Card Coil Design Guide

Application note

Intelligent EEPROM with contactless interface compliant to ISO/IEC 15693 and ISO/IEC 18000-3 mode 1

Devices

- SRF 55V02S
- SRF 55V10S
- SRF 55V02P
- SRF 55V10P
- SRF 55V02S HC
- SRF 55V10S HC
- SRF 55V02P HC
- SRF 55V10P HC

About this document

Scope and purpose

This document gives guidelines, definitions, and formulas on how to calculate the antenna parameters for contactless products of the SRF 55Vxx my-d™ family further called "my-d™ cards". my-d™ cards are defined as smart cards, which are compliant with ISO/IEC 15693-1. Furthermore, the theory and the results provided in this document can also be used to calculate the antenna parameters for transponder antennas of a different shapes than cards, all based on SRF 55Vxx. Using antenna dimensions other than those defined by ISO/IEC 15693-1, might have a major impact on the operating distance of such transponders.

Generally, for each new transponder antenna system (my-d™ transponder or inlay on one side and a reader on the other side) a new antenna design needs to be defined. In order to meet the system requirements, Infineon Technologies recommends extensive testing with my-d™ transponder inlays and all different reader devices which will be used to interrogate my-d™ transponder inlays.

Intended audience

The information within this document is intended for antenna designers and card manufacturers, who want to understand the theory behind card coil design and card coil characterization.

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1 Introduction

1.1 ISO/IEC standard platform

The ISO/IEC 15693 standard offers a technology platform for contactless smart cards with different components on the reader as well as on the card side. The open scenario strategy for the ISO/IEC 15693 standard allows various suppliers to provide different components for this system. Nevertheless, maximum compatibility of all components that claim to be part of a contactless system is an essential goal that needs to be kept. For the physical design of a VICC, based on my-d™ ICs, the goal of maximum compatibility leads to a coil design procedure, which is the content of this document.

1.2 my-d™ card

The nominal dimensions of the my-d™ card must be as specified in ISO/IEC 15693-1. Only a coil has to be added to SRF 55Vxx, and no more additional components are necessary. As described in the ISO/IEC 15693-1 hole slot design, smart cards with a slot could be designed, see Figure 1. In that case, the coil must be positioned, such that the slot has no influence to either SRF 55Vxx or to the coil.

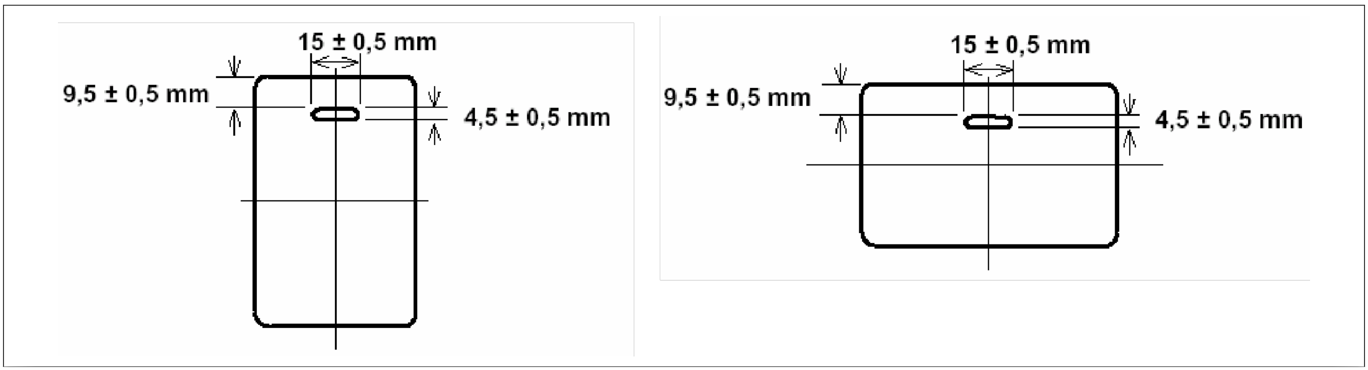

Figure 1 **Hole slot design for portrait and landscape orientation**

If my-d™ IC modules are to be used in applications such as baggage tags, parcel services or logistics, transponder inlay packages are preferential. For this purpose coils of any kind (for example: Wired, Printed, Etched, etc..,) in various shapes or materials can be used.

