

General Description

The SX1211 is a low cost single-chip transceiver operating in the frequency ranges from 863-870, 902-928 MHz and 950-960 MHz. The SX1211 is optimized for very low power consumption (3mA in receiver mode). It incorporates a baseband modem with data rates up to 100 kb/s. Data handling features include a sixty-four byte FIFO, packet handling, automatic CRC generation and data whitening. Its highly integrated architecture allows for minimum external component count whilst maintaining design flexibility. All major RF communication parameters are programmable and most of them may be dynamically set. It complies with European (ETSI EN 300-220 V2.1.1) and North American (FCC part 15) regulatory standards.

Applications

- Wireless alarm and security systems
- Wireless sensor networks
- Automated Meter Reading
- Home and building automation
- Industrial monitoring and control

Features

- Low Rx power consumption: 3mA
- Low Tx power consumption: 25 mA @ +10 dBm
- Good reception sensitivity: down to -104 dBm at 25 kb/s in FSK, -111 dBm at 2kb/s in OOK
- Programmable RF output power: up to +12.5 dBm in 8 steps
- Packet handling feature with data whitening and automatic CRC generation
- RSSI (Received Signal Strength Indicator) range from noise floor to 0 dBm
- Bit rates up to 100 kb/s, NRZ coding
- On-chip frequency synthesizer
- FSK and OOK modulation
- Incoming sync word recognition
- Built-in Bit-Synchronizer for incoming data and clock synchronization and recovery
- 5 x 5 mm TQFN package

Ordering Information

Table 1: Ordering Information

| Part number | Temperature Range | Package |
|---------------|-------------------|-------------------|
| SX1211I084TRT | -40 °C to +85 °C | Lead Free TQFN-32 |

- TR refers to Tape and Reel delivery
- T refers to Lead Free packaging
- This device is WEEE and RoHS compliant

Block Diagram

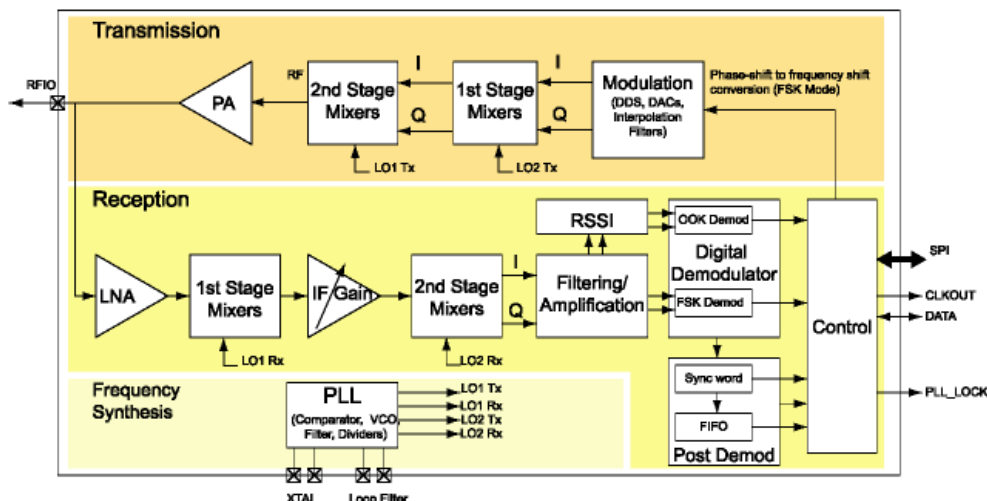


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Acronyms

| | | | |
|-------|---|------|------------------------------------|
| BOM | Bill Of Materials | LO | Local Oscillator |
| BR | Bit Rate | LSB | Least Significant Bit |
| BW | Bandwidth | MSB | Most Significant Bit |
| CCITT | Comité Consultatif International Téléphonique et Télégraphique - ITU | NRZ | Non Return to Zero |
| CP | Charge Pump | NZIF | Near Zero Intermediate Frequency |
| CRC | Cyclic Redundancy Check | OOK | On Off Keying |
| DAC | Digital to Analog Converter | PA | Power Amplifier |
| DDS | Direct Digital Synthesis | PCB | Printed Circuit Board |
| DLL | Dynamically Linked Library | PFD | Phase Frequency Detector |
| ETSI | European Telecommunications Standards Institute | PLL | Phase-Locked Loop |
| FCC | Federal Communications Commission | RBW | Resolution BandWidth |
| Fdev | Frequency Deviation | RF | Radio Frequency |
| FIFO | First In First Out | RSSI | Received Signal Strength Indicator |
| FS | Frequency Synthesizer | Rx | Receiver |
| FSK | Frequency Shift Keying | SAW | Surface Acoustic Wave |
| GUI | Graphical User Interface | SPI | Serial Peripheral Interface |
| IC | Integrated Circuit | SR | Shift Register |
| ID | IDentificator | Stby | Standby |
| IF | Intermediate Frequency | Tx | Transmitter |
| IRQ | Interrupt ReQuest | uC | Microcontroller |
| ITU | International Telecommunication Union | VCO | Voltage Controlled Oscillator |
| LFSR | Linear Feedback Shift Register | XO | Crystal Oscillator |
| LNA | Low Noise Amplifier | XOR | eXclusive OR |

1. Block Diagram and General Description

The SX1211 is a single chip FSK and OOK transceiver capable of operation in the 863-870 MHz and 902-928 MHz license free ISM frequency bands, and 950 - 960 MHz frequency bands. It complies with both European and North American standards, EN 300-220 V2.1.1 (June 2006 release) and FCC Part 15 (10-1-2006 edition). A unique feature of this circuit is its extremely low current consumption in receiver mode of 3mA (typ). The SX1211 comes in a 5x5 mm TQFN-32 package.

1.1. Simplified Block Diagram

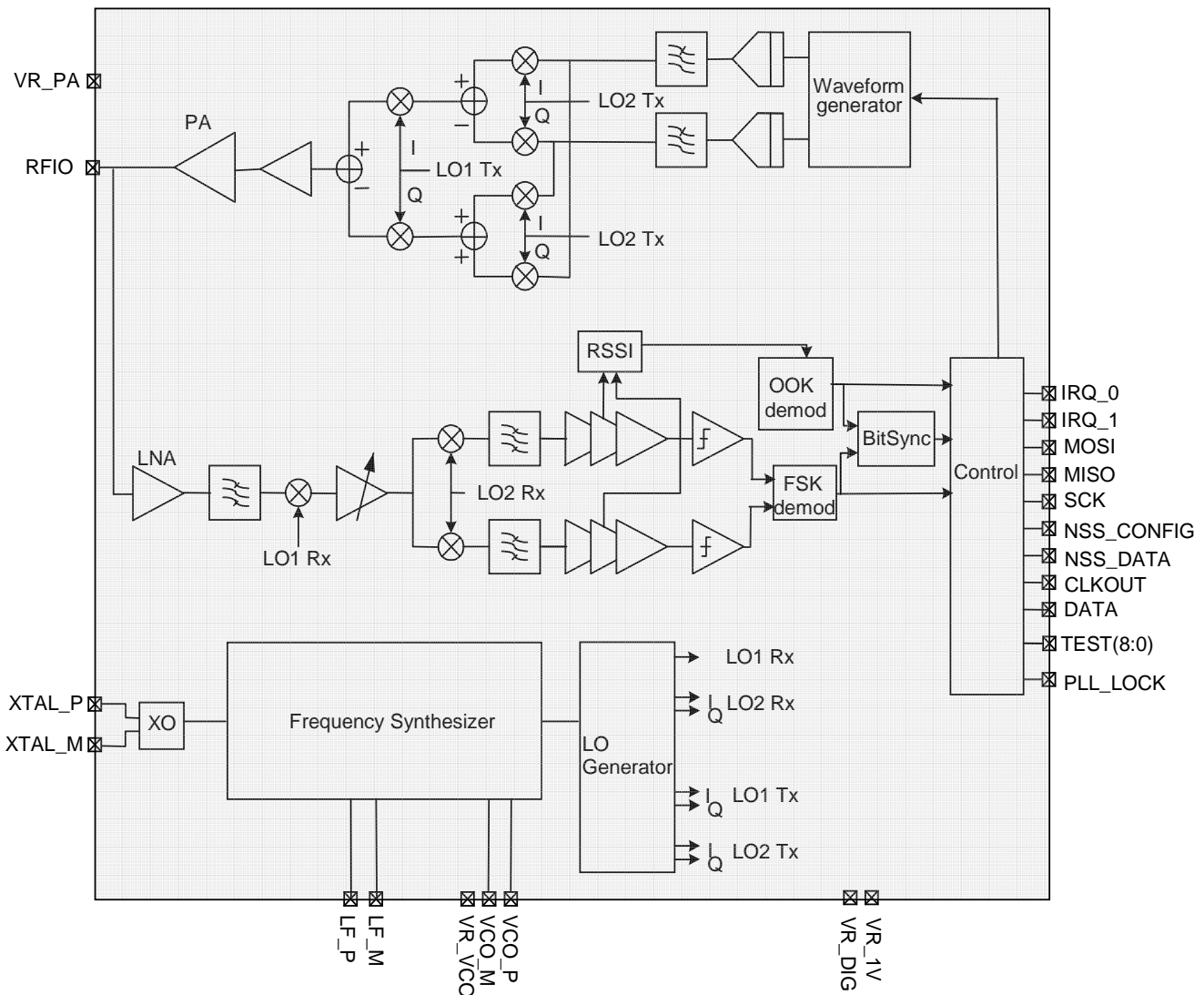


Figure 1: SX1211 Block Diagram

1.2. Pin Diagram

The following diagram shows the pins arrangement on the QFN package, top view.

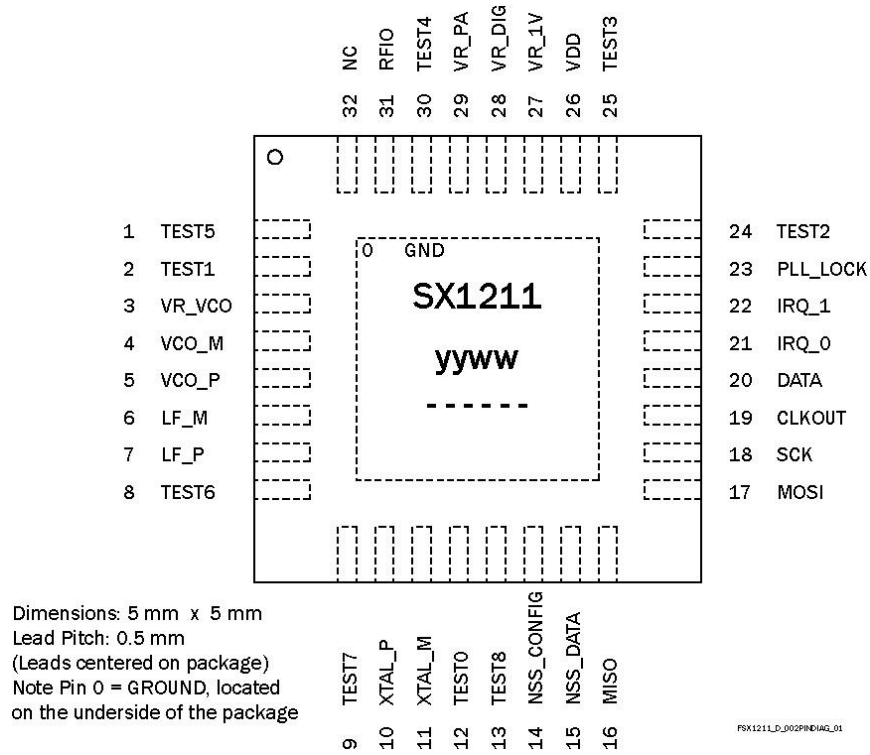


Figure 2: SX1211 Pin Diagram

Notes:

- yyww refers to the date code
- ----- refers to the lot number

1.3. Pin Description

Table 2: SX1211 Pinouts

| Number | Name | Type | Description |
|--------|------------|------|---|
| 0 | GND | I | Exposed ground pad |
| 1 | TEST5 | I/O | Connect to GND |
| 2 | TEST1 | I/O | Connect to GND |
| 3 | VR_VCO | O | Regulated supply of the VCO |
| 4 | VCO_M | I/O | VCO tank |
| 5 | VCO_P | I/O | VCO tank |
| 6 | LF_M | I/O | PLL loop filter |
| 7 | LF_P | I/O | PLL loop filter |
| 8 | TEST6 | I/O | Connect to GND |
| 9 | TEST7 | I/O | Connect to GND |
| 10 | XTAL_P | I/O | Crystal connection |
| 11 | XTAL_M | I/O | Crystal connection |
| 12 | TEST0 | I | Connect to GND |
| 13 | TEST8 | O | Do not connect |
| 14 | NSS_CONFIG | I | SPI CONFIG enable |
| 15 | NSS_DATA | I | SPI DATA enable |
| 16 | MISO | O | SPI data output |
| 17 | MOSI | I | SPI data input |
| 18 | SCK | I | SPI clock input |
| 19 | CLKOUT | O | Clock output |
| 20 | DATA | I/O | NRZ data input and output (Continuous mode) |
| 21 | IRQ_0 | O | Interrupt output |
| 22 | IRQ_1 | O | Interrupt output |
| 23 | PLL_LOCK | O | PLL lock detection output |
| 24 | TEST2 | I/O | Connect to GND |
| 25 | TEST3 | I/O | Connect to GND |
| 26 | VDD | I | Supply voltage |
| 27 | VR_1V | O | Regulated supply of the analog circuitry |
| 28 | VR_DIG | O | Regulated supply of digital circuitry |
| 29 | VR_PA | O | Regulated supply of the PA |
| 30 | TEST4 | I/O | Connect to GND |
| 31 | RFIO | I/O | RF input/output |
| 32 | NC | - | Connect to GND |

Note: pin 13 (Test 8) should be left unconnected on any design.

2. Electrical Characteristics



2.1. ESD Notice

The SX1211 is a high performance radio frequency device. It satisfies general ESD quality rules, except on pins 3-4-5-27-28-29-31. 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

| Symbol | Description | Min. | Max. | Unit |
|--------|---------------------|------|------|------|
| VDDmr | Supply voltage | -0.3 | 3.7 | V |
| Tmr | Storage temperature | -55 | 125 | °C |
| Pmr | Input level | - | 0 | dBm |

2.3. Operating Range

Table 4: Operating Range

| Symbol | Description | Min. | Max. | Unit |
|--------|----------------|------|------|------|
| VDDop | Supply Voltage | 2.1 | 3.6 | V |
| Trop | Temperature | -40 | +85 | °C |
| ML | Input Level* | - | 0 | dBm |

Note: above -10 dBm input power, the receive current can increase over the specification.

2.4. Chip Specification

Conditions: Temp = 25 °C, VDD = 3.3 V, crystal frequency = 12.8 MHz, carrier frequency = 869 or 915 MHz, modulation FSK, data rate = 25 kb/s, Fdev = 50 kHz, fo = 50 kHz, fc-fo = 100 kHz, unless otherwise specified.

2.4.1. Power Consumption

| Symbol | Description | Conditions | Min | Typ | Max | Unit |
|--------|---|---|--------|----------|----------|----------|
| IDDSL | Supply current in sleep mode | | - | 0.3 | - | µA |
| IDDST | Supply current in standby mode, CLKOUT disabled | Crystal oscillator running | - | 55 | 80 | µA |
| IDDFS | Supply current in FS mode | Frequency synthesizer running | - | 1.3 | 1.7 | mA |
| IDDR | Supply current in receiver mode | | - | 3.0 | 3.5 | mA |
| IDDT | Supply current in transmitter mode | Output power = 10 dBm Output power = 1 dBm | - - | 25 16 | 30 21 | mA mA |

Table 5: Power Consumption Specification

2.4.2. Frequency Synthesis

Table 6: Frequency Synthesizer Specification

| Symbol | Description | Conditions | Min | Typ | Max | Unit |
|--------|------------------------------------|---|------|------|-----|------|
| FR | Frequency ranges | Programmable but requires a specific BOM. | 863 | - | 870 | MHz |
| | | | 902 | - | 928 | MHz |
| | | | 950 | - | 960 | MHz |
| BR_F | Bit rate (FSK) | NRZ | 1.56 | - | 100 | kb/s |
| BR_O | Bit rate (OOK) | NRZ | 1.56 | - | 32 | kb/s |
| FDA | Frequency deviation (FSK) | | 33 | 50 | 200 | kHz |
| XTAL | Crystal oscillator frequency | | 12 | 12.8 | 15 | MHz |
| FSTEP | Frequency synthesizer step | Variable, depending on the frequency. | - | 2 | - | kHz |
| TS_OSC | Oscillator wake-up time | From sleep mode. | - | 1.5 | 5 | ms |
| TS_FS | Frequency synthesizer wake-up time | From Stby to frequency at most 10 kHz away from the target. | - | 500 | 800 | µs |
| TS_HOP | Frequency synthesizer hop time | 200 kHz step at most 10 kHz away from the target | - | 200 | - | µs |
| | | 1MHz step at most 10 kHz away from the target | - | 220 | - | µs |
| | | 10 MHz step at most 10 kHz away from the target | - | 350 | - | µs |

2.4.3. Transmitter

Table 7: Transmitter Specification

| Symbol | Description | Conditions | Min | Typ | Max | Unit |
|--------|--|--|-----|------|-----|--------|
| RFOP | RF output power, programmable with 8 steps of typ. 3dB | Maximum power setting | - | 12.5 | - | dBm |
| | | Minimum power setting | - | -8.5 | - | |
| PN | Phase noise | Measured with a 600 kHz offset, at the transmitter output. | - | -112 | - | dBc/Hz |
| SPT | Transmitted spurious | At any offset between 200 kHz and 600 kHz, unmodulated carrier, Fdev = 50 kHz. | - | - | -47 | dBc |
| TS_TR | Transmitter wake-up time | From FS to Tx ready. | - | 120 | 500 | µs |
| TS_TR2 | Transmitter wake-up time | From Stby to Tx ready. | - | 600 | 900 | µs |

2.4.4. Receiver

Table 8: Receiver Specification

| Symbol | Description | Conditions | Min | Typ | Max | Unit |
|---------|--|--|-----|------|--------|------|
| RFS_F | Sensitivity (FSK) | 869 MHz, BR=25 kb/s, Fdev =50 kHz, fc=100 kHz | - | -104 | - | dBm |
| | | 869 MHz, BR=66.7 kb/s, Fdev=100 kHz, fc=200 kHz | - | -100 | - | dBm |
| | | 915 MHz, BR=25 kb/s, Fdev=50 kHz, fc=100 kHz | - | -102 | - | dBm |
| | | 915 MHz, BR = 66.7 kb/s, Fdev=100 kHz, fc=200 kHz | - | -98 | - | dBm |
| RFS_O | Sensitivity (OOK) | 869 MHz, 2kb/s NRZ fc=50 kHz, fo=50 kHz | - | -110 | - | dBm |
| | | 869 MHz, 16.7 kb/s NRZ fc=100 kHz, fo=100 kHz | - | -102 | - | dBm |
| | | 915 MHz, 2kb/s NRZ fc=50 kHz, fo=50 kHz | - | -108 | - | dBm |
| | | 915 MHz, 16.7 kb/s NRZ fc=100 kHz, fo=100 kHz | - | -102 | - | dBm |
| CCR | Co-channel rejection | | - | -12 | - | dBc |
| ACR | Adjacent channel rejection | Offset = 600 kHz, same modulation as wanted signal | - | 42 | - | dBc |
| | | Offset = 300 kHz, same modulation as wanted signal | - | 24 | - | dBc |
| | | Offset = 1.2 MHz, same modulation as wanted signal | - | 57 | - | dBc |
| BI | Blocking immunity | Offset = 1 MHz, unmodulated | - | 53 | - | dBc |
| | | Offset = 2 MHz, unmodulated, no SAW | - | -37 | - | dBm |
| | | Offset = 10 MHz, unmodulated, no SAW | - | -33 | - | dBm |
| RXBW_F | Receiver bandwidth in FSK mode | Single side BW Polyphase Off | 50 | - | 250 | kHz |
| RXBW_O | Receiver bandwidth in OOK mode | Single side BW Polyphase On | 50 | - | 400 | kHz |
| IIP3 | Input 3 rd order intercept point | Interferers at 1MHz and 1.950 MHz offset | - | -28 | - | dBm |
| TS_RE | Receiver wake-up time | From FS to Rx ready | - | 280 | 500 | µs |
| TS_RE2 | Receiver wake-up time | From Stby to Rx ready | - | 600 | 900 | µs |
| TS_RSSI | RSSI sampling time | From Rx ready | - | - | 1/Fdev | s |

Notes:

- fc and fo describe the bandwidth of the active channel filters as described in section 3.4.4.2
- All sensitivities are measured receiving a PN15 sequence, for a BER of 0.1%

2.4.5. Digital Specification

Conditions: Temp = 25 °C, VDD = 3.3 V, crystal frequency = 12.8 MHz, unless otherwise specified.

Table 9: Digital Specification

| Symbol | Description | Conditions | Min | Typ | Max | Unit |
|------------|--|------------------------|---------|-----|---------|------|
| VIH | Digital input level high | | 0.8*VDD | - | - | V |
| VIL | Digital input level low | | - | - | 0.2*VDD | V |
| VOH | Digital output level high | I _{max} =1mA | 0.9*VDD | - | - | V |
| VOL | Digital output level low | I _{max} =-1mA | - | - | 0.1*VDD | V |
| SCK_CONFIG | SPI config clock frequency | | - | - | 2 | MHz |
| SCK_DATA | SPI data clock frequency | | - | - | 1.6 | MHz |
| T_DATA | DATA hold and setup time | | 2 | - | - | µs |
| T_MOSI_C | MOSI setup time for SPI Config. | | 250 | - | - | ns |
| T_MOSI_D | MOSI setup time for SPI Data. | | 312 | - | - | ns |
| T_NSSC_L | NSS_CONFIG low to SCK rising edge. SCK falling edge to NSS_CONFIG high. | | 500 | - | - | ns |
| T_NSSD_L | NSS_DATA low to SCK rising edge. SCK falling edge to NSS_DATA high. | | 625 | - | - | ns |
| T_NSSC_H | NSS_CONFIG rising to falling edge. | | 500 | - | - | ns |
| T_NSSD_H | NSS_DATA rising to falling edge. | | 625 | - | - | ns |

3. Architecture Description

This section describes in depth the architecture of this ultra low-power transceiver.

