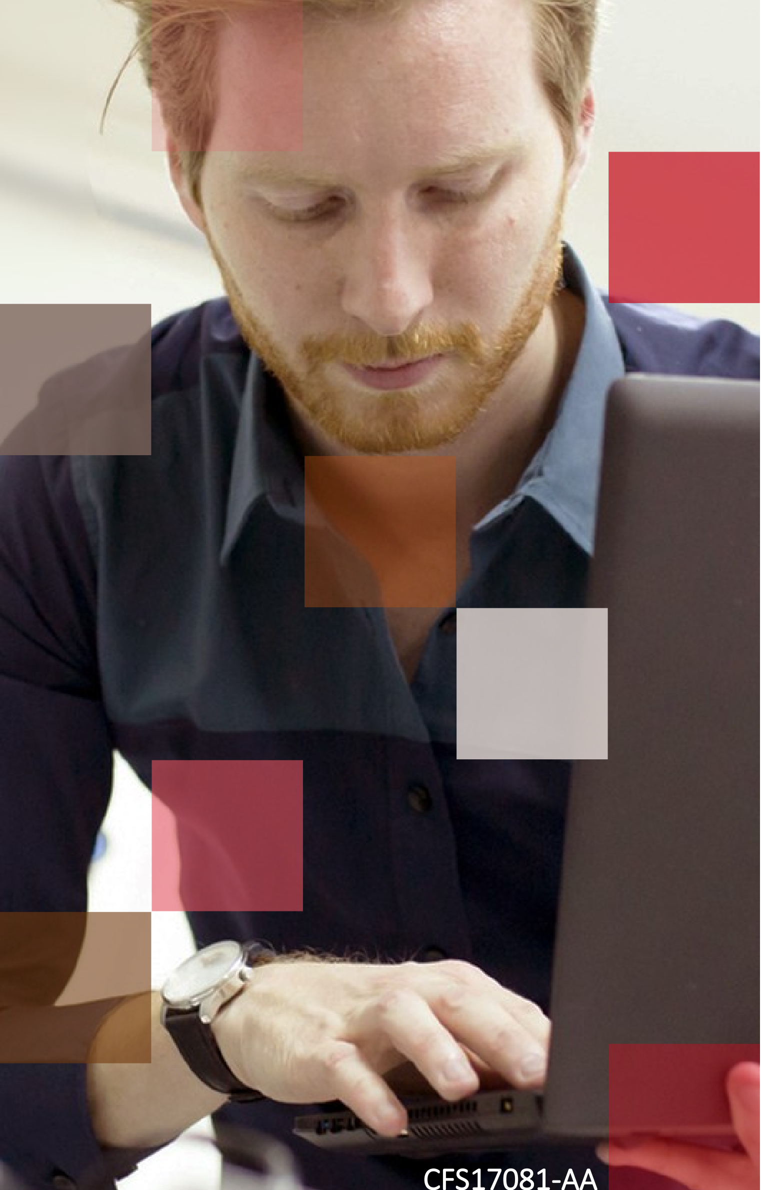


Designing an antenna for a SpringCard module

Elements of methodology

Concerns K663, H663, E663 & S663 modules

Nov 2016

CFS17081-AA

Agenda

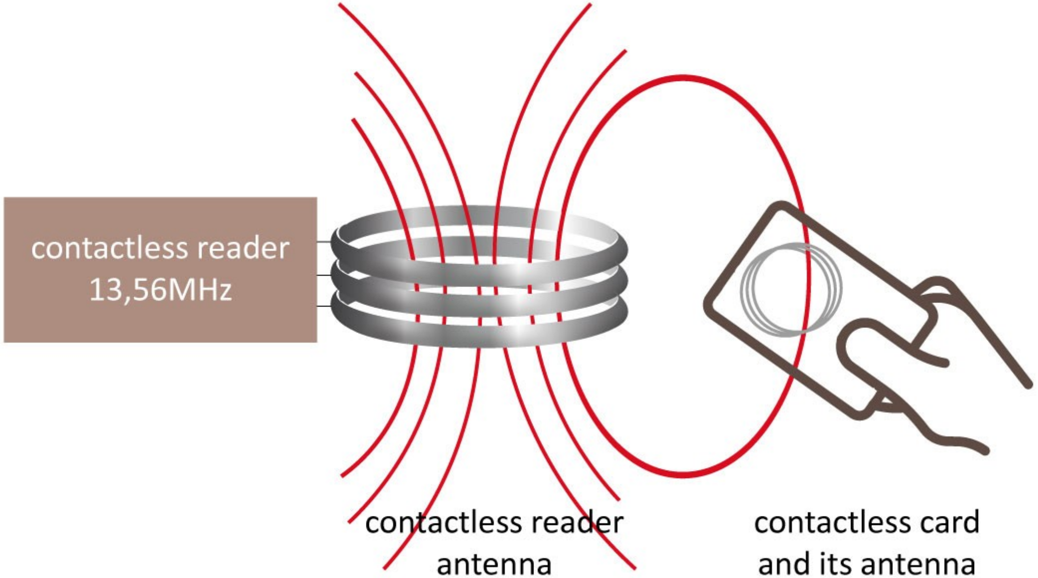
- Indroduction
- Symmetric or asymmetric antenna ?
- Antenna shape and size
- Impact of the electromagnetic environment
- Drawing the antenna
- Ferrite Shielding
- Tuning / Matching

INTRODUCTION

INTRODUCTION .1

NFC/RFID readers use inductive coupling (AC magnetic field) to remotely power the contactless cards or RFID tags, and to communicate with them. The AC carrier frequency is 13.56MHz (HF ISM band).

