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Card Coil Design Guide for MIFARE DESFire Light

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Keywords	Contactless, MIFARE DESFire Light, ISO/IEC 14443, Resonance, Coil, Inlay, Antenna
Abstract	This document provides guidance for engineers designing magnetic loop antenna coils for MIFARE DESFire Light ICs

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1.0	20190131	Initial version

1 Introduction

MIFARE DESFire Light, a passive device (without battery) is powered by a magnetic field generated by the PCD. To get the magnetic flux cut by the PICC, it requires also a loop antenna.

This document describes some notes to the design of loop antennas for MIFARE DESFire Light. The detailed loop antenna design is explained in [1]. Although such antennas are relatively straightforward in principle and look very similar when comparing various contactless smartcards, experience proves that their parameters do have a noticeable impact on performance.

In this document, some antenna layout examples are attached for your reference but please adapt and verify them before you go for production. In this document the term „MIFARE DESFire Light card“ refers to a MIFARE DESFire Light IC-based contactless card.

1.1 How to use this document

In this document only the antenna design hints and notes specific to MIFARE DESFire Light are explained. All the basics and design details are explained in [1]. Please use [1]as the base document and apply wherever requires the notes mentioned here.

1.2 Terms and Abbreviations

Table 1. Abbreviations

Acronym	Description
CCDG	Card Coil Design Guide
PCD	Proximity Coupling Device
PICC	Proximity IC Card

2 Card Coil Design Notes for MIFARE DESFire Light

There are different classes of antennas widely used in contactless applications for the MIFARE DESFire Light PICC. For different antenna classes the design of PICC coils are different. Even different application requirements also lead to different antenna design.

Basically, three parameters are important for the card coil design: coil area, coil quality factor and resonance frequency of the transponder under loaded conditions.

2.1 Different classes of antenna according to ISO/IEC 14443-1

In Figure 1 different antenna sizes according to ISO/IEC 14443-1 [4] are shown.

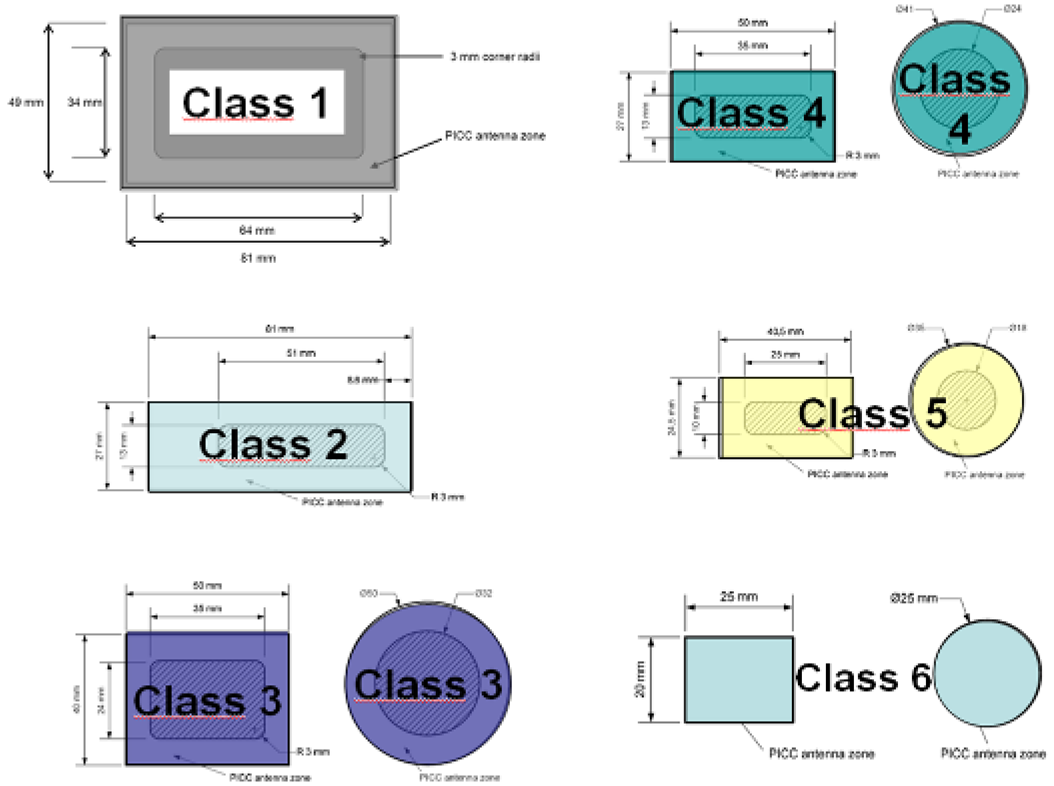

Figure 1. Different Coil antenna sizes according to ISO/IEC 14443-1

2.2 Average card coil area

Make the card coil area as big as possible. Rounded corners are better than sharp corners.

