# AN12755

## MIFARE DESFire EV3 card coil design guide

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Application note
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**Document information**

| Information | Content |
|---|---|
| Keywords | Contactless, MIFARE DESFire EV3, ISO/IEC 14443, resonance, coil, inlay, antenna, card coil design |
| Abstract | This document provides guidance for engineers designing magnetic loop antenna coils for MIFARE DESFire EV3. |

# Revision history

**Revision history**

| Rev | Date | Description |
|---|---|---|
| 1.2 | 20201217 | • The format of this application note has been redesigned to comply with the new identity guidelines of NXP Semiconductors.<br>• Security status changed into "COMPANY PUBLIC", no content change |
| 1.1 | 20200928 | Guidelines for flip-chip assembly in Section 3 included |
| 1.0 | 20200814 | Initial version |

# 1 Introduction

MIFARE DESFire EV3, 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 also requires a loop antenna.

This document describes some notes to the design of such loop antennas for MIFARE DESFire EV3.

The detail 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 examples are attached for your reference but please adapt and verify them before you go for production. In addition, customers who want to reuse existing MIFARE DESFire EV1 or MIFARE DESFire EV2 card coil antenna design or design a completely new antenna can also get information as to what considerations to make.

In this document, the term „MIFARE DESFire card" refers to a MIFARE DESFire IC-based contactless card.

## 1.1 How to use this document

In this document, only the hints and notes specific to MIFARE DESFire EV3 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 |
| EV1 | Evolution 1 |
| EV2 | Evolution 2 |
| EV3 | Evolution 3 |
| PCD | Proximity coupling device |
| PICC | Proximity IC card |
| $f_R$ / fres | Resonance frequency |

# 2 Card coil design notes for MIFARE DESFire EV3

There are different classes of antennas widely used in contactless application for the MIFARE DESFire EV3 PICC. For different antenna classes, the design of PICC coils is 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 the 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.

