cdot Rp} \times \omega_0}$	$C_2 = \frac{1}{L\omega_0^2} - C_1$

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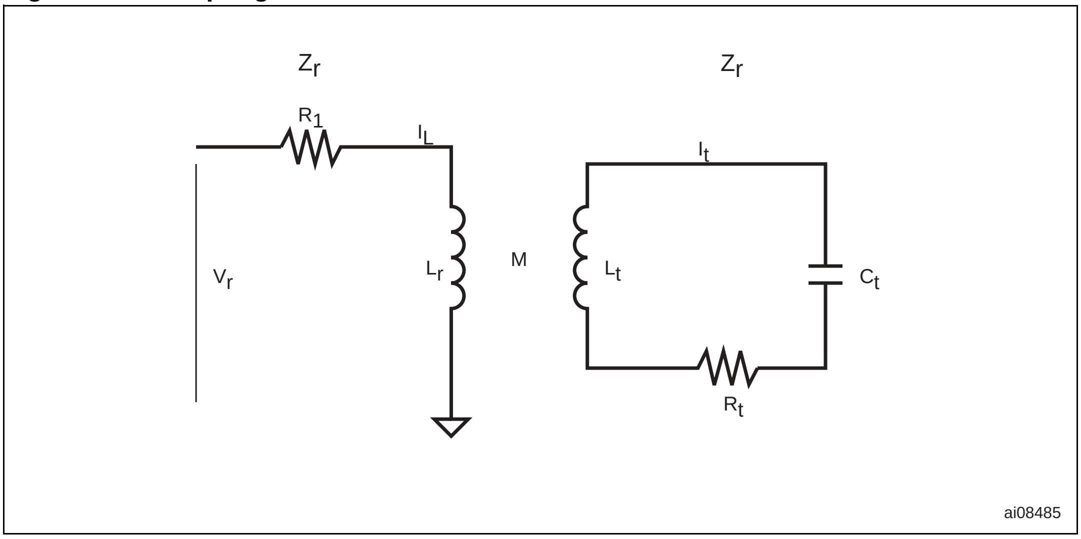
Appendix B Calculation Details of Current Calculation

To calculate the current, we use the complete system with tuning circuit and the influence of the tag when it is near the reader antenna.

For this, we need to know the mutual inductance between the reader antenna and the Tag.

Figure 16. Coupling factor model



Equation 23

$$\begin{cases} Z_R = R + jL_R\omega \\ Z_T = R_T + jL_T\omega + \frac{1}{jL_T\omega} = R_T + j\left(L_T\omega - \frac{1}{C_T\omega}\right) \end{cases}$$

Equation 24

$$\begin{cases} V_R = Z_R \cdot I_R + jM\omega I_R \\ 0 = Z_T + jM\omega I_R \end{cases}$$

Equation 25

$$V_R = \left(Z_R + \frac{M^2\omega^2}{Z_T}\right) \cdot I_R$$

Equation 26: To calculate the Current, I_R in Reader Antenna

$$I_R = \frac{V_R \cdot Z_T}{Z_T \cdot Z_R + M^2\omega^2}$$

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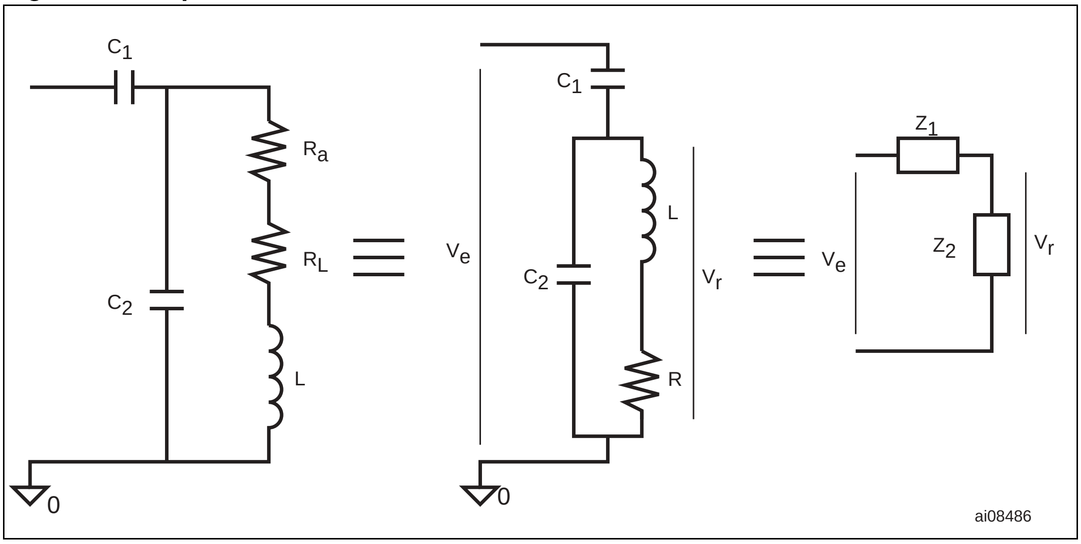
5.7 V_R Calculation

