Card Coil Design Guide for Infineon TEGRION™ Security Controllers

Guideline and definitions for coil design

Application Note

About this document

Scope and purpose

This document serves as a guideline for the design of card coils for smart cards based on Infineon's dual-interface or contactless TEGRION™ security controllers manufactured in 28 nm technology. The final product is intended to be compliant with the relevant standards and specifications and shall fulfill the respective application requirements. The recommendations are for guidance only. The specific behaviour of the coil design shall be verified by measurement as described within this document.

The *Infineon Card Coil Calculator* software tool [9] supports the design of a card coil according to the application requirements.

Intended audience

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

Revision 1.0
2024-02-28

Table of contents

1 Components of a contactless card

A contactless card consists mainly of four components that influence the behavior of the resonant circuit:

- Security controller IC
- Module
- Card material
- Card coil

1.1 Equivalent circuit of the card

Figure 1 depicts an electrical equivalent circuit of a contactless card that applies to the following discussion. The given electrical elements represent the main components of cards with contactless interface.

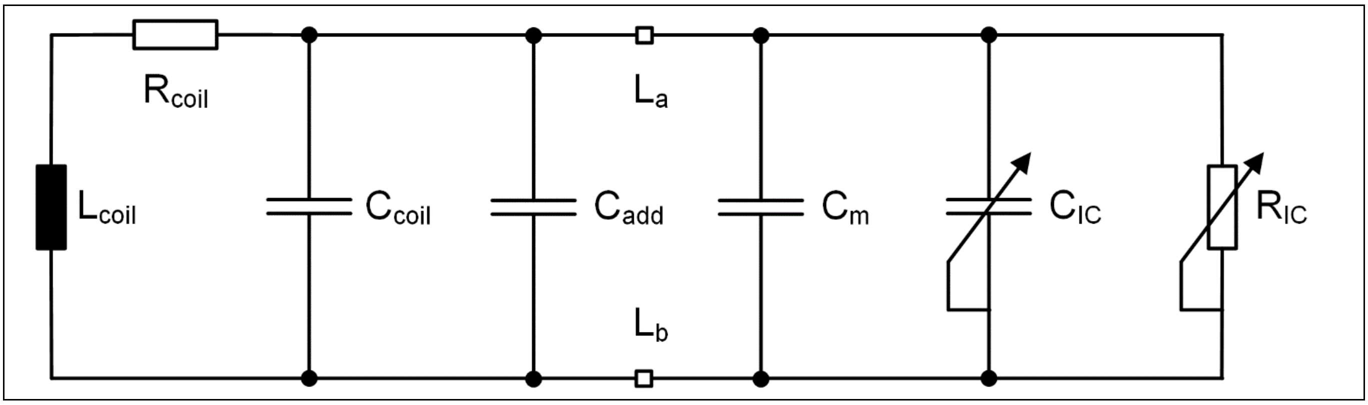

Figure 1 Equivalent circuit of the card

L_{coil}	…	Coil inductance
R_{coil}	…	Coil resistance
C_{coil}	…	Coil capacitance
C_{add}	…	Additional capacitance
L_a, L_b	…	Contact areas of the module for connecting the card coil
C_m	…	Module capacitance
C_{IC}	…	IC input capacitance
R_{IC}	…	IC input resistance (load resistor)

1.2 Security controller IC

The security controller IC is the “heart” of the contactless card. It determines the features of a card and the application-relevant performance.

The IC input capacitance and the required operating voltage determine features like the maximum operating distance and the ability to operate several cards simultaneously. The correct measurement of the IC input capacitance versus the operating voltage is a complex procedure and is not within the scope of this document.

The values of the IC input capacitance C_{IC} depends on the IC’s operating condition. The nominal value of the IC input capacitance (without module) is specified with 27 pF, 56 pF or 78 pF, depending on the product.

The following tables list the typical IC input capacitance values of the IC without module (bare die) with their corresponding tolerances and the measurement conditions:

Table 1 IC input capacitance (bare die) overview

Typical IC input capacitance			Measurement condition
Nominal value 27 pF	**Nominal value 56 pF**	**Nominal value 78 pF**	
26.9 ± 10% pF	54.4 ± 10% pF	75.6 ± 10% pF	Threshold condition[1]: 13.56 MHz, 2.8 V_{peak}

1.3 Module

The module or package is the housing for the security controller IC. It allows easy handling of the IC and protects it against physical stress like extensive bending or UV rays. Additionally, it provides contact areas L_a and L_b for different coil connecting methods.

From an electrical point of view, the mounting of the IC in the module adds an additional capacitance C_m to the resonant circuit of the card. However, the capacitance of the module is almost negligible compared to the IC's capacitance. So the input capacitance of the whole package (IC and module) is mainly determined by the IC itself.

Infineon's security controllers are available in different module types. In the *Infineon Card Coil Calculator* [9] the target package should be selected to consider its capacitance for the coil design.

1.4 Card material

Due to its dielectric property, the material of the card body (usually PVC or PC) influences the capacitance of a contactless card. In order to give some idea of the influence of the card materials and manufacturing process, the card lamination process would reduce the resonance frequency by about 300 – 500 kHz (depending on the relative permittivity ε_r of the card material). This value is mainly influenced by the card manufacturing process and shall therefore be considered in the verification of a coil design. Keep this dependency in mind when changing the card material and verify the new card material within the given limits.

1.5 Card coil

The card coil is the electrical component which supplies the power to the IC and also enables communication between the card and the reader. A well-designed card coil fully supports Infineon's Security controller ICs to achieve their maximum performance.

The requirements for a suitable card coil can be obtained from the following specifications and aspects:

- *ISO/IEC 14443* [1], [2], [3], [4] and *ISO/IEC 10373-6* [5] compliance regarding operating field strength range, modulation waveform and load modulation amplitude
- *EMV Contactless Interface Specification* [8] compliance
- Application specific requirements, such as reading distance or communication speed
- Security controller's contactless interface characteristics

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[1] The IC input capacitance is specified at threshold condition only. For the definition of the threshold and unloaded condition please see Chapter 5.2.

2 Electrical and geometrical parameters of a coil

2.1 Physical coil dimensions

Generally, the larger the coil, the better the performance in terms of power transfer from the PCD to the card. However, there might be restricted or reserved areas for the coil turns on the card. The restricted area for the coil has to be defined according to the application requirements. For example, if there are any embossing and/or magnetic stripe areas on the card, the coil and the IC module have to be positioned in way, that they do not interfere with these restricted areas. This has to be taken into account in addition to the manufacturing tolerance of the coil.

2.2 Geometrical coil parameters

In most cases a simple rectangular coil meets the requirements. A typical coil is shown in Figure 2. Figure 3 describes the differences between an etched or printed coil and a wired coil type.

