The SX1272/73 transceivers feature the LoRa™ long range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

Using Semtech’s patented LoRa™ modulation technique SX1272/73 can achieve a sensitivity of over -137 dBm using a low cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimal for any application requiring range or robustness. LoRa™ also provides significant advantages in both blocking and selectivity over conventional modulation techniques, solving the traditional design compromise between range, interference immunity and energy consumption.

These devices also support high performance (G)FSK modes for systems including WMBus, IEEE802.15.4g. The SX1272/73 deliver exceptional phase noise, selectivity, receiver linearity and IIP3 for significantly lower current consumption than competing devices.

### Applications
- Automated Meter Reading
- Home and Building Automation
- Wireless Alarm and Security Systems
- Industrial Monitoring and Control
- Long range Irrigation Systems

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- QFN 28 Package - Operating Range from -40 to +85°C
- Pb-free, Halogen free, RoHS/WEEE compliant product
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1. General Description

The SX1272/73 incorporates the LoRa™ spread spectrum modem which is capable of achieving significantly longer range than existing systems based on FSK or OOK modulation. With this new modulation scheme sensitivities 8 dB better than equivalent data rate FSK can be achieved with a low-cost, low-tolerance crystal reference. This increase in link budget provides much longer range and robustness without the need for a TCXO or external amplification. LoRa™ also provides significant advances in selectivity and blocking performance, further improving communication reliability. For maximum flexibility the user may decide on the spread spectrum modulation bandwidth (BW), spreading factor (SF) and error correction rate (CR). Another benefit of the spread modulation is that each spreading factor is orthogonal - thus multiple transmitted signals can occupy the same channel without interfering. This also permits simple coexistence with existing FSK based systems. Standard GFSK, FSK, OOK, and GMSK modulation is also provided to allow compatibility with existing systems or standards such as wireless MBUS and IEEE 802.15.4g.

The SX1272 offers three bandwidth options of 125 kHz, 250 kHz, and 500 kHz with spreading factors ranging from 6 to 12. The SX1273 offers the same bandwidth options with spreading factors from 6 to 9.

1.1. Simplified Block Diagram

Figure 1. SX1272/73 Block Diagram
1.2. Product Versions

The features of the two product variants SX1272 and SX1273 are detailed in the following table.

### Table 1  SX1272/73 Device Variants and Key Parameters

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Frequency Range</th>
<th>Spreading Factor</th>
<th>Bandwidth</th>
<th>Effective Bitrate</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SX1272</td>
<td>860 - 1020 MHz</td>
<td>6 - 12</td>
<td>125 - 500 kHz</td>
<td>0.24 - 37.5 kbps</td>
<td>-117 to -137 dBm</td>
</tr>
<tr>
<td>SX1273</td>
<td>860 - 1020 MHz</td>
<td>6 - 9</td>
<td>125 - 500 kHz</td>
<td>1.7 - 37.5 kbps</td>
<td>-117 to -130 dBm</td>
</tr>
</tbody>
</table>

1.3. Pin Diagram

The following diagram shows the pin arrangement of the QFN package, top view.

![Pin Diagram](image)
# 1.4. Pin Description

Table 2  Pin Description

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>GROUND</td>
<td>-</td>
<td>Exposed ground pad</td>
</tr>
<tr>
<td>1</td>
<td>VBAT1</td>
<td>-</td>
<td>Supply voltage</td>
</tr>
<tr>
<td>2</td>
<td>VR_ANA</td>
<td>-</td>
<td>Regulated supply voltage for analogue circuitry</td>
</tr>
<tr>
<td>3</td>
<td>VR_DIG</td>
<td>-</td>
<td>Regulated supply voltage for digital blocks</td>
</tr>
<tr>
<td>4</td>
<td>XTA</td>
<td>I/O</td>
<td>XTAL connection or TCXO input</td>
</tr>
<tr>
<td>5</td>
<td>XTB</td>
<td>I/O</td>
<td>XTAL connection</td>
</tr>
<tr>
<td>6</td>
<td>RESET</td>
<td>I/O</td>
<td>Reset trigger input</td>
</tr>
<tr>
<td>7</td>
<td>NC</td>
<td>-</td>
<td>Can be connected to Ground</td>
</tr>
<tr>
<td>8</td>
<td>NC</td>
<td>-</td>
<td>Can be connected to Ground</td>
</tr>
<tr>
<td>9</td>
<td>DIO0</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>10</td>
<td>DIO1/DCLK</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>11</td>
<td>DIO2/DATA</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>12</td>
<td>DIO3</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>13</td>
<td>DIO4</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>14</td>
<td>DIO5</td>
<td>I/O</td>
<td>Digital I/O, software configured</td>
</tr>
<tr>
<td>15</td>
<td>VBAT2</td>
<td>-</td>
<td>Supply voltage</td>
</tr>
<tr>
<td>16</td>
<td>GND</td>
<td>-</td>
<td>Ground</td>
</tr>
<tr>
<td>17</td>
<td>SCK</td>
<td>I</td>
<td>SPI Clock input</td>
</tr>
<tr>
<td>18</td>
<td>MISO</td>
<td>O</td>
<td>SPI Data output</td>
</tr>
<tr>
<td>19</td>
<td>MOSI</td>
<td>I</td>
<td>SPI Data input</td>
</tr>
<tr>
<td>20</td>
<td>NSS</td>
<td>I</td>
<td>SPI Chip select input</td>
</tr>
<tr>
<td>21</td>
<td>RF_MOD</td>
<td>O</td>
<td>NC</td>
</tr>
<tr>
<td>22</td>
<td>GND</td>
<td>O</td>
<td>Ground</td>
</tr>
<tr>
<td>23</td>
<td>RXTX</td>
<td>O</td>
<td>Rx/Tx switch control: high in Tx</td>
</tr>
<tr>
<td>24</td>
<td>RFO</td>
<td>O</td>
<td>RF output</td>
</tr>
<tr>
<td>25</td>
<td>RFI</td>
<td>I</td>
<td>RF input</td>
</tr>
<tr>
<td>26</td>
<td>GND</td>
<td>O</td>
<td>Ground</td>
</tr>
<tr>
<td>27</td>
<td>PA_BOOST</td>
<td>O</td>
<td>Optional high-power PA output</td>
</tr>
<tr>
<td>28</td>
<td>VR_PA</td>
<td>O</td>
<td>Regulated supply for the PA</td>
</tr>
</tbody>
</table>
1.5. Package Marking

Figure 3. Package Marking

<table>
<thead>
<tr>
<th>CHAR</th>
<th>ROWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/11/17/17</td>
<td>5</td>
</tr>
</tbody>
</table>

Marking for the 6 x 6 mm MLPQ 28 Lead package:

- nnnn = Part Number (Example: 1272)
- yyww = Date Code (Example: 1352)
- xxxxxxx = Semtech Lot No. (Example: E901010)
- xxxxxx = 0101-10
2. Electrical Characteristics

2.1. ESD Notice

The SX1272/73 is a high performance radio frequency device. It satisfies:

- Class II of the JEDEC standard JESD22-A114-B (Human Body Model) on all pins.
- Class III of the JEDEC standard JESD22-C101C (Charged Device Model) on all pins

It should thus be handled with all the necessary ESD precautions to avoid any permanent damage.

2.2. Absolute Maximum Ratings

Stresses above the values listed below may cause permanent device failure. Exposure to absolute maximum ratings for extended periods may affect device reliability.

Table 3  Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDDmr</td>
<td>Supply Voltage</td>
<td>-0.5</td>
<td>3.9</td>
<td>V</td>
</tr>
<tr>
<td>Tmr</td>
<td>Temperature</td>
<td>-55</td>
<td>+115</td>
<td>°C</td>
</tr>
<tr>
<td>Tj</td>
<td>Junction temperature</td>
<td>-</td>
<td>+125</td>
<td>°C</td>
</tr>
<tr>
<td>Pmr</td>
<td>RF Input Level</td>
<td>-</td>
<td>+10</td>
<td>dBm</td>
</tr>
</tbody>
</table>

Note  Specific ratings apply to +20 dBm operation (see Section 5.4.3).

2.3. Operating Range

Table 4  Operating Range

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDDop</td>
<td>Supply voltage</td>
<td>1.8</td>
<td>3.7</td>
<td>V</td>
</tr>
<tr>
<td>Top</td>
<td>Operational temperature range</td>
<td>-40</td>
<td>+85</td>
<td>°C</td>
</tr>
<tr>
<td>Clop</td>
<td>Load capacitance on digital ports</td>
<td>-</td>
<td>25</td>
<td>pF</td>
</tr>
<tr>
<td>ML</td>
<td>RF Input Level</td>
<td>-</td>
<td>+10</td>
<td>dBm</td>
</tr>
</tbody>
</table>

Note  A specific supply voltage range applies to +20 dBm operation (see Section 5.4.3).

2.4. Thermal Properties

Table 5  Operating Range

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>THETA_JA</td>
<td>Package $\theta_{ja}$ (Junction to ambient)</td>
<td>-</td>
<td>22.185</td>
<td>-</td>
<td>°C/W</td>
</tr>
<tr>
<td>THETA_JC</td>
<td>Package $\theta_{jc}$ (Junction to case ground paddle)</td>
<td>-</td>
<td>0.757</td>
<td>-</td>
<td>°C/W</td>
</tr>
</tbody>
</table>
2.5. Chip Specification

The tables below give the electrical specifications of the transceiver under the following conditions: Supply voltage $V_{BAT1} = V_{BAT2} = V_{DD} = 3.3$ V, temperature $= 25 \, ^{\circ}C$, $F_{XOSC} = 32$ MHz, $P_{RF} = 915$ MHz, $P_{out} = +13$ dBm, 2 level FSK modulation without pre-filtering, $F_{DA} = 5$ kHz, Bit Rate $= 4.8$ kbps and terminated in a matched 50 Ohm impedance, unless otherwise specified. Shared Rx and Tx path matching.

*Note*  Unless otherwise specified, the performance in the 868 MHz band is identical or better.

2.5.1. Power Consumption

*Table 6  Power Consumption Specification*

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDDSL</td>
<td>Supply current in Sleep mode</td>
<td></td>
<td>-</td>
<td>0.1 uA</td>
<td>1 uA</td>
<td>uA</td>
</tr>
<tr>
<td>IDDIDLE</td>
<td>Supply current in Idle mode</td>
<td>RC oscillator enabled</td>
<td>-</td>
<td>1.5 uA</td>
<td>- uA</td>
<td>uA</td>
</tr>
<tr>
<td>IDDST</td>
<td>Supply current in Standby mode</td>
<td>Crystal oscillator enabled</td>
<td>-</td>
<td>1.4 mA</td>
<td>1.6 mA</td>
<td>mA</td>
</tr>
<tr>
<td>IDDFS</td>
<td>Supply current in Synthesizer mode</td>
<td>FSRx</td>
<td>-</td>
<td>4.5 mA</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td>IDDR</td>
<td>Supply current in Receive mode</td>
<td>$LnaBoost$ Off $LnaBoost$ On</td>
<td>-</td>
<td>10.5 mA</td>
<td>11.2 mA</td>
<td>mA</td>
</tr>
<tr>
<td>IDDT</td>
<td>Supply current in Transmit mode with impedance matching</td>
<td>$RFOP = +20$ dBm on PA_BOOST $RFOP = +17$ dBm on PA_BOOST $RFOP = +13$ dBm on RFO pin $RFOP = +7$ dBm on RFO pin</td>
<td>-</td>
<td>125 mA</td>
<td>-</td>
<td>mA</td>
</tr>
</tbody>
</table>

2.5.2. Frequency Synthesis

*Table 7  Frequency Synthesizer Specification*

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRF</td>
<td>Synthesizer frequency range</td>
<td>Programmable</td>
<td>860</td>
<td>-</td>
<td>1020 MHz</td>
<td>MHz</td>
</tr>
<tr>
<td>FXOSC</td>
<td>Crystal oscillator frequency</td>
<td></td>
<td>-</td>
<td>32 MHz</td>
<td>-</td>
<td>MHz</td>
</tr>
<tr>
<td>TS_OSC</td>
<td>Crystal oscillator wake-up time</td>
<td></td>
<td>-</td>
<td>250 us</td>
<td>-</td>
<td>us</td>
</tr>
<tr>
<td>TS_FS</td>
<td>Frequency synthesizer wake-up time to PLLock signal</td>
<td>From Standby mode</td>
<td>-</td>
<td>60 us</td>
<td>-</td>
<td>us</td>
</tr>
<tr>
<td>TS_HOP</td>
<td>Frequency synthesizer hop time at most 10 kHz away from the target frequency</td>
<td>$200$ kHz step $1$ MHz step $5$ MHz step $7$ MHz step $12$ MHz step $20$ MHz step $25$ MHz step</td>
<td>-</td>
<td>20 us</td>
<td>-</td>
<td>us</td>
</tr>
<tr>
<td>FSTEP</td>
<td>Frequency synthesizer step</td>
<td>$FSTEP = FXOSC/2^{19}$</td>
<td>-</td>
<td>61 Hz</td>
<td>-</td>
<td>Hz</td>
</tr>
<tr>
<td>FRC</td>
<td>RC Oscillator frequency</td>
<td>After calibration</td>
<td>-</td>
<td>62.5 kHz</td>
<td>-</td>
<td>kHz</td>
</tr>
</tbody>
</table>
Note For Maximum Bit Rate the maximum modulation index is 0.5.

2.5.3. FSK/OOK Mode Receiver

All receiver tests are performed with RxBw = 10 kHz (Single Side Bandwidth) as programmed in RegRxBw, receiving a PN15 sequence. Sensitivities are reported for a 0.1% BER (with Bit Synchronizer enabled), unless otherwise specified. Blocking tests are performed with an unmodulated interferer. The wanted signal power for the Blocking Immunity, ACR, IIP2, IIP3 and AMR tests is set 3 dB above the receiver sensitivity level.

Table 8 Receiver Specification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFS_F</td>
<td>Direct tie of RFI and RFO pins, shared Rx, Tx paths FSK sensitivity, highest LNA gain.</td>
<td>FDA = 5 kHz, BR = 1.2 kbps</td>
<td>-119</td>
<td>-115</td>
<td>-110</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 5 kHz, BR = 4.8 kbps</td>
<td>-119</td>
<td>-110</td>
<td>-107</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 40 kHz, BR = 38.4 kbps*</td>
<td>-105</td>
<td>-105</td>
<td>-105</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 20 kHz, BR = 38.4 kbps**</td>
<td>-106</td>
<td>-106</td>
<td>-106</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 62.5 kHz, BR = 250 kbps***</td>
<td>-92</td>
<td>-92</td>
<td>-92</td>
<td>dBm</td>
</tr>
<tr>
<td>RFS_O</td>
<td>Split RF paths, LnaBoost is turned on, the RF switch insertion loss is not accounted for.</td>
<td>FDA = 5 kHz, BR = 1.2 kbps</td>
<td>-123</td>
<td>-120</td>
<td>-118</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 5 kHz, BR = 4.8 kbps</td>
<td>-119</td>
<td>-116</td>
<td>-113</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 40 kHz, BR = 38.4 kbps*</td>
<td>-110</td>
<td>-110</td>
<td>-110</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 20 kHz, BR = 38.4 kbps**</td>
<td>-110</td>
<td>-110</td>
<td>-110</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FDA = 62.5 kHz, BR = 250 kbps***</td>
<td>-97</td>
<td>-97</td>
<td>-97</td>
<td>dBm</td>
</tr>
<tr>
<td>CCR</td>
<td>Co-Channel Rejection</td>
<td>FDA = 2 kHz, BR = 1.2 kbps, RxBw = 5.2 kHz, Offset = +/- 25 kHz</td>
<td>-54</td>
<td>-54</td>
<td>-54</td>
<td>dB</td>
</tr>
<tr>
<td>ACR</td>
<td>Adjacent Channel Rejection</td>
<td>FDA = 5 kHz, BR = 4.8 kbps</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offset = +/- 25 kHz</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>dB</td>
</tr>
<tr>
<td>BI</td>
<td>Blocking Immunity</td>
<td>Offset = +/- 1 MHz</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offset = +/- 2 MHz</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offset = +/- 10 MHz</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>dB</td>
</tr>
<tr>
<td>AMR</td>
<td>AM Rejection, AM modulated interferer with 100% modulation depth, fm = 1 kHz, square</td>
<td>Offset = +/- 1 MHz</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offset = +/- 2 MHz</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offset = +/- 10 MHz</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>dB</td>
</tr>
</tbody>
</table>
### Transmitter Specification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF_OP</td>
<td>RF output power in 50 ohms on RFO pin (High efficiency PA).</td>
<td>Programmable with steps</td>
<td>+11</td>
<td>+14</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>δRF_{OP_ V}</td>
<td>RF output power stability on RFO pin versus voltage supply</td>
<td>VDD = 2.5 V to 3.3 V</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VDD = 1.8 V to 3.7 V</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>RF_{OPH}</td>
<td>RF output power in 50 ohms, on PA_BOOST pin (Regulated PA)</td>
<td>Programmable with 1dB steps</td>
<td>-</td>
<td>+17</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>RF_{OPH_ MAX}</td>
<td>Max RF output power, on PA_BOOST pin</td>
<td>High power mode</td>
<td>-</td>
<td>+20</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>δRF_{OPH_ V}</td>
<td>RF output power stability on PA_BOOST pin versus voltage supply.</td>
<td>VDD = 2.4 V to 3.7 V</td>
<td>-</td>
<td>+/-1</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>δRF_{T}</td>
<td>RF output power stability versus temperature on both RF pins.</td>
<td>From T = -40 °C to +85 °C</td>
<td>-</td>
<td>+/-1</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>PHN</td>
<td>Transmitter Phase Noise</td>
<td>Low Consumption PLL, 915 MHz</td>
<td>-</td>
<td>-102</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 kHz offset</td>
<td>-</td>
<td>-114</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MHz offset</td>
<td>-</td>
<td>-120</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Phase Noise PLL, 915 MHz</td>
<td>-</td>
<td>-106</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 kHz offset</td>
<td>-</td>
<td>-117</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MHz offset</td>
<td>-</td>
<td>-122</td>
<td>-</td>
<td>dBc/Hz</td>
</tr>
</tbody>
</table>

* RxBw = 83 kHz (Single Side Bandwidth)
** RxBw = 50 kHz (Single Side Bandwidth)
*** RxBw = 250 kHz (Single Side Bandwidth)
2.5.5. Electrical specification for LoRa™ modulation

The table below gives the electrical specifications for the transceiver operating with LoRa™ modulation. Following conditions apply unless otherwise specified:

- Supply voltage = 3.3 V.
- Temperature = 25°C.
- \( f_{\text{XOSC}} = 32 \, \text{MHz} \).
- Band: \( f_{\text{RF}} = 915 \, \text{MHz} \).
- Bandwidth (BW) = 125 kHz.
- Spreading Factor (SF) = 12.
- Error Correction Code (EC) = 4/6.
- Packet Error Rate (PER) = 1%
- CRC on payload enabled.
- Output power = 13 dBm in transmission.
- Payload length = 10 bytes.
- Preamble Length = 12 symbols (programmed register \( \text{PreambleLength}=8 \))
- With matched impedances

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDDR_L</td>
<td>Supply current in receiver LoRa™ mode</td>
<td>LnaBoost Off, BW = 125 kHz</td>
<td>-</td>
<td>9.7</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LnaBoost Off, BW = 250 kHz</td>
<td>-</td>
<td>10.5</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LnaBoost Off, BW = 500 kHz</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LnaBoost On, BW = 125 kHz</td>
<td>-</td>
<td>10.8</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LnaBoost On, BW = 250 kHz</td>
<td>-</td>
<td>11.6</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LnaBoost On, BW = 500 kHz</td>
<td>-</td>
<td>13</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td>IDDT_L</td>
<td>Supply current in transmitter mode</td>
<td>RFOP = 13 dBm</td>
<td>-</td>
<td>28</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RFOP = 7 dBm</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td>IDDT_H_L</td>
<td>Supply current in transmitter mode with an external impedance transformation</td>
<td>Using PA_BOOST pin</td>
<td>-</td>
<td>90</td>
<td>-</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RFOP = 17 dBm</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>BI_L</td>
<td>Blocking immunity, FRF=868 MHz</td>
<td>offset = +/- 1 MHz</td>
<td>-</td>
<td>82.5</td>
<td>86.5</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td>CW interferer</td>
<td>offset = +/- 2 MHz</td>
<td>-</td>
<td>86.5</td>
<td>89</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>offset = +/- 10 MHz</td>
<td>-</td>
<td>89</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>IIP3_L</td>
<td>3rd order input intercept point, highest LNA gain, FRF=868 MHz, CW interferer</td>
<td>F1 = FRF + 1 MHz</td>
<td>-</td>
<td>-12.5</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2 = FRF + 1.995 MHz</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>dBm</td>
</tr>
</tbody>
</table>

Table 10 Electrical specifications: LoRa™ mode
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIP2_L</td>
<td>2nd order input intercept point, highest LNA gain, FRF = 868 MHz, CW interferer.</td>
<td>F1 = FRF + 20 MHz, F2 = FRF + 20 MHz + Δf</td>
<td>-</td>
<td>57</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>BR_L</td>
<td>Bit rate, Long-Range Mode</td>
<td>From SF6, CR = 4/5, BW = 500 kHz to SF12, CR = 4/8, BW = 125 kHz</td>
<td>0.24</td>
<td>-</td>
<td>37.5</td>
<td>kbps</td>
</tr>
<tr>
<td>RFS_L250</td>
<td>RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 250 kHz bandwidth using split Rx/Tx path</td>
<td>SF = 6, SF = 7, SF = 8, SF = 9, SF = 10, SF = 11, SF = 12</td>
<td>-</td>
<td>-121</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>RFS_L500</td>
<td>RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 500 kHz bandwidth using split Rx/Tx path</td>
<td>SF = 6, SF = 7, SF = 8, SF = 9, SF = 10, SF = 11, SF = 12</td>
<td>-</td>
<td>-111</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>RFS_L125</td>
<td>RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 125 kHz bandwidth using split Rx/Tx path</td>
<td>SF = 6, SF = 7, SF = 8, SF = 9, SF = 10, SF = 11, SF = 12</td>
<td>-</td>
<td>-118</td>
<td>-</td>
<td>dBm</td>
</tr>
<tr>
<td>CCR_LCW</td>
<td>Co-channel rejection Single CW tone = Sens +6 dB 1% PER</td>
<td>SF = 7, SF = 8, SF = 9, SF = 10, SF = 11, SF = 12</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>CCR_LL</td>
<td>Co-channel rejection Interferer is a LoRa™ signal using same BW and same SF. Pw = Sensitivity +3 dB</td>
<td>SF = 7, SF = 12</td>
<td>-</td>
<td>-6</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>ACR_LCW</td>
<td>Adjacent channel rejection FRF = 868 MHz Interferer is 1.5*BW_L from the wanted signal center frequency 1% PER, Single CW tone = Sensitivity + 3 dB</td>
<td>SF = 7, SF = 12</td>
<td>-</td>
<td>60</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>IMR_LCW</td>
<td>Image rejection after calibration 1% PER, Single CW tone = Sens +3 dB</td>
<td>SF = 7, SF = 12</td>
<td>-</td>
<td>66</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>FERR_L</td>
<td>Maximum tolerated frequency offset between transmitter and receiver, no sensitivity degradation</td>
<td>BW_L = 125 kHz, BW_L = 250 kHz, BW_L = 500 kHz</td>
<td>-30</td>
<td>-</td>
<td>30</td>
<td>kHz</td>
</tr>
</tbody>
</table>

Table 10 Electrical specifications: LoRa™ mode
2.5.6. Digital Specification

Conditions: Temp = 25° C, VDD = 3.3 V, FXOSC = 32 MHz, unless otherwise specified.

Table 11  Digital Specification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIH</td>
<td>Digital input level high</td>
<td></td>
<td>0.8</td>
<td>-</td>
<td>-</td>
<td>VDD</td>
</tr>
<tr>
<td>VIL</td>
<td>Digital input level low</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>VDD</td>
</tr>
<tr>
<td>VOH</td>
<td>Digital output level high</td>
<td>Imax = 1 mA</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>VDD</td>
</tr>
<tr>
<td>VOL</td>
<td>Digital output level low</td>
<td>Imax = -1 mA</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>VDD</td>
</tr>
<tr>
<td>FSCK</td>
<td>SCK frequency</td>
<td></td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>MHz</td>
</tr>
<tr>
<td>tch</td>
<td>SCK high time</td>
<td></td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>tcl</td>
<td>SCK low time</td>
<td></td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>trise</td>
<td>SCK rise time</td>
<td></td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>tfall</td>
<td>SCK fall time</td>
<td></td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>tsetup</td>
<td>MOSI setup time</td>
<td>From MOSI change to SCK rising edge</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>thold</td>
<td>MOSI hold time</td>
<td>From SCK rising edge to MOSI change</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>tsetup</td>
<td>NSS setup time</td>
<td>From NSS falling edge to SCK rising edge</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>thold</td>
<td>NSS hold time</td>
<td>From SCK falling edge to NSS rising edge</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>tnhigh</td>
<td>NSS high time between SPI accesses</td>
<td></td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
<tr>
<td>T_DATA</td>
<td>DATA hold and setup time</td>
<td></td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>ns</td>
</tr>
</tbody>
</table>
3. SX1272/73 Features

This section gives a high-level overview of the functionality of the SX1272/73 low-power, highly integrated transceiver. The following figure shows a simplified block diagram of the SX1272/73.

![Simplified SX1272 Block Schematic Diagram](image)

SX1272/73 is a half-duplex, low-IF transceiver. Here the received RF signal is first amplified by the LNA. The LNA input is single ended to minimize the external BoM and for ease of design. Following the LNA output, the conversion to differential is made to improve the second order linearity and harmonic rejection. The signal is then down-converted to in-phase and quadrature (I&Q) components at the intermediate frequency (IF) by the mixer stage. A pair of sigma delta ADCs then perform data conversion, with all subsequent signal processing and demodulation performed in the digital domain. The digital state machine also controls the automatic frequency correction (AFC), received signal strength indicator (RSSI) and automatic gain control (AGC). It also features the higher-level packet and protocol level functionality of the top level sequencer (TLS).

The frequency synthesizer generates the local oscillator (LO) frequency for both receiver and transmitter. The PLL is optimized for user-transparent low lock time and fast auto-calibrating operation. In transmission, frequency modulation is performed digitally within the PLL bandwidth. The PLL also features optional prefiltering of the bit stream to improve spectral purity.

SX1272/73 feature a pair of RF power amplifiers. The first, connected to RFO, can deliver up to +14 dBm, is unregulated for high power efficiency and can be connected directly to the RF receiver input via a pair of passive components to form a single antenna port high efficiency transceiver. The second PA, connected to the PA_BOOST pin, can deliver up to +20 dBm via a dedicated matching network.

SX1272/73 also includes two timing references, an RC oscillator and a 32 MHz crystal oscillator.

All major parameters of the RF front end and digital state machine are fully configurable via an SPI interface which gives access to SX1272/73’s configuration registers. This includes a mode auto sequencer that oversees the transition and calibration of the SX1272/73 between intermediate modes of operation in the fastest time possible.
The SX1272/73 are equipped with both standard FSK and long range spread spectrum (LoRa™) modems. Depending upon the mode selected either conventional OOK or FSK modulation may be employed or the LoRa™ spread spectrum modem.

3.1. LoRa™ Modem

The LoRa™ modem uses a proprietary spread spectrum modulation technique. This modulation, in contrast to legacy modulation techniques, permits an increase in link budget and increased immunity to in-band interference. At the same time the frequency tolerance requirement of the crystal reference oscillator is relaxed - allowing a performance increase for a reduction in system cost. For a fuller description of the design trade-offs and operation of the SX1272/73 please consult Section 4.1 of the datasheet.

3.2. FSK/OOK Modem

In FSK/OOK mode the SX1272/73 supports standard modulation techniques including OOK, FSK, GFSK, MSK and GMSK. The SX1272/73 is especially suited to narrow band communication thanks the low-IF architecture employed and the built-in AFC functionality. For full information on the FSK/OOK modem please consult Section 4.2 of this document.
4. SX1272/73 Digital Electronics

4.1. The LoRa™ Modem

The LoRa™ modem uses spread spectrum modulation and forward error correction techniques to increase the range and robustness of radio communication links compared to traditional FSK or OOK based modulation. Examples of the performance improvement possible for several settings are summarised in the table below. The spreading factor and error correction rate are design variables that allow the designer to optimise the trade-off between occupied bandwidth, data rate, link budget improvement and immunity to interference. In the table below a coding rate of 4/5 is used.