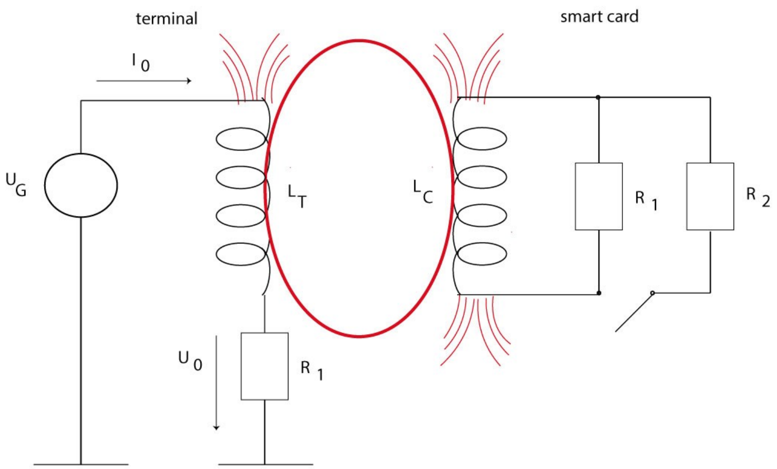
The complete NFC/RFID system is a transformer, in which the reader is the primary circuit and the card the secondary circuit.



INTRODUCTION .2

The characteristics of the transformer, i.e. the overall performance of the reader + card system, depends on many factors:

- The geometry of both the reader’s antenna and the card’s antenna, and their relative position,
- The electrical characteristics of both the reader’s driver circuit and of the card,
- The surrounding environment, which may have an impact on the magnetic waves.



INTRODUCTION .3

This guide explains the methodology used to design an antenna for one of the following SpringCard NFC/RFID modules (either running a coupler or smart reader firmware):

H663 – K663 – E663 – S663

All these modules are based on the NXP CLRC663 multi-protocol NFC frontend IC.

Most of the concepts introduced in this short guide are taken from NXP's AN11019 "CRLC663, MFRC630, MFCR631, SLRC610 Antenna Design" Application Notes (http://www.nxp.com/documents/application_note/AN11019.pdf).

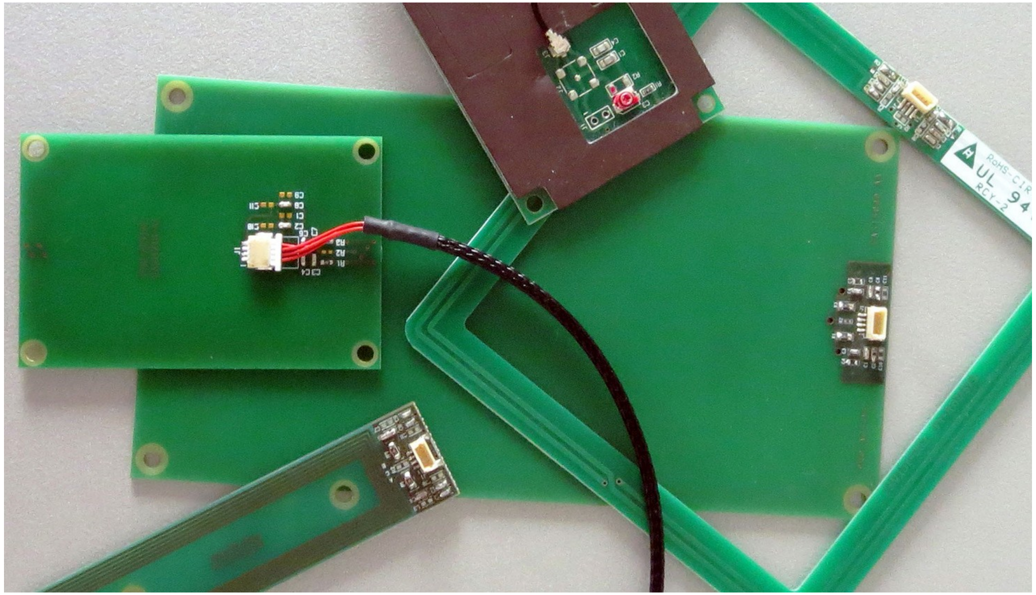
This short guide's main purpose is to show the path that an engineering team must follow to design correctly a NFC/RFID antenna. It doesn't go deep into technical data, simulation and measures. Please always refer to the above-mentioned NXP's Application Note for all the implementation details.

INTRODUCTION .4

For the beginner, designing a HF antenna is not easy. Tuning, testing and validating the antenna is more than that: **an expert’s job**.

SpringCard’s engineers are used to design HF antennas, both for SpringCard’s own products and for customers requesting a particular form factor or specific electromagnetic characteristics.

Don’t hesitate to contact SpringCard if you’re seeking assistance while designing your custom antenna. At least, please contact us so we could validate its characteristics -and its compliance with the x663 module- before going into production stage.



SYMMETRIC OR ASYMMETRIC ANTENNA?

SYMMETRIC OR ASYMMETRIC ANTENNA? .1

Asymmetric antenna

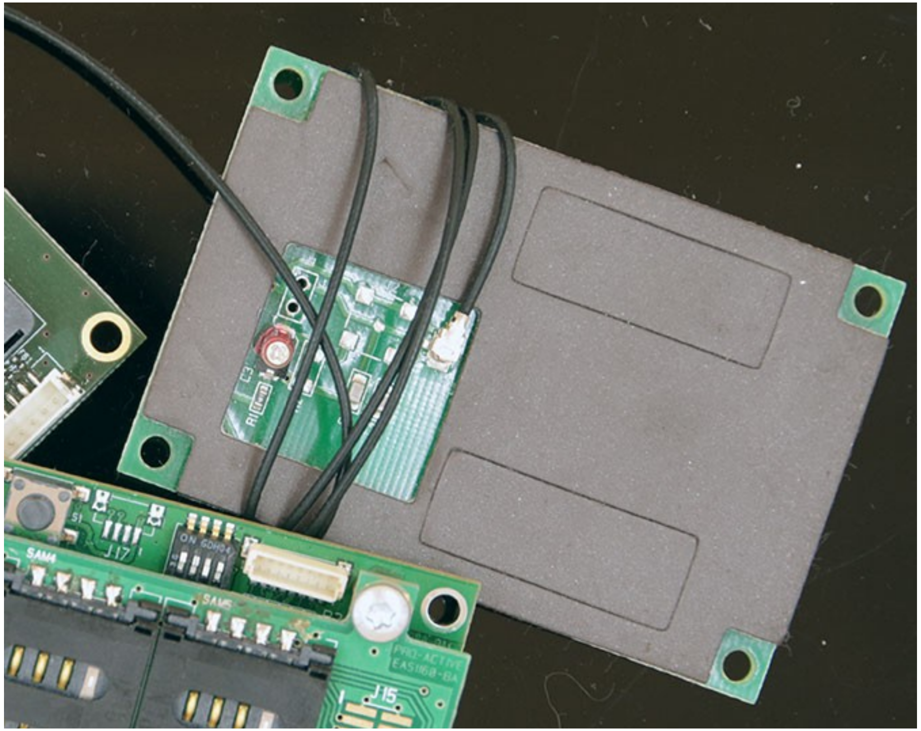
An asymmetric, or unbalanced antenna, consists of one coil only.