3.1. Power Supply Strategy

To provide stable sensitivity and linearity characteristics over a wide supply range, the SX1211 is internally regulated. This internal regulated power supply structure is described below:

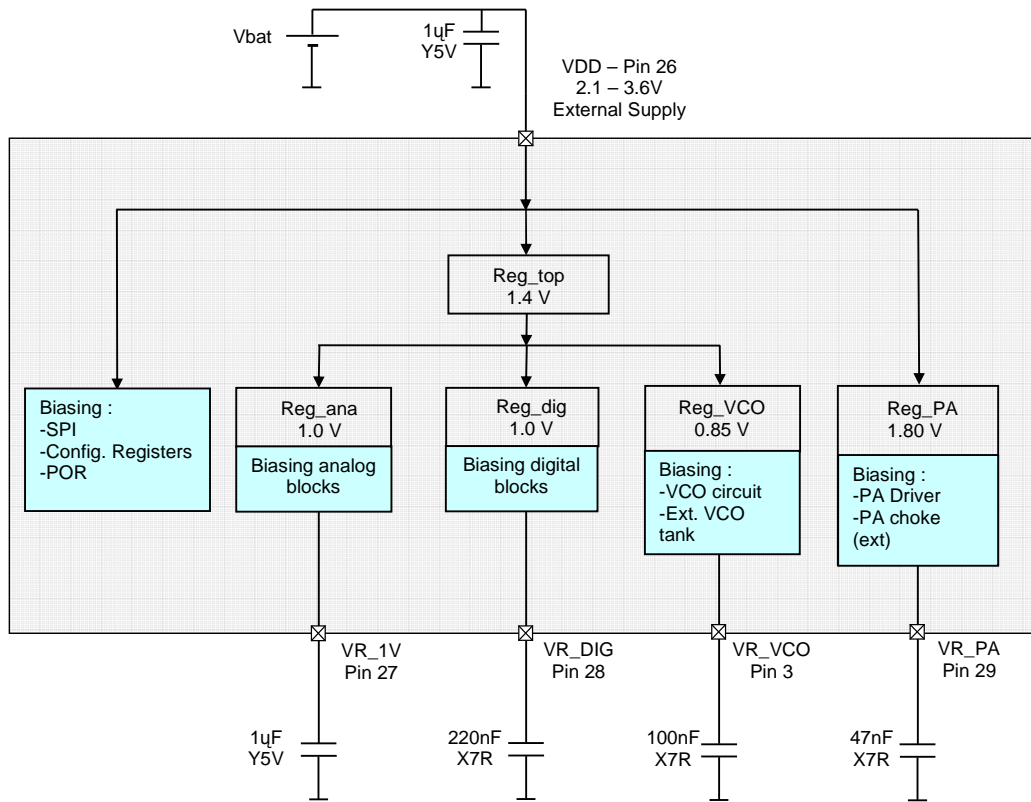


Figure 3: Power Supply Breakdown

To ensure correct operation of the regulator circuit, the decoupling capacitor connection shown in Figure 3 is required. These decoupling components are mandatory for any design.

3.2. Frequency Synthesis Description

The frequency synthesizer of the SX1211 is a fully integrated integer-N type PLL. The PLL circuit requires only six external components - the reference oscillator crystal, the PLL loop filter and the VCO tank circuit.

3.2.1. Crystal Resonator Specification

Table 10: Crystal Resonator Specification shows the crystal resonator specification for the crystal reference oscillator circuit of the SX1211. This specification covers the full range of operation of the SX1211 and is employed in the reference design (see section 7),

| Name | Description | Min. value | Typ. value | Max. value | Unit |
|-----------------------------|--|------------|------------|------------|----------|
| Fxtal | Nominal frequency | 12 | 12.800 | 15 | MHz |
| Cload | Load capacitance for Fxtal | 13.5 | 15 | 16.5 | pF |
| Rm | Motional resistance | - | - | 100 | ohms |
| Co | Shunt capacitance | 1 | - | 7 | pF |
| ΔF_{xtal} | Calibration tolerance at 25+/-3°C | -15 | - | +15 | ppm |
| $\Delta F_{xtal}(\Delta T)$ | Stability over temperature range [-40°C ; +85°C] | -20 | - | +20 | ppm |
| $\Delta F_{xtal}(\Delta t)$ | Aging tolerance in first 5 years | -2 | - | +2 | ppm/year |

Table 10: Crystal Resonator Specification

Note that the initial frequency tolerance, temperature stability and ageing performance should be chosen in accordance with the target operating temperature range and the receiver bandwidth selected.

3.2.2. CLKOUT Output

The reference frequency, or a sub-multiple of it, can be provided on CLKOUT (pin 19) by activating the bit OSCParam_Clkout_on. The division ratio is programmed through bits OSCParam_Clkout_freq. The two applications of the CLKOUT output are:

- To provide a clock output for a companion uC, 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-up.
- 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 SX1211, ensure that the CLKOUT signal is disabled when unused.

3.2.3. PLL Architecture

The crystal oscillator (XO) forms the reference oscillator of an Integer-N Phase Locked Loop (PLL), whose operation is discussed in the following section. Figure 4 shows a block schematic of the SX1211 PLL. Here the crystal reference frequency and the software controlled dividers R, P and S determine the output frequency of the PLL.

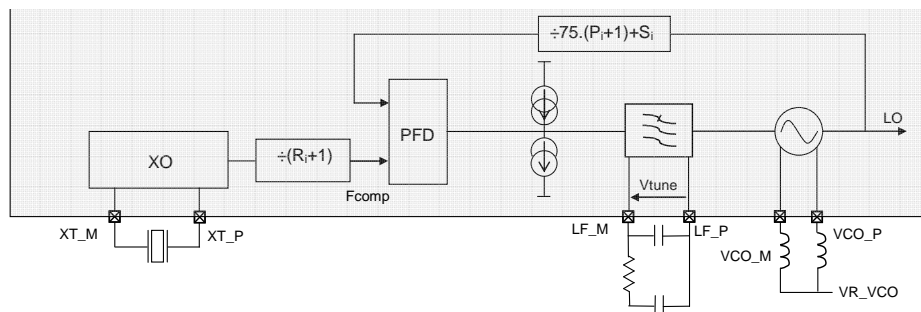


Figure 4: Frequency Synthesizer Description

The VCO tank inductors are connected on an external differential input. Similarly, the loop filter is also located externally. However, there is an internal 8 pF capacitance at VCO input that should be subtracted from the desired loop filter capacitance.

The output signal of the VCO is used as the input to the local oscillator (LO) generator stage, illustrated in Figure 5. The VCO frequency is subdivided and used in a series of up (down) conversions for transmission (reception).

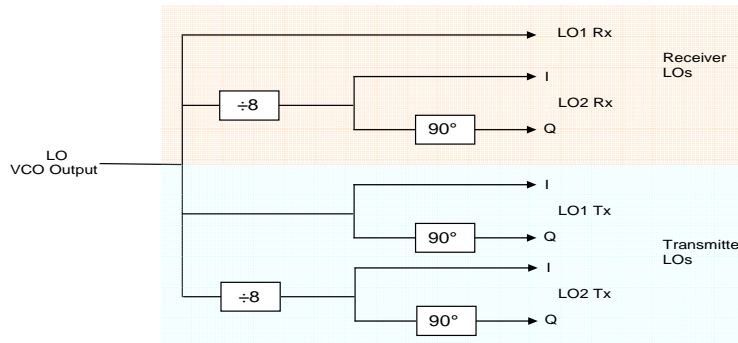


Figure 5: LO Generator

3.2.4. PLL Tradeoffs

With an integer-N PLL architecture, the following criterion must be met, to ensure correct operation:

- The comparison frequency F_{comp} of the Phase Frequency Detector (PFD) input must remain higher than six times the PLL bandwidth (PLLBW) to guarantee loop stability and to reject harmonics of the comparison frequency F_{comp} . This is expressed in the inequality:

$$PLLBW \leq \frac{F_{comp}}{6}$$

- However the PLLBW has to be sufficiently high to allow adequate PLL lock times
- Because the divider ration R determines F_{comp} , it should be set close to 119, leading to $F_{comp} \approx 100$ kHz which will ensure suitable PLL stability and speed.

With the recommended Bill Of Materials (BOM) of the reference design of section 7, the PLL prototype is the following:

- $64 \leq R \leq 169$
- $S < P+1$
- PLLBW = 15 kHz nominal
- Startup times and reference frequency spurs as specified.

3.2.5. Voltage Controlled Oscillator

The integrated VCO requires only two external tank circuit inductors. As the input is differential, two components of the same value should be used. The performance of these inductors is key to both the phase noise and the power consumption of the PLL. Thus, a pair of high Q factor inductances mounted orthogonally to other inductors (in particular the PA choke) is advised to reduce spurious coupling between the PA and VCO. Furthermore such measures may reduce radiated pulling effects and undesirable transient behavior, thus minimizing spectral occupancy. Note that ensuring a symmetrical layout of the VCO inductors will further improve PLL spectral purity.

For best performance wound type inductors, with tight tolerance, should be used as described in the reference design section.

3.2.5.1. SW Settings of the VCO

To guarantee the best operation of the VCO over the SX1211's frequency and temperature ranges, the following settings should be programmed into the SX1211:

| Target channel (MHz) | 863-870 | 902-915 | 915-928 | 950-960 |
|----------------------|---------|---------|---------|---------|
| Freq_band | 10 | 00 | 01 | 10 |

Table 11: MCPParam_Freq_band Setting

3.2.5.2. Trimming the VCO Tank by Hardware and Software

To ensure that the whole band may be accurately addressed by the R, P and S dividers of the synthesizer, it is necessary to ensure that the VCO is correctly centered. Note that for the reference design (see section 7) no centering is necessary. However, any deviation from the reference design may require the optimization procedure, outlined below, to be performed. This procedure is simplified thanks to the built in VCO trimming feature which is controlled over the SPI interface. Moreover, this tuning does not require any RF test equipment, simply by measuring the voltage between pins 6 (LFM) and 7 (LFP) - herein referred to as V_{tune} - the VCO is in tune if the voltage is within the range:

$$100 \leq V_{tune}(mV) \leq 200$$

Note that this measurement should be conducted when in transmit mode at the center frequency of the desired band (for example 869 MHz in the 868-870 MHz band), with the appropriate MCPParam_Freq_band setting.

If this inequality is not satisfied then, starting from 00, iteratively adjust the MCPParam_VCO_trim bits whilst monitoring V_{tune} . This allows the VCO voltage to be trimmed in 60 mV increments. Should the desired voltage range be inaccessible, the voltage may be adjusted further by changing the tank circuit inductance value, remembering that an increase in inductance will increase V_{tune} .

Note for mass production: The VCO capacitance is piece to piece dependant. As such, the optimization proposed above should be verified on several prototypes, to ensure that the population is centered on 150 mV.

3.2.6. PLL Loop Filter

To adequately reject spurious components arising from the comparison frequency F_{comp} , an external 2nd order loop filter is employed.

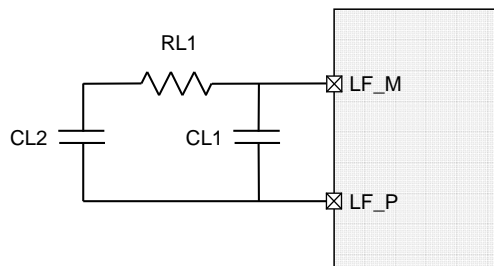


Figure 6: Loop Filter

Following the recommendations made in section 3.2.4, the loop filter proposed in the reference design's bill of material on section 7.3 should be used. The loop filter settings are frequency band independent and are hence relevant to all implementations of the SX1211.

3.2.7. PLL Lock Detection Indicator

The SX1211 also features a PLL lock detect indicator. This is useful for optimizing power consumption, by adjusting the synthesizer wake up time (TS_FS), since the PLL startup time is lower than specified under nominal conditions. The lock status can be read on bit IRQParam_PLL_lock, and must be cleared by writing a “1” to this same register. In addition, the lock status can be reflected in pin 23 PLL_LOCK, by setting the bit IRQParam_Enable_lock_detect.

3.2.8. Frequency Calculation

As shown in

Figure 4, the PLL structure comprises three different dividers, R, P and S, which set the output frequency through the LO. A second set of dividers is also available to allow rapid switching between a pair of frequencies: R1/P1/S1 and R2/P2/S2. These six dividers are programmed by six bytes of the register MCPParam from addresses 6 to 11.

3.2.8.1. FSK Mode

The following formula gives the relationship between the local oscillator, and R, P and S values, when using FSK modulation.

$$F_{rf, fsk} = \frac{9}{8} F_{lo}$$

$$F_{rf, fsk} = \frac{9}{8} \frac{F_{xtal}}{R+1} [75(P+1) + S]$$

3.2.8.2. OOK Mode

Due to the manner in which the baseband OOK symbols are generated, the signal is always offset by the FSK frequency deviation (Fdev - as programmed in MCPParam_Freq_dev). Hence, the center of the transmitted OOK signal is:

$$F_{rf, ook, tx} = \frac{9}{8} F_{lo} - F_{dev}$$

$$F_{rf, ook, tx} = \frac{9}{8} \frac{F_{xtal}}{R+1} [75(P+1) + S] - F_{dev}$$

Consequently, in receive mode, the local oscillator frequency also needs to be offset, due to the SX1211 Low Intermediate Frequency (Low-IF) architecture. To ensure that this low IF (denote IF2) is at the baseband receiver center frequency of 100 kHz, as suggested in section 3.4.4, the user must ensure:

$$F_{rf, ook, rx} = \frac{9}{8} F_{lo} - IF2$$

$$F_{rf, ook, rx} = \frac{9}{8} \frac{F_{xtal}}{R+1} [75(P+1) + S] - IF2$$

3.2.9. Software for Frequency Calculation

The R1, P1 and S1, and R2, P2, S2 dividers, are configured over the SPI interface and programmed by 8 bits each, at addresses 6 to 11. The frequency pairs may hence be switched in a single SPI cycle

3.2.9.1. GUI Software

To aid the user with calculating appropriate R, P and S values, software is available to perform the frequency calculation. Please refer to its user guide for assistance on its use.

3.2.9.2. SW .dll for Automatic Production Bench

The Dynamically Linked Library (DLL) used by the software to perform these calculations is also provided, free of charge, to users, for inclusion in automatic production testing. Key benefits of this are:

- No hand trimming of the reference frequency required: the actual reference frequency of the Device Under Test (DUT) can be easily measured (e.g. from the CLKOUT output of the SX1211) and the tool will calculate the best frequencies to compensate for the crystal initial error.
- Channel plans can be calculated and stored in the application's memory, then adapted to the actual crystal oscillation frequency.

3.3. Transmitter Description

The SX1211 is set to transmit mode when MCPParam_Chip_mode = 100.

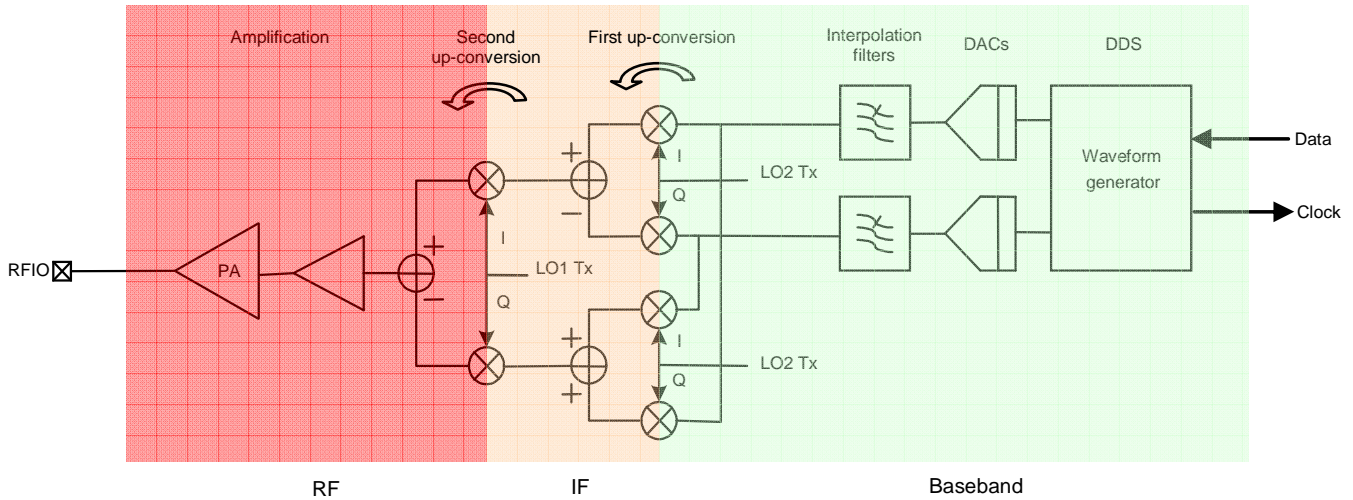


Figure 7: Transmitter Architecture

3.3.1. Architecture Description

The baseband I and Q signals are digitally generated by a DDS whose digital to analog converters (DAC) followed by two anti-aliasing low-pass filters transform the digital signal into analog in-phase (I) and quadrature (Q) components whose frequency is the selected frequency deviation (F_{dev}).

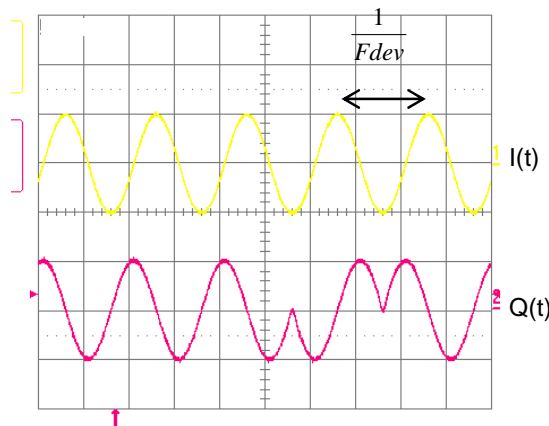


Figure 8: $I(t)$, $Q(t)$ Overview

In FSK mode, the relative phase of I and Q is switched by the input data between -90° and $+90^\circ$ with continuous phase. The modulation is therefore performed at this initial stage, since the information contained in the phase difference will be converted into a frequency shift when the I and Q signals are up-converted in the first mixer stage. This first up-conversion stage is duplicated to enhance image rejection. The FSK convention is such that:

$$DATA = '1' \Rightarrow Frf + Fdev$$

$$DATA = '0' \Rightarrow Frf - Fdev$$

In OOK mode, the phase difference between the I and Q channels is kept constant (independent of the transmitted data). Thus, the first stage of up-conversion creates a fixed frequency signal at the low IF = Fdev (This explains why the transmitted OOK spectrum is offset by Fdev). OOK Modulation is accomplished by switching on and off the PA and PA regulator stages. By convention:

$$DATA = '1' \Rightarrow PAon$$

$$DATA = '0' \Rightarrow PAoff$$

After the interpolation filters, a set of four mixers combines the I and Q signals and converts them into a pair of complex signals at the second intermediate frequency, equal to 1/8 of the LO frequency, or 1/9 of the RF frequency. These two new I and Q signals are then combined and up-converted to the final RF frequency by two quadrature mixers fed by the LO signal. The signal is pre-amplified, then the transmitter output is driven by a final power amplifier stage.

3.3.2. Bit Rate Setting

In Continuous transmit mode, setting the Bit Rate is useful to determine the frequency of DCLK. As explained in section 4.3.2, DCLK will trigger an interrupt on the uC each time a new bit has to be radiated.

$$BR = \frac{F_{XTAL}}{64 * [1 + val(MCParam_BR)]}$$

3.3.3. Fdev Setting in FSK Mode

The frequency deviation, Fdev, of the FSK transmitter is programmed through bits MCParam_Freq_dev:

$$Fdev = \frac{F_{XTAL}}{32 * [1 + val(MCParam_Freq_dev)]}$$

For correct operation the modulation index β should be such that:

$$\beta = 2 * \frac{Fdev}{BR} \geq 2$$

Furthermore, assuming communication between a pair of SX1211s, then Fdev > 33 kHz - to ensure a correct sensitivity at receiver side. If the SX1211 is transmitting to any other FM receiver, there is no restriction on Fdev.

3.3.4. Fdev Setting in OOK Mode

Fdev has no physical meaning in OOK transmit mode. However, as has been shown - due to the DDS baseband signal generation, the OOK tone is always offset by "-Fdev" (see formulas in section 3.2.8). It is hence suggested that Fdev retains its default value of 100 kHz in OOK mode.

3.3.5. Suggested Interpolation Filter Setting

After digital to analog conversion, both I and Q signals are smoothed by interpolation filters. This block low-pass filters the digitally generated signal, and prevents the alias signals from entering the modulators. Its bandwidth can be programmed with the register RXParam_InterpFiltTx, and should be set to:

$$BW \cong 3 * \left[F_{dev} + \frac{BR}{2} \right]$$

Where F_{dev} is the programmed frequency deviation as set in $MCPParam_Freq_dev$, and BR is the physical Bit Rate of transmission.

Note: low interpolation filter bandwidth will attenuate the baseband I/Q signals thus reducing the power of the FSK signal. Conversely, excessive bandwidth will degrade spectral purity.

3.3.6. Power Amplifier

The Power Amplifier (PA) integrated in the SX1211 operates under a regulated voltage supply of 1.8 V. The external PA choke inductor is biased by an internal regulator output made available on pin 29 (VR_PA). Thanks to these features, the PA output power is consistent over the power supply range. This is important for mobile applications where this allows both predictable RF performance and battery life.

3.3.6.1. Rise and Fall Times Control

As the SX1211 is also an OOK device, the PA ramp times can be accurately controlled through the $TParam_PA_ramp$ bits. Those bits directly control the slew rate of VR_PA output (pin 29).