Table 12  Example LoRa™ Modem Performances

<table>
<thead>
<tr>
<th>Bandwidth (kHz)</th>
<th>Spreading Factor</th>
<th>Nominal Rb (bps)</th>
<th>Sensitivity (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>6</td>
<td>9380</td>
<td>-122</td>
</tr>
<tr>
<td>125</td>
<td>12</td>
<td>293</td>
<td>-137</td>
</tr>
<tr>
<td>250</td>
<td>6</td>
<td>18750</td>
<td>-119</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>586</td>
<td>-134</td>
</tr>
<tr>
<td>500</td>
<td>6</td>
<td>37500</td>
<td>-116</td>
</tr>
<tr>
<td>500</td>
<td>12</td>
<td>1172</td>
<td>-131</td>
</tr>
</tbody>
</table>

Typically such performance gains require high stability frequency references, with LoRa™ this is not the case. Low crystal tolerances are easily accommodated reducing the overall BoM cost for a given increase in link budget.

For European operation the range of crystal tolerances acceptable for each sub-band (of the ERC 70-03) is given in the specifications table. For US based operation a frequency hopping mode is available that automates both the LoRa™ spread spectrum and frequency hopping spread spectrum processes.

Another important facet of the LoRa™ modem is its increased immunity to interference. The LoRa™ modem is capable of co-channel GMSK rejection of up to 25 dB. This immunity to interference permits the simple coexistence of LoRa™ modulated systems either in bands of heavy spectral usage or in hybrid communication networks that use LoRa™ to extend range when legacy modulation schemes fail.
4.1.1. Link Design Using the LoRa™ Modem

4.1.1.1. Overview

The LoRa™ modem is setup as shown in the following figure. This configuration permits the simple replacement of the FSK modem with the LoRa™ modem via the configuration register setting RegOpMode. This change can be performed on the fly (in Sleep operating mode) thus permitting the use of both standard FSK or OOK in conjunction with the long range capability. The LoRa™ modulation and demodulation process is proprietary, it uses a form of spread spectrum modulation combined with cyclic error correction coding. The combined influence of these two factors is an increase in link budget and enhanced immunity to interference.

![Figure 5. LoRa™ Modem Connectivity](image)

A simplified outline of the transmit and receive processes is also shown above. Here we see that the LoRa™ modem has an independent dual port data buffer FIFO that is accessed through an SPI interface common to all modes. Upon selection of LoRa™ mode, the configuration register mapping of the SX1272/73 changes. For full details of this change please consult the register description of Section 6.

So that it is possible to optimise the LoRa™ modulation for a given application, access is given to the designer to three critical design parameters. Each one permitting a trade off between link budget, immunity to interference, spectral occupancy and nominal data rate. These parameters are spreading factor, modulation bandwidth and error coding rate.
4.1.1.2. Spreading Factor

The spread spectrum LoRa™ modulation is performed by representing each bit of payload information by multiple chips of information. The rate at which the spread information is sent is referred to as the symbol rate \( (R_s) \), the ratio between the nominal symbol rate and chip rate is the spreading factor and represents the number of symbols sent per bit of information. The range of values accessible with the LoRa™ modem are shown in the following table.

Table 13 Range of Spreading Factors

<table>
<thead>
<tr>
<th>Spreading Factor (RegModemConfig2)</th>
<th>Spreading Factor (Chips / symbol)</th>
<th>LoRa Demodulator SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>64</td>
<td>-5 dB</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>-7.5 dB</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
<td>-10 dB</td>
</tr>
<tr>
<td>9</td>
<td>512</td>
<td>-12.5 dB</td>
</tr>
<tr>
<td>10</td>
<td>1024</td>
<td>-15 dB</td>
</tr>
<tr>
<td>11</td>
<td>2048</td>
<td>-17.5 dB</td>
</tr>
<tr>
<td>12</td>
<td>4096</td>
<td>-20 dB</td>
</tr>
</tbody>
</table>

Note that the spreading factor, \( \text{SpreadingFactor} \), must be known in advance on both transmit and receive sides of the link as different spreading factors are orthogonal to each other. Note also the resulting signal to noise ratio (SNR) required at the receiver input. It is the capability to receive signals with negative SNR that increases the sensitivity, so link budget and range, of the LoRa receiver.

**Spreading Factor 6**

SF = 6 is a special use case for the highest data rate transmission possible with the LoRa modem. To this end several settings must be activated in the SX1272/73 registers when it is in use. These settings are only valid for SF6 and should be set back to their default values for other spreading factors:

- Set \( \text{SpreadingFactor} = 6 \) in RegModemConfig2
- The header must be set to Implicit mode.
- Set the bit field DetectionOptimize of register RegLoRaDetectOptimize to value "0b101".
- Write 0x0C in the register RegDetectionThreshold.

4.1.1.3. Coding Rate

To further improve the robustness of the link the LoRa™ modem employs cyclic error coding to perform forward error detection and correction. Such error coding incurs a transmission overhead - the resultant additional data overhead per transmission is shown in the table below.

Table 14 Cyclic Coding Overhead

<table>
<thead>
<tr>
<th>Coding Rate (RegModemConfig1)</th>
<th>Cyclic Coding Rate</th>
<th>Overhead Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4/5</td>
<td>1.25</td>
</tr>
<tr>
<td>2</td>
<td>4/6</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>4/7</td>
<td>1.75</td>
</tr>
<tr>
<td>4</td>
<td>4/8</td>
<td>2</td>
</tr>
</tbody>
</table>
Forward error correction is particularly efficient in improving the reliability of the link in the presence of interference. So that the coding rate (and so robustness to interference) can be changed in response to channel conditions - the coding rate can optionally be included in the packet header for use by the receiver. Please consult Section 4.1.1.6 for more information on the LoRa™ packet and header.

4.1.1.4. Signal Bandwidth

An increase in signal bandwidth permits the use of a higher effective data rate, thus reducing transmission time at the expense of reduced sensitivity improvement. There are of course regulatory constraints in most countries on the permissible occupied bandwidth. Contrary to the FSK modem, which is described in terms of the single sideband bandwidth, the LoRa™ modem bandwidth refers to the double sideband bandwidth (or total channel bandwidth). The range of bandwidths relevant to most regulatory situations is given in the LoRa™ modem specifications table (see Section 2.5.5).

<table>
<thead>
<tr>
<th>Bandwidth (kHz)</th>
<th>Spreading Factor</th>
<th>Coding rate</th>
<th>Nominal Rb (bps)</th>
<th>Sensitivity (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>12</td>
<td>4/5</td>
<td>293</td>
<td>-136</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>4/5</td>
<td>586</td>
<td>-133</td>
</tr>
<tr>
<td>500</td>
<td>12</td>
<td>4/5</td>
<td>1172</td>
<td>-130</td>
</tr>
</tbody>
</table>

4.1.1.5. LoRa™ Transmission Parameter Relationship

With a knowledge of the key parameters that can be controlled by the user we define the LoRa™ symbol rate as:

\[
Rs = \frac{BW}{2^SF}
\]

where BW is the programmed bandwidth and SF is the spreading factor. The transmitted signal is a constant envelope signal. Equivalently, one chip is sent per second per Hz of bandwidth.
4.1.1.6. **LoRa™ Packet Structure**

The LoRa™ modem employs two types of packet format, explicit and implicit. The explicit packet includes a short header that contains information about the number of bytes, coding rate and whether a CRC is used in the packet. The packet format is shown in the following figure.

The LoRa™ packet comprises three elements:
- A preamble.
- An optional header.
- The data payload.

![Figure 6. LoRa™ Packet Structure](image)

**Preamble**

The preamble is used to synchronize receiver with the incoming data flow. By default the packet is configured with a 12 symbol long sequence. This is a programmable variable so the preamble length may be extended, for example in the interest of reducing to receiver duty cycle in receive intensive applications. The transmitted preamble length may be changed by setting the registers `RegPreambleMsb` and `RegPreambleLsb` from 6 to 65535, yielding total preamble lengths of 6 + 4 to 65535 + 4 symbols, once the fixed overhead of the preamble data is considered. This permits the transmission of near arbitrarily long preamble sequences.

The receiver undertakes a preamble detection process that periodically restarts. For this reason the preamble length should be configured identical to the transmitter preamble length. Where the preamble length is not known, or can vary, the maximum preamble length should be programmed on the receiver side.

**Header**

Depending upon the chosen mode of operation two types of header are available. The header type is selected by the `ImplicitHeaderModeOn` bit found within the `RegModemConfig1` register.

**Explicit Header Mode**

This is the default mode of operation. Here the header provides information on the payload, namely:
- The payload length in bytes.
- The forward error correction code rate
- The presence of an optional 16-bits CRC for the payload.
The header is transmitted with maximum error correction code (4/8). It also has its own CRC to allow the receiver to discard invalid headers.

In Explicit Header Mode the presence of the payload CRC selected on the transmit side through the use of the bit RxPayloadCrcOn located in the register `RegModemConfig1`.

The corresponding bit (RxPayloadCrcOn) is hence unused on the receive side. Instead, upon reception of the payload, may consult the bit CrcOnPayload in the register `RegHopChannel`. If the bit CrcOnPayload is at ‘1’ then the user should then check the IRQ Flag PayloadCrcError to ensure that the CRC is valid.

If the bit CrcOnPayload is at ‘0’, it means there was no CRC on the payload and thus the IRQ Flag PayloadCrcError will not be triggered in the event of payload errors.

<table>
<thead>
<tr>
<th>Explicit Header</th>
<th>Transmitter</th>
<th>Receiver</th>
<th>CRC Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of the bit RxPayloadCrcOn</td>
<td>0</td>
<td>0</td>
<td>CRC is not checked</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>CRC is not checked</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>CRC is checked</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>CRC is checked</td>
</tr>
</tbody>
</table>

**Implicit Header Mode**

In certain scenarios, where the payload, coding rate and CRC presence are fixed or known in advance, it may be advantageous to reduce transmission time by invoking implicit header mode. In this mode the header is removed from the packet. In this case the payload length, error coding rate and presence of the payload CRC must be manually configured on both sides of the radio link.

*Note that with SF = 6 selected implicit header mode is the only mode of operation possible.*

To avail of the payload CRC in Implicit Header Mode, it is necessary to set the bit RxPayloadCrcOn in the register `RegModemConfig1` on both sides (TX and RX).

<table>
<thead>
<tr>
<th>Implicit Header</th>
<th>Transmitter</th>
<th>Receiver</th>
<th>CRC Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of the bit RxPayloadCrcOn</td>
<td>0</td>
<td>0</td>
<td>CRC is not checked</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>CRC is always wrong</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>CRC is not checked</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>CRC is checked</td>
</tr>
</tbody>
</table>

**Low Data Rate Optimization**

Given the potentially long duration of the packet at high spreading factors the option is given to improve the robustness of the transmission to variations in frequency over the duration of the packet transmission and reception. The bit `LowDataRateOptimize` increases the robustness of the LoRa link at these low effective data rates, its use is mandated with spreading factors of 11 and 12 at 125 kHz bandwidth.
Payload

The packet payload is a variable-length field that contains the actual data coded at the error rate either as specified in the header in explicit mode or in the register settings in implicit mode. An optional CRC may be appended. For more information on the payload and how it is loaded from the data buffer FIFO please see Section 4.1.2.3.

4.1.1.7. Time on air

For a given combination of spreading factor (SF), coding rate (CR) and signal bandwidth (BW) the total on-the-air transmission time of a LoRa™ packet can be calculated as follows. From the definition of the symbol rate it is convenient to define the symbol period:

\[ T_s = \frac{1}{R_s} \]

The LoRa packet duration is the sum of the duration of the preamble and the transmitted packet. The preamble length is calculated as follows:

\[ T_{\text{preamble}} = (n_{\text{preamble}} + 4.25)T_{\text{sym}} \]

where \( n_{\text{preamble}} \) is the programmed preamble length, taken from the registers \texttt{RegPreambleMsb} and \texttt{RegPreambleLsb}. The payload duration depends upon the header mode that is enabled. The following formula gives the number of payload symbols.

\[ n_{\text{payload}} = 8 + \max\left( \left\lceil \frac{8PL - 4SF + 28 + 16CRC - 20IH}{4(SF-2DE)} \right\rceil (CR + 4), 0 \right) \]

Where PL is the number of bytes of payload, SF is the spreading factor, IH = 1 when implicit header mode is enabled and IH = 0 when explicit header mode is used. DE set to 1 indicates the use of the low data rate optimization, 0 when disabled. CRC indicates the presence of the payload CRC = 1 when on 0 when off. CR is the programmed coding rate from 1 to 4.

The \( \lceil \cdot \rceil \) function indicates that the portion of the equation in square brackets should be rounded up to the next integer value. The \( \max \) function compares the evaluated \( \lceil \cdot \rceil \) function result and returns 0 or the result - whichever is higher.

\[ T_{\text{payload}} = n_{\text{payload}} \times T_s \]

Addition of the preamble and payload durations gives the total packet time on air.

\[ T_{\text{packet}} = T_{\text{preamble}} + T_{\text{payload}} \]

4.1.1.8. Frequency Hopping with LoRa™

Frequency hopping spread spectrum (FHSS) is typically employed when the duration of a single packet could exceed regulatory requirements relating to the maximum permissible channel dwell time. This is most notably the case in US operation where the 902 to 928 MHz ISM band which makes provision for frequency hopping operation. To ease the implementation of FHSS systems the frequency hopping mode of the LoRa™ modem can be enabled by setting \texttt{FreqHoppingPeriod} to a non-zero value in register \texttt{RegHopPeriod}. 
**Principle of Operation**

The principle behind the FHSS scheme is that a portion of each LoRa™ packet is transmitted on each hopping channel from a look up table of frequencies managed by the host microcontroller. After a predetermined hopping period the transmitter and receiver change to the next channel in a predefined list of hopping frequencies to continue transmission and reception of the next portion of the packet. The time which the transmission will dwell in any given channel is determined by \( FreqHoppingPeriod \) which is an integer multiple of symbol periods:

\[
HoppingPeriod[x] = Ts \times FreqHoppingPeriod
\]

The frequency hopping transmission and reception process starts at channel 0. The preamble and header are transmitted first on channel 0. At the beginning of each transmission the channel counter \( FhssPresentChannel \) (located in the register \( RegHopChannel \)) is incremented and the interrupt signal \( FhssChangeChannel \) is generated. The new frequency must then be programmed within the hopping period to ensure it is taken into account for the next hop, the interrupt \( ChangeChannelFhss \) is then to be cleared by writing a logical ‘1’.

FHSS Reception always starts on channel 0. The receiver waits for a valid preamble detection before starting the frequency hopping process as described above. Note that in the eventuality of header CRC corruption, the receiver will automatically request channel 0 and recommence the valid preamble detection process.

**Timing of Channel Updates**

The interrupt requesting the channel change, \( FhssChannelChange \), is generated upon transition to the new frequency. The frequency hopping process is illustrated in the diagram below:

![Diagram of FHSS operation](image-url)

*Figure 7. Interrupts generated in the case of successful frequency hopping communication.*
4.1.2. LoRa™ Digital Interface

The LoRa™ modem comprises three types of digital interface, static configuration registers, status registers and a FIFO data buffer. All are accessed through the SX1272/73's SPI interface - full details of each type of register are given below. Full listings of the register addresses used for SPI access are given in Section 6.3.

4.1.2.1. LoRa™ Configuration Registers

Configuration registers are accessed through the SPI interface. Registers are readable in all device mode including Sleep. However, they should be written only in Sleep and Standby modes. Please note that the automatic top level sequencer (TLS modes) are not available in LoRa™ mode and the configuration register mapping changes as shown in Table 39. The content of the LoRa™ configuration registers is retained in FSK/OOK mode. For the functionality of mode registers common to both FSK/OOK and LoRa™ mode, please consult the Analog and RF Front End section of this document (Section 5).

4.1.2.2. Status Registers

Status registers provide status information during receiver operation.

4.1.2.3. LoRa™ Mode FIFO Data Buffer

Overview

The SX1272/73 is equipped with a 256 byte RAM data buffer which is uniquely accessible in LoRa mode. This RAM area, herein referred to as the FIFO Data buffer, is fully customizable by the user and allows access to the received, or to be transmitted, data. All access to the LoRa™ FIFO data buffer is done via the SPI interface. A diagram of the user defined memory mapping of the FIFO data buffer is shown below. These FIFO data buffer can be read in all operating modes except sleep and store data related to the last receive operation performed. It is automatically cleared of old content upon each new transition to receive mode.

![Figure 8. LoRa™ data buffer](image)
Principle of Operation

Thanks to its dual port configuration, it is possible to simultaneously store both transmit and receive information in the FIFO data buffer. The register `RegFifoTxBaseAddr` specifies the point in memory where the transmit information is stored. Similarly, for receiver operation, the register `RegFifoRxBaseAddr` indicates the point in the data buffer where information will be written to in event of a receive operation.

By default, the device is configured at power up so that half of the available memory is dedicated to Rx (`RegFifoRxBaseAddr` initialized at address 0x00) and the other half is dedicated for Tx (`RegFifoTxBaseAddr` initialized at address 0x80).

However, due to the contiguous nature of the FIFO data buffer, the base addresses for Tx and Rx are fully configurable across the 256 byte memory area. Each pointer can be set independently anywhere within the FIFO. To exploit the maximum FIFO data buffer size in transmit or receive mode, the whole FIFO data buffer can be used in each mode by setting the base addresses `RegFifoTxBaseAddr` and `RegFifoRxBaseAddr` at the bottom of the memory (0x00).

The FIFO data buffer is cleared when the device is put in SLEEP mode, consequently no access to the FIFO data buffer is possible in sleep mode. However, the data in the FIFO data buffer are retained when switching across the other LoRa™ modes of operation, so that a received packet can be retransmitted with minimum data handling on the controller side. The FIFO data buffer is not self-clearing (unless if the device is put in sleep mode) and the data will only be “erased” when a new set of data is written into the occupied memory location.

The FIFO data buffer location to be read from, or written to, via the SPI interface is defined by the address pointer `RegFifoAddrPtr`. Before any read or write operation it is hence necessary to initialize this pointer to the corresponding base value. Upon reading or writing to the FIFO data buffer (`RegFifo`) the address pointer will then increment automatically.

The register `RegRxNbBytes` defines the size of the memory location to be written in the event of a successful receive operation. The register `RegPayloadLength` indicates the size of the memory location to be transmitted. In implicit header mode, the register `RegRxNbBytes` is not used as the number of payload bytes is known. Otherwise, in explicit header mode, the initial size of the receive buffer is set to the packet length in the received header. The register `RegFifoRxCurrentAddr` indicates the location of the last packet received in the FIFO so that the last packet received can be easily read by pointing the register `RegFifoAddrPtr` to this register.

It is important to note that all the received data will be written to the FIFO data buffer even if the CRC is invalid, permitting user defined post processing of corrupted data. It is also important to note that when receiving, if the packet size exceeds the buffer memory allocated for the Rx, it will overwrite the transmit portion of the data buffer.

4.1.2.4. Interrupts in LoRa Mode

Two registers are used to control the interrupt signals (IRQ) available in LoRa mode: the register `RegIrqFlags` contains the state of the interrupts themselves and the register `RegIrqFlagsMask` which can be used to mask the interrupts.

The interrupt mask `RegIrqFlagsMask`, allows the user to mask individual interrupts, in this case setting a bit to ‘1’ will mask - so deactivate the interrupt at the same position in the `RegIrqFlags` register. By default all the interrupts are unmasked, so available.

In the register `RegIrqFlags`, a ‘1’ indicates a given IRQ has been trigged and then the IRQ must be clear by writing a ‘1’.
4.1.3. Operation of the LoRa™ Modem

4.1.3.1. Operating Mode Control

The operating modes of the LoRa™ modem are accessed by enabling LoRa™ mode (setting the LongRangeMode bit of RegOpMode). Depending upon the operating mode selected the range of functionality and register access is given by the following table:

Table 15  LoRa™ Operating Mode Functionality

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLEEP</td>
<td>Low-power mode. In this mode only SPI and configuration registers are accessible. Lora FIFO is not accessible. Note that this is the only mode permissible to switch between FSK/OOK mode and LoRa mode.</td>
</tr>
<tr>
<td>STANDBY</td>
<td>Both crystal oscillator and LoRa baseband blocks are turned on. RF front-end and PLLs are disabled</td>
</tr>
<tr>
<td>FSTX</td>
<td>This is a frequency synthesis mode for transmission. The PLL selected for transmission is locked and active at the transmit frequency. The RF front-end is off.</td>
</tr>
<tr>
<td>FSRX</td>
<td>This is a frequency synthesis mode for reception. The PLL selected for reception is locked and active at the receive frequency. The RF front-end is off.</td>
</tr>
<tr>
<td>TX</td>
<td>When activated the SX1272/73 powers all remaining blocks required for transmit, ramps the PA, transmits the packet and returns to Standby mode.</td>
</tr>
<tr>
<td>RXCONTINUOUS</td>
<td>When activated the SX1272/73 powers all remaining blocks required for reception, processing all received data until a new user request is made to change operating mode.</td>
</tr>
<tr>
<td>RXSINGLE</td>
<td>When activated the SX1272/73 powers all remaining blocks required for reception, remains in this state until a valid packet has been received and then returns to Standby mode.</td>
</tr>
<tr>
<td>CAD</td>
<td>When in CAD mode, the device will check a given channel to detect LoRa preamble signal</td>
</tr>
</tbody>
</table>

It is possible to access any mode from any other mode by changing the value in the RegOpMode register.
4.1.4. Frequency Settings

Recalling that the frequency step is given by:

\[ F_{STEP} = \frac{F_{XOSC}}{2^{19}} \]

In order to set LO frequency values following registers are available.

Fr is a 24-bit register which defines carrier frequency. The carrier frequency relates to the register contents by following formula:

\[ F_{RF} = F_{STEP} \times Fr(23,0) \]

4.1.5. Frequency Error Indication

The SX1272 derives its RF centre frequency from a crystal reference oscillator which has a finite frequency precision. Errors in reference frequency will manifest themselves as errors of the same proportion from the RF centre frequency.

In LoRa receive mode the SX1272 is capable of measuring the frequency offset between the receiver centre frequency and that of an incoming LoRa signal. The image below shows the estimated frequency offset and corresponding PER for various coding rates as a function of frequency offset. Here we can see that the modem is intolerant of frequency offsets in the region of +/- 20% of the bandwidth and will accurately report the error over this same range.

![Applied versus measured frequency offset and influence on PER.](image)

The error is read by reading the three RegFei registers. The contents of which are a signed 20 bit two's compliment word, FreqError. The frequency error is determined from the register contents by:

\[ F_{Error} = \frac{\text{FreqError} \times 2^{24}}{F_{xtal}} \]

Where Fxtal is the crystal frequency.

Please note that the measured FEI should not be applied to the RF centre frequency to perform AFC. The FEI measurement is provided for information only.
4.1.6. LoRa™ Modem State Machine Sequences

The sequence for transmission and reception of data to and from the LoRa™ modem, together with flow charts of typical sequences of operation, are detailed below.

Data Transmission Sequence

In transmit mode power consumption is optimized by enabling RF, PLL and PA blocks only when packet data needs to be transmitted. Figure 10 shows a typical LoRa™ transmit sequence.

- Static configuration registers can only be accessed in Sleep mode, Standby mode or FSTX mode.
- The LoRa™ FIFO should only be filled in Standby mode and cannot be filled in Sleep mode.
- Data transmission is initiated by sending TX mode request.
- Upon completion the TxDone interrupt is issued and the radio returns to Standby mode.
- Following transmission the radio can be manually placed in Sleep mode or the FIFO refilled for a subsequent Tx operation.

Figure 10. LoRa™ modulation transmission sequence.
LoRa™ Transmit Data FIFO Filling
In order to write packet data into FIFO user should:
1. Set FifoAddrPtr to FifoTxBaseAddrs.
2. Write PayloadLength bytes to the FIFO (RegFifo)

Data Reception Sequence
Figure 11 shows typical LoRa™ receive sequences for both single and continuous receiver modes of operation.

Figure 11. LoRa™ receive sequence.
The LoRa™ modem can work in two distinct reception modes:

1. Single receive mode
2. Continuous receive mode

**Single Reception Operating Mode**

In this mode, the modem searches for a preamble during a given period of time. If a preamble hasn’t been found at the end of the time window, the chip generates the RxTimeout interrupt and goes back to Standby mode. The length of the reception window (in symbols) is defined by the RegSymbTimeout register and should be in the range of 4 (minimum time for the modem to acquire lock on a preamble) up to 1023 symbols.

At the end of the payload, the RxDone interrupt is generated together with the interrupt PayloadCrcError if the payload CRC is not valid. However, even when the CRC is not valid, the data are written in the FIFO data buffer for post processing. Following the RxDone interrupt the radio goes to Standby mode.

The modem will also automatically return in Standby mode when the interrupts RxDone is generated. Therefore, this mode should only be used when the time window of arrival of the packet is known. In other cases, the RX continuous mode should be used.

In Rx single mode low-power is achieved by turning off PLL and RF blocks as soon as a packet has been received. The flow is as follows:

1. Set FifoAddrPtr to FifoRxBaseAddr.
2. Static configuration register device can be written in either Sleep mode, Standby mode or FSRX mode.
3. A single packet receive operation is initiated by selecting the operating mode RXSINGLE.
4. The receiver will then await the reception of a valid preamble. Once received, the gain of the receive chain is set. Following the ensuing reception of a valid header, indicated by the ValidHeader interrupt in explicit mode. The packet reception process commences. Once the reception process is complete the RxDone interrupt is set. The radio then returns automatically to Standby mode to reduce power consumption.
5. The receiver status register PayloadCrcError should be checked for packet payload integrity.
6. If a valid packet payload has been received then the FIFO should be read (See Payload Data Extraction below). Should a subsequent single packet reception need to be triggered, then the RXSINGLE operating mode must be re-selected to launch the receive process again - taking care to reset the SPI pointer (FifoAddrPtr) to the base location in memory (FifoRxBaseAddr).

**Continuous Reception Operating Mode**

In continuous receive mode, the modem scans the channel continuously for a preamble. Each time a preamble is detected the modem tracks it until the packet is received and then carries on waiting for the next preamble.

If the preamble length exceeds the anticipated value set by the registers RegPreambleMsb and RegPreambleLsb (measured in symbol periods) the preamble will be dropped and the search for a preamble restarted. However, this scenario will not be flagged by any interrupt. In continuous RX mode, opposite to the single RX mode, the RxTimeout interrupt will never occur and the device will never go in Standby mode automatically.

It is also important to note that the demodulated bytes are written in the data buffer memory in the order received. Meaning, the first byte of a new packet is written just after the last byte of the preceding packet. The RX modem address pointer is never reset as long as this mode is enabled. It is therefore necessary for the companion microcontroller controller to handle the address pointer to make sure the FIFO data buffer is never full.
In continuous mode the received packet processing sequence is given below.

1. Whilst in Sleep or Standby mode select RXCONT mode.
2. Upon reception of a valid header CRC the RxDone interrupt is set. The radio remains in RXCONT mode waiting for the next RX LoRa™ packet.
3. The PayloadCrcError flag should be checked for packet integrity.
4. If packet has been correctly received the FIFO data buffer can be read (see below).
5. The reception process (steps 2 - 4) can be repeated or receiver operating mode exited as desired.

In continuous mode status information are available only for the last packet received, i.e. the corresponding registers should be read before the next RxDone arrives.

Rx Single and Rx Continuous Use Cases
The LoRa single reception mode is used mainly in battery operated systems or in systems where the companion microcontroller has a limited availability of timers. In such systems, the use of the timeout present in Rx Single reception mode allows the end user to limit the amount of time spent in reception (and thus limiting the power consumption) while not using any of the companion MCU timers (the MCU can then be in sleep mode while the radio is in the reception mode). The RxTimeout interrupt generated at the end of the reception period is then used to wake-up the companion MCU. One of the advantages of the RxSingle mode is that the interrupt RxTimeout will not be triggered if the device is currently receiving data, thus giving the priority to the reception of the data over the timeout. However, if during the reception, the device loses track of the data due to external perturbation, the device will drop the reception, flag the interrupt RxTimeout and go in Standby mode to decrease the power consumption of the system.

On the other hand, The LoRa continuous reception mode is used in systems which do not have power restrictions or on system where the use of a companion MCU timer is preferred over the radio embedded timeout system. In RxContinuous mode, the radio will track any LoRa signal present in the air and carry on the reception of packets until the companion MCU sets the radio into another mode of operation. Upon reception the interrupt RxDone will be trigged but the device will stay in Rx Mode, ready for the reception of the next packet.

Payload Data Extraction from FIFO
In order to retrieve received data from FIFO the user must ensure that ValidHeader, PayloadCrcError, RxDone and RxTimeout interrupts in the status register RegIrqFlags are not asserted to ensure that packet reception has terminated successfully (i.e. no flags should be set).

In case of errors the steps below should be skipped and the packet discarded. In order to retrieve valid received data from the FIFO the user must:

- **RegRxNbBytes** Indicates the number of bytes that have been received thus far.
- **RegFifoAddrPtr** is a dynamic pointer that indicates precisely where the Lora modem received data has been written up to.
- Set **RegFifoAddrPtr** to **RegFifoRxCurrentAddr**. This sets the FIFO pointer to the location of the last packet received in the FIFO. The payload can then be extracted by reading the register RegFifo, RegRxNbBytes times.