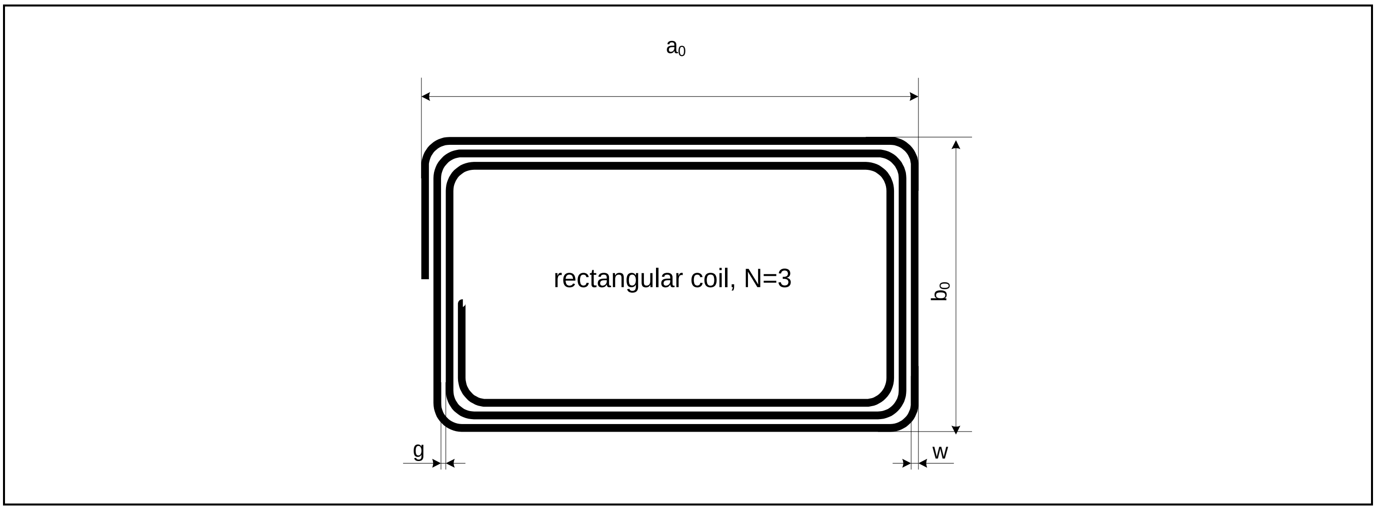

Figure 2 **Geometrical coil parameters (given for an etched or printed coil)**

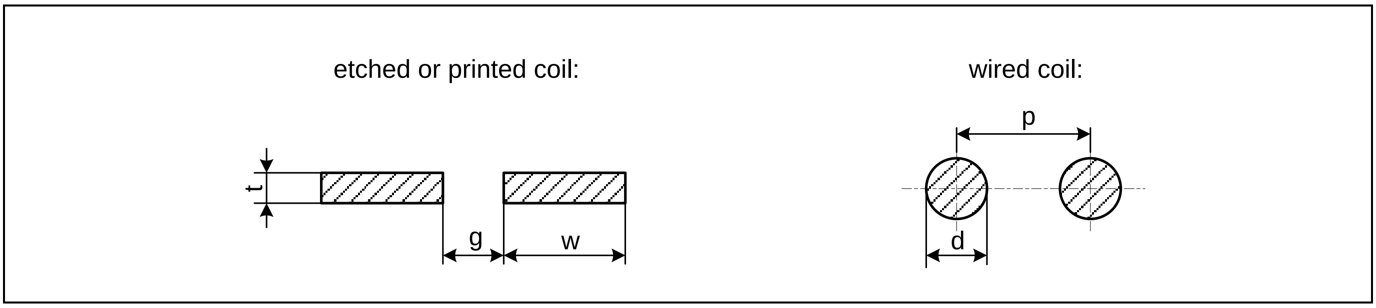

Figure 3 **Etched or printed vs. wired coil type**

a_0…	Coil length	g …	Gap between tracks (etched or printed coil)
b_0 …	Coil width	t …	Track thickness (etched or printed coil)
N …	Number of turns	d …	Wire diameter (wired coil)
w …	Track width (etched or printed coil)	p …	Wire pitch (wired coil)

The coil length a_0 and coil width b_0 represent the outer dimensions for etched or printed coils and the center-to-center dimensions for wired coils.

2.3 Electrical coil parameters

From an electrical point of view, the coil is not an ideal inductor but also has a resistive and a capacitive component. The values of these components are of essential importance for the card's electrical and functional properties. The figure below gives the equivalent electrical circuit of the coil.

To calculate and tune the electrical coil parameters the *Infineon Card Coil Calculator* [9] may be used.

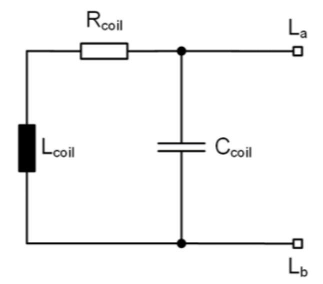

Figure 4 Equivalent circuit of the coil

2.3.1 Coil capacitance, C_{coil}

The capacitance C_{coil} mainly results from the close distance between the turns of the coil. The value of C_{coil} can be directly influenced in various ways:

- For etched or printed coils: by changing the track width w, the track thickness t or the gap g between the tracks
- For wired coils: by changing the wire pitch p or the wire diameter d
- By changing the card material: C_{coil} is influenced by the card material's dielectrical property, which is described by the relative permittivity ε_r

Typically, the parasitic capacitance of a card coil is 2 to 4 pF.

2.3.2 Coil inductance, L_{coil}

The coil inductance L_{coil} influences decisively the overall performance of the card. The inductance together with the total capacitance defines the resonance frequency of the circuit. A high inductance does not necessarily imply a better power condition for the IC. Due to the usually higher power consumption of the IC, a lower coil inductance may deliver better performance. In fact, the resonance frequency of the coil should be fine-tuned by changing the parameters which influence the inductance of the coil. The coil inductance depends on the geometrical parameters as described in Figure 2 and Figure 3.

$$L_{coil} = f(a_0, b_0, t, g, w, d, p, N)$$

2.3.3 Coil resistance, R_{coil}

The resistive component R_{coil} of the coil causes additional power loss in the card coil. The intention is to keep this loss small compared to the power consumption of the IC. If R_{coil} is too high the reader has to provide more energy to operate the card.

Due to physical effects like skin effect and proximity effect the coil resistance R_{coil} depends on the operating frequency, the coil material, and the coil dimensions.

The specification of the limits for R_{coil} refers to the quality factor Q_{coil} of the coil.

$$Q_{coil} = \frac{\omega \cdot L_{coil}}{R_{coil}} \quad \text{with} \quad \omega = 2\pi f_c \qquad \text{and} \qquad f_c = 13.56\ MHz$$

The overall quality factor of the card system is determined by the quality factors of the card coil and the IC itself. Its value is always a trade-off between maximal power range and minimal loading effect of the card on the reader. Infineon recommends to keep the quality factor of the coil above a value of 20 in order to achieve a balanced overall quality factor of the card system.

To ensure an adequate quality factor for the coil, a wire diameter of 112 µm for wired copper coils and a minimum track width of 200 µm for etched copper coils should be used. For wire diameters of 112 µm, the resulting overall quality factor is mainly determined by the IC. Cards with wire diameters less than 80 µm will suffer from low Q_{coil}. For printed coils a detailed statement is not possible due to the variety of materials and manufacturing processes available. The value of the coil resistance has to be verified by measurement according to Chapter 5.

2.3.4 Resonance frequency, f_{res}

The characteristic resonance frequency f_{res} of a damped RLC resonant circuit, like a card coil, is defined as the frequency at which the impedance of the circuit is at a minimum or purely resistive. This can be seen as the frequency, where the card coil is able to transfer the maximum amount of energy received from the RF field of a reader device to the IC. It is mainly determined by the coil inductance L_{coil} and coil capacitance C_{coil} and can be measured using methods as described in Chapter 5.

Generally, the resonance frequency f_{res} of the card is calculated using the following formula:

$$f_{res} = \frac{1}{2 \cdot \pi \cdot \sqrt{L_{coil} \cdot (C_{coil} + C_{add} + C_m + C_{IC})}}$$

The recommended nominal target value of the resonance frequency f_{res} of a complete card depends on the chosen product and the coil size. Very high resonance frequencies will degrade the performance of the individual card.

2.4 Coil design aspects

Designing a coil allows some variance which can be used to optimize the card performance. Coil size and resonance frequency are the well-known main parameters, but also the inductance-to-capacitance ratio of the resonant circuit has a significant influence on the card's performance.

2.4.1 Coil size

From the perspective of performance, the coil area should always be as large as possible. However, the coil size is always given by customer or project requirements and is often additionally restricted by embossing areas, visual card designs, or similar other constraints.

2.4.2 Target resonance frequency

Generally, the target resonance frequency can be chosen from a wide range that starts at 13.56 MHz and can go up to 18 MHz or even beyond. To ensure an optimal card performance in a majority of scenarios, the recommended resonance frequency for the specific coil class and target application should be used.

Note: For card coil design the threshold resonance frequency $f_{res,\,TH}$ at threshold condition is relevant! For methods how to measure this value and information on the difference to the unloaded resonance frequency see Chapter 5.2.

Table 2 gives an overview of resonance frequency recommendations for different coil sizes with focus on best trade-off between communication quality, performance and stackability[1].

Table 2 Recommended $f_{res,\,TH}$ for various "coil size – input capacitance" combinations

Coil size acc. to *ISO/IEC 14443-1* [1]	**Nominal IC input capacitance**		
	27 pF	**56 pF**	**78 pF**
Class 1	16.50 MHz	15.40 MHz	-
Class 2, Class 3	-	15.40 MHz	-
Class 4 and smaller	-	-	13.56 MHz

"-" = Combination not recommended by Infineon

2.4.3 Inductance/capacitance ratio

The performance of an IC based card can be further fine-tuned by varying the inductance/capacitance ratio, while keeping the desired resonance frequency constant. Due to the characteristic power consumption of microcontroller-based cards, investigations have shown that increasing the capacitance (at the same time decreasing the inductance to keep the resonance frequency constant) can lead to a better power supply condition of the IC.

