DESIGN AND IMPLEMENT NFC APPLICATIONS

SESSION 2: ANTENNA DESIGN CONSIDERATIONS FOR NXP NFC READERS

September 2016
Agenda

Design and implement NFC applications

Session I, 7th September
Product support package for NXP NFC readers
https://attendee.gotowebinar.com/rt/2329750067403618817

Session II, 28th September
Antenna design considerations for NXP NFC reader solutions
https://attendee.gotowebinar.com/rt/282682617345186049

Session III, 18th October
The NFC Cockpit - the complete design tool for engineers
https://attendee.gotowebinar.com/rt/4665515186055692345

Session IV, 31th October
NFC Reader Library - SW support for NFC frontend solutions
https://attendee.gotowebinar.com/rt/7151741873899128067
Design and implement NFC applications

Session 2, 28th September
Antenna design considerations for NXP NFC reader solutions

- NFC antenna design support (e.g. PN5180)
- Theoretical fundamentals and antenna principles
- “Asymmetric” versus “symmetric” antenna design
- NFC antenna tuning for a “symmetric” antenna (DPC)
NFC implementation process

Evaluate the functionality

- Investigate, which NFC functionality you need for your application (e.g., only read cards or write tags or exchange information with another device etc.)

Select IC

- Nobody gives you more options to choose from. Start with the specs given in this brochure, then go online to get detailed parametric searches.

Evaluate Features

- Explore the possibilities with one of our development boards, then use that same board to start prototyping.

Prototyping

- PCB design & antenna design

Hardware

- CONNECTED TAGS: Write your code for your MCU using the available code example. Connect additional memory over I2C to your controller enabling e.g., firmware update.
- NFC FRONTENDS & CONTROLLER WITH CUSTOMIZABLE FW: Write your code for your MCU using the NFC library, incorporating support for all relevant cards and phones.
- NFC CONTROLLER: Write your code for your MCU using the available code examples calling the functions already embedded in the FW of the NFC controller

Software

Test & Debug

- Standards-based design and support for the most popular development tools make it easy to fine-tune performance, catch errors, and fix bugs.

Get Certified

- Our NFC solutions are designed to help you meet CE, FCC, and other regional requirements, and make it easier to pass EMVCo certification.

NXP support

- Full range of development kits for every NFC product, partly coming with precompiled images
- Compatibility with common single board computers including Raspberry Pi, Beaglebone and Arduino boards
- NFC connect for NFC frontends
- Possibility to re-use designs of NXP development kits
- NFC library
- NFC gadget
- Sample code
- App notes
- Online training
- Tutorials
- Design files of demokits

Development boards for X, Y, Z are pre-certified for EMVCo

Technical NFC Community

Independent Design Houses certified by NXP
NFC ANTENNA DESIGN SUPPORT (E.G. PN5180)
Where to find NFC antenna tuning support material e.g. PN5180
Where to find NFC antenna tuning support material

OM25180FDK: PN5180 NFC frontend development kit

Contents

- PNEV5180B board with 65x65mm antenna optimized for EMVCo applications
- 30 mm x 50 mm antenna with matching components optimized for NFC applications
- Three small antenna matching PCBs for custom antenna matching
- NFC sample card (NTAG216)
- 10 PN5180 IC samples (HVQFN package)

Features

- Quick evaluation of PN5180 NFC frontend IC.
- Connect a custom antenna to PNEV5180 board
- Define and optimize the analog settings for any connected antenna
- Develop NFC applications based on the NFC Reader Library

Ordering details

- Orderable part number: OM25180FDK
- 12NC: 935307319699
- URL: [http://www.nxp.com/demoboard/om25180fdk.html](http://www.nxp.com/demoboard/om25180fdk.html)
Where to find NFC antenna tuning support material e.g. PN5180
THEORETICAL FUNDAMENTALS AND NFC ANTENNA PRINCIPLES
Typical contactless reader architecture

- **Backend System**
- **Embedded reader module**
  - **Firmware**
  - **SAM**
  - **Reader IC**
  - **Generic embedded µController**
  - **Ex: PN5180, PN7462, PN71xx, CLRC663, ...**
  - **Analog matching network**
  - **13MHz loop Antenna**
  - **NFC antenna section**
- **Contactless card**
  - RFID card, NFC Tag, NFC phone, or any other NFC object
The vast majority of RFID systems operate according to the principle of **inductive coupling**.