Alternatively, it is possible to manually point to the location of the last packet received, from the start of the current packet, by setting **RegFifoAddrPtr** to **RegFifoRxByteAddr** minus **RegRxNbBytes**. The payload bytes can then be read from the FIFO by reading the **RegFifo** address **RegRxNbBytes** times.
Packet Filtering based on Preamble Start

The LoRa™ modem does not automatically filter received packets based upon an address. However, the SX1272/73 permits software filtering of the received packets based on the contents of the first few bytes of payload. A brief example is given below for a 4 byte address, however, the address length can be selected by the designer.

The objective of the packet filtering process is to determine the presence, or otherwise, of a valid packet designed for the receiver. If the packet is not for the receiver then the radio returns to sleep mode in order to improve battery life. The software packet filtering process follows the steps below:

- Each time the RxDone interrupt is received, latch the RegFifoRxByteAddr[7:0] register content in a variable, this variable will be called start_address. The RegFifoRxByteAddr[7:0] register of the SX1272 gives in real time the address of the last byte written in the data buffer + 1 (or the address at which the next byte will be written by the receive LoRa™ modem). So by doing this, we make sure that the variable start_address always contains the start address of the next packet.

- Upon reception of the interrupt ValidHeader, start polling the RegFifoRxByteAddr[7:0] register until it begins to increment. The speed at which this register will increment depends on the spreading factor, the error correction code and the modulation bandwidth. (Note that this interrupt is still generated in implicit mode).

- As soon as RegFifoRxByteAddr[7:0] >= start address + 4, the first 4 bytes (address) are stored in the FIFO data buffer. These can be read and tested to see if the packet is destined for the radio and either remaining in Rx mode to receive the packet or returning to sleep mode if not.

Receiver Timeout Operation

In LoRa™ Rx Single mode, a receiver timeout functionality is available that permits the receiver to listen for a predetermined period of time before generating an interrupt signal to indicate that no valid packets have been received. The timer is absolute and commences as soon as the radio is placed in single receive mode. The interrupt itself, RxTimeout, can be found in the interrupt register RegIrqFlags. In Rx Single mode, the device will return to Standby mode as soon as the interrupt occurs. The user must then clear the interrupt or go into Sleep mode before returning into Rx Single mode. The programmed timeout value is expressed as a multiple of the symbol period and is given by:

\[
\text{Timeout} = \text{LoraRxTimeout} \cdot Ts
\]
Channel activity detection

The use of a spread spectrum modulation technique presents challenges in determining whether the channel is already in use by a signal that may be below the noise floor of the receiver. The use of the RSSI in this situation would clearly be impracticable. To this end the channel activity detector is used to detect the presence of other LoRa™ signals. Figure 12 shows the channel activity detection (CAD) process:
Principle of Operation

The channel activity detection mode is designed to detect a LoRa preamble on the radio channel with the best possible power efficiency. Once in CAD mode, the SX1272/73 will perform a very quick scan of the band to detect a LoRa\textsuperscript{TM} packet preamble.

During a CAD the following operations take place:

- The PLL locks
- The radio receiver captures LoRa\textsuperscript{TM} preamble symbol of data from the channel. The radio current consumption during that phase is approximately 10 mA.
- The radio receiver and the PLL turn off and the modem digital processing starts.
- The modem searches for a correlation between the radio captured samples and the ideal preamble waveform. This correlation process takes a little bit less than a symbol period to perform. The radio current consumption during that phase is greatly reduced.
- Once the calculation is finished the modem generates the CadDone interrupt. If the correlation was successful, the CadDetected is generated simultaneously.
- The chip goes back to Standby mode.
- If a preamble was detected, clear the interrupt, then initiate the reception by putting the radio in RX single mode or RX continuous mode.

The time taken for the channel activity detection is dependent upon the LoRa\textsuperscript{TM} modulation settings used. For a given configuration the typical CAD detection time is shown in the graph below, expressed as a multiple of the LoRa\textsuperscript{TM} symbol period. Of this period the radio is in receiver mode for \((2^{\text{SF}} + 32) / \text{BW}\) seconds. For the remainder of the CAD cycle the radio is in a reduced consumption state.

![Graph showing Channel activity detection (CAD) time as a function of spreading factor.](image)

*Figure 13. Channel activity detection (CAD) time as a function of spreading factor.*
To illustrate this process and the respective consumption in each mode, the CAD process follows the sequence of events outlined below:

![Figure 14. Consumption Profile of the LoRa CAD Process](image)

The receiver is then in full receiver mode for just over half of the activity detection, followed by a reduced consumption processing phase where the consumption varies with the LoRa bandwidth as shown in the table below.

<table>
<thead>
<tr>
<th>Bandwidth (kHz)</th>
<th>Full Rx, IDDR_L (mA)</th>
<th>Processing, IDDC_L (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>10.8</td>
<td>5.6</td>
</tr>
<tr>
<td>250</td>
<td>11.6</td>
<td>6.5</td>
</tr>
<tr>
<td>500</td>
<td>13</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 16 LoRa CAD Consumption Figures**

4.1.6.1. Digital IO Pin Mapping

Six of SX1272/73's general purpose IO pins are available used in LoRa™ mode. Their mapping is shown below and depends upon the configuration of registers RegDioMapping1 and RegDioMapping2.

**Table 17 DIO Mapping LoRa™ Mode**
4.2. FSK/OOK Modem

4.2.1. Bit Rate Setting

The bit rate setting is referenced to the crystal oscillator and provides a precise means of setting the bit rate (or equivalently chip rate) of the radio. In continuous transmit mode (Section 4.2.13) the data stream to be transmitted can be input directly to the modulator via pin 9 (DIO2/DATA) asynchronously, unless Gaussian filtering is used, in which case the DCLK signal on pin 10 (DIO1/DCLK) is used to clock-in the data stream. See section 4.2.2.3 for details of the Gaussian filter.

In Packet mode or in Continuous mode with Gaussian filtering enabled, the Bit Rate (BR) is controlled by bits BitRate in RegBitrateMsb and RegBitrateLsb

\[
\text{BitRate} = \frac{\text{FXOSC}}{\text{BitRate}(15,0) + \frac{\text{BitrateFrac}}{16}}
\]

Note: BitrateFrac bits have no effect (i.e may be considered equal to 0) in OOK modulation mode.

The quantity BitrateFrac is hence designed to allow very high precision (max. 250 ppm programming resolution) for any bitrate in the programmable range. Table 18 below shows a range of standard bitrates and the accuracy to within which they may be attained.

**Table 18  Bit Rate Examples**

<table>
<thead>
<tr>
<th>Type</th>
<th>BitRate (15:8)</th>
<th>BitRate (7:0)</th>
<th>(G)FSK (G)MSK</th>
<th>OOK</th>
<th>Actual BR (b/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical modem baud rates (multiples of 1.2 kbps)</td>
<td>0x68</td>
<td>0x2B</td>
<td>1.2 kbps</td>
<td>1.2 kbps</td>
<td>1200.015</td>
</tr>
<tr>
<td></td>
<td>0x34</td>
<td>0x15</td>
<td>2.4 kbps</td>
<td>2.4 kbps</td>
<td>2400.060</td>
</tr>
<tr>
<td></td>
<td>0x1A</td>
<td>0x0B</td>
<td>4.8 kbps</td>
<td>4.8 kbps</td>
<td>4799.760</td>
</tr>
<tr>
<td></td>
<td>0x0D</td>
<td>0x05</td>
<td>9.6 kbps</td>
<td>9.6 kbps</td>
<td>9600.960</td>
</tr>
<tr>
<td></td>
<td>0x06</td>
<td>0x83</td>
<td>19.2 kbps</td>
<td>19.2 kbps</td>
<td>19196.16</td>
</tr>
<tr>
<td></td>
<td>0x03</td>
<td>0x41</td>
<td>38.4 kbps</td>
<td></td>
<td>38415.36</td>
</tr>
<tr>
<td></td>
<td>0x01</td>
<td>0xA1</td>
<td>76.8 kbps</td>
<td></td>
<td>76738.60</td>
</tr>
<tr>
<td></td>
<td>0x00</td>
<td>0xD0</td>
<td>153.6 kbps</td>
<td></td>
<td>153846.1</td>
</tr>
<tr>
<td>Classical modem baud rates (multiples of 0.9 kbps)</td>
<td>0x02</td>
<td>0x2C</td>
<td>57.6 kbps</td>
<td></td>
<td>57553.95</td>
</tr>
<tr>
<td></td>
<td>0x01</td>
<td>0x16</td>
<td>115.2 kbps</td>
<td></td>
<td>115107.9</td>
</tr>
</tbody>
</table>
4.2.2. FSK/OOK Transmission

4.2.2.1. FSK Modulation

FSK modulation is performed inside the PLL bandwidth by changing the fractional divider ratio in the feedback loop of the PLL. The high resolution of the sigma-delta modulator allows for very narrow frequency deviation. The frequency deviation $F_{DEV}$ is given by:

$$F_{DEV} = F_{STEP} \times \frac{F{dev}}{13}$$

To ensure correct modulation the following limit applies:

$$F_{DEV} + \frac{BR}{2} \leq (250) kHz$$

Note: No constraint applies to the modulation index of the transmitter, but the frequency deviation must be set between 600 Hz and 200 kHz.

4.2.2.2. OOK Modulation

OOK modulation is applied by switching on and off the power amplifier. Digital control and ramping are available to improve the transient power response of the OOK transmitter.

4.2.2.3. Modulation Shaping

Modulation shaping can be applied in both OOK and FSK modulation modes to improve the narrowband response of the transmitter. Both shaping features are controlled with $PaRamp$ bits in $RegPaRamp$.

- In FSK mode, a Gaussian filter with $BT = 0.5$ or 1 can be used to filter the modulation stream, at the input of the sigma-delta modulator. If the Gaussian filter is enabled when the SX1272/73 is in Continuous mode, DCLK signal on pin 10 (DIO1/DCLK) will trigger an interrupt on the uC each time a new bit has to be transmitted. Please refer to section 4.2.13.2 for details.
- When OOK modulation is used the PA bias voltages are ramped up and down smoothly when the PA is turned on and off to reduce spectral splatter.
Note  The transmitter must be restarted if the ModulationShaping setting is changed in order to recalibrate the built-in filter.

4.2.3.  FSK/OOK Reception

4.2.3.1.  FSK Demodulator
The FSK demodulator of the SX1272/73 is designed to demodulate FSK, GFSK, MSK and GMSK modulated signals. It is most efficient when the modulation index ($\beta$) of the signal is greater than 0.5 and below 10:

$$0.5 \leq \beta = \frac{2 \times F_{Dev}}{BR} \leq 10$$

The output of the FSK demodulator can be fed to the Bit Synchronizer to provide the companion processor with a synchronous data stream in Continuous mode.

4.2.3.2.  OOK Demodulator
The OOK demodulator performs a comparison of the RSSI output and a threshold value. Three different threshold modes are available, configured through bits $OokThreshType$ in $RegOokPeak$.

The recommended mode of operation is the “Peak” threshold mode, illustrated in Figure 15:

![Figure 15. OOK Peak Demodulator Description](image)

In peak threshold mode the comparison threshold level is the peak value of the RSSI reduced by 6 dB. In the absence of an input signal, or during the reception of a logical ‘0’, the acquired peak value is decremented by one $OokPeakThreshStep$ every $OokPeakThreshDec$ period.

When the RSSI output is null for a long time (for instance after a long string of “0” received or if no transmitter is present) the peak threshold level will continue falling until it reaches the “Floor Threshold” programmed in $OokFixedThresh$. 

---

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The default settings of the OOK demodulator lead to the performance stated in the electrical specification. However, in applications in which sudden received signal power reduction is possible, the three parameters should be optimized accordingly.

**Optimizing the Floor Threshold**

`OokFixedThresh` determines the sensitivity of the OOK receiver, as it sets the comparison threshold for weak input signals (i.e. those close to the noise floor). Significant sensitivity improvements can be generated if configured correctly.

Note that the noise floor of the receiver at the demodulator input depends on:

- The noise figure of the receiver.
- The gain of the receive chain from antenna to base band.
- The matching - including SAW filter if any.
- The bandwidth of the channel filters.

It is therefore important to note that the setting of `OokFixedThresh` will be application dependant. The following procedure is recommended to optimize `OokFixedThresh`.

1. Set SX1272/3 in OOK Rx mode
2. Adjust Bit Rate, Channel filter BW
3. Default OokFixedThresh setting
4. No input signal
5. Continuous Mode
6. Monitor DIO2/DATA pin
7. Increment OokFixedThresh
8. Glitch activity on DATA?
9. Optimization complete

![Figure 16. Floor Threshold Optimization](image)

The new floor threshold value found during this test should be used for OOK reception with those receiver settings.

**Optimizing OOK Demodulator for Fast Fading Signals**

A sudden drop in signal strength can cause the bit error rate to increase. For applications where the expected signal drop can be estimated, the following OOK demodulator parameters `OokPeakThreshStep` and `OokPeakThreshDec` can be optimized as described below for a given number of threshold decrements per bit. Refer to `RegOokPeak` to access those settings.
Alternative OOK Demodulator Threshold Modes
In addition to the Peak OOK threshold mode, the user can alternatively select two other types of threshold detectors:

- **Fixed Threshold:** The value is selected through `OokFixedThresh`
- **Average Threshold:** Data supplied by the RSSI block is averaged (this operation mode should only be used with DC-free encoded data).

4.2.3.3. Bit Synchronizer

The bit synchronizer provides a clean and synchronized digital output based upon timing recovery information gleaned from the received data edge transitions. Its output is made available on pin DIO1/DCLK in Continuous mode and can be disabled through register settings. However, for optimum receiver performance, especially in Continuous receive mode, its use is strongly advised.

The Bit Synchronizer is automatically activated in Packet mode. Its bit rate is controlled by `BitRateMsb` and `BitRateLsb` in `RegBitrate`.

To ensure correct operation of the Bit Synchronizer the following conditions have to be satisfied:

- A preamble (0x55 or 0xAA) of at least 12 bits is required for synchronization, the longer the synchronization phase is the better the ensuing packet detection rate will be.
- The subsequent payload bit stream must have at least one edge transition (either rising or falling) every 16 bits during data transmission.
- The absolute error between transmitted and received bit rate must not exceed 6.5%.
4.2.3.4. Frequency Error Indicator

This frequency error indicator measures the frequency error between the programmed RF centre frequency and the carrier frequency of the modulated input signal to the receiver. When the FEI is performed the frequency error is measured and the signed result is loaded in FeiValue in RegFei in 2’s complement format. The time required for an FEI evaluation is 4 bit periods.

To ensure correct operation of the FEI:
- The measurement must be launched during the reception of preamble.
- The sum of the frequency offset and the 20 dB signal bandwidth must be lower than the base band filter bandwidth. i.e. The whole modulated spectrum must be received.

The 20 dB bandwidth of the signal can be evaluated as follows (double-side bandwidth):

\[ BW_{20\text{dB}} = 2 \times \left( F_{DEV} + \frac{BR}{2} \right) \]

The frequency error, in Hz, can be calculated with the following formula:

\[ FEI = F_{STEP} \times FeiValue \]

The FEI is enabled automatically upon the transition to receive mode and automatically updated every 4 bits.

4.2.3.5. AFC

The AFC is based on the FEI measurement therefore the same input signal and receiver setting conditions apply. When the AFC procedure is performed the AfcValue is directly subtracted from the register that defines the frequency of operation of the chip, FRF. The AFC is executed each time the receiver is enabled, if AfcAutoOn = 1.

When the AFC is enabled (AfcAutoOn = 1) the user has the option to:
- Clear the former AFC correction value if AfcAutoClearOn = 1. Allowing the next frequency correction to be performed from the initial centre frequency.
- Start the AFC evaluation from the previously corrected frequency. This may be useful in systems in which the centre frequency experiences cumulative drift - such as the ageing of a crystal reference.

The SX1272/73 offers an alternate receiver bandwidth setting during the AFC phase allowing the accommodation of larger frequency errors. The setting RegAfcBw sets the receive bandwidth during the AFC process. In a typical receiver application, once the AFC is performed, the radio will revert to the receiver communication or channel bandwidth (RegRxBw) for the ensuing communication phase.

Note that the FEI measurement is valid only during the reception of preamble. The provision of the PreambleDetect flag can hence be used to detect this condition and allow a reliable AFC or FEI operation to be triggered. This process can be performed automatically by using the appropriate options in StartDemodOnPreamble found in the RegRxConfig register.

A detailed description of the receiver setup to enable the AFC is provided in section 4.2.7.
4.2.3.6.  Preamble Detector

The Preamble Detector indicates the reception of a carrier modulated with a 0101...sequence. It is insensitive to the frequency offset, as long as the receiver bandwidth is large enough. The size of detection can be programmed from 1 to 3 bytes with `PreambleDetectorSize` in `RegPreambleDetect` as defined in the next table.

Table 19  Preamble Detector Settings

<table>
<thead>
<tr>
<th>PreambleDetectorSize</th>
<th># of Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>1</td>
</tr>
<tr>
<td>01</td>
<td>2 (recommended)</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>reserved</td>
</tr>
</tbody>
</table>

For normal operation, `PreambleDetectTol` should be set to be set to 10 (0x0A) with a qualifying preamble size of 2 bytes.

The `PreambleDetect` interrupt (either in `RegIrqFlags1` or mapped to a specific DIO) then goes high every time a valid preamble is detected assuming `PreambleDetectorOn`=1.

The preamble detector can also be used as a gate to ensure that AFC and AGC are performed on valid preamble. See section 4.2.7. for details.

4.2.3.7.  Image Rejection Mixer

The SX1272/73 employs an image rejection mixer (IRM) which, uncalibrated, gives 35 dB image rejection. The low phase noise PLL is used to perform calibration of the receiver chain. This increases the typical image rejection to 48 dB. This process is fully automated in FSK/OOK mode and radio power-up.

4.2.3.8.  Image and RSSI Calibration

An automatic calibration process is used to calibrate the phase and gain of both I and Q receive paths. This calibration allows enhanced image frequency rejection and improves the RSSI precision. This calibration process is launched under the following circumstances:

- Automatically at Power On Reset or after a Manual Reset of the chip (refer to section 7.2). For applications where the temperature remains stable, or if the Image Rejection is not a major concern, this single calibration will suffice.
- Automatically when a pre-defined temperature change is observed.
- Upon User request, by setting bit `ImageCalStart` in `RegImageCal`, when the device is in Standby mode. Note that in LoRa™ mode the calibration command is inaccessible. To perform the calibration the radio must be returned temporarily to FSK/OOK mode.

A selectable temperature change, set with `TempThreshold` (5, 10, 15 or 20°C), is detected and reported in `TempChange` if the temperature monitoring is turned On with `TempMonitorOff`= 0.

This interrupt flag can be used by the application to launch a new image calibration at a convenient time if `AutoImageCalOn`=0, or immediately when this temperature variation is detected, if `AutoImageCalOn`=1.
The calibration process takes approximately 10 ms.

4.2.3.9.  Timeout Function

The SX1272/73 includes a Timeout function, which allows the automation of a duty-cycled receive operation where the radio periodically wakes from sleep mode into receiver mode.

- **Timeout** interrupt is generated \(\text{TimeoutRxRssi} \times 16 \times T_{bit}\) after switching to Rx mode if the \(\text{Rssi}\) flag does not raise within this time frame (\(\text{RssiValue} > \text{RssiThreshold}\)).

- **Timeout** interrupt is generated \(\text{TimeoutRxPreamble} \times 16 \times T_{bit}\) after switching to Rx mode if the \(\text{PreambleDetect}\) flag does not raise within this time frame.

- **Timeout** interrupt is generated \(\text{TimeoutSignalSync} \times 16 \times T_{bit}\) after switching to Rx mode if the \(\text{SyncAddress}\) flag does not raise within this time frame.

This timeout interrupt can be used to warn the companion processor to shut down the receiver and return to a lower power mode. To become active, these timeouts must also be enabled by setting the correct \(\text{RxTrigger}\) parameters in \(\text{RegRxConfig}\):

### Table 20  RxTrigger Settings to Enable Timeout Interrupts

<table>
<thead>
<tr>
<th>Receiver Triggering Event</th>
<th>RxTrigger (2:0)</th>
<th>Timeout on Rssi</th>
<th>Timeout on Preamble</th>
<th>Timeout on SyncAddress</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>000</td>
<td>Off</td>
<td>Off</td>
<td></td>
</tr>
<tr>
<td>(\text{Rssi}) Interrupt</td>
<td>001</td>
<td>Active</td>
<td>Off</td>
<td>Active</td>
</tr>
<tr>
<td>(\text{PreambleDetect})</td>
<td>110</td>
<td>Off</td>
<td>Active</td>
<td></td>
</tr>
<tr>
<td>(\text{Rssi}) Interrupt &amp; (\text{PreambleDetect})</td>
<td>111</td>
<td>Active</td>
<td>Active</td>
<td></td>
</tr>
</tbody>
</table>

4.2.4.  Operating Modes in FSK/OOK Mode

4.2.5.  General Overview

The SX1272/73 has several working modes, manually programmed in \(\text{RegOpMode}\). Fully automated mode selection, packet transmission and reception is also possible using the Top Level Sequencer described in Section 4.2.9.

### Table 21  Basic Transceiver Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Selected mode</th>
<th>Symbol</th>
<th>Enabled blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Sleep mode</td>
<td>Sleep</td>
<td>None</td>
</tr>
<tr>
<td>001</td>
<td>Standby mode</td>
<td>Stdby</td>
<td>Top regulator and crystal oscillator</td>
</tr>
<tr>
<td>010</td>
<td>Frequency synthesiser to Tx frequency</td>
<td>FSTx</td>
<td>Frequency synthesizer at Tx frequency (Frf)</td>
</tr>
<tr>
<td>011</td>
<td>Transmit mode</td>
<td>Tx</td>
<td>Frequency synthesizer and transmitter</td>
</tr>
<tr>
<td>100</td>
<td>Frequency synthesiser to Rx frequency</td>
<td>FSRx</td>
<td>Frequency synthesizer at frequency for reception (Frf-IF)</td>
</tr>
<tr>
<td>101</td>
<td>Receive mode</td>
<td>Rx</td>
<td>Frequency synthesizer and receiver</td>
</tr>
</tbody>
</table>

When switching from a mode to another the sub-blocks are woken up according to a pre-defined optimized sequence.
4.2.6.  Startup Times

The startup time of the transmitter or the receiver is dependent upon which mode the transceiver was in at the beginning. For a complete description, Figure 18 below shows a complete startup process, from the lower power mode “Sleep”.

![Startup Process Diagram](image)

**Figure 18. Startup Process**

TS_OSC is the startup time of the crystal oscillator which depends on the electrical characteristics of the crystal. TS_FS is the startup time of the PLL including systematic calibration of the VCO.

Typical values of TS_OSC and TS_FS are given in Section 2.5.2.

4.2.6.1.  Transmitter Startup Time

The transmitter startup time, $TS_{TR}$, is calculated as follows in FSK mode:

$$TS_{TR} = 5\mu s + 1.25 \times PaRamp + \frac{1}{2} \times Tbit,$$

where $PaRamp$ is the ramp-up time programmed in $RegPaRamp$ and $Tbit$ is the bit time.

In OOK mode, this equation can be simplified to the following:

$$TS_{TR} = 5\mu s + \frac{1}{2} \times Tbit.$$

4.2.6.2.  Receiver Startup Time

The receiver startup time, $TS_{RE}$, only depends upon the receiver bandwidth effective at the time of startup. When AFC is enabled ($AfcAutoOn=1$) the $AfcBw$ should be used instead of $RxBw$ to extract the receiver startup time:
### Table 22  Receiver Startup Time Summary

<table>
<thead>
<tr>
<th>RxBw if AfcAutoOn=0</th>
<th>TS_RE (+/-5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6 kHz</td>
<td>2.33 ms</td>
</tr>
<tr>
<td>3.1 kHz</td>
<td>1.94 ms</td>
</tr>
<tr>
<td>3.9 kHz</td>
<td>1.56 ms</td>
</tr>
<tr>
<td>5.2 kHz</td>
<td>1.18 ms</td>
</tr>
<tr>
<td>6.3 kHz</td>
<td>984 us</td>
</tr>
<tr>
<td>7.8 kHz</td>
<td>791 us</td>
</tr>
<tr>
<td>10.4 kHz</td>
<td>601 us</td>
</tr>
<tr>
<td>12.5 kHz</td>
<td>504 us</td>
</tr>
<tr>
<td>15.6 kHz</td>
<td>407 us</td>
</tr>
<tr>
<td>20.8 kHz</td>
<td>313 us</td>
</tr>
<tr>
<td>25.0 kHz</td>
<td>264 us</td>
</tr>
<tr>
<td>31.3 kHz</td>
<td>215 us</td>
</tr>
<tr>
<td>41.7 kHz</td>
<td>169 us</td>
</tr>
<tr>
<td>50.0 kHz</td>
<td>144 us</td>
</tr>
<tr>
<td>62.5 kHz</td>
<td>119 us</td>
</tr>
<tr>
<td>83.3 kHz</td>
<td>97 us</td>
</tr>
<tr>
<td>100.0 kHz</td>
<td>84 us</td>
</tr>
<tr>
<td>125.0 kHz</td>
<td>71 us</td>
</tr>
<tr>
<td>166.7 kHz</td>
<td>85 us</td>
</tr>
<tr>
<td>200.0 kHz</td>
<td>74 us</td>
</tr>
<tr>
<td>250.0 kHz</td>
<td>63 us</td>
</tr>
</tbody>
</table>

TS_RE or later after setting the device in Receive mode, any incoming packet will be detected and demodulated by the transceiver.

### 4.2.6.3. Time to RSSI Evaluation

The first RSSI sample will be available TS_RSSI after the receiver is ready: equivalently TS_RE + TS_RSSI after the receive mode instruction was issued.

![Timeline](image)

**Figure 19. Time to Rssi Sample**

TS_RSSI depends on the receiver bandwidth as well as the RssiSmoothing option that was selected. The formula used to calculate TS_RSSI is provided in section 5.5.4.
4.2.6.4.  Tx to Rx Turnaround Time

![Diagram showing the timeline for Tx to Rx transition]

**Figure 20.  Tx to Rx Turnaround**

*Note*  The SPI instruction times are omitted, as they can generally be very small as compared to other timings (up to 10 MHz SPI clock).

4.2.6.5.  Rx to Tx

![Diagram showing the timeline for Rx to Tx transition]

**Figure 21.  Rx to Tx Turnaround**
4.2.6.6. Receiver Hopping, Rx to Rx

Two methods are possible:

First method

<table>
<thead>
<tr>
<th>Timeline</th>
<th>1. set new Frf</th>
<th>2. set RestartRxWithPllLock</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rx Mode, Channel A</td>
<td>Rx Mode, Channel B</td>
</tr>
</tbody>
</table>

Second method

<table>
<thead>
<tr>
<th>Timeline</th>
<th>1. set FastHopOn=1</th>
<th>2. set new Frf (*)</th>
<th>3. wait for TS_HOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rx Mode, Channel A</td>
<td>Rx Mode, Channel B</td>
<td>(*) RegFrfLsb must be written to trigger a frequency change</td>
</tr>
</tbody>
</table>

Figure 22. Receiver Hopping

The second method is quicker and should be used if a very quick RF sniffing mechanism is to be implemented.

4.2.6.7. Tx to Tx

<table>
<thead>
<tr>
<th>Timeline</th>
<th>~PaRamp</th>
<th>+TS_HOP</th>
<th>+TS_HOP</th>
<th>+TS_TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Tx Mode, Channel A</td>
<td>FSTx</td>
<td>Set Tx mode</td>
<td>Tx Mode, Channel B</td>
</tr>
</tbody>
</table>

Figure 23. Transmitter Hopping

4.2.7. Receiver Startup Options

The SX1272/73 receiver can automatically control the gain of the receive chain (AGC) and adjust the receiver LO frequency (AFC). Those processes are carried out on a packet-by-packet basis. They occur:

- When the receiver is turned On.
- When the Receiver is restarted upon user request, through the use of trigger bits RestartRxWithoutPllLock or RestartRxWithPllLock in RegRxConfig.
- When the receiver is automatically restarted after the reception of a valid packet or after a packet collision.
Automatic restart capabilities are detailed in Section 4.2.8. The receiver startup options available in SX1272/73 are described in Table 23.

**Table 23  Receiver Startup Options**

<table>
<thead>
<tr>
<th>Triggering Event</th>
<th>Realized Function</th>
<th>AgcAutoOn</th>
<th>AfcAutoOn</th>
<th>RxTrigger (2:0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>000</td>
</tr>
<tr>
<td>Rssi Interrupt</td>
<td>AGC</td>
<td>1</td>
<td>0</td>
<td>001</td>
</tr>
<tr>
<td></td>
<td>AGC &amp; AFC</td>
<td>1</td>
<td>1</td>
<td>001</td>
</tr>
<tr>
<td>PreambleDetect</td>
<td>AGC</td>
<td>1</td>
<td>0</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>AGC &amp; AFC</td>
<td>1</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Rssi Interrupt</td>
<td>AGC</td>
<td>1</td>
<td>0</td>
<td>111</td>
</tr>
<tr>
<td>&amp; PreambleDetect</td>
<td>AGC &amp; AFC</td>
<td>1</td>
<td>1</td>
<td>111</td>
</tr>
</tbody>
</table>

When AgcAutoOn=0, the LNA gain is manually selected by choosing \( LnaGain \) bits in \( \text{RegLna} \).