2.3 Coil Q-Factor

To achieve best performance and to cover manufacturing tolerances, for MIFARE DESFire Light, the recommended Coil Q values are given in Table 2.

2.3.1 Measurement of Coil Q-Factor

There are different ways to measure the Q-Factor of the coil antenna, which may end up with different results. Follow the way described in the Card Coil Design Guide [1] or ask your NXP technical support.

2.4 Definition for “unloaded” and “loaded” conditions.

“***loaded conditions***”, or just “loaded”, means that the MIFARE DESFire Light IC gets enough power to be able to fully operate. With the NXP setup used (defined in [2]), those conditions are achieved, when the power at the network analyzer output is set to the value of +10 dBm.

“***unloaded conditions***”, or just “unloaded”, means that the MIFARE DESFire Light IC doesn’t get enough power in order to even start to operate. With the NXP setup used (defined in [2]), those conditions are achieved, when the power at the network analyzer output is set to the value of -30 dBm.

Both conditions were created with a NXP dedicated measurement setup, which is described in [2]. All measurement results presented further down in this document have been obtained with this setup and under “loaded” and “unloaded” conditions as defined earlier in this paragraph.

2.5 Loaded resonance frequency of the transponder

The loaded resonance frequency of the transponder is the resulting resonance frequency, if the MIFARE DESFire Light contactless IC is operated under loaded conditions.

In general, the appropriate resonance frequency of the transponder depends on the input capacitance of the MIFARE DESFire Light IC. To achieve best performance and to cover manufacturing tolerances, for MIFARE DESFire Light, the recommend loaded resonance frequency is given in Table 2.

2.5.1 Measurement of loaded resonance frequency of the transponder

There are different ways to measure the resonance frequency of the transponder, which may end up with different results. Follow the way described in the Card Coil Design Guide [1] or ask your NXP technical support.

2.6 NXP recommendation for PICC coil design

Table 2 summarizes the recommendations for PICC coil design.

Table 2. PICC coil design recommendation

Antenna class	Recommended chip of MIFARE DESFire Light	Recommended loaded transponder resonance frequency (f_R)	Recommended Coil Q	Comments
Class 1	17 pF	13.56 MHz < fR < 16 MHz	> 30	Transponder optimum loaded resonance frequency for single card operation is close to 14.5MHz. Transponder optimum loaded resonance frequency for stacked 2 cards operation is close to 15.5MHz.
Class 2	50 pF	13.56 MHz < fR < 14.50 MHz	> 40	For 106 kbps and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz.
Class 3	50 pF	13.56 MHz < fR < 14.50 MHz	> 40	For 106 kbps and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz.
Class 4	50 pF	13.56 MHz < fR < 14.50 MHz	> 40	For 106 kbps and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz.
Class 5	50 pF	13.56 MHz < fR < 14.50 MHz	> 40	For 106 kbps and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz.
Class 6	50 pF	13.56 MHz < fR < 14.10 MHz	> 40	For 106 kbps and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz.

Those recommended quality factor values for the coil are important to get the best power transfer and to increase the so-called power range of the transponder. Those recommended values will also remain valid for higher bit rates than 106 kbps (up to 848 kbps).

For Class 1 antennas (17 pF input capacitance IC version) a minimum coil Q-Factor of 30 is recommended. The resulting transponder Q-factor under “unloaded” conditions is similar to this value. Once the IC starts to operate, the transponder (loaded) Q-Factor is decreasing and this is leading to a loaded Q-Factor in the range of Q = 8-9. This value is a good compromise in the middle of the Range Q = 6-15, which results in a good performance for all data transfer rates (from 106 kbps to 848 kbps).

All those considerations are valid as well for class 2 to class 6 antennas (50 pF input capacitance IC version), only difference is that a minimum coil Q-Factor of 40 is recommended.

Note: Increasing the communication bit rate may reduce the communication distance especially for the small antennas (smaller than Class 1). This could be caused by unsufficient coupling between reader and card antenna, as bigger designed antennas typically show a slight performance margin, but smaller once rather not.

