This application note explains and shows how to use different low power modes on the PN76 family NFC controllers using the nfc low power modes example of the SDK.
## Revision history

<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>v.1.0</td>
<td>20230705</td>
<td>Initial version</td>
</tr>
</tbody>
</table>
1 Introduction

The PN76 family has many options to save power. This application note highlights some of the most used functions and features. The goal is that the user understands the purpose of the different lower power modes, knows how to configure and run them. To explain different modes and its usage, the PN76 SDK example 'nfc_low_power_modes' is used.

As not every function is highlighted within this application note, it is highly recommended to read the [1] datasheet, [2] user manual, and [3] API reference documentation.

1.1 Environment

Following tools, hardware and software have been used:

- PNEV7642A development board: Link
- MCUXpresso IDE: Link
- MCUXpresso PN7642 SDK: Link
- Debugger (MCU-Link, SEGGER J-Link, ...): Link
- SEGGER J-Link RTT Viewer: Link

This document does not explain how to install, configure, or set up the PNEV7642 development board and its environment. For getting started with the PNEV7642 development board, read the evaluation board quick start guide [5].

1.2 Debugging

When the chip enters ultra-low power modes the debugger loses connection. Most probably without any immediate warning.

The SDK offers the option to use UART as debug output instead of Semihost (console within IDE). For the low-power examples, it is recommended to use UART and the J-Link Section 4 "RTT Viewer". The RTT viewer is easy to reconnect after the connection has been lost due to going to low power and waking up later on.
2 Low-power modes

2.1 Ultra low-power card detection (ULPCD)

The ultra low-power card detection (ULPCD) offers the highest current saving. In this mode, the only wake-up sources to escape from the card detection loop are either a detected antenna detuning, a signal on GPIO3 or a reset (RESET_N) of the PN7642.

**NOTE:** The ULPCD cannot be used together with the DC-DC function.

For more information about the ULPCD capabilities and description, see the [1] data sheet or [2] user manual. The usage of ULPCD is explained in following Section 3.4 "Option 5: Run ULPCD with calibration".

2.1.1 ULPCD API

All APIs and their description can be found in the PN7642 NFC controller user API documentation: [3]

The ULPCD API belongs to the Power Control and Reset Management (PCRM) system services:

```c
PN76_Status_t PN76_Sys_PCMR_EnterULPCD ( PN76_PCMR_ULPCD_Config_t bUlpcdConfig,
                                           uint16_t dwWakeUpCntValue,
                                           uint8_t bUlpcdEnable )
```

**Parameters**

- `bUlpcdConfig`: Selection of ULPCD Configuration as in Enum `PN76_PCMR_ULPCD_Config_t`
- `dwWakeUpCntValue`: 12 bit wake-up counter value: resolution=1ms -> max time slot=4.096s. This is used only in case of TIMER as wakeup.
- `bUlpcdEnable`: Ultra low power RF detection enabled/Disabled. Value to be TRUE means 1 for ULPDET Enable or FALSE means 0 for ULPDET Disabled. Any other value is not considered for ULPDET.

**Return values**

- `PN76_STATUS_SUCCESS`: SUCCESS is never returned as the system enters into Ultra low power mode in case of successful entry to ULP mode.
- `PN76_STATUS_PARAMETER_ERROR`: Incase invalid wakeup source is selected or wake-up interval is more than 12bits

Figure 1. API: Enter ULPCD

**ATTENTION:** To this date, the description of the API is wrong (to be fixed in the next release).

The second parameters `dwWakeUpCntValue` purpose is to configure the time between the consecutive rf-pings, and so the name `dwWakeUpCntValue` is misleading, since there is no wake-up source timer.
2.2 Ultra low power standby

In the ultra low-power Standby mode, everything is turned off except a timer based on an ultra low frequency oscillator (ULFO). In this mode only two options are available to wake up:

1. Wake-up by time-out (resolution: 1 ms, max time-out 4096 ms)
   a. An external RF-Field is ignored and does not cause a wake-up.
2. External RF-Field detected or wake-up by time-out.
   a. The wake-up timer is mandatory.

This mode is typically used if you want to save as much power possible and waking up in intervals, or triggered by an external RF-Field, is good enough.

The main difference to ULP CD (ultra low-power card detection) is that there is no card detection cycle and a wake-up timer is mandatory.

2.2.1 ULP Standby API

All APIs and their description can be found in the PN7642 NFC controller user API documentation: [3]

The ULP Standby API belongs to the PCRM (Power Control and Reset Management) System Services:

```c
void PN76_Sys_PCRM_EnterUlpStandby()
{
    PN76_Status_t
    PN76_Sys_PCRM_EnterUlpStandby
        ( PN76_PCRM_UltraLowPower_WakeUp_Config_t wWakeupSource,
          uint16_t dwWakeupCntValue
        )
}
```

Switch into Ultra Low Power standby mode.