### 4.2.8. Receiver Restart Methods

The options for restart of the receiver are covered below. This is typically of use to prepare for the reception of a new signal whose strength or carrier frequency is different from the preceding packet to allow the AGC or AFC to be re-evaluated.

#### 4.2.8.1. Restart Upon User Request

In Receive mode the user can request a receiver restart - this can be useful in conjunction with the use of a Timeout interrupt following a period of inactivity in the channel of interest. Two options are available:

- **No change in the Local Oscillator upon restart**: the AFC is disabled, and the \( Frf \) register has not been changed through SPI before the restart instruction: set bit \( \text{RestartRxWithoutPllLock} \) in \( \text{RegRxConfig} \) to 1.
- **Local Oscillator change upon restart**: if AFC is enabled (\( \text{AfcAutoOn}=1 \)), and/or the \( Frf \) register had been changed during the last Rx period: set bit \( \text{RestartRxWithPllLock} \) in \( \text{RegRxConfig} \) to 1.

**Note**  
**ModeReady must be at logic level 1 for a new RestartRx command to be taken into account.**

#### 4.2.8.2. Automatic Restart after valid Packet Reception

The bits \( \text{AutoRestartRxMode} \) in \( \text{RegSyncConfig} \) control the automatic restart feature of the SX1272/73 receiver, when a valid packet has been received:

- **If \( \text{AutoRestartRxMode} = 00 \)**, the function is off, and the user should manually restart the receiver upon valid packet reception (see section 4.2.8.1).
- **If \( \text{AutoRestartRxMode} = 01 \)**, after the user has emptied the FIFO following a \( \text{PayloadReady} \) interrupt, the receiver will automatically restart itself after a delay of \( \text{InterPacketRxDelay} \), allowing for the distant transmitter to ramp down, hence avoiding a false RSSI detection on the ‘tail’ of the previous packet.
- **If \( \text{AutoRestartRxMode} = 10 \)** should be used if the next reception is expected on a new frequency, i.e. \( Frf \) is changed after the reception of the previous packet. An additional delay is systematically added, in order for the PLL to lock at a new frequency.
4.2.8.3. Automatic Restart when Packet Collision is Detected

In receive mode the SX1272/73 is able to detect packet collision and restart the receiver. Collisions are detected by a sudden rise in received signal strength, detected by the RSSI. This functionality can be useful in network configurations where many asynchronous slaves attempt periodic communication with a single a master node.

The collision detector is enabled by setting bit RestartRxOnCollision to 1.

The decision to restart the receiver is based on the detection of RSSI change. The sensitivity of the system can be adjusted in 1 dB steps by using register RssiCollisionThreshold in RegRxConfig.

4.2.9. Top Level Sequencer

Depending on the application it may be desirable to be able to change the mode of the circuit according to a predefined sequence without access to the serial interface. In order to define different sequences or scenarios a user-programmable state machine called the Top Level Sequencer (herein referred to as the Sequencer) can automatically control the chip modes.

**NOTE THAT THIS FUNCTIONALITY IS ONLY AVAILABLE IN FSK/OOK MODE.**

The Sequencer is activated by setting the SequencerStart bit in RegSeqConfig1 to 1 in Sleep or Standby mode (called initial mode).

It is also possible to force the Sequencer off by setting the Stop bit in RegSeqConfig1 to 1 at any time.

*Note* SequencerStart and Stop bit must never be set at the same time.

4.2.9.1. Sequencer States

As shown in the table below, with the aid of a pair of interrupt timers (T1 and T2), the sequencer can take control of the chip operation in all modes.

<table>
<thead>
<tr>
<th><strong>Table 24 Sequencer States</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sequencer State</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>SequencerOff State</td>
</tr>
<tr>
<td>Idle State</td>
</tr>
<tr>
<td>Transmit State</td>
</tr>
<tr>
<td>Receive State</td>
</tr>
<tr>
<td>PacketReceived</td>
</tr>
<tr>
<td>LowPowerSelection</td>
</tr>
</tbody>
</table>
### 4.2.9.2. Sequencer Transitions

The transitions between sequencer states are listed in the forthcoming table.

#### Table 25 Sequencer Transition Options

<table>
<thead>
<tr>
<th>Variable</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>RxTimeout</td>
<td>Defines the action to be taken on a RxTimeout interrupt. RxTimeout interrupt can be a TimeoutRxRssi, TimeoutRxPreamble or TimeoutSignalSync interrupt.</td>
</tr>
<tr>
<td><strong>Variable</strong></td>
<td><strong>Transition</strong></td>
</tr>
<tr>
<td>IdleMode</td>
<td>Selects the chip mode during Idle state: 0: Standby mode 1: Sleep mode</td>
</tr>
<tr>
<td>FromStart</td>
<td>Controls the Sequencer transition when the SequencerStart bit is set to 1 in Sleep or Standby mode: 00: to LowPowerSelection 01: to Receive state 10: to Transmit state 11: to Transmit state on a FifoThreshold interrupt</td>
</tr>
<tr>
<td>LowPowerSelection</td>
<td>Selects Sequencer LowPower state after a to LowPowerSelection transition 0: SequencerOff state with chip on Initial mode 1: Idle state with chip on Standby or Sleep mode depending on IdleMode Note: Initial mode is the chip LowPower mode at Sequencer start.</td>
</tr>
<tr>
<td>FromIdle</td>
<td>Controls the Sequencer transition from the Idle state on a T1 interrupt: 0: to Transmit state 1: to Receive state</td>
</tr>
<tr>
<td>FromTransmit</td>
<td>Controls the Sequencer transition from the Transmit state: 0: to LowPowerSelection on a PacketSent interrupt 1: to Receive state on a PacketSent interrupt</td>
</tr>
<tr>
<td>FromReceive</td>
<td>Controls the Sequencer transition from the Receive state: 000 and 111: unused 001: to PacketReceived state on a PayloadReady interrupt 010: to LowPowerSelection on a PayloadReady interrupt 011: to PacketReceived state on a CrcOk interrupt. If CRC is wrong (corrupted packet, with CRC on but CrcAutoClearOn is off), the PayloadReady interrupt will drive the sequencer to RxTimeout state. 100: to SequencerOff state on a Rssi interrupt 101: to SequencerOff state on a SyncAddress interrupt 110: to SequencerOff state on a PreambleDetect interrupt Irrespective of this setting, transition to LowPowerSelection on a T2 interrupt</td>
</tr>
<tr>
<td>FromRxTimeout</td>
<td>Controls the state-machine transition from the Receive state on a RxTimeout interrupt (and on PayloadReady if FromReceive = 011): 00: to Receive state via ReceiveRestart 01: to Transmit state 10: to LowPowerSelection 11: to SequencerOff state Note: RxTimeout interrupt is a TimeoutRxRssi, TimeoutRxPreamble or TimeoutSignalSync interrupt.</td>
</tr>
</tbody>
</table>
4.2.9.3. Timers

Two timers (Timer1 and Timer2) are also available in order to define periodic sequences. These timers are used to generate interrupts, which can trigger transitions of the Sequencer.

T1 interrupt is generated (Timer1Resolution * Timer1Coefficient) after T2 interrupt or SequencerStart command. T2 interrupt is generated (Timer2Resolution * Timer2Coefficient) after T1 interrupt.

The timer mechanism is summarized on the following diagram.

![Timer1 and Timer2 Mechanism](image)

**Figure 24. Timer1 and Timer2 Mechanism**

*Note* The timer sequence is completed independently of the actual Sequencer state. Thus, both timers need to be on to achieve periodic cycling.
### Table 26  Sequencer Timer Settings

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| Timer1Resolution | Resolution of Timer1  
                  | 00: disabled  
                  | 01: 64 us  
                  | 10: 4.1 ms  
                  | 11: 262 ms  |
| Timer2Resolution | Resolution of Timer2  
                  | 00: disabled  
                  | 01: 64 us  
                  | 10: 4.1 ms  
                  | 11: 262 ms  |
| Timer1Coefficient | Multiplying coefficient for Timer1 |
| Timer2Coefficient | Multiplying coefficient for Timer2 |
4.2.9.4. Sequencer State Machine

The following graphs summarize every possible transition between each Sequencer state. The Sequencer states are highlighted in grey. The transitions are represented by arrows. The condition activating them is described over the transition arrow. For better readability, the start transitions are separated from the rest of the graph.

Transitory states are highlighted in light grey, and exit states are represented in red. It is also possible to force the Sequencer off by setting the Stop bit in RegSeqConfig1 to 1 at any time.

Figure 25. Sequencer State Machine
4.2.10. Data Processing in FSK/OOK Mode

4.2.10.1. Block Diagram

Figure below illustrates the SX1272/73 data processing circuit. Its role is to interface the data to/from the modulator/demodulator and the uC access points (SPI and DIO pins). It also controls all the configuration registers.

The circuit contains several control blocks which are described in the following paragraphs.

![Control Diagram](image)

**Figure 26. SX1272/73 Data Processing Conceptual View**

The SX1272/73 implements several data operation modes each with their own data path through the data processing section. Depending on the data operation mode selected some control blocks are active whilst others remain disabled.

4.2.10.2. Data Operation Modes

The SX1272/73 has two different data operation modes selectable by the user:

- **Continuous mode**: each bit transmitted or received is accessed in real time at the DIO2/DATA pin. This mode may be used if adequate external signal processing is available.

- **Packet mode (recommended)**: user only provides/retrieves payload bytes to/from the FIFO. The packet is automatically built with preamble, Sync word, and optional CRC and DC-free encoding schemes. The reverse operation is performed in reception. The uC processing overhead is hence significantly reduced compared to Continuous mode. Depending on the optional features activated (CRC, etc) the maximum payload length is limited to 255, 2047 bytes or unlimited.

Each of these data operation modes is fully described in the following sections.
4.2.11. FIFO

Overview and Shift Register (SR)

In packet mode of operation both data to be transmitted and that has been received are stored in a configurable FIFO (First In First Out). It is accessed via the SPI interface and provides several interrupts for transfer management.

The FIFO is 1 byte wide hence it only performs byte (parallel) operations, whereas the demodulator functions serially. A shift register is therefore employed to interface the two devices. In transmit mode it takes bytes from the FIFO and outputs them serially (MSB first) at the programmed bit rate to the modulator. Similarly, in Rx the shift register gets bit by bit data from the demodulator and writes them byte by byte to the FIFO. This is illustrated in figure below.

![Figure 27. FIFO and Shift Register (SR)](image)

Note: When switching to Sleep mode, the FIFO can only be used once the ModeReady flag is set (immediately from all modes except from Tx)

The FIFO size is fixed to 64 bytes.

Interrupt Sources and Flags

- **FifoEmpty**: If the FIFO is empty, the interrupt source is high. Otherwise, it is low. Note that when retrieving data from the FIFO, the FIFO is updated on NSS falling edge, i.e., when the FIFO is updated to low state the currently started read operation must be completed. In other words, the FIFO state must be checked after each read operation for a decision on the next one (FifoEmpty = 0: more byte(s) to read; FifoEmpty = 1: no more byte to read).

- **FifoFull**: If the FIFO is full, the interrupt source is high. Otherwise it is low.

- **FifoOverrunFlag**: If a new byte is written by the user (in Tx or Standby modes) or the SR (in Rx mode) while the FIFO is already full, data is lost and the flag should be cleared by writing a 1, note that the FIFO will also be cleared.

- **PacketSent**: If the SR's last bit has been sent, the interrupt source goes high.

- **FifoLevel**: Threshold can be programmed by FifoThreshold in RegFifoThresh. Its behavior is illustrated in figure below.
Notes

- **FifoLevel interrupt** is updated only after a read or write operation on the FIFO. Thus the interrupt cannot be dynamically updated by only changing the **FifoThreshold** parameter.

- **FifoLevel interrupt** is valid as long as **FifoFull** does not occur. An empty FIFO will restore its normal operation.

**FIFO Clearing**

Table below summarizes the status of the FIFO when switching between different modes.

**Table 27 Status of FIFO when Switching Between Different Modes of the Chip**

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>FIFO status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stdby</td>
<td>Sleep</td>
<td>Not cleared</td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td>Stdby</td>
<td>Not cleared</td>
<td></td>
</tr>
<tr>
<td>Stdby/Sleep</td>
<td>Tx</td>
<td>Not cleared</td>
<td>To allow the user to write the FIFO in Stdby/Sleep before Tx</td>
</tr>
<tr>
<td>Stdby/Sleep</td>
<td>Rx</td>
<td>Cleared</td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td>Tx</td>
<td>Cleared</td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td>Stdby/Sleep</td>
<td>Not cleared</td>
<td>To allow the user to read FIFO in Stdby/Sleep mode after Rx</td>
</tr>
<tr>
<td>Tx</td>
<td>Any</td>
<td>Cleared</td>
<td></td>
</tr>
</tbody>
</table>

**4.2.11.1.  Sync Word Recognition**

**Overview**

Sync word recognition (also called Pattern recognition) is activated by setting **SyncOn** in **RegSyncConfig**. The bit synchronizer must also be activated in Continuous mode (automatically done in Packet mode).

The block behaves like a shift register as it continuously compares the incoming data with its internally programmed Sync word and sets **SyncAddressMatch** when a match is detected. This is illustrated in Figure 29 below.
During the comparison of the demodulated data, the first bit received is compared with bit 7 (MSB) of RegSyncValue1 and the last bit received is compared with bit 0 (LSB) of the last byte whose address is determined by the length of the Sync word.

When the programmed Sync word is detected the user can assume that this incoming packet is for the node and can be processed accordingly.

SyncAddressMatch is cleared when leaving Rx or FIFO is emptied.

**Configuration**

- **Size:** Sync word size can be set from 1 to 8 bytes (i.e. 8 to 64 bits) via SyncSize in RegSyncConfig. In Packet mode this field is also used for Sync word generation in Tx mode.
- **Value:** The Sync word value is configured in SyncValue(63:0). In Packet mode this field is also used for Sync word generation in Tx mode.

*Note*  SyncValue choices containing 0x00 bytes are not allowed

**Packet Handler**

The packet handler is the block used in Packet mode. Its functionality is fully described in section 4.2.14.

**Control**

The control block configures and controls the full chip's behavior according to the settings programmed in the configuration registers.
4.2.12. Digital IO Pins Mapping

Six general purpose IO pins are available on the SX1272/73 and their configuration in Continuous or Packet mode is controlled through RegDioMapping1 and RegDioMapping2.

**Table 28 DIO Mapping, Continuous Mode**

<table>
<thead>
<tr>
<th>DIOx Mapping</th>
<th>Sleep</th>
<th>Standby</th>
<th>FSRx/Tx</th>
<th>Rx</th>
<th>Tx</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIO0</td>
<td></td>
<td></td>
<td></td>
<td>SyncAddress</td>
<td>TxReady</td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>RxReady</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIO1</td>
<td></td>
<td></td>
<td></td>
<td>Dclk</td>
<td></td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIO2</td>
<td></td>
<td></td>
<td></td>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>Data</td>
<td></td>
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<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>DIO3</td>
<td></td>
<td></td>
<td></td>
<td>Timeout</td>
<td></td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>TempChange / LowBat</td>
<td>TempChange / LowBat</td>
</tr>
<tr>
<td>DIO4</td>
<td></td>
<td></td>
<td></td>
<td>PllLock</td>
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</tr>
<tr>
<td>00</td>
<td>-</td>
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<td></td>
<td></td>
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<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>SyncAddress</td>
<td>TempChange / LowBat</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>ModeReady</td>
<td>ModeReady</td>
</tr>
<tr>
<td>DIO5</td>
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<td></td>
<td></td>
<td>ClkOut</td>
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<td></td>
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<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>ClkOut</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>ModeReady</td>
<td>ModeReady</td>
</tr>
</tbody>
</table>

**Table 29 DIO Mapping, Packet Mode**

<table>
<thead>
<tr>
<th>DIOx Mapping</th>
<th>Sleep</th>
<th>Standby</th>
<th>FSRx/Tx</th>
<th>Rx</th>
<th>Tx</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIO0</td>
<td></td>
<td></td>
<td></td>
<td>PayloadReady</td>
<td>PacketSent</td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>ClkOut</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>TempChange / LowBat</td>
<td>TempChange / LowBat</td>
</tr>
<tr>
<td>DIO1</td>
<td></td>
<td></td>
<td></td>
<td>FifoLevel</td>
<td>FifoLevel</td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoEmpty</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoFull</td>
<td>FifoFull</td>
</tr>
<tr>
<td>11</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIO2</td>
<td></td>
<td></td>
<td></td>
<td>FifoFull</td>
<td>FifoFull</td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoEmpty</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoFull</td>
<td>FifoFull</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DIO3</td>
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<td></td>
<td></td>
<td>FifoEmpty</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoEmpty</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>FifoEmpty</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIO4</td>
<td></td>
<td></td>
<td></td>
<td>PayloadReady</td>
<td>PacketSent</td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>ClkOut</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>DIO5</td>
<td></td>
<td></td>
<td></td>
<td>ClkOut</td>
<td></td>
</tr>
<tr>
<td>00</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td>ClkOut</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
<td>Rssi / PreambleDetect</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
<td>ModeReady</td>
<td>ModeReady</td>
</tr>
</tbody>
</table>
4.2.13. Continuous Mode

4.2.13.1. General Description

As illustrated in Figure 30 in Continuous mode the NRZ data to (from) the (de)modulator is directly accessed by the uC on the bidirectional DIO2/DATA pin. The FIFO and packet handler are thus inactive.

![Continuous Mode Conceptual View](image)

Figure 30. Continuous Mode Conceptual View

4.2.13.2. Tx Processing

In Tx mode a synchronous data clock for an external uC is provided on DIO1/DCLK pin. Clock timing with respect to the data is illustrated in Figure 31. DATA is internally sampled on the rising edge of DCLK so the uC can change logic state anytime outside the grayed out setup/hold zone.

![Tx Processing in Continuous Mode](image)

Figure 31. Tx Processing in Continuous Mode

Note that the use of DCLK is required when the modulation shaping is enabled (see section 4.2.13.2).
4.2.13.3. Rx Processing

If the bit synchronizer is disabled the raw demodulator output is made directly available on DATA pin and no DCLK signal is provided.

Conversely, if the bit synchronizer is enabled, synchronous cleaned data and clock are made available respectively on DIO2/DATA and DIO1/DCLK pins. DATA is sampled on the rising edge of DCLK and updated on the falling edge as illustrated below.

![Diagram of Rx Processing in Continuous Mode](image)

**Figure 32. Rx Processing in Continuous Mode**

*Note* In Continuous mode it is always recommended to enable the bit synchronizer to clean the DATA signal even if the DCLK signal is not used by the uC (bit synchronizer is automatically enabled in Packet mode).

4.2.14. Packet Mode

4.2.14.1. General Description

In Packet mode the NRZ data to (from) the (de)modulator is not directly accessed by the uC but stored in the FIFO and accessed via the SPI interface.

In addition the SX1272/73 packet handler performs several packet oriented tasks such as Preamble and Sync word generation, CRC calculation/check, whitening/dewhitening of data, Manchester encoding/decoding, address filtering, etc. This simplifies software and reduces uC overhead by performing these repetitive tasks within the RF chip itself.

Another important feature is ability to fill and empty the FIFO in Sleep/Stdby mode to ensure minimum power consumption when accessing payload data.
The Bit Synchronizer is automatically enabled in Packet mode.

4.2.14.2. Packet Format

Fixed Length Packet Format

Fixed length packet format is selected when bit PacketFormat is set to 0 and PayloadLength is set to any value greater than 0.

In applications where the packet length is fixed in advance, this mode of operation may be of interest to minimize RF overhead (no length byte field is required). All nodes, whether Tx only, Rx only or Tx/Rx should be programmed with the same packet length value.

The length of the payload is limited to 2047 bytes.

The length programmed in PayloadLength relates only to the payload which includes the message and the optional address byte. In this mode the payload must contain at least one byte i.e. address or message byte.

An illustration of a fixed length packet is shown below. It contains the following fields:

- Preamble (1010...)
- Sync word (Network ID)
- Optional Address byte (Node ID)
- Message data
- Optional 2-bytes CRC checksum

![Packet Mode Conceptual View](image-url)
Variable Length Packet Format

Variable length packet format is selected when bit PacketFormat is set to 1.

This mode is useful in applications where the length of the packet is not known in advance and can vary over time. It is then necessary for the transmitter to send the length information together with each packet in order for the receiver to operate properly.

In this mode the length of the payload, indicated by the length byte, is given by the first byte of the FIFO and is limited to 255 bytes. Note that the length byte itself is not included in its calculation. In this mode the payload must contain at least 2 bytes i.e. length + address or message byte.

An illustration of a variable length packet is shown below. It contains the following fields:

- Preamble (1010...)
- Sync word (Network ID)
- Length byte
- Optional Address byte (Node ID)
- Message data
Optional 2-bytes CRC checksum

Unlimited length packet format is selected when bit PacketFormat is set to 0 and PayloadLength is set to 0. The user can then transmit and receive packet of arbitrary length and PayloadLength register is not used in Tx/Rx modes for counting the length of the bytes transmitted/received.

In Tx the data is transmitted depending on the TxStartCondition bit. On the Rx side the data processing features like Address filtering, Manchester encoding and data whitening are not available if the sync pattern length is set to zero (SyncOn = 0). The filling of the FIFO in this case can be controlled by the bit FifoFillCondition. The CRC detection in Rx is also not supported in this mode of the packet handler, however CRC generation in Tx is operational. The interrupts like CrcOk & PayloadReady are not available either.

An unlimited length packet shown below is made up of the following fields:
- Preamble (1010...).
- Sync word (Network ID).
- Optional Address byte (Node ID).
- Message data
- Optional 2-bytes CRC checksum (Tx only)

Figure 35. Variable Length Packet Format

Figure 36. Unlimited Length Packet Format
4.2.14.3. **Tx Processing**

In Tx mode the packet handler dynamically builds the packet by performing the following operations on the payload available in the FIFO:

- Add a programmable number of preamble bytes.
- Add a programmable Sync word.
- Optionally calculating CRC over complete payload field (optional length byte + optional address byte + message) and appending the 2 bytes checksum.
- Optional DC-free encoding of the data (Manchester or whitening).

Only the payload (including optional address and length fields) is required to be provided by the user in the FIFO.

The transmission of packet data is initiated by the Packet Handler only if the chip is in Tx mode and the transmission condition defined by `TxStartCondition` is fulfilled. If transmission condition is not fulfilled then the packet handler transmits a preamble sequence until the condition is met. This happens only if the preamble length /= 0, otherwise it transmits a zero or one until the condition is met to transmit the packet data.

The transmission condition itself is defined as:

- If `TxStartCondition` = 1, the packet handler waits until the first byte is written into the FIFO, then it starts sending the preamble followed by the sync word and user payload
- If `TxStartCondition` = 0, the packet handler waits until the number of bytes written in the FIFO is equal to the number defined in `RegFifoThresh` + 1
- If the condition for transmission was already fulfilled i.e. the FIFO was filled in Sleep/Stdby then the transmission of packet starts immediately on enabling Tx

4.2.14.4. **Rx Processing**

In Rx mode the packet handler extracts the user payload to the FIFO by performing the following operations:

- Receiving the preamble and stripping it off.
- Detecting the Sync word and stripping it off.
- Optional DC-free decoding of data.
- Optionally checking the address byte.
- Optionally checking CRC and reflecting the result on `CrcOk`.

Only the payload (including optional address and length fields) is made available in the FIFO.

When the Rx mode is enabled the demodulator receives the preamble followed by the detection of sync word. If fixed length packet format is enabled then the number of bytes received as the payload is given by the `PayloadLength` parameter.

In variable length mode the first byte received after the sync word is interpreted as the length of the received packet. The internal length counter is initialized to this received length. The `PayloadLength` register is set to a value which is greater than the maximum expected length of the received packet. If the received length is greater than the maximum length stored in `PayloadLength` register the packet is discarded otherwise the complete packet is received.

If the address check is enabled then the second byte received in case of variable length and first byte in case of fixed length is the address byte. If the address matches to the one in the `NodeAddress` field reception of the data continues otherwise it's stopped. The CRC check is performed if `CrcOn` = 1 and the result is available in `CrcOk` indicating that the
CRC was successful. An interrupt (PayloadReady) is also generated on DIO0 as soon as the payload is available in the FIFO. The payload available in the FIFO can also be read in Sleep/Standby mode. If the CRC fails the PayloadReady interrupt is not generated and the FIFO is cleared. This function can be overridden by setting CrcAutoClearOff = 1, forcing the availability of PayloadReady interrupt and the payload in the FIFO even if the CRC fails.

4.2.14.5. Handling Large Packets
When PayloadLength exceeds FIFO size (64 bytes) whether in fixed, variable or unlimited length packet format, in addition to PacketSent in Tx and PayloadReady or CrcOk in Rx, the FIFO interrupts/flags can be used as described below:

- For Tx:
  FIFO can be prefilled in Sleep/Standby but must be refilled “on-the-fly” during Tx with the rest of the payload.
  1) Pre-fill FIFO (in Sleep/Standby first or directly in Tx mode) until FifoThreshold or FifoFull is set
  2) In Tx, wait for FifoThreshold or FifoEmpty to be set (i.e. FIFO is nearly empty)
  3) Write bytes into the FIFO until FifoThreshold or FifoFull is set.
  4) Continue to step 2 until the entire message has been written to the FIFO (PacketSent will fire when the last bit of the packet has been sent).

- For Rx:
  FIFO must be emptied “on-the-fly” during Rx to prevent FIFO overrun.
  1) Start reading bytes from the FIFO when FifoEmpty is cleared or FifoThreshold becomes set.
  2) Suspend reading from the FIFO if FifoEmpty fires before all bytes of the message have been read.
  3) Continue to step 1 until PayloadReady or CrcOk fires.
  4) Read all remaining bytes from the FIFO either in Rx or Sleep/Standby mode.

4.2.14.6. Packet Filtering
The SX1272/73 packet handler offers several mechanisms for packet filtering, ensuring that only useful packets are made available to the uC, significantly reducing system power consumption and software complexity.

Sync Word Based
Sync word filtering/recognition is used for identifying the start of the payload and also for network identification. As previously described, the Sync word recognition block is configured (size, value) in RegSyncConfig and RegSyncValue(i) registers. This information is used both for appending Sync word in Tx and filtering packets in Rx.

Every received packet which does not start with this locally configured Sync word is automatically discarded and no interrupt is generated.

When the Sync word is detected payload reception automatically starts and SyncAddressMatch is asserted.

**Note**  Sync Word values containing 0x00 are forbidden.
Address Based
Address filtering can be enabled via the AddressFiltering bits. It adds another level of filtering above Sync word (i.e. Sync must match first) and is typically useful in a multi-node networks where a network ID is shared between all nodes (Sync word) and each node has its own ID (address).

Two address based filtering options are available:

- **AddressFiltering = 01**: Received address field is compared with internal register NodeAddress. If they match then the packet is accepted and processed, otherwise it is discarded.

- **AddressFiltering = 10**: Received address field is compared with internal registers NodeAddress and BroadcastAddress. If either is a match, the received packet is accepted and processed, otherwise it is discarded. This additional check with a constant is useful for implementing broadcast in a multi-node networks.

Please note that the received address byte, as part of the payload, is not stripped off the packet and is made available in the FIFO. In addition, NodeAddress and AddressFiltering only apply to Rx. On Tx side, if address filtering is expected, the address byte should simply be put into the FIFO like any other byte of the payload.

As address filtering requires a Sync word match hence both features share the same interrupt flag SyncAddressMatch.

Length Based
In variable length Packet mode, PayloadLength must be programmed with the maximum payload length permitted. If received length byte is smaller than this maximum then the packet is accepted and processed, otherwise it is discarded.

Please note that the received length byte, as part of the payload, is not stripped off the packet and is made available in the FIFO.

To disable this function the user should set the value of the PayloadLength to 2047.

CRC Based
The CRC check is enabled by setting bit CrcOn in RegPacketConfig1. It is used for checking the integrity of the message.

- On Tx side a two byte CRC checksum is calculated on the payload part of the packet and appended to the end of the message.
- On Rx side the checksum is calculated on the received payload and compared with the two checksum bytes received. The result of the comparison is stored in bit CrcOk.

By default, if the CRC check fails then the FIFO is automatically cleared and no interrupt is generated. This filtering function can be disabled via CrcAutoClearOff bit and in this case, even if CRC fails, the FIFO is not cleared and only PayloadReady interrupt goes high. Please note that in both cases, the two CRC checksum bytes are stripped off by the packet handler and only the payload is made available in the FIFO. Two CRC implementations are selected with bit CrcWhiteningType.