Table 3 gives an overview of the effects of the various design measures. Designing a coil is always a trade-off between positive (green arrow) and negative (red arrow) effects. For Infineon's recommended coil designs, loading effect and self-heating are noncritical parameters.

Table 3 Overview of effects caused by coil design measures

Design measure	**H_{min}**	**LMA**	**Loading effect**	**Self-heating**
Increasing coil size / coupling factor	↓	↑	↑	↑
Decreasing[2] f_{res} by increasing capacitance C_{IC}, C_{coil}	↓	↑	↑	→
Decreasing[2] f_{res} by increasing inductance L_{coil}	↓	↑	↑	↓
Decreasing inductance L_{coil} and increasing capacitance C_{IC}, C_{coil} at the same time	↓	↑	↑	↑

H_{min}	…	Minimum required field strength to power the IC
LMA	…	Load modulation amplitude generated by the card
Loading effect	…	Loading of the reader caused by the card. A too high loading may lead to field strength degradation and strongly deformed modulation waveforms.
Self-heating	…	At high field strengths the high current flow in the IC causes high temperatures due to IC internal power dissipation.

H_{min} and LMA values are also dependent on the coupling factor between the PCD and the PICC. The better the coupling, the greater will be the positive effects of the above measures. For situations with low coupling factors (e.g. special readers with very small coil sizes compared to the card coil), these effects may be less pronounced or even non-existent.

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[1] Stackability is to be considered for Class 1 coils only. Please see Chapter 3 for the definition of PICC classes.

[2] Only feasible if f_{res} is greater than 13.56 MHz

2.4.4 Coil efficiency

Card coils which are optimized for maximum performance and reading range can induce high voltages and therefore deliver high currents to the IC if used in very high operating field strength scenarios. This can lead to reaching or even exceeding the absolute maximum ratings for the IC input voltage V_{IN_LALB} or the IC input current I_{IN_LALB}. Infineon recommends paying attention the absolute maximum rating conditions when designing card coils, as being exposed to these conditions for extended periods of time could potentially compromise the reliability of the IC.

The induced voltage V_i of an air-core coil depends on the magnetic field strength H, the magnetic permeability μ_0, the number of turns N, the coil area A, and the frequency of the magnetic field f_C:

$$V_i = H \cdot \mu_0 \cdot N \cdot A \cdot 2\pi f_C$$

Under high-field conditions and for typical card coils the IC input resistor R_{IC} is very small compared to the reactance of the circuit. In addition, the coil resistor R_{coil} is small compared to the inductive reactance of the coil. Therefore, the following assumptions are valid:

$$R_{IC} \to 0$$

$$R_{coil} \ll 2\pi f_C \cdot L_{coil}$$

Based on the equivalent circuit illustrated in Figure 1, the IC input current can then be approximated as follows:

$$\lim_{R_{IC}\to 0} I_{IN\_LALB} = \frac{V_i}{2\pi f_C \cdot L_{coil}} = H \cdot \frac{\mu_0 \cdot N \cdot A}{L_{coil}}$$

The *Infineon Card Coil Calculator* [9] estimates the IC input current for a given maximum operating field strength and issues a warning in case a designed coil is too efficient and the resulting IC input current is higher that the specified maximum value.

3 Definitions of the PICC classes

ISO/IEC 14443-1 [1] defines various PICC classes, respectively coil sizes. The following section gives a brief overview of Class 1 and Class 2 coils. For detailed information please refer to *ISO/IEC 14443-1* [1].

3.1 PICC Class 1

The coil of a Class 1 PICC shall be located within a zone defined by two rectangles, as shown in Figure 5:

- external rectangle: 81 mm x 49 mm
- internal rectangle: 64 mm x 34 mm, centered in the external rectangle, with 3 mm corner radii, with a maximum area of 300 mm² (except for the connections to the ends of the coil)

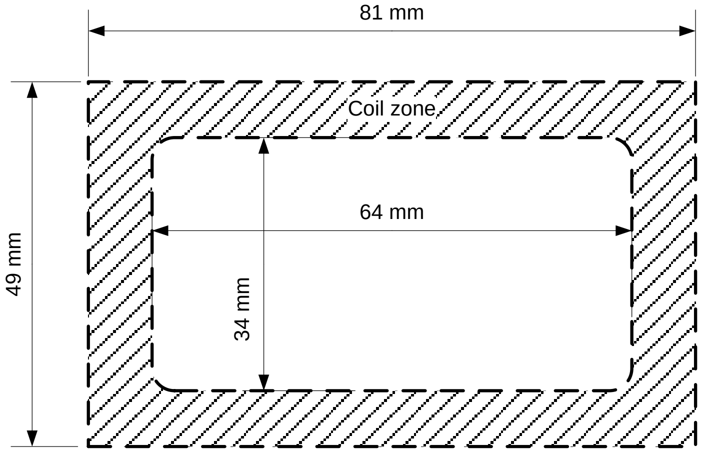

Figure 5 **Location of the coil of the “Class 1” PICC**

3.2 PICC Class 2

The coil of a Class 2 PICC shall be located within a zone defined by two rectangles, as shown in Figure 6:

- external rectangle: 81 mm x 27 mm
- internal rectangle: 51 mm x 13 mm, located at 7 mm and 8.5 mm from the external rectangle, with 3 mm corners radii

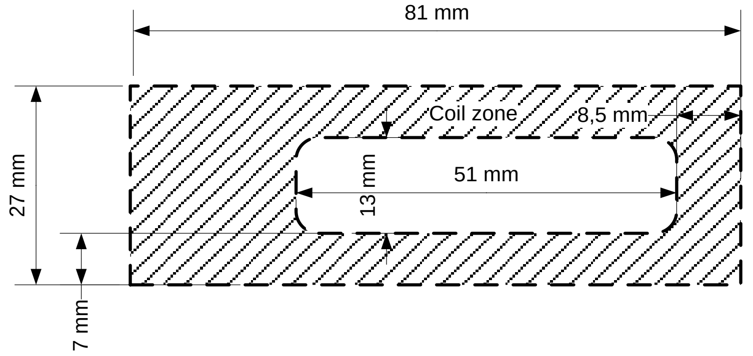

Figure 6 **Location of the coil of the “Class 2” PICC**

4 Design examples and reference designs

4.1 Design flow

Experience has shown that the actual behavior of the coil always differs more or less from the calculated values. Therefore, it is highly recommended to follow the design flow as shown in Figure 7.