Parameters

- **wWakeupSource**: Selection of wake-up source in Enum PN76_PCRM_UltraLowPower_WakeUp_Config_t.
- **dwWakeupCntValue**: 12 bit wake-up counter value; resolution=1ms -> max time slot=4.096s. This is used only in case of TIMER as wake-up source.

Return values

- **PN76_STATUS_SUCCESS**: SUCCESS is never returned as the system enters into Ultra low power in case of successful entry to ULP mode.
- **PN76_STATUS_PARAMETER_ERROR**: Incase invalid wakeup source is selected or wake-up interval is more than 12bits

**ATTENTION**: To this date, the description of the API is wrong (to be fixed in the next release). The wake-up timer is mandatory in both cases, regardless of the wake-up source being timer or RF-Field!
## Table 1. EnterUlpStandby wake-up sources

<table>
<thead>
<tr>
<th>wWakeupSource</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_PN76_PCRM_ULP_WAKEUP_SOURCE TIMER</td>
<td>The chip will enter ULP standby and wake-up after the timer, set by &quot;dwWakeUpCntValue&quot;, expires. An external RF-Field is ignored.</td>
</tr>
<tr>
<td>E_PN76_PCRM_ULP_WAKEUP_SOURCE_RFFIELD</td>
<td>The chip will enter ULP standby and wake-up either after the timer expires or an external RF-Field is detected.</td>
</tr>
</tbody>
</table>
3 NFC low-power mode example

The MCUXpresso SDK [4] contains a low-power mode example called "nfc_low_power_mode". Exercising different low-power modes. This chapter makes a deep-dive into the example and highlight the used APIs as well as pointing out how to use them.

Figure 3. MCUXpresso low-power mode example

The examples purpose is to showcase certain functionality. For product purposes, it is recommended to get yourself familiar with the used APIs and alter the example to your needs or transfer the necessities to your application code.

How to install MCUXpresso, import the SDK and its examples, read the evaluation board quick start guide [5]. This is assumed to be known for this application note.

Running the low-power mode example prompts following options:

Figure 4. Low-power mode example options

Following chapters explain option 3, 4 and 5 in more detail. Which APIs are used. What is the expected behavior and how to apply this to the users application code.

Options 1, 2 and 6 are not explained in this version of the document.

3.1 Boot reason

Before the example is prompting the options to exercise different low-power modes, the boot reason of the IC is checked. This is done in the method "BootLowPowerCheck(/)" and serves multiple purposes.

First, the boot reason is evaluated to see if further actions have to be taken. Like going to ULPCD card detection, coming from a calibration cycle. Second, to prompt the boot reason in the debug output.

The cause of the boot can be retrieved by reading the register "PCRM_SYS_BOOT1_STS".

Table 2. PCRM_SYS_BOOT1_STS_REG bit fields

<table>
<thead>
<tr>
<th>Description</th>
<th>PCRM LP System Boot 1 Status Register</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bits</strong></td>
<td><strong>Field</strong></td>
</tr>
<tr>
<td>0</td>
<td>BOOT_POR</td>
</tr>
<tr>
<td>1</td>
<td>BOOT_RXPROT</td>
</tr>
<tr>
<td>2</td>
<td>BOOT_VUPDET</td>
</tr>
<tr>
<td>3</td>
<td>BOOT_TEMP</td>
</tr>
<tr>
<td>4</td>
<td>BOOT_WUC</td>
</tr>
</tbody>
</table>
### Table 2. PCRM_SYS_BOOT1_STS_REG bit fields...continued