Table 12: PA Rise/Fall Times

| $MCPParam_PA_ramp$ | t_{VR_PA} | t_{PA_OUT} (rise / fall) |
|----------------------|--------------|-----------------------------|
| 00 | 3 μs | 2.5 / 2 μs |
| 01 | 8.5 μs | 5 / 3 μs |
| 10 | 15 μs | 10 / 6 μs |
| 11 | 23 μs | 20 / 10 μs |

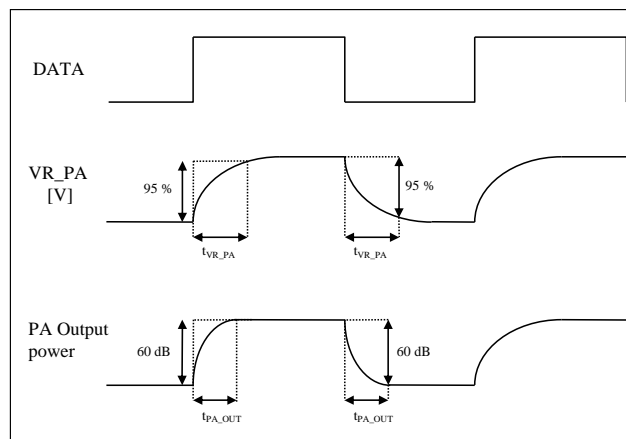


Figure 9: PA Control

3.3.6.2. Optimum Load Impedance

As the PA and the LNA front-ends in the SX1211 share the same Input/Output pin, they are internally matched to impedances close to 50 Ω .

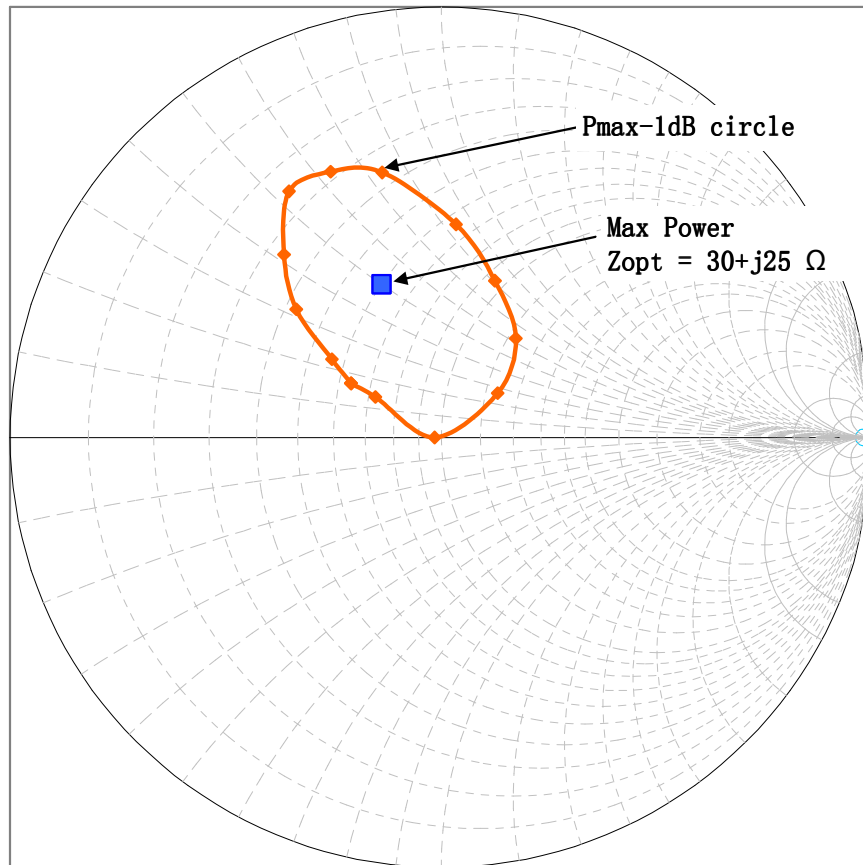


Figure 10: Optimal Load Impedance Chart

Please refer to the reference design section for an optimized PA load setting.

3.3.6.3. Suggested PA Biasing and Matching

The matching proposed is the following one:

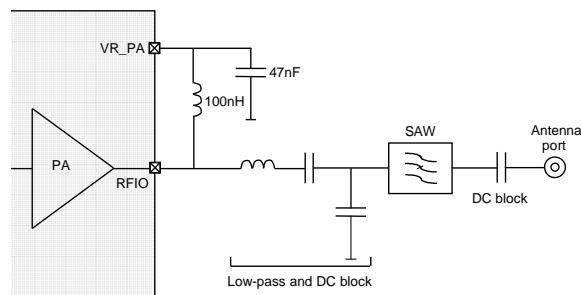


Figure 11: Suggested PA Biasing and Output Matching

Please refer to section 7 of this document for the optimized matching arrangement for frequency band.

3.3.7. Transmitter Spectral Purity

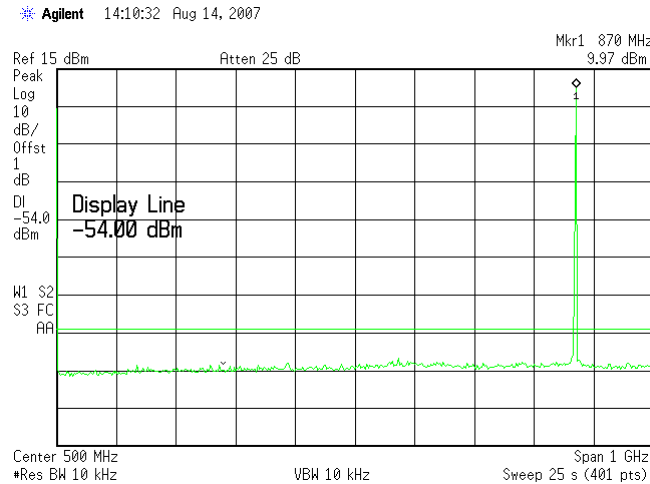


Figure 12: 869 MHz Spectral Purity DC-1GHz

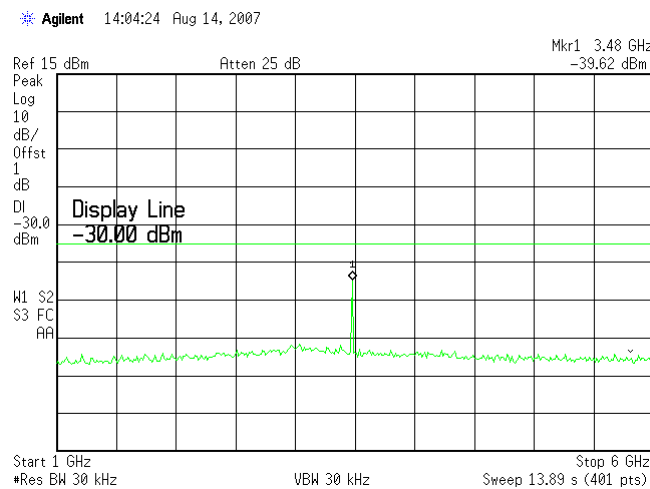


Figure 13: 869 MHz Spectral Purity 1-6GHz

3.3.8. Common Input and Output Front-End

The receiver and the transmitter share the same RFIO pin (pin 31). Figure 14 below shows the configuration of the common RF front-end.

In transmit mode, the PA and the PA regulator are active, with the voltage on the VR_PA pin equal to the nominal voltage of the regulator (1.8 V). The external inductance is used to bias the PA.

In receive mode, both PA and PA regulator are off and VR_PA is tied to ground. The external inductance LT1 is then used to bias the LNA.

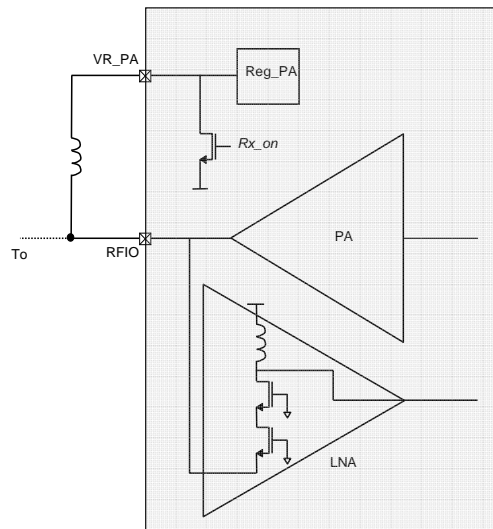


Figure 14: Front-end Description

3.4. Receiver Description

The SX1211 is set to receive mode when MCPParam_Chip_mode = 011.

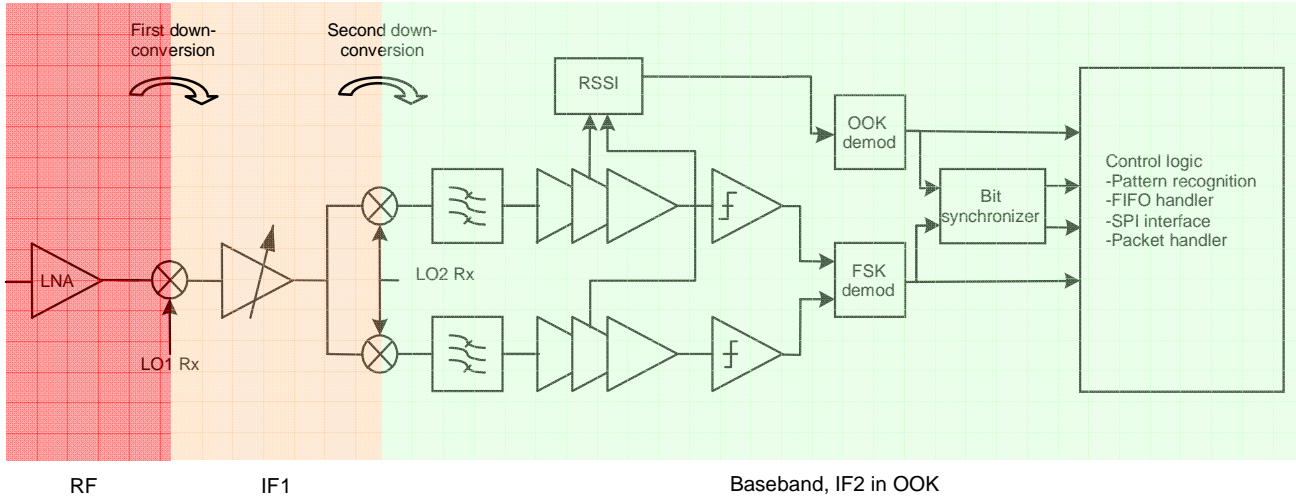


Figure 15: Receiver Architecture

3.4.1. Architecture

The SX1211 receiver employs a super-heterodyne architecture. Here, the first IF is 1/9th of the RF frequency (approximately 100MHz). The second down-conversion mixes the I and Q signals to base band in the case of the FSK receiver (Zero IF) and to a low-IF (IF2) for the OOK receiver.

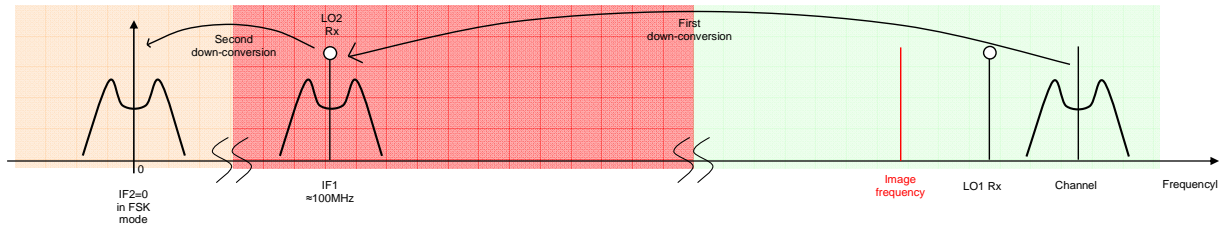


Figure 16: FSK Receiver Setting

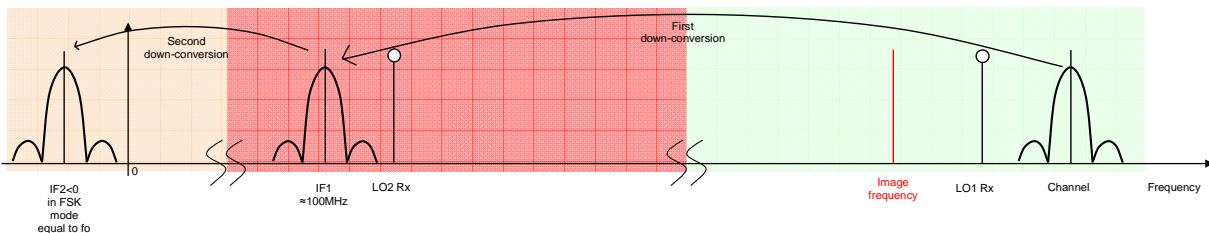


Figure 17: OOK Receiver Setting

After the second down-conversion stage, the received signal is channel-select filtered and amplified to a level adequate for demodulation. Both FSK and OOK demodulation are available. Finally, an optional Bit Synchronizer (BitSync) is provided, to be supply a synchronous clock and data stream to a companion uC in Continuous mode,

or to fill the FIFO buffers with glitch-free data in Buffered mode. The operation of the receiver is now described in detail.

Note: Receiver image rejection is achieved by the SAW filter.

3.4.2. LNA and First Mixer

In receive mode, the RFIO pin is connected to a fixed gain, common-gate, Low Noise Amplifier (LNA). The performance of this amplifier is such that the Noise Figure (NF) of the receiver can be estimated to be ≈ 7 dB.

3.4.3. IF Gain and Second I/Q Mixer

Following the LNA and first down-conversion, there is an IF amplifier whose gain can be programmed from -13.5 dB to 0 dB in 4.5 dB steps, via the register MCPParam_IF_gain. The default setting corresponds to 0 dB gain, but lower values can be used to increase the RSSI dynamic range. Refer to section 3.4.7 for additional information.

3.4.4. Channel Filters

The second mixer stages are followed by the channel select filters. The channel select filters have a strong influence on the noise bandwidth and selectivity of the receiver and hence its sensitivity. Each filter comprises a passive and active section.

3.4.4.1. Passive Filter

Each channel select filter features a passive second-order RC filter, with a bandwidth programmable through the bits RXParam_PassiveFilt. As the wider of the two filters, its effect on the sensitivity is negligible, but its bandwidth has to be setup instead to optimize blocking immunity. The value entered into this register sets the single side bandwidth of this filter. For best performance it must be set to 3 to 4 times the cutoff frequency of the active Butterworth (or polyphase) filter described in the next section.

$$3 * F_{C_{ButterFilt}} \leq BW_{passive,filter} \leq 4 * F_{C_{ButterFilt}}$$

3.4.4.2. Active Filter

The 'fine' channel selection is performed by an active, third-order, Butterworth filter, which acts as a low-pass filter for the zero-IF configuration (FSK), or a complex poly-phase filter for the Low-IF (OOK) configuration. The RXParam_PolypFilt_on bit enables/disables the polyphase filter.

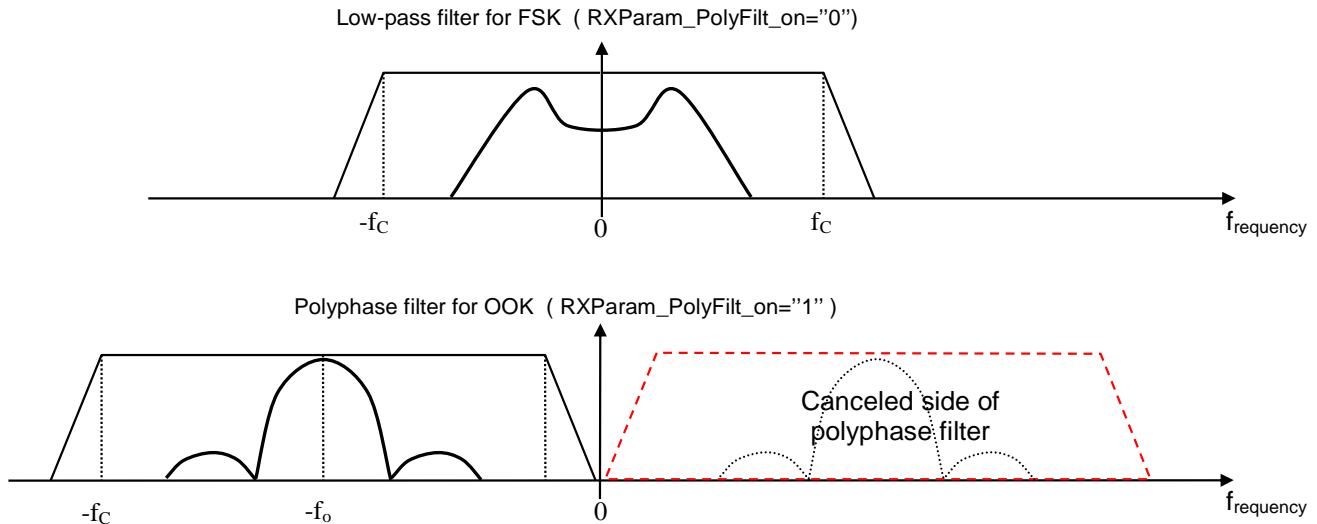


Figure 18: Active Channel Filter Description

As can be seen from Figure 18, the required bandwidth of this filter varies between the two demodulation modes.

- FSK mode: The 99% energy bandwidth of an FSK modulated signal is approximated to be:

$$BW_{99\%,FSK} = 2 * \left[Fdev + \frac{BR}{2} \right]$$

The bits RXParam_ButterFilt set f_c , the cutoff frequency of the filter. As we are in a Zero-IF configuration, the FSK lobes are centered around the virtual “DC” frequency. The choice of f_c should be such that the modulated signal falls in the filter bandwidth, anticipating the Local Oscillator drift over the operating temperature and lifespan of the device:

$$2 * f_c > BW_{99\%,FSK} + LO_{drifts}$$

Please refer to the charts in section 3.4.5 for an accurate overview of the filter bandwidth vs. setting.

- OOK mode: The bits RXParam_PolypFilt_center set f_o , the center frequency of the polyphase filter when activated. f_o should always be chosen to be equal to the low Intermediate Frequency of the receiver. This is why, in the GUI described in section 3.2.9.1 of this document, the low IF frequency of the OOK receiver denoted IF2 has been replaced by f_o . The following setting is recommended:

$$f_o = 100kHz$$

$$RXParam_PolypFilt = "0011"$$

Then, the 99% energy bandwidth of an OOK modulated signal is approached by:

$$BW_{99\%,OOK} = \frac{2}{Tbit} = 2.BR$$

The value stored in RXParam_ButterFilt determines f_c , the filter cut-off frequency. So the user should set f_c according to:

$$2 * (f_c - f_o) > BW_{99\%,OOK} + LO_{drifts}$$

Again, f_c as a function of RXParam_ButterFilt is given in the section 3.4.6.

N.B. In the specific case where the frequency of the companion transmitter is not well controlled (i.e. it can drift by more than +/-100kHz), the user can artificially set the f_0 to a higher value (such as 150kHz), and increase the filter bandwidth. This, of course, leads to a concomitant decrease in sensitivity.

3.4.5. Channel Filters Setting in FSK Mode

F_c , the 3dB cutoff frequency of the Butterworth filter used in FSK reception, is programmed through the bit RXParam_ButterFilt. However, the whole receiver chain influences this cutoff frequency. Thus the channel select and resultant filter bandwidths are summarized in the following chart:

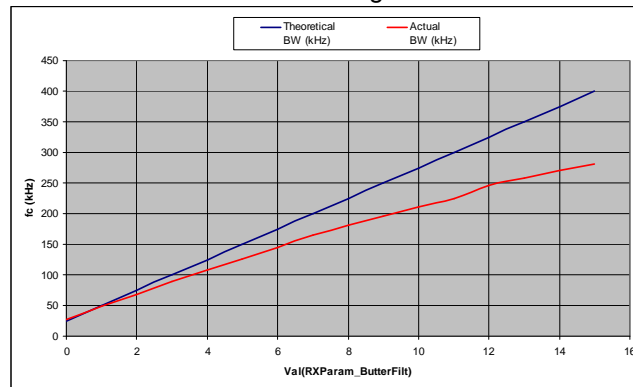


Figure 19: Butterworth Filter's Actual BW

3.4.6. Channel Filters Setting in OOK Mode

The center frequency, f_0 , is always set to 100kHz. The following chart shows the receiver bandwidth when changing RXParam_Butterfilt bits, while the polyphase filter is activated.

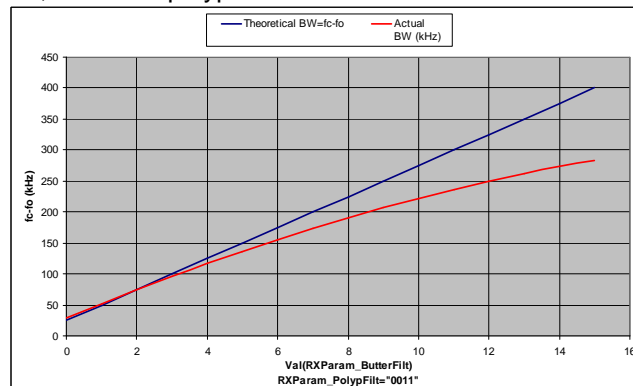


Figure 20: Polyphase Filter's Actual BW

3.4.7. RSSI

3.4.7.1. General Description

After filtering, the I and Q signals are amplified by a chain of 11 amplifiers, each with 6 dB gain. The outputs of these amplifiers are used to evaluate the Received Signal Strength (RSSI). A limiting amplifier is located after the I

and Q amplifiers chains to provide the input signal to the FSK demodulator. Conversely, the OOK demodulator derives its output from the RSSI block.

The overall accuracy of the RSSI is dependent upon both process and external components. So although the RSSI resolution is 0.5 dB, its absolute accuracy is not expected to be better than +/-3 dB. Reliable absolute RSSI measurement will require additional calibration.

3.4.7.2. Performance

The RSSI evaluates the signal strength by sampling I(t) and Q(t) signals 16 times in each Fdev period. An average is then performed over a sliding window of 16 samples. Hence, the RSSI output register RXPParam_RSSI is updated 16 times in each Fdev period and outputs one correct value per Fdev. For accurate timing information on the RSSI, please refer to Figure 49.

The dynamic range of the RSSI is over 70 dB, from the sensitivity level.