The asymmetric antenna includes a matching circuit that is finely tuned to expose a 50Ω impedance. The asymettric antenna generally feature a trim capacitor that must be adjusted on-the-field for optimal performances.

If is connected through a 50Ω coaxial cable to a reader module designed for asymmetric antenna. These are K663A and H663A only.

An asymmetric antenna give less operating distance than the same-size symmetric antenna, and is more difficult to produce due to the trim capacitor.

Therefore, the design of an asymmetric antenna is out of the scope of this document. Please contact us if you definitively need a coax-connected antenna in your setup.



SYMMETRIC OR ASYMMETRIC ANTENNA? .2

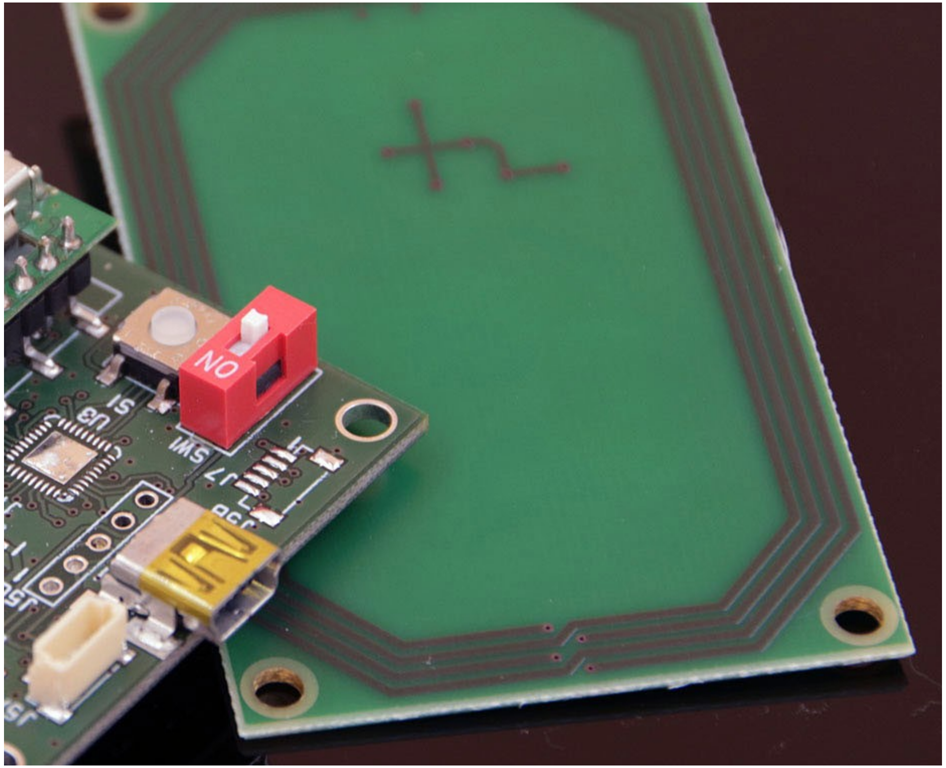
Symmetric antenna

An symmetric, or balanced antenna, consists of two coils, one turning clockwise, the other anti-clockwise.

There is no matching circuit on the antenna itself. The antenna is connected to the reader using 3 lines : Tx1 and Tx2 are the ends of the two coils, and the middle point is connected to the ground (GND).

We recommend the use of 2 twisted pairs (Tx1+GND and Tx2+GND) to preserve the symmetry of the circuit. T**he cable between the antenna and the reader module shall be no longer than 30cm**. Also don’t place electronics components nor communication lines inside the coils.

A **symmetric antenna offers better performances** than the symmetric antenna with the same size, and doesn't need to embed trimable components.



EXPECTED OPERATING VOLUME
→ ANTENNA SIZE

EXPECTED OPERATING RANGE .1

Think ergonomics first.

The contactless project in which you are involved aims at producing a contactless device. As people will use the device you must consider the Human-Machine Interface (HMI). Learn about the habits in the field of application. The expected operating volume is the key information to design correctly your antenna.

Starting with a target antenna shape and size, imposed by external constraints (existing shell with limited room for instance) is also possible, but in this case the resulting characteristics of the NFC/RFID must be accepted 'as is' as there's no freedom in the design process.

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EXPECTED OPERATING RANGE .2

Touch’N’Go use case

The card is placed in front of the reader, and the user keeps the card steady until the transaction is done. Typical examples are payment terminals (POS) or access control readers.

In the Touch'N'Go scenario, the question of the operating range is simplified to a 1D data: distance is measured along the single axis of the antenna.

Wave'N'Go use case

Users are moving and don't stop (or at least expect not to) using the reader. For example, think of users walking quickly through a turnstile in the subway or a skiers about to take a ski lift.