1.3 Requirements for a my-d™ card coil

The following list discusses the necessary properties of a suitable my-d™ card coil:

- At least compliant to ISO/IEC 15693 part 1-3 respectively ISO/IEC 18000-3 mode 1 requirements
- Maximum operating distance for a certain system

  The maximal operating distance strongly depends on the strength of the field applied by the reader. The field strength must be as defined by the ISO/IEC 15693, part 2. The coil must be designed to achieve maximum operating distance without any impact on the functionality of SRF 55Vxx implemented on a card
- Different coil design technologies are allowed to manufacture the my-d™ coil

  The my-d™ card is designed to be compatible with the ISO/IEC 15693 system, and also allows different technologies of coil design (for example: Wired, Printed, Etched, etc..,)
- Compatibility of cards based on different coil technology

  Even my-d™ cards with different coil technology inside have to be compatible. They must not influence each other in the field of a reader and must not impact the system
- Flip chip technology

  If my-d™ transponder inlays are to be constructed, the flip chip packaging might be used to connect the IC with the antenna substrate. Using this technology the wire bond pad pitch limitations are overcome which is its main advantage. Solder bumping technologies of SRF 55Vxx pads should do the conductive connection of SRF 55Vxx to the antenna substrate. Solder bump height depends on the assembly of the antenna and have a strong effect on flip chip process yield (height varies from 3 µm to 30 µm)

1.4 Configuration for antenna coil

An antenna coil for my-d™ inlay transponder can be configured in many different ways, depending on the purpose of the application and the dimensional constraints. Various configurations of transponder antenna coils are shown in Figure 2. For a longer read range, the antenna must be properly tuned to 13.56 MHz. A typical number of turns of the coil is in the range, for example 3 - 5 for 13.56 MHz and a rectangular antenna.

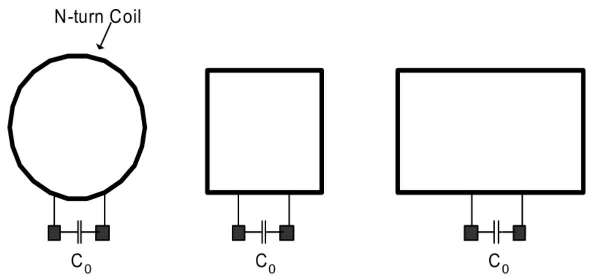

Figure 2 Various configurations of the transponder antenna

2 Theory discussion

2.1 my-d™ card

The coil is a electrical component, which supplies the power for SRF 55Vxx and enables additionally the communication of SRF 55Vxx with the reader. It is connected to SRF 55Vxx with the pads L_A and L_B. A well-designed coil fully supports SRF 55Vxx to its maximum performance. A badly designed coil will drastically weaken the possible performance of the my-d™ card. To understand the importance of a correct coil design the main theoretical issues are given in the following sections.

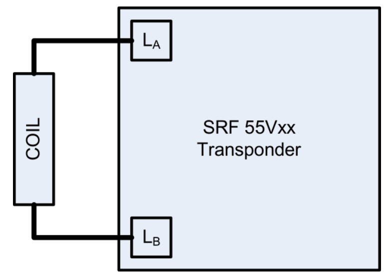

Figure 3 SRF 55Vxx with coil

2.2 Equivalent circuit of SRF 55Vxx

The equivalent circuit of SRF 55Vxx is represented by the input resistance R_{IC} and its input capacitance C_{IC} as shown in Figure 4. The value of the input resistance R_{IC} and the input capacitance C_{IC} depends on the applied input voltage V_{LA-LB} as shown in Figure 5 and Figure 6. For the calculations, it is recommended to use the R_{IC} and C_{IC} values measured at the typical operating conditions as mentioned in Table 1.

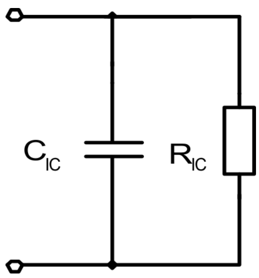

Figure 4 Equivalent circuit of SRF 55Vxx

If SRF 55Vxx is mounted into the module, then, from the electrical point of view, the mount capacitance C_{Mount} is added to the inner capacitance of the SRF 55Vxx IC (rectifier capacitance). It is quite difficult to measure the C_{Mount} value correctly. Therefore the entire input chip capacitance C_{IC} (module and IC) is measured and it comprises chip rectifier capacitance and the module capacitance:

$$C_{IC} = C_{Mount} + C_{Chip} \tag{1}$$

The chip quality factor Q_{IC} can be easily calculated using the following equation:

$$Q_{IC} = \omega_{res} \times C_{IC} \times R_{IC} \tag{2}$$

2.3 Input resistance (R_{IC}) and input capacitance (C_{IC})

Figure 5 shows the typical behavior of the input resistance over the applied voltage $V_{LA\text{-}LB}$ at the operating frequency f_{res} = 13.56 MHz and the ambient temperature (T_A) = 25°C.