- Typical contactless smartcards contain no internal power supply. They need to get all their required energy from the magnetic field in which they operate.

- The PCD transmitter coil generates an electromagnetic field with a frequency of 13.56Mhz.

- A small part of the emitted field penetrates the antenna coil of the transponder, which is some distance away from the reader coil.

- A voltage $U_I$ is generated in the transponder’s antenna by inductance. This voltage is rectified and serves as the power supply.
  - A transformers-type coupling is created between the reader coil and the transponder coil.

- The PCD energy must be available to the PICC during the entire transaction.
NFC antenna: Transformer principle
Reader & contactless card communication

PCD: Proximity Coupling Device (“reader“)
PICC: Proximity Integrated Circuit Card (“card“)
NFC antenna: Transformer principle

Coupling coefficient

The coupling coefficient depends on:
- The geometric dimensions of both conductor loops.
- The position of the conductor loops in relation to each other.
- The magnetic properties of the medium ($\mu_0$)

Energy

Data

$$k = \mu_0 \cdot \frac{r^2}{2\sqrt{(r^2+x^2)^3}} \cdot \frac{A_2}{\sqrt{L_{01} \cdot L_{02}}}$$

Permeability constant

Geometrical quantity

"Fixed"

$k = 1 \rightarrow$ total coupling

$k = 0 \rightarrow$ full decoupling
Optimum antenna size (radius)

- For every read range $x$ of an NFC system, there is an optimal antenna radius $R$.
- A rough approximation is that:

$$k = \mu_0 \cdot \frac{r^2}{2\sqrt{(r^2+x^2)^3}} \cdot \frac{A_2}{\sqrt{L_01 \cdot L_02}}$$

$$r = x$$
Large antenna vs small antenna

- Card A:
  - $\text{PCD } r=2 \text{ cm } \rightarrow x \approx 5.5 \text{ cm}$
  - $\text{PCD } r=5 \text{ cm } \rightarrow x \approx 7.2 \text{ cm}$

- Card B:
  - $\text{PCD } r=2 \text{ cm } \rightarrow x \approx 2.8 \text{ cm}$
  - $\text{PCD } r=5 \text{ cm } \rightarrow x \approx 1.8 \text{ cm}$

- Card C:
  - $\text{PCD } r=2 \text{ cm } \rightarrow x \approx 2.2 \text{ cm}$
  - $\text{PCD } r=5 \text{ cm } \rightarrow x \approx - \text{ cm}$
Metal environment influences

Eddy currents

- Metal surfaces in the immediate vicinity of the reader antenna have several negative effects.
- Our reader antenna’s magnetic field generates eddy currents in metallic surfaces.
- These eddy currents produce a magnetic flow opposite to that of the reader device.

- Ferrites are basically poor electrical conductors but are very good at propagating magnetic flux (mostly of iron oxide Fe₂O₃).
- The ferrite material “shields” the metal behind it.
- It significantly reduces the generated eddy currents.
Shielding and environment impact

• The figures show three different field strength characteristics over reading distance x, for the same antenna coil:
  - Free air coil (7.5 cm)
  - Coil surrounded by a metal plate (5 cm)
  - Coil surrounded by a metal plate shielded by a ferrite plate (7.5 cm)
• We can achieve almost original operating distance using ferrite shielding. However, the ferrite detunes the antenna and produces:
  - Increased inductance
  - Increased Q-factor
  - Changed magnetic field distribution

Conclusion: The antenna must be suited to its environment
“ASYMMETRIC” VS “SYMMETRIC” ANTENNA TUNING
NFC antenna tuning naming convention
“Asymmetric” and “symmetric” antenna tuning

“Asymmetric“ antenna design (e.g. CLRC663)
Automatically limits the current and field strength under loading/detuning
Not optimum transfer function

“Symmetric“ antenna design (new for e.g. PN5180)
Provides more power transfer and better transfer function
Requires current / field strength limiter
Typical load detuning effect in “asymmetrical” antenna tuning

The load increases $\rightarrow I_{TVDD}$ and field strength is reduced

The load decreases, but $I_{TVDD}$ does not exceed the limit
Typical load detuning effect in “symmetrical” antenna tuning

Fig. Loading with Reference PICC

The load decreases → Increases power and $I_{TVDD}$

$I_{TVDD}$ & field strength may exceed the limit !!!