**PCRM LP System Boot 1 Status Register**

<table>
<thead>
<tr>
<th>Bits</th>
<th>Field</th>
<th>Access</th>
<th>Reset Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>BOOT_VDDIO_START</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason this is valid if STBY/SUSPEND entered with VDDIO LOSS</td>
</tr>
<tr>
<td>6</td>
<td>BOOT_VDDIO_LOSS</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>7</td>
<td>BOOT_PVDDLDO_OVERCURRENT</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>8</td>
<td>RESERVED</td>
<td>-</td>
<td>0x0</td>
<td>reserved</td>
</tr>
<tr>
<td>9</td>
<td>RESERVED</td>
<td>-</td>
<td>0x0</td>
<td>reserved</td>
</tr>
<tr>
<td>10</td>
<td>BOOT_ULPCD_GPADC_READY_TIMEOUT</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD exit as GPADC READY is not asserted from GPADC Analog</td>
</tr>
<tr>
<td>11</td>
<td>BOOT_RX_ULPDET</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>12</td>
<td>BOOT_LPDET</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>13</td>
<td>BOOT_GPIO0</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>14</td>
<td>BOOT_GPIO1</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>15</td>
<td>BOOT_GPIO2</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>16</td>
<td>BOOT_GPIO3</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>17</td>
<td>RESERVED</td>
<td>r</td>
<td>0x0</td>
<td>Reserved</td>
</tr>
<tr>
<td>18</td>
<td>RESERVED</td>
<td>r</td>
<td>0x0</td>
<td>Reserved</td>
</tr>
<tr>
<td>19</td>
<td>BOOT_I2C</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>20</td>
<td>BOOT_SPI</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>21</td>
<td>WAKEUP_RX_ULP</td>
<td>r</td>
<td>0x0</td>
<td>Indicates if VEN is masked due to wake-up with rx_ulp. This bit is cleared</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>with ULPCDET_WKUP_VEN_MASK_CLR</td>
</tr>
<tr>
<td>22</td>
<td>BOOT_ULPCD_RX_ULPDET</td>
<td>r</td>
<td>0x0</td>
<td>RX ULPDET resulted in boot in ULPCD mode</td>
</tr>
<tr>
<td>23</td>
<td>RESERVED</td>
<td>r</td>
<td>0x0</td>
<td>Reserved</td>
</tr>
<tr>
<td>24</td>
<td>BOOT_USB</td>
<td>r</td>
<td>0x0</td>
<td>Bootup Reason</td>
</tr>
<tr>
<td>25</td>
<td>BOOT_ULPCD_LDO_VDDPA_OVERCURRENT</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD LDO VDDPA overcurrent</td>
</tr>
<tr>
<td>26</td>
<td>BOOT_ULP_STANDBY</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD Standby</td>
</tr>
<tr>
<td>27</td>
<td>BOOT_ULPCD_GPIO_ABORT</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD GPIO Abort</td>
</tr>
<tr>
<td>28</td>
<td>BOOT_ULPCD_CALIBRATION_DONE</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD calibration complete</td>
</tr>
<tr>
<td>29</td>
<td>BOOT_ULPCD_CARD_DETECT</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD card detect</td>
</tr>
<tr>
<td>30</td>
<td>BOOT_ULPCD_CLKDET_ERROR</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD CLK_DET error</td>
</tr>
<tr>
<td>31</td>
<td>BOOT_ULPCD_XTAL_TIMEOUT</td>
<td>r</td>
<td>0x0</td>
<td>ULPCD exit due to XTAL timeout</td>
</tr>
</tbody>
</table>

### 3.2 Option 3: Enter ultra low-power standby with counter as wake-up

Option 3 of the low-power modes example sets the chip into ultra low power standby with the wake-up counter set to the chosen option (in this showcase "1" which represents 1 second):
After the interval selection, it directly enters low-power mode. After 1 second, the chip wakes up again. If we reconnect RTT viewer, we can see that the boot reason is wake-up counter expiry:

3.2.1 Code flow

The code flow for this option is rather simple. At the switch the case "ULP_STANDBY_WITH_WAKEUP_COUNTER_MODE" is taken, the method "Demo_UltraLowPowerStandby(...)" with chosen interval called.

The method "Demo_UltraLowPowerStandby(…)" is very simple as well and only calling the system service API from the PN76 to enter ultra low-power standby: "PN76_Sys_PCRM_EnterUlpStandby(…)"
3.3 Option 4: Enter ultra low-power standby with external RF as wake-up

This option is calling the ultra low-power standby method with the configuration parameter set to "E_PN76_PCRM_ULP_WAKEUP_SOURCE_RFFIELD". This sets the chip into ultra low-power standby and its waking up either by timer expiry or external RF-Field.

See Section 2.2.1 for more details of the used API.

Selecting option 4 and interval of "2" (having more time to put manually something RF-Field emitting on the antenna) will put it to ULP standby:

![Option 4 execution](image)

Bringing a device, which emits an RF-Field (e.g. cell phone), into the antennas area will wake-up the chip with the boot reason of external RF detected (do not forget to reconnect the RTT viewer as connection is lost when entering ULP):

![Boot due external RF](image)

3.4 Option 5: Run ULPCD with calibration

By entering option 5, and some more configurations, the ULPCD is first calibrated and restarted for the actual detection.
After entering all the options, the chip goes into ULPCD. On the eval board, you can see the blue LED slightly turning on every ~320 ms (ULPCD RF-Field cycle). At this time, the RF-Field is turned on for a very short period (RF-On duration from above) to check for any potential detuning.