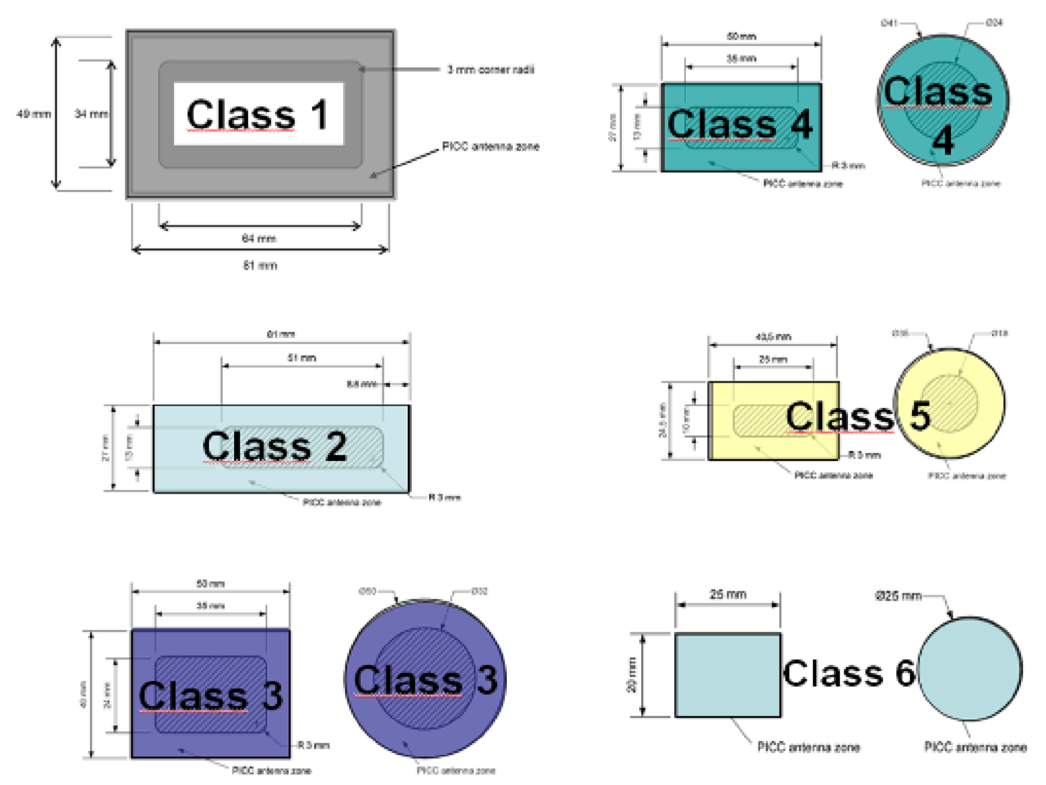


Figure 1. Different coil antenna sizes according to ISO/IEC 14443-1

## 2.2 Average card coil area

Make the card coil area as large as possible. The bending corners are better than sharp corners.

## 2.3 Coil Q-factor

To get optimum performance and to cover manufacturing tolerances, for MIFARE DESFire EV3, 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, 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 EV3 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 EV3 IC does not 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 an 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 IC is operated under loaded conditions.

In general, the appropriate resonance frequency of the transponder depends on the card ICs and applications. To get optimum performance and to cover manufacturing tolerances, for MIFARE DESFire EV3, the recommended 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.

**Note the following points applicable to the 17 pF chip version:**

- MIFARE DESFire EV3 works properly between 13.56 - 16 MHz loaded fres. However, for optimization of speed at a 1.5 A/m field strength, a **loaded fres of 15.0 - 15.5 MHz is most ideal and recommended**.
- For maximum operating distance, the loaded fres is ideally close to 14.5 MHz.
- A loaded fres too close at 13.56 MHz (e.g 14.00 MHz) might have an impact on detuning of the reader antenna and might cause reading issues on some reader models.

**Table 2. PICC coil design recommendation**

| Antenna class | Recommended chip of MIFARE DESFire EV3 | Recommended loaded transponder resonance frequency ($f_R$) | Recommended Coil Q | Comments |
|---|---|---|---|---|
| Class 1 | 17 pF | 13.56 MHz < $f_R$ < 16 MHz | > 30 | Transponder optimum loaded resonance frequency for stacked 2 cards operation is close to 15.5 MHz. |
| Class 2 | 70 pF | 13.56 MHz < $f_R$ < 14.50 MHz | > 40 | For 106 kbit/s and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz. |
| Class 3 | 70 pF | 13.56 MHz < $f_R$ < 14.50 MHz | > 40 | For 106 kbit/s and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz. |
| Class 4 | 70 pF | 13.56 MHz < $f_R$ < 14.50 MHz | > 40 | For 106 kbit/s and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz. |
| Class 5 | 70 pF | 13.56 MHz < $f_R$ < 14.50 MHz | > 40 | For 106 kbit/s and single card application. The optimum loaded resonance frequency is slightly above 13.56 MHz. |
| Class 6 | 70 pF | 13.56 MHz < $f_R$ < 14.10 MHz | > 40 | For 106 kbit/s 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 a good 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 kbit/s (up to 848 kbit/s).

For class 1 antennas (17 pF IC version) a minimum Coil Q-Factor = 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 kbit/s to 848 kbit/s).

All those considerations are valid as well for class 2 to class 6 antennas (70 pF IC version), only difference is that a minimum Coil Q-Factor = 40 is recommended.

Check sections Section 2.9.1 in this document for further reference on this topic. Note: Increasing the communication bit rate may reduce the communication distance especially for the small antennas (smaller than class 1).

## 2.7 Practical design hints and recommendations for 17 pF chip version

### 2.7.1 ID1-sized antennas

Hints for antenna design

- Within the confines 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.

For ID1 size (class 1) antenna, the 17 pF chip version is recommended. For all other classes, the usage of the 70 pF version of the MIFARE DESFire EV3 chip is recommended.

