Antenna design guide for NLM001x

Including full example

About this document

Scope and purpose

This antenna design guide is intended to be used for determination of correct parameters for rectangular and square PCB near-field communication (NFC) antenna designs for Infineon's NLM0011/NLM0010.

A complete example is calculated to help start the antenna design.

Intended audience

This document is intented for application and system engineers.

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1 General equations and basic principle of NFC antennas

1.1 Basic antenna principle

The basic principle of antenna design is to create a circuit resonating at close to 13.56 MHz with an inductance (antenna) and an internal or external tuning capacitor. This is because NFC readers operate at 13.56 MHz.

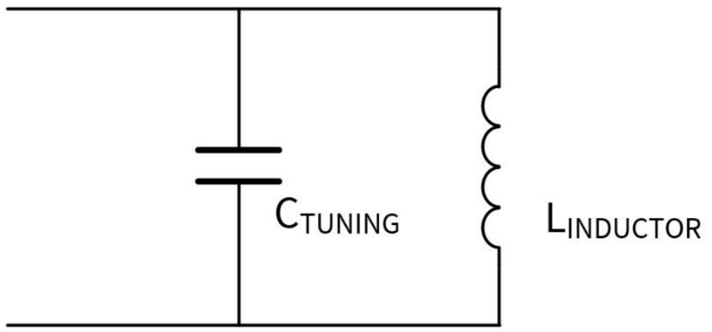

Figure 1 Basic principle

The antenna acts as the inductor. The tuning capacitor can be either only internal or only external, or both. However, because the Bill of Materials (BOM) should be kept as low as possible, in the example only the internal capacity is used here. The typical value of the internal capacity is given in the datasheet of NLM001x. If an external capacitor is used in addition, this must be considered in the calculation. This is necessary for example when the inductance of the antenna cannot be achieved without an external tuning capacitor because of small antenna size.

1.2 General equations

For the calculation of NFC antennas, some general equations are used.

The first equation is used to calculate the resonant frequency:

$$f_{TUNING} = \frac{1}{2\pi\sqrt{L_{INDUCTOR} \cdot C_{TUNING}}} \qquad (equ. 1)$$

Therefore:

$$C_{TUNING} = \frac{1}{4\pi^2 f_{TUNING}^2 \cdot L_{INDUCTOR}} \qquad (equ. 2)$$

If a PCB antenna should be designed, the formula for calculating (or approximating) the inductor value of the antenna can be assumed as:

$$L_{INDUCTOR} = \frac{\mu_0}{\pi} \cdot [x_1 + x_2 - x_3 + x_4] \cdot N^E \qquad (equ. 3)$$

Where x_1, x_2, x_3, x_4 are given by:

$$x_1 = a_{avg} \cdot ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(a_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right] \qquad (equ.3.1)$$

$$x_2 = b_{avg} \cdot ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(b_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right] \qquad (equ.3.2)$$

$$x_3 = 2 \cdot \left[a_{avg} + b_{avg} - \sqrt{a_{avg}^2 + b_{avg}^2}\right] \qquad (equ.3.3)$$

$$x_4 = \frac{a_{avg} + b_{avg}}{4} \qquad (equ.3.4)$$

With a_{avg}, b_{avg}, d:

$$a_{avg} = a - N \cdot (g + w) \qquad (equ.3.5)$$

$$b_{avg} = b - N \cdot (g + w) \qquad (equ.3.6)$$

$$d = \frac{2 \cdot (t + w)}{\pi} \qquad (equ.3.7)$$

1.3 Parameters

$L_{INDUCTOR}$ *(H)*	is calculated using equation 1
C_{TUNING} *(F)*	is given in the datasheet
f_{TUNING} *(Hz)*	is defined by the NFC standard with 13.56 MHz (but is slightly modified, as shown later in the example)
$\mu_0 \left(\frac{N}{A^2}\right)$	permeability constant $\mu_0 = 1.2566 \cdot 10^{-6} \frac{N}{A^2}$ (copper)
N	number of turns
E	turn exponent

Typical values for printed antennas are 1.7 … 1.8. This depends on the number of turns, environmental influences and corner rounding.

Under the assumption that all turns are concentrated on the outline of the antenna, so all magnetic flux passes the enclosed area of all turns (no stray field) and the magnetic coupling between the turns is 100 percent, the inductance is proportional to N^2(E=2). As this is not possible, the typical value for the turn exponent E for printed antennas is 1.7 … 1.8.

a (mm)	total length (antenna)
b (mm)	total width (antenna)
w (mm)	track width (antenna)
g (mm)	gap between tracks (antenna)
t (µm)	track thickness (antenna), typical value 35 µm