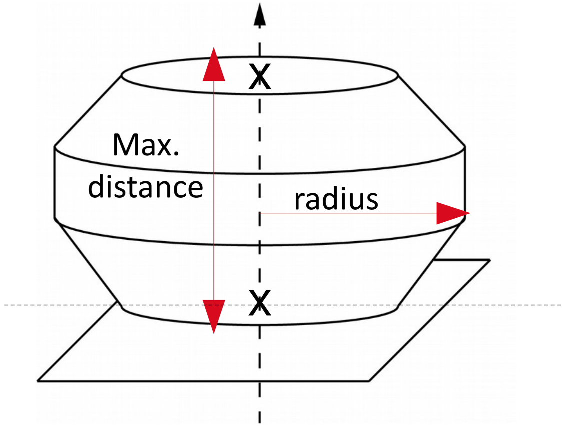
In the Wave'N'Go scenario, the operating range is a 3D volume because of movements.

OPERATING VOLUME

From the user experience consideration, draw the expected operating volume

- **The maximum distance** that is expected – don't forget to take in account the distance between the antenna itself and the front surface of the product's shell.

- **The radius** of the expected operating volume. In the Wave'N'Go use case, it is good to have a large operating volume, to try and "catch" the card while it is approaching, and to keep the communication active while it is already going away. In the Touch'N'Go use case, the volume could be narrower.



Observe that due to the shape of the magnetic waves, the operating volume is a barrel and not a cylinder. And if you go for a square antenna, you'll get a strange-shaped barrel, but not a cube!

There are some limitations, due both to the output power of the modules and to the EMC regulation (max. radiated power). **Max. distance can't be > 10cm**, and **radius shall be < 7.5cm** (diameter < 15cm).

VOLUME VS CARD SIZE

It is better to know the size of the contactless cards (or NFC objects) that are involved before designing your reader.

As a first rule of thumb, consider that **the maximum operating distance is reached when the size of the reader's antenna is close to the size of the card's antenna**. A bigger antenna will not increase the operating distance. A smaller antenna will decrease it.

As a second rule of thumb, **the width of the operating volume is limited by the projection of the card's antenna onto the reader's plan**: half of the card's antenna must be embraced by the reader's antenna.

Therefore, you must know the size of the contactless cards (or NFC objects) your system is likely to work with, so you may size your antenna accordingly. Not too small, not too big.

PICC & Class

- ☐ ID-1 size: class 1, 2 or 3 (see ISO 14443-1)
- ☐ Smaller than ID-1 -as tags, keyfobs-: class 4 or 5
- ☐ Very small (class 6 and smaller)
- ☐ Smartphone
- ☐ Other

VOLUME VS PROTOCOLS

The card technology (i.e. the underlying protocols) must also be taken care of.

ISO 14443-A is generally easy to implement, because of its 100% modulation that ensures a good signal/noise ratio. ISO 14443-B is more touchy, since the modulation index must remain close to 10%. **Both ISO 14443 technologies require a field > 1.5 A/m** to behave correctly.

Some **NFC mobile phones**, that are supposed to emulate ISO 14443 cards, are in fact unable to communicate incorrectly under **1.8 A/m**. More than that, they present an **high load to the reader** (low static impedance due to the PCBs, screen and battery), so the RF field is likely to collapse if the smartphone goes too close to the reader's antenna.

On the other hand, **ISO 15693 starts working with a field > 0.150 A/m** -but must not go higher than 5 A/m (7.5 A/m for ISO 14443).

Card technology

- ☐ ISO 14443, NFC tag, Mifare family...
- ☐ ISO 15693, RFID label
- ☐ ISO 18092, NFC peer-to-peer
- ☐ Other ?
- ☐ All of them / don't know yet

ANTENNA RADIUS

From our rules of thumb and the information collected from the precedent slides,

- Choose ***r*** (antenna radius) = max operating distance with an ISO 14443 ID-1 card.
- Is ***r*** greater than 120% of the radius of the operating volume? Great! Otherwise, increase ***r*** to 120% of the radius of the operating volume.
- If the typical card is smaller than ID-1, reduce ***r*** under 200% of the card's diagonal (or diameter) to prevent a "hole" in the middle of the antenna.

Don't want a round antenna? No problem. Use ***r*** as half the diagonal of the square or rectangle. Avoid 'flat' rectangles because they introduce a preferred orientation for the card, which is a bad user experience (unless you are designing a card printer or dispender).

Is the suggested radius too large for your product? Revise the specifications downwards.
Choose ISO 15693 instead of ISO 14443.
Use BLE instead of NFC.

DRAWING THE ANTENNA

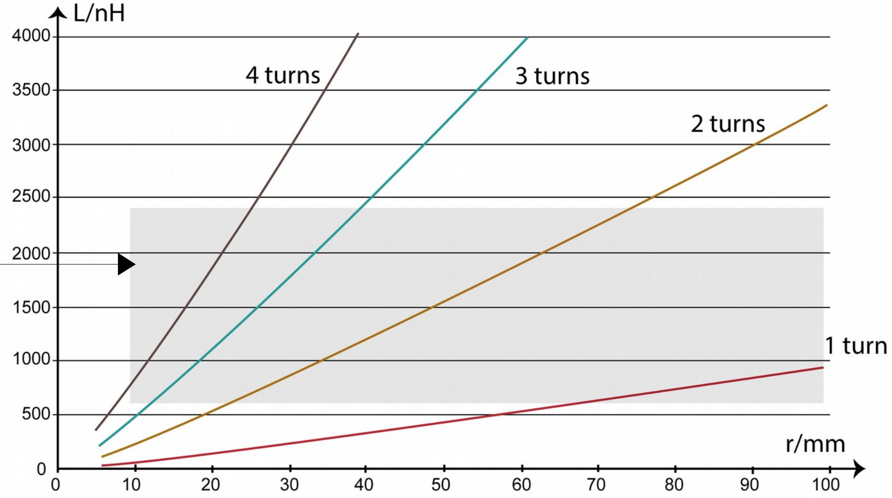
DRAWING THE ANTENNA .1

We are designing a loop antenna

- ***r***, the radius, has been chosen through our rules of thumb,
- ***N***, the number of coils, is the other key parameter of a loop antenna. For a PCB antenna, ***N*** is 1, 2, 3 ou 4. For a symmetric antenna, it is easier if have ***N*** = 2 or 4.

Starting from your chosen ***r***, find the best ***N*** in the diagram on the right, and read ***L***, the inductance of the antenna.