3.4.7.3. RSSI IRQ Source

The SX1211 can also be used to detect a RSSI level above a threshold. This function can be activated by bit IRQParam_RSSI_irq, while the threshold level is selected by bits IRQParam_RSSI_thresh. This interrupt can be mapped to the pins IRQ0 or IRQ1 by bits IRQParam_Rx_stby_irq0 or IRQParam_Rx_stby_irq1. The IRQ is eventually cleared by writing a "1" to IRQ_Param_RSSI_irq.

The following figure shows the timing diagram of RSSI in interrupt mode.

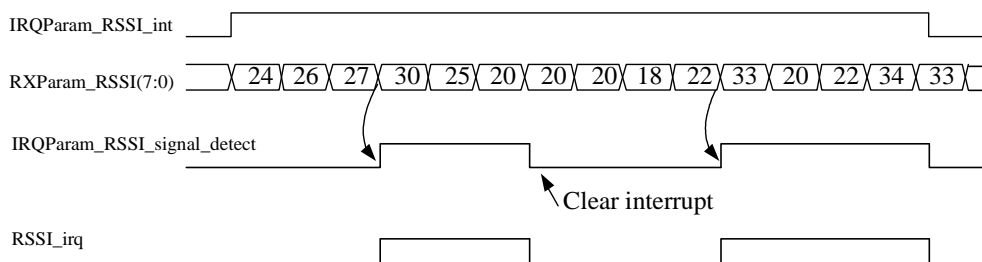


Figure 21: RSSI IRQ Timings

3.4.8. Fdev Setting in Receive Mode

The effect of the Fdev setting is different between FSK and OOK modes:

3.4.8.1. FSK Rx Mode

In FSK mode the Fdev setting has no impact on the circuit architecture. The user should leave it set to the default value.

3.4.8.2. OOK Rx Mode

The frequency deviation Fdev, as described above, sets the sampling rate of the RSSI block. It is therefore necessary to set Fdev to the recommended IF2 frequency of 100 kHz:

$$F_{dev} = IF2 = 100kHz$$

$$MCPParam_Freq_dev = "00000011"$$

3.4.9. FSK Demodulator

The FSK demodulator provides data polarity information, based on the relative phase of the input I and Q signals at baseband. Its outputs can be fed to the Bit Synchronizer to recover the timing information. The user can also use the raw, unsynchronized, output of the FSK demodulator in Continuous mode.

The FSK demodulator of the SX1211 operates most effectively for FSK signals with a modulation index greater than or equal to two:

$$\beta = \frac{2 * F_{dev}}{BR} \geq 2$$

3.4.10. OOK Demodulator

The OOK demodulator performs a comparison of the RSSI output and a threshold. Three different threshold modes are available, programmed through bits RXParam_OOK_thresh_type.

The recommended "Peak" threshold mode is described on Figure 22:

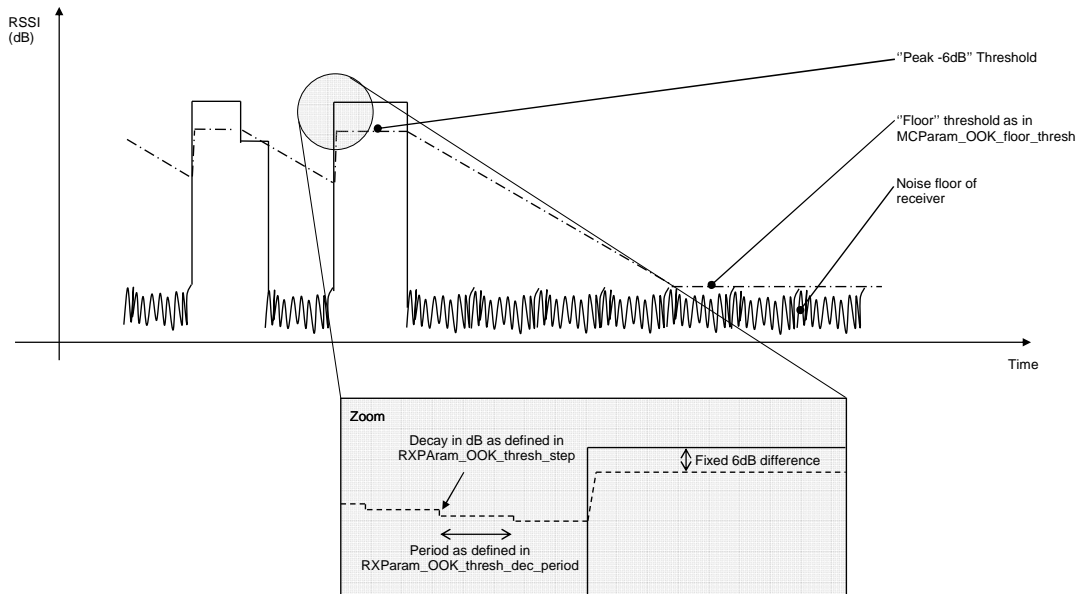


Figure 22: OOK Demodulator Description

In peak threshold mode the comparison threshold used is the peak value of the RSSI, lowered by 6dB. In the absence of an input signal or, equivalently, during the reception of a logical "0", the acquired peak value is decremented by one RXParam_OOK_thresh_step every RXParam_OOK_thresh_dec_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" that is programmed through the register MCPParam_OOK_floor_thresh.

The default settings of the OOK demodulator lead to the performance stated in the electrical specification. However, in applications in which sudden signal drops are awaited during a reception, the three parameters shall be optimized accordingly.

3.4.10.1. Optimizing the Floor Threshold

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

The noise floor of the receiver depends on:

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

It is therefore important to note that the setting of MCPParam_OOK_Floor_thresh will be application dependant. The following procedure is proposed to optimise MCPParam_OOK_Floor_thresh.

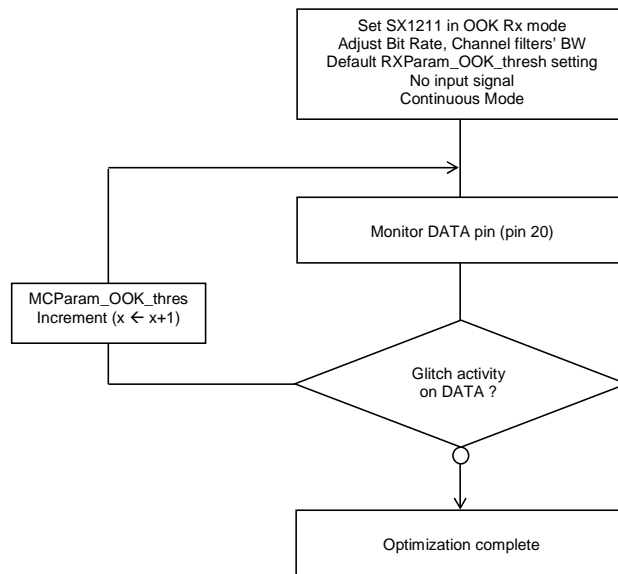


Figure 23: Floor Threshold Optimization

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

3.4.10.2. Optimizing OOK Demodulator Response for Fast Dropping Signals

As shown in Figure 22, a sudden drop in signal strength will cause the bit error rate to rise. For applications where the expected signal drop can be estimated the OOK demodulator parameters: RXPParam_OOK_thresh_step and RXPParam_OOK_thresh_dec_period can be tuned as shown below for a given number of drops per bit RXPParam_OOK_thresh_dec_period given by

- 000 → once in each chip period (d)
- 001 → once in 2 chip periods
- 010 → once in 4 chip periods
- 011 → once in 8 chip periods

- 100 → twice in each chip period
- 101 → 4 times in each chip period
- 110 → 8 times in each chip period
- 111 → 16 times in each chip period

With each drop of size RXParam_OOK_thresh_step given by:

- 000 → 0.5 dB (d)
- 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

3.4.10.3. Alternative Threshold Types

In addition to the “Peak” type of threshold, the user can alternatively select two other types of threshold:

- Fixed threshold: its value is selected through bits MCPParam_OOK_floor_thresh.
- Average threshold: the data supplied by the RSSI block is averaged with the following cutoff frequency:

$$RXParam_OOK_cutoff = 00 \Rightarrow F_{cutoff} = \frac{BR}{8 * \pi}$$

In this case, the cutoff frequency is higher, and a sequence of up to 8 consecutive “0s” or “1s” can be supported.

$$RXParam_OOK_cutoff = 11 \Rightarrow F_{cutoff} = \frac{BR}{32 * \pi}$$

With the second setting, the cutoff frequency is four times smaller, allowing the reception up to 32 consecutive “1”s or “0”s.

3.4.11. Bit Synchronizer

The Bit Synchronizer (BitSync) is a block that provides a clean and synchronized digital output, free of glitches.

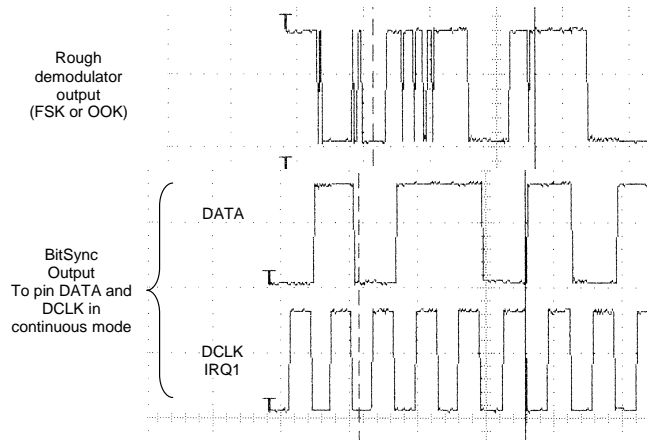


Figure 24: BitSync Description

The BitSync can be disabled through the bits RXPParam_Bitsync_off, and by holding pin IRQ1 low. However, for optimum receiver performance, its use when running Continuous mode is strongly advised. With this option a DCLK signal is present on pin IRQ_1.

BitSync is automatically activated in Buffered and Packet modes. The bit synchronizer bit-rate is controlled by MCPParam_BR. For a given bit rate, this parameter is determined by:

$$BR = \frac{F_{XTAL}}{64 * [1 + MCPParam_BR]}$$

For proper operation, the Bit Synchronizer must first receive three bytes of alternating logic value preamble, i.e. "0101" sequences. After this startup phase, the rising edge of DCLK signal is centered on the demodulated bit. Subsequent data transitions will preserve this centering.

This has two implications:

- Firstly, if the Bit Rates of Transmitter and Receiver are known to be the same, the SX1211 will be able to receive an infinite unbalanced sequence (all "0s" or all "1s") with no restriction.
- If there is a difference in Bit Rate between Tx and Rx, the amount of adjacent bits at the same level that the BitSync can withstand can be estimated as:

$$NumberOfBits = \frac{1}{2} * \frac{BR}{\Delta BR}$$

This implies approximately 6 consecutive unbalanced bytes when the Bit Rate precision is 1%, which is easily achievable (crystal tolerance is in the range of 50 to 100 ppm).

3.4.12. Data Output

After OOK or FSK demodulation, the baseband signal is made available to the user on pin 20, DATA, when Continuous mode is selected.

In Buffered and Packet modes, the data can of course be retrieved from the FIFO through the SPI interface.

4. Data Processing

4.1. Overview

4.1.1. Block Diagram

As illustrated below, the SX1211's data processing is built around several blocks which are described in the following paragraphs.

Its role is to interface the data to/from the modulator/demodulator and the uC access points (SPI, IRQ and DATA pins). It also controls all the configuration registers.

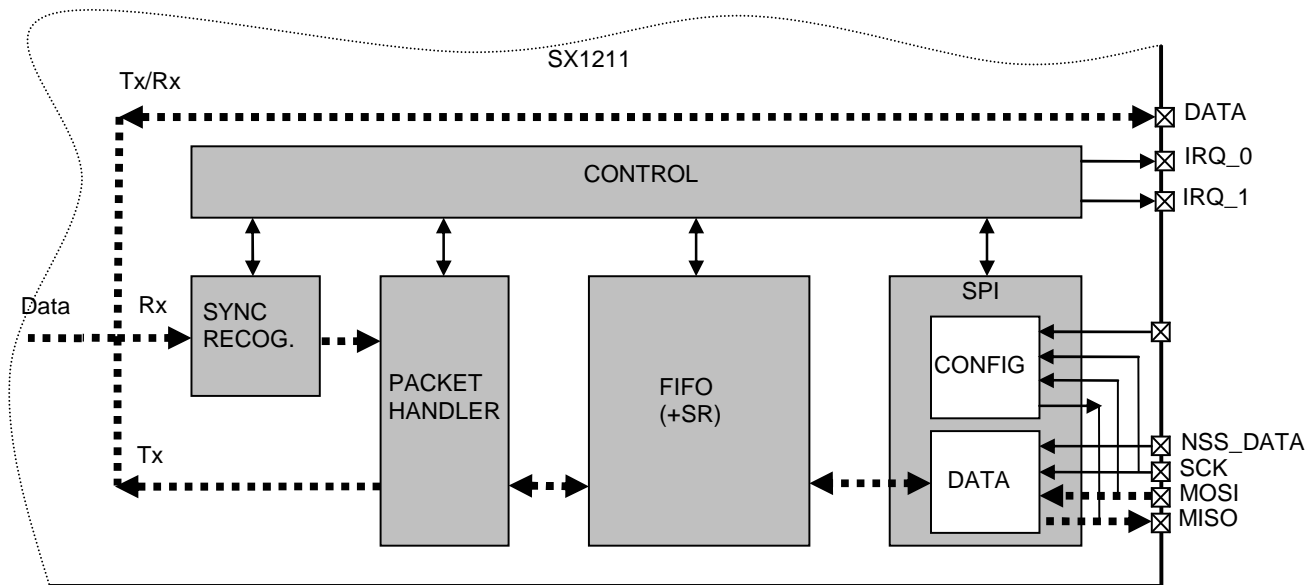


Figure 25: SX1211's Data Processing Conceptual View

As explained below, the SX1211 implements several data operation modes, each with their own data path through the data processing section. Depending on which data operation mode is selected, some blocks are active while others remain inactive.

4.1.2. Data Operation Modes

The SX1211 has three different data operation modes selectable by the user:

- **Continuous mode:** each bit transmitted or received is accessed in real time at the DATA pin. This mode may be used if adequate external signal processing is available.
- **Buffered mode:** each byte transmitted or received is stored in a FIFO and accessed via the SPI bus. uC processing overhead is hence significantly reduced compared to Continuous mode operation. The packet length is unlimited.
- **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, DC free encoding and the reverse operation is performed in reception. The uC processing overhead is hence reduced further compared to Buffered mode. The payload length is limited to 64 bytes (maximum FIFO size).

Table 13: Data Operation Mode Selection

| MCPParam_Data_mode | Data Operation Mode |
|--------------------|---------------------|
| 00 | Continuous |
| 01 | Buffered |
| 1x | Packet |

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

4.2. Building Blocks Description

4.2.1. SPI Interface

4.2.1.1. Overview

As illustrated in the figure below, the SX1211's SPI interface is actually made of two sub blocks:

- **SPI Config:** used in all data operation modes to read and write the configuration registers which control all the parameters of the chip (operating mode, bit rate, etc...)
- **SPI Data:** used in Buffered and Packet mode to write and read data bytes to and from the FIFO. (FIFO interrupts can be used to manage the FIFO content.)

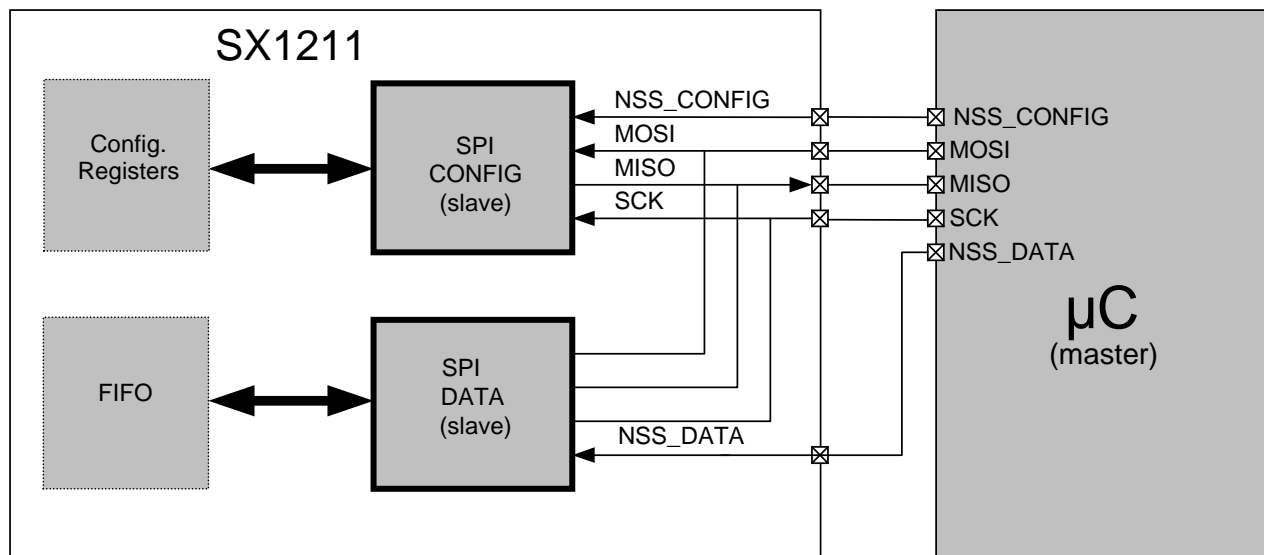


Figure 26: SPI Interface Overview and uC Connections

Both interfaces are configured in slave mode while the uC is the master. They have separate selection pins (NSS_CONFIG and NSS_DATA) but share the remaining pins:

- **SCK (SPI Clock):** clock signal provided by the uC
- **MOSI (Master Out Slave In):** data input signal provided by the uC
- **MISO (Master In Slave Out):** data output signal provided by the SX1211

As described below, only one interface can be selected at a time (NSS_CONFIG has the priority):

Table 14: Config vs. Data SPI Interface Selection

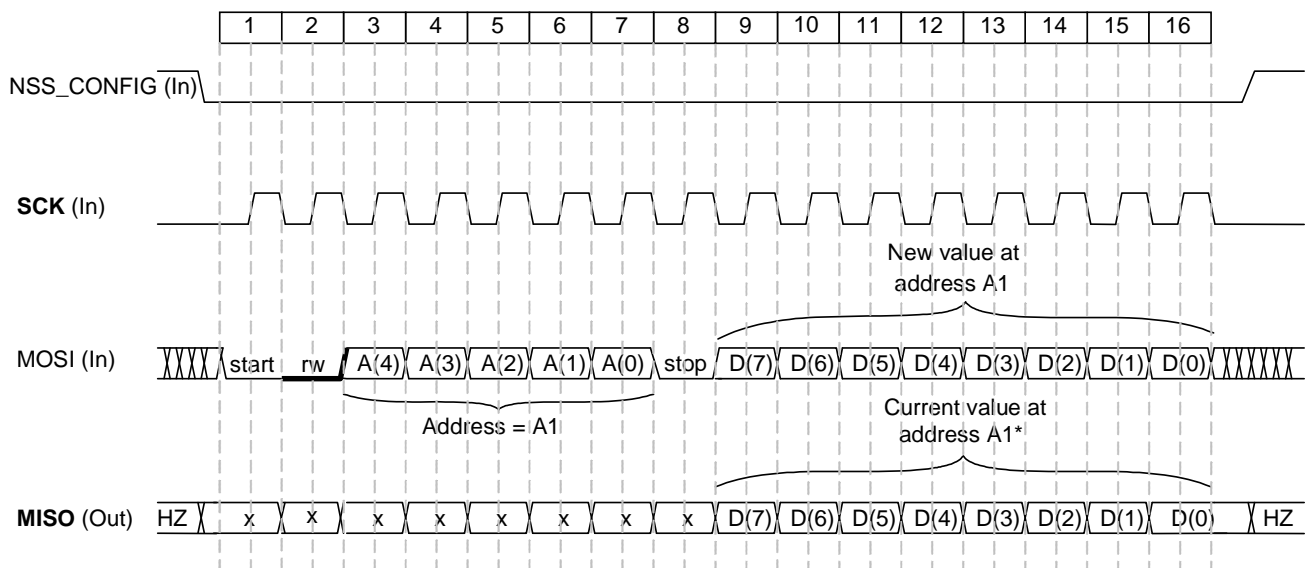
| NSS_DATA | NSS_CONFIG | SPI Interface |
|----------|------------|---------------|
| 0 | 0 | Config |
| 0 | 1 | Data |
| 1 | 0 | Config |
| 1 | 1 | None |

Following paragraphs describe how to use each of these interfaces.

4.2.1.2. SPI Config

- Write Register

To write a value into a configuration register the timing diagram below should be carefully followed by the uC. The register's new value is effective from the rising edge of NSS_CONFIG.



* when writing the new value at address A1, the current content of A1 can be read by the uC.
(In)/(Out) refers to SX1211 side

Figure 27: Write Register Sequence

Note that when writing more than one register successively, it is not compulsory to toggle NSS_CONFIG back high between two write sequences. The bytes are alternatively considered as address and value. In this instance, all new values will become effective on rising edge of NSS_CONFIG.

- Read Register

To read the value of a configuration register the timing diagram below should be carefully followed by the uC.