2.7 Practical design hints and recommendations for 17 pF chip version

2.7.1 Class 1 wire wound antennas

Hints for antenna design:

Within the boarders of the application and the card manufacturing processes used, try to maximize the antenna size. The outermost turn of the antenna coil should be placed as close as possible to the edge of the card represented by an 81 x 49 mm rectangle. Class 1 antenna examples (with two different parameters) are shown in Figure 2.

Note: international standards and industry specifications may restrict the choice of the maximum allowed antenna coil size.

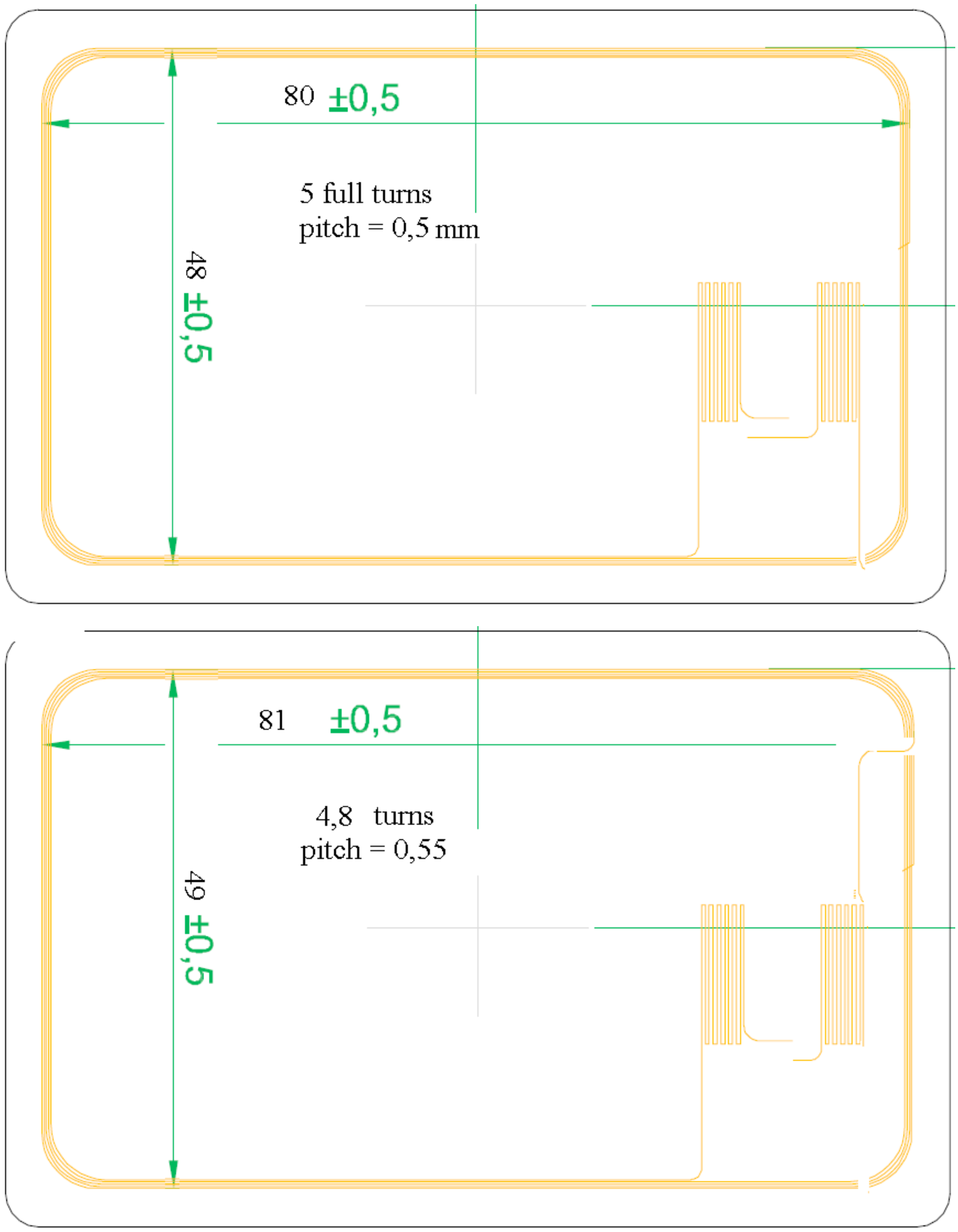

Figure 2. Class 1 antenna examples (with two different parameters)

For Class 1 (ID-11 size) antenna, the 17 pF input capacitance IC version is recommended. For all other classes (from ID-2 to ID-6) the usage of the 50 pF input capacitance IC version of the MIFARE DESFire Light chip is recommended.