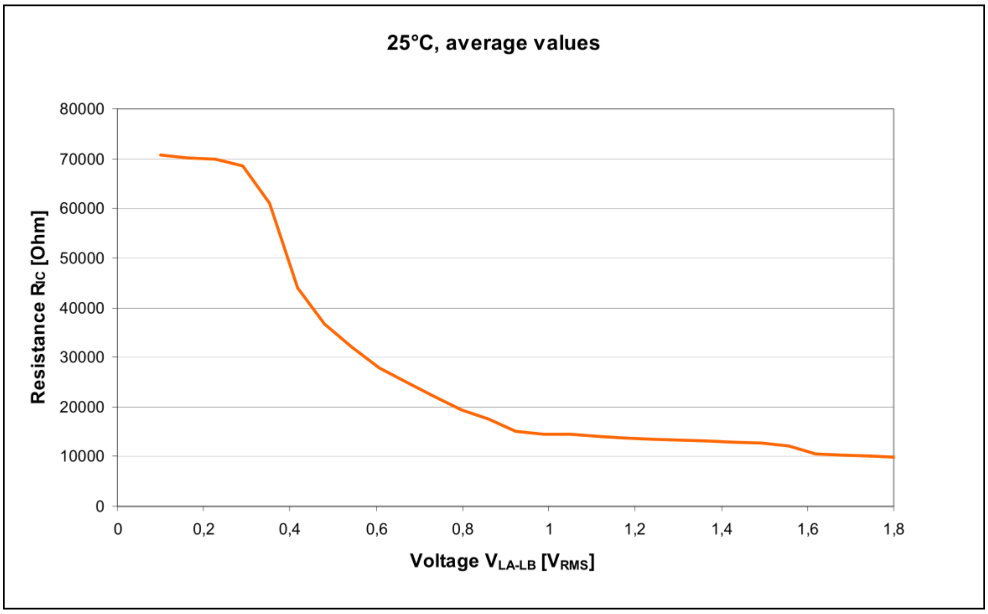

Figure 5 Voltage ($V_{LA\text{-}LB}$) vs input resistance (R_{IC})

Figure 6 shows the typical behavior of the input capacitance over the applied voltage $V_{LA\text{-}LB}$ at the operating frequency f_{res} = 13.56 MHz and the ambient temperature (T_A) = 25°C.

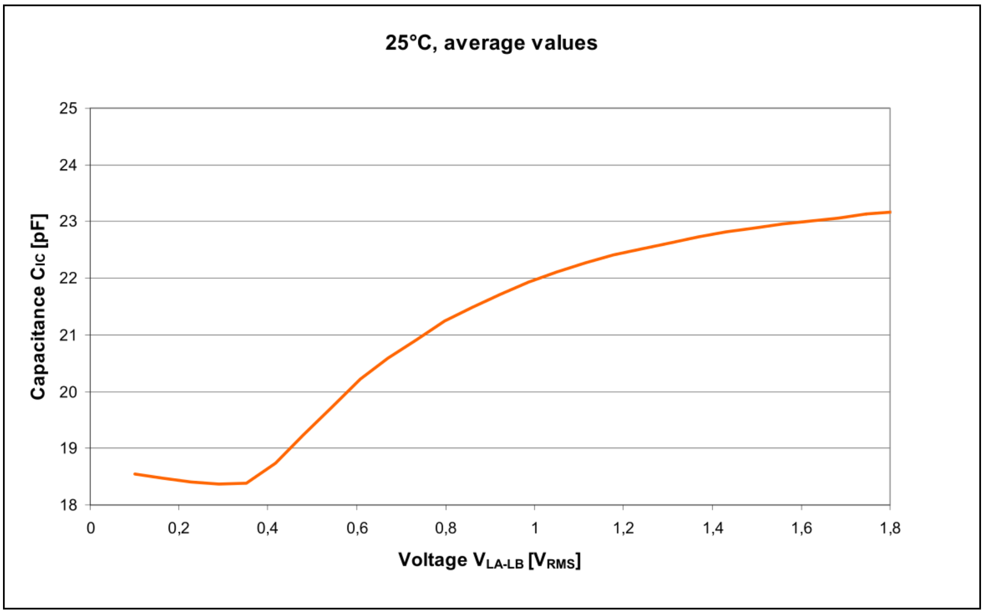

Figure 6 Voltage ($V_{LA\text{-}LB}$) vs input capacitance (C_{IC})

Electrical parameters of SRF 55Vxx, C_{IC}, and R_{IC} vary with the input voltage applied to the chip. For a proper coil design, the following nominal values that are measured at the typical operating conditions should be used:

Table 1 SRF 55Vxx operating conditions

Chip type	C_{IC} [pF]	R_{IC} [kΩ]
my-d™ SRF 55V02P/S	23.1 ± 5%	15
my-d™ SRF 55V10P/S	23.1 ± 5%	15
my-d™ SRF 55V02P HC	97.0 ± 5%	4.2

Measurement conditions:

- f_{res}: 13.56 MHz
- V_{LA-LB}: 1.6 V_{RMS}
- T_A: 25°C

Note: Typical values of the input data may vary over temperature, voltage, frequency, and manufacturing process variations.