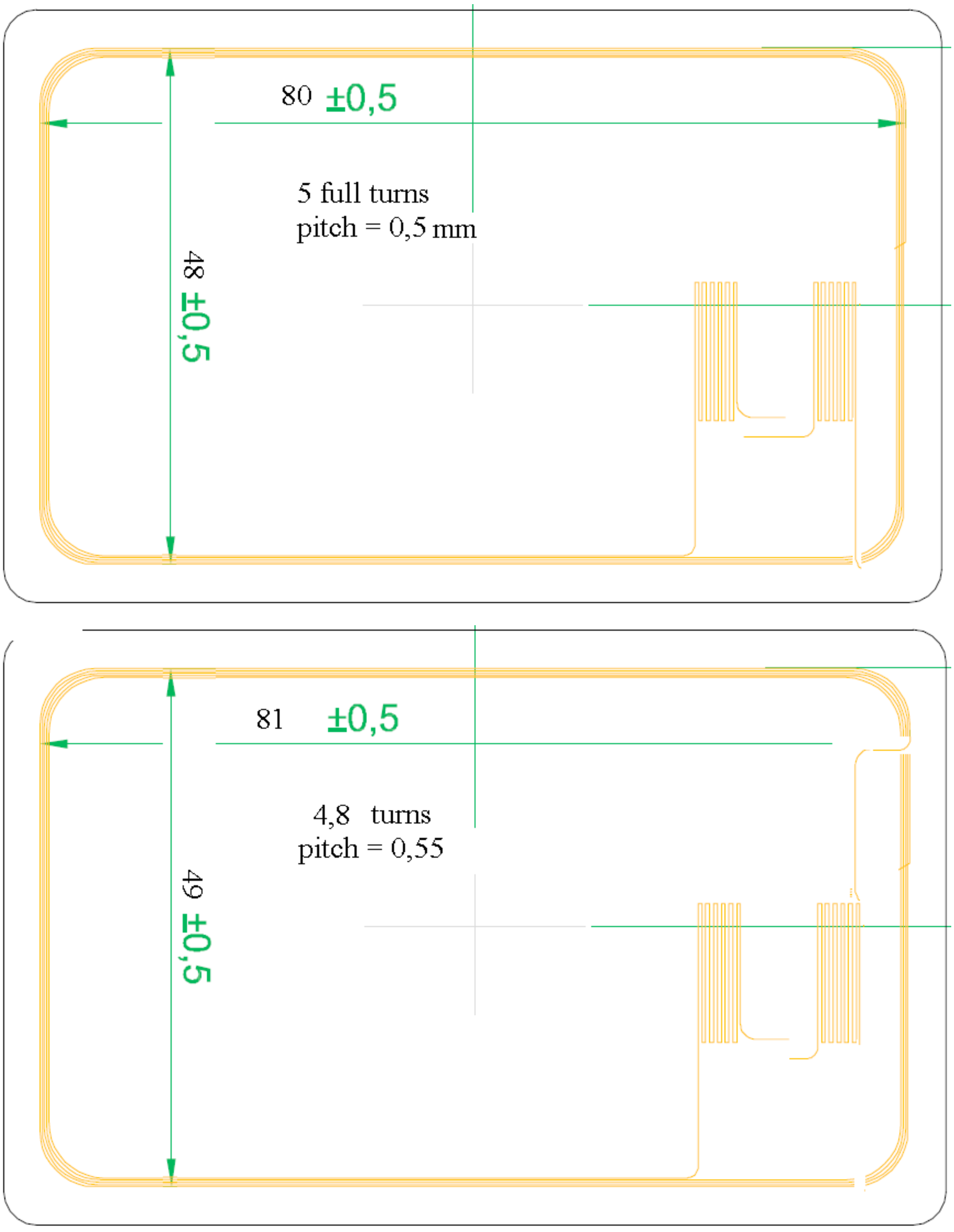


**Figure 2. Class 1 antenna examples (with two different parameters)**

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 class 1 card antennas**

## 2.8 Practical design hints and recommendations for 70 pF chip version

For class 2 and up to class 6 antennas, it is recommended to use 70 pF chip version.