The shaded area contains the 'best' inductance values.



L < 400nH → the coupling with the card will be too weak for operation

L > 3µH → it will be impossible to find a correct matching circuit.

DRAWING THE ANTENNA .2

Let's verify that our antenna actually allows NFC/RFID operation

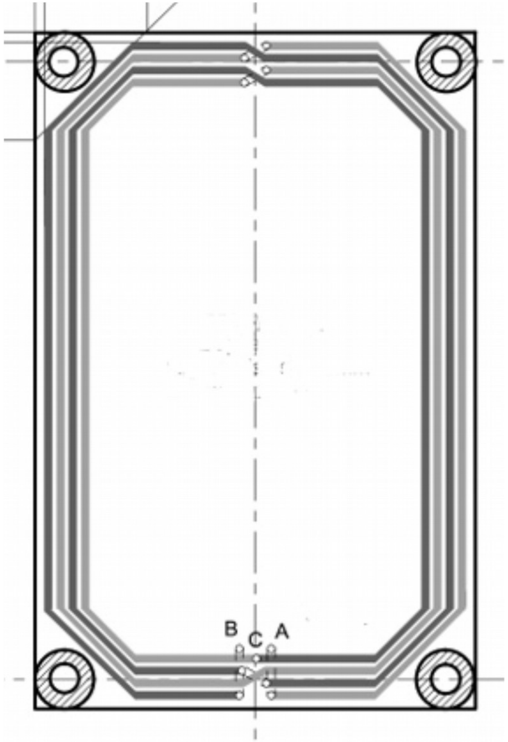
The nominal field at the centre of the antenna, $\boldsymbol{H_0}$, is determined by the formula:

$$H_0 = \frac{N I_0}{2r}$$

Where

- $\boldsymbol{r}$ is the radius of the antenna,
- $\boldsymbol{N}$ is the number of loops,
- $\boldsymbol{I_0}$ is the nominal intensity of the current in the antenna. This current is limited by the characteristics of the reader's output driver. For a x663 module, we'll consider that $\boldsymbol{I_0}$ is equal to 140mA.

So, what's your theorical $\boldsymbol{H_0}$?



DRAWING THE ANTENNA .3

What's your theorical H_0?

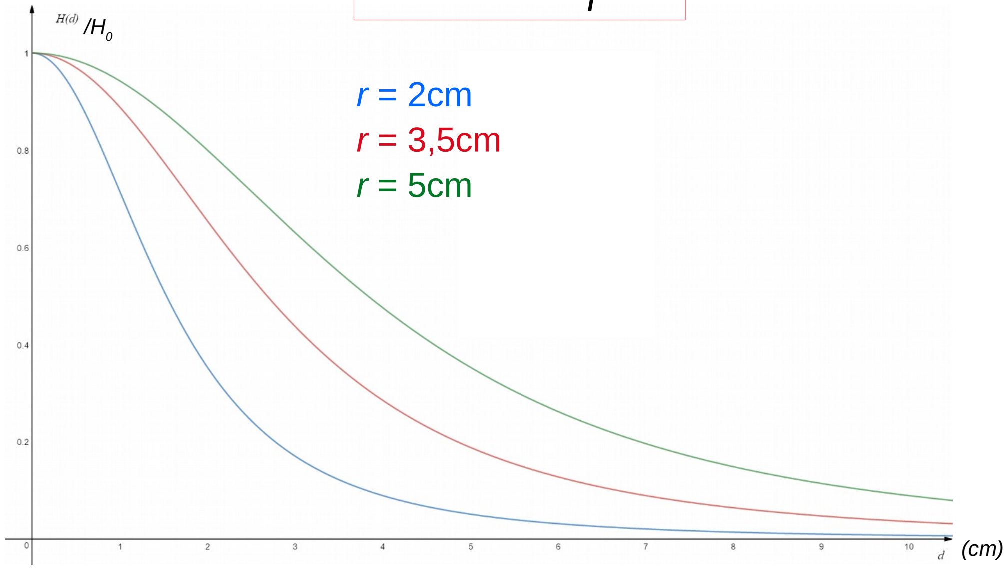
- **Between 2.0 and 5.0 A/m?** This is a good start!
- **Lower than 2.0 A/m?** May be OK for ISO 15693 tags. Will not work with NFC mobile phones. May not work with some ISO 14443 cards.
- **Greater than 5.0 A/m?** Sounds surprising. Verify the calculations.

Not enough A/m with SpringCard x663 modules? It may be possible to design another product based on a chip with a more powerful output driver. Contact us!

DRAWING THE ANTENNA .4

The field decreases with the distance. Use this formula (where ***d*** is the distance to the antenna):

$$H(d) = \frac{H_0}{\left(1+\left(\frac{d}{r}\right)^2\right)^{\frac{3}{2}}}$$



Verify that you have enough field for the card you intend to use, at the max distance that you have specified earlier.

Operating distance is too short?
Increase ***r*** and try again. Or consider a product with more output power (see previous page).

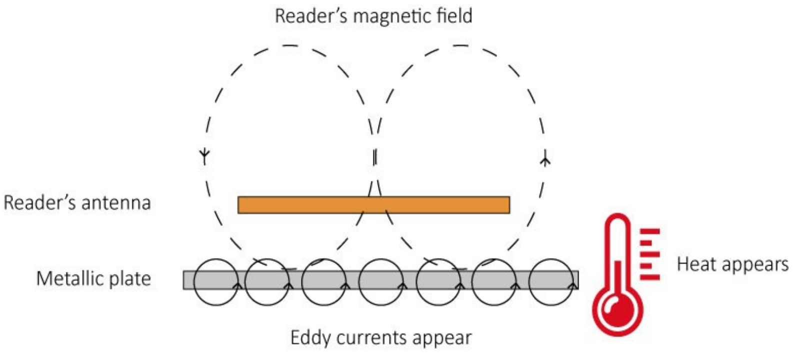
IMPACT OF THE ELECTROMAGNETIC ENVIRONMENT

ELECTROMAGNETIC ENVIRONMENT .1

How the water boils on induction hobs?