2.4 Electrical parameters of the coil

From the electrical point of view, the coil not only an ideal inductivity (L_S) but has also a resistive (R_S) and a capacitive component (C_S). The value of these components is essential importance for the card's electrical and functional properties. Figure 7 gives the equivalent electrical circuit that applies to a my-d™ card coil.

The quality factor of the coil is calculated using the following equation:

$$Q_L = \frac{2 \times \pi \times f_{op} \times L_s}{R_s} \tag{3}$$

With the operating frequency f_{op} = 13.56 MHz.

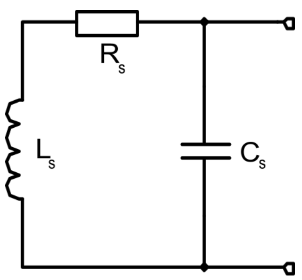

Figure 7 Equivalent circuit of the coil

From the above formula (3), it is obvious that the resistive part of the coil R_S must be as small as possible to achieve a high coil quality factor Q_L. With a higher coil quality factor Q_L the operating distance will increase.

2.5 Coil inductance

The inductivity of the rectangular coil may be estimated with the following equation.

Estimation of coil inductance:

$$L_s\left[nH\right] = 2 \times l\left[cm\right] \times \left(\ln \frac{l[mm]}{D[mm]} - 1.04\right) \times N^P \tag{4}$$

- l → Length of one turn of the coil (mm)
- N → Number of turns
- D → Diameter of wire or width of the conductor (mm)
- P → Exponent of N depends on the coil manufacturing technology

P gives the exponent for the calculation of the inductivity and depends on the different coil manufacturing technologies. Table 2 gives the estimated values for turn exponent P.

Table 2 Coil manufacturing parameter

P	Coil manufacturing technology
1.8	Wired coil
1.7	Etched coil
1.5 - 1.7	Printed coil

Note: *The above equation is only considered for a first estimation. The real value of the inductivity has to be verified by measurement.*

2.6 Equivalent circuit of the my-d™ card

Figure 8 shows the electrical equivalent circuit of a card incorporating SRF 55Vxx, which applies to the discussion below.

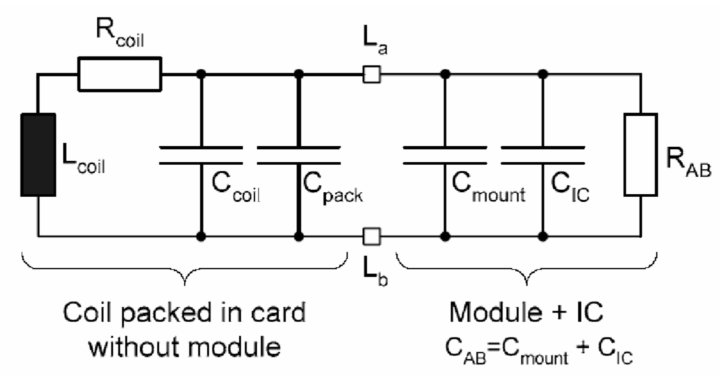

Figure 8 Equivalent circuit of a my-d™ card

The entire capacitance of the my-d™ card comprises mainly four components: The coil capacitance (C_{coil}), parasitic package capacitance (C_{pack}), the parasitic mounting capacitance (C_{mount}), and chip input capacitance (C_{IC}).

$$C_{res} = C_{coil} + C_{pack} + C_{mount} + C_{IC} \tag{5}$$

Due to the dielectric property of the card package material, package capacitance C_{pack} has to be added to the my-d™ resonant circuit. This value is influenced by the card manufacturing process and must be considered in the verification of a coil design.

2.6.1 Resonance frequency of the my-d™ card

The entire capacitance together with the inductance of the coil influences the resonance frequency of the card/label and its performance:

$$f_{res} = \frac{1}{2 \times \pi \times \sqrt{L_{coil} \times (C_{coil} + C_{pack} + C_{mount} + C_{IC})}} \tag{6}$$

The resonance frequency of a my-d™ card is a very characteristic value, but it is quite difficult to measure its absolute value correctly. The equipment for the measurements of the resonance frequency is very expensive and therefore not very suitable for an easy card coil design.

The purposed design procedure needs no measurement of resonance frequencies but reduces the design to the measurement of inductivity, resistance, and capacitance of the passive components. This allows easy design and verification.

2.6.2 Quality factor of the my-d™ card

Another very important characteristic value of the circuit above is the total quality factor of the my-d™ card. Q_t depends on both the quality factor of the coil and the quality factor of SRF 55Vxx IC, as stated in the following equation:

$$Q_t = \frac{1}{\frac{1}{Q_L} + \frac{1}{Q_{IC}}} \tag{7}$$

The quality factor of the coil (Q_L) is more or less constant value as the ratio L_s/R_s is constant. Therefore the my-d™ card quality factor (Q_t) is mainly regulated by the quality factor of the Q_{IC}.