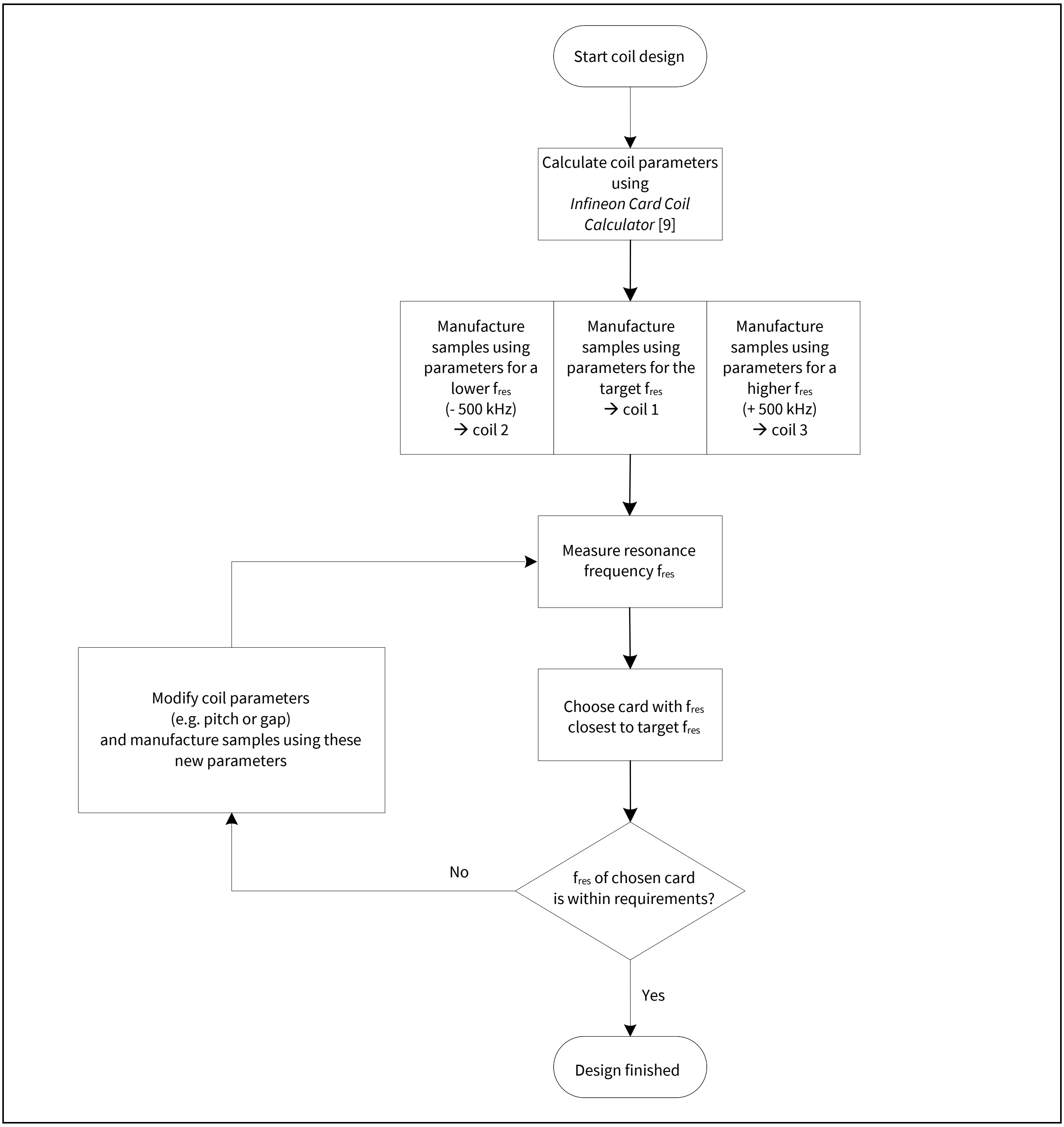

Figure 7 Recommended coil design flow

4.2 Reference designs

This chapter introduces design examples for several coil classes. The designs shown here are so-called “reference designs” and are recommended by Infineon for various applications.

Depending on the nominal IC input capacitance of the chosen Infineon product and the target application, one of the following reference designs should be used:

Table 4 **Overview of reference designs and their target resonance frequencies**

Nominal IC input capacitance	Coil size	
	Class 1	Class 2
27 pF	16.50 MHz	-
56 pF	15.40 MHz	15.40 MHz

The different module capacitances have to be considered when calculating the antenna parameters because they have an influence on the resulting resonance frequency f_{res} of the card. The *Infineon Card Coil Calculator* [9] provides a list of packages to be selected for the coil design process.

Note: *The given reference designs are calculated on inlay-basis. During the card manufacturing process, the resulting resonance frequency of the card will shift towards lower values due to card lamination (please see Chapter 1.4 for details). This effect has to be considered when choosing the target resonance frequency for a coil design.*

4.2.1 Class 1 reference designs

Card coils whose dimensions correspond to Class 1 according to *ISO/IEC 14443-1* [1] are mainly used for ID or Transport applications. They make use of the complete area offered by an ID-1 sized card and typically have a good contactless performance due to the relatively large size. The reference designs shown below have been optimized to be electrically compliant to *ISO/IEC 14443* [1] [2] [3] [4] requirements.

Target specifications:

- Coil dimensions: according to Class 1 definition (see Chapter 3)
- Manufacturing technology: wire embedded coil
- Coil material: Copper wire, 112 µm diameter, conductivity $\sigma = 5.8 \times 10^7$ S/m
- Card material: PVC, relative permittivity $\varepsilon_r = 3.0$
- Security controller IC in a dual-interface module (e.g. S-MFC8.6-6-x)
- Target resonance frequency f_{res} of the final laminated card: 16.5 MHz or 15.4 MHz, depending on design
- Assumed resonance frequency shift due to lamination: 300 - 400 kHz

4.2.1.1 Class 1 design for ID or Transport applications with 27 pF products

Coil parameters:

- Coil length: 80 mm
- Coil width: 48 mm
- Pitch = 0.85 mm
- Wire diameter = 0.112 mm
- Number of turns = 4
- Inductance = 2.95 µH
- Resonance frequency (of the inlay, before lamination) = 16.81 MHz
- Resonance frequency target (after lamination) = 16.50 MHz

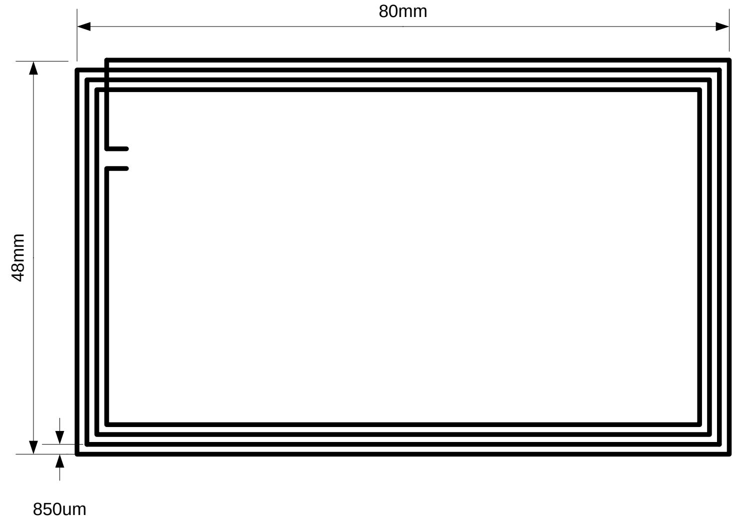

Figure 8 Class 1 reference design for ID or Transport applications with 27 pF products

4.2.1.2 Class 1 design for ID or Transport applications with 56 pF products

Coil parameters:

- Coil length: 79 mm
- Coil width: 48 mm
- Pitch = 1.20 mm
- Wire diameter = 0.112 mm
- Number of turns = 3
- Inductance = 1.70 µH
- Resonance frequency (of the inlay, before lamination) = 15.92 MHz
- Resonance frequency target (after lamination) = 15.40 MHz

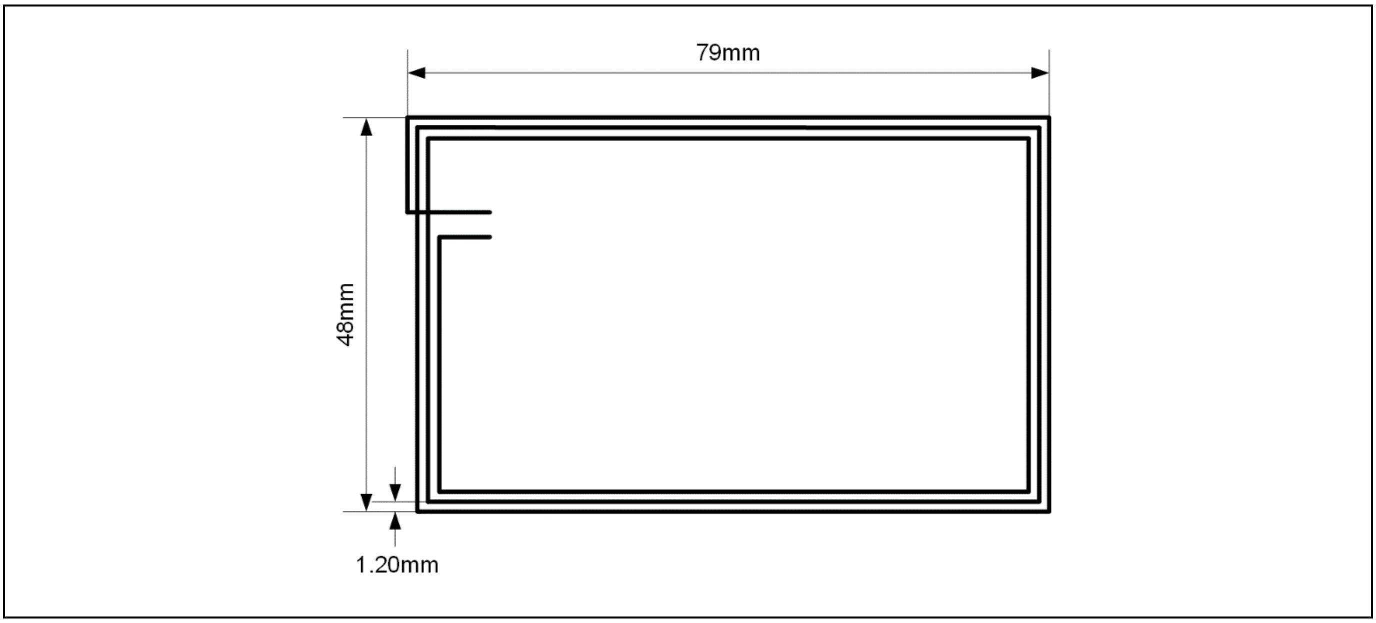

Figure 9 **Class 1 reference design for ID or Transport applications with 56 pF products**