An electric **current** flows through an **induction coil**. This create a **magnetic field**. The field excites the electrons in the metal pan. The electrons move, and their move produces **heat**!

The same effect happens if there is a metal plate near the reader's antenna: the reader’s magnetic field is used to produce heat instead of being a communication medium!



The performance of the reader is decreased because a significant part of the RF energy is vasted in the metal.

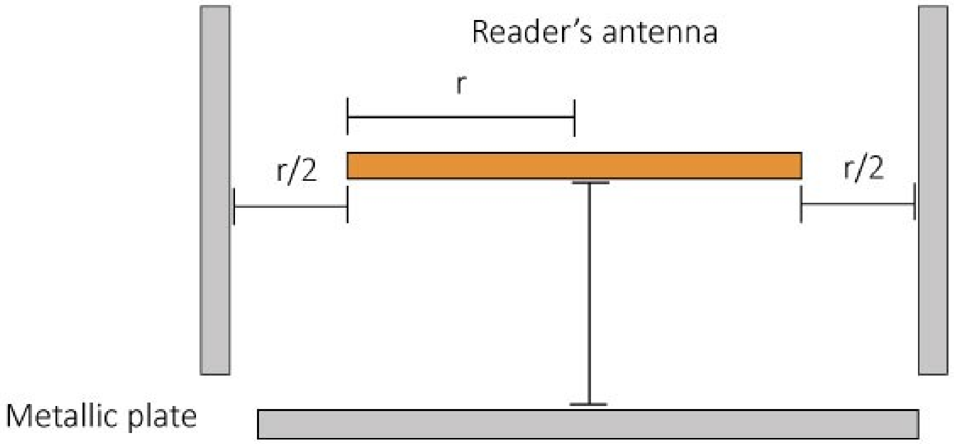
ELECTROMAGNETIC ENVIRONMENT .2

In order to preserve performance of the antenna it must be kept 'far' from any conductive material, in all directions.

How far is far enough?

For an antenna of radius ***r***, at least

- ***r / 2*** on the sides of the antenna,
- ***r*** behind the antenna (and in front of it if the reader is not placed in 'open air').



ELECTROMAGNETIC ENVIRONMENT .3

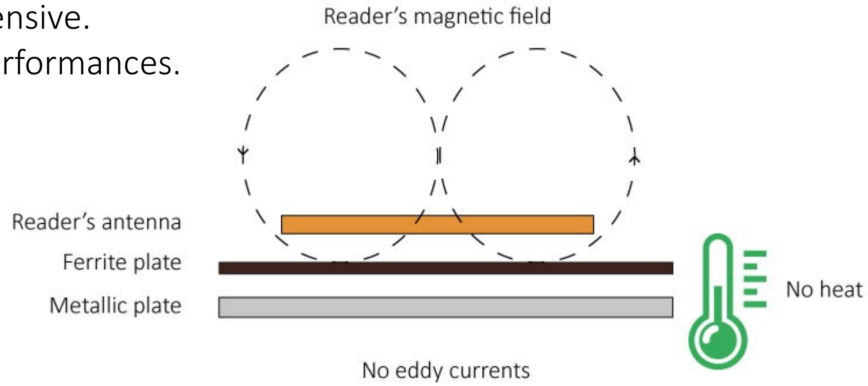
Using a ferrite shield to limit the impact of the environment

Soft ferrites are non-conductive, **ferrimagnetic materials**, that are widely used to channel the magnetic waves in transformers. A flat (0.8mm to a few millimeters depth) **ferrite sheet** could be used to limit the impact of a metallic environment over the performances of a NFC/RFID reader.

Not all ferrites are suitable for an AC field @13.56MHz!

There are many types of ferrite. Some are very good but also very expensive.
The one listed COMAB offers a good compromise between cost and performances.
Contact us if you need to source some.

There's no perfect ferrite shield: the magnetic field always passes through -even in small quantity.



Important: a ferrite shield changes the antenna characteristics.
That's why you must choose the ferrite (if any) before going to the last step (tuning).

TUNING/MATCHING
(CIRCUIT & SIMULATION)

TUNING/MATCHING CIRCUIT .1

Now we have a loop antenna, i.e. an inductor (*L*)

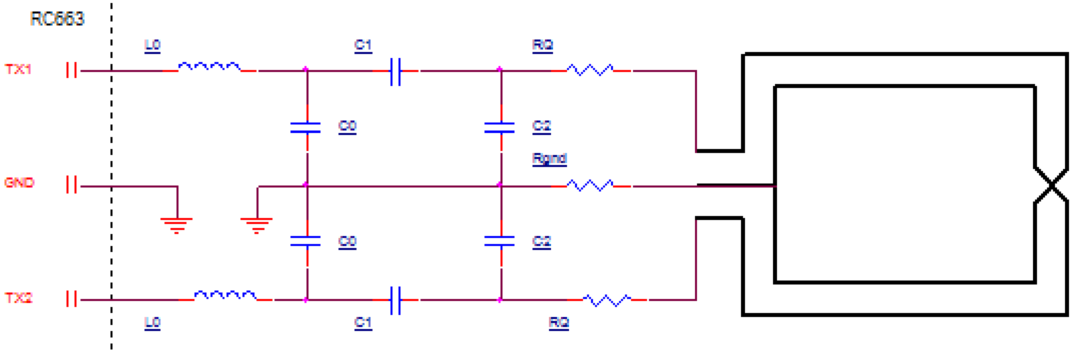
We must add some extra components to design a complete R,L,C circuit, with 2 goals in mind:

1. **Tune the circuit** for a resonance around the carrier frequency, with a bandwidth large enough to pass the communication side-bands in both directions (± 26kHz, ± 106kHz, ± 848kHz). In other words, the antenna and its matching circuit must be a **band-pass filter**, centred on 13.56MHz, with a quality factor $Q \approx 35$.

2. **Adapt the impedance** so that the module's output current remains in the acceptable range: I_0 < 140mA (nominal) and I_{max} < 200mA peak-to-peak in any situation. This lead to an overall impedance **Z ≈ 40 Ω**, that must be purely resistive (on-phase) at 13.56MHz.