Solution: Dynamic Power Control

Fig. Loading with smartphone (metal)
“Asymmetrical” vs “symmetrical” small antenna tuning w.o. DPC

Behavior at short distance
1. **Asymmetric** antenna delivers enough field strength at close distance
2. **Symmetric** antenna at close distance (= strong coupling) the detuning to a lower impedance
   - causes higher ITVDD.
   - causes higher field strength.
   - might kill the reader IC.
   - might exceed ISO and EMVCo limits.

Behavior at long distance
1. **Asymmetric** antenna does not deliver enough field strength at large distance
2. **Symmetric** antenna at long operating distance (= low coupling) the improved transfer function
   - allows a higher Q-factor in the antenna coil circuit.
   - improves the Tx shaping (options).
   - improves the power transfer (RF field).
   - improves the Rx filtering, i.e. the “Rx sensitivity”.

![Graph showing behavior at short and long distances](image-url)
“Asymmetrical” vs “symmetrical” small antenna tuning with DPC

Behavior at long distance

**Symmetric** antenna at long operating distance (= low coupling) the improved transfer function
- allows a higher Q-factor in the antenna coil circuit.
- improves the Tx shaping (options).
- improves the power transfer (RF field).
- improves the Rx filtering, i.e. the “Rx sensitivity”.

Behavior at short distance

**Symmetric** antenna at close distance (= strong coupling) with DPC delivers enough field strength but not too much due to the DPC regulation
- controls (and limits) the ITVDD.
- controls (and limits) the field strength.
- protects the reader IC.
- ensures to keep the ISO and EMVCo limits.

Fig. EMVCo “asymmetrical and “symmetrical” tunings with small antenna
NFC ANTENNA TUNING PROCEDURE
(E.G. SYMMETRIC ANTENNA FOR DPC)
NFC antenna tuning procedure

1. Define target impedance and Q factor
   *To optimize RF output power or battery life*
2. EMC filter design
   *Filtering of unwanted harmonics*
3. Measure antenna coil
   *Determine LCR values of the antenna coil*
4. Calculate matching components
   *Using provided excel sheet*
5. Assembly and measurement
   *Physically test the impedance calculated*
6. Adapt simulation
   *Correct antenna coil measure*
7. Correction and re-assembly
   *Solder new matching circuit and test*
8. Receiver circuit
   *Tune reader sensitivity*

**Procedure is exactly the same for “asymmetric and “symmetric” antenna tuning**
Antenna tuning with PNEV5180B board
Breaking antenna section

- NFC antenna section can be easily separated from the main board
Antenna tuning with PNEV5180B board

Material used

- PNEV5180B board (included in OM25180CDK kit)
- Antenna matching PCB (included in OM25180CDK kit)
- 70x50mm PCB antenna (Choose your own)
STEP 1: DEFINE TARGET IMPEDANCE AND Q-FACTOR
Define target impedance

- We need to adjust the target impedance the NFC reader IC “sees” according to the performance we want to achieve.
  - Maximum output power
  - Minimum current consumption (battery life)
- The target impedance is chosen so that the highest possible output power does not exceed the maximum driver current (datasheet).

\[ R_L = 20 \quad \ldots \quad 80 \Omega \quad \text{for PN5180} \]

Our example:
\[ Z = 20 \]

For PN5180 \( I_{TVDD} < 250mA \)

(1) This diagram only covers the Tx part

- Maximum output power (Operating distance)
- Minimum current Consumption (Battery life)

Different load detuning effect depending on “symmetric” or “asymmetric” antenna tuning

Radiated energy

Load (e.g. Metal, PICC)

The load detunes the antenna
Define Q-factor

- A high Q factor leads to high current in the antenna coil and thus improves the power transmission to the transponder

\[ B = \frac{f}{Q} \]

- In contrast, the transmission bandwidth of the antenna is inversely proportional to the Q factor.
  - A low bandwidth, caused by an excessively high Q factor, can therefore significantly reduce the modulation sideband received from the transponder.
  
\[ Q < f \cdot T \]
\[ Q < 13.56MHz \cdot 3\mu s \]
\[ Q < 30 \]

- The quality factor of the antenna is calculated with:

\[ Q_a = \frac{\omega \cdot L_a}{R_a} \]

- If the calculated \( Q_a \) is higher than the target value, an external damping resistor \( (R_q) \) has to be added.