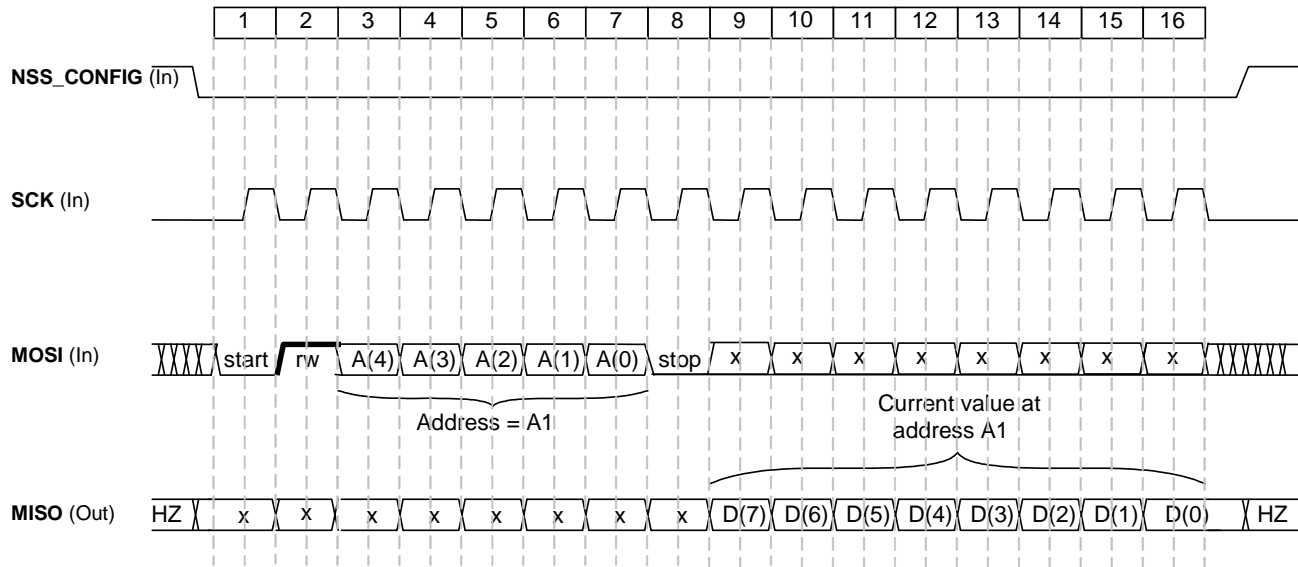


Figure 28: Read Register Sequence

Note that when reading more than one register successively, it is not compulsory to toggle NSS_CONFIG back high between two read sequences. The bytes are alternatively considered as address and value.

4.2.1.3. SPI Data

- Write Byte (before/during Tx)

To write bytes into the FIFO the timing diagram below should be carefully followed by the uC.

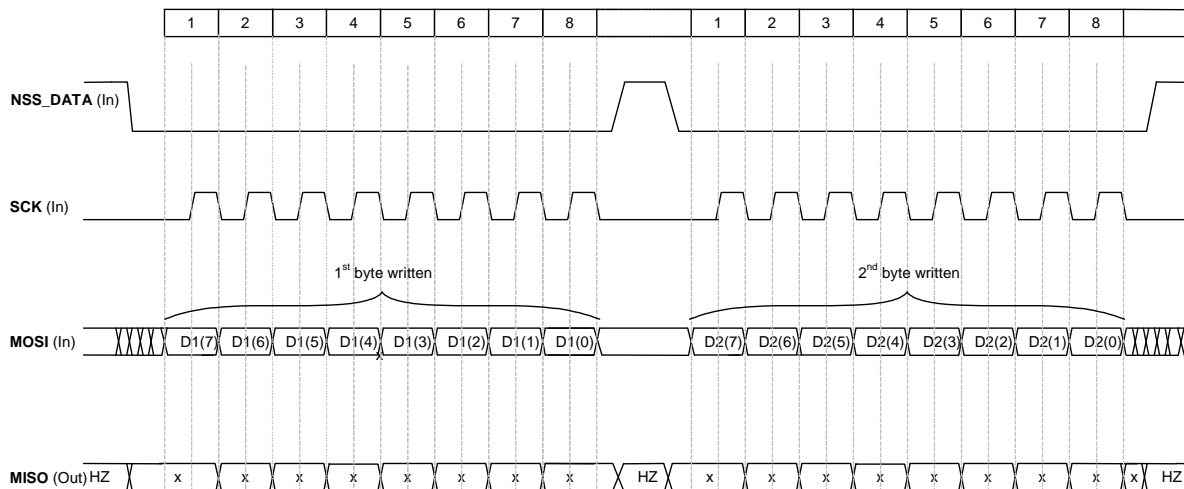


Figure 29: Write Bytes Sequence (ex: 2 bytes)

Note that it is compulsory to toggle NSS_DATA back high between each byte written. The byte is pushed into the FIFO on the rising edge of NSS_DATA

- Read Byte (after/during Rx)

To read bytes from the FIFO the timing diagram below should be carefully followed by the uC.

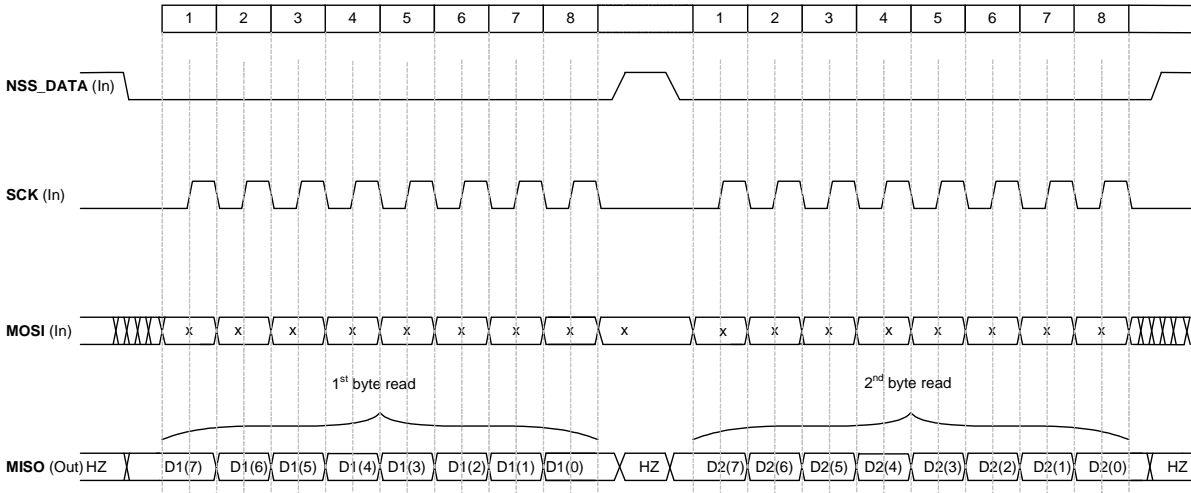


Figure 30: Read Bytes Sequence (ex: 2 bytes)

Note that it is compulsory to toggle NSS_DATA back high between each byte read.

4.2.2. FIFO

4.2.2.1. Overview and Shift Register (SR)

The SX1211 contains a FIFO (First In First Out) which is used in Buffered and Packet mode, to store both data to be transmitted and that has been received. It is accessed via the SPI Data interface and provides several interrupts for transfer management.

The FIFO is 1 byte (8 bits) 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.

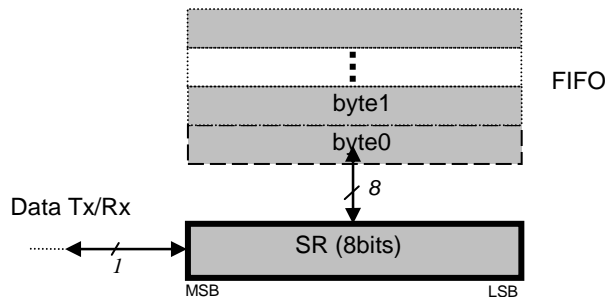


Figure 31: FIFO and Shift Register (SR)

4.2.2.2. Size Selection

The FIFO width is programmable, to 16, 32, 48 or 64 bytes via MCPParam_Fifo_size

4.2.2.3. Interrupt Sources and Flags

Except for `Fifo_threshold`, all interrupt sources and flags are configured in the `IRQParam` section of the configuration register.

- `/Fifoempty`: `/Fifoempty` interrupt source is low when byte0, i.e. whole FIFO, is empty. Otherwise it is high.
- `Write_byte`: `Write_byte` interrupt source goes high for 1 bit period each time a new byte is transferred from the SR to the FIFO (i.e. each time a new byte is received)
- `Fifofull`: `Fifofull` interrupt source is high when the last FIFO byte, i.e. the whole FIFO, is full. Otherwise it is low.
- `Fifo_overrun_clr`: `Fifo_overrun_clr` flag is set when 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.
- `Tx_done`: `Tx_done` interrupt source goes high when FIFO is empty and the SR's last bit has been send to the modulator (i.e. the last bit of the packet has been sent).

One bit period must be waited after the rising edge of `Tx_done` for effective RF transmission of last bit. Practically this may not require special care in the uC software due to IRQ processing time.

- `Fifo_threshold`: `Fifo_threshold` interrupt source's behavior depends on the running mode (Tx, Rx or Stby mode) and the threshold itself can be programmed via `MCPParam_Fifo_thresh` (B value). Full behavior is described in Figure 32.

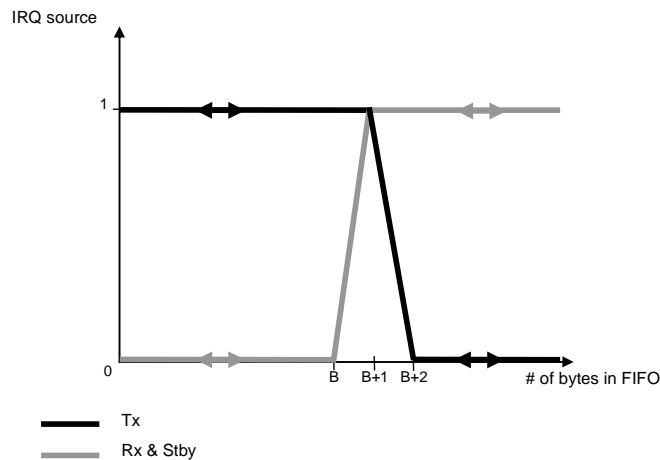


Figure 32: FIFO Threshold IRQ Source Behavior

4.2.2.4. FIFO Clearing

Table 15 below summarizes the status of the FIFO when switching between different modes

Table 15: Status of FIFO when Switching Between Different Modes of the Chip

| From | To | FIFO Status | Comments |
|------|-------|-------------|--|
| Stby | Tx | Cleared | In Buffered mode, FIFO cannot be written in Stby before Tx |
| | | Not cleared | In Packet mode, FIFO can be written in Stby before Tx |
| Stby | Rx | Cleared | |
| Rx | Tx | Cleared | |
| Rx | Stby | Not cleared | In Packet & Buffered modes FIFO can be read in Stby after Rx |
| Tx | Rx | Cleared | |
| Tx | Stby | Not cleared | |
| Any | Sleep | Cleared | |

4.2.3. Sync Word Recognition

4.2.3.1. Overview

Sync word recognition (also called Pattern recognition in previous products) is activated by setting `RXParam_Sync_on`. The bit synchronizer must also be activated.

The block behaves like a shift register; it continuously compares the incoming data with its internally programmed Sync word and asserts the Sync IRQ source when a match is detected. This is illustrated in Figure 33.

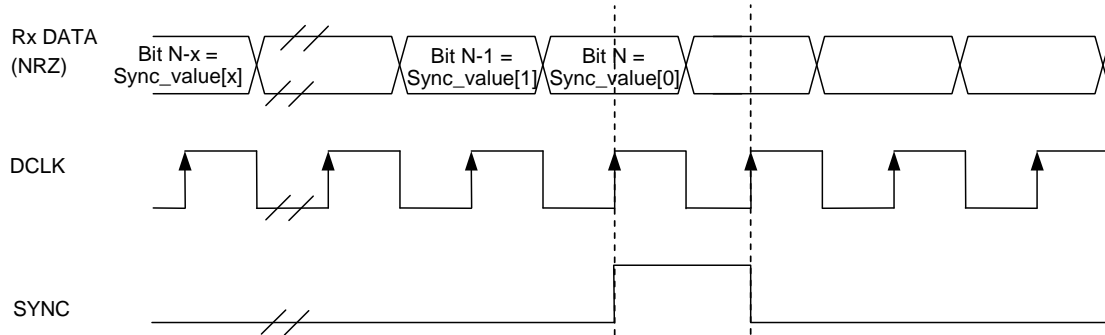


Figure 33: Sync Word Recognition

During the comparison of the demodulated data, the first bit received is compared with bit 7 (MSB) of byte at address 22 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 him and can be processed accordingly.

4.2.3.2. Configuration

- Size: Sync word size can be set to 8, 16, 24 or 32 bits via `RXParam_Sync_size`. In Packet mode this field is also used for Sync word generation in Tx mode.
- Error tolerance: The number of errors tolerated in the Sync word recognition can be set to 0, 1, 2 or 3 via `RXParam_Sync_tol`.
- Value: The Sync word value is configured in `SYNCPParam_Sync_value`. In Packet mode this field is also used for Sync word generation in Tx mode.

4.2.4. Packet Handler

The packet handler is the block used in Packet mode. Its functionality is fully described in section 4.5.

4.2.5. Control

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

4.3. Continuous Mode

4.3.1. General Description

As illustrated in Figure 34, in Continuous mode the NRZ data to (from) the (de)modulator is directly accessed by the uC on the bidirectional DATA pin (20). The SPI Data, FIFO and packet handler are thus inactive.

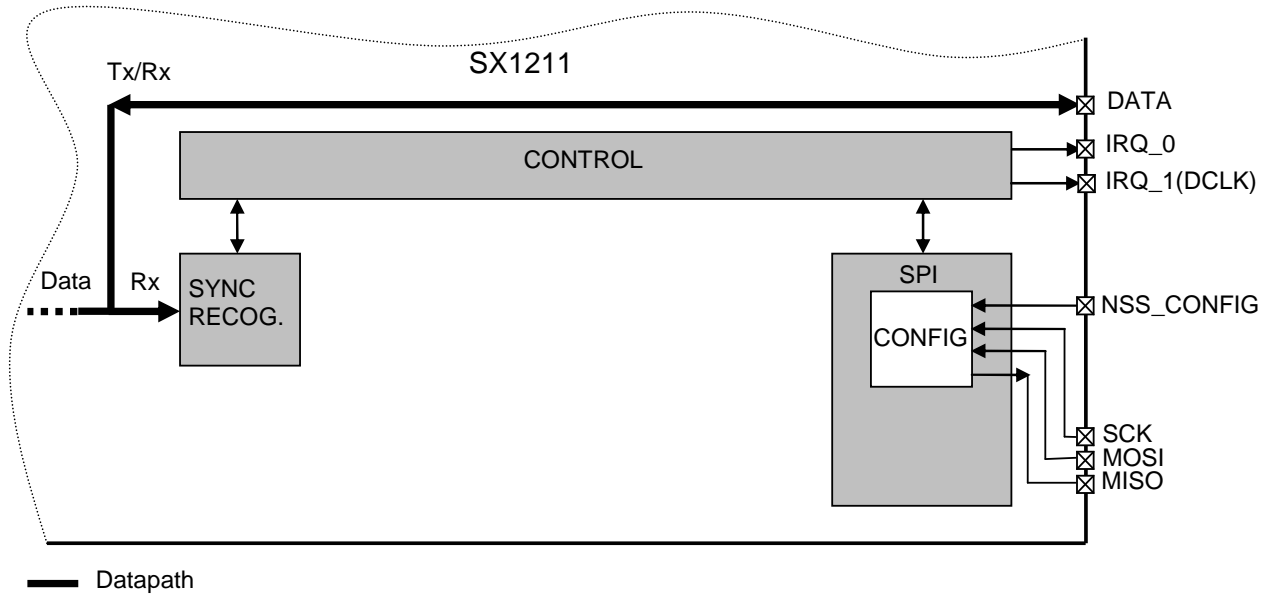


Figure 34: Continuous Mode Conceptual View

4.3.2. Tx Processing

In Tx mode, a synchronous data clock for an external uC is provided on IRQ_1 pin. Its timing with respect to the data is illustrated in Figure 35. DATA is internally sampled on the rising edge of DCLK so the uC can change logic state anytime outside the greyed out setup/hold zone.

The use of DCLK is compulsory in FSK and optional in OOK.

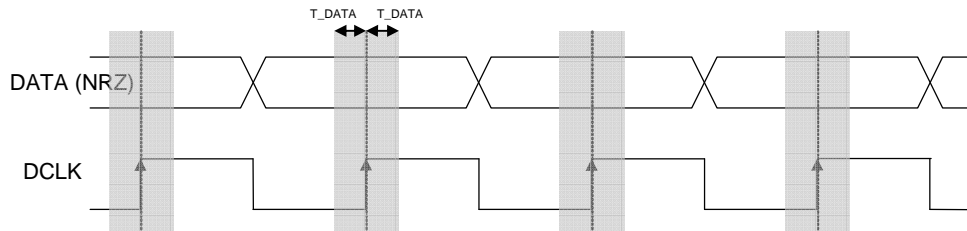


Figure 35: Tx Processing in Continuous Mode

4.3.3. 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 DATA and IRQ_1 pins. DATA is updated by SX1211 on DCLK's falling edge as illustrated in Figure 36.

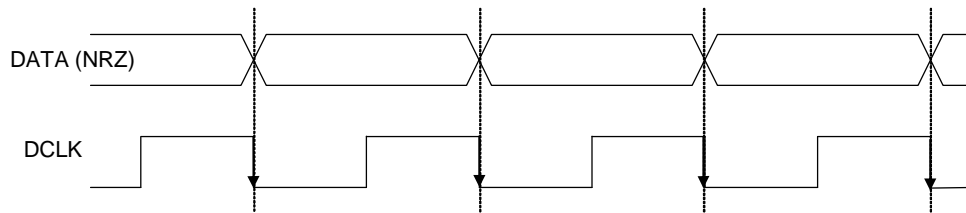


Figure 36: Rx Processing in Continuous Mode

Note that 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 Buffered and Packet mode).

4.3.4. Interrupt Signals Mapping

The tables below give the description of the interrupts available in Continuous mode.

| | Rx_stby_irq_0 | Rx |
|-------|---------------|------|
| IRQ_0 | 00 (d) | Sync |
| | 01 | RSSI |
| | 1x | - |
| IRQ_1 | | DCLK |

Table 16: Interrupt Mapping in Continuous Rx Mode

Note: In Continuous mode, no interrupt is available in Stby mode

| | Tx |
|-------|------|
| IRQ_0 | - |
| IRQ_1 | DCLK |

Table 17: Interrupt Mapping in Continuous Tx Mode

4.3.5. uC Connections

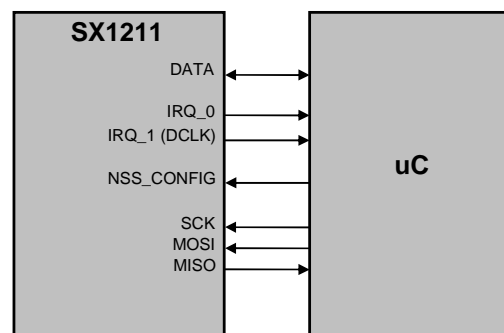


Figure 37: uC Connections in Continuous Mode

Note that some connections may not be needed depending on the application:

- IRQ_0: if Sync and RSSI interrupts are not used
- IRQ_1: if the chip is never used in Tx mode (DCLK connection is not compulsory in Rx).
- MISO: if no read register access is needed.

Please refer to Table 26 for SX1211's pins configuration

4.3.6. Example of Usage

On both sides:

- Configure all data processing related registers listed below appropriately. In this example we assume that both Bit synchronizer and Sync word recognition are on.

Table 18: Relevant Configuration Registers in Continuous Mode (data processing related only)

| | | Tx | Rx | Description |
|-------------------|---------------|----|----|--|
| MCPParam | Data_mode_x | X | X | Defines data operation mode (→ Continuous) |
| IRQParam | Rx_stby_irq_0 | | X | Defines IRQ_0 source in Rx mode |
| RXParam | Sync_on | | X | Enables Sync word recognition |
| | Sync_size | | X | Defines Sync word size |
| | Sync_tol | | X | Defines the error tolerance on Sync word recognition |
| SYNCPParam | Sync_value | | X | Defines Sync word value |

On Tx side:

- Go to Tx mode (and wait for Tx to be ready, see Figure 50)
- Send all packet's bits on DATA pin synchronously with DCLK signal provided on IRQ_1
- Go to Sleep mode

On Rx side:

- Program Rx interrupts: IRQ_0 mapped to Sync (Rx_stby_irq_0="00") and IRQ_1 mapped to DCLK (Bit synchronizer enabled)
- Go to Rx mode (note that Rx is not ready immediately, see Figure 49)
- Wait for Sync interrupt
- Get all packet bits on DATA pin synchronously with DCLK signal provided on IRQ_1
- Go to Sleep mode

4.4. Buffered Mode

4.4.1. General Description

As illustrated in Figure 38, in Buffered 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 Data interface. This frees the uC for other tasks between processing data from the SX1211, furthermore it simplifies software development and reduces uC performance requirements (speed, reactivity). Note that in this mode the packet handler stays inactive.

An important feature is also the ability to empty the FIFO in Stby mode, ensuring low power consumption and adding greater software flexibility.

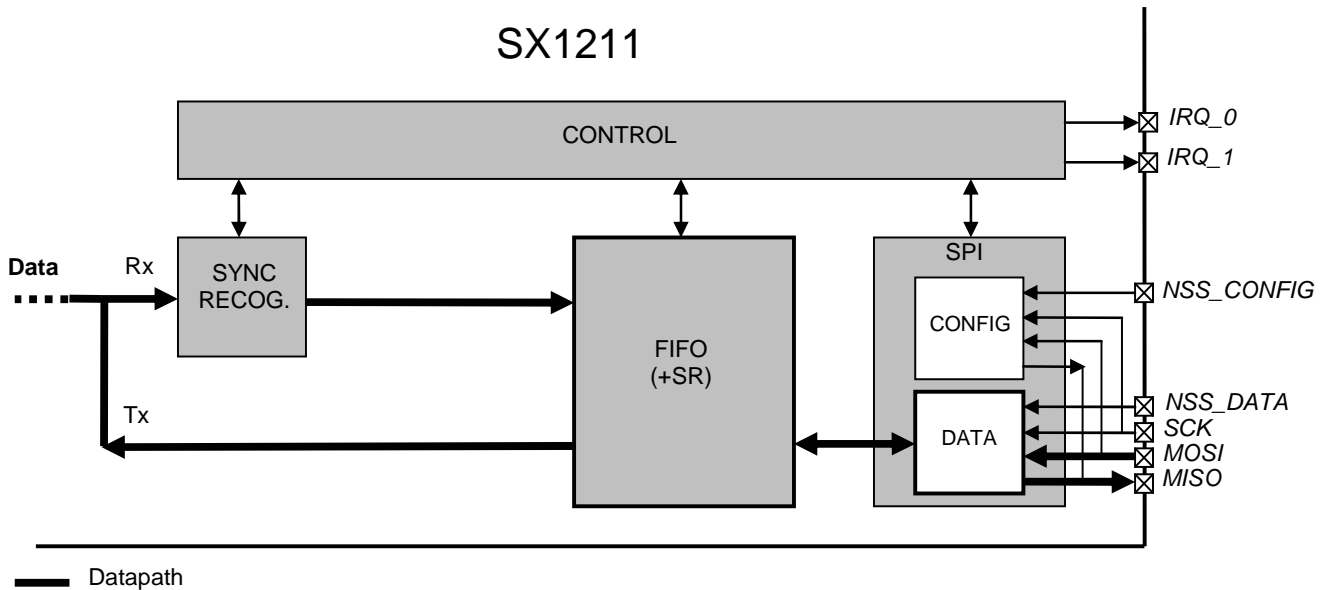


Figure 38: Buffered Mode Conceptual View

Note that Bit Synchronizer is automatically enabled in Buffered mode. The Sync word recognition must be activated by the user if needed.