4.2.2 Class 2 reference designs

Class 2 coils are typically used for Payment applications in combination with dual-interface modules. The smaller size of these coils results from the necessity to support embossing areas as defined in *ISO/IEC 7811-1* [6]. The reference design shown below has been optimized to be electrically compliant with *EMV Contactless Interface Specification* [8] requirements, but also to ensure optimal interoperability with point of Sale (POS) readers.

Target specifications:

- Coil dimensions: according to Class 2 definition (see Chapter 3)
- Manufacturing technology: wire embedded coil
- Coil material: Copper wire, 112 µm diameter, conductivity $\sigma = 5.8 \times 10^7$ S/m
- Card material: PVC, relative permittivity $\varepsilon_r = 3.0$
- Security controller IC in a dual-interface module (e.g. S-MFC8.6-6-x)
- Target resonance frequency f_{res} of the final laminated card: 15.4 MHz
- Assumed resonance frequency shift due to lamination: 300 - 400 kHz

4.2.2.1 Class 2 design for Payment applications with 56 pF products

- Coil length: 81 mm
- Average coil length: 70.47 mm = (81 mm x 13.3 mm + 58.5 mm x 11.7 mm) / 25 mm
- Coil width: 25 mm
- Wire pitch = 0.96 mm
- Number of turns = 4
- Inductance = 1.77 µH
- Resonance frequency (of the inlay, before lamination) = 15.80 MHz
- Resonance frequency target (after lamination) = 15.40 MHz

Note: The Infineon Card Coil Calculator [9] is not optimized for asymmetrical antenna shapes. Therefore, the average coil length as calculated above has to be entered as "Coil length (mm)" parameter.

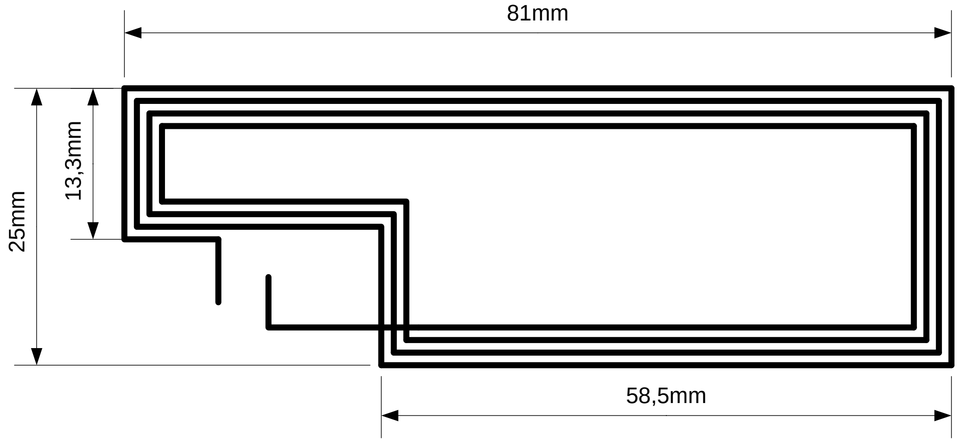

Figure 10 **Class 2 dual-interface reference design for EMV compliant Payment applications**

5 Coil characterization and system tests

There are several tests to ensure optimum functionality of the contactless card.

- **Coil characterization** (Chapter 5.1): is carried out to determine the electrical coil parameters, such as inductance, resistance and capacitance.
- **Resonance frequency measurement** (Chapter 5.2).
- **Basic communication test** (Chapter 5.3) between the card and the reader ensures that the IC is properly connected to the coil.
- Optionally, to ensure **full compliance to required standards and specifications**, tests defined in *ISO/IEC 10373-6* [5] or *EMV Contactless Interface Specifications* [8] should be performed.

5.1 Coil characterization

According to the equivalent circuit of the coil (see Figure 4), the coil can be characterized by determining the circuit's inductance L_{coil}, the resistance R_{coil}, and the capacitance C_{coil}.

For Figure 11 the coil is assumed to be a serial connection of only a resistor R_s and an inductor L_s (without capacitor). This assumption is correct for low frequencies where the parasitic capacitance has a negligible influence on the impedance compared to the coil inductance. Therefore, the real inductance L_{coil} should be measured at a relatively low frequency (≈ 1 MHz).

At higher frequencies the influence of the capacitance increases and thus the inductance for this simplified equivalent circuit model increases. This effect can be used to determine the capacitance of the coil.

The capacitance C_{coil} can be determined by:

$$C_{coil} \approx \frac{1}{(2\pi f_m)^2} \cdot \left(\frac{1}{L_{coil}} - \frac{1}{L_m}\right)$$

f_m	…	Frequency at which L_m is measured, e.g. 30 MHz; must be below the natural resonance frequency of the coil
L_{coil}	…	Coil inductance determined at low frequency
L_m	…	Inductance measured at f_m

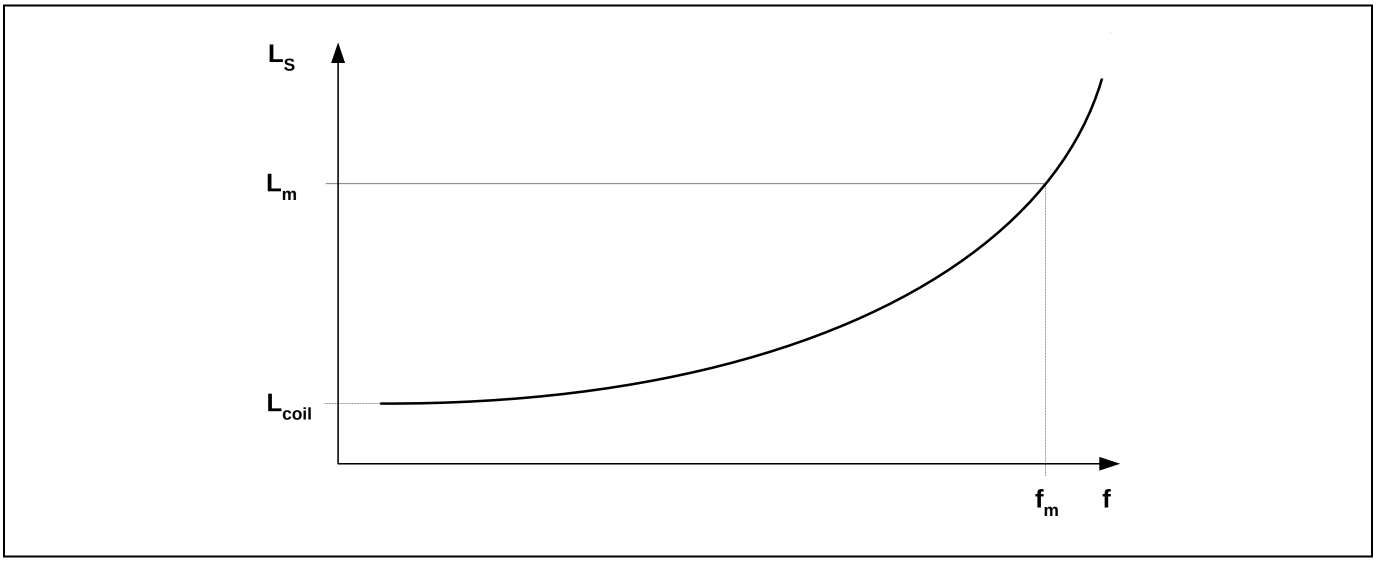

Figure 11 Example plot of measured inductance versus frequency

The coil resistance R_{coil} should be measured at the system frequency (13.56 MHz).