- The value of (each side of the antenna) is calculated by:

\[ R_q = 0.5 \left( \frac{\omega \cdot L_a}{Q} \right) \]

\( Q \approx 28 \)
STEP 2: MEASURE ANTENNA COIL
Step 2: Antenna coil characterization

Antenna + matching circuit = resonance circuit

NFC Reader IC (e.g. PN5180)

EMC filter

Matching Circuit

Antenna coil

* This circuit only covers the TX part
How to measure antenna coil

- The antenna loop has to be connected to an impedance or network analyzer at 13.56 MHz to measure the series equivalent components.

- High-end network analyzer (i.e. Rohde & Schwarz ZVL)
  - Powerful, accurate and easy to use.

- Low-end network analyzer (i.e. miniVNA PRO)
  - Cheap, accurate enough and easy to use.

**Fig. Antenna series equivalent circuit**

- **Inductance** (L): mainly defined by the number of turns of the antenna.
- **Resistance** (R): mainly defined by the diameter and length of the antenna wires.
- **Capacitance** (C): mainly defined by the distance of antenna wires from each other and number of turns.
Measuring antenna coil with miniVNA Pro - Calibration (Open)
Measuring antenna coil with miniVNA Pro - Calibration (Short)

[Image of antenna coil and miniVNA Pro interface]

[Graph showing RF parameters: 1: 13.559.950Hz, RL 0.01dB, RP -179.95°, Z 0.0Ω, Rs -0.0Ω, Xs -0.0Ω, Swr Infinity: 1, Mag 1.001]
Measuring antenna coil with miniVNA Pro - Calibration (Load – 50Ohms)
Measuring antenna coil with miniVNA Pro

Setup

Antenna coil

\[ R_{\text{Coil}} \]

\[ C_{\text{pa}} \]

S11
Measuring antenna coil with miniVNA Pro - Results

$L_a = \frac{X_S}{2\pi \cdot 13.56 MHz}$

$L = 608 \text{ nH}$  
Good enough!

$R_{Coil} \approx 0.7 \Omega$  
Not very accurate, but will be adapted later…  
In reality R is typically less than measured here.

$C_{pa} \approx 0.1 \text{ pF}$  
We don’t know.  
Let's start with a good guess.
STEP 3: EMC FILTER DESIGN
Step 3: EMC filter design

Antenna + matching circuit = resonance circuit

NFC Reader IC (e.g. PN5180)

EMC filter

Matching Circuit

Antenna coil

* This circuit only covers the TX part
EMC filter design for “asymmetric” antenna tuning

The EMC is a low pass filter reducing 2nd and higher harmonics and performs impedance transformation. A convenient cutoff frequency ($f_c$) is between:

$$f_c = 14.5 \text{ MHz} \ldots 22 \text{ MHz}$$

We begin specifying, this range of values has proven to be very useful in practice:

$$L_0 = 330 \text{ nH} \ldots 560 \text{ nH}$$

With $f_c$ and $L_0$, we can easily calculate $C_0$:

$$w_c = \frac{1}{\sqrt{C_0 \cdot L_0}} \Rightarrow C_0 = \frac{1}{(2 \cdot \pi \cdot f_c)^2 \cdot L_0}$$

Example: $f_c = 21 \text{ MHz}$ and $L_0 = 470 \text{ nH}$:

$$C_0 = 122.2 \text{ pF} \Rightarrow C_{01} = 68 \text{ pF}$$
$$C_{02} = 56 \text{ pF}$$
EMC filter design for “symmetric” antenna tuning

- The EMC is a low pass filter reducing 2\textsuperscript{nd} and higher harmonics and performs impedance transformation.