For good energy and data transmission, a high-quality Q_t factor is desirable. However, high Q_t also reduces the bandwidth and the system becomes more affected by frequency tolerances (for more details refer to Chapter 4.1).

Note: To increase the Q_t it is sometimes necessary to add an additional tuning capacitance in parallel to the chip. The my-d™ chip tuning is not the content of this document and it will not be further discussed.

3 Interrogation field strength (H)

The following section describes some equations that ease the calculation of the total quality factor Q_t of the my-d™ card and minimal field strength H_{min}.

3.1 Parallel circuit of the my-d™ coil

In order to calculate the my-d™ card quality factor easily, it is recommended to first convert the serial connection from coil inductance and coil resistance into the equivalent parallel circuit as shown below.

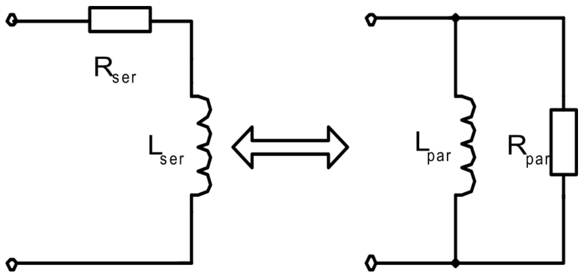

Figure 9 **my-d™ coil parallel circuit**

$Q_{ser} = \frac{\omega \times L_{ser}}{R_{ser}}$	$Q_{par} = \frac{R_{par}}{\omega \times L_{ser}}$
$R_{ser} = \frac{R_{par}}{1 + Q_{par}^2}$	$R_{par} = R_{ser}\left(1 + Q_{ser}^2\right)$
$X_{ser} = \frac{X_{par}}{1 + \frac{1}{Q_{par}^2}}$	$X_{par} = X_{ser}\left(1 + \frac{1}{Q_{ser}^2}\right)$

3.2 Parallel circuit of the my-d™ card

Using the transformations above, the resulting equivalent circuit is:

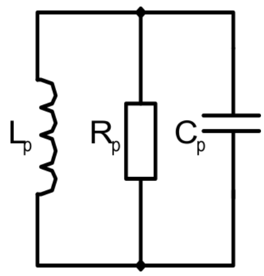

Figure 10 **my-d™ card parallel circuit**

Where:

$$R_p = \frac{R_{IC} \times R_{par}}{R_{IC} + R_{par}} \quad (8)$$

$$C_p = C_{res} = C_{coil} + C_{pack} + C_{IC} \quad (9)$$

$$L_p \approx L_s \tag{10}$$

And the quality factor of my-d™ card can be calculated using the following equation:

$$Q_t = \frac{R_p}{\omega_{res} \times L_p} \tag{11}$$

$$\omega_{res} = 2 \times \pi \times f_{res} \tag{12}$$

$$f_{res} = \frac{1}{2 \times \pi \sqrt{L_p \times C_p}} \tag{13}$$

With the resonance frequency f_{res} = 13.56 MHz.

From the above equation, it is obvious that the chip quality factor and the operating distance are strongly limited by the entire resistances of the equivalent circuit. Therefore it is recommended to keep the entire resistance as low as possible.

4 Minimal field strength (H_{min})

The field strength "H" measured in ampere per meters (A/m) is the significant factor for the transmission range. H_{min} is the minimum required field strength needed for the operation of the transponder at the maximum operating distance. When the field with a field strength H is applied by the reader, the induced voltage u_i, is generated by induction in the antenna coil.

$$u_i = \mu_0 \times 2 \times \pi \times f_{op} \times A \times N \times H \tag{14}$$

- f_{op} → Frequency of the reader antenna field
- A → Average area enclosed by coil windings
- N → Number of coil windings
- H → Magnetic field strength

The voltage $u_{VA\text{-}VB}$ is the minimal supply voltage needed for the correct operation of SRF 55Vxx:

$$u_{V_A - V_B} = \frac{\omega_{op} \times \mu_0 \times A \times N \times H_{\min}}{\sqrt{\omega_{op}^2 \times \left(\frac{L_p}{R_p}\right)^2 + \left(\frac{\omega_0^2 - \omega_{op}^2}{\omega_0^2}\right)^2}} \tag{15}$$

Minimal magnetic field strength H_{min} is calculated using the following equation:

$$H_{\min} = \frac{u_{VA - VB} \times \sqrt{\omega_{op}^2 \times \left(\frac{L_p}{R_p}\right)^2 + \left(\frac{\omega_0^2 - \omega_{op}^2}{\omega_0^2}\right)^2}}{\omega_{op} \times \mu_0 \times A \times N} \tag{16}$$

- $\omega_{op} = 2\pi f_{op}$ (frequency of the reader antenna field)
- $\omega_0 = 2\pi f_0$ (resonance frequency of the transponder)
- L_p → Transformed parallel inductance
- R_p → Transformed parallel resistance

The evaluation of the formula above shows that the minimum field strength also depends on the average area enclosed by the coil windings, number of the coil windings, generated supply voltage, frequency of the reader antenna field, and transponder resonance frequency.