Two equivalent measurement methods with different equipment and measurement setups are described in the following chapters.

5.1.1 Coil characterization with an impedance analyzer

Measurement setup:

- Agilent 4194A impedance analyzer
- Agilent 16047E test fixture

The Agilent 16047E test fixture is directly connected to the instrument ports. Due to the metal parts of the impedance analyzer and the test fixture, a piece of wire[1] (≈ 40 mm) is used to enlarge the distance between the coil and the measurement devices, thereby avoiding falsification of the results.

Attention: *Ensure that there is no metal or any electrically conductive materials in the vicinity of the device under test (DUT) during the measurement!*

Two equivalent methods to determine the electrical parameters of the coil with an impedance analyzer are described below:

LS-RS method:

1. Adjust the frequency range, e.g.: Start = 100 kHz , End = 30 MHz
2. Compensation: Short, Open (please ensure that the piece of wire for measurement is connected already before the compensation).
3. Function → Select “LS-RS”
4. Set the marker to 1 MHz and read the inductance value L_{coil}.
5. Set the marker to 30 MHz and read the inductance value L_m required for capacitance calculation.
6. Set the marker to 13.56 MHz and read the resistance value R_{coil}.

Equivalent circuit method:

1. Adjust the frequency range e.g.: Start = 100 kHz , End = 30 MHz
2. Compensation: Short, Open (please ensure that the piece of wire for measurement is connected already before the compensation).
3. Function → Select “Impedance: Z,ϴ”
4. Start the measurement
5. Choose the appropriate EQV function (see Figure 4) and press the “Calc” button to determine R_{coil}, L_{coil} and C_{coil}.

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[1] Needs to be included during the calibration/compensation process of the measurement setup!

5.1.2 Coil characterization with an LCR meter

Measurement setup:

- Agilent 4285A LCR Meter
- Agilent 16047E test tixture

A piece of wire should be used to increase the spacing between the LCR meter and the coil as described in Chapter 5.1.1.

Measurement instructions:

1. Compensation: Short, Open
2. Select the function Ls-Rs
3. Measure at 1 MHz and read the inductance value L_{coil}.
4. Measure at 30 MHz and read the inductance value L_m required for capacitance calculation.
5. Measure at 13.56 MHz and read the resistance value R_{coil}.

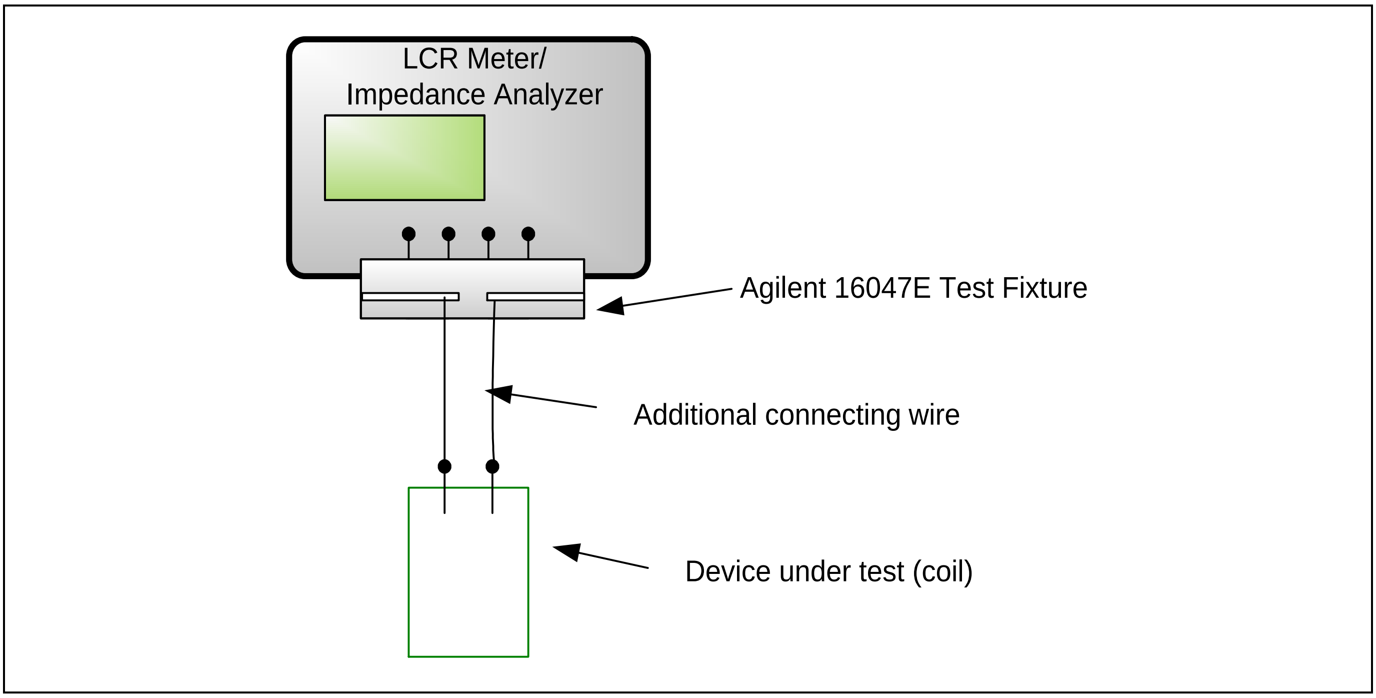

Figure 12 **Measurement setup for coil characterization with an LCR meter or impedance analyzer**

5.2 Resonance frequency measurement

Due to the nonlinear characteristic of the IC input capacitance in relation to the input voltage, the resonance frequency of a contactless card is **dependent on the field strength**:

$$f_{res} = f(H)$$

There are two different operating conditions where the resonance frequency is measured:

- Threshold resonance frequency $f_{res,TH}$ at threshold condition (threshold field strength)
- Unloaded resonance frequency $f_{res,UL}$ at unloaded condition (low field strength)

Threshold condition defines the minimum field strength where the IC has just started up and is in operational condition. The IC start-up must be monitored with a network analyzer during the measurement.

Note: *The resonance frequency at threshold condition is the value that is relevant for the card coil design process!*

Unloaded condition represents a field strength, where the IC is not powered at all, therefore the parasitic capacitance of the IC's internal rectifier will not influence the measurement results. Therefore, there is no need to reproduce a certain IC state. Consequently, it is less complex and can be performed quickly. It's useful for plausibility checks (e.g. is the IC properly connected to the coil) and for monitoring the mass production. The unloaded resonance frequency is always higher than the threshold resonance frequency. Please make use of the *Infineon Card Coil Calculator* [9] to determine the $f_{res,\,UL}$ for a specific card sytem.

The resonance frequency measurement is based on the impedance measurement of a measuring coil coupled to the card under test.