Figure 3 shows further examples of typical parameters for different ID1-sized antenna designs. Besides geometrical coil parameters (orange colored area), also measured (blue colored area) and calculated (green colored area) electrical parameters are listed in comparison.

	Embedded Wire rectangular Antennas						
Dimensions	outline	mm	72,6 x 42	80,2 x 48	80 x 47,5	80 x 48	80,5 x 48
	wire diam.	mm	0,112	0,112	0,112	0,112	0,112 ?
	wire pitch	mm	0,14	0,45	0,45	0,45	0,3
	turns		5	5	4,9	5	5
measured	Ls @ 1MHz	µH	4,83	4,89	4,69	4,90	5,23
	Rs Q 1 MHz	Ohm	2,05	2,29	2,22	2,24	2,37
	fres	MHz	36,84	38,45	42,58	39,46	39,19
	Rp @ fres	kOhm	55,00	69,00	90,00	90,00	55,00
Calculated	Q @ fres		63,00	66,00	72,00	70,00	
	Cp	pF	3,87	3,51	2,98	3,32	3,16
	Rs	Ohm	3,92	3,78	3,22	3,38	4,49
	Q		105,03	110,11	124,00	123,70	99,16

Figure 3. Typical parameters of different realizations of class 1 card antennas

2.7.2 Class 1 etched antennas

One of possible antenna design realizations is shown in Figure 4.

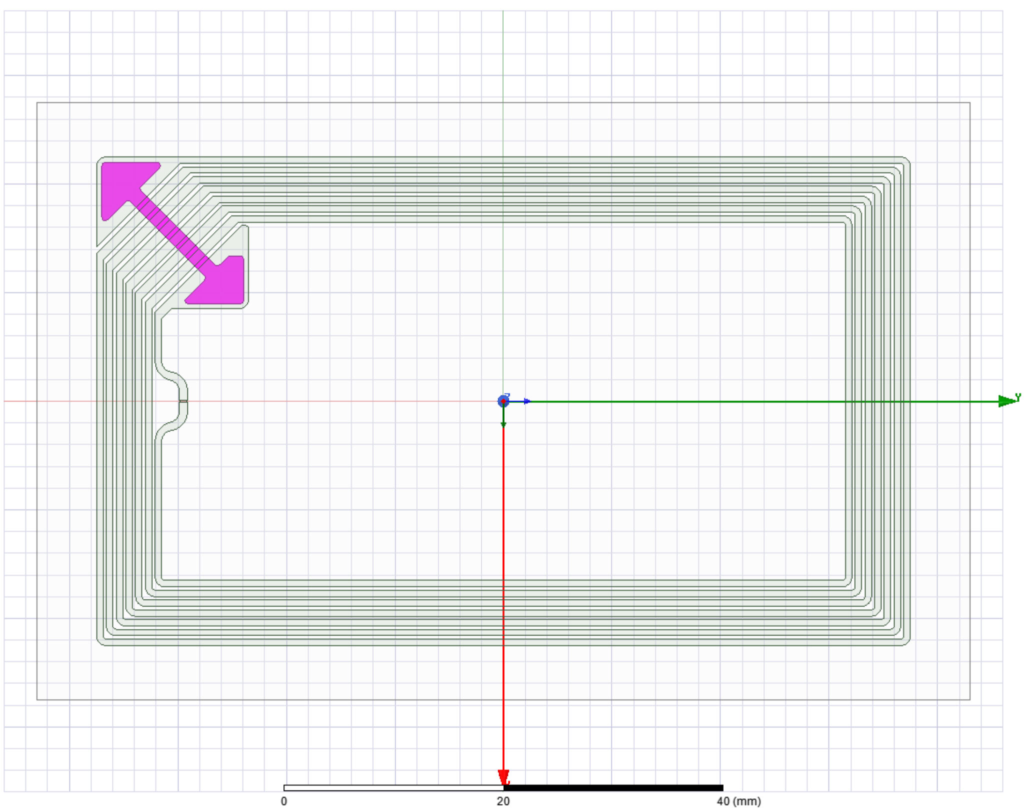

Figure 4. Class 1 Etched Antenna example - HFSS Simulation Model

The geometrical parameters of the antenna are given in Table 3

Table 3. Geometrical Parameters of a Class 1 etched antenna design

Parameter	Value
Antenna Dimension, mm x mm	75 x 45
Material:	Aluminum
Trackwidth, mm	0,6
Gap between tracks, mm	0,3
Track thickness (coil), mm	0,03
Track thickness (bridge), mm	0,01
Number of Turns	7
Carrier Material:	Polyester
Carrier Thickness, mm	0,038
Carrier Dielectric constant, Er:	3,2

and simulative electrical parameters are presented in Table 4.