Inspecting the RF-Field with an oscilloscope shows a very short pulse every ~320 ms (depending on the setting above and the LFO settings):
If you bring a card into the RF-field, the chip is waking up and the boot reason will be card detection (reconnect the RTT viewer to see the output, as it loses connection when entering ULPCD):

![ULPCD boot reason card detection](image)

### 3.4.1 Code flow

Following the flow of the code, we see that the API "PN76_Sys_PCRM_EnterULPCD()" is called with "E_PN76_PCRM_ULPCD_CALIBRATION" as first parameter:

```c
/* Perform ULPCD Calibration Cycle */
status = PN76_Sys_PCRM_EnterULPCD(E_PN76_PCRM_ULPCD_CALIBRATION, wULPCDwakeUpTime, 0);
/* Control never reaches here, adding for warning removal */
return PN76_STATUS_SUCCESS;
```

![Example: Enter ULPCD calibration mode](image)

As the comment at line 344 implies, the debugger is never supposed to reach this line. This is due to the behavior of the ultra low-power modes. Everything is shut down except the bare minimum to exercise ULPCD. Also the core itself is turned off and the debugger loses connection.

**Note:** Ultra-low power modes cannot be live debugged!

For the ULPCD calibration, make sure that nothing is placed onto the antenna. As the current values are taken as unloaded condition.

After the calibration is done, the chip wakes up automatically. Following the code flow the function "BootLowPowerCheck()" shall be investigated closer:

```c
/* Check of for the BOOT reason after wake up */
BootLowPowerCheck();
```

![Example: Method BootLowPowerCheck()](image)

This method distinguishes between the different boot reasons. As we are coming from ULPCD calibration, file lpm.c line 387, should evaluate as true and call "ULPCD_Demo(...)":

```c
if (dwBootRegVal & PCRM_SYS_BOOT1_STS_BOOT_ULPCD_CALIBRATION_DONE_MASK)
{
    ULPCD_Demo(wULPCDWakeUpTime);
}
```

![Example: Checking wake-up reason](image)

The initialization of parameter "wULPCDWakeUpTime" is done by using define. This define can be adjusted to the users liking:
Opening the method "ULPCD_Demo(…)") shows that now the API to enter into ULPCD is called with the option "E_PN76_PCRM_ULPCD_CARD_DETECTION" rather then "E_PN76_PCRM_ULPCD_CALIBRATION" as before:

The parameter "wLPCDWakeUpTime" is the before mentioned define. The description of it is misleading. See chapter Section 2.1.1 for more details.

After calling this API, the PN76 enters ULPCD with the purpose of card detection. It will not wake-up from it until one of the following reasons:

- Antenna detuning (can be due to an external card or any conductive metal)
- Chip reset (power cycle, RESET_N, VEN, …)
- GPIO3
3.4.2 Abort with GPIO3

Another option always available to go out of ULPCD mode is abort via GPIO3. As the development board can have multiple configurations the below shown option is not the most elegant, but the one working without caring about the boards configuration.

To abort via GPIO3, we have to apply +3.3 V to GPIO3.

Use a jumper wire to connect J47.4 (P3V3_BRD) to pin 30 on the module board:

![Figure 18. GPIO3 abort wiring](image)

P.30 is the second pin of the right row (above 29).

If the chip is woken up, you should see the green LED on.
4 RTT Viewer

The J-Link RTT Viewer is a GUI tool from SEGGER which attaches to either an existing J-Link connection of a debugger or opening a connection on its own. Instead of having the IDE console as in/output the J-Link RTT Viewer is used. This is more lightweight, easier to reattach.

Either at import of the example you can choose "UART" or "Semihost". While UART represents the RTT Viewer option and Semihost the output in the IDE console. Later you can still switch the debug console at the quick settings: Quick Settings → SDK Debug Console → Semihost/UART

![Figure 19. MCUXpresso Debug Console Option]
The configuration to attach to the PN7642 is as below:

![J-Link RTT Viewer configuration](image)

The address of the RTT control block is: **0x20008000**
5  Tips and tricks

Q: What shall I do if the chip is cycling through ULP Standby and I cannot connect with a debugger anymore?
A: This usually happens if your application has no reason to stay active and directly goes into ULP Standby again. The easiest solution on the development board would be to bring the chip into USB Mass-Storage and replace the application with some other which is not using any low-power modes (e.g. LED Blinky).

Else you can try to catch the chip in its active state by trying multiple times. Or hold reset, release the reset and press connect of the debugger at the same time.

Q: I cannot use the J-Link RTT viewer because I do not have a SEGGER J-Link, what shall I do?
A: If you have a MCU-Link Pro or LPC-Link2 instead, you can flash J-Link lite on them. With J-Link Lite, you can use the RTT viewer. Another option would be to use semihost and make the output of the boot reason with LEDs. So that after the boot up at least you see visually what the boot reason has been.

Q: How to visualize the RF-Field?
A: You can use the probe of the oscilloscope and connect the Ground clamp to the tip of the probe itself. By placing this loop on the antenna, you should be able to trigger easily on a rising edge to capture the RF-Field. Depending on your chosen interval time, I would adjust the time axis to your chosen interval x 4.
6 References

[3] PN7642 NFC controller user API documentation
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