Figure 11 shows the behavior of the field strength H versus the resonance frequency of the my-d™ card. Any deviation of the resonance frequency f_0 from the frequency of the reader field f_{op} will increase the minimal field strength needed to address the transponder.

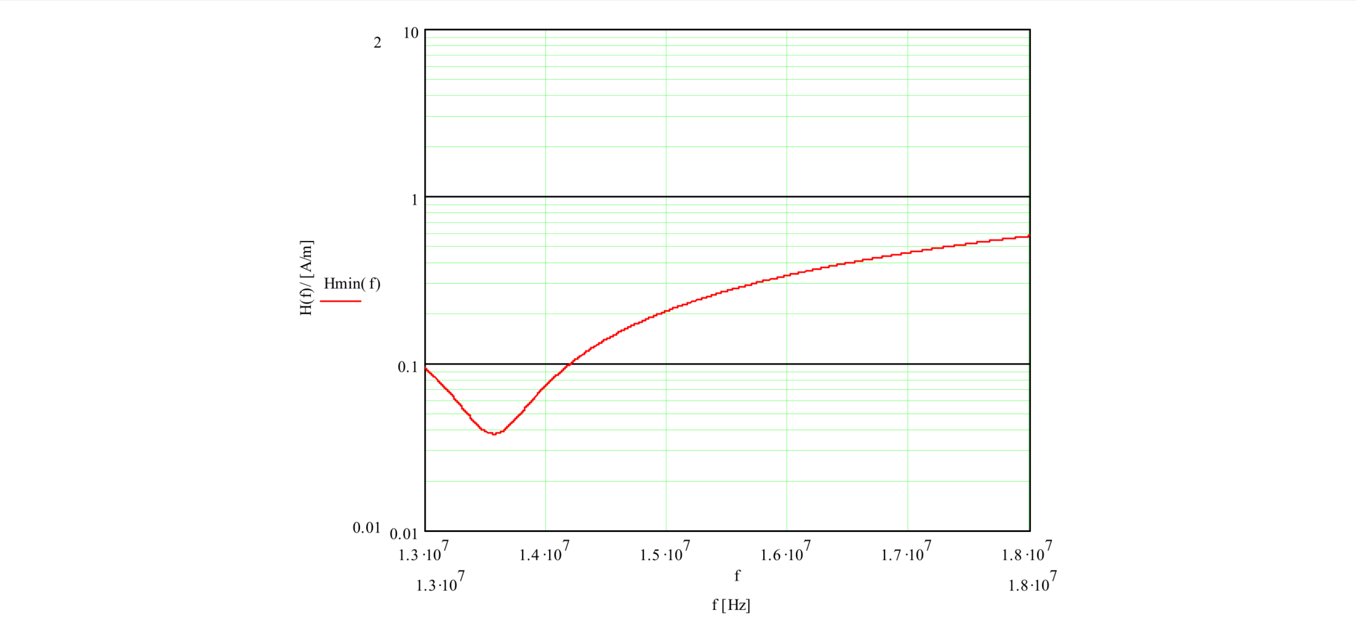

Figure 11 **Minimal field strength vs resonance frequency**

Therefore it can be concluded that the resonance frequency f_{op} of the optimally designed transponder equals to the frequency of the antenna reader field that is:

$$f_{op} = f_0 = 13.56\ MHz \tag{17}$$

According to the ISO/IEC 15693-2 the minimum operating field strength is defined as:

$$H_{\min} = 150\ mA/m \tag{18}$$

Note that ISO/IEC 15693-2 defines the minimum field strength and the operating range for the card with dimensions as specified by ISO/IEC 15693-1. In case of a transponder inlay with coils dimensions and shapes different than those specified by the ISO/IEC 15693-1, the value of the minimal field strength can deviate from the values specified by ISO/IEC 15693-2.

4.1 Influence of the my-d™ quality factor (Q) to the minimal field strength (H_{min})

The Q factor is a measure of the voltage and current set-up in a resonant circuit at a resonant frequency. Its reciprocal denotes the circuit damping and it is directly proportional to the field strength that is as the field strength increases the quality factor decreases and vice versa:

$$H_{\min} \approx \frac{1}{Q_t} \tag{19}$$

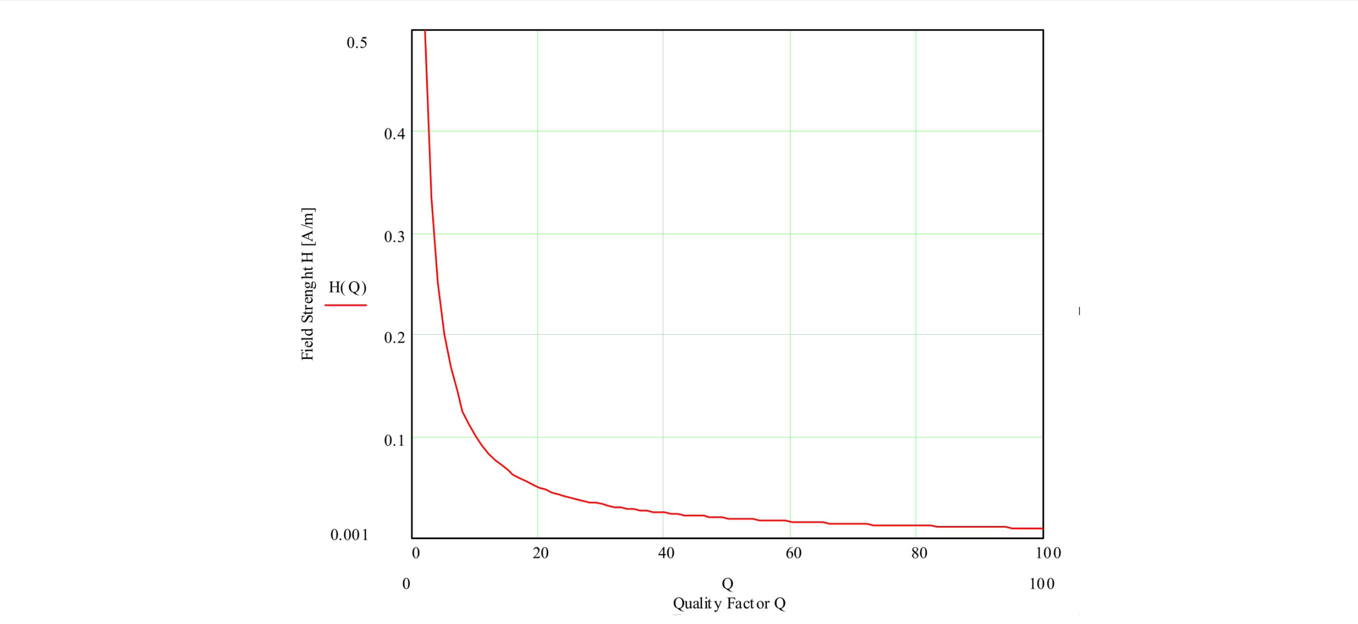

Figure 12 **Minimal field strength vs coil quality factor**

The quality factor of the my-d™ influences directly the minimal field strength and consequently the maximum operating distance between the reader and the my-d™ card. The quality factor must be selected as high as possible.

In order to reach better operation distance, the optimally selected quality factor of the my-d™ card should be approximately: $Q_t > 20$

5 Measuring the coil parameters

According to the equivalent circuit of the coil (see Figure 7), the coil can be characterized by determining the inductivity L_S, the resistivity R_S, and the parasitic capacitance C_S.

The resistance R_S shall be measured at the system frequency (13.56 MHz).

At low frequencies, the parasitic capacitance C_S has a negligible influence on the impedance compared to the coil inductivity. Therefore the real inductivity should be measured at a relatively low frequency (approximately: 1 MHz).

At higher frequencies, the influence of the parasitic capacitance increases and apparently raises the inductivity. This effect can be used to determine the parasitic capacitance C_S of the coil.

The parasitic capacitance C_S can be calculated using the following equation:

$$C_S = \frac{1}{\omega_m^2} \times \left(\frac{1}{L_S} - \frac{1}{L_m}\right) \tag{20}$$

With:

$$\omega_m = 2\pi f_m \tag{21}$$

- f_m → Frequency where L_m is measured
- L_m → Inductivity measured at f_m
- L_S → Coil inductivity determined at low frequency

The parameters of the coil can be determined by using one out of the following setups.

5.1 Coil characterization with an impedance analyzer

Measurement setup:

- Impedance analyzer (for example: Agilent 4194A)
- Test fixture (for example: Agilent 16047E)

Measurement instructions:

- Adjust frequency range: 100 kHz to 30 MHz
- Compensation: Short, Open
- Function: Select “Impedance: Z, Θ”
- Start measurement
- Select the EQV function and press the “Calc” button

5.2 Coil characterization with LCR meter

Measurement setup:

- LCR meter (for example: Agilent 4285A)
- LCR meter (for example: Agilent 4285A)

Measurement instructions:

- Compensation: Short, Open

- Select the function Ls-Rs
- Select the frequency of interest
- Measure the inductivity (L_{coil}) at 1 MHz (L_{coil})
- Measure the inductivity (L_m) at f_m (> 15 MHz)
- Calculate the parasitic capacitance C_S with the formula given above

The quality factor can be calculated using the obtained parameters. If the inductivity varies the quality factor will stay quite constant. The capacitance shall increase with the increased inductivity that is with more windings of the coil.