Table 4. Electrical Parameters of a Class 1 etched antenna design

Parameter	Value
SRF, MHz	33,6412
R (@1MHz), Ohm	2,3814
L (@1MHz), uH	5,8623
R (@13,56MHz), Ohm	6,8700
L (@13,56MHz), uH	6,9165
C, pF	3,81
Cic, pF	17
Fres_PICC, MHz	14,5200

The drawing of this antenna (in DXF Format) is available and attached to this document.

To verify the simulation results an etched copper prototype has been (Fig 5) built and evaluated.

Figure 5. Class 1 Etched Antenna example - Prototype

Fig 6 shows a "loaded" resonance frequency and quality factors, whereas Fig 7 shows a "unloaded" resonance frequency and quality factors of the prototype.

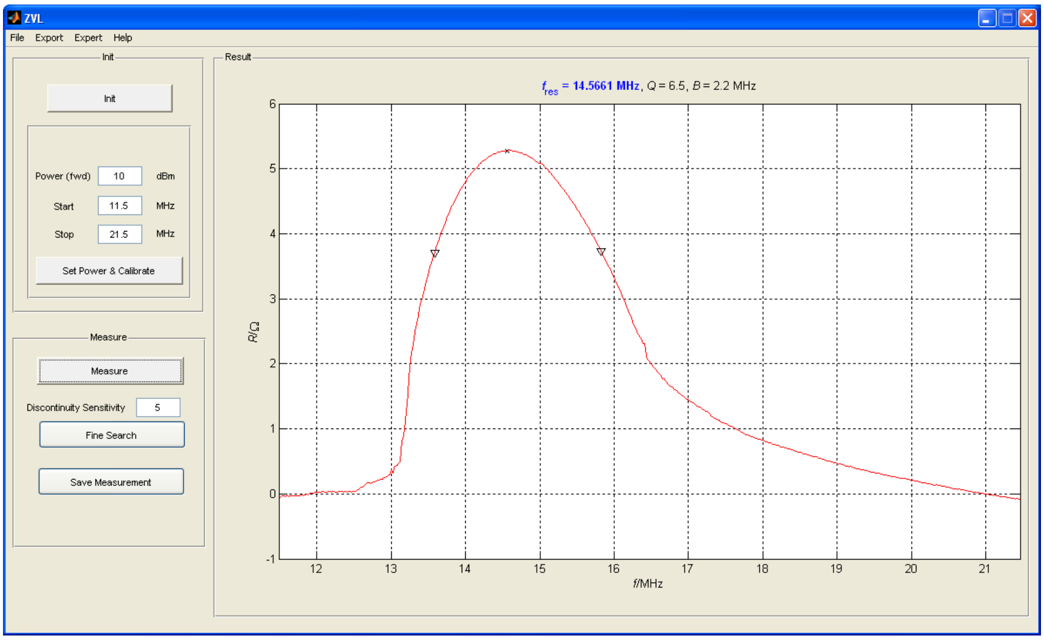

Figure 6. Loaded resonance frequency (14,56 MHz) and Quality factor (6,5) - Prototype

