Introduction

This document describes a simplified method to design a double-layer antenna for the products listed in Table 1. This method is based on eDesignSuite, a free on-line tool (available on www.st.com) featuring a calculation module that helps customers to design single-layer, rectangular coil antennas for NFC applications.

Antenna tuning frequency adjustment and validation is required as part of the procedure. The maximum acceptable value for the external tuning capacitance is discussed regarding RF communication requirements.

Table 1. Applicable products

<table>
<thead>
<tr>
<th>Type</th>
<th>Applicable products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ST25DV-I2C and ST25DV-PWM series Dynamic NFC Tags</td>
</tr>
<tr>
<td></td>
<td>M24LR and M24SR series Dynamic NFC Tags</td>
</tr>
</tbody>
</table>
Contents

1 Tag electrical model .................................................. 5
2 Tag antenna tuning ..................................................... 6
3 Tag antenna equivalent model ...................................... 7
   3.1 eDesignSuite NFC antenna calculation module features .... 8
4 Designing double layer antennas with eDesignSuite ............ 9
   4.1 Simplified equivalent electrical model of a double layer antenna 9
   4.2 Practical study .................................................... 10
   4.3 Double layer antenna design methodology with eDesignSuite 10
5 Revision history ....................................................... 12
List of tables

Table 1. Applicable products ................................................................. 1
Table 2. Document revision history ....................................................... 12
List of figures

Figure 1. RFID tag physical model ................................................................. 5
Figure 2. RFID tag electrical model ............................................................. 5
Figure 3. Spiral coil typical impedance vs. frequency ................................... 7
Figure 4. Simplified antenna equivalent model ........................................... 7
Figure 5. Diagram form of a double layer antenna ...................................... 9
Figure 6. Double layer antenna simple electrical model ............................... 9
Figure 7. Top view of top and bottom antenna layers ................................. 10
1 Tag electrical model

Figure 1 shows a tag in a variable magnetic field: its electrical model is sketched in Figure 2, where $Z_a$ represents the spiral antenna impedance, $Z_c$ the RFID/NFC tag IC impedance and $V_{oc}$ the open circuit voltage delivered by the antenna.

![Figure 1. RFID tag physical model](image1)

![Figure 2. RFID tag electrical model](image2)
2 Tag antenna tuning

The optimization of the communication distance requires to maximize the power transfer between tag antenna and the RFID/NFC tag IC under minimum operating conditions. This occurs when

Equation 1: \( Z_a^* = Z_c \) \( (Z_a^* \) is the complex conjugate of \( Z_a \))

Expressing the impedances of tag antenna and tag IC as, respectively, \( Z_a = R_a + j X_a \) and \( Z_c = R_s + j X_s \), the condition leads to

Equation 2: \( R_a = R_s \) and \( X_a = -X_s \)

At minimum operating condition, serial equivalent resistance of the tag IC and of the antenna are both in a range of few ohms, hence it is possible to consider that the first part of Equation 2 is satisfied.

Regarding power reception, RFID/NFC tag IC can be modeled as a resistance (representing the current consumption) in parallel to a capacitor, hence its reactance \( X_s \) is capacitive:

\[ X_s = -\frac{1}{C_s \omega} \]

with \( \omega = 2 \pi f \), where \( f \) is the desired tuning frequency and \( C_s \) represents the series equivalent capacitance of the chip.

For the antenna design the datasheets provide the value of tuning capacitance \( C_{\text{tune}} \), that is \( C_s \) at minimum operating power.

Then, following Equation 2, the design of a 13.56 MHz tag antenna consists in building a spiral coil with inductive reactance \( X_a \) satisfying \( X_a = \frac{1}{C_{\text{tune}} \omega} \) for the desired tuning frequency \( f_{\text{tune}} \).
3 Tag antenna equivalent model

*Figure 3* shows the typical impedance of a spiral coil as a function of frequency: the impedance varies according to frequency and shows a self-resonant frequency $f_{\text{self_res}}$:

- $f > f_{\text{self_res}}$: $X_a < 0$ and the spiral coil impedance is capacitive
- $f < f_{\text{self_res}}$: $X_a > 0$ and the spiral coil impedance is inductive

*Figure 3. Spiral coil typical impedance vs. frequency*

NFC/RFID antennas must have a self-resonant frequency higher than 13.56 MHz to have a small serial equivalent resistance and operate in the inductive range.

A simplified equivalent model of antenna impedance based on frequency independent components is shown in *Figure 4*:

- $L_{\text{pa}}$ correspond to the self-inductance of antenna, measured at very low frequency
- $C_{\text{pa}}$ is a stray capacitance that can be calculated from $L_{\text{pa}}$ and the antenna self-resonant frequency using

\[
L_{\text{pa}} \cdot C_{\text{pa}} \cdot (2 \pi f_{\text{self_res}})^2 = 1
\]

- $R_{\text{pa}}$ corresponds to the serial equivalent resistance measured at self-resonant frequency.

*Figure 4. Simplified antenna equivalent model*
3.1 eDesignSuite NFC antenna calculation module features

The self-inductance of a spiral coil can be approximated using well-known formulas. However, the lower the self-resonant frequency (high number of turns, small spacing), the higher is the $C_{pa}$ impact on antenna impedance, and antenna reactance $X_a$ cannot be approximated by the formula $X_a = L_{pa} \times 2 \pi f$.

As described in application notes AN2866 and AN2972 (available on www.st.com), tag antenna can be designed based on antenna self-inductance, neglecting in a first step the stray capacitance. This process requires to produce antenna variants, finding the right design by successive approximations. For antennas etched on application PCBs, this trial-and-error process is not efficient.

STMicroelectronics eDesignSuite NFC antenna module provides an accurate value of coil antenna reactance $X_a$ by calculating the self-inductance and combining it with the effects of the stray capacitance. eDesignSuite antenna module displays as a result the serial equivalent inductance obtained from the formula $L_a$ (in H) = $X_a / (2 \pi \times 13.56$ MHz).

The expected precision is in the 5% range. For antennas whose self-resonant frequency is too low to guarantee this precision, a specific message warns the user.
4 Designing double layer antennas with eDesignSuite

To guarantee a good precision, eDesignSuite NFC antenna module is limited to one-layer antennas. However, it is possible to use it to design a double-layer antenna.

4.1 Simplified equivalent electrical model of a double layer antenna

*Figure 5* shows the diagram a double layer antenna. Turn rotation is the same on both layers. L1 is the inductance of layer 1 spiral, and L2 the inductance of spiral on layer 2.

**Figure 5. Diagram form of a double layer antenna**

L1 and L2 are connected in series and coupled magnetically by a coupling factor k, as shown in *Figure 6*.

**Figure 6. Double layer antenna simple electrical model**

The total equivalent self-inductance is $L_{tot} = L1 + L2 + k(L1 \times L2)^{1/2} + k(L1 \times L2)^{1/2}$.

If the two coils have an equal number of turns, the same dimensions, track width and spacing, then $L1 = L2 = L$. In the ideal case where the two coils are perfectly coupled, $k = 1$ and the total self-inductance is:

**Equation 4:** $L_{tot} = L + L + L + L = 4L$

Coupling factor between the two identical spiral coil depends upon the distance between layers and the size of coils, usually is lower than 1. The total antenna inductance becomes:

**Equation 5:** $L_{tot} = L + L + kL + kL = 2L(1 + k)$

This simplified model does not take into account the effect of the parasitic capacitance between the two coils.
4.2 Practical study

When performing electromagnetic simulation of double layer antennas and their single layer counterparts, it comes that for layer spacings between 0.1 and 0.8 mm the k factor from Equation 5 varies roughly from 0.9 to 0.5.

In other words, $L_{tot}$ varies from 3 to 3.8 $L$, where $L$ is the equivalent inductance of the single layer part of the antenna.

4.3 Double layer antenna design methodology with eDesignSuite

Based on the data presented before the following methodology can be used to design a double layer antenna using the NFC antenna design module of eDesignSuite.

1. Define the desired antenna equivalent inductance $L_{tot}$ (see AN2866 and AN2972 for more details about antenna inductance choice and tuning frequency validation).
2. Compute the single layer spiral coil with $L = L_{tot} / 4$ equivalent inductance using eDesignSuite.
3. Layout the double layer antenna on PCB using the dimensions calculated in 2, keeping the same turn orientation on both layers. Figure 7 shows an example of good spiral coil implementation (clockwise turning spirals): top layer spiral turns from outside to inside, bottom layer spiral turns from inside to outside.

![Figure 7. Top view of top and bottom antenna layers](image)

4. Add the footprint for an external tuning capacitance, needed to compensate the difference between the real antenna tuning frequency and the desired one.
5. On prototype, measure the actual tag tuning frequency $f_1$ with the NFC/RFID tag IC mounted.
6. Compute the additional tuning capacitance $C_{add}$ from the NFC/RFID tag IC tuning capacitance $C_{tune}$, the desired tuning frequency $f_{tune}$ and the actual tuning frequency $f_1$ (previously measured) using the formula $C_{add} = [(f_1 / f_{tune})^2 - 1] * C_{tune}$. Note that the additional tuning capacitance increases the tag intrinsic Q factor proportionately: an ideal external tuning capacitance with 30% of the tag IC internal tuning capacitance leads to a 30% increase of the tag Q factor, resulting in a 30% increase of the rising and falling times of reader modulation envelop received by the tag IC. The tag IC may not be able to decode reader command properly in low power conditions and system performance may be impacted. Impact of additional tuning capacitance depends on its
own Q factor and tag IC Q factor. As a consequence, a tag performance validation is necessary in addition to tag tuning frequency validation.

7. Tag performance validation: with the additional tuning capacitance mounted, measure the communication distance, and compare it to the expected one. In parallel, measure the tag IC RF input differential voltage at maximum operating distance: if it is much larger than the minimum operating voltage documented in NFC/RFID tag IC datasheet, total Q factor is too high.

8. Design adjustment: if an excessive tag Q factor is suspected, decrease the additional tuning capacitance value: a combination of frequency change and Q factor decrease may restore a good performance level.

9. Decreasing the Q factor of the tag without changing the additional tuning capacitance value can be achieved using an extra parallel resistor, but is not recommended due to the impact on cost (bill of materials). Antenna design modification is preferred (go back to step 1) with a new antenna inductance to compensate the additional capacitance value.

10. Validate tag performance and fine-tune the tuning frequency.
5 Revision history

Table 2. Document revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-Feb-2021</td>
<td>1</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE – PLEASE READ CAREFULLY

STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, enhancements, modifications, and improvements to ST products and/or to this document at any time without notice. Purchasers should obtain the latest relevant information on ST products before placing orders. ST products are sold pursuant to ST’s terms and conditions of sale in place at the time of order acknowledgment.

Purchasers are solely responsible for the choice, selection, and use of ST products and ST assumes no liability for application assistance or the design of Purchasers’ products.

No license, express or implied, to any intellectual property right is granted by ST herein.

Resale of ST products with provisions different from the information set forth herein shall void any warranty granted by ST for such product.

ST and the ST logo are trademarks of ST. For additional information about ST trademarks, please refer to www.st.com/trademarks. All other product or service names are the property of their respective owners.

Information in this document supersedes and replaces information previously supplied in any prior versions of this document.

© 2021 STMicroelectronics – All rights reserved