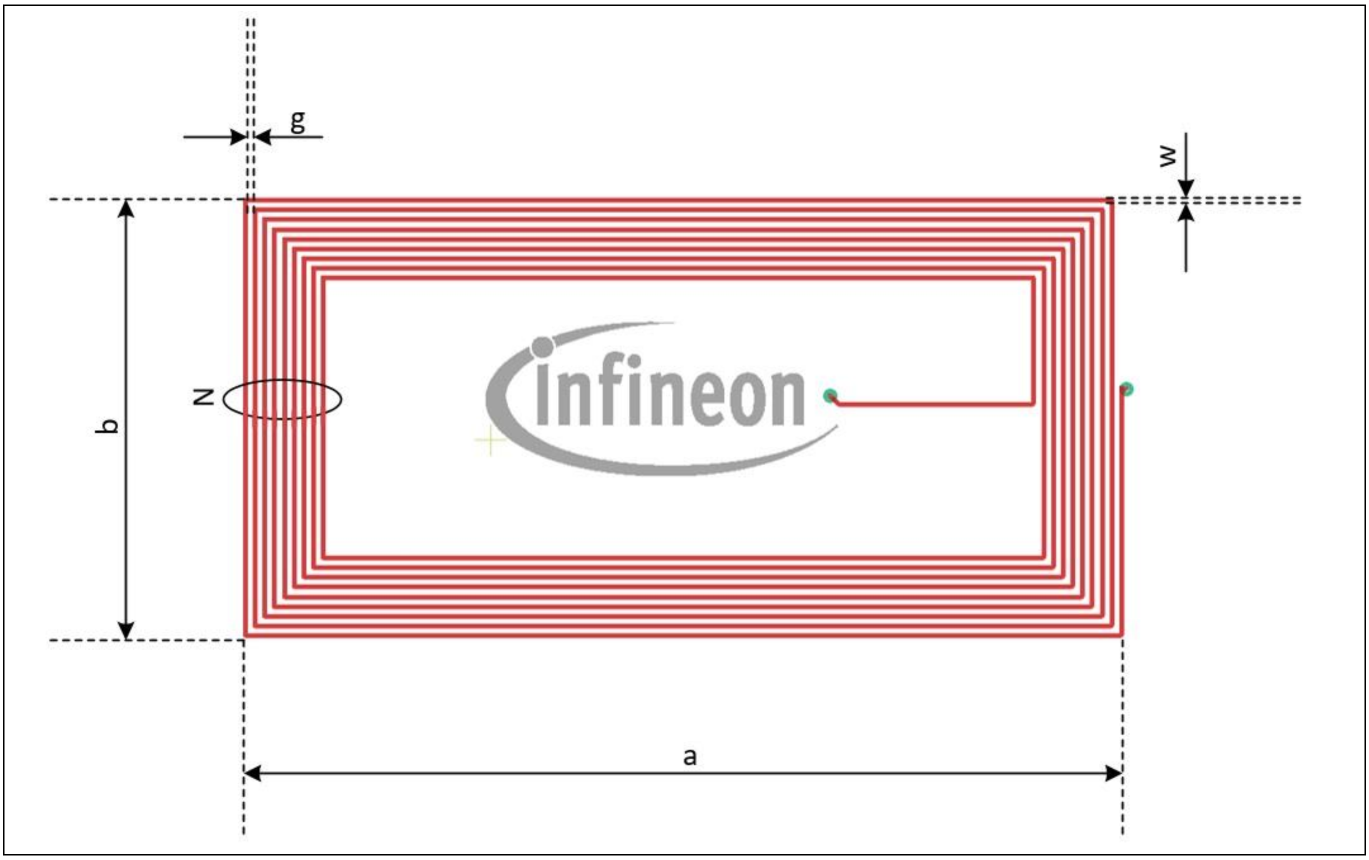

Figure 2 **Antenna parameters**

2 Procedure for antenna design

The target is to get an inductance (L), which fits equation 1.

This inductance is a function of the antenna dimensions (a and b), the distance between the tracks (g), the width of the tracks (w), the thickness of the tracks (t) and the number of turns (N).

The larger the antenna becomes, the fewer turns and the wider the tracks that can be used. For smaller antennas, more turns with narrower tracks are recommended.

In this way, several approximations can be done, in which the parameters are adjusted until the desired inductance has been achieved. Since the internal capacitance is specified by the component (NLM001x), the inductance is the only parameter that can be tuned.

However, it is also possible to work with external capacitors. In some cases, for example if the target antenna size is very small, it may be necessary to add an external capacitor to achieve the targeted inductance. This external capacitor must be selected so that the sum of the internal and external capacitance in the calculation shown in the example leads to the targeted value of the inductance (equation 1). The value of the tuning capacity is made up of the sum of internal and external capacity ($C_{TUNING} = C_{internal} + C_{external}$).

For this example no external capacitor is used.

Attention: ***Environmental factors and component tolerances lead to deviations in the theoretical values. Therefore, it makes sense to check the antenna afterwards and adjust it if necessary (antenna design/tuning capacitor).***

3 Full calculation example

For our calculation we assume the target f_{TUNING} to be around 13.8 MHz. It is set slightly higher than 13.56 MHz in order to protect the device by limiting the amount of harvested energy.