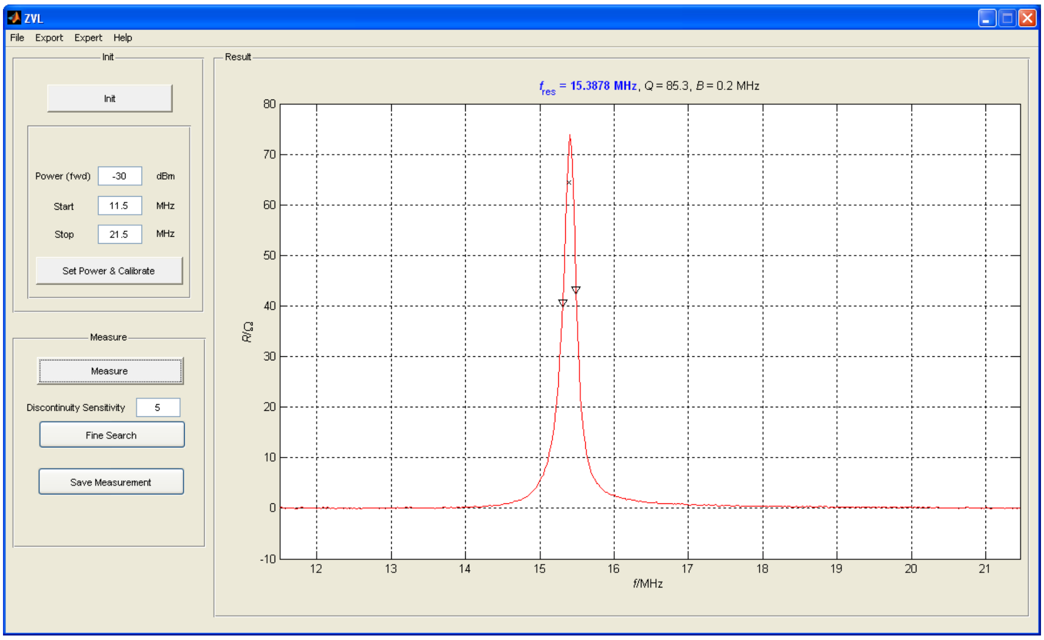

Figure 7. Unloaded resonance frequency (15,39 MHz) and Quality factor (85,3) - Prototype

The label sensitivity (Hmin) at 13,56 MHz is measured to be 0,175 A/m (Fig 8) for Level 3 activation.

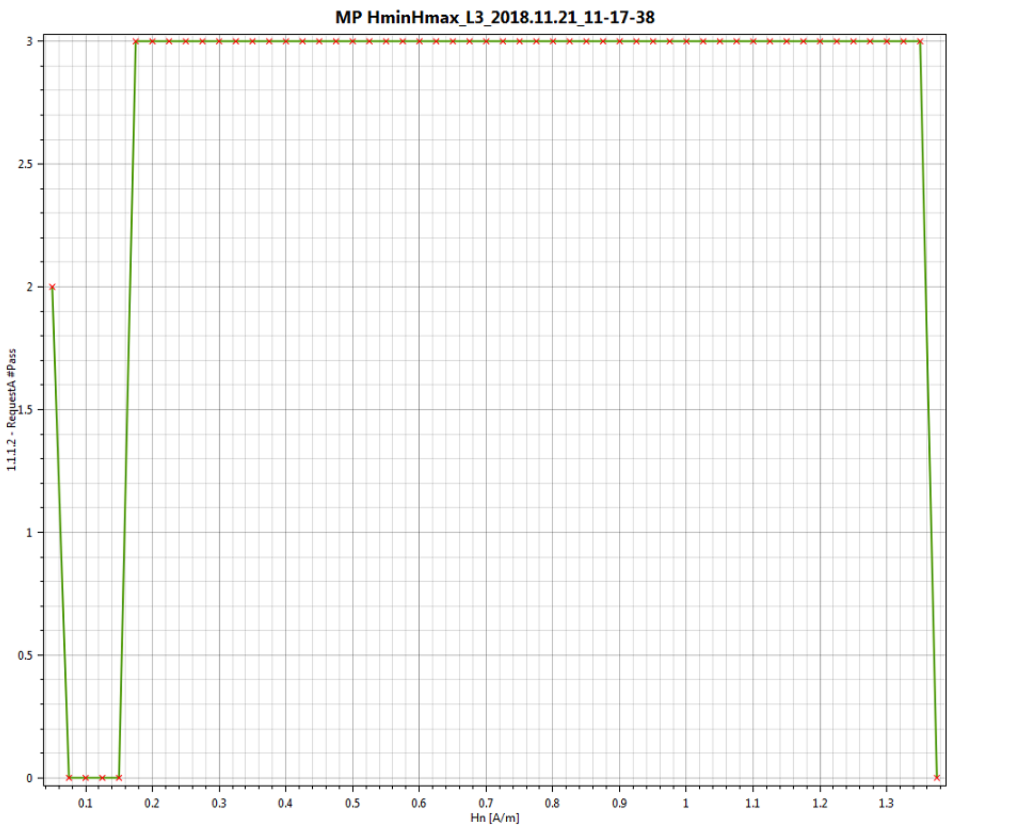

Figure 8. The label sensitivity (Hmin) at 13,56 MHz - Prototype

2.8 Practical design hints and recommendations for 50 pF chip version

For Class 2 and up to Class 6 antenna sizes, it is recommended to use 50 pF input capacitance IC version.