Figure 17. Equivalent circuits



Note:

$$R = R_a + R_L$$

$$V_R = \frac{V_e \times Z_2}{Z_1 + Z_2}$$

$$V_R = \frac{(R + jL\omega) \cdot jC_1\omega}{(R + jL\omega) \cdot jC_1\omega + jRC_2\omega - LC_2\omega^2 + 1} \times V_e$$

$$Z_1 = \frac{1}{jC_1\omega}$$

$$Z_2 = \frac{R + jL\omega}{jRC_2\omega - LC_2\omega^2 + 1}$$

$$V_R = \frac{\frac{R + jL\omega}{jRC_2\omega - LC_2\omega^2 + 1}}{\frac{R + jL\omega}{jRC_2\omega - LC_2\omega^2 + 1} + \frac{1}{jC_1\omega}} \times V_e$$

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$$V_R = \frac{R + jL\omega}{jRC_2\omega - LC_2\omega^2 + 1} \times \frac{(jRC_2\omega - LC_2\omega^2 + 1) \cdot jC_1\omega}{(R + jL\omega) \cdot jC_1\omega + jRC_2\omega - LC_2\omega^2 + 1} \times V_e$$

$$V_R = \frac{(R + jL\omega) \cdot jC_1\omega}{(R + jL\omega) \cdot jC_1\omega + jRC_2\omega - LC_2\omega^2 + 1} \times V_e$$

5.8 Current Calculation

$$I_R = \frac{\dfrac{jRC_1\omega - LC_1\omega^2}{jR(C_1 + C_2)\omega - L(C_1 + C_2)\omega + 1} \times \left(R_T + \dfrac{1 - L_TC_T\omega^2}{jC_T\omega}\right)}{\left(R_T + \dfrac{1 - L_TC_T\omega^2}{jC_T\omega}\right) \times (R + jL_R\omega) + M^2\omega^2} \times V_e$$