![EMC Filter Diagram]

- A convenient cutoff frequency ($f_c$) is lower:
  \[
  f_c = 14.5 \text{ MHz} \ldots 14.7 \text{ MHz}
  \]

- We begin specifying $L_0$, the value should be lower than measured $L_a$. Better performance as closer to this value.
  \[
  L_0 \leq \frac{L_a}{2} \quad L_0 \sim \frac{L_a}{2}
  \]

- With $f_c$ and $L_0$, we can easily calculate $C_0$:
  \[
  w_c = \frac{1}{\sqrt{C_0 \cdot L_0}} \quad \Rightarrow \quad C_0 = \frac{1}{(2 \cdot \pi \cdot f_c)^2 \cdot L_0}
  \]

- Example: $f_c = 14.6$ MHz and $L_0 = 470$ nH:
  \[
  C_0 = 252.8 \text{ pF} \quad \Rightarrow \quad C_{01} = 220 \text{ pF} \\
  C_{02} = 30 \text{ pF}
  \]

DPC calibration and correlation test required
EMC filter design for “symmetric” antenna tuning
PNEV5180B board EMC filter

- Default PCB EMC values:
  - \( L_0 = 470 \text{ nH}; \ C_0 = 220 \text{ pF}; \ f_{\text{cut-off}} = 15.65 \text{ MHz} \)

- Symmetrical impedance rules:
  - \( L_0 < \frac{L_a}{2} \Rightarrow 470 \text{ nH} < 608 \text{ nH} / 2 \)
  - \( f \sim 14.6 \text{ MHz} \Rightarrow C_0 = 252.8 \text{ pF} \)

- Changes required
  - Add a 33pF in parallel to the EMC filter

To fulfill requirements a 33pF capacitor is needed!
EMC filter design for “symmetric” antenna tuning

Capacitors assembly

Add 2 capacitors $C_0 = 33 \text{ pF}$

PNEV5180B board (included in OM25180CDK kit)

Antenna matching PCB (included in OM25180CDK kit)
STEP 4: CALCULATE MATCHING COMPONENTS
Step 4: Calculate matching components

Antenna + matching circuit = resonance circuit

NFC Reader IC (e.g. PN5180)

EMC filter

Matching Circuit

Antenna coil

* This circuit only covers the TX part
Calculate matching components

Excel sheet

- **INPUT VALUES**
  - Antenna coil measured / estimated values ($L_a$, $C_a$, $R_a$)
  - $Q$-factor
  - $f_{EMC}$
  - Target impedance ($Z_{match}$).
  - $L_0$ of EMC filter

- **OUTPUT VALUES**
  - $R_S$, $C_0$, $C_1$ and $C_2$
Simulate with RFSIM99 tool

1) Enter the path for RFSIM99

2) Start simulation

Step 1: Set path of RFSIM99

Step 2: Simulate
Simulate with RFSIM99

These are not real commercial values.

Add components in parallel and set actual values to be assembled.

RFSim99: simple freeware simulation tool
Simulate with RFSIM99

\[ Z = 19.92 \text{ Ohm} \]
STEP 5:
ASSEMBLY AND MEASUREMENT
Matching components assembly

<table>
<thead>
<tr>
<th>Excel file</th>
<th>PCB matching board</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₁</td>
<td>C013 // C014</td>
</tr>
<tr>
<td></td>
<td>C015 // C016</td>
</tr>
<tr>
<td>C₂</td>
<td>C027 // C024</td>
</tr>
<tr>
<td></td>
<td>C035 // C036</td>
</tr>
<tr>
<td>Rₜ</td>
<td>R003 // R22</td>
</tr>
<tr>
<td></td>
<td>R009 // R23</td>
</tr>
</tbody>
</table>
Matching components assembly

Demo board

Matching board

Antenna
Matching components assembly
Antenna tuning measurement with miniVNA Pro

Measurement between Tx1 and Tx2
Antenna tuning measurement
Measured vs simulation

Simulated: $Z = 19.92 - j0.03\Omega$

Measured: $Z = 21.9 + j1.5\Omega$
STEP 6: ADAPT SIMULATION
Adapt simulation

- Measured / estimated $L_a$, $R_a$ and $C_a$ antenna parameters are imprecise.
- Tune $R_a$ and $C_a$ parameters until the simulation looks like the reality.