### 2.8.1 ID ½ sized (class 2) antenna

Geometrical parameters of one possible class 2 size antenna design, as well as its location within the ID1 card area is shown in Figure 4.

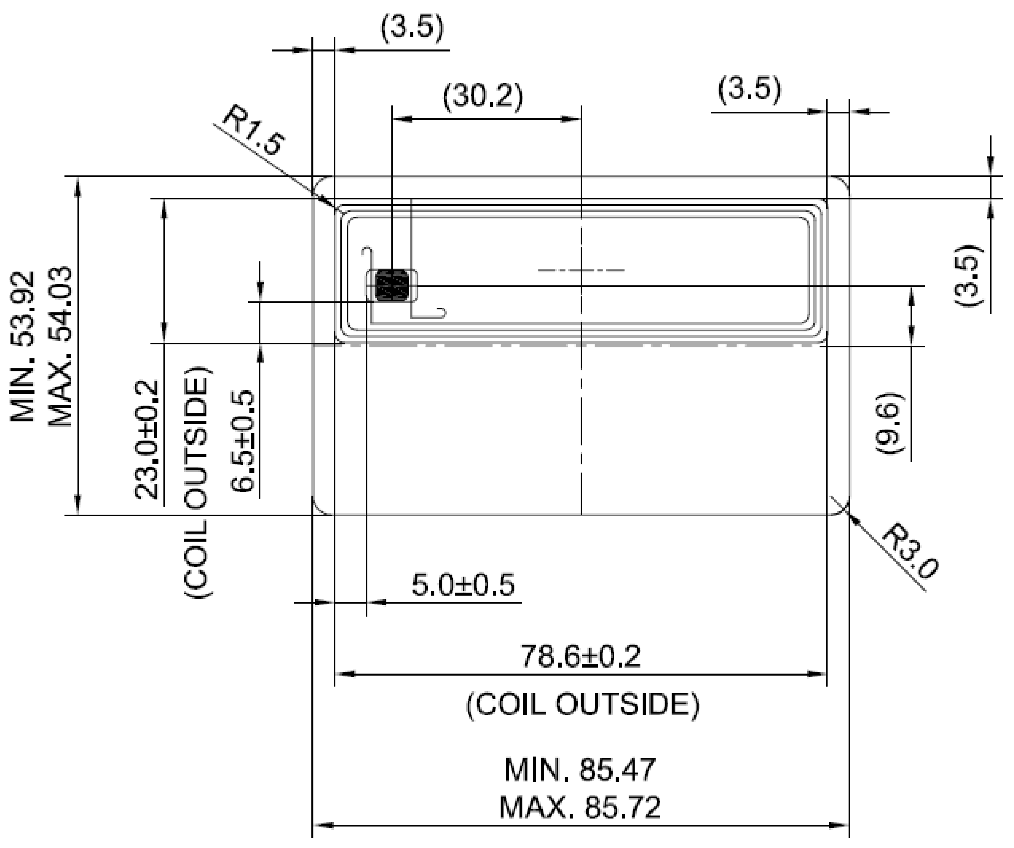


**Figure 4. Class 2 antenna example**

## 2.9 Antenna coil design considerations for unloaded and loaded conditions (17 pF IC)

### 2.9.1 Quality factor and bandwidth of the transponder

The quality factor of a transponder $Q_T$ is an important parameter defined at air interface. The value of $Q_T$ has to be properly chosen in order to guarantee sufficient performance for both power and data transmission.

The quality factor of the transponder results from the quality factor values of its' both components, the antenna ($Q_A$) and the chip ($Q_C$), and is dictated by the component with lower Q-factor, in this case by the $Q_C$. Taking into account that both chip electrical parameters (capacitance $C_C$ and resistance $R_C$) are power-dependent, it is obvious that the $Q_T$ also changes with power and frequency. This point is relevant when considering $Q_T$ under "loaded" and "unloaded" conditions.