4.4.2. Tx Processing

After entering Tx in Buffered mode, the chip expects the uC to write into the FIFO, via the SPI Data interface, all the data bytes to be transmitted (preamble, Sync word, payload...).

Actual transmission of first byte will start either when the FIFO is not empty (i.e. first byte written by the uC) or when the FIFO is full depending on bit `IRQParam_Tx_start_irq_0`.

In Buffered mode the packet length is not limited, i.e. as long as there are bytes inside the FIFO they are sent.

When the last byte is transferred to the SR, `/Fifoempty` IRQ source is asserted to warn the uC, at that time FIFO can still be filled with additional bytes if needed.

When the last bit of the last byte has left the SR (i.e. 8 bit periods later), the `Tx_done` interrupt source is asserted and the user can exit Tx mode after waiting at least 1 bit period from the last bit processed by modulator.

If the transmitter is switched off (for example due to entering another chip mode) during transmission it will stop immediately, even if there is still unsent data.

Figure 39 illustrates Tx processing with a 16 byte FIFO depth and `Tx_start_irq_0=0`. Please note that in this example the packet length is equal to FIFO size, but this does not need to be the case, the uC can use the FIFO interrupts anytime during Tx to manage FIFO contents and write additional bytes.

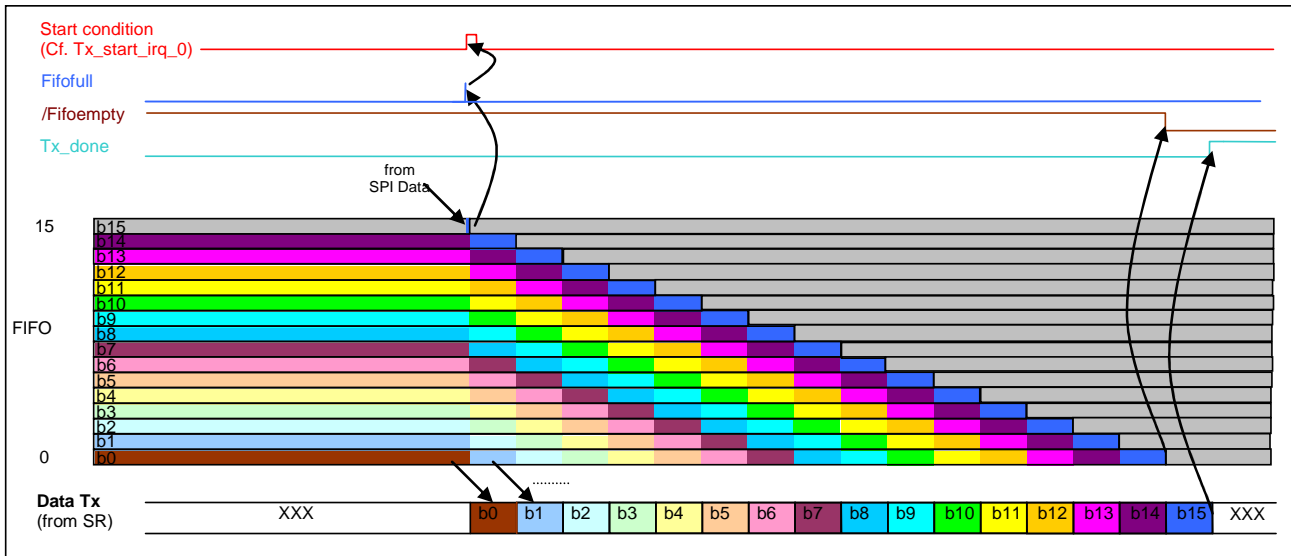


Figure 39: Tx processing in Buffered Mode (FIFO size = 16, Tx_start_irq_0=0)

4.4.3. Rx Processing

After entering Rx in Buffered mode, the chip requires the uC to retrieve the received data from the FIFO. The FIFO will actually start being filled with received bytes either; when a Sync word has been detected (in this case only the bytes following the Sync word are filled into the FIFO) or when the Fifo_fill bit is asserted by the user - depending on the state of bit, IRQParam_Fifo_fill_method.

In Buffered mode, the packet length is not limited i.e. as long as Fifo_fill is set, the received bytes are shifted into the FIFO.

The uC software must therefore mediate the transfer of the FIFO contents by interrupt and ensure reception of the correct number of bytes. (In this mode, even if the remote transmitter has stopped, the demodulator will output random bits from noise)

When the FIFO is full, Fifofull IRQ source is asserted to alert the uC, that at that time, the FIFO can still be unfilled without data loss. If the FIFO is not unfilled, once the SR is also full (i.e. 8 bits periods later) Fifo_overrun_clr is asserted and SR's content is lost.

Figure 40 illustrates an Rx processing with a 16 bytes FIFO size and Fifo_fill_method=0. Please note that in the illustrative example of section 4.4.6, the uC does not retrieve any byte from the FIFO through SPI Data, causing overrun.

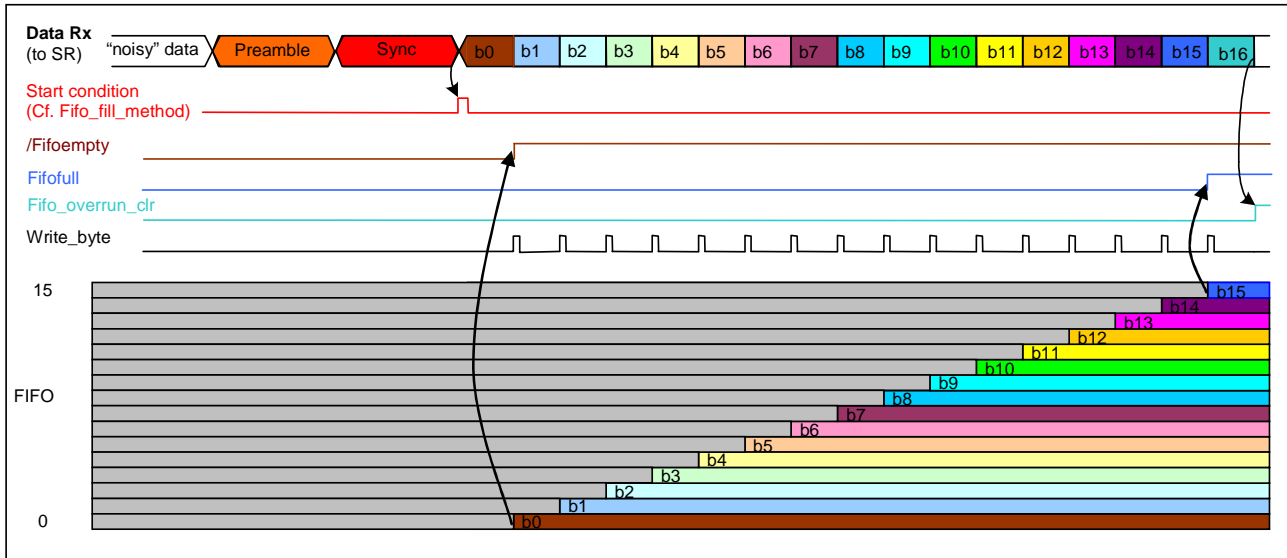


Figure 40: Rx Processing in Buffered Mode (FIFO size=16, Fifo_fill_method=0)

4.4.4. Interrupt Signals Mapping

The tables below describe the interrupts available in Buffered mode.

| | Rx_stby_irq_x | Rx | Stby |
|-------|---------------|----------------|----------------|
| IRQ_0 | 00 (d) | - | - |
| | 01 | Write_byte | - |
| | 10 | /Fifoempty | /Fifoempty |
| | 11 | Sync | - |
| IRQ_1 | 00 (d) | - | - |
| | 01 | Fifofull | Fifofull |
| | 10 | RSSI | - |
| | 11 | Fifo_threshold | Fifo_threshold |

Table 19: Interrupt Mapping in Buffered Rx and Stby Modes

| | | Tx |
|-------|----------------|------------|
| IRQ_1 | IRQ_0 | /Fifoempty |
| | Tx_irq_1=0 (d) | Fifofull |
| | Tx_irq_1=1 | Tx_done |

Table 20: Interrupt Mapping in Buffered Tx Mode

4.4.5. uC Connections

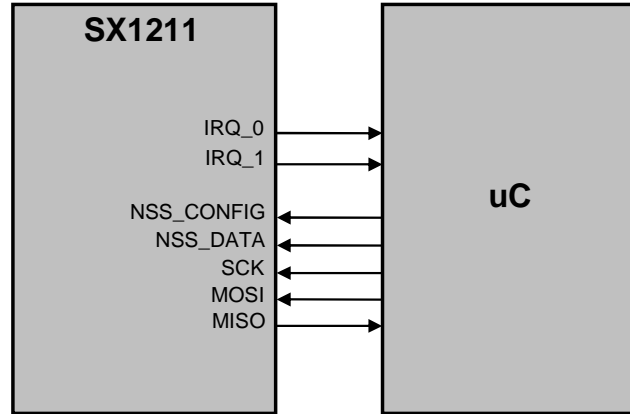


Figure 41: uC Connections in Buffered Mode

Note that depending upon the application, some uC connections may not be needed:

- IRQ_0: if none of the relevant IRQ sources are used.
- IRQ_1: if none of the relevant IRQ sources are used.
- MISO: if no read register access is needed and the chip is used in Tx mode only.

Please refer to Table 26 for the SX1211's pin configuration.

4.4.6. Example of Usage

On both sides:

- Configure all data processing related registers listed below appropriately. In this example we assume Sync word recognition is on and Fifo_fill_method=0.

| | | Tx | Rx | Description |
|-------------------|------------------|----|----|--|
| MCPParam | Data_mode_x | X | X | Defines data operation mode (→Buffered) |
| | Fifo_size | X | X | Defines FIFO size |
| | Fifo_thresh | X | X | Defines FIFO threshold |
| IRQParam | Rx_stby_irq_0 | | X | Defines IRQ_0 source in Rx & Stby modes |
| | Rx_stby_irq_1 | | X | Defines IRQ_1 source in Rx & Stby modes |
| | Tx_irq_1 | X | | Defines IRQ_1 source in Tx mode |
| | Fifo_fill_method | | X | Defines FIFO filling method |
| | Fifo_fill | | X | Controls FIFO filling status |
| | Tx_start_irq_0 | X | | Defines Tx start condition and IRQ_0 source |
| RXParam | Sync_size | | X | Defines Sync word size |
| | Sync_tol | | X | Defines the error tolerance on Sync word detection |
| SYNCPParam | Sync_value | | X | Defines Sync word value |

Table 21: Relevant Configuration Registers in Buffered Mode (data processing related only)

Tx side:

- Program Tx start condition and IRQs: Start Tx when FIFO is not empty (Tx_start_irq_0=1) and IRQ_1 mapped to Tx_done (Tx_irq_1=1)
- Go to Tx mode (and wait for Tx to be ready, see Figure 50)
- Write packet bytes into FIFO. Tx starts when the first byte is written (Tx_start_irq_0=1). We assume the FIFO is being filled via SPI Data faster than being unfilled by SR.

- Wait for Tx_done interrupt (+1 bit period)
- Go to Sleep mode

Rx side:

- Program Rx/Stby interrupts: IRQ_0 mapped to /Fifoempty (Rx_stby_irq_0=10) and IRQ_1 mapped to Fifo_threshold (Rx_stby_irq_1=01). Configure Fifo_thresh to an appropriate value (ex: to detect packet end if its length is known)
- Go to Rx mode (note that Rx is not ready immediately, Cf section 5.3.1).
- Wait for Fifo_threshold interrupt (i.e. Sync word has been detected and FIFO filled up to the defined threshold).
- If it is packet end, go to Stby (SR's content is lost).
- Read packet bytes from FIFO until /Fifoempty goes low (or correct number of bytes is read).
- Go to Sleep mode.

4.5. Packet Mode

4.5.1. General Description

Similarly to Buffered mode, 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 Data interface.

Additionally, the SX1211's packet handler performs several packet oriented tasks like Preamble and Sync word generation, CRC calculation/check, whitening/dewhitening of data, address filtering, etc. This simplifies software even more and reduces uC overhead by performing these repetitive tasks on the RF chip itself.

Another important feature is ability to fill and empty the FIFO in Stby mode, ensuring optimum power consumption and adding more flexibility for the software.

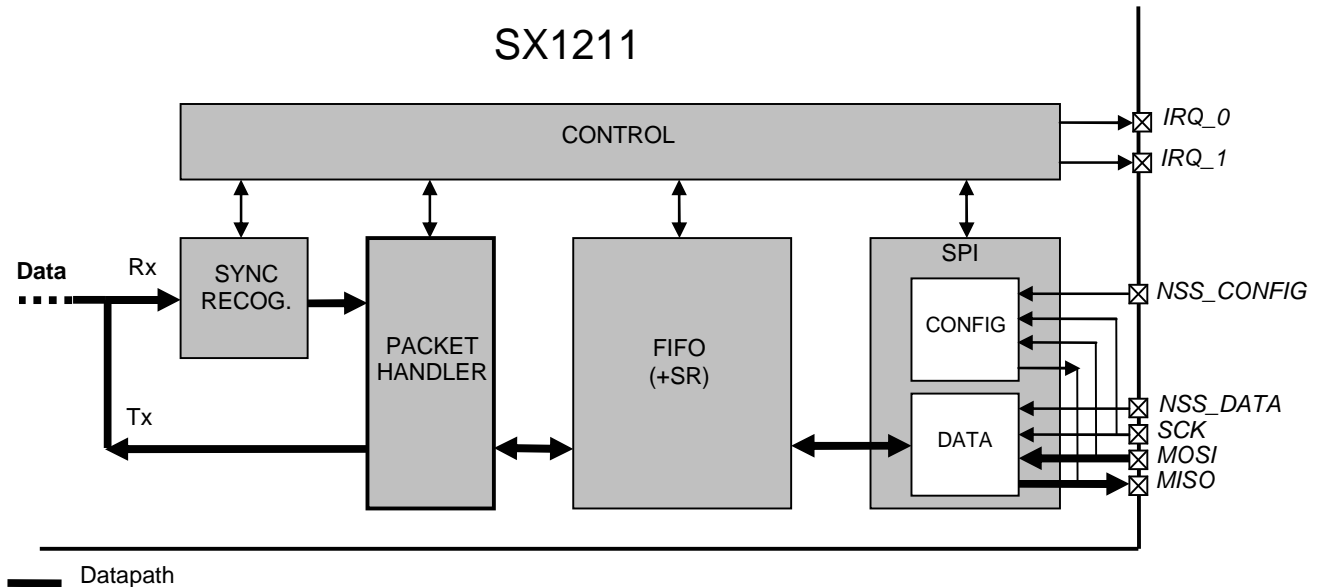


Figure 42: Packet Mode Conceptual View

Note that Bit Synchronizer and Sync word recognition are automatically enabled in Packet mode.

4.5.2. Packet Format

Two types of packet formats are supported: fixed length and variable length, selectable by the PKTParam_Pkt_format bit. The maximum size of the payload is limited by the size of the FIFO selected (16, 32, 48 or 64 bytes).

4.5.2.1. Fixed Length Packets

In applications where the packet length is fixed in advance, this mode may be of interest to minimize RF overhead (no length field to be sent). 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 set by the PKTParam_Payload_length register and is limited by the size of the FIFO selected.

The length stored in this register 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 in Figure 43. It 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.

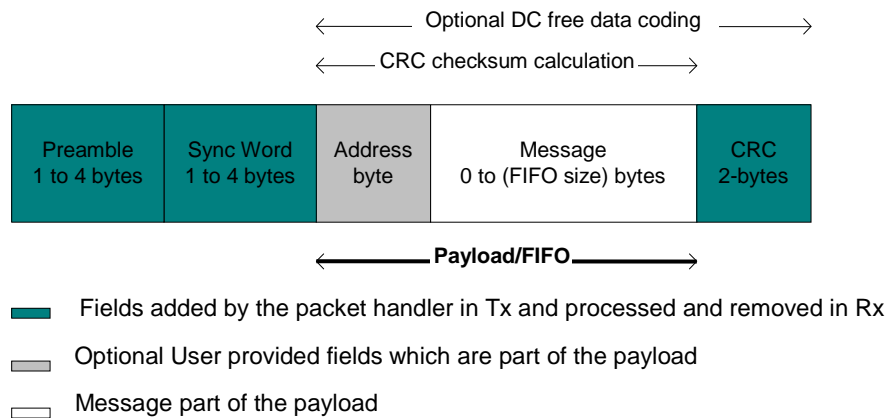


Figure 43: Fixed Length Packet Format

4.5.2.2. Variable Length Packets

This mode is necessary 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 of Figure 44, is given by the first byte of the FIFO and is limited only by the width of the FIFO selected. 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 in Figure 44. It is made up of the following fields:

- Preamble (1010...).
- Sync word (Network ID).

- Length byte
- Optional Address byte (Node ID).
- Message data.
- Optional 2-bytes CRC checksum.

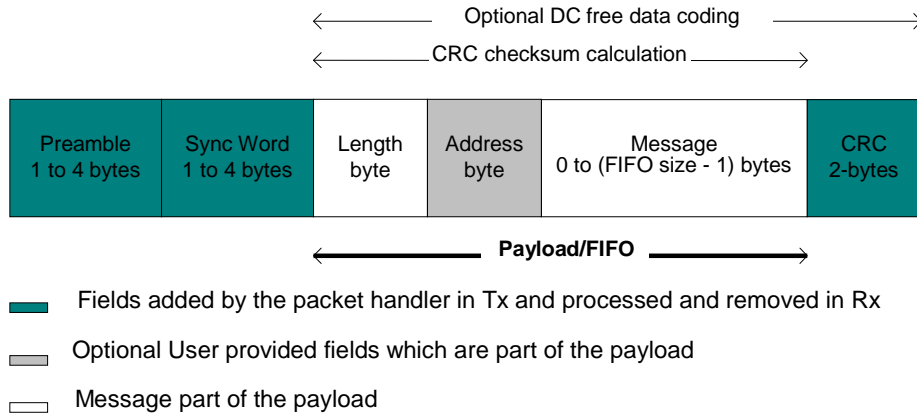


Figure 44: Variable Length Packet Format

4.5.3. 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.
- Performing optional DC-free encoding of the data (Manchester or whitening).

Only the payload (including optional address and length fields) is to be provided by the user in the FIFO. Assuming that the chip is already in Tx mode then, depending on `IRQParam_Tx_start_irq_0` bit, packet transmission (starting with programmed preamble) will start either after the first byte is written into the FIFO (`Tx_start_irq_0=1`) or after the number of bytes written reaches the user defined threshold (`Tx_start_irq_0=0`). The FIFO can also be fully or partially filled in Stby mode via `PKTParam_Fifo_stby_access`. In this case, the start condition will only be checked when entering Tx mode.

At the end of the transmission (`Tx_done = 1`), the user must explicitly exit Tx mode if required. (e.g. back to Stby)

Note that while in Tx mode, before and after actual packet transmission (not enough bytes or `Tx_done`), additional preamble bytes are automatically sent to the modulator. When the start condition is met, the current additional preamble byte is completely sent before the transmission of the next packet (i.e. programmed preamble) is started.

4.5.4. 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 `CRC_status` bit and `CRC_OK` IRQ source.

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

Payload_ready and CRC_OK interrupts (the latter only if CRC is enabled) can be generated to indicate the end of the packet reception.

By default, if the CRC check is enabled and fails for the current packet, then the FIFO is automatically cleared and neither of the two interrupts are generated and new packet reception is started. This autoclear function can be disabled via PKTParam_CRC_autoclr bit and, in this case, even if CRC fails, the FIFO is not cleared and only Payload_ready IRQ source is asserted.

Once fully received, the payload can also be fully or partially retrieved in Stby mode via PKTParam_Fifo_stby_access. At the end of the reception, although the FIFO automatically stops being filled, it is still up to the user to explicitly exit Rx mode if required. (e.g. go to Stby to get payload).

4.5.5. Packet Filtering

SX1211's packet handler offers several mechanisms for packet filtering ensuring that only useful packets are made available to the uC, reducing significantly system power consumption and software complexity.

4.5.5.1. Sync Word Based

Sync word filtering/recognition is automatically enabled in Packet mode. It 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, error tolerance, value) via RXParam_Sync_size, RXParam_Sync_tol and SYNCParam configuration 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 Sync IRQ source is asserted.

4.5.5.2. Address Based

Address filtering can be enabled via the PKTParam_Adrs_filt bits. It adds another level of filtering, above Sync word, 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).

Three address based filtering options are available:

- Adrs_filt = 01: Received address field is compared with internal register Node_Adrs. If they match then the packet is accepted and processed, otherwise it is discarded.
- Adrs_filt = 10: Received address field is compared with internal register Node_Adrs and the constant 0x00. 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.
- Adrs_filt = 11: Received address field is compared with internal register Node_Adrs and the constants 0x00 & 0xFF. If any of the three matches, then the received packet is accepted and processed, otherwise it is discarded. These additional checks with constants are useful for implementing broadcast commands of all nodes.

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.

Also note that Node_Adrs and Adrs_filt 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.