<table>
<thead>
<tr>
<th>Crc Type</th>
<th>CrcWhiteningType</th>
<th>Polynomial</th>
<th>Seed Value</th>
<th>Complemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCITT</td>
<td>0 (default)</td>
<td>$x^{16} + x^{12} + x^5 + 1$</td>
<td>0x1D0F</td>
<td>Yes</td>
</tr>
<tr>
<td>IBM</td>
<td>1</td>
<td>$x^{16} + x^{15} + x^2 + 1$</td>
<td>0xFFFF</td>
<td>No</td>
</tr>
</tbody>
</table>

A C code implementation of each CRC type is proposed in Application Section 7.
4.2.14.7. DC-Free Data Mechanisms

The payload to be transmitted may contain long sequences of 1's and 0's, which introduces a DC bias in the transmitted signal. The radio signal thus produced has a non-uniform power distribution over the occupied channel bandwidth. It also introduces data dependencies in the normal operation of the demodulator. Thus it is useful if the transmitted data is random and DC free.

For such purposes, two techniques are made available in the packet handler: Manchester encoding and data whitening.

*Note* Only one of the two methods can be enabled at a time.

**Manchester Encoding**

Manchester encoding/decoding is enabled if $DcFree = 01$ and can only be used in Packet mode.

The NRZ data is converted to Manchester code by coding '1' as “10” and '0' as “01”.

In this case, the maximum chip rate is the maximum bit rate given in the specifications section and the actual bit rate is half the chip rate.

Manchester encoding and decoding is only applied to the payload and CRC checksum while preamble and Sync word are kept NRZ. However, the chip rate from preamble to CRC is the same and defined by $BitRate$ in $RegBitRate$ (Chip Rate = Bit Rate NRZ = 2 x Bit Rate Manchester).

Manchester encoding/decoding is thus transparent with NRZ transferred between FIFO and MCU.

**Data Whitening**

Another technique called whitening or scrambling is widely used for randomizing the user data before radio transmission. The data is whitened using a random sequence on the Tx side and de-whitened on the Rx side using the same sequence. Compared to Manchester coding, whitening has the added advantage that the NRZ data rate is retained i.e. the effective actual bit rate is not halved.

The whitening/de-whitening process is enabled if $DcFree = 10$. A 9-bit LFSR is used to generate a random sequence. The payload and 2-byte CRC checksum is then XORed with this random sequence as shown below. The data is de-whitened on the receiver side by XORing with the same random sequence.

Payload whitening/de-whitening is thus made transparent to the user who still provides/retrieves NRZ data to/from the FIFO.
4.2.14.8. Beacon Tx Mode

In some short range wireless network topologies a repetitive message, also known as beacon, is transmitted periodically by a transmitter. The Beacon Tx mode allows for the re-transmission of the same packet without having to fill the FIFO multiple times with the same data.

When BeaconOn in RegPacketConfig2 is set to 1 the FIFO can be filled only once in Sleep or Stdby mode with the required payload. After a first transmission, FifoEmpty will go high as usual, but the FIFO content will be restored when the chip exits Transmit mode. FifoEmpty, FifoFull and FifoLevel flags are also restored.

This feature is only available in Fixed packet format with the Payload Length smaller than the FIFO size. The control of the chip modes (Tx-Sleep-Tx....) can either be undertaken by the microcontroller, or be automated in the Top Sequencer. See example in section 4.2.14.8.

The Beacon Tx mode is exited by setting BeaconOn to 0 and clearing the FIFO by setting FifoOverrun to 1.

4.2.15. io-homecontrol® Compatibility Mode

The SX1272/73 features a io-homecontrol® compatibility mode. Please contact your local Semtech representative for details on its implementation.
4.3. SPI Interface

The SPI interface gives access to the configuration register via a synchronous full-duplex protocol corresponding to CPOL = 0 and CPHA = 0 in Motorola/Freescale nomenclature. Only the slave side is implemented.

Three access modes to the registers are provided:

- **SINGLE** access: an address byte followed by a data byte is sent for a write access whereas an address byte is sent and a read byte is received for the read access. The NSS pin goes low at the beginning of the frame and goes high after the data byte.

- **BURST** access: the address byte is followed by several data bytes. The address is automatically incremented internally between each data byte. This mode is available for both read and write accesses. The NSS pin goes low at the beginning of the frame and stay low between each byte. It goes high only after the last byte transfer.

- **FIFO** access: if the address byte corresponds to the address of the FIFO, then succeeding data byte will address the FIFO. The address is not automatically incremented but is memorized and does not need to be sent between each data byte. The NSS pin goes low at the beginning of the frame and stay low between each byte. It goes high only after the last byte transfer.

The figure below shows a typical SPI single access to a register.

![Figure 39. SPI Timing Diagram (single access)](image)

MOSI is generated by the master on the falling edge of SCK and is sampled by the slave (i.e. this SPI interface) on the rising edge of SCK. MISO is generated by the slave on the falling edge of SCK.

A transfer is always started by the NSS pin going low. MISO is high impedance when NSS is high.

The first byte is the address byte. It is comprises:

- A wr bit, which is 1 for write access and 0 for read access.
- Then 7 bits of address, MSB first.

The second byte is a data byte, either sent on MOSI by the master in case of a write access or received by the master on MISO in case of read access. The data byte is transmitted MSB first.

Proceeding bytes may be sent on MOSI (for write access) or received on MISO (for read access) without a rising NSS edge and re-sending the address. In FIFO mode, if the address was the FIFO address then the bytes will be written / read at the FIFO address. In Burst mode, if the address was not the FIFO address, then it is automatically incremented for each new byte received.
The frame ends when NSS goes high. The next frame must start with an address byte. The SINGLE access mode is therefore a special case of FIFO / BURST mode with only 1 data byte transferred.

During the write access the byte transferred from the slave to the master on the MISO line is the value of the written register before the write operation.
5. SX1272/73 Analog & RF Frontend Electronics

5.1. Power Supply Strategy

The SX1272/73 employs an internal voltage regulation scheme which provides stable operating voltage, and hence device characteristics, over the full industrial temperature and operating voltage range. This includes up to +17 dBm of RF output power which is maintained from 1.8 V to 3.7 V and +20 dBm from 2.4 V to 3.7 V.

The SX1272/73 can be powered from any low-noise voltage source via pins VBAT1 and VBAT2. Decoupling capacitors should be connected, as suggested in the reference design of the applications section of this document, on VR_PA, VR_DIG and VR_ANA pins to ensure correct operation of the built-in voltage regulators.

5.2. Low Battery Detector

A low battery detector is also included allowing the generation of an interrupt signal in response to the supply voltage dropping below a programmable threshold that is adjustable through the register RegLowBat. The interrupt signal can be mapped to any of the DIO pins by programming RegDioMapping.

Note: This can be used in FSK or LoRa mode, but can only be configured while in FSK mode.

5.3. Frequency Synthesis

5.3.1. Crystal Oscillator

The crystal oscillator is the main timing reference of the SX1272/73. It is used as the reference for the PLL’s frequency synthesis and as the clock signal for all digital processing.

The crystal oscillator startup time, TS_OSC, depends on the electrical characteristics of the crystal reference used, for more information on the electrical specification of the crystal see section 7.1. The crystal connects to the Pierce oscillator of pins XTA and XTB. The SX1272/73 optimizes the startup time and automatically triggers the PLL when the oscillator signal is stable.

Optionally, an external clock can be used to replace the crystal oscillator. This typically takes the form of a tight tolerance temperature compensated crystal oscillator (TCXO). When using an external clock source the bit TcxoInputOn of register RegTcxo should be set to 1 and the external clock has to be provided on XTA (pin 4). XTB (pin 5) should be left open.

The peak-peak amplitude of the input signal must never exceed 1.8 V. Please consult your TCXO supplier for an appropriate value of decoupling capacitor, C_D.

![TCXO Connection Diagram](image-url)
5.3.2. CLKOUT Output

The reference frequency, or a fraction of it, can be provided on DIO5 (pin 12) by modifying bits ClkOut in RegDioMapping2. Two typical applications of the CLKOUT output include:

- To provide a clock output for a companion processor, thus saving the cost of an additional oscillator. CLKOUT can be made available in any operation mode except Sleep mode and is automatically enabled at power on reset.
- To provide an oscillator reference output. Measurement of the CLKOUT signal enables simple software trimming of the initial crystal tolerance.

*Note* To minimize the current consumption of the SX1272/73, please ensure that the CLKOUT signal is disabled when not required.

5.3.3. PLL

The local oscillator of the SX1272/73 is derived from a fractional-N PLL that is referenced to the crystal oscillator circuit. Two PLLs are available for transmit mode operation - either low phase noise or low current consumption to maximize either transmit power consumption or transmit spectral purity respectively. Both PLLs feature a programmable bandwidth setting where one of four discrete preset bandwidths may be accessed. For reference the relative performance of both low consumption and low phase noise PLLs, for each programmable bandwidth setting, is shown in the following figure.
Figure 41. Typical Phase Noise Performances of the Low Consumption and Low Phase Noise PLLs.

Note In receive mode only the low consumption PLL is available.

The SX1272/73 PLL uses a 19-bit sigma-delta modulator whose frequency resolution, constant over the whole frequency range, is given by:

\[ F_{STEP} = \frac{F_{XOSC}}{2^{19}} \]
The carrier frequency is programmed through RegFrf, split across addresses 0x06 to 0x08:

\[ F_{RF} = F_{STEP} \times Frf(23,0) \]

Note  The Frf setting is split across 3 bytes. A change in the center frequency will only be taken into account when the least significant byte FrfLsb in RegFrfLsb is written. This allows the potential for user generation of m-ary FSK at very low bit rates. This is possible where frequency modulation is achieved by direct programming of the programmed RF centre frequency. To enable this functionality set the FastHopOn bit of register RegPllHop.

5.3.4. RC Oscillator

All timing operations in the low-power Sleep state of the Top Level Sequencer rely on the accuracy of the internal low-power RC oscillator. This oscillator is automatically calibrated at the device power-up not requiring any user input.
5.4. Transmitter Description

The transmitter of SX1272/73 comprises the frequency synthesizer, modulator (both LoRa™ and FSK/OOK) and power amplifier blocks, together with the DC biasing and ramping functionality that is provided through the VR_PA block.

5.4.1. Architecture Description

The architecture of the RF front end is shown in the following diagram. Here we see that the unregulated PA0 is connected to the RFO pin features a single low power amplifier device. The PA_BOOST pin is connected to the internally regulated PA1 and PA2 circuits. Here PA2 is a high power amplifier that permits continuous operation up to +17 dBm and duty cycled operation up to +20 dBm. For full details of operation at +20 dBm please consult Section 5.4.3.

![RF Front-end Architecture Shows the Internal PA Configuration.](image)

5.4.2. RF Power Amplifiers

Three power amplifier blocks, PA0 - PA2, are available in the SX1272/73. PA0 is a high efficiency amplifier capable of yielding RF power programmable in 1 dB steps from -1 dBm to +14 dBm directly into a 50 ohm load with low current consumption. PA0 is connected to pin RFO (pin 24).

PA1 and PA2 are both connected to pin PA_BOOST (pin 27). There are two potential configurations of these power amplifiers, fixed or programmable. In the fixed configuration they can deliver up to +20 dBm. In programmable configuration they can provide from +17 dBm to +2 dBm in 1 dB programmable steps. Naturally, low impedance matching and harmonic filtering is required to ensure RF power delivery and regulatory compliance. (See the applications section of this document for more details).

<table>
<thead>
<tr>
<th>PaSelect</th>
<th>Mode</th>
<th>Power Range</th>
<th>Pout Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>PA0 output on pin RFO</td>
<td>-1 to +14 dBm</td>
<td>-1 dBm + OutputPower</td>
</tr>
<tr>
<td>1</td>
<td>PA1 and PA2 combined on pin PA_-BOOST</td>
<td>+2 to +17 dBm</td>
<td>+2 dBm + OutputPower</td>
</tr>
<tr>
<td>1</td>
<td>PA1+PA2 on PA_BOOST with high output power +20 dBm settings (see 5.4.3)</td>
<td>+5 to +20 dBm</td>
<td>+5 dBm + OutputPower</td>
</tr>
</tbody>
</table>

Table 31 Power Amplifier Mode Selection Truth Table
5.4.3. High Power +20 dBm Operation

The SX1272/73 has a high power +20 dBm capability on PA_BOOST pin, with the following settings:

Table 32 High Power Settings

<table>
<thead>
<tr>
<th>Register</th>
<th>Address</th>
<th>Value for High Power</th>
<th>Default value PA0 or +17dBm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegPaDac</td>
<td>0x5A</td>
<td>0x87</td>
<td>0x84</td>
<td>High power PA control</td>
</tr>
</tbody>
</table>

Notes - High Power settings must be turned off when using PA0
- The Over Current Protection limit should be adapted to the actual power level, in RegOcp

Specific Absolute Maximum Ratings and Operating Range restrictions apply to the +20 dBm operation. They are listed in Table 33 and Table 34.

Table 33 Operating Range, +20 dBm Operation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC_20dBm</td>
<td>Duty Cycle of transmission at +20 dBm output</td>
<td>-</td>
<td>1</td>
<td>%</td>
</tr>
<tr>
<td>VSWR_20dBm</td>
<td>Maximum VSWR at antenna port, +20 dBm output</td>
<td>-</td>
<td>3:1</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 34 Operating Range, +20 dBm Operation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDDop_20dBm</td>
<td>Supply voltage, +20 dBm output</td>
<td>2.4</td>
<td>3.7</td>
<td>V</td>
</tr>
</tbody>
</table>

The duty cycle of transmission at +20 dBm is limited to 1%, with a maximum VSWR of 3:1 at antenna port, over the standard operating range (-40 to +85 °C). For any other operating conditions, contact your Semtech representative.
5.4.4. Over Current Protection
The power amplifiers of SX1272/73 are protected against current over supply in adverse RF load conditions by the over current protection block. This has the added benefit of protecting battery chemistries with limited peak current capability and minimising worst case PA consumption in battery life calculations. The current limiter value is controlled by the $OcpTrim$ bits in $RegOcp$ and is calculated according to the following formulas:

$$I_{MAX} = \begin{cases} 
45 + 5 \times OcpTrim \, [mA] & \text{for } 0 \text{ to } 15 \\
-30 + 10 \times OcpTrim \, [mA] & \text{for } 16 \text{ to } 27 \\
240 \, [mA] & \text{for } 27+ 
\end{cases}$$

Table 35 Trimming of the OCP Current

<table>
<thead>
<tr>
<th>$OcpTrim$</th>
<th>$I_{MAX}$</th>
<th>$I_{MAX}$ Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 15</td>
<td>45 to 120 mA</td>
<td>$45 + 5 \times OcpTrim , [mA]$</td>
</tr>
<tr>
<td>16 to 27</td>
<td>130 to 240 mA</td>
<td>$-30 + 10 \times OcpTrim , [mA]$</td>
</tr>
<tr>
<td>27+</td>
<td>240 mA</td>
<td>240 [mA]</td>
</tr>
</tbody>
</table>

Note: $I_{MAX}$ sets a limit on the current drain of the Power Amplifier only, hence the maximum current drain of the SX1272/73 is equal to $I_{MAX} + IDD$.

5.5. Receiver Description

5.5.1. Overview
The SX1272/73 features a digital receiver with the analog to digital conversion process performed directly following the LNA-Mixer block. In addition to the LoRa™ modulation scheme the low-IF receiver is able to demodulate ASK, OOK, (G)FSK and (G)MSK modulation. All filtering, demodulation, gain control, synchronization and packet handling is performed digitally allowing a high degree of programmable flexibility. The receiver also has automatic gain calibration, this improves the precision of RSSI measurement and enhances image rejection.

5.5.2. Receiver Enabled and Receiver Active States
In the receiver operating mode two states of functionality are defined. Upon initial transition to receiver operating mode the receiver is in the ‘receiver-enabled’ state. In this state the receiver awaits for either the user defined valid preamble or RSSI detection criterion to be fulfilled. Once met the receiver enters ‘receiver-active’ state. In this second state the received signal is processed by the packet engine and top level sequencer. For a complete description of the digital functions of the SX1272/73 receiver please see Section 5.5 of the datasheet.
5.5.3. Automatic Gain Control In FSK/OOK Mode

The AGC feature allows receiver to handle a wide Rx input dynamic range from the sensitivity level up to maximum input level of 0 dBm or more, whilst optimizing the system linearity.

The following table shows typical NF and IIP3 performances for the SX1272/73 LNA gains available.

Table 36 LNA Gain Control and Performances

<table>
<thead>
<tr>
<th>RX input level (Pin)</th>
<th>Gain Setting</th>
<th>LnaGain</th>
<th>Relative LNA Gain [dB]</th>
<th>NF [dB]</th>
<th>IIP3 [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin &lt;= AgcThresh1</td>
<td>G1</td>
<td>‘001’</td>
<td>0 dB</td>
<td>7</td>
<td>-12</td>
</tr>
<tr>
<td>AgcThresh1 &lt; Pin &lt;= AgcThresh2</td>
<td>G2</td>
<td>‘010’</td>
<td>-6 dB</td>
<td>11</td>
<td>-8</td>
</tr>
<tr>
<td>AgcThresh2 &lt; Pin &lt;= AgcThresh3</td>
<td>G3</td>
<td>‘011’</td>
<td>-12 dB</td>
<td>16</td>
<td>-5</td>
</tr>
<tr>
<td>AgcThresh3 &lt; Pin &lt;= AgcThresh4</td>
<td>G4</td>
<td>‘100’</td>
<td>-24 dB</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>AgcThresh4 &lt; Pin &lt;= AgcThresh5</td>
<td>G5</td>
<td>‘110’</td>
<td>-26 dB</td>
<td>34</td>
<td>10</td>
</tr>
<tr>
<td>AgcThresh5 &lt; Pin</td>
<td>G6</td>
<td>‘111’</td>
<td>-48 dB</td>
<td>44</td>
<td>10</td>
</tr>
</tbody>
</table>
The AGC reference power level is determined as follows:

\[
\text{AGC Reference [dBm]} = -174 \text{ dBm} + 10 \times \log(2 \times \text{Rx Bw}) + \text{SNR} + \text{AgcReferenceLevel}
\]

with \( \text{SNR} = 8 \text{ dB} \) (considered a fixed value).

A detailed description of the receiver setup to enable the AGC is provided in section 4.2.7.

5.5.4. RSSI in FSK/OOK Mode

The RSSI provides a measure of the incoming signal power at RF input port measured within the receiver bandwidth. The signal power is available in \( \text{RssiValue} \). This value is absolute in units of dBm and with a resolution of 0.5 dB. The formula below relates the register value to the absolute input signal level at the RF input port:

\[
\text{RssiValue} = -2 \cdot \text{RF level [dBm]} + \text{RssiOffset [dB]}
\]

The RSSI value can be compensated to take into account the loss in the matching network or even the gain of an additional LNA by using \( \text{RssiOffset} \). The offset can be chosen in 1 dB steps from -16 to +15 dB. When compensation is applied the effective signal strength is read as follows:

\[
\text{RSSI[dBm]} = -\frac{\text{RssiValue}}{2}
\]

The RSSI value is smoothed on a user defined number of measured RSSI samples. The precision of the RSSI value is related to the number of RSSI samples used. \( \text{RssiSmoothing} \) selects the number of RSSI samples from a minimum of 2 samples up to 256 samples in increments of power of 2. Table 37 gives the estimation of the RSSI accuracy for a 10 dB SNR and response time versus the number of RSSI samples programmed in \( \text{RssiSmoothing} \).
Table 37  RssiSmoothing Options

<table>
<thead>
<tr>
<th>RssiSmoothing</th>
<th>Number of Samples</th>
<th>Estimated Accuracy</th>
<th>Response Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘000’</td>
<td>2</td>
<td>± 6 dB</td>
<td></td>
</tr>
<tr>
<td>‘001’</td>
<td>4</td>
<td>± 5 dB</td>
<td></td>
</tr>
<tr>
<td>‘010’</td>
<td>8</td>
<td>± 4 dB</td>
<td></td>
</tr>
<tr>
<td>‘011’</td>
<td>16</td>
<td>± 3 dB</td>
<td></td>
</tr>
<tr>
<td>‘100’</td>
<td>32</td>
<td>± 2 dB</td>
<td></td>
</tr>
<tr>
<td>‘101’</td>
<td>64</td>
<td>± 1.5 dB</td>
<td></td>
</tr>
<tr>
<td>‘110’</td>
<td>128</td>
<td>± 1.2 dB</td>
<td></td>
</tr>
<tr>
<td>‘111’</td>
<td>256</td>
<td>± 1.1 dB</td>
<td></td>
</tr>
</tbody>
</table>

The RSSI is calibrated when the image and RSSI calibration process is launched. Please see Section Table 4.2.3.8 for details.

5.5.5. RSSI and SNR in LoRa™ Mode

The RSSI values reported by the LoRa™ modem differ from those expressed by the FSK/OOK modem. The following formula shows the method used to interpret the LoRa™ RSSI values:

\[ \text{RSSI (dBm)} = -139 + Rssi, \text{ (with LnaBoost On)} \]

The same formula can be re-used to evaluate the signal strength of the received packet:

\[ \text{Packet Strength (dBm)} = -139 + \text{PacketRssi} * 0.25, \text{ (with LnaBoost On and SNR >= 0)} \]

Due to the nature of the LoRa modulation, it is possible to receive packets below the noise floor. In this situation, the SNR is used in conjunction of the PacketRssi to compute the signal strength of the received packet:

\[ \text{Packet Strength (dBm)} = -139 + \text{PacketRssi} + \text{PacketSnr} * 0.25, \text{ (with LnaBoost On and SNR < 0)} \]

Note:

1.  \( \text{PacketRssi (in RegPktRssiValue), is an averaged version of Rssi (in RegRssiValue). Rssi can be read at any time (during packet reception or not), and should be averaged to give more precise results.} \)

2.  The constants, -139, may vary with the front-end setup of the SX1272 (LnaBoost On or Off, presence of an external LNA, mismatch at the LNA input…). It is recommended to adjust these values with a single-point calibration procedure to increase RSSI accuracy.

3.  As signal strength increases (RSSI>-100dBm), the linearity of PacketRssi is not guaranteed and results will diverge from the ideal 1dB/dB curve. When very good RSSI precision is required over the whole dynamic range of the receiver, two options are proposed:

   - Rssi in RegRssiValue offers better linearity. Rssi can be sampled during the reception of the payload (between ValidHeader and RxDone IRQ), and used to extract a more high-signal RSSI measurement. Rssi is updated every 1/BW (i.e. 8us in 125kHz mode, 4us in 250kHz, etc…)

   - When SNR>=0, the standard formula can be adjusted to correct the slope:

\[ \text{RSSI = -139+16/15 * PacketRssi} \]
5.5.6. Channel Filter

The role of the channel filter is to reject noise and interference outside of the wanted channel. The SX1272/73 channel filtering is implemented with a 16-tap finite impulse response (FIR) filter. Rejection of the filter is high enough that the filter stop-band performance is not the dominant influence on adjacent channel rejection performance. This is instead limited by the SX1272/73 PLL phase noise.

Note To respect sampling criterion in the decimation chain of the receiver, the communication bit rate cannot be set at a higher than twice the single side receiver bandwidth (BitRate < 2 x RxBw)

The programmed single side bandwidth \( RxBw \) of the channel filter is determined by the parameters \( RxBwMant \) and \( RxBwExp \) in RegRxBw:

\[
RxBw = \frac{FXOSC}{RxBwMant \times 2^{RxBwExp + 2}}
\]

The following channel filter bandwidths are hence accessible in the case of a 32 MHz reference oscillator.

Table 38 Available RxBw Settings

<table>
<thead>
<tr>
<th>RxBwMant (binary/value)</th>
<th>RxBwExp (decimal)</th>
<th>RxBw (kHz) FSK / OOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>10b / 24</td>
<td>7</td>
<td>2.6</td>
</tr>
<tr>
<td>01b / 20</td>
<td>7</td>
<td>3.1</td>
</tr>
<tr>
<td>00b / 16</td>
<td>7</td>
<td>3.9</td>
</tr>
<tr>
<td>10b / 24</td>
<td>6</td>
<td>5.2</td>
</tr>
<tr>
<td>01b / 20</td>
<td>6</td>
<td>6.3</td>
</tr>
<tr>
<td>00b / 16</td>
<td>6</td>
<td>7.8</td>
</tr>
<tr>
<td>10b / 24</td>
<td>5</td>
<td>10.4</td>
</tr>
<tr>
<td>01b / 20</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>00b / 16</td>
<td>5</td>
<td>15.6</td>
</tr>
<tr>
<td>10b / 24</td>
<td>4</td>
<td>20.8</td>
</tr>
<tr>
<td>01b / 20</td>
<td>4</td>
<td>25.0</td>
</tr>
<tr>
<td>00b / 16</td>
<td>4</td>
<td>31.3</td>
</tr>
<tr>
<td>10b / 24</td>
<td>3</td>
<td>41.7</td>
</tr>
<tr>
<td>01b / 20</td>
<td>3</td>
<td>50.0</td>
</tr>
<tr>
<td>00b / 16</td>
<td>3</td>
<td>62.5</td>
</tr>
<tr>
<td>10b / 24</td>
<td>2</td>
<td>83.3</td>
</tr>
<tr>
<td>01b / 20</td>
<td>2</td>
<td>100.0</td>
</tr>
<tr>
<td>00b / 16</td>
<td>2</td>
<td>125.0</td>
</tr>
<tr>
<td>10b / 24</td>
<td>1</td>
<td>166.7</td>
</tr>
<tr>
<td>01b / 20</td>
<td>1</td>
<td>200.0</td>
</tr>
<tr>
<td>00b / 16</td>
<td>1</td>
<td>250.0</td>
</tr>
</tbody>
</table>

Other settings reserved

5.5.7. Temperature Measurement

A stand alone temperature measurement block is used in order to measure the temperature in all mode except Sleep and Standby. It is enabled by default and can be stopped by setting TempMonitorOff to 1. The result of the measurement is stored in TempValue in RegTemp.
Due to process variations the absolute accuracy of the result is +/- 10 °C. Higher precision requires a calibration procedure at a known temperature. The figure below shows the influence of just such a calibration process. For more information, including source code, please consult the applications section of this document.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>181</td>
<td>74</td>
<td>89</td>
</tr>
<tr>
<td>75</td>
<td>190</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>65</td>
<td>201</td>
<td>54</td>
<td>69</td>
</tr>
<tr>
<td>55</td>
<td>211</td>
<td>44</td>
<td>62</td>
</tr>
<tr>
<td>45</td>
<td>222</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>35</td>
<td>232</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>25</td>
<td>242</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>15</td>
<td>252</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>-10</td>
<td>5</td>
</tr>
<tr>
<td>-15</td>
<td>33</td>
<td>-33</td>
<td>-18</td>
</tr>
<tr>
<td>-25</td>
<td>44</td>
<td>-44</td>
<td>-29</td>
</tr>
<tr>
<td>-35</td>
<td>50</td>
<td>-56</td>
<td>-41</td>
</tr>
<tr>
<td>-45</td>
<td>63</td>
<td>-63</td>
<td>-48</td>
</tr>
</tbody>
</table>

Figure 45. Temperature Sensor Response
6. Description of the Registers

The register mapping depends upon whether FSK/OOK or LoRa™ mode has been selected. The following table summarises the location and function of each register and gives an overview of the changes in register mapping between both modes of operation.