For a transponder resonant LCR circuit, $Q_T$ can be determined in frequency domain. $Q_T$ is related to the bandwidth, which can be measured from the resistance trace as shown in Figure 5 [3].

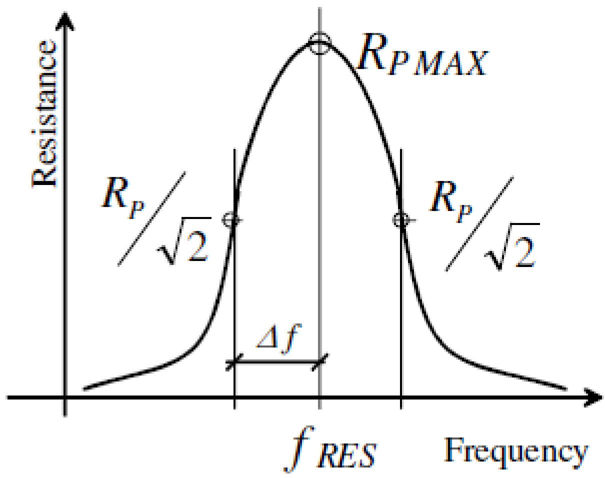


**Figure 5. Resistance trace for determining the transponder bandwidth**

$Q_T$ can be calculated by using Equation 1, which connects three relevant parameters (quality factor $Q_T$, resonance frequency $f_{res}$ and bandwidth $B$) with each other:

$$Q_T = \frac{f_{res}}{2 \cdot \Delta f} = \frac{f_{res}}{B} \quad (1)$$

where $f_{res}$ is a transponder resonance frequency and $\Delta f$ is defined as in Figure 5.

**Note**: This is only valid, if the broadband equivalent circuit representation really is a parallel resonant circuit.

## 2.10 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 6 demonstrates how this bandwidth can be calculated for 424 bit/s data rate.

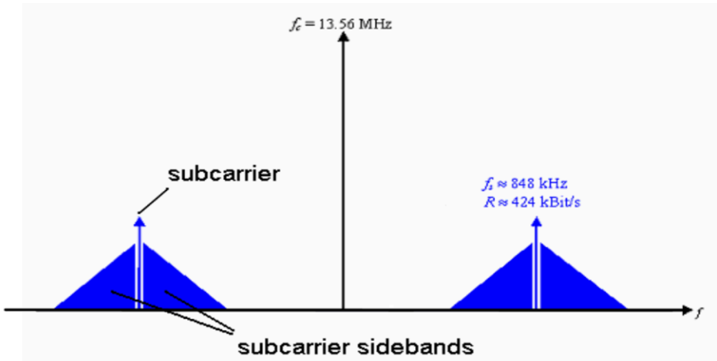


**Figure 6. Theoretical needed PICC bandwidth for a data transfer at 424 kB/s**

Other possible data rates and their relationship to their associated required bandwidth is given in Table 3.

**Table 3. Theoretical PICC needed bandwidth for a data transfer with different data rates**

| Data rates [kbit/s] | B [MHz] |
|---|---|
| 106 | 1.8 |
| 212 | 1.9 |
| 424 | 2.1 |
| 848 | 2.5 |
| 106 | 1.8 |

**One important remark**: If a transponder bandwidth is smaller, than theoretically required bandwidth, 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 more damped than 3 dB, (which was accepted for a bandwidth definition), but are still sufficient for successful communication.

**Note for higher antenna classes (class 2 to class 6):** With coil size reduction the inductance of the coil decreases. Additionally, there is a recommendation to utilize 70 pF IC version together with antennas smaller than class 1. This results in the increase of the transponder $Q_T$ factor. 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 Guidelines for flip chip assembly

We would advise to our customers to only use the PI coated version of our chips for flip chip assembly.