4.5.5.3. Length Based

In variable length Packet mode, PKTParam_Payload_length must be programmed with the maximum 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 PKTParam_Payload_length to the value of the FIFO size selected.

4.5.5.4. CRC Based

The CRC check is enabled by setting bit PKTParam_CRC_on. 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 the PKTParam_CRC_status bit and CRC_OK IRQ source.

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 PKTParam_CRC_autoclr bit and in this case, even if CRC fails, the FIFO is not cleared and only Payload_ready 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.

The CRC is based on the CCITT polynomial as shown in Figure 45. This implementation also detects errors due to leading and trailing zeros.

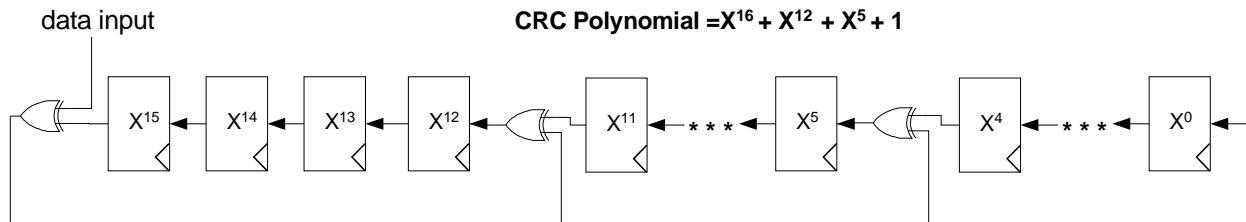


Figure 45: CRC Implementation

4.5.6. 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's 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. Please note that only one of the two methods should be enabled at a time.

4.5.6.1. Manchester Encoding

Manchester encoding/decoding is enabled by setting bit PKTParam_Manchester_on 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 MCPParam_BR (Chip Rate = Bit Rate NRZ = 2 x Bit Rate Manchester).

Manchester encoding/decoding is thus made transparent for the user, who still provides/retrieves NRZ data to/from the FIFO.

| | 1/BR ...Sync | | | | | | | | 1/BR Payload... | | | | | | | | | | |
|---------------------------------|--------------|---|---|---|---|---|---|---|-----------------|---|---|---|---|---|---|---|---|---|-----|
| RF chips @ BR | ... | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | ... |
| User/NRZ bits Manchester OFF | ... | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | ... |
| User/NRZ bits Manchester ON | ... | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | ... |

Figure 46: Manchester Encoding/Decoding

4.5.6.2. 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. Comparing to Manchester technique it has the advantage of keeping NRZ datarate i.e. actual bit rate is not halved.

The whitening/de-whitening process is enabled by setting bit PKTParam_Whitening_on. 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 in Figure 47. The data is de-whitened on the receiver side by XORing with the same random sequence. Payload whitening/de-whitening is thus made transparent for the user, who still provides/retrieves NRZ data to/from the FIFO.

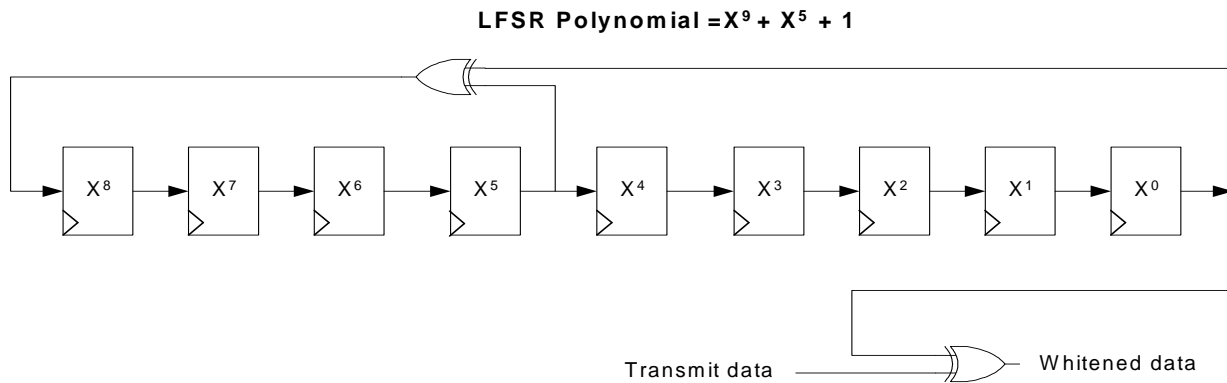


Figure 47: Data Whitening

4.5.7. Interrupt Signal Mapping

Tables below give the description of the interrupts available in Packet mode.

Table 22: Interrupt Mapping in Rx and Stby in Packet Mode

| | Rx_stby_irq_x | Rx | Stby |
|--------------|---------------|---------------------|----------------|
| IRQ_0 | 00 (d) | Payload_ready | - |
| | 01 | Write_byte | - |
| | 10 | /Fifoempty | /Fifoempty |
| | 11 | Sync or Adrs_match* | - |
| IRQ_1 | 00 (d) | CRC_OK | - |
| | 01 | Fifofull | Fifofull |
| | 10 | RSSI | - |
| | 11 | Fifo_threshold | Fifo_threshold |

*The latter if Address filtering is enabled

| | | Tx |
|-------|----------------------|----------------|
| IRQ_0 | Tx_start_irq_0=0 (d) | Fifo_threshold |
| | Tx_start_irq_0=1 | /Fifoempty |
| IRQ_1 | Tx_irq_1=0 (d) | Fifofull |
| | Tx_irq_1=1 | Tx_done |

Table 23: Interrupt Mapping in Tx Packet Mode

4.5.8. uC Connections

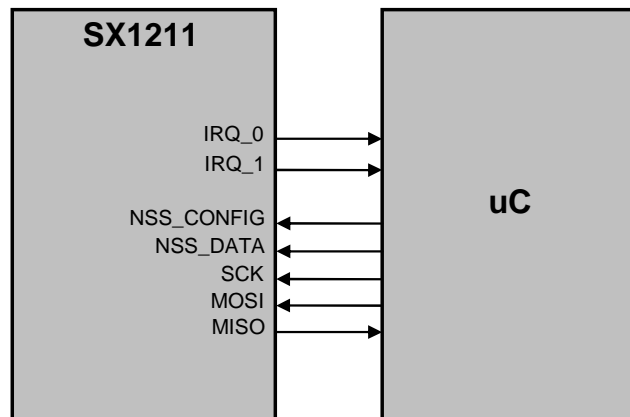


Figure 48: uC Connections in Packet Mode

Note that some connections may not be needed depending on the application.

- IRQ_0: if none of the relevant IRQ sources is used
- IRQ_1: if none of the relevant IRQ sources is used
- MISO: if no read register access is needed and chip is used in Tx only.

Please refer to Table 26 for the SX1211's pin configuration.

4.5.9. Example of Usage

On both sides:

Configure all data processing related registers listed below appropriately. In this example we assume CRC is enabled with autoclear on.

| | | Tx | Rx | Description |
|------------|----------------|------------------|----|--|
| MCPParam | Data_mode_x | X | X | Defines data operation mode (→Packet) |
| | Fifo_size | X | X | Defines FIFO size |
| | Fifo_thresh | X | X | Defines FIFO threshold |
| IRQParam | Rx_stby_irq_0 | | X | Defines IRQ_0 source in Rx & Stby modes |
| | Rx_stby_irq_1 | | X | Defines IRQ_1 source in Rx & Stby modes |
| | Tx_irq_1 | X | | Defines IRQ_1 source in Tx mode |
| | Tx_start_irq_0 | X | | Defines Tx start condition and IRQ_0 source |
| RXParam | Sync_size | X | X | Defines Sync word size |
| | Sync_tol | | X | Defines the error tolerance on Sync word detection |
| SYNCPParam | Sync_value | X | X | Defines Sync word value |
| PKTPParam | Manchester_on | X | X | Enables Manchester encoding/decoding |
| | Payload_length | X ⁽¹⁾ | X | Length in fixed format, max Rx length in variable format |
| | Node_adrs | | X | Defines node address for Rx address filtering |

| | | | | |
|--|------------------|---|---|--|
| | Pkt_format | X | X | Defines packet format (fixed or variable length) |
| | Preamble_size | X | | Defines the size of preamble to be transmitted |
| | Whitening_on | X | X | Enables whitening/de-whitening process |
| | CRC_on | X | X | Enables CRC calculation/check |
| | Adrs_filt | | X | Enables and defines address filtering |
| | CRC_autoclr | | X | Enables FIFO autoclear if CRC failed |
| | Fifo_stby_access | X | X | Defines FIFO access in Stby mode |

⁽¹⁾fixed format only

Table 24: Relevant Configuration Registers Relevant in Packet Mode (data processing related only)

On Tx side:

- Program Tx start condition and IRQs: Start Tx when FIFO not empty (Tx_start_irq_0=1) and IRQ_1 mapped to Tx_done (Tx_irq_1=1)
- Go to Stby mode
- Write all payload bytes into FIFO (Fifo_stby_access=0, Stby interrupts can be used if needed)
- Go to Tx mode. When Tx is ready (automatically handled) Tx starts (Tx_start_irq_0=1).
- Wait for Tx_done interrupt (+1 bit period)
- Go to Sleep mode

On Rx side:

- Program Rx/Stby interrupts: IRQ_0 mapped to /Fifoempty (Rx_stby_irq_0=10) and IRQ_1 mapped to CRC_OK (Rx_stby_irq_1=00)
- Go to Rx (note that Rx is not ready immediately, see section 5.3.1)
- Wait for CRC_OK interrupt
- Go to Stby
- Read payload bytes from FIFO until /Fifoempty goes low. (Fifo_stby_access =1)
- Go to Sleep mode

4.5.10. Additional Information

If the number of bytes filled for transmission is greater than the actual length of the packet to be transmitted and Tx_start_irq_0 = 1, then the FIFO is cleared after the packet has been transmitted. Thus the extra bytes in the FIFO are lost. On the other hand if Tx_start_irq_0 = 0 then the extra bytes are kept into the FIFO. This opens up the possibility of transmitting more than one packet by filling the FIFO with multiple packet messages.

It is not possible to receive multiple packets. Once a packet has been received and filled into the FIFO all its content needs to be read i.e. the FIFO must be empty for a new packet reception to be initiated.

The Payload_ready interrupt goes high when the last payload byte is available in the FIFO and remains high until all its data are read. Similar behavior is applicable to Adrs_match and CRC_OK interrupts.

The CRC result is available in the CRC_status bit as soon as the CRC_successful and Payload_ready interrupt sources are triggered. In Rx mode, CRC_status is cleared when the complete payload has been read from the FIFO. If the payload is read in Stby mode, then CRC_status is cleared when the user goes back to Rx mode and a new Sync word is detected.

The Fifo_fill_method and Fifo_fill bits don't have any meaning in the Packet mode and should be set to their default values only.

5. Operating Modes

This section summarizes the settings for each operating mode of the SX1211, and explains the functionality available and the timing requirements for switching between modes.

5.1. Modes of Operation

Table 25: Operating Modes

| Mode | MCParm_Chip_mode | Active blocks |
|----------|------------------|--|
| Sleep | 000 | SPI, POR |
| Standby | 001 | SPI, POR, Top regulator, digital regulator, XO, CLKOUT (if activated through OSCParam_Clkout) |
| FS | 010 | Same + VCO regulator, all PLL and LO generation blocks |
| Receive | 011 | Same as FS mode + LNA, first mixer, IF amplifier, second mixer set, channel filters, baseband amplifiers and limiters, RSSI, OOK or FSK demodulator, BitSync and all digital features if enabled |
| Transmit | 100 | Same as FS mode + DDS, Interpolation filters, all up-conversion mixers, PA driver, PA and external VR_PA pin output for PA choke. |

5.2. Digital Pin Configuration vs. Chip Mode

Table 26 describes the state of the digital IOs in each of the above described modes of operation.

Table 26: Pin Configuration vs. Chip Mode

| Chip Mode Pin | Sleep mode | Standby mode | FS mode | Receive mode | Transmit mode | Comment |
|---------------------------|--|---|---|--|--|---|
| NSS_CONFIG | INPUT | INPUT | INPUT | INPUT | INPUT | NSS_CONFIG has the priority over NSS_DATA |
| NSS_DATA | INPUT | INPUT | INPUT | INPUT | INPUT | |
| IRQ_0 | High-Z | OUTPUT(1) | OUTPUT(1) | OUTPUT | OUTPUT | |
| IRQ_1 | High-Z | OUTPUT(1) | OUTPUT(1) | OUTPUT | OUTPUT | |
| DATA | High-Z | High-Z | High-Z | OUTPUT | INPUT | |
| CLKOUT | High-Z | OUTPUT | OUTPUT | OUTPUT | OUTPUT | |
| MISO | OUTPUT if NSS_CON FIG='0' or NSS_DAT A = '0' | OUTPUT if NSS_CONFI G='0' or NSS_DATA = '0' | OUTPUT if NSS_CONFI G='0' or NSS_DATA = '0' | OUTPUT if NSS_CON FIG='0' or NSS_DAT A = '0' | OUTPUT if NSS_CON FIG='0' or NSS_DAT A = '0' | |
| MOSI | INPUT | INPUT | INPUT | INPUT | INPUT | |
| SCK | INPUT | INPUT | INPUT | INPUT | INPUT | |

Notes:

(1): High-Z if Continuous mode is activated

(2): valid logic states must be applied to inputs at all times to avoid unwanted leakage currents.

5.3. Switching Times and Procedures

As an ultra-low power device, the SX1211 can be configured for low minimum average power consumption. To minimize consumption the following optimized transitions between modes are shown.

5.3.1. Optimized Receive Cycle

The lowest-power Rx cycle is the following:

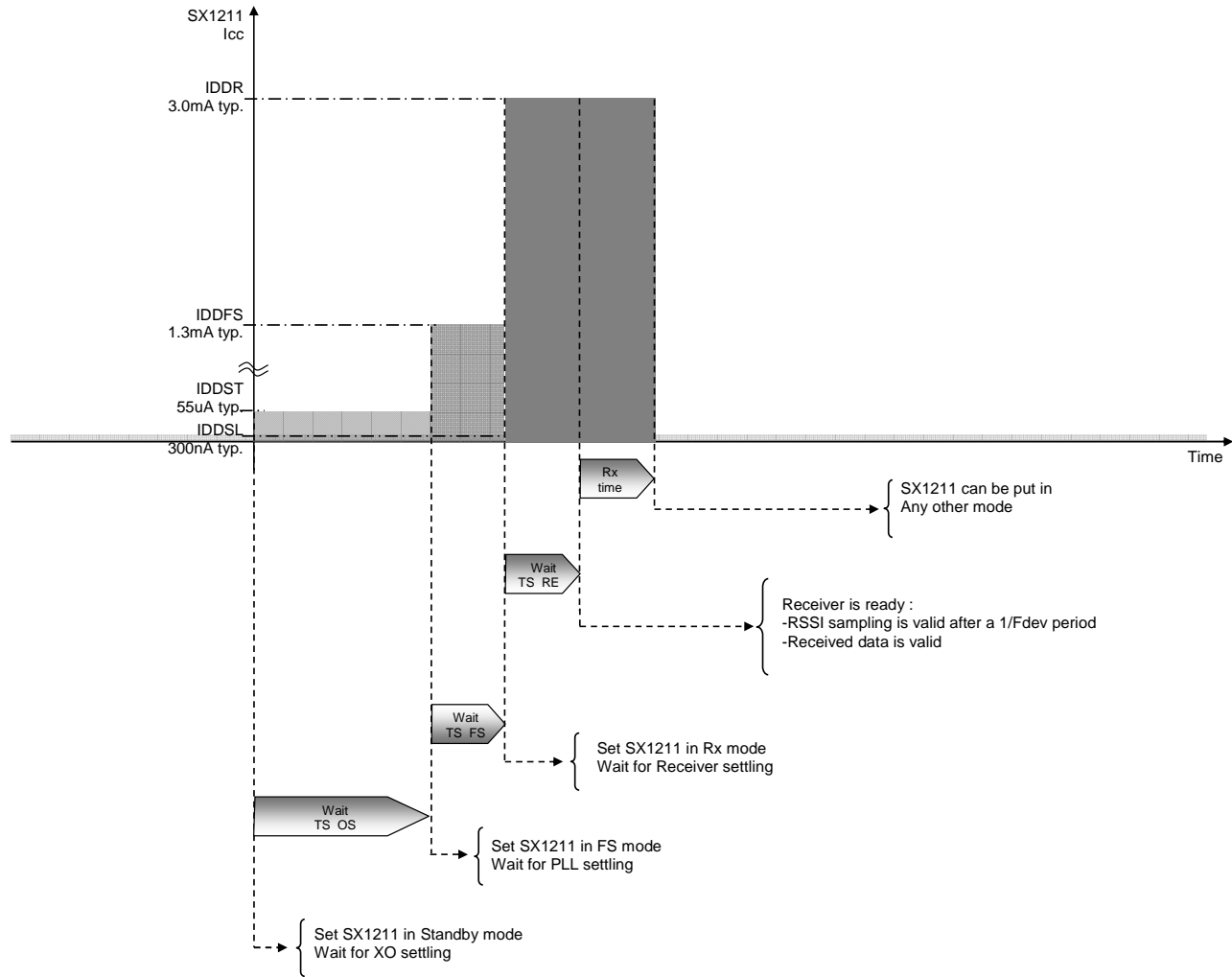


Figure 49: Optimized Rx Cycle

Note: If the lock detect indicator is available on an external interrupt pin of the companion uC, it can be used to optimize TS_FS, without having to wait the maximum specified TS_FS.

5.3.2. Optimized Transmit Cycle

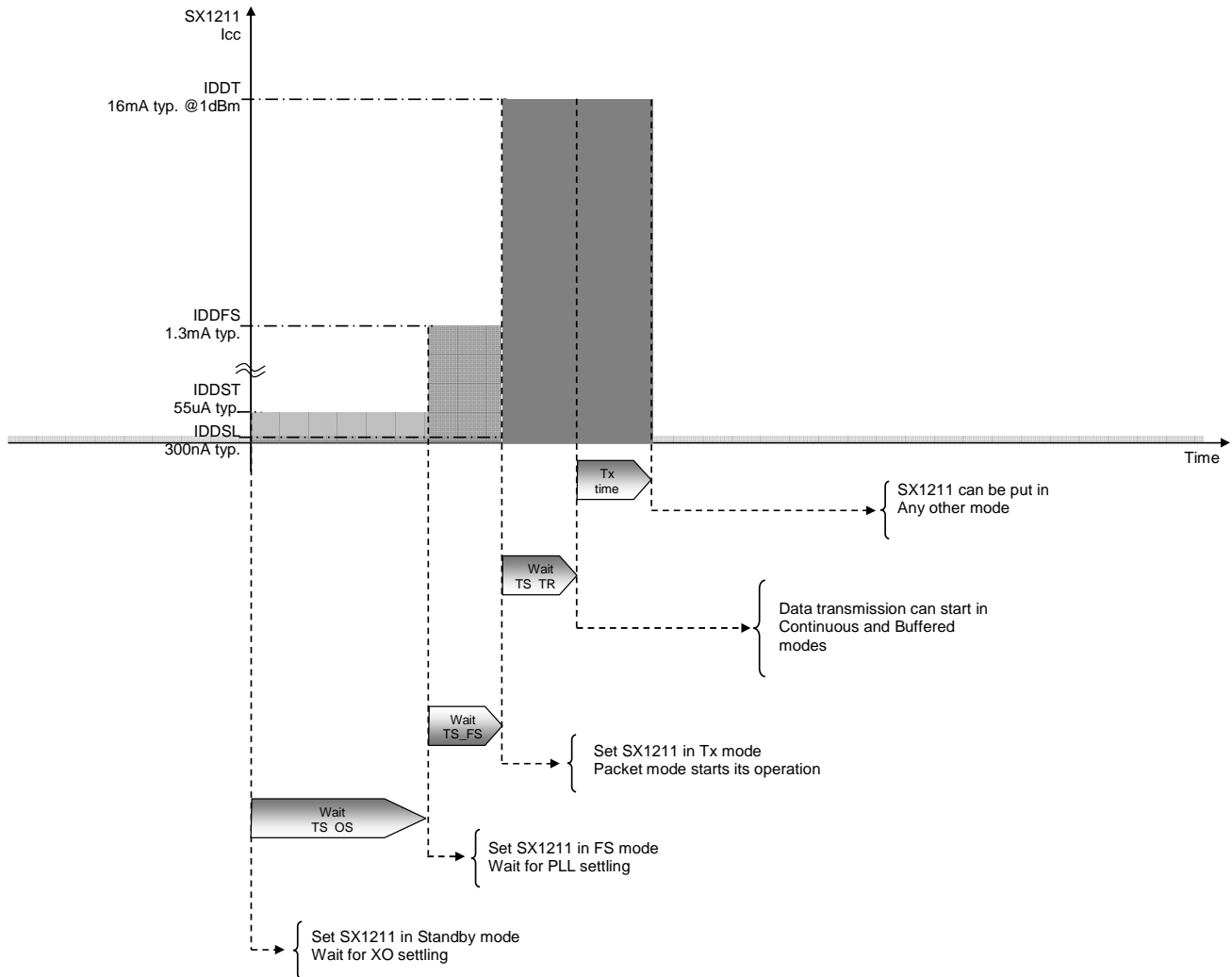


Figure 50: Optimized Tx Cycle

Note: As stated in the preceding section, TS_FS time can be improved by using the external lock detector pin as external interrupt trigger.