2.8.1 Class 6 etched antenna

One of possible antenna design realizations is shown in Fig 9.

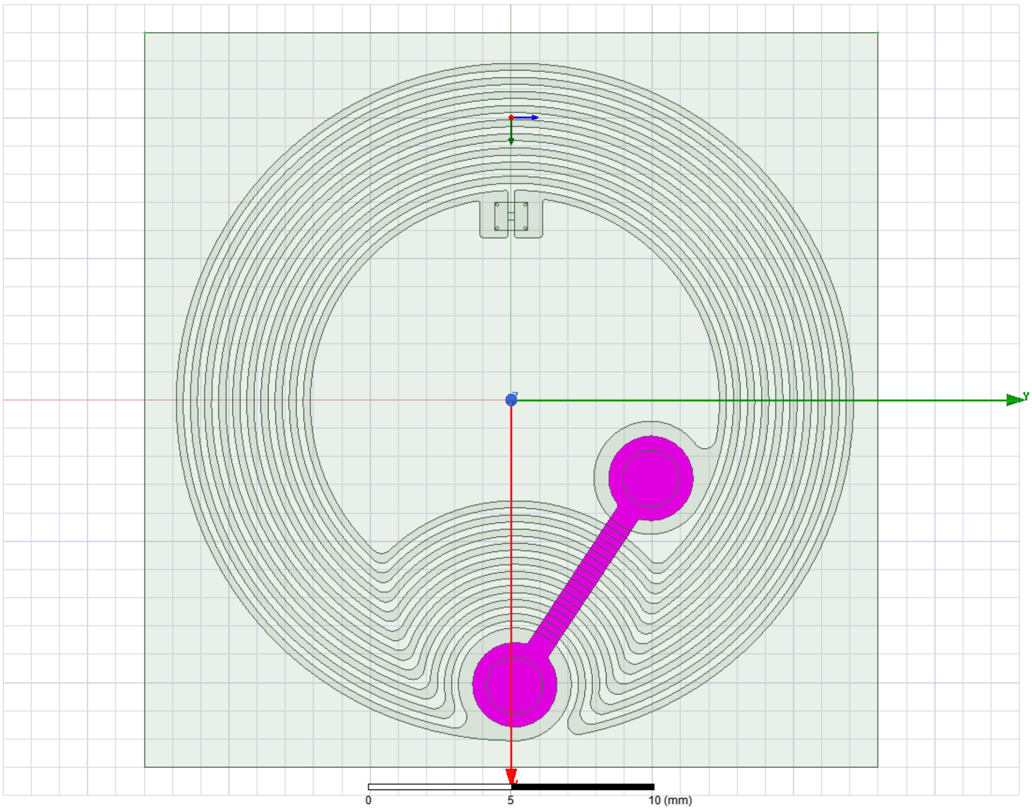

Figure 9. Class 6 Etched Antenna example - HFSS Simulation Model

Geometrical parameters of this antenna design is shown in Table 5.

Table 5. Geometrical Parameters of a Class 6 Etched Antenna design

Parameter	Value
Antenna Diameter, mm	24
Material:	Aluminum
Trackwidth, mm	0,25
Gap between tracks, mm	0,25
Track thickness (coil), mm	0,03
Track thickness (bridge), mm	0,01
Number of Turns	10
Carrier Material:	Polyester

Parameter	Value
Carrier Thickness, mm	0,038
Carrier Dielectric constant, Er:	3,2

and simulative electrical parameters are presented in Table 6.

Table 6. Electrical Parameters of a Class 6 Etched Antenna design

Parameter	Value
SRF, MHz	77,4140
R (@1MHz), Ohm	2,2765
L (@1MHz), uH	2,5668
R (@13,56MHz), Ohm	3,8604
L (@13,56MHz), uH	2,6054
C, pF	1,64
Cic, pF	50
Fres_PICC, MHz	13,9300

The drawing of this antenna (in DXF Format) is available and attached to this application note.

2.9 Required transponder bandwidth for (PICC --> PCD) data transfer

The demand for data transfer sets certain requirements on the transponder bandwidth *B*, which limits the transponder quality factor Q_T. The needed bandwidth is related to the modulation scheme, coding and data rates, used.

The highest data rate, which is defined in the standard, requires the largest transponder bandwidth.

Figure 10 demonstrates how this bandwidth can be calculated for 424 bit/s data rate.