The bond pad location is illustrated in Figure 7.

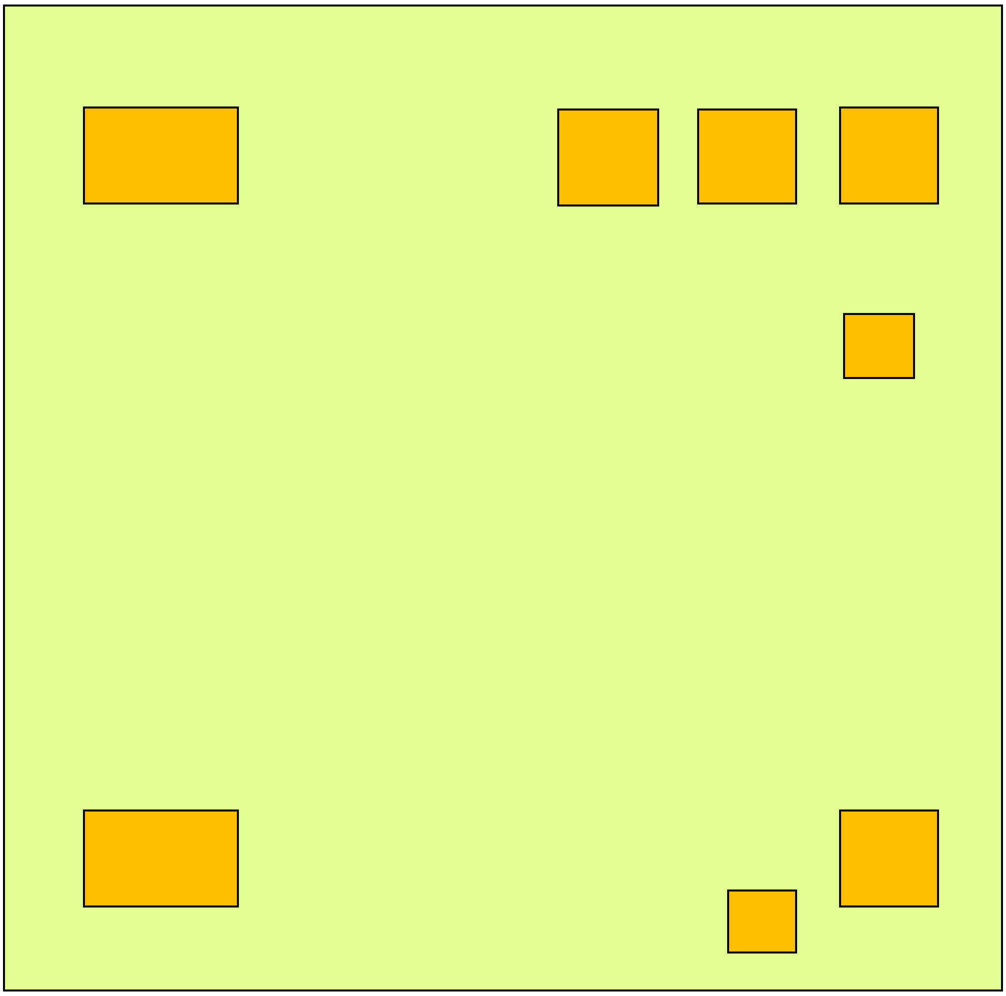

**Figure 7. Bond pad location for MIFARE DESFire EV3**

Bond pad details are explained in the wafer and delivery specification of MIFARE DESFire EV3, see [4].

One possible solution is described below and illustrated in Figure 8. Also, other solutions could be possible work but have not been evaluated by NXP.

The bumps for the antenna contacts should be placed on the aluminum. There will be three aluminum pads - one for LA, one for LB, one for the other bumps.