6.1. Register Table Summary

Table 39 Registers Summary

<table>
<thead>
<tr>
<th>Address</th>
<th>Register Name</th>
<th>FSK/OOK Mode</th>
<th>LoRa™ Mode</th>
<th>Reset (POR)</th>
<th>Default (FSK)</th>
<th>Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>RegFifo</td>
<td></td>
<td></td>
<td>0x00</td>
<td></td>
<td>FIFO read/write access</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x01</td>
<td>RegOpMode</td>
<td></td>
<td></td>
<td>0x01</td>
<td></td>
<td>Operating mode &amp; LoRa™ / FSK selection</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x02</td>
<td>RegBitrateMsb</td>
<td>Unset</td>
<td></td>
<td>0x1A</td>
<td></td>
<td>Bit Rate setting, Most Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x03</td>
<td>RegBitrateLsb</td>
<td></td>
<td></td>
<td>0x08</td>
<td></td>
<td>Bit Rate setting, Least Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x04</td>
<td>RegFdevMsb</td>
<td></td>
<td></td>
<td>0x00</td>
<td></td>
<td>Frequency Deviation setting, Most Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x05</td>
<td>RegFdevLsb</td>
<td></td>
<td></td>
<td>0x52</td>
<td></td>
<td>Frequency Deviation setting, Least Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x06</td>
<td>RegFrFs</td>
<td></td>
<td></td>
<td>0xE4</td>
<td></td>
<td>RF Carrier Frequency, Most Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x07</td>
<td>RegFrFsMid</td>
<td></td>
<td></td>
<td>0xC0</td>
<td></td>
<td>RF Carrier Frequency, Intermediate Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x08</td>
<td>RegFrFsLsb</td>
<td></td>
<td></td>
<td>0x00</td>
<td></td>
<td>RF Carrier Frequency, Least Significant Bits</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x09</td>
<td>RegPaConfig</td>
<td></td>
<td></td>
<td>0xF</td>
<td></td>
<td>PA selection and Output Power control</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x0A</td>
<td>RegPaRamp</td>
<td></td>
<td></td>
<td>0x19</td>
<td></td>
<td>Control of PA ramp time, low phase noise PLL</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x0B</td>
<td>RegOcp</td>
<td></td>
<td></td>
<td>0x2B</td>
<td></td>
<td>Over Current Protection control</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x0C</td>
<td>RegLna</td>
<td></td>
<td></td>
<td>0x20</td>
<td></td>
<td>LNA settings</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x0D</td>
<td>RegRxConfig</td>
<td>RegFifoAddrPtr</td>
<td></td>
<td>0x08</td>
<td>0x1E</td>
<td>AFC, AGC, ctrl</td>
<td>FIFO SPI pointer</td>
</tr>
<tr>
<td>0x0E</td>
<td>RegRssiConfig</td>
<td>RegFifoTxBaseAddr</td>
<td></td>
<td>0x02</td>
<td>RSSI</td>
<td>Start Tx data</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x0F</td>
<td>RegRssiCollision</td>
<td>RegFifoRxBaseAddr</td>
<td></td>
<td>0xA</td>
<td>RSSI Collision detector</td>
<td>Start Rx data</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x10</td>
<td>RegRssiThresh</td>
<td>FifoRxCurrentAddr</td>
<td></td>
<td>0xFF</td>
<td>RSSI Threshold control</td>
<td>Start address of last packet received</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x11</td>
<td>RegRssiValue</td>
<td>RegRxFlagsMask</td>
<td></td>
<td>n/a</td>
<td>n/a</td>
<td>RSSI value in dBm</td>
<td>Optional IRQ flag mask</td>
</tr>
<tr>
<td>0x12</td>
<td>RegRxBw</td>
<td>RegRxFlags</td>
<td></td>
<td>0x15</td>
<td>Channel Filter BW Control</td>
<td>IRQ flags</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x13</td>
<td>RegAfcbw</td>
<td>RegRxNbBytes</td>
<td></td>
<td>0x0B</td>
<td>AFC Channel Filter BW</td>
<td>Number of received bytes</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x14</td>
<td>RegOokPeak</td>
<td>RegRxHeaderCnt ValueMsb</td>
<td></td>
<td>0x28</td>
<td>OOK demodulator</td>
<td>Number of valid headers received</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x15</td>
<td>RegOokFix</td>
<td>RegRxHeaderCnt ValueLsb</td>
<td></td>
<td>0xC</td>
<td>Threshold of the OOK demod</td>
<td>Number of valid packets received</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x16</td>
<td>RegOokAvg</td>
<td>RegRxPacketCnt ValueMsb</td>
<td></td>
<td>0x12</td>
<td>Average of the OOK demod</td>
<td>Number of valid packets received</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x17</td>
<td>Reserved17</td>
<td>RegRxPacketCnt ValueLsb</td>
<td></td>
<td>0x47</td>
<td>-</td>
<td>-</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x18</td>
<td>Reserved18</td>
<td>RegModemStat</td>
<td></td>
<td>0x32</td>
<td>-</td>
<td>Live LoRa™ modem status</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x19</td>
<td>Reserved19</td>
<td>RegPktSnrValue</td>
<td></td>
<td>0x3E</td>
<td>-</td>
<td>Esimation of last packet SNR</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>0x1A</td>
<td>RegAfFei</td>
<td>RegPktRssiValue</td>
<td></td>
<td>0x00</td>
<td>AFC and FEI control</td>
<td>RSSI of last packet</td>
<td>FSK Mode</td>
</tr>
<tr>
<td>Address</td>
<td>Register Name</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>----------------</td>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0x1B</td>
<td>RegAfcMsbs</td>
<td>Frequency correction value of the AFC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x1C</td>
<td>RegAfcLsb</td>
<td>FHSS start channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x1D</td>
<td>RegFeiMsbs</td>
<td>Value of the calculated frequency error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x1E</td>
<td>RegFeiLsb</td>
<td>Modem PHY config 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x1F</td>
<td>RegPreambleDetect</td>
<td>Settings of the Preamble Detector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x20</td>
<td>RegRxTimeout1</td>
<td>Receiver timeout value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x21</td>
<td>RegRxTimeout2</td>
<td>Size of preamble</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x22</td>
<td>RegRxTimeout3</td>
<td>LoRa™ payload length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x23</td>
<td>RegRxDelay</td>
<td>LoRa™ maximum payload length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x24</td>
<td>RegOsc</td>
<td>RC Oscillators Settings, CLK-OUT frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x25</td>
<td>RegPreambleMsbs</td>
<td>Address of last byte written in FIFO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x26</td>
<td>RegPreambleLsb</td>
<td>LoRa™ rx data pointer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x27</td>
<td>RegSyncConfig</td>
<td>Sync Word Recognition control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x28</td>
<td>RegSyncValue1</td>
<td>Estimated frequency error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x29</td>
<td>RegSyncValue2</td>
<td>Sync Word bytes, 1 through 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x2A</td>
<td>RegSyncValue3</td>
<td>RESERVED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x2B-0x2F</td>
<td>RegSyncValue4</td>
<td>RESERVED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x2C</td>
<td>RegSyncValue5</td>
<td>Wideband RSSI measurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x2D-0x2F</td>
<td>RegSyncValue6-8</td>
<td>RESERVED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x30</td>
<td>RegPacketConfig1</td>
<td>Packet mode settings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x31</td>
<td>RegPacketConfig2</td>
<td>LoRa detection Optimize for SF6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x32</td>
<td>RegPayloadLength</td>
<td>Payload length setting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x33</td>
<td>RegNodeAdrs</td>
<td>Invert LoRa I and Q signals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x34</td>
<td>RegBroadcastAdrs</td>
<td>Broadcast address</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x35</td>
<td>RegFifoThresh</td>
<td>Fifo threshold, Tx start condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x36</td>
<td>RegSeqConfig1</td>
<td>Top level Sequencer settings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x37</td>
<td>RegSeqConfig2</td>
<td>Change the LoRa Detection threshold for SF6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0x38</td>
<td>RegTimerResol</td>
<td>Timer 1 and 2 resolution control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Address | Register Name | Reset (POR) | Default (FSK) | Description
--- | --- | --- | --- | ---
0x39 | RegTimer1Coef | 0xF5 | 0x12 | Timer 1 setting
0x39 | RegSyncWord | | | LoRa™ Sync Word
0x3A | RegTimer2Coef | 0x20 | | Timer 2 setting
0x3B | RegImageCal | 0x82 | 0x02 | Image calibration engine control
0x3B | RegInvertIQ2 | | | Optimize for inverted IQ
0x3C | RegTemp | | | Temperature Sensor value
0x3D | RegLowBat | 0x02 | | Low Battery Indicator Settings
0x3E | RegIrqFlags1 | 0x80 | n/a | Status register: PLL Lock state, Timeout, RSSI
0x3F | RegIrqFlags2 | 0x40 | n/a | Status register: FIFO handling flags, Low Battery
0x40 | RegDioMapping1 | 0x00 | | Mapping of pins DIO0 to DIO3
0x41 | RegDioMapping2 | 0x00 | | Mapping of pins DIO4 and DIO5, ClkOut frequency
0x42 | RegVersion | 0x22 | | Semtech ID relating the silicon revision
0x43 | RegAgcRef | 0x13 | | Adjustment of the AGC thresholds
0x44 | RegAgcThresh1 | 0x0E | | 
0x45 | RegAgcThresh2 | 0x5B | | 
0x46 | RegAgcThresh3 | 0xDB | | 
0x4B | RegPllHop | 0x2E | | Control the fast frequency hopping mode
0x58 | RegTcxo | 0x09 | | TCXO or XTAL input setting
0x5A | RegPaDac | 0x84 | | Higher power settings of the PA
0x5C | RegPll | 0xD0 | | Control of the PLL bandwidth
0x5E | RegPllLowPn | 0xD0 | | Control of the Low Phase Noise PLL bandwidth
0x63 | RegPaManual | 0x00 | | Enables manual PA control
0x6C | RegFormerTemp | - | | Stored temperature during the former IQ Calibration
0x70 | RegBitRateFrac | 0x00 | | Fractional part in the Bit Rate division ratio

### Notes
- Reset values are automatically refreshed in the chip at Power On Reset
- Default values are the Semtech recommended register values, optimizing the device operation
- Registers for which the Default value differs from the Reset value are denoted by an * in the tables of section 6.2
6.2. FSK/OOK Mode Register Map

This section details the SX1272/73 register mapping and the precise contents of each register in FSK/OOK mode.

Convention: r: read, w: write, t: trigger, c: clear

Table 40 Register Map

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegFifo (0x00)</td>
<td>7-0</td>
<td>Fifo</td>
<td>rw</td>
<td>0x00</td>
<td>FIFO data input/output</td>
</tr>
<tr>
<td>RegOpMode (0x01)</td>
<td>7</td>
<td>LongRangeMode</td>
<td>r</td>
<td>0x00</td>
<td>0 → FSK/OOK Mode 1→ LoRa™ Mode This bit can be modified only in Sleep mode. A write operation on other device modes is ignored.</td>
</tr>
<tr>
<td></td>
<td>6-5</td>
<td>ModulationType</td>
<td>rw</td>
<td>0x00</td>
<td>Modulation scheme: 00 → FSK 01 → OOK 10 -11 → reserved</td>
</tr>
<tr>
<td></td>
<td>4-3</td>
<td>ModulationShaping</td>
<td>rw</td>
<td>0x00</td>
<td>Data shaping: In FSK: 00 → no shaping 01 → Gaussian filter BT = 1.0 10 → Gaussian filter BT = 0.5 11 → Gaussian filter BT = 0.3 In OOK: 00 → no shaping 01 → filtering with f_{cutoff} = bit_rate 10 → filtering with f_{cutoff} = 2*bit_rate (for bit_rate &lt; 125 kbps) 11 → reserved</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>Mode</td>
<td>rw</td>
<td>0x01</td>
<td>Transceiver modes 000 → Sleep mode 001 → Stdby mode 010 → FS mode TX (FSTx) 011 → Transmitter mode (Tx) 100 → FS mode RX (FSRx) 101 → Receiver mode (Rx) 110 → reserved 111 → reserved</td>
</tr>
<tr>
<td>RegBitrateMsb (0x02)</td>
<td>7-0</td>
<td>BitRate(15:8)</td>
<td>rw</td>
<td>0x1A</td>
<td>MSB of Bit Rate (chip rate if Manchester encoding is enabled)</td>
</tr>
</tbody>
</table>
| RegBitrateLsb (0x03) | 7-0   | BitRate(7:0) | rw | 0x0B | LSB of bit rate (chip rate if Manchester encoding is enabled) 

\[
BitRate = \frac{FXOSC}{BitRate(15:0) + BitRateFrac \times 16}
\]

Default value: 4.8 kbps
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegFdevMsb (0x04)</td>
<td>7-6</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-0</td>
<td>Fdev(13:8)</td>
<td>rw</td>
<td>0x00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$F_{dev} = F_{step} \times F_{dev}(15:0)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Default value: 5 kHz</td>
</tr>
<tr>
<td>RegFdevLsb (0x05)</td>
<td>7-0</td>
<td>Fdev(7:0)</td>
<td>rw</td>
<td>0x52</td>
<td>LSB of the frequency deviation</td>
</tr>
<tr>
<td>RegFrfMsb (0x06)</td>
<td>7-0</td>
<td>Frf(23:16)</td>
<td>rw</td>
<td>0xE4</td>
<td>MSB of the RF carrier frequency</td>
</tr>
<tr>
<td>RegFrfMid (0x07)</td>
<td>7-0</td>
<td>Frf(15:8)</td>
<td>rw</td>
<td>0xC0</td>
<td>MSB of the RF carrier frequency</td>
</tr>
<tr>
<td>RegFrfLsb (0x08)</td>
<td>7-0</td>
<td>Frf(7:0)</td>
<td>rw</td>
<td>0x00</td>
<td>LSB of RF carrier frequency</td>
</tr>
<tr>
<td>RegPaConfig (0x09)</td>
<td>7</td>
<td>PaSelect</td>
<td>rw</td>
<td>0x00</td>
<td>Selects PA output pin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 → RFO pin. Maximum power of +13 dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 → PA_BOOST pin. Maximum power of +20 dBm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-4</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-0</td>
<td>OutputPower</td>
<td>rw</td>
<td>0x0F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pout = 2 + OutputPower [dBm], on PA_BOOST pin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pout = -1 + OutputPower [dBm], on RFO pin</td>
</tr>
<tr>
<td>RegPaRamp (0x0A)</td>
<td>7-5</td>
<td>unused</td>
<td>r</td>
<td>-</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>LowPnTxPllOff</td>
<td>rw</td>
<td>0x01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 → Standard PLL used in Rx mode, Lower PN PLL in Tx</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 → Standard PLL used in both Tx and Rx modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-0</td>
<td>PaRamp</td>
<td>rw</td>
<td>0x09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 → 3.4 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0001 → 2 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0010 → 1 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0011 → 500 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0100 → 250 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0101 → 125 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0110 → 100 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0111 → 62 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000 → 50 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1001 → 40 us (d)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1010 → 31 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1011 → 25 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1100 → 20 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1101 → 15 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1110 → 12 us</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1111 → 10 us</td>
</tr>
</tbody>
</table>
### Registers for the Processor

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegOcp (0x0B)</td>
<td>7-6</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>OcpOn</td>
<td>rw</td>
<td>0x01</td>
<td>Enables overload current protection (OCP) for the PA: 0 → OCP disabled 1 → OCP enabled</td>
</tr>
<tr>
<td></td>
<td>4-0</td>
<td>OcpTrim</td>
<td>rw</td>
<td>0x0B</td>
<td>Trimming of OCP current: ( I_{\text{max}} = 45 + 5 \times \text{OcpTrim} ) [mA] if OcpTrim ≤ 15 (120 mA) / ( I_{\text{max}} = -30 + 10 \times \text{OcpTrim} ) [mA] if 15 &lt; OcpTrim ≤ 27 (130 to 240 mA) ( I_{\text{max}} = 240 \text{mA} ) for higher settings ( I_{\text{max}} = 100 \text{mA} )</td>
</tr>
</tbody>
</table>

### Registers for the Receiver

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegLna (0x0C)</td>
<td>7-5</td>
<td>LnaGain</td>
<td>rw</td>
<td>0x01</td>
<td>LNA gain setting: 000 → reserved 001 → G1 = highest gain 010 → G2 = highest gain – 6 dB 011 → G3 = highest gain – 12 dB 100 → G4 = highest gain – 24 dB 101 → G5 = highest gain – 36 dB 110 → G6 = highest gain – 48 dB 111 → reserved Note: Reading this address always returns the current LNA gain (which may be different from what had been previously selected if AGC is enabled.</td>
</tr>
<tr>
<td></td>
<td>4-2</td>
<td>-</td>
<td>r</td>
<td>0x00</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td>1-0</td>
<td>LnaBoost</td>
<td>rw</td>
<td>0x00</td>
<td>Improves the system Noise Figure at the expense of Rx current consumption: 00 → Default setting, meeting the specification 11 → Improved sensitivity</td>
</tr>
</tbody>
</table>

<p>| RegRxConfig (0x0D) | 7    | RestartRxOnCollision | rw | 0x00 | Turns on the mechanism restarting the receiver automatically if it gets saturated or a packet collision is detected 0 → No automatic Restart 1 → Automatic restart On |
|                   | 6    | RestartRxWithoutPllLock | wt | 0x00 | Triggers a manual Restart of the Receiver chain when set to 1. Use this bit when there is no frequency change, RestartRxWithPllLock otherwise. |
|                   | 5    | RestartRxWithPllLock | wt | 0x00 | Triggers a manual Restart of the Receiver chain when set to 1. Use this bit when there is a frequency change, requiring some time for the PLL to re-lock. |
|                   | 4    | AfcAutoOn      | rw | 0x00 | 0 → No AFC performed at receiver startup 1 → AFC is performed at each receiver startup |
|                   | 3    | AgcAutoOn      | rw | 0x01 | 0 → LNA gain forced by the LnaGain Setting 1 → LNA gain is controlled by the AGC |
|                   | 2-0  | RxTrigger      | rw | 0x06* | Selects the event triggering AGC and/or AFC at receiver startup. See Table 23 for a description. |</p>
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegRssiConfig (0x0E)</td>
<td>7-3</td>
<td>RssiOffset</td>
<td>rw</td>
<td>0x00</td>
<td>Signed RSSI offset, to compensate for the possible losses/gains in the front-end (LNA, SAW filter...) 1dB / LSB, 2’s complement format</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>RssiSmoothing</td>
<td>rw</td>
<td>0x02</td>
<td>Defines the number of samples taken to average the RSSI result: 000 → 2 samples used 001 → 4 samples used 010 → 8 samples used 011 → 16 samples used 100 → 32 samples used 101 → 64 samples used 110 → 128 samples used 111 → 256 samples used</td>
</tr>
<tr>
<td>RegRssiCollision (0x0F)</td>
<td>7-0</td>
<td>RssiCollisionThreshold</td>
<td>rw</td>
<td>0xA0</td>
<td>Sets the threshold used to consider that an interferer is detected, witnessing a packet collision. 1dB/LSB (only RSSI increase) Default: 10dB</td>
</tr>
<tr>
<td>RegRssiThresh (0x10)</td>
<td>7-0</td>
<td>RssiThreshold</td>
<td>rw</td>
<td>0xFF</td>
<td>RSSI trigger level for the Rssi interrupt: - RssiThreshold / 2 [dBm]</td>
</tr>
<tr>
<td>RegRssiValue (0x11)</td>
<td>7-0</td>
<td>RssiValue</td>
<td>r</td>
<td>-</td>
<td>Absolute value of the RSSI in dBm, 0.5dB steps. RSSI = - RssiValue/2 [dBm]</td>
</tr>
<tr>
<td>RegRxBw (0x12)</td>
<td>7</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td>6-5</td>
<td>reserved</td>
<td>rw</td>
<td>0x00</td>
<td>reserved</td>
</tr>
<tr>
<td></td>
<td>4-3</td>
<td>RxBwMant</td>
<td>rw</td>
<td>0x02</td>
<td>Channel filter bandwidth control: 00 → RxBwMant = 16 10 → RxBwMant = 24 01 → RxBwMant = 20 11 → reserved</td>
</tr>
</tbody>
</table>
|                | 2-0 | RxBwExp | rw | 0x05 | Channel filter bandwidth control: FSK Mode: \[
RxBW = \frac{FXOSC}{RxBwMant \times 2^{RxBwExp + 2}}\] |
| RegAfcBw (0x13) | 7-5 | reserved | rw | 0x00 | reserved |
|                | 4-3 | RxBwMantAfc | rw | 0x01 | RxBwMant parameter used during the AFC |
|                | 2-0 | RxBwExpAfc | rw | 0x03 | RxBwExp parameter used during the AFC |
| RegOokPeak (0x14) | 7-6 | reserved | rw | 0x00 | reserved |
|                | 5 | BitSyncOn | rw | 0x01 | Enables the Bit Synchronizer. 0 → Bit Sync disabled (not possible in Packet mode) 1 → Bit Sync enabled |
|                | 4-3 | OokThreshType | rw | 0x01 | Selects the type of threshold in the OOK data slicer: 00 → fixed threshold 10 → average mode 01 → peak mode (default) 11 → reserved |
|                | 2-0 | OokPeakThreshStep | rw | 0x00 | Size of each decrement of the RSSI threshold in the OOK demodulator: 000 → 0.5 dB 001 → 1.0 dB 010 → 1.5 dB 011 → 2.0 dB 100 → 3.0 dB 101 → 4.0 dB 110 → 5.0 dB 111 → 6.0 dB |
### Name (Address) | Bits | Variable Name | Mode | Default value | FSK/OOK Description
--- | --- | --- | --- | --- | ---
| | 7-0 | OokFixedThreshold | rw | 0x0C | Fixed threshold for the Data Slicer in OOK mode. Floor threshold for the Data Slicer in OOK when Peak mode is used. |
| | 7-5 | OokPeakThreshDec | rw | 0x00 | Period of decrement of the RSSI threshold in the OOK demodulator: 000 → once per chip, 001 → once every 2 chips, 010 → once every 4 chips, 011 → once every 8 chips, 100 → twice in each chip, 101 → 4 times in each chip, 110 → 8 times in each chip, 111 → 16 times in each chip. |
| | 4 | reserved | rw | 0x01 | Static offset added to the threshold in average mode in order to reduce glitching activity (OOK only): 00 → 0.0 dB, 01 → 2.0 dB, 10 → 4.0 dB, 11 → 6.0 dB. |
| | 3-2 | OokAverageOffset | rw | 0x00 | Filter coefficients in average mode of the OOK demodulator: 00 → f_C = chip rate / 32π, 01 → f_C = chip rate / 8π, 10 → f_C = chip rate / 4π, 11 → f_C = chip rate / 2π. |
| | 1-0 | OokAverageThreshFilt | rw | 0x02 | Frequency error = FeiValue x Fstep. |
| | 7-0 | reserved | rw | 0x47 0x32 0x3E | reserved. Keep the Reset values. |
| | 7-5 | unused | r | - | unused |
| | 4 | AgcStart | wt | 0x00 | Triggers an AGC sequence when set to 1. |
| | 3 | reserved | rw | 0x00 | reserved |
| | 2 | unused | - | - | unused |
| | 1 | AfcClear | wc | 0x00 | Clear AFC register set in Rx mode. Always reads 0. |
| | 0 | AfcAutoClearOn | rw | 0x00 | Only valid if AfcAutoOn is set to 1. AFC register is not cleared at the beginning of the automatic AFC phase. |
| | 7-0 | AfcValue(15:8) | rw | 0x00 | MSB of the AfcValue, 2's complement format. Can be used to overwrite the current AFC value. |
| | 7-0 | AfcValue(7:0) | rw | 0x00 | LSB of the AfcValue, 2's complement format. Can be used to overwrite the current AFC value. |
| | 7-0 | FeiValue(15:8) | rw | - | MSB of the measured frequency offset, 2's complement. Must be read before RegFeiLsb. |
| | 7-0 | FeiValue(7:0) | rw | - | LSB of the measured frequency offset, 2's complement. Frequency error = FeiValue x Fstep.
## SX1272/73 Data Sheet

### Wireless & Sensing Products

### FSK/OOK Description

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>Enables Preamble detector when set to 1. The AGC settings supersede this bit during the startup / AGC phase.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegPreambleDetect (0x1F)</td>
<td>7</td>
<td>PreambleDetectorOn</td>
<td>rw</td>
<td>0x01 *</td>
<td>Turned off 0 → Turned on 1 → Turned on</td>
</tr>
<tr>
<td></td>
<td>6-5</td>
<td>PreambleDetectorSize</td>
<td>rw</td>
<td>0x01 *</td>
<td>Number of Preamble bytes to detect to trigger an interrupt 00 → 1 byte 10 → 3 bytes 01 → 2 bytes 11 → Reserved</td>
</tr>
<tr>
<td></td>
<td>4-0</td>
<td>PreambleDetectorTol</td>
<td>rw</td>
<td>0x0A *</td>
<td>Number or chip errors tolerated over PreambleDetectorSize. 4 chips per bit.</td>
</tr>
<tr>
<td>RegRxTimeout1 (0x20)</td>
<td>7-0</td>
<td>TimeoutRxRssi</td>
<td>rw</td>
<td>0x00</td>
<td>Timeout interrupt is generated TimeoutRxRssi<em>16</em>Tbit after switching to Rx mode if Rssi interrupt doesn't occur (i.e. RssiValue &gt; RssiThreshold) 0x00: TimeoutRxRssi is disabled</td>
</tr>
<tr>
<td>RegRxTimeout2 (0x21)</td>
<td>7-0</td>
<td>TimeoutRxPreamble</td>
<td>rw</td>
<td>0x00</td>
<td>Timeout interrupt is generated TimeoutRxPreamble<em>16</em>Tbit after switching to Rx mode if Preamble interrupt doesn't occur 0x00: TimeoutRxPreamble is disabled</td>
</tr>
<tr>
<td>RegRxTimeout3 (0x22)</td>
<td>7-0</td>
<td>TimeoutSignalSync</td>
<td>rw</td>
<td>0x00</td>
<td>Timeout interrupt is generated TimeoutSignalSync<em>16</em>Tbit after the Rx mode is programmed, if SyncAddress doesn't occur 0x00: TimeoutSignalSync is disabled</td>
</tr>
<tr>
<td>RegRxDelay (0x23)</td>
<td>7-0</td>
<td>InterPacketRxDelay</td>
<td>rw</td>
<td>0x00</td>
<td>Additional delay before an automatic receiver restart is launched: Delay = InterPacketRxDelay<em>4</em>Tbit</td>
</tr>
</tbody>
</table>

### RC Oscillator registers

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegOsc (0x24)</td>
<td>7-4</td>
<td>unused</td>
<td>r</td>
<td>unused</td>
<td>Triggers the calibration of the RC oscillator when set. Always reads 0. RC calibration must be triggered in Standby mode.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>RccCalStart</td>
<td>wt</td>
<td>0x00</td>
<td>Selects CLKOUT frequency: 000 → FXOSC 001 → FXOSC / 2 010 → FXOSC / 4 011 → FXOSC / 8 100 → FXOSC / 16 101 → FXOSC / 32 110 → RC (automatically enabled) 111 → OFF</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>ClkOut</td>
<td>rw</td>
<td>0x07 *</td>
<td>Selects CLKO frequency: 000 → FXOSC 001 → FXOSC / 2 010 → FXOSC / 4 011 → FXOSC / 8 100 → FXOSC / 16 101 → FXOSC / 32 110 → RC (automatically enabled) 111 → OFF</td>
</tr>
</tbody>
</table>