TUNING/MATCHING CIRCUIT .2

Design the matching circuit



TX1 and **TX2** are the x663's output driver.
These pins deliver 0/5V square signals.
Note that they are the input of the receiver circuit as well.

L_0 and C_0 form an EMC filter.
They cut-down the harmonics of the 13.56MHz carrier to transform the square signal into a sinus.

C_1 and C_2 are the matching capacitances. Together with the antenna's intrinsic inductance (L), they allow to center the system at 13.56MHz. Bear in mind that the antenna's PCB may introduce a small intrinsic capacitance.

R_Q makes it possible to adjust the quality factor Q until the bandwitch is satisfying. Also bear in mind that the antenna's PCB has a small-yet-noticeable intrinsic resistance.

TUNING/MATCHING SIMULATION

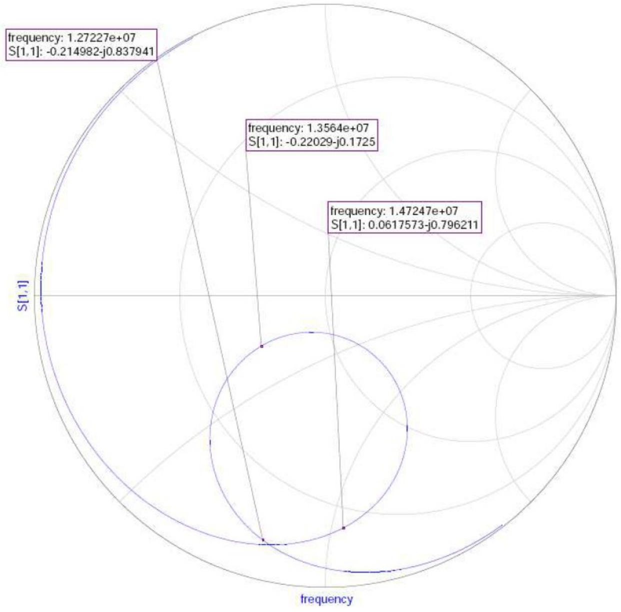
Qucs (Quite universal simulator) is a free, lightweight software to simulate an analog circuit (http://qucs.sourceforge.net/)

Since the antenna is perfectly symmetrical, there is no need to connect explicitly the middle point to ground. This allows to remap TX2 to GND for simulation.

Start with L_0=470nH and C_0=122pF (68pH in parallel with 56pF).

The values for C_1 and C_2 may be reached through an iterative process.
Use the **Smith chart** to find the best values for these components.
The point for f = 13.56MHz shall be on the horizontal axis (on-phase at 13,56MHz)

Terminate by adjusting R_Q to reach the expected Q.



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TUNING/MATCHING (REAL WORLD)

REAL WORLD .1

Now let's work on the actual PCB!

We have an estimation of the value of every component, but at this step, we must observe the characteristics of the actual PCB, in the target environment, to know:

- What is the exact L?
- What are the intrinsic resistance and capacitance?
- What is the impact of the environment, of the ferrite shield (if some)?

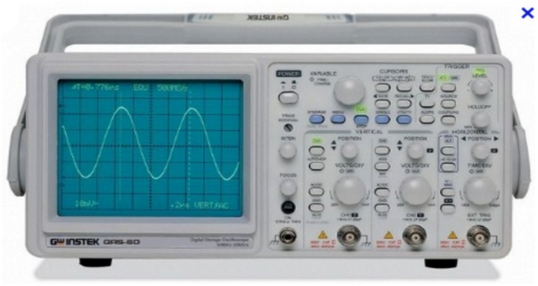
So… there's no choice but to assemble a working prototype and measure its characteristics.

REAL WORLD .2

Which tools do we need to measure the PCB – and set the value of the components?

A Vector Netwok Analyzer (VNA)

An oscilloscope:
bandwidth>60MHz



A clamp-on amperemeter:
0 to 500mA ;
bandwidth>20MHz

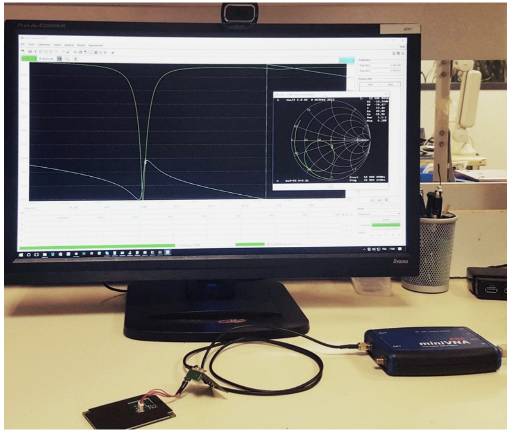
TUNING WITH THE VNA

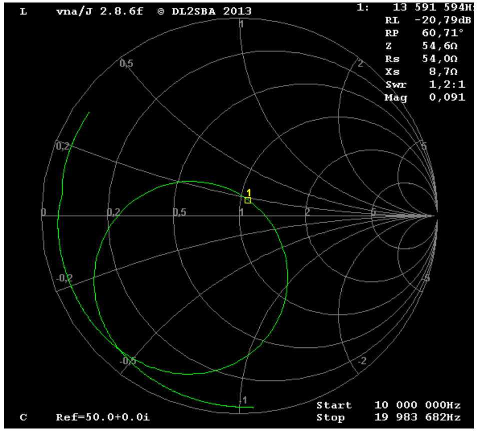
Measure the antenna with the Vectored Network Analyzer

Connect the VNA to the antenna (without the x663 module).

Remember that the antenna is symmetric, so you may work on only one half of the circuit (between TX1 and GND for instance). The complete network (***Z***) will be deduced from the observed ***Z/2***.

Draw the **Smith chart** using the VNA, and ajust C_1 and C_2 values if needed to have the point for f = 13.56MHz on the horizontal axis (on-phase).