Measured: $Z = 21.9 + j1.5\Omega$

Simulation: $Z = 21.91 + j1.6\Omega$

- $R_a = 0.7 \Omega \Rightarrow R_a = 0.25 \Omega$
- $C_a = 0.1pF \Rightarrow C_a = 2.3pF$
Fine tune matching components and simulate again

- Update \( C_a, L_a, R_a \)
- Fine tune \( C_1, C_2, R_s \) to achieve target impedance again. Use available values.

\[ Z = 20 \, \Omega \]
STEP 7:
CORRECTION AND RE-ASSEMBLY
Final assembly

Demo board

Matching board

Antenna
Final antenna tuning measurement results

First matching: $Z = 21.9 + j1.5\Omega$

Fine tuned: $Z = 20.6 + j1.5\Omega$
STEP 8:
RECEIVER CIRCUIT
Receiver circuit

Standard values

Antenna + matching circuit = resonance circuit

- NFC Reader IC (e.g. PN5180)
- Receiver Circuit
- EMC
- Matching Circuit
- Antenna

This step

Done
Receiver circuit
Standard values

- Goal: the voltage level at RX\textsubscript{n} and RX\textsubscript{p} pins must be high enough to achieve a good sensitivity, but must not exceed the given limit.

- Recommended circuit has a resistor and a capacitor in series. Typically the serial resistor $R_{rx}$ is in the range of 1…10kΩ.

- Start with 4.7k value and adjust sensitivity reading/writing AGC\_VALUE register.
**Receiver circuit**

**Standard values**

<table>
<thead>
<tr>
<th>Excel file</th>
<th>PCB matching board</th>
<th>PCB demo board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rrx</td>
<td>R006, R015</td>
<td></td>
</tr>
<tr>
<td>Crx</td>
<td></td>
<td>C306, C321</td>
</tr>
</tbody>
</table>

![Image of PCB with marked components](image_url)
DETUNING EFFECT UNDER LOADING CONDITIONS
Antenna loading & detuning
Metal (smartphone)

\[ Z = 4.2 + j0 \ \Omega \]

Due to symmetric matching, \( Z \) decreases \( \Rightarrow \) \( I_{TVDD} \) increases

Without properly calibrated DPC the PN5180 might be killed!

Webinar session
18/10/2016
Antenna loading & detuning
Reference PICC

Due to symmetric matching, $Z$ decreases $\Rightarrow I_{TVDD}$ increases

Without properly calibrated DPC the PN5180 might be killed!

$Z = 4.8 + j2.2\Omega$

Webinar session
18/10/2016
WRAP UP
Summary of NFC antenna design steps

Matching Steps:

1. Target impedance and Q-factor= 20…80 Ω (PN5180), Q<30
2. Design EMC Filter (L₀ and C₀) -> f_{EMC} ≈ 14.6MHz
3. Measure antenna coil (Lₐ, Rₐ and Cₐ)
4. Calculate start values (C₁, C₂, Rₐ using Excelsheet)
5. Assemble & measure
6. Adapt RFSIM99 simulation to meet reality (Rₐ and Cₐ)
7. Correct matching in simulation (C₁ and C₂)
8. Assemble & measure
9. Assemble Rₓ standard values

Done.
Coming sessions

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We help companies leverage the mobile and contactless revolution

**Software development** in Android and iOS
**Embedded software** for MCUs
**JCOP, Java Card** operating Systems
**Hardware design and development**
Digital, analog, sensor acquisition, power management
**Wireless communications** WiFi, ZigBee, Bluetooth, BLE
**Contactless antenna** RF design, evaluation and testing

**MIFARE applications**
End-to-end systems, readers and card-related designs

**EMVco applications**
Readers, cards, design for test compliance (including PCI)

**Secure Element management**
GlobalPlatform compliant backend solutions

**Secure services provisioning** OTA, TSM services

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NXP
Design and implement NFC applications
Session 2: Antenna design considerations for NXP NFC reader solutions
Jordi Jofre (Speaker)
Angela Gemio (Host)

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