### Packet Handling registers

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegPreambleMsb (0x25)</td>
<td>7-0</td>
<td>PreambleSize(15:8)</td>
<td>rw</td>
<td>0x00</td>
<td>Size of the preamble to be sent (from TxStartCondition fulfilled). (MSB byte)</td>
</tr>
<tr>
<td>RegPreambleLsb (0x26)</td>
<td>7-0</td>
<td>PreambleSize(7:0)</td>
<td>rw</td>
<td>0x03</td>
<td>Size of the preamble to be sent (from TxStartCondition fulfilled). (LSB byte)</td>
</tr>
<tr>
<td>Name (Address)</td>
<td>Bits</td>
<td>Variable Name</td>
<td>Mode</td>
<td>Default value</td>
<td>FSK/OOK Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>RegSyncConfig (0x27)</td>
<td>7-6</td>
<td>AutoRestartRxMode</td>
<td>rw</td>
<td>0x02</td>
<td>Controls the automatic restart of the receiver after the reception of a valid packet (PayloadReady or CrcOk): 00 → Off 01 → On, without waiting for the PLL to re-lock 10 → On, wait for the PLL to lock (frequency changed) 11 → reserved</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>PreamblePolarity</td>
<td>rw</td>
<td>0x00</td>
<td>Sets the polarity of the Preamble 0 → 0xAA (default) 1 → 0x55</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>SyncOn</td>
<td>rw</td>
<td>0x01</td>
<td>Enables the Sync word generation and detection: 0 → Off 1 → On</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>FifoFillCondition</td>
<td>rw</td>
<td>0x00</td>
<td>FIFO filling condition: 0 → if SyncAddress interrupt occurs 1 → as long as FifoFillCondition is set</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>SyncSize</td>
<td>rw</td>
<td>0x03</td>
<td>Size of the Sync word: (SyncSize + 1) bytes, (SyncSize) bytes if ioHomeOn=1</td>
</tr>
<tr>
<td>RegSyncValue1 (0x28)</td>
<td>7-0</td>
<td>SyncValue(63:56)</td>
<td>rw</td>
<td>0x01</td>
<td>1st byte of Sync word. (MSB byte) Used if SyncOn is set.</td>
</tr>
<tr>
<td>RegSyncValue2 (0x29)</td>
<td>7-0</td>
<td>SyncValue(55:48)</td>
<td>rw</td>
<td>0x01</td>
<td>2nd byte of Sync word Used if SyncOn is set and (SyncSize +1) &gt;= 2.</td>
</tr>
<tr>
<td>RegSyncValue3 (0x2A)</td>
<td>7-0</td>
<td>SyncValue(47:40)</td>
<td>rw</td>
<td>0x01</td>
<td>3rd byte of Sync word. Used if SyncOn is set and (SyncSize +1) &gt;= 3.</td>
</tr>
<tr>
<td>RegSyncValue4 (0x2B)</td>
<td>7-0</td>
<td>SyncValue(39:32)</td>
<td>rw</td>
<td>0x01</td>
<td>4th byte of Sync word. Used if SyncOn is set and (SyncSize +1) &gt;= 4.</td>
</tr>
<tr>
<td>RegSyncValue5 (0x2C)</td>
<td>7-0</td>
<td>SyncValue(31:24)</td>
<td>rw</td>
<td>0x01</td>
<td>5th byte of Sync word. Used if SyncOn is set and (SyncSize +1) &gt;= 5.</td>
</tr>
<tr>
<td>RegSyncValue6 (0x2D)</td>
<td>7-0</td>
<td>SyncValue(23:16)</td>
<td>rw</td>
<td>0x01</td>
<td>6th byte of Sync word. Used if SyncOn is set and (SyncSize +1) &gt;= 6.</td>
</tr>
<tr>
<td>RegSyncValue7 (0x2E)</td>
<td>7-0</td>
<td>SyncValue(15:8)</td>
<td>rw</td>
<td>0x01</td>
<td>7th byte of Sync word. Used if SyncOn is set and (SyncSize +1) &gt;= 7.</td>
</tr>
<tr>
<td>RegSyncValue8 (0x2F)</td>
<td>7-0</td>
<td>SyncValue(7:0)</td>
<td>rw</td>
<td>0x01</td>
<td>8th byte of Sync word. Used if SyncOn is set and (SyncSize +1) = 8.</td>
</tr>
<tr>
<td>Name (Address)</td>
<td>Bits</td>
<td>Variable Name</td>
<td>Mode</td>
<td>Default value</td>
<td>FSK/OOK Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
<td>---------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>RegPacketConfig1 (0x30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>PacketFormat</td>
<td>rw</td>
<td>0x01</td>
<td>Defines the packet format used: 0 → Fixed length 1 → Variable length</td>
<td></td>
</tr>
<tr>
<td>6-5</td>
<td>DcFree</td>
<td>rw</td>
<td>0x00</td>
<td>Defines DC-free encoding/decoding performed: 00 → None (Off) 01 → Manchester 10 → Whitening 11 → reserved</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CrcOn</td>
<td>rw</td>
<td>0x01</td>
<td>Enables CRC calculation/check (Tx/Rx): 0 → Off 1 → On</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CrcAutoClearOff</td>
<td>rw</td>
<td>0x00</td>
<td>Defines the behavior of the packet handler when CRC check fails: 0 → Clear FIFO and restart new packet reception. No PayloadReady interrupt issued. 1 → Do not clear FIFO. PayloadReady interrupt issued.</td>
<td></td>
</tr>
<tr>
<td>2-1</td>
<td>AddressFiltering</td>
<td>rw</td>
<td>0x00</td>
<td>Defines address based filtering in Rx: 00 → None (Off) 01 → Address field must match NodeAddress 10 → Address field must match NodeAddress or BroadcastAddress 11 → reserved</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>CrcWhiteningType</td>
<td>rw</td>
<td>0x00</td>
<td>Selects the CRC and whitening algorithms: 0 → CCITT CRC implementation with standard whitening 1 → IBM CRC implementation with alternate whitening</td>
<td></td>
</tr>
<tr>
<td>RegPacketConfig2 (0x31)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>unused</td>
<td>r</td>
<td>-</td>
<td>unused</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>DataMode</td>
<td>rw</td>
<td>0x01</td>
<td>Data processing mode: 0 → Continuous mode 1 → Packet mode</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IoHomeOn</td>
<td>rw</td>
<td>0x00</td>
<td>Enables the io-homecontrol® compatibility mode 0 → Disabled 1 → Enabled</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IoHomePowerFrame</td>
<td>rw</td>
<td>0x00</td>
<td>reserved - Linked to io-homecontrol® compatibility mode</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BeaconOn</td>
<td>rw</td>
<td>0x00</td>
<td>Enables the Beacon mode in Fixed packet format</td>
<td></td>
</tr>
<tr>
<td>2-0</td>
<td>PayloadLength(10:8)</td>
<td>rw</td>
<td>0x00</td>
<td>Packet Length Most significant bits</td>
<td></td>
</tr>
<tr>
<td>RegPayloadLength (0x32)</td>
<td>7-0</td>
<td>PayloadLength(7:0)</td>
<td>rw</td>
<td>0x40</td>
<td>If PacketFormat = 0 (fixed), payload length. If PacketFormat = 1 (variable), max length in Rx, not used in Tx.</td>
</tr>
<tr>
<td>RegNodeAdrs (0x33)</td>
<td>7-0</td>
<td>NodeAddress</td>
<td>rw</td>
<td>0x00</td>
<td>Node address used in address filtering.</td>
</tr>
<tr>
<td>RegBroadcastAdrs (0x34)</td>
<td>7-0</td>
<td>BroadcastAddress</td>
<td>rw</td>
<td>0x00</td>
<td>Broadcast address used in address filtering.</td>
</tr>
</tbody>
</table>
### RegFifoThresh (0x35)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TxStartCondition</td>
<td>7</td>
<td>rw</td>
<td>0x01</td>
<td>Defines the condition to start packet transmission: 0 → FifoLevel (i.e. the number of bytes in the FIFO exceeds FifoThreshold) 1 → FifoEmpty goes low (i.e. at least one byte in the FIFO)</td>
<td></td>
</tr>
<tr>
<td>unused</td>
<td>6</td>
<td>r</td>
<td>-</td>
<td>unused</td>
<td></td>
</tr>
<tr>
<td>FifoThreshold</td>
<td>5-0</td>
<td>rw</td>
<td>0x0f</td>
<td>Used to trigger FifoLevel interrupt, when: number of bytes in FIFO ≥ FifoThreshold + 1</td>
<td></td>
</tr>
</tbody>
</table>

### Sequencer registers

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SequencerStart</td>
<td>7</td>
<td>wt</td>
<td>0x00</td>
<td>Controls the top level Sequencer  When set to '1', executes the &quot;Start&quot; transition. The sequencer can only be enabled when the chip is in Sleep or Standby mode.</td>
<td></td>
</tr>
<tr>
<td>SequencerStop</td>
<td>6</td>
<td>wt</td>
<td>0x00</td>
<td>Forces the Sequencer Off. Always reads '0'</td>
<td></td>
</tr>
<tr>
<td>IdleMode</td>
<td>5</td>
<td>rw</td>
<td>0x00</td>
<td>Selects chip mode during the state: 0: Standby mode 1: Sleep mode</td>
<td></td>
</tr>
<tr>
<td>FromStart</td>
<td>4-3</td>
<td>rw</td>
<td>0x00</td>
<td>Controls the Sequencer transition when SequencerStart is set to 1 in Sleep or Standby mode: 00: to LowPowerSelection 01: to Receive state 10: to Transmit state 11: to Transmit state on a FifoLevel interrupt</td>
<td></td>
</tr>
<tr>
<td>LowPowerSelection</td>
<td>2</td>
<td>rw</td>
<td>0x00</td>
<td>Selects the Sequencer LowPower state after a to LowPowerSelection transition: 0: SequencerOff state with chip on Initial mode 1: Idle state with chip on Standby or Sleep mode depending on IdleMode</td>
<td></td>
</tr>
<tr>
<td>FromIdle</td>
<td>1</td>
<td>rw</td>
<td>0x00</td>
<td>Controls the Sequencer transition from the Idle state on a T1 interrupt: 0: to Transmit state 1: to Receive state</td>
<td></td>
</tr>
<tr>
<td>FromTransmit</td>
<td>0</td>
<td>rw</td>
<td>0x00</td>
<td>Controls the Sequencer transition from the Transmit state: 0: to LowPowerSelection on a PacketSent interrupt 1: to Receive state on a PacketSent interrupt</td>
<td></td>
</tr>
</tbody>
</table>
### RegSeqConfig2 (0x37)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-5 FromReceive</td>
<td>rw 0x00</td>
<td>Controls the Sequencer transition from the Receive state 000 and 111: unused 001: to PacketReceived state on a PayloadReady interrupt 010: to LowPowerSelection on a PayloadReady interrupt 011: to PacketReceived state on a CrcOk interrupt (1) 100: to SequencerOff state on a Rssi interrupt 101: to SequencerOff state on a SyncAddress interrupt 110: to SequencerOff state on a PreambleDetect interrupt Irrespective of this setting, transition to LowPowerSelection on a T2 interrupt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-3 FromRxTimeout</td>
<td>rw 0x00</td>
<td>Controls the state-machine transition from the Receive state on a RxTimeout interrupt (and on PayloadReady if FromReceive = 011): 00: to Receive State, via ReceiveRestart 01: to Transmit state 10: to LowPowerSelection 11: to SequencerOff state</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-0 FromPacketReceived</td>
<td>rw 0x00</td>
<td>Controls the state-machine transition from the PacketReceived state: 00: to SequencerOff state 001: to Transmit state on a FifoEmpty interrupt 010: to LowPowerSelection 011: to Receive via FS mode, if frequency was changed 100: to Receive state (no frequency change)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### RegTimerResol (0x38)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-4 unused</td>
<td>r -</td>
<td>unused</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-2 Timer1Resolution</td>
<td>rw 0x00</td>
<td>Resolution of Timer 1 00: Timer1 disabled 01: 64 us 10: 4.1 ms 11: 262 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-0 Timer2Resolution</td>
<td>rw 0x00</td>
<td>Resolution of Timer 2 00: Timer2 disabled 01: 64 us 10: 4.1 ms 11: 262 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### RegTimer1Coef (0x39)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-0 Timer1Coefficient</td>
<td>rw 0xF5</td>
<td>Multiplying coefficient for Timer 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### RegTimer2Coef (0x3A)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default Value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-0 Timer2Coefficient</td>
<td>rw 0x20</td>
<td>Multiplying coefficient for Timer 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Service registers

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegImageCal (0x3B)</td>
<td>7-0</td>
<td>AutoImageCalOn</td>
<td>rw</td>
<td>0x00</td>
<td>Controls the Image calibration mechanism. <strong>0</strong>: Calibration of the receiver depending on the temperature is disabled. <strong>1</strong>: Calibration of the receiver depending on the temperature enabled.</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>AutoImageCalOn</td>
<td>rw</td>
<td>0x00</td>
<td>*</td>
</tr>
<tr>
<td>6</td>
<td>ImageCalStart</td>
<td>wt</td>
<td>-</td>
<td></td>
<td>Triggers the I/Q and RSSI calibration when set in Standby mode.</td>
</tr>
<tr>
<td>5</td>
<td>ImageCalRunning</td>
<td>r</td>
<td>0x00</td>
<td></td>
<td>Set to 1 while the Image and RSSI calibration are running. Toggles back to 0 when the process is completed.</td>
</tr>
<tr>
<td>4</td>
<td>unused</td>
<td>r</td>
<td>-</td>
<td></td>
<td>unused</td>
</tr>
<tr>
<td>3</td>
<td>TempChange</td>
<td>r</td>
<td>0x00</td>
<td></td>
<td>IRQ flag witnessing a temperature change exceeding TempThreshold since the last Image and RSSI calibration: <strong>0</strong>: Temperature change lower than TempThreshold. <strong>1</strong>: Temperature change greater than TempThreshold.</td>
</tr>
<tr>
<td>2-1</td>
<td>TempThreshold</td>
<td>rw</td>
<td>0x01</td>
<td></td>
<td>Temperature change threshold to trigger a new I/Q calibration: <strong>00</strong>: 5 °C. <strong>01</strong>: 10 °C. <strong>10</strong>: 15 °C. <strong>11</strong>: 20 °C.</td>
</tr>
<tr>
<td>0</td>
<td>TempMonitorOff</td>
<td>rw</td>
<td>0x00</td>
<td></td>
<td>Controls the temperature monitor operation: <strong>0</strong>: Temperature monitoring done in all modes except Sleep and Standby. <strong>1</strong>: Temperature monitoring stopped.</td>
</tr>
</tbody>
</table>

### Status registers

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegTemp (0x3C)</td>
<td>7-0</td>
<td>TempValue</td>
<td>r</td>
<td>-</td>
<td>Measured temperature: <strong>-1°C per Lsb</strong>. Needs calibration for absolute accuracy.</td>
</tr>
<tr>
<td></td>
<td>7-4</td>
<td>unused</td>
<td>r</td>
<td>-</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>LowBatOn</td>
<td>rw</td>
<td>0x00</td>
<td>Low Battery detector enable signal: <strong>0</strong>: LowBat detector disabled. <strong>1</strong>: LowBat detector enabled.</td>
</tr>
<tr>
<td>RegLowBat (0x3D)</td>
<td>2-0</td>
<td>LowBatTrim</td>
<td>rw</td>
<td>0x02</td>
<td>Trimming of the LowBat threshold: <strong>000</strong>: 1.695 V. <strong>001</strong>: 1.764 V. <strong>010</strong>: 1.835 V (d). <strong>011</strong>: 1.905 V. <strong>100</strong>: 1.976 V. <strong>101</strong>: 2.045 V. <strong>110</strong>: 2.116 V. <strong>111</strong>: 2.185 V.</td>
</tr>
</tbody>
</table>
### RegIrqFlags1 (0x3E)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>ModeReady</td>
<td>r</td>
<td>-</td>
<td>Set when the operation mode requested in Mode, is ready</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sleep: Entering Sleep mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Standby: XO is running</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- FS: PLL is locked</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Rx: RSSI sampling starts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Tx: PA ramp-up completed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when changing the operating mode.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>RxReady</td>
<td>r</td>
<td>-</td>
<td>Set in Rx mode, after RSSI, AGC and AFC.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when leaving Rx.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>TxReady</td>
<td>r</td>
<td>-</td>
<td>Set in Tx mode, after PA ramp-up.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when leaving Tx.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PLLock</td>
<td>r</td>
<td>-</td>
<td>Set (in FS, Rx or Tx) when the PLL is locked.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when it is not.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Rssi</td>
<td>rwc</td>
<td>-</td>
<td>Set in Rx when the RssiValue exceeds RssiThreshold.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when leaving Rx or setting this bit to 1.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Timeout</td>
<td>r</td>
<td>-</td>
<td>Set when a timeout occurs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when leaving Rx or FIFO is emptied.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>PreambleDetect</td>
<td>rwc</td>
<td>-</td>
<td>Set when the Preamble Detector has found valid Preamble.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit clear when set to 1</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>SyncAddressMatch</td>
<td>rwc</td>
<td>-</td>
<td>Set when Sync and Address (if enabled) are detected.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when leaving Rx or FIFO is emptied.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>This bit is read only in Packet mode, rwc in Continuous mode</td>
<td></td>
</tr>
</tbody>
</table>

### RegIrqFlags2 (0x3F)

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FifoFull</td>
<td>r</td>
<td>-</td>
<td>Set when FIFO is full (i.e. contains 66 bytes), else cleared.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>FifoEmpty</td>
<td>r</td>
<td>-</td>
<td>Set when FIFO is empty, and cleared when there is at least 1 byte in the FIFO.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>FifoLevel</td>
<td>r</td>
<td>-</td>
<td>Set when the number of bytes in the FIFO strictly exceeds FifoThreshold, else cleared.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>FifoOverrun</td>
<td>rwc</td>
<td>-</td>
<td>Set when FIFO overrun occurs. (except in Sleep mode) Flag(s) and FIFO are cleared when this bit is set. The FIFO then becomes immediately available for the next transmission / reception.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>PacketSent</td>
<td>r</td>
<td>-</td>
<td>Set in Tx when the complete packet has been sent.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cleared when exiting Tx</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>PayloadReady</td>
<td>r</td>
<td>-</td>
<td>Set in Rx when the payload is ready (i.e. last byte received and CRC, if enabled and CrcAutoClearOff is cleared, is Ok). Cleared when FIFO is empty.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>CrcOk</td>
<td>r</td>
<td>-</td>
<td>Set in Rx when the CRC of the payload is Ok. Cleared when FIFO is empty.</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>LowBat</td>
<td>rwc</td>
<td>-</td>
<td>Set when the battery voltage drops below the Low Battery threshold. Cleared only when set to 1 by the user.</td>
<td></td>
</tr>
</tbody>
</table>

**IO control registers**
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegDioMapping1 (0x40)</td>
<td>7-6</td>
<td>Dio0Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>Mapping of pins DIO0 to DIO5</td>
</tr>
<tr>
<td></td>
<td>5-4</td>
<td>Dio1Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>See Table 17 for mapping in LoRa mode</td>
</tr>
<tr>
<td></td>
<td>3-2</td>
<td>Dio2Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>See Table 28 for mapping in Continuous mode</td>
</tr>
<tr>
<td></td>
<td>1-0</td>
<td>Dio3Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>See Table 29 for mapping in Packet mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RegDioMapping2 (0x41)</td>
<td>7-6</td>
<td>Dio4Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>Mapping of pins DIO4 to DIO5</td>
</tr>
<tr>
<td></td>
<td>5-4</td>
<td>Dio5Mapping</td>
<td>rw</td>
<td>0x00</td>
<td>See Table 17 for mapping in LoRa mode</td>
</tr>
<tr>
<td></td>
<td>3-1</td>
<td>reserved</td>
<td>rw</td>
<td>0x00</td>
<td>reserved. Retain default value</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>MapPreambleDetect</td>
<td>rw</td>
<td>0x00</td>
<td>Allows the mapping of either Rssi Or PreambleDetect to the DIO pins, as summarized on Table 28 and Table 29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 → Rssi interrupt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 → PreambleDetect interrupt</td>
</tr>
</tbody>
</table>

Version register

| RegVersion (0x42) | 7-0 | Version | r | 0x22 | Version code of the chip. Bits 7-4 give the full revision number; bits 3-0 give the metal mask revision number. |

Additional registers

<p>| RegAgcRef (0x43) | 7-6 | unused | r | - | unused |
| | 5-0 | AgcReferenceLevel | rw | 0x13 | Sets the floor reference for all AGC thresholds: AGC Reference [dBm] = -174 dBm + 10<em>log(2</em>RxBw) + SNR + AgcReferenceLevel SNR = 8 dB, fixed value |
| RegAgcThresh1 (0x44) | 7-5 | unused | r | - | unused |
| | 4-0 | AgcStep1 | rw | 0x0E | Defines the 1st AGC Threshold |
| RegAgcThresh2 (0x45) | 7-4 | AgcStep2 | rw | 0x05 | Defines the 2nd AGC Threshold: |
| | 3-0 | AgcStep3 | rw | 0x0B | Defines the 3rd AGC Threshold: |
| RegAgcThresh3 (0x46) | 7-4 | AgcStep4 | rw | 0x0D | Defines the 4th AGC Threshold: |
| | 3-0 | AgcStep5 | rw | 0x0B | Defines the 5th AGC Threshold: |
| RegPllHop (0x4B) | 7 | FastHopOn | rw | 0x00 | Bypasses the main state machine for a quick frequency hop. Writing RegFrflsb will trigger the frequency change. 0 → Frf is validated when FSTx or FSRx is requested |
| | | | | | 1 → Frf is validated triggered when RegFrflsb is written |
| | 6-4 | reserved | r | 0x02 | reserved |
| | 3-0 | PaManualDutyCycle | rw | 0x0E | See app note 1200.32 |
| RegTcxo (0x58) | 7-5 | reserved | rw | 0x00 | reserved. Retain default value |
| | 4 | TcxoInputOn | rw | 0x00 | Controls the crystal oscillator |
| | | | | | 0 → Crystal Oscillator with external Crystal |
| | | | | | 1 → External clipped sine TCXO AC-connected to XTA pin |
| | | 3-0 | reserved | rw | 0x09 | Reserved. Retain default value. |</p>
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Default value</th>
<th>FSK/OOK Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegPaDac (0x5A)</td>
<td>7-3</td>
<td>reserved</td>
<td>rw</td>
<td>0x10</td>
<td>reserved. Retain default value</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>PaDac</td>
<td>rw</td>
<td>0x04</td>
<td>Enables the +20 dBm option on PA_BOOST pin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x04 -&gt; Default value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x07 -&gt; +20 dBm on PA_BOOST when OutputPower = 1111</td>
</tr>
<tr>
<td>RegPll (0x5C)</td>
<td>7-6</td>
<td>PllBandwidth</td>
<td>rw</td>
<td>0x03</td>
<td>Controls the PLL bandwidth:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00 -&gt; 75 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>01 -&gt; 150 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 -&gt; 225 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11 -&gt; 300 kHz</td>
</tr>
<tr>
<td></td>
<td>5-0</td>
<td>reserved</td>
<td>rw</td>
<td>0x10</td>
<td>Reserved. Retain default value</td>
</tr>
<tr>
<td>RegPllLowPn (0x5E)</td>
<td>7-6</td>
<td>PllBandwidth</td>
<td>rw</td>
<td>0x03</td>
<td>Controls the Low Phase Noise PLL bandwidth:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00 -&gt; 75 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>01 -&gt; 150 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 -&gt; 225 kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11 -&gt; 300 kHz</td>
</tr>
<tr>
<td></td>
<td>5-0</td>
<td>reserved</td>
<td>rw</td>
<td>0x10</td>
<td>Reserved. Retain default value</td>
</tr>
<tr>
<td>RegPaManual (0x63)</td>
<td>7-5</td>
<td>reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved. Retain default value</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>ManualPaControl</td>
<td>rw</td>
<td>0x01</td>
<td>0x01 enables manual PA control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>See AN1200.32</td>
</tr>
<tr>
<td></td>
<td>3-0</td>
<td>reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved. Retain default value</td>
</tr>
<tr>
<td>RegFormerTemp (0x6C)</td>
<td>7-0</td>
<td>FormerTemp</td>
<td>rw</td>
<td>-</td>
<td>Temperature saved during the latest IQ (RSSI and Image)-calibrated. Same format as</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TempValue in RegTemp.</td>
</tr>
<tr>
<td>RegBitrateFrac (0x70)</td>
<td>7-4</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
<td>unused</td>
</tr>
<tr>
<td></td>
<td>3-0</td>
<td>BitRateFrac</td>
<td>rw</td>
<td>0x00</td>
<td>Fractional part of the bit rate divider (Only valid for FSK)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>If BitRateFrac &gt; 0 then:</td>
</tr>
</tbody>
</table>
|                       |      |                   |      |               | \[
|                       |      |                   |      |               | \[
|                       |      |                   |      |               | BitRate = \[
|                       |      |                   |      |               | FXOSC                                |
|                       |      |                   |      |               | BitRate(15,0) + BitRateFrac \[
|                       |      |                   |      |               | 16 \]                                |

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6.3. LoRa™ Mode Register Map

This section details the SX1272/73 register mapping and the precise contents of each register in LoRa™ mode.

It is essential to understand that the LoRa modem is controlled independently of the FSK modem. Therefore, care should be taken when accessing the registers, especially as some register may have the same name in LoRa or FSK mode.

The LoRa registers are only accessible when the device is set in Lora mode (and, in the same way, the FSK register are only accessible in FSK mode). However, in some cases, it may be necessary to access some of the FSK register while in LoRa mode. To this aim, the `AccesSharedReg` bit was created in the `RegOpMode` register. This bit, when set to ‘1’, will grant access to the FSK register 0x0D up to the register 0x3F. Once the setup has been done, it is strongly recommended to clear this bit so that LoRa register can be accessed normally.

Convention: r: read, w: write, c: set to clear and t: trigger

Table 41 Register Map, LoRa Mode

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Reset</th>
<th>LoRa™ Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegFifo (0x00)</td>
<td>7-0</td>
<td>Fifo</td>
<td>rw</td>
<td>0x00</td>
<td>LoRa™ base-band FIFO data input/output. FIFO is cleared and not accessible when device is in SLEEP mode</td>
</tr>
</tbody>
</table>