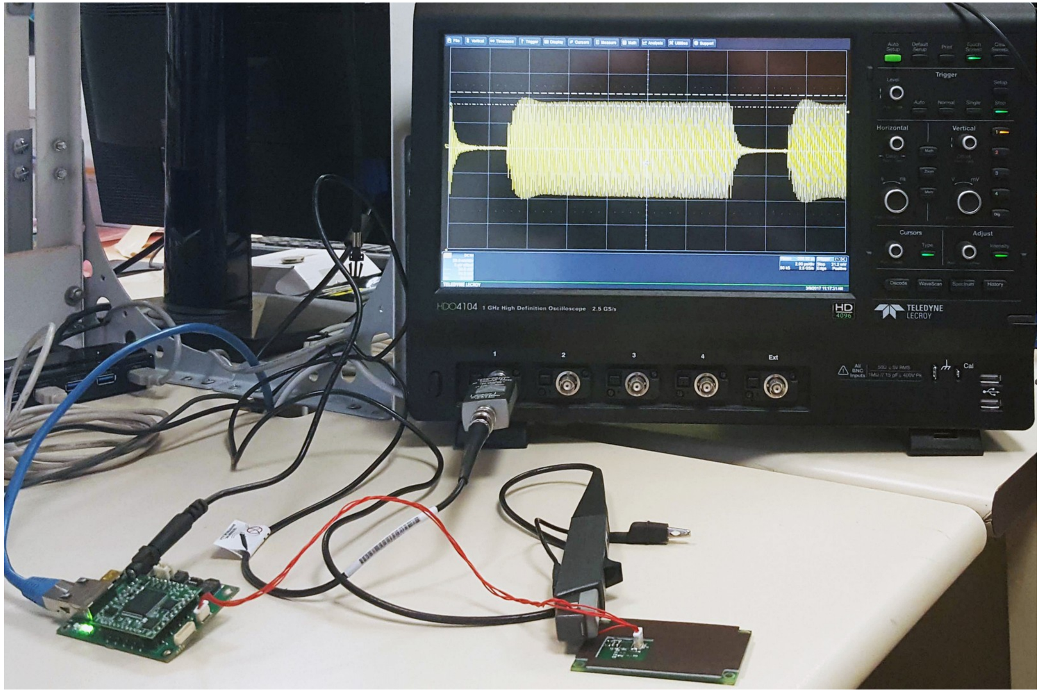


CURRENT IN THE ANTENNA

Connect the antenna to the module and use the clamp-on amperemeter to measure the current
(you may also observe the voltage drop in R_Q)

Have the module provide a constant field
(command **rf_on** in console).

Verify that I < 140mA.



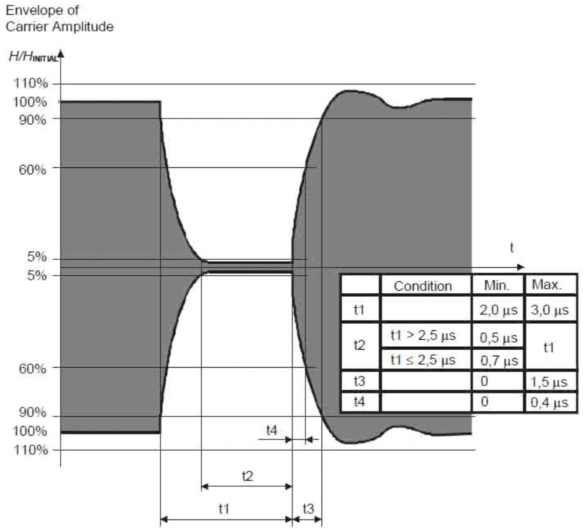
Use a small coil to pick-up the field level with your oscilloscope

Connect the module to the antenna, and enter the ISO 14443-A wave form test mode (in console: **rf_wave_a**).

Verify that the shape is correct according to the ISO standard (<u>t1 – t2</u> is the key point) and that there is <u>no overshoot</u>.

If this is not the case, increase $\boldsymbol{R_Q}$.

Type A Wave form



	Condition	Min.	Max.
t1		2,0 µs	3,0 µs
t2	t1 > 2,5 µs	0,5 µs	t1
	t1 ≤ 2,5 µs	0,7 µs	
t3		0	1,5 µs
t4		0	0,4 µs

VERIFYING WAVE FORMS - B

Use a small coil to pick-up the field level with your oscilloscope

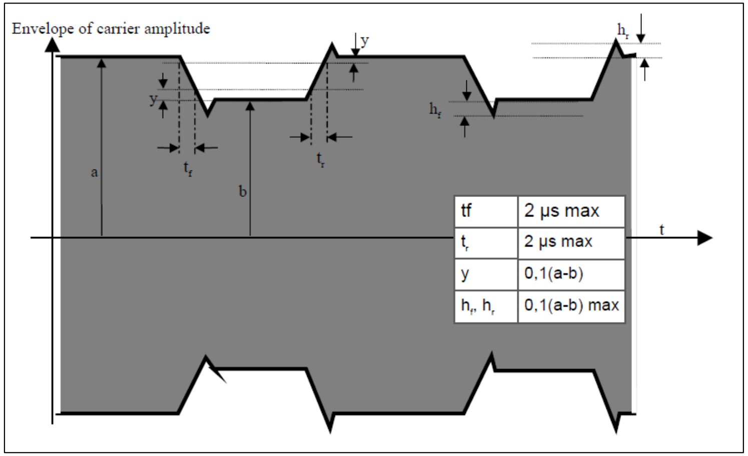
Connect the module to the antenna, and enter the ISO 14443-B wave form test mode (in console: **rf_wave_b**).

Verify that the modulation index is correct $\frac{(a-b)}{(a+b)} \approx 10\,\%$

and that there is <u>no overshoot or undershoot</u>.

If this is not the case, increase $\boldsymbol{R_Q}$.

Type B Wave form



EDITOR’S INFORMATION

Published by **SPRINGCARD SAS** company with a capital of 227 000 €

RCS EVRY B 429 665 482 - NAF 722C - VAT# : FR 27 429 665 482

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Our solutions provide social and technical evolution.

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