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Appendix C Demo kit board

Figure 18. Layout of Demo-kit Board

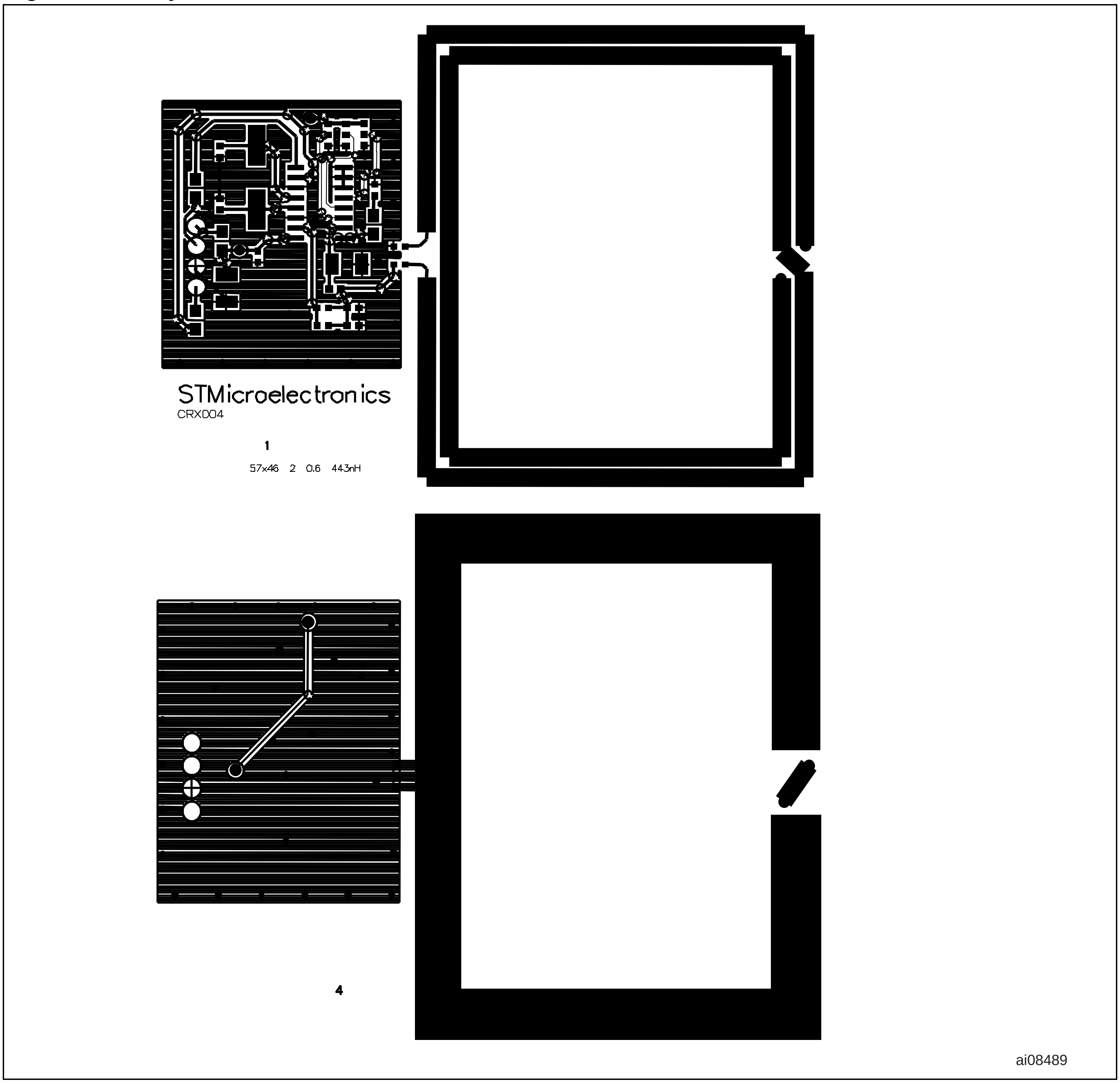

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Figure 19. Component Implementation

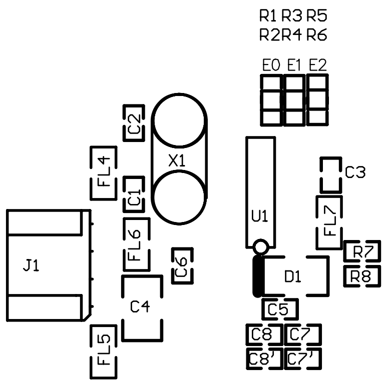

Table 10. Bill of Materials

Designators	Value	Footprint	Comment
R7	0R	0603	±1%, 0.1W
R8	0R	0603	±1%, 0.1W
R2	0R	0603	±1%, 0.1W
R4	0R	0603	±1%, 0.1W
R6	0R	0603	±1%, 0.1W
FL4	0R	0805	±1%, 0.1W
FL5	0R	0805	±1%, 0.1W
FL6	0R	0805	±1%, 0.1W
C6	100nF	0603	±5%, 50V
C8	100p	0603	±5%, 50V
C7	120p	0603	±5%, 50V
X1	13.56MHz	XTALCMS	
C7'	33p	0603	±5%, 50V
D1	1N4148	1210	Option
C3	20nF	0603	±5%, 50V
C4	22uF	1210	Tantalum ±10%, 6.3V
C5	10p	0603	±5%, 50V
C1	7pF	0603	±5%, 50V
C2	7pF	0603	±5%, 50V
C8'	8p	0603	±5%, 50V
J1	Connector	HE14_4H	
U1	CRX14	SO16	ST
FL7	Ferrite	0805	Wurth 742-792-042

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Table 10. Bill of Materials

Designators	Value	Footprint	Comment
R1	OPT	0603	
R3	OPT	0603	
R5	OPT	0603	

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6 Revision history

Table 11. Document Revision History

Date	Version	Revision Details
10-Dec-2003	1.0	First Issue.
06-Dec-2005	2.0	Document moved to new template. Equations *4* and *5* corrected. Titles added to *Appendix C*, *Figure 17*, *Table 1*, *Table 4*, *Table 5*, *Table 6* and *Table 7*. Title of *Figure 16: Coupling factor model* modified. ω_1 and ω_2 and note added to *Figure 12: Coupling between One Tag and One Reader Antenna*.
13-Feb-2006	3.0	CRX14 pinout modified in *Figure 15: Basic Schematic*.

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