5.3.3. Transmitter Frequency Hop Optimized Cycle

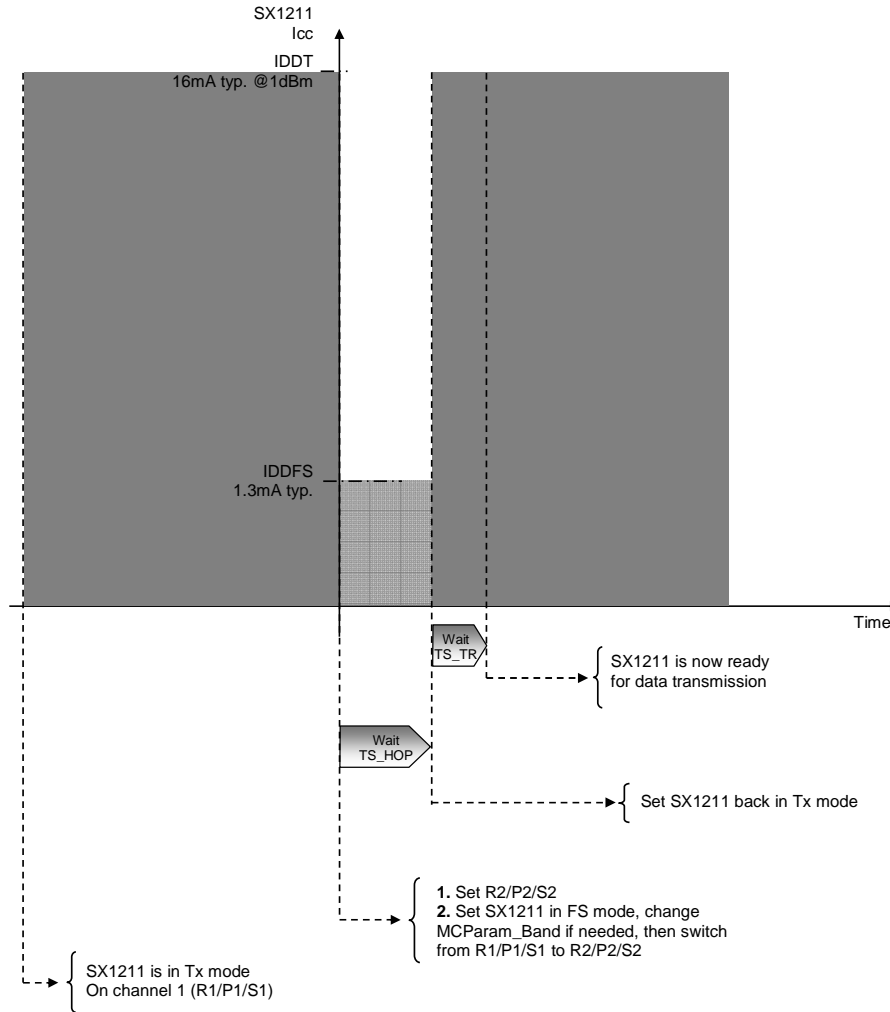


Figure 51: Tx Hop Cycle

5.3.4. Receiver Frequency Hop Optimized Cycle

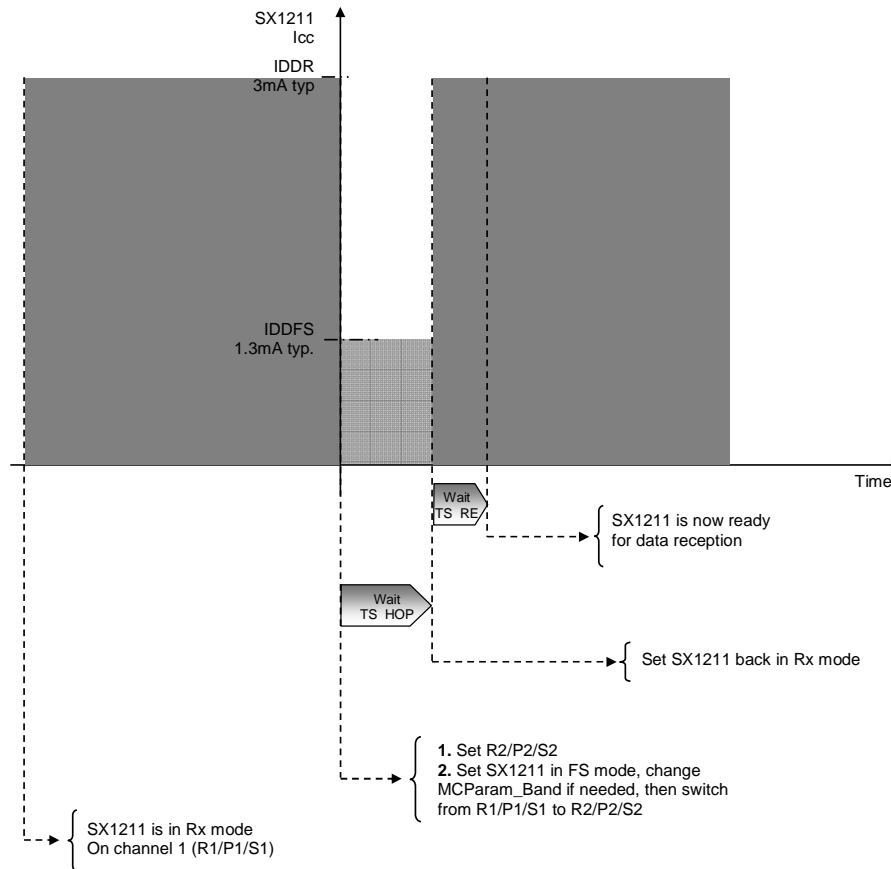


Figure 52: Rx Hop Cycle

5.3.5. Rx→Tx and Tx→Rx Jump Cycles

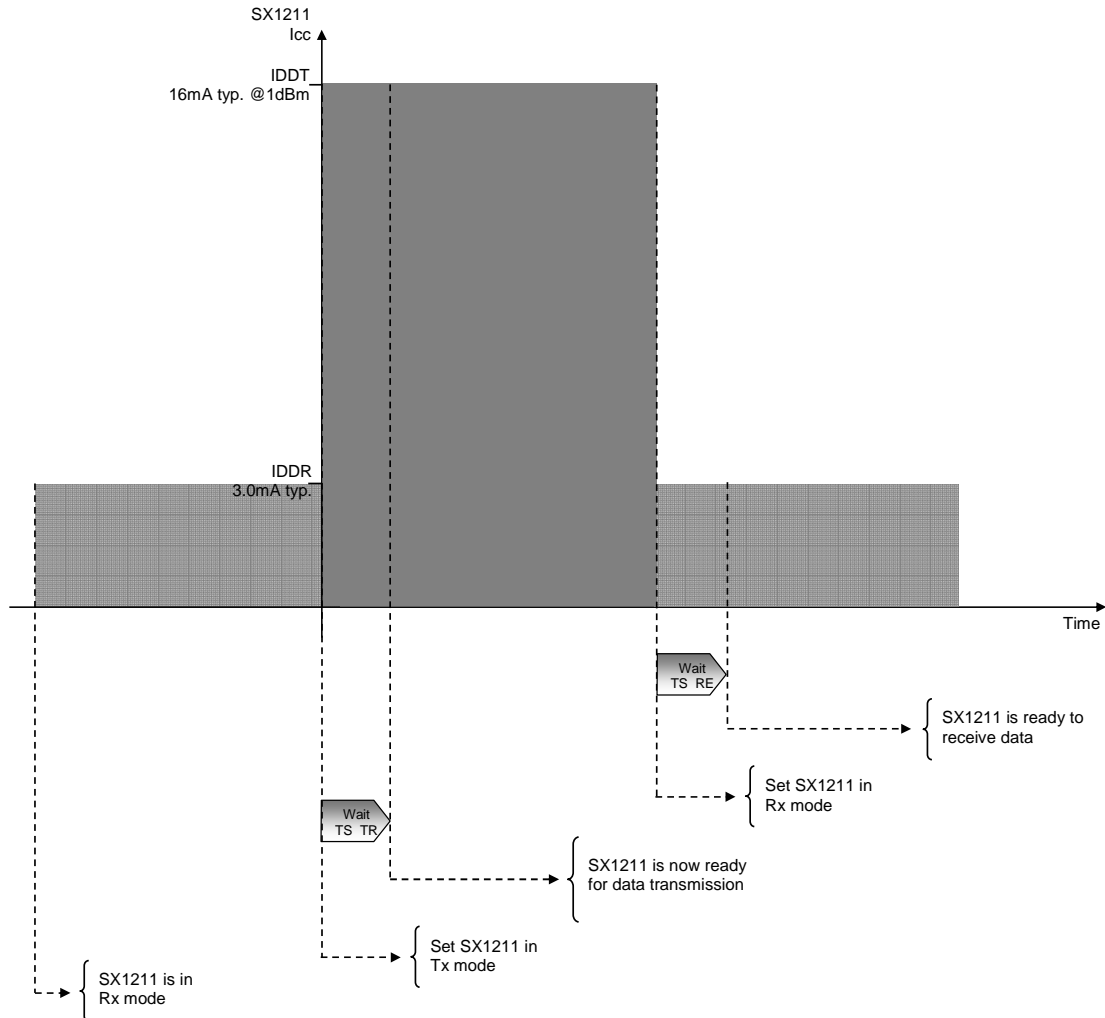


Figure 53: Rx → Tx → Rx Cycle

5.4. Power-On Reset

If the application requires the disconnection of VDD from the SX1211, despite of the extremely low Sleep Mode current, the user should wait for 10 ms before the device is actually able to communicate through the SPI port.

6. Configuration and Status Registers

6.1. General Description

Table 27 sums-up the control and status registers of the SX1211:

Table 27: Registers List

| Name | Size | Address | Description |
|------------|--------|---------|--|
| MCPParam | 13 x 8 | 0 - 12 | Main parameters common to transmit and receive modes |
| IRQParam | 3 x 8 | 13 - 15 | Interrupt registers |
| RXParam | 6 x 8 | 16 - 21 | Receiver parameters |
| SYNCPParam | 4 x 8 | 22 - 25 | Pattern |
| TXParam | 1 x 8 | 26 | Transmitter parameters |
| OSCPParam | 1 x 8 | 27 | Crystal oscillator parameters |
| PKTPParam | 3 x 8 | 28 - 31 | Packet handler parameters |

6.2. Main Configuration Register - MCPParam

The detailed description of the MCPParam register is given in Table 28.

Table 28: MCPParam Register Description

| Name | Bits | Address (dec) | RW | Description |
|-----------------|------|---------------|-----|---|
| Chip_mode | 7-5 | 0 | r/w | Transceiver mode: 000 → sleep mode - Sleep 001 → stand-by mode - Stby (d) 010 → frequency synthesizer mode - FS 011 → receive mode - Rx 100 → transmit mode - Tx |
| Freq_band | 4-3 | 0 | r/w | Frequency band: 00 → 902 – 915 MHz 01 → 915 – 928 MHz (d) 10 → 950 – 960 MHz and 863 - 870 MHz (with another VCO tank) |
| VCO_trim | 2-1 | 0 | r/w | Fine VCO trimming: 00 → Vtune as set by tank inductors values (d) 01 → Vtune + 1 x 60 mV typ. 10 → Vtune + 2 x 60 mV typ. 11 → Vtune + 3 x 60 mV typ. |
| RPS_select | 0 | 0 | r/w | Selection between the two sets of frequency dividers of the PLL, Ri/Pi/Si 0 → R1/P1/S1 used (d) 1 → R2/P2/S2 used |
| Modul_select | 7-6 | 1 | r/w | Type of modulation: 01 → OOK 10 → FSK (d) |
| Data_mode_0 | 5 | 1 | r/w | Data operation mode LSB. Data_mode(1:0): 00 → Continuous (d) 01 → Buffered 1x → Packet |
| OOK_thresh_type | 4-3 | 1 | r/w | OOK demodulator threshold type: 00 → fixed threshold mode 01 → peak mode (d) 10 → average mode 11 → reserved |

| | | | | |
|------------------|-----|----|-----|--|
| Data_mode_1 | 2 | 1 | r/w | Data operation mode's MSB. Cf Data_mode_0 |
| IF_gain | 1-0 | 1 | r/w | Gain on the IF chain: 00 → maximal gain (0dB) (d) 01 → -4.5 dB 10 → -9dB 11 → -13.5 dB |
| Freq_dev | 7-0 | 2 | r/w | Single side frequency deviation: $Fdev = \frac{f_{XTAL}}{32 \cdot (D + 1)}, 0 \leq D \leq 255$, where D is the value in the register. (d): D = "00000011" => Fdev = 100 kHz |
| Res | 7 | 3 | r/w | Reserved (d): "0" |
| BR | 6-0 | 3 | r/w | Bit Rate = $\frac{f_{XTAL}}{64 \cdot (C + 1)}$, 0 ≤ C ≤ 127, where C is the value in the register. (d): C = "0000111" => Bit Rate = 25 kb/s NRZ |
| OOK_floor_thresh | 7-0 | 4 | r/w | Floor threshold in OOK Rx mode. By default 6 dB. (d): "00001100" assuming 0.5 dB RSSI step |
| Fifo_size | 7:6 | 5 | r/w | FIFO size selection: 00 → 16 bytes (d) 01 → 32 bytes 10 → 48 bytes 11 → 64 bytes |
| Fifo_thresh | 5-0 | 5 | r/w | FIFO threshold for interrupt source (Cf section 4.2.2.3) (d): B = "001111" |
| R1 | 7-0 | 6 | r/w | R counter, active when RPS_select="0" (d):77h; default values of R1, P1, S1 generate (915.0 MHz-Fdev) |
| P1 | 7-0 | 7 | r/w | P counter, active when RPS_select="0" (d): 64h; default values of R1, P1, S1 generate (915.0 MHz-Fdev) |
| S1 | 7-0 | 8 | r/w | S counter, active when RPS_select="0" (d): 32h; default values of R1, P1, S1 generate (915.0 MHz-Fdev) |
| R2 | 7-0 | 9 | r/w | R counter, active when RPS_select="1" (d): 74h; default values of R2, P2, S2 generate (920.0 MHz-Fdev) |
| P2 | 7-0 | 10 | r/w | P counter, active when RPS_select="1" (d): 62h; default values of R2, P2, S2 generate (920.0 MHz-Fdev) |
| S2 | 7-0 | 11 | r/w | S counter, active when RPS_select="1" (d): 32h; default values of R2, P2, S2 generate (920.0 MHz-Fdev) |
| Res | 7-5 | 12 | r/w | Reserved (d): "001" |
| PA_ramp | 4-3 | 12 | r/w | Controls the ramp times of the PA regulator output voltage in OOK mode: 00 → 3us 01 → 8.5 us 10 → 15 us 11 → 23 us (d) |
| Res | 2-0 | 12 | r/w | Reserved (d):"000" |

6.3. Interrupt Configuration Parameters - IRQParam

The detailed description of the IRQParam register is given in Table 29.

Table 29: IRQParam Register Description

| Name | Bits | Address (dec) | RW | Description |
|------------------|------|---------------|-----------|---|
| Rx_stby_irq_0 | 7-6 | 13 | r/w | <p>IRQ_0 source in Rx and Standby modes:</p> <p>If Data_mode(1:0) = 00 (Continuous mode): 00 → Sync (d) 01 → RSSI 10 → Sync 11 → Sync</p> <p>If Data_mode(1:0) = 01 (Buffered mode): 00 → - (d) 01 → Write_byte 10 → /Fifoempty* 11 → Sync</p> <p>If Data_mode(1:0) = 1x (Packet mode): 00 → Payload_ready (d) 01 → Write_byte 10 → /Fifoempty* 11 → Sync or Adrs_match (the latter if address filtering is enabled)</p> <p>*also available in Standby mode (Cf sections 4.4.4 and 4.5.7)</p> |
| Rx_stby_irq_1 | 5-4 | 13 | r/w | <p>IRQ_1 source in Rx and Standby modes:</p> <p>If Data_mode(1:0) = 00 (Continuous mode): xx → DCLK</p> <p>If Data_mode(1:0) = 01 (Buffered mode): 00 → - (d) 01 → Fifofull* 10 → RSSI 11 → Fifo_threshold*</p> <p>If Data_mode(1:0) = 1x (Packet mode): 00 → CRC_ok (d) 01 → Fifofull* 10 → RSSI 11 → Fifo_threshold*</p> <p>*also available in Standby mode (Cf sections 4.4.4 and 4.5.7)</p> |
| Tx_irq_1 | 3 | 13 | r/w | <p>IRQ_1 source in Tx mode:</p> <p>If Data_mode(1:0) = 00 (Continuous mode): x → DCLK</p> <p>If Data_mode(1:0) = 01 (Buffered mode) or 1x (Packet mode): 0 → Fifofull (d) 1 → Tx_done</p> |
| Fifofull | 2 | 13 | r | Fifofull IRQ source Goes high when FIFO is full. |
| /Fifoempty | 1 | 13 | r | /Fifoempty IRQ source Goes low when FIFO is empty |
| Fifo_overrun_clr | 0 | 13 | r/w/ c | Goes high when an overrun error occurred. Writing a 1 clears flag and FIFO |
| Fifo_fill_method | 7 | 14 | r/w | FIFO filling method (Buffered mode only): |

| | | | | |
|-----------------|-----|----|-----------|---|
| | | | | 0 → Automatically starts when a sync word is detected (d) 1 → Manually controlled by Fifo_fill |
| Fifo_fill | 6 | 14 | r/w/ c | FIFO filling status/control (Buffered mode only): <ul style="list-style-type: none"> ▪ If Fifo_fill_method = '0': (d) Goes high when FIFO is being filled (sync word has been detected) Writing '1' clears the bit and waits for a new sync word (if Fifo_overrun_clr=0) <ul style="list-style-type: none"> ▪ If Fifo_fill_method = '1': 0 → Stop filling the FIFO 1 → Start filling the FIFO |
| Tx_done | 5 | 14 | r | Tx_done IRQ source Goes high when the last bit has left the shift register. |
| Tx_start_irq_0 | 4 | 14 | r/w | Tx start condition and IRQ_0 source: If Data_mode(1:0) = 01 (Buffered mode): 0 → Tx starts if FIFO is full, IRQ_0 mapped to /Fifoempty (d) 1 → Tx starts if FIFO is not empty, IRQ_0 mapped to /Fifoempty If Data_mode(1:0) = 1x (Packet mode): 0 → Start transmission when the number of bytes in FIFO is greater than or equal to the threshold set by MCPParam_Fifo_thresh parameter (Cf section 4.2.3), IRQ_0 mapped to Fifo_threshold (d) 1 → Tx starts if FIFO is not empty, IRQ_0 mapped to /Fifoempty |
| Res | 3 | 14 | r/w | (d): "0", should be set to "1" |
| RSSI_irq | 2 | 14 | r/w/ c | RSSI IRQ source: Goes high when a signal above RSSI_irq_thresh is detected Writing '1' clears the bit |
| PLL_locked | 1 | 14 | r/w/ c | PLL status: 0 → not locked 1 → locked Writing a '1' clears the bit |
| PLL_lock_en | 0 | 14 | r/w | PLL_locked mapped to pin 23: 0 → no, pin 23 is HI 1 → yes (d) |
| RSSI_irq_thresh | 7-0 | 15 | | RSSI threshold for interrupt (coded as RSSI) (d): "00000000" |

6.4. Receiver Configuration parameters - RXParam

The detailed description of the RXParam register is given in Table 30.

Table 30: RXParam Register Description

| Name | Bits | Address (d) | RW | Description |
|------------------|------|-------------|-----|---|
| PassiveFilt | 7-4 | 16 | r/w | Typical single side bandwidth of the passive low-pass filter. PassiveFilt = 0000 → 65 kHz 0001 → 82 kHz 0010 → 109 kHz 0011 → 137 kHz 0100 → 157 kHz 0101 → 184 kHz 0110 → 211 kHz 0111 → 234 kHz 1000 → 262 kHz 1001 → 321 kHz 1010 → 378 kHz (d) 1011 → 414 kHz 1100 → 458 kHz 1101 → 514 kHz 1110 → 676 kHz 1111 → 987 kHz |
| ButterFilt | 3-0 | 16 | r/w | Sets the receiver bandwidth. For BW information please refer to sections 3.4.5 (FSK) and 3.4.6 (OOK). (d): "0011" |
| PolypFilt_center | 7-4 | 17 | r/w | Central frequency of the polyphase filter (100kHz recommended): $f_0 = 200kHz \cdot \frac{F_{xtal} MHz}{12.8MHz} \cdot \frac{1 + Val(PolypFilt_center)}{8}$ (d): "0011" => $f_0 = 100$ kHz |
| Res | 3-0 | 17 | r/w | Reserved (d): "1000" |
| PolypFilt_on | 7 | 18 | r/w | Enable the polyphase filter, in OOK Rx mode: 0 → off (d) 1 → on |
| Bitsync_off | 6 | 18 | r/w | Bit synchronizer: control in Continuous Rx mode: 0 → on (d) 1 → off |
| Sync_on | 5 | 18 | r/w | Sync word recognition: 0 → off (d) 1 → on |
| Sync_size | 4-3 | 18 | r/w | Sync word size: 00 → 8 bits 01 → 16 bits 10 → 24 bits 11 → 32 bits (d) |
| Sync_tol | 2-1 | 18 | r/w | Number of errors tolerated in the Sync word recognition: 00 → 0 error (d) 01 → 1 error 10 → 2 errors 11 → 3 errors |
| Res | 0 | 18 | r/w | Reserved (d): "0" |
| Res | 7-0 | 19 | r/w | Reserved (d): "00000111" |

| Name | Bits | Address (d) | RW | Description |
|-----------------------|------|-------------|-----|--|
| RSSI_val | 7-0 | 20 | r | RSSI output, 0.5 dB / bit Caution: not to be written |
| OOK_thresh_step | 7-5 | 21 | r/w | Size of each decrement of the RSSI threshold in the OOK demodulator 000 → 0.5 dB (d) 100 → 3.0 dB 001 → 1.0 dB 101 → 4.0 dB 010 → 1.5 dB 110 → 5.0 dB 011 → 2.0 dB 111 → 6.0 dB |
| OOK_thresh_dec_period | 4-2 | 21 | r/w | Period of decrement of the RSSI threshold in the OOK demodulator: 000 → once in each chip period (d) 001 → once in 2 chip periods 010 → once in 4 chip periods 011 → once in 8 chip periods 100 → twice in each chip period 101 → 4 times in each chip period 110 → 8 times in each chip period 111 → 16 times in each chip period |
| OOK_avg_thresh_cutoff | 1-0 | 21 | r/w | Cutoff frequency of the averaging for the average mode of the OOK threshold in demodulator 00 → $f_c \approx BR / 8.\pi$ (d) 01 → Reserved 10 → Reserved 11 → $f_c \approx BR / 32.\pi$ |

6.5. Sync Word Parameters - SYNCParam

The detailed description of the SYNCParam register is given in Table 31.

Table 31: SYNCParam Register Description

| Name