6 Summary

It is recommended to follow the rules below when constructing the coil antenna for the my-d™ card or for the transponder inlay with SRF 55Vxx:

- Maximum operating distance is achieved if my-d™ chip or transponder inlay resonate at the carrier frequency (13.56 MHz) that is

$$f_{op} = f_0 = 13.56\ MHz \tag{22}$$

- Solving the resonance frequency equation for the value of the coil inductance at the carrier frequency:

$$L_s = \frac{1}{\left(2 \times \pi \times f_{op}\right) \times C_{res}} \tag{23}$$

- The coil quality factor should be selected as high as possible in order to increase the energy available for my-d™ chip as well as the operating distance:

$$Q_L > \ > \tag{24}$$

- The quality factor of the my-d™ card should be in the range between:

$$Q_t = 10 ... 30 \tag{25}$$

- Minimum operating field strength (according to ISO/IEC 15693-2)

$$H_{\min} = 150\ mA/m \tag{26}$$

Note: This value is not applicable for the transponder inlays which have other dimensions than defined by ISO/IEC 15693-1.

A Example

The following example summaries all the relevant parameters together with applicable formulas for calculation of the my-d™ transponder inlay (tag) with the average dimensions (67 mm^2 x 37 mm^2):

Parameters	Unit	Value	Calculation/description
Supply voltage	$U_{VA\text{-}VB}$	2 V_{RMS}	-
Operating frequency	f_{op}	13.56 MHz	Frequency of the magnetic field
Inductivity per one turn	L_A	0.097 µH	-
Average coil area	A	2479 mm^2	L = 70 mm, W = 40 mm (67 mm^2 x 37 mm^2)
Number of coil turns	N	6	-
Coil resistance	R_s	2.26 Ω	Measured value. Increased due to the used external capacitance
Coil inductance	L_s	3.52 µH	$L_s = L_A \times N^2$
Coil quality factor	Q_L	132.7	$Q_L = \frac{2 \times \pi \times f_{op} \times L_s}{R_s}$
Resonance capacitance	C_{res}	39 pF	$f_{res} = \frac{1}{2 \times \pi \times \sqrt{L_s \times C_{res}}}$
Chip input capacitance	C_{IC}	23.1 pF	-
External capacitance	C_{ext}	15.9 pF	$C_{ext} = C_{res} - C_{IC}$
Chip input resistance	R_{IC}	15 kΩ	-
Chip quality factor	Q_{IC}	29.5	$Q_{IC} = \omega_{res} \times C_{res} \times R_{IC}$
Quality factor of the tag	Q_t	24.1	$Q_t = \frac{1}{\frac{1}{Q_L} + \frac{1}{Q_{IC}}}$
Parallel inductivity	L_p	3.52 µH	$L_p \approx L_s \times \frac{1 + Q_L^2}{Q_L^2}$
Parallel load	R_p	10.89 kΩ	$R_{pc} = R_s \times \left(1 + Q_L^2\right),\ R_p = \frac{R_{IC} \times R_{pc}}{R_{IC} + R_{pc}}$
Quality factor of the tag	Q_t	36.3	$Q_t = \frac{R_p}{\omega_{res} \times L_p}$
Minimum field strength	H_{min}	43,0 mA/m	$H_{\min} = \frac{U_{VA-VB} \times L_p}{\mu_0 \times A \times N \times R_p}$

References

[1] ISO/IEC 15693-1:2010 *Identification cards — Contactless integrated circuit cards — vicinity cards — Part 1: Physical characteristics (Second edition)*; 2010-10

[2] ISO/IEC 15693-2:2019: *Cards and security devices for personal identification — Contactless vicinity objects — Part 2: Air interface and initialization (Third edition)*; 2019-04

[3] ISO/IEC 15693-3:2019: *Cards and security devices for personal identification — Contactless vicinity objects — Part 3: Anticollision and transmission protocol (Third edition)*; 2019-04

[4] ISO/IEC 18000-3:2010: *Information technology — Radio frequency identification for item management — Part 3: Parameters for air interface communications at 13.56 MHz (Third edition)*; 2010-11

Glossary

EEPROM

electrically erasable programmable read-only memory (EEPROM)

IC

integrated circuit (IC)

IEC

International Electrotechnical Commission (IEC)
The international committee responsible for drawing up electrotechnical standards.

ISO

International Organization for Standardization (ISO)

VICC

vicinity integrated circuit card (VICC)

Revision history

Reference	Description
Revision 3.0, 2023-03-02	
All	Migrated to latest template and updated editorial changes
Revision 2.0, 2007-05-25	
All	• Added my-d™ light SRF 55V01P and my-d™ vicinity SRF 55V02P HC • Editorial changes
Revision 1.0, 2004-09-29	
All	Initial release

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