5.2.1 Equipment

- A Vector Network Analyzer, e.g. Hewlett Packard 8753D, Agilent 4395A, Omicron Lab Bode 100 or equivalent
- Measuring coil with 2 turns, as depicted in Figure 13

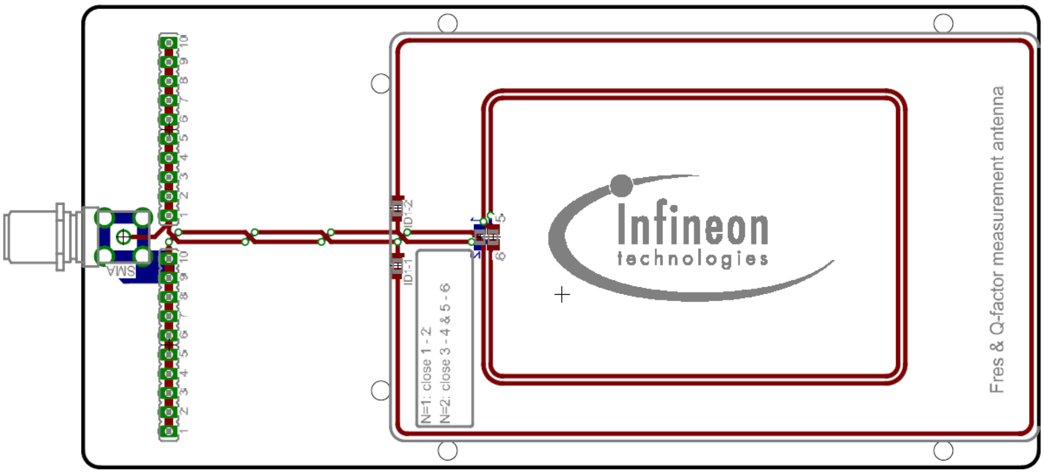

Figure 13 **Measuring coil for resonance frequency measurement**

5.2.2 Implementation

The resonance frequency is the frequency at which the real part of the measured impedance (Re{Z}, Z:R) is maximal (as defined in *ISO/IEC 10373-6* [5]). For both measurements, threshold and unloaded, the network analyzer has to be calibrated once using a calibration kit and the proper frequency and power settings (see Table 5). The calibration has to be performed without the measuring coil connected. If an attenuator or amplifier is used for the measurement (see below), the calibration has to be performed with the attenuator or the amplifier connected! The calibration data can be stored and the proper data can be loaded before starting a measurement.

Table 5 Recommended network analyzer parameter settings

Network analyzer (examples)	Frequency range	Output power range	
		Unloaded condition	Threshold condition
HP 8753D	10.0 MHz - 20.0 MHz[1]	-30 dBm	Up to +12 dBm
Agilent 4395A with 43961A RF impedance test adapter	10.0 MHz - 20.0 MHz	-25 dBm	Cannot be reached (4396A1 has 6 dB loss!)
Bode 100 with B-AMP12 amplifier	10.0 MHz - 20.0 MHz	-27 dBm	Up to +25 dBm with B-AMP12

If the network analyzer does not support a minimum power setting for the unloaded condition as stated in Table 5, a proper attenuator should be used to connect the measuring coil.

Table 6 Attenuator for unloaded condition (optional)

Minimum power setting	Attenuator	Effective power
-15 dBm	10 dB	-25 dBm
-5 dBm	20 dB	-25 dBm

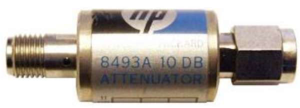

Figure 14 Example for a 10 dB attenuator (SMA)

The attenuation might cause additional noise and might lower the quality of the measurement results. Nevertheless, measurements show that the results are OK up to an attenuation of 20 dB. Additionally, the results can be improved by using the averaging and/or smoothing features of the network analyzer.

---

[1] Due to mismatch of the measuring coil (Z <> 50 Ω) and an internal source switching the Hewlett Packard 8753D Network Analyzer generates a power discontinuity at exactly 16.0 MHz, which can make the measurement difficult and/or inexact. Therefore, the frequency range for threshold condition measurement is divided into two parts (below and above 16.0 MHz). The frequency range can be adapted to the expected resonance frequency to get a better frequency resolution and thus more accurate results.

5.2.3 Threshold resonance frequency

For this measurement the DUT is placed directly on top of the measuring coil (see Figure 15). A minimal influence of the rather strong coupling between the measuring coil and the DUT has to be accepted due to the network analyzer's power limitation.

Figure 15 Setup for threshold resonance frequency measurement

Description of measurement:

1. Load the required calibration data
2. Connect the measuring coil to the network analyzer
3. Configure the device to measure the real part of the impedance of the measuring coil Re{Z11} (Conversion = "Z:Refl", Format = "Real")
4. Put the DUT concentrically onto the measuring coil
5. Perform a power sweep (e.g.: -10 dBm to 15 dBm or 25 dBm, step size: 1 dBm) and measure the resonance frequency at every power setting (the resonance frequency is the frequency where the real part of the impedance is maximal)
6. Plot the resonance frequency values versus the power setting
7. Determine the threshold resonance frequency as shown in Figure 16

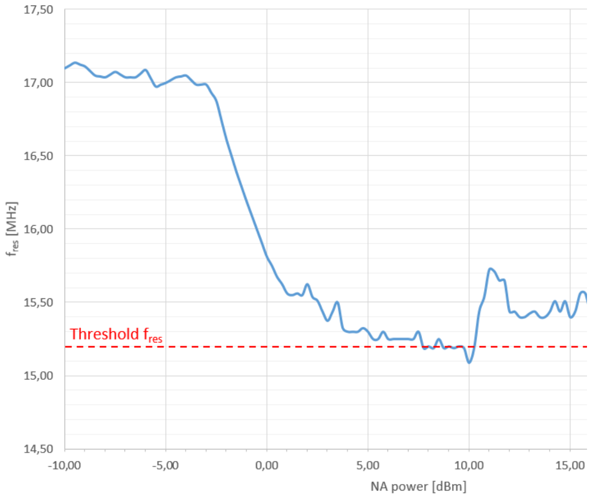

Figure 16 Resonance frequency as a function of the network analyzer output power

5.2.4 Unloaded resonance frequency

For this measurement the DUT is exposed to rather low field strengths. To avoid any influence of the coupling between the DUT and the measuring coil, a spacer is mounted onto the measuring coil (see Figure 17). Thus, the distance between the DUT and the coil is ~1 cm. The spacer shall not influence the parasitic capacitance of the DUT's coil.

Description of measurement:

1. Calibrate the device or load the required calibration data
2. Connect the measuring coil to the network analyzer
3. Configure the device to measure the real part of the impedance of the measuring coil Re{Z11} (Conversion = "Z:Refl", Format = "Real")
4. Put the DUT concentrically onto the spacer above the measuring coil
5. Set appropriate power as given for the corresponding instruments (see Table 5)
6. The unloaded resonance frequency is the frequency where the real part of the impedance is maximal (see Figure 18)

5.2.5 Measurement with HP 8753D

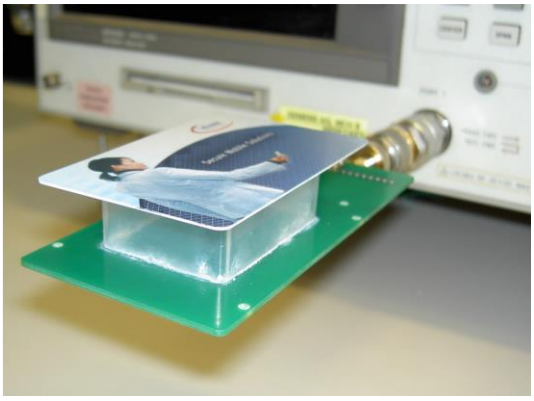

Figure 17 Setup for unloaded resonance frequency measurement

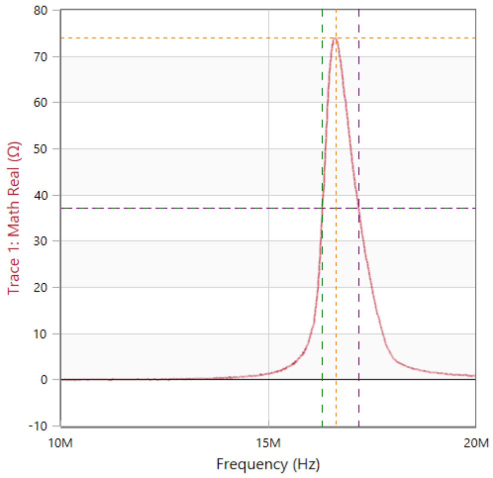

Figure 18 Unloaded resonance frequency measurement, $f_{res,UL}$ = 17.1 MHz

5.2.6 Measurement with Agilent 4395A

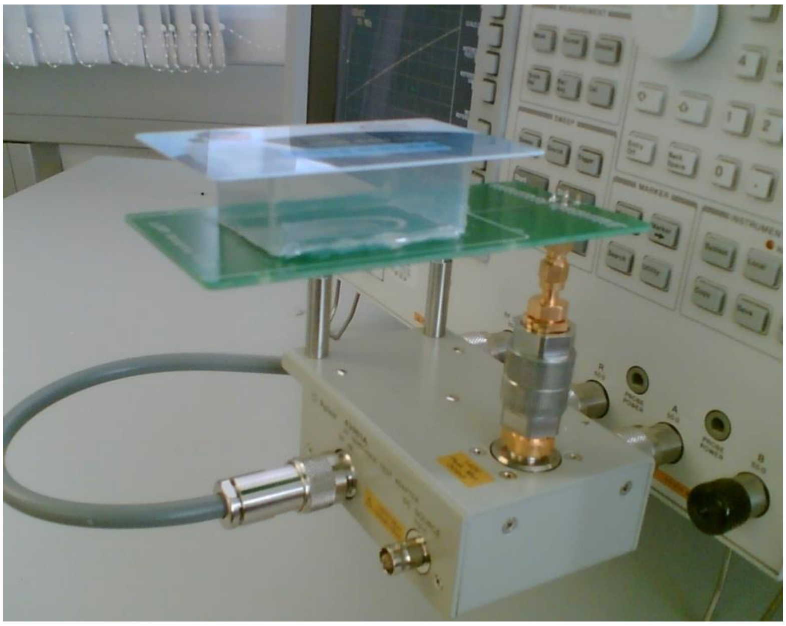

Figure 19 Setup for unloaded resonance frequency measurement with APC7 to SMA adapter

Figure 19 shows the setup for measuring the unloaded resonance frequency using the Agilent 43961A RF Impedance Test Adapter and an APC7 to SMA adapter to connect the measuring coil.

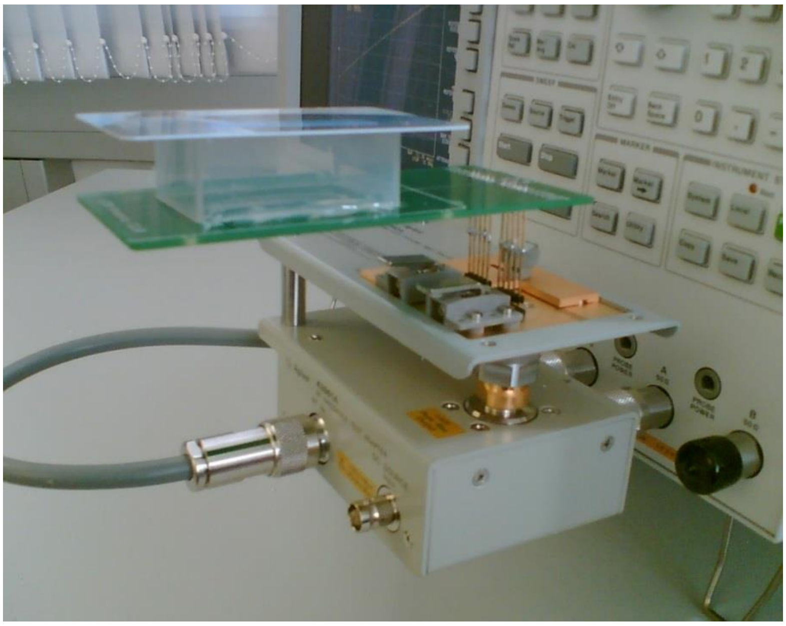

Figure 20 Setup for unloaded resonance frequency measurement with Agilent 16092A spring clip fixture

In Figure 20, an alternative setup for the unloaded resonance frequency measurement can be seen. Here the measuring coil is connected to the Agilent 43961A RF Impedance Test Adapter via an Agilent 16092A spring clip fixture.

5.2.7 Conclusion

There are two different resonance frequency measurement methods at different operation conditions: unloaded (low field strength) and threshold (threshold field strength) resonance frequency.

The relevant value for the card coil design is the threshold resonance frequency.

The value of the unloaded resonance frequency is always higher than the threshold resonance frequency. The offset is only constant for a specific IC input capacitance and coil design. Due to the fact that this measuring method is easy and quick, the unloaded resonance frequency is useful for monitoring the card manufacturing process. This means if the unloaded resonance frequency value is stable, then the threshold resonance frequency should also be fine.

5.3 Communication tests and standards compliancy testing

A simple communication test can be done using a PC/SC desktop reader or a POS Payment reader by placing the card on the reader device and reading its Aswer-To-Reset (ATR) data using an appropriate software tool. This will ensure that the IC is properly connected to the card coil and works as intended.

However, this test cannot ensure that the card will be fully interoperable with all kinds of reader devices or be compliant with the relevant standards. Therefore, Infineon Technologies strongly recommends testing the card against the *ISO/IEC 14443* [1], [2], [3], [4] specification using *ISO/IEC 10373-6* [5] test methods. For EMV Payment cards, a full EMV Level 1 analog test on EMV certified measurement equipment or a debug session at an EMV certified test laboratory should be done before releasing the coil design for certification or mass production.

6 FAQ - frequently asked questions

Question 1: We have a Class 1 coil design for Infineon's previous generation dual-interface security controllers (SLC52 or SLC 36/37) with 27 pF nominal IC input capacitance. Can we reuse the design with your current generation dual-interface TEGRION™ security controller?

Answer 1: This will probably work well, however it is highly recommended to confirm the full compliance to *ISO/IEC 14443* [2] [3] [4] requirements by measurement.

Question 2: We have a qualified and certified Class 2 card coil design for Payment applications for Infineon's previous generation dual-interface security controllers (SLC32 or SLC36/37) with 56 pF nominal IC input capacitance. The target resonance frequency of our design is ~14.0 MHz. Can we reuse the design with your current generation TEGRION™ security controller?

Answer 2: This will probably not work well. Due to the different IC design and more refined production process of the TEGRION™ security controller, the card coil's resonance frequency needs to be adjusted towards higher values to achieve best performance and full compliance to *EMV Contactless Interface Specifications* [8]. Please also refer to the recommended target card f_{res} for Class 2 coils for Payment applications in Table 2 and Infineon's Class 2 reference design for EMV compliant Payment applications as shown in Chapter 4.2.2.1.

Question 3: We have a small non-Class 2 coil design (e.g. 2/3 size or smaller) for Infineon's previous generation dual-interface security controllers (SLC32 or SLC 36/37) with 56 pF nominal IC input capacitance. Can we reuse the design with your current generation TEGRION™ security controller?

Answer 3: If your design has a comparably large active coil area (e.g. 2/3 size), it might work well. However, it is highly recommended to confirm this by measurements, since a resonance frequency adjustment might be necessary to achieve the best performance and full compliance to *EMV Contactless Interface Specifications* [8]. Smaller coil designs (Class 3-6) have not been tested and qualified with Infineon's TEGRION™ security controller and might not work without major modifications.

Question 4: Can the Infineon TEGRION™ security controller be used with Payment cards, that utilize laminates with metallic particles in their card construction (so-called holographic laminates or holofoils)?

Answer 4: Generally, yes, but the influence of the holographic laminate on the contactless performance of the card needs to be considered during the design of the card coil. The same recommendation to perform measurements applies here as outlined in Answer 3 above.

References

[1] International Standard ISO/IEC 14443-1, Fourth Edition, 2018-04

[2] International Standard ISO/IEC 14443-2, Fourth Edition, 2020-07

[3] International Standard ISO/IEC 14443-3, Fourth Edition, 2018-07

[4] International Standard ISO/IEC 14443-4, Fourth Edition, 2018-07

[5] International Standard ISO/IEC 10373-6, Fourth Edition, 2020-07

[6] International Standard ISO/IEC 7811-1, Fifth Edition, 2018-08

[7] International Standard ISO/IEC 7811-2, Fifth Edition, 2018-08

[8] EMV Contactless Interface Specification, Version 3.1, December 2020

[9] Infineon Card Coil Calculator Tool (https://softwaretools.infineon.com/tools)

[10] Handbook of Agilent 4285A LCR Meter

[11] Handbook of Hewlett Packard 8753D Network Analyzer

[12] User Manual of Omicron Lab Bode 100 Network Analyzer, Version 6.0, 2017

Glossary

AC
alternating current (AC)

DUT
device under test (DUT)

IC
integrated circuit (IC)

PC
polycarbonate (PC)

PCD
proximity coupling device (PCD)
A reader device for NFC cards.

PCM
process control monitoring (PCM)

PICC
proximity integrated circuit card (PICC)
A contactless smart card which can be read without inserting it into a reader device

PVC
polyvinyl chloride (PVC)

Revision history

Reference	Description
Revision 1.0, 2024-02-28	
All	Initial version

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Edition 2024-02-28
Published by
Infineon Technologies AG
81726 Munich, Germany

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