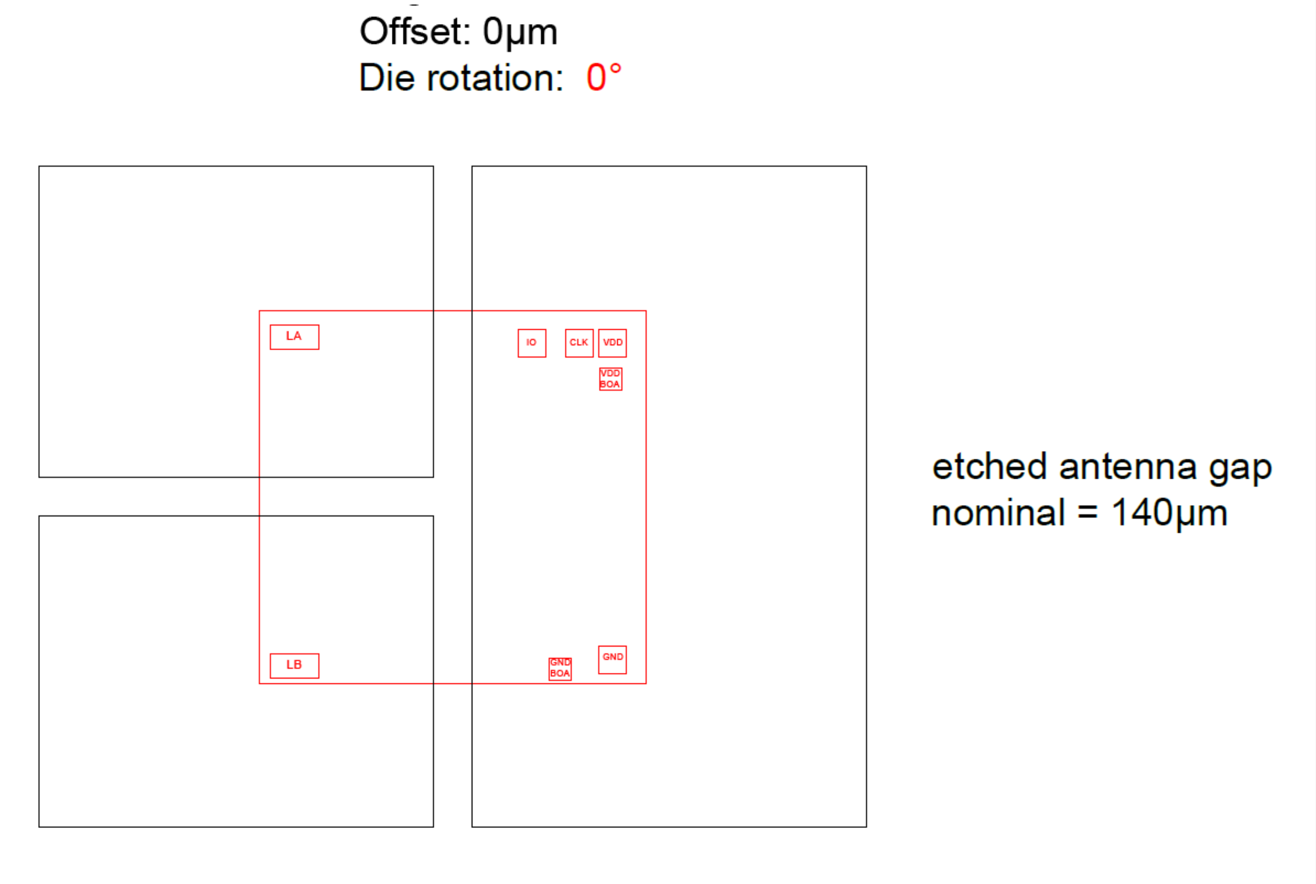


Figure 8. Die landing pad design example

## 4 References

[1] AN11093 Card coil design guide, document number: 0117xx, available on https://www.nxp.com/docs/en/application-note/AN11340.pdf

[2] PICC and VICC resonance frequency measurement (see pdf file attached to this document)

[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 14443-1:2010

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## Tables



 

# Figures

## Contents





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