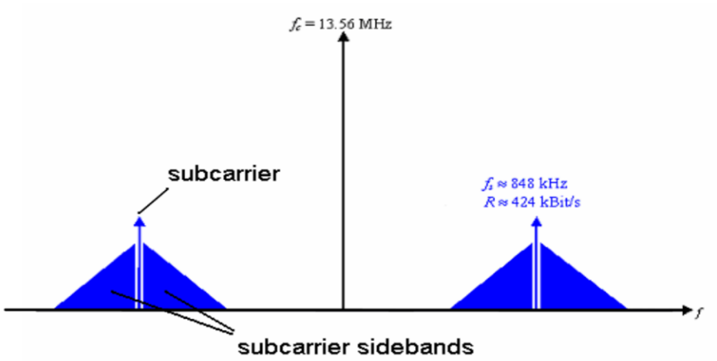

Figure 10. Transponder Bandwidth considerations

Other possible data rates and their relationship to their associated required bandwidth is given in Table 7.

Table 7. Theoretical PICC needed bandwidth for a data transfer with different data rates

Data rates [kbps]	B [MHz]
106	1,8
212	1,9
424	2,1
848	2,5
106	1,8

Note: if a transponder bandwidth is smaller, as recommended, this does not automatically mean that the communication will not be possible. What will happen is that the sideband levels of the card answer will be damped more than 3 dB. It is not recommended, but still sufficient for successful communication.

Note for higher antenna classes (Class 2 to Class 6): The inductance of the coil size reduces the coil size. It is recommended to use 50pF input capacitance IC versions for antenna sizes smaller than Class 1. This results in the increase of the transponder factor, Q_T. It is recommended to control resulting Q_T or bandwidth *B* of the new designed small transponder, to enable successful communication for all desired data rates.

3 References

1. AN11093 Card Coil Design Guide, Document Number: 0117**[1]
2. PICC and VICC Resonance Frequency Measurement
3. M. Gebhart, Air Interface, Antennas and Signals in Contactless Near-Field Communication 2nd lecture in Selected Topics of Advanced Analog Chip Design, 439.224
4. Contactless Card Standard ISO/IEC 14443-1:2018

1 ** ... BU S&C document version number

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Tables

Tab. 1. Abbreviations 3
Tab. 2. PICC coil design recommendation 6
Tab. 3. Geometrical Parameters of a Class 1 etched antenna design 10
Tab. 4. Electrical Parameters of a Class 1 etched antenna design 10
Tab. 5. Geometrical Parameters of a Class 6 Etched Antenna design 13
Tab. 6. Electrical Parameters of a Class 6 Etched Antenna design 14
Tab. 7. Theoretical PICC needed bandwidth for a data transfer with different data rates 15

Figures

Fig. 1. Different Coil antenna sizes according to ISO/IEC 14443-1 4
Fig. 2. Class 1 antenna examples (with two different parameters) 8
Fig. 3. Typical parameters of different realizations of class 1 card antennas 9
Fig. 4. Class 1 Etched Antenna example - HFSS Simulation Model 9
Fig. 5. Class 1 Etched Antenna example - Prototype 11
Fig. 6. Loaded resonance frequency (14,56 MHz) and Quality factor (6,5) - Prototype 11
Fig. 7. Unloaded resonance frequency (15,39 MHz) and Quality factor (85,3) - Prototype 12
Fig. 8. The label sensitivity (Hmin) at 13,56 MHz - Prototype 12
Fig. 9. Class 6 Etched Antenna example - HFSS Simulation Model 13
Fig. 10. Transponder Bandwidth considerations 15

Contents

1	**Introduction**	**3**
1.1	How to use this document	3
1.2	Terms and Abbreviations	3
2	**Card Coil Design Notes for MIFARE DESFire Light**	**4**
2.1	Different classes of antenna according to ISO/IEC 14443-1	4
2.2	Average card coil area	4
2.3	Coil Q-Factor	4
2.3.1	Measurement of Coil Q-Factor	5
2.4	Definition for “unloaded” and “loaded” conditions.	5
2.5	Loaded resonance frequency of the transponder	5
2.5.1	Measurement of loaded resonance frequency of the transponder	5
2.6	NXP recommendation for PICC coil design	5
2.7	Practical design hints and recommendations for 17 pF chip version	7
2.7.1	Class 1 wire wound antennas	7
2.7.2	Class 1 etched antennas	9
2.8	Practical design hints and recommendations for 50 pF chip version	13
2.8.1	Class 6 etched antenna	13
2.9	Required transponder bandwidth for (PICC --> PCD) data transfer	15
3	**References**	**16**
4	**Legal information**	**17**

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