Common Register Settings

<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Reset</th>
<th>LoRa™ Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegOpMode (0x01)</td>
<td>7</td>
<td>LongRangeMode</td>
<td>rw</td>
<td>0x0</td>
<td>0 → FSK/OOK Mode 1 → LoRa™ Mode This bit can be modified only in Sleep mode. A write operation on other device modes is ignored.</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>AccessSharedReg</td>
<td>rw</td>
<td>0x0</td>
<td>This bit operates when device is in Lora mode; if set it allows access to FSK registers page located in address space (0x0D:0x3F) while in LoRa mode 0 → Access LoRa registers page 0x0D: 0x3F 1 → Access FSK registers page (in mode LoRa) 0x0D: 0x3F</td>
</tr>
<tr>
<td></td>
<td>5-3</td>
<td>unused</td>
<td>r</td>
<td>0x00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>Mode</td>
<td>rwt</td>
<td>0x01</td>
<td>Device modes 000 → SLEEP 001 → STDBY 010 → Frequency synthesis TX (FSTX) 011 → Transmit (TX) 100 → Frequency synthesis RX (FSRX) 101 → Receive continuous (RXCONTINUOUS) 110 → receive single (RXSINGLE) 111 → Channel activity detection (CAD)</td>
</tr>
<tr>
<td>(0x02)</td>
<td>7-0</td>
<td>reserved</td>
<td>r</td>
<td>0x00</td>
<td>-</td>
</tr>
<tr>
<td>(0x03)</td>
<td>7-0</td>
<td>reserved</td>
<td>r</td>
<td>0x00</td>
<td>-</td>
</tr>
<tr>
<td>(0x04)</td>
<td>7-0</td>
<td>reserved</td>
<td>r</td>
<td>0x00</td>
<td>-</td>
</tr>
<tr>
<td>(0x05)</td>
<td>7-0</td>
<td>reserved</td>
<td>r</td>
<td>0x00</td>
<td>-</td>
</tr>
<tr>
<td>RegFrMsb (0x06)</td>
<td>7-0</td>
<td>Frf(23:16)</td>
<td>rw</td>
<td>0xE4</td>
<td>MSB of RF carrier frequency</td>
</tr>
<tr>
<td>RegFrMib (0x07)</td>
<td>7-0</td>
<td>Frf(15:8)</td>
<td>rw</td>
<td>0xC0</td>
<td>MIB of RF carrier frequency</td>
</tr>
<tr>
<td>Name (Address)</td>
<td>Bits</td>
<td>Variable Name</td>
<td>Mode</td>
<td>Reset</td>
<td>LoRa™ Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
<td>---------------</td>
<td>------</td>
<td>-------</td>
<td>-------------------</td>
</tr>
</tbody>
</table>
| RegFrLsb (0x08) | 7-0 | Frf(7:0) | rwt | 0x00 | LSB of RF carrier frequency 
\[ f_{RF} = \frac{F(XOSC) \cdot Frf}{2^{19}} \]
Resolution is 61.035 Hz if F(XOSC) = 32 MHz. Default value is 0xe4c000 = 915 MHz. Register values must be modified only when device is in SLEEP or STANDBY mode. |
| RegPaConfig (0x09) | 7 | PaSelect | rw | 0x00 | Selects PA output pin 
0 → RFIO pin. Output power is limited to 13 dBm. 
1 → PA_BOOST pin. Output power is limited to 20 dBm |
| | 6-4 | unused | r | - | unused |
| | 3-0 | OutputPower | rw | 0x0F | power amplifier max output power: 
Pout = 2 + OutputPower(3:0) on PA_BOOST. 
Pout = -1 + OutputPower(3:0) on RFIO. |
| RegPaRamp (0x0A) | 3-0 | PaRamp(3:0) | rw | 0x09 | Rise/Fall time of ramp up/down in FSK 
0000 → 3.4 ms 
0001 → 2 ms 
0010 → 1 ms 
0011 → 500 us 
0100 → 250 us 
0101 → 125 us 
0110 → 100 us 
0111 → 62 us 
1000 → 50 us 
1001 → 40 us 
1010 → 31 us 
1011 → 25 us 
1100 → 20 us 
1101 → 15 us 
1110 → 12 us 
1111 → 10 us |
| | 7-6 | unused | r | 0x00 | unused |
| RegOcp (0x0B) | 5 | OcpOn | rw | 0x01 | Enables overload current protection (OCP) for PA: 
0 → OCP disabled 
1 → OCP enabled |
| | 4-0 | OcpTrim | rw | 0x0B | Trimming of OCP current: 
Imax = 45+5*OcpTrim [mA] if OcpTrim <= 15 (120 mA) 
Imax = 30+10*OcpTrim [mA] if 15 < OcpTrim <= 27 (130 to 240 mA) 
Imax = 240mA for higher settings 
Default Imax = 100mA |
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Reset</th>
<th>LoRa™ Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegLna (0x0C)</td>
<td>7-5</td>
<td>LnaGain</td>
<td>rwx</td>
<td>0x01</td>
<td>LNA gain setting: 000 → not used, 001 → G1 = maximum gain, 010 → G2, 011 → G3, 100 → G4, 101 → G5, 110 → G6 = minimum gain, 111 → not used</td>
</tr>
<tr>
<td>4-2 reserved</td>
<td></td>
<td></td>
<td>r</td>
<td>0x00</td>
<td>-</td>
</tr>
<tr>
<td>1-0 LnaBoost</td>
<td></td>
<td></td>
<td>rw</td>
<td>0x00</td>
<td>00 → Default LNA current, 11 → Boost on, 150% LNA current.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lora page registers</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegFifoAddrPtr (0x0D)</td>
</tr>
<tr>
<td>RegFifoTxBaseAddr (0x0E)</td>
</tr>
<tr>
<td>RegFifoRxBaseAddr (0x0F)</td>
</tr>
<tr>
<td>RegFifoRxCurrentAddr (0x10)</td>
</tr>
<tr>
<td>RegIrqFlagsMask (0x11)</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>Name (Address)</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>RegInsnbBytes (0x13)</td>
</tr>
<tr>
<td>RegRxHeaderCnt ValueMsb (0x14)</td>
</tr>
<tr>
<td>RegRxHeaderCnt ValueLsb (0x15)</td>
</tr>
<tr>
<td>RegRxPacketCntValueMsb (0x16)</td>
</tr>
<tr>
<td>RegRxPacketCntValueLsb (0x17)</td>
</tr>
<tr>
<td>RegModemStat (0x18)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
| RegPktSnrValue (0x19) | 7-0 | PacketSnr | r | n/a | Estimation of SNR on last packet received. In two’s complement format multiplied by 4.  
\[
SNR\text{[dB]} = \frac{\text{PacketSnr\ twos\ complement}}{4}
\]
<table>
<thead>
<tr>
<th>Name (Address)</th>
<th>Bits</th>
<th>Variable Name</th>
<th>Mode</th>
<th>Reset</th>
<th>LoRa™ Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RegPktRssiValue (0x1A)</td>
<td>7-0</td>
<td>PacketRssi</td>
<td>r</td>
<td>n/a</td>
<td>RSSI of the latest packet received (dBm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[RSSI[\text{dBm}] = - 139 + \text{PacketRssi} \text{ when } \text{SNR} \geq 0]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{or} [RSSI[\text{dBm}] = - 139 + \text{PacketRssi} + \text{PacketSnr} \times 0.25 \text{ when } \text{SNR} &lt; 0]</td>
</tr>
<tr>
<td>RegRssiValue (0x1B)</td>
<td>7-0</td>
<td>Rssi</td>
<td>r</td>
<td>n/a</td>
<td>Current RSSI value (dBm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[RSSI[\text{dBm}] = - 139 + \text{Rssi}]</td>
</tr>
<tr>
<td>RegHopChannel (0x1C)</td>
<td>7</td>
<td>PllTimeout</td>
<td>r</td>
<td>n/a</td>
<td>PLL failed to lock while attempting a TX/RX/CAD operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{1 } \rightarrow \text{ PLL did not lock}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{0 } \rightarrow \text{ PLL did lock}</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>CrcOnPayload</td>
<td>r</td>
<td>n/a</td>
<td>CRC Information extracted from the received packet header (Explicit header mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{0 } \rightarrow \text{ Header indicates CRC off}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{1 } \rightarrow \text{ Header indicates CRC on}</td>
</tr>
<tr>
<td></td>
<td>5-0</td>
<td>FhssPresentChannel</td>
<td>r</td>
<td>n/a</td>
<td>Current value of frequency hopping channel in use.</td>
</tr>
<tr>
<td>RegModemConfig 1 (0x1D)</td>
<td>7-6</td>
<td>Bw</td>
<td>rw</td>
<td>0x0</td>
<td>Signal bandwidth:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{00 } \rightarrow \text{ 125 kHz}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{01 } \rightarrow \text{ 250 kHz}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{10 } \rightarrow \text{ 500 kHz}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{11 } \rightarrow \text{ reserved}</td>
</tr>
<tr>
<td></td>
<td>5-3</td>
<td>CodingRate</td>
<td>rw</td>
<td>'001'</td>
<td>Error coding rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{001 } \rightarrow \text{ 4/5}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{010 } \rightarrow \text{ 4/6}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{011 } \rightarrow \text{ 4/7}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{100 } \rightarrow \text{ 4/8}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{All other values } \rightarrow \text{ reserved}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{In implicit header mode should be set on receiver to determine expected coding rate. See Section 4.1.1.3.}</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>ImplicitHeaderModeOn</td>
<td>rw</td>
<td>0x0</td>
<td>\text{0 } \rightarrow \text{ Explicit Header mode}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{1 } \rightarrow \text{ Implicit Header mode}</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>RxPayloadCrcOn</td>
<td>rw</td>
<td>0x0</td>
<td>Enable CRC generation and check on payload:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{0 } \rightarrow \text{ CRC disable}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{1 } \rightarrow \text{ CRC enable}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{If CRC is needed, RxPayloadCrcOn should be set:}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{- in Implicit header mode: on Tx and Rx side}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{- in Explicit header mode: on the Tx side alone (recovered from the header in Rx side)}</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>LowDataRateOptimize</td>
<td>rw</td>
<td>0x0</td>
<td>\text{0 } \rightarrow \text{ Disabled}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\text{1 } \rightarrow \text{ Enabled; mandated for SF11 and SF12 with BW = 125 kHz}</td>
</tr>
<tr>
<td>Name (Address)</td>
<td>Bits</td>
<td>Variable Name</td>
<td>Mode</td>
<td>Reset</td>
<td>LoRa™ Description</td>
</tr>
<tr>
<td>----------------</td>
<td>------</td>
<td>---------------</td>
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<td>-------</td>
<td>-------------------</td>
</tr>
<tr>
<td>RegModemConfig 2 (0x1E)</td>
<td>7-4</td>
<td>SpreadingFactor</td>
<td>rw</td>
<td>0x7</td>
<td>SF rate (expressed as a base-2 logarithm) 6 → 64 chips / symbol 7 → 128 chips / symbol 8 → 256 chips / symbol 9 → 512 chips / symbol 10 → 1024 chips / symbol 11 → 2048 chips / symbol 12 → 4096 chips / symbol other values reserved.</td>
</tr>
<tr>
<td>3</td>
<td>TxContinuousMode</td>
<td>rw</td>
<td>0</td>
<td>0 → normal mode, a single packet is sent 1 → continuous mode, send multiple packets across the FIFO (used for spectral analysis)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>AgcAutoOn</td>
<td>rw</td>
<td>0x01</td>
<td>0 → LNA gain set by register LnaGain 1 → LNA gain set by the internal AGC loop</td>
<td></td>
</tr>
<tr>
<td>1-0</td>
<td>SymbTimeout(9:8)</td>
<td>rw</td>
<td>0x00</td>
<td>RX Time-Out MSB</td>
<td></td>
</tr>
<tr>
<td>RegSymbTimeoutLsb (0x1F)</td>
<td>7-0</td>
<td>SymbTimeout(7:0)</td>
<td>rw</td>
<td>0x64</td>
<td>RX Time-Out LSB RX operation time-out value expressed as number of symbols: $\text{Timeout} = \text{SymbTimeout} \times Ts$</td>
</tr>
<tr>
<td>RegPreambleMsb (0x20)</td>
<td>7-0</td>
<td>PreambleLength(15:8)</td>
<td>rw</td>
<td>0x0</td>
<td>Preamble length MSB, $= \text{PreambleLength} \times 4.25$ Symbols See Section 4.1.1.6 for more details.</td>
</tr>
<tr>
<td>RegPreambleLsb (0x21)</td>
<td>7-0</td>
<td>PreambleLength(7:0)</td>
<td>rw</td>
<td>0x8</td>
<td>Preamble Length LSB</td>
</tr>
<tr>
<td>RegPayloadLength (0x22)</td>
<td>7-0</td>
<td>PayloadLength(7:0)</td>
<td>rw</td>
<td>0x1</td>
<td>Payload length in bytes. The register needs to be set in implicit header mode for the expected packet length. A 0 value is not permitted</td>
</tr>
<tr>
<td>RegMaxPayloadLength (0x23)</td>
<td>7-0</td>
<td>PayloadMaxLength(7:0)</td>
<td>rw</td>
<td>0xFF</td>
<td>Maximum payload length; if header payload length exceeds value a header CRC error is generated. Allows filtering of packet with a bad size.</td>
</tr>
<tr>
<td>RegHopPeriod (0x24)</td>
<td>7-0</td>
<td>FreqHoppingPeriod(7:0)</td>
<td>rw</td>
<td>0x0</td>
<td>Symbol periods between frequency hops. (0 = disabled). 1st hop always happen after the 1st header symbol</td>
</tr>
<tr>
<td>RegFifoRxByteAddr (0x25)</td>
<td>7-0</td>
<td>FifoRxByteAddrPtr</td>
<td>r</td>
<td>n/a</td>
<td>Current value of RX databuffer pointer (address of last byte written by Lora receiver)</td>
</tr>
<tr>
<td>(0x26) - (0x27)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegFeiMsb (0x28)</td>
<td>7-4</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Estimated frequency error from modem in 2’s compliment format. MSB of RF Frequency error $F_{Error} = \frac{F_{Error} \times 2^{24}}{F_{stal}}$</td>
</tr>
<tr>
<td>(RegFeiMid (0x29)</td>
<td>7-0</td>
<td>FreqError(15:8)</td>
<td>r</td>
<td>0x0</td>
<td>Middle byte of RF Frequency Error</td>
</tr>
<tr>
<td>Name (Address)</td>
<td>Bits</td>
<td>Variable Name</td>
<td>Mode</td>
<td>Reset</td>
<td>LoRa™ Description</td>
</tr>
<tr>
<td>--------------------------</td>
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<td>--------------------------</td>
<td>------</td>
<td>-------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>RegFeiLsb (0x2A)</td>
<td>7-0</td>
<td>FreqError(7:0)</td>
<td>r</td>
<td>0x0</td>
<td>LSB of RF Frequency Error</td>
</tr>
<tr>
<td>(0x2B)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegRssiWideband (0x2C)</td>
<td>7-0</td>
<td>RssiWideband(7:0)</td>
<td>r</td>
<td>n/a</td>
<td>Wideband RSSI measurement used to locally generate a random number</td>
</tr>
<tr>
<td>(0x2D) - (0x30)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegDetectOptimize (0x31)</td>
<td>7</td>
<td>AutomaticIFOn</td>
<td>rw</td>
<td>0x01</td>
<td>Should be set to 0x0 after each reset (POR on manual)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>See errata note for more information</td>
</tr>
<tr>
<td></td>
<td>6-3</td>
<td>Reserved</td>
<td>r</td>
<td>0x40</td>
<td>Reserved</td>
</tr>
<tr>
<td></td>
<td>2-0</td>
<td>DetectionOptimize</td>
<td>rw</td>
<td>0x03</td>
<td>LoRa detection Optimize</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x03 → SF7 to SF12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x05 → SF6</td>
</tr>
<tr>
<td>(0x32)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegInvertIQ (0x33)</td>
<td>7</td>
<td>Reserved</td>
<td>rw</td>
<td>0x0</td>
<td>Reserved</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>InvertIQRX</td>
<td>rw</td>
<td>0x0</td>
<td>Invert the LoRa I and Q signals in RX path</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 → normal mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 → I and Q signals are inverted</td>
</tr>
<tr>
<td></td>
<td>5-1</td>
<td>Reserved</td>
<td>rw</td>
<td>0x13</td>
<td>Reserved</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>InvertIQTX</td>
<td>rw</td>
<td>0x0</td>
<td>Invert the LoRa I and Q signals in TX path</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 → normal mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 → I and Q signals are inverted</td>
</tr>
<tr>
<td>(0x34) - (0x36)</td>
<td>7-0</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegDetectionThreshold (0x37)</td>
<td>7-0</td>
<td>DetectionThreshold</td>
<td>rw</td>
<td>0x0A</td>
<td>LoRa detection threshold</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x0A → SF7 to SF12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0x0C → SF6</td>
</tr>
<tr>
<td>(0x38)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegSyncWord (0x39)</td>
<td>7-0</td>
<td>SyncWord</td>
<td>rw</td>
<td>0x12</td>
<td>LoRa Sync Word</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Value 0x34 is reserved for LoRaWAN networks</td>
</tr>
<tr>
<td>(0x3A)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegInvertIQ2 (0x3B)</td>
<td>7-0</td>
<td>InvertIQ2</td>
<td>rw</td>
<td>0x1D</td>
<td>Set to 0x19 when RX inverted IQ is set. See AN1200.24</td>
</tr>
<tr>
<td>(0x3C)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
<tr>
<td>RegChirpFilter (0x3D)</td>
<td>7-0</td>
<td>Reserved</td>
<td>rw</td>
<td>0xA0</td>
<td>Set to 0x31 for ETSI-G1 compliance with 14 dBm RF output power when using bandwidth 500 kHz</td>
</tr>
<tr>
<td>(0x3E) - (0x3F)</td>
<td>-</td>
<td>Reserved</td>
<td>r</td>
<td>n/a</td>
<td>Reserved</td>
</tr>
</tbody>
</table>
7. Application Information

7.1. Crystal Resonator Specification

Table 42 shows the crystal resonator specification for the crystal reference oscillator circuit of the SX1272/73. This specification covers the full range of operation of the SX1272/73 and is employed in the reference design.

Table 42 Crystal Specification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FXOSC</td>
<td>XTAL Frequency</td>
<td>-</td>
<td>32</td>
<td>-</td>
<td>-</td>
<td>MHz</td>
</tr>
<tr>
<td>RS</td>
<td>XTAL Serial Resistance</td>
<td>-</td>
<td>15</td>
<td>40</td>
<td>-</td>
<td>Ohms</td>
</tr>
<tr>
<td>C0</td>
<td>XTAL Shunt Capacitance</td>
<td>-</td>
<td>1.5</td>
<td>3</td>
<td>-</td>
<td>pF</td>
</tr>
<tr>
<td>CFOOT</td>
<td>External Foot Capacitance</td>
<td>On each pin XTA and XTB</td>
<td>8</td>
<td>15</td>
<td>22</td>
<td>pF</td>
</tr>
<tr>
<td>CLOAD</td>
<td>Crystal Load Capacitance</td>
<td></td>
<td>6</td>
<td>-</td>
<td>12</td>
<td>pF</td>
</tr>
</tbody>
</table>

Notes
- the initial frequency tolerance, temperature stability and aging performance should be chosen in accordance with the target operating temperature range and the receiver bandwidth selected.
- the loading capacitance should be applied externally, and adapted to the actual Cload specification of the XTAL.

7.2. Reset of the Chip

A power-on reset of the SX1272/73 is triggered at power up. Additionally, a manual reset can be issued by controlling pin 6.

7.2.1. POR

If the application requires the disconnection of VDD from the SX1272/73, despite of the extremely low Sleep Mode current, the user should wait for 10 ms from of the end of the POR cycle before commencing communications over the SPI bus. Pin 6 (Reset) should be left floating during the POR sequence.

![POR Timing Diagram](image)

Figure 46. POR Timing Diagram

Please note that any CLKOUT activity can also be used to detect that the chip is ready.
7.2.2. Manual Reset
A manual reset of the SX1272/73 is possible even for applications in which VDD cannot be physically disconnected. Pin 6 should be pulled high for a hundred microseconds and then released. The user should then wait for 5 ms before using the chip.

```
VDD

> 100 us

Wait for 5 ms

Chip is ready from this point on

Pin 6 (input)

High-Z

1

High-Z
```

![Image](Figure 47. Manual Reset Timing Diagram)

Note Whilst pin 6 is driven high an over current consumption of up to ten milliamperes can be seen on VDD.

7.3. Top Sequencer: Listen Mode Examples
In this scenario the circuit spends most of the time in Idle mode during which only the RC oscillator is on. Periodically the receiver wakes up and looks for incoming signal. If a wanted signal is detected the receiver is kept on and data are analyzed. Otherwise, if there was no wanted signal for a defined period of time, the receiver is switched off until the next receive period.

During Listen mode the Radio stays most of the time in a Low Power mode resulting in very low average power consumption. The general timing diagram of this scenario is given in Figure 48.

```
Listen mode: principle

Receive

Idle (Sleep + RC)

Receive

Idle
```

![Image](Figure 48. Listen Mode: Principle)

An interrupt request is generated on a packet reception. The user can then take appropriate action.

Depending on the application and environment, there are several ways to implement Listen mode:

- Wake on a PreambleDetect interrupt.
- Wake on a SyncAddress interrupt.
- Wake on a PayloadReady interrupt.

7.3.1. Wake on Preamble Interrupt
In one possible scenario, the sequencer polls for a Preamble detection. If a preamble signal is detected, the sequencer is switched off and the circuit stays in Receive mode until the user switches modes. Otherwise, the receiver is switched off until the next Rx period.
7.3.1.1.  **Timing Diagram**

When no signal is received, the circuit wakes every Timer1 + Timer2 and switches to Receive mode for a time defined by Timer2, as shown on the following diagram. If no Preamble is detected, it then switches back to Idle mode, i.e. Sleep mode with RC oscillator on.

![Figure 49. Listen Mode with No Preamble Received](image)

If a Preamble signal is detected the Sequencer is switched off. The `PreambleDetect` signal can be mapped to DIO4 in order to request the user's attention.

![Figure 50. Listen Mode with Preamble Received](image)
7.3.1.2. Sequencer Configuration

The following graph shows Listen mode - Wake on PreambleDetect state machine:

This example configuration is achieved as follows:

**Table 43 Listen Mode with PreambleDetect Condition Settings**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>IdleMode</td>
<td>1: Sleep mode</td>
</tr>
<tr>
<td>FromStart</td>
<td>00: To LowPowerSelection</td>
</tr>
<tr>
<td>LowPowerSelection</td>
<td>1: To Idle state</td>
</tr>
<tr>
<td>FromIdle</td>
<td>1: To Receive state on T1 interrupt</td>
</tr>
<tr>
<td>FromReceive</td>
<td>110: To Sequencer Off on PreambleDetect interrupt</td>
</tr>
</tbody>
</table>

$T_{\text{Timer}2}$ defines the maximum duration the chip stays in Receive mode as long as no Preamble is detected. In order to optimize power consumption $T_{\text{Timer}2}$ must be set just long enough for Preamble detection.

$T_{\text{Timer}1} + T_{\text{Timer}2}$ defines the cycling period, i.e. time between two Preamble polling starts. In order to optimize average power consumption, $T_{\text{Timer}1}$ should be relatively long. However, increasing $T_{\text{Timer}1}$ also extends packet reception duration.

In order to insure packet detection and optimize the receiver's power consumption the received packet Preamble should be as long as $T_{\text{Timer}1} + 2 \times T_{\text{Timer}2}$.

An example of DIO configuration for this mode is described in the following table:

**Table 44 Listen Mode with PreambleDetect Condition Recommended DIO Mapping**

<table>
<thead>
<tr>
<th>DIO</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>01</td>
<td>CrcOk</td>
</tr>
<tr>
<td>1</td>
<td>00</td>
<td>FifoLevel</td>
</tr>
<tr>
<td>3</td>
<td>00</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>PreambleDetect – Note: MapPreambleDetect bit should be set.</td>
</tr>
</tbody>
</table>
7.3.2. Wake on SyncAddress Interrupt

In another possible scenario, the sequencer polls for a Preamble detection and then for a valid SyncAddress interrupt. If events occur, the sequencer is switched off and the circuit stays in Receive mode until the user switches modes. Otherwise, the receiver is switched off until the next Rx period.

7.3.2.1. Timing Diagram

Most of the sequencer running time is spent duty cycling the receiver and idle modes with no wanted signal present. As shown by the timing diagram in Figure 52, the circuit wakes periodically for a short time, defined by RxTimeout. The circuit is in a Low Power mode for the rest of Timer1 + Timer2 (i.e. Timer1 + Timer2 - TrxTimeout)

![Figure 52. Listen Mode with no SyncAddress Detected](image)

If a preamble is detected before RxTimeout timer ends the circuit stays in Receive mode and waits for a valid SyncAddress detection. If none is detected by the end of Timer2, Receive mode is deactivated and the polling cycle resumes, without any user intervention.

![Figure 53. Listen Mode with Preamble Received and no SyncAddress](image)

But if a valid Sync Word is detected a SyncAddress interrupt is fired, the Sequencer is switched off and the circuit stays in Receive mode as long as the user doesn't switch modes.
7.3.2.2. Sequencer Configuration

The following graph shows Listen mode - Wake on SyncAddress state machine:

This example configuration is achieved as follows:

Table 45 Listen Mode with SyncAddress Condition Settings

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>IdleMode</td>
<td>1: Sleep mode</td>
</tr>
<tr>
<td>FromStart</td>
<td>00: To LowPowerSelection</td>
</tr>
</tbody>
</table>
TimeoutRxPreamble should be set to the expected transmit preamble duration (depends on PreambleDetectSize and BitRate).

Timer1 should be set to 64 µs (shortest possible duration).

Timer2 is set so that Timer1 + Timer2 defines the time between two start of reception.

In order to ensure packet detection and optimize the receiver power consumption the received packet Preamble should be defined so that Preamble = Timer2 - SyncAddress with SyncAddress = (SyncSize + 1)*8/Bitrade.

An example of DIO configuration for this mode is described in the following table:

**Table 46  Listen Mode with PreambleDetect Condition Recommended DIO Mapping**

<table>
<thead>
<tr>
<th>DIO</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>01</td>
<td>CrcOk</td>
</tr>
<tr>
<td>1</td>
<td>00</td>
<td>FifoLevel</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>SyncAddress</td>
</tr>
<tr>
<td>3</td>
<td>00</td>
<td>FifoEmpty</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>PreambleDetect – Note: MapPreambleDetect bit should be set.</td>
</tr>
</tbody>
</table>
7.4. Top Sequencer: Beacon Mode

In this mode, a single message is periodically re-transmitted. If the Payload being sent is always identical and **PayloadLength** is smaller than the FIFO size, the use of the **BeaconOn** bit in **RegPacketConfig2** together with the Sequencer permit to achieve periodic beacon without any user intervention.

7.4.1. Timing diagram

In this mode, the Radio is switched to Transmit mode every **T_{Timer1} + T_{Timer2}** and back to Idle mode after **PacketSent**, as shown in the diagram below. The Sequencer insures minimal time is spent in Transmit mode and therefore power consumption is optimized.

![Beacon Mode Timing Diagram](image)

*Figure 56. Beacon Mode Timing Diagram*

7.4.2. Sequencer Configuration

The Beacon mode state machine is presented in the following graph. It should be noted that the sequencer enters an infinite loop and can only be stopped by setting **SequencerStop** bit in **RegSeqConfig1**.

![Beacon Mode State Machine](image)

*Figure 57. Beacon Mode State Machine*
This example is achieved by programming the Sequencer as follows:

**Table 47  Beacon Mode Settings**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>IdleMode</td>
<td>1: Sleep mode</td>
</tr>
<tr>
<td>FromStart</td>
<td>00: To LowPowerSelection</td>
</tr>
<tr>
<td>LowPowerSelection</td>
<td>1: To Idle state</td>
</tr>
<tr>
<td>FromIdle</td>
<td>0: To Transmit state on T1 interrupt</td>
</tr>
<tr>
<td>FromTransmit</td>
<td>0: To LowPowerSelection on PacketSent interrupt</td>
</tr>
</tbody>
</table>

\(T_{Timer1} + T_{Timer2}\) define the time between the start of two transmissions.
7.5. Example CRC Calculation

The following routine may be implemented to mimic the CRC calculation of the SX1272/73:

```c
// CRC type
#define CRC_TYP_CITT 0
#define CRC_TYP_IBM 1

// Polynomial = X^16 + X^12 + X^5 + 1
#define POLYNOMIAL_CITT 0x1821
// Polynomial = X^16 + X^15 + X^2 + 1
#define POLYNOMIAL_IBM 0x8385

// Seeds
#define CRC_IBM_SEED 0x00FF
#define CRC_CITT_SEED 0x010F

/**
 * CRC algorithm implementation
 * \param[in] crc Previous CRC value
 * \param[in] data New data to be added to the CRC
 * \param[in] polynomial CRC polynomial selection [CRC_TYP_CITT, CRC_TYP_IBM]
 *
 * \return crc New computed CRC
 */
uint16_t ComputeCrc(uint16_t crc, uint8_t data, uint16_t polynomial) {
    uint8_t i;
    for (i = 0; i < 8; i++) {
        if ((crc & 0x0080) >> 7) {
            crc <<= 1; // shift left once
            crc ^= polynomial; // XOR with polynomial
        } else {
            crc <<= 1; // shift left once
            data <<= 1; // Next data bit
        }
    }
    return crc;
}

/**
 * CRC algorithm implementation
 * \param[in] buffer Array containing the data
 * \param[in] buflength Buffer length
 * \param[in] crcType Selects the CRC polynomial [CRC_TYP_CITT, CRC_TYP_IBM]
 *
 * \return crc Buffer computed CRC
 */
uint16_t RadioPacketCrc(uint8_t data, uint8_t buflength, uint16_t crcType) {
    uint8_t i;
    uint16_t crc;
    uint16_t polynomial = (crcType == CRC_TYP_IBM) ? POLYNOMIAL_IBM : POLYNOMIAL_CITT;
    crc = (crcType == CRC_TYP_IBM) ? CRC_IBM_SEED : CRC_CITT_SEED;
    for (i = 0; i < buflength; i++) {
        crc = ComputeCrc(crc, data[i], polynomial);
    }
    if (crcType == CRC_TYP_IBM) {
        return crc;
    } else {
        return (~crc);
    }
}
```

Figure 58. Example CRC Code
7.6. Example Temperature Reading

The following routine may be implemented to read the temperature and calibrate the sensor:

```c
/*
 * Reads the raw temperature
 * Raw temperature is an 12-bit value in 2's complement format
 *
 void RadioGetRawTemp()
 {
     int8_t temp = 0;
     int8_t regValue = 0;

     regValue = RadioRead( 0x3C );

     if ( regValue & 0x80 )
     {
         temp *= -1;
     }

     return temp;
 }

 /*
 * Computes the temperature compensation factor
 * Agrees with [52] actualTemp Actual temperature measured by an external device
 * @retval compensationFactor Computed compensation factor
 */

 void RadioCalibrateTemp( int8_t actualTemp )
 {
     return actualTemp - RadioGetRawTemp();
 }

 /*
 * Gets the actual compensated temperature
 * Agrees with [52] compensationFactor Return value of the calibration function
 * @retval actualComp Actual temperature value
 */

 int8_t RadioGetTemp( int8_t compensationFactor )
 {
     return RadioGetRawTemp() * compensationFactor;
 }

 /*
 * Usage example
 */

 void main( void )
 {
     int8_t temp;
     int8_t actualTemp = 0;
     int8_t compensationFactor = 0;

     // Ask user for the temperature during calibration
     actualTemp = AskUserTemperature();
     compensationFactor = RadioCalibrateTemp( actualTemp );

     while( true )
     {
         temp = RadioGetTemp( compensationFactor );
     }
 }
```

**Figure 59. Example Temperature Reading**
8. Packaging Information

8.1. Package Outline Drawing

The SX1272/73 is available in a 28-lead QFN package as shown in Figure 60.

**Figure 60. Package Outline Drawing**
8.2. Recommended Land Pattern

**NOTES:**

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).

2. THIS LAND PATTERN IS FOR REFERENCE PURPOSE ONLY.
   CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR COMPANY’S MANUFACTURING GUIDELINES ARE MET.

3. THERMAL VIAS IN THE LAND PATTERN OF THE EXPOSED PAD SHALL BE CONNECTED TO A SYSTEM GROUND PLANE. FAILURE TO DO SO MAY COMPROMISE THE THERMAL AND/OR FUNCTIONAL PERFORMANCE OF THE DEVICE.

4. SQUARE PACKAGE - DIMENSIONS APPLY IN BOTH "X" AND "Y" DIRECTIONS.

*Figure 61. Recommended Land Pattern*
8.3. Tape and Reel Information

Figure 62. Tape and Reel Information

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ao</td>
<td>6.30 ± 0.1</td>
</tr>
<tr>
<td>Bo</td>
<td>6.30 ± 0.1</td>
</tr>
<tr>
<td>Ko</td>
<td>1.10 ± 0.1</td>
</tr>
<tr>
<td>F</td>
<td>7.50 ± 0.1</td>
</tr>
<tr>
<td>P1</td>
<td>12.00 ± 0.1</td>
</tr>
<tr>
<td>W</td>
<td>16.00 ± 0.3</td>
</tr>
</tbody>
</table>

(i) Measured from centrelines of sprocket hole to centrelines of pocket.
(ii) Cumulative tolerance of 10 sprocket holes is ± 0.20.
(iii) Measured from centrelines of sprocket hole to centreline of pocket.
(iv) Other material available.
(v) Typical SR of form tape Max 10^5 OHM/SQ

All dimensions in millimetres unless otherwise stated.
9. Revision History

Table 48 Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>June 2013</td>
<td>First release.</td>
</tr>
<tr>
<td>2</td>
<td>July 2014</td>
<td>Inclusion of FEI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correction of ToA formula</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve description in the RSSI and IQ calibration mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correction of default value in FSK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added undocumented register</td>
</tr>
<tr>
<td>2.1</td>
<td>October 2014</td>
<td>Corrected Rssi formula in LoRa mode (text +Register Table)</td>
</tr>
<tr>
<td>3</td>
<td>March 2015</td>
<td>Clarified operation modes for Rx Single and Rx Continuous mode in LoRa</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added use cases for Rx Single and Rx Continuous mode in LoRa mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clarified used of LoRa RxPayloadCrcOn in Register Table</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added description of register RegSyncWord in LoRa register table</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changed Stand-By typo into Standby</td>
</tr>
<tr>
<td>3.1</td>
<td>March 2017</td>
<td>Typo in table 12</td>
</tr>
<tr>
<td>4</td>
<td>January 2019</td>
<td>Added RegInvertIQ2 and clarified RegInvertIQ in LoRa mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added RegPaManual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added RegChirpFilter in LoRa mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added AutomaticIFOn</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clarified RegLowPower</td>
</tr>
</tbody>
</table>