C_{TUNING} *(F)*	23.5 pF
f_{TUNING} *(Hz)*	13.8 MHz
$\mu_0 \left(\frac{N}{A^2}\right)$	$1{,}2566 \cdot 10^{-6}\,\frac{N}{A^2}$

3.1 Step 1 – calculate targeted L

Based on equation 1:

$$f_{TUNING} = \frac{1}{2\pi\sqrt{L_{INDUCTOR} \cdot C_{TUNING}}}$$

The targeted L can be calculated (equation 2):

$$L_{INDUCTOR} = \frac{1}{4\pi^2 f_{TUNING}^2 \cdot C_{TUNING}}$$

$$L_{INDUCTOR} = \frac{1}{4\pi^2 (13.8\ MHz)^2 \cdot 23.5\ pF} = 5{,}66\ \mu H$$

That means we have to choose the parameters to result in 5.66 µH.

L is now calculated according to equation 3:

$$L_{INDUCTOR} = \frac{\mu_0}{\pi} \cdot [x_1 + x_2 - x_3 + x_4] \cdot N^E$$

So let us assume the following parameter values:

a	50 mm
b	25 mm
w	0.254 mm
g	0.3 mm
t	35 µm
N	9
E	1.76

3.2 Step 2 – calculate a_{avg}, b_{avg} and d

$$a_{avg} = a - N \cdot (g + w)$$

$$a_{avg} = a - N \cdot (g + w) = 50\, mm - 9 \cdot (0.3\, mm + 0.254) = 45.014\, mm$$

$$b_{avg} = b - N \cdot (g + w)$$

$$b_{avg} = b - N \cdot (g + w) = 25\, mm - 9 \cdot (0.3\, mm + 0.254\, mm) = 20.014\, mm$$

$$d = \frac{2 \cdot (t + w)}{\pi}$$

$$d = \frac{2 \cdot (t + w)}{\pi} = \frac{2 \cdot (0.035\, mm + 0.254\, mm)}{\pi} = 0.184\, mm$$

3.3 Step 3 – calculate x_1, x_2, x_3 and x_4

$$x_1 = a_{avg} \cdot ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(a_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right] =$$

$$= 45.014\, mm \cdot ln\left[\frac{2 \cdot 45.014\, mm \cdot 20.014\, mm}{0.184\, mm \cdot \left(45.014\, mm + \sqrt{(45.014\, mm)^2 + (20.014\, mm)^2}\right)}\right] = 208.99\, mm$$

$$x_2 = b_{avg} \cdot ln\left[\frac{2 \cdot a_{avg} \cdot b_{avg}}{d \cdot \left(b_{avg} + \sqrt{a_{avg}^2 + b_{avg}^2}\right)}\right] =$$

$$= 20.014\, mm \cdot ln\left[\frac{2 \cdot 45.014\, mm \cdot 20.014\, mm}{0.184\, mm \cdot \left(20.014\, mm + \sqrt{(45.014\, mm)^2 + (20.014\, mm)^2}\right)}\right] = 99.09\, mm$$

$$x_3 = 2 \cdot \left[a_{avg} + b_{avg} - \sqrt{a_{avg}^2 + b_{avg}^2}\right] =$$

$$= 2 \cdot \left[45.014\,mm + 20.014\,mm - \sqrt{(45.014\,mm)^2 + (20.014\,mm)^2}\right] = 31.53\,mm$$

$$x_4 = \frac{a_{avg} + b_{avg}}{4} =$$

$$= \frac{45.014\,mm + 20.014\,mm}{4} = 16.257\,mm$$

3.4 Step 4 – calculate L

$$L_{INDUCTOR} = \frac{\mu_0}{\pi} \cdot [x_1 + x_2 - x_3 + x_4] \cdot N^E =$$

$$= \frac{1.2566 \cdot 10^{-6} \frac{N}{A^2}}{\pi} \cdot [208.99\,mm + 99.09\,mm - 31.53\,mm + 16.257\,mm] \cdot 9^{1.76} = 0.0055988\,\frac{N\,mm}{A^2}$$

With units:

$$H = \frac{kg \cdot m^2}{A^2 s^2}$$

$$N = \frac{kg \cdot m}{s^2}$$

➔ $L_{INDUCTOR} = 0.0055988 \frac{kg \cdot m \cdot mm}{A^2 \cdot s^2} = 0.0000055988\,\frac{kg \cdot m^2}{A^2 \cdot s^2} = 0.0000055988\,H \approx 5.6\mu H$

3.5 Step 5 – check f_{TUNING}

$$f_{TUNING} = \frac{1}{2\pi\sqrt{L_{INDUCTOR} \cdot C_{TUNING}}} =$$

$$= \frac{1}{2\pi\sqrt{5.6\mu H \cdot 23.5pF}} = \frac{1}{2\pi\sqrt{5.6 \cdot 10^{-6}\,H \cdot 23.5 \cdot 10^{-12} F}} = 13.87\,MHz$$

For this example we get a f_{TUNING} by around 13.8 MHz. So this is close enough and no further parameter optimization is required.
If the f_{TUNING} is not close enough, please change the parameters as in chapter 3.1 and start again at step 1 until the targeted value for f_{TUNING} is reached.

Revision history

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V 1.0	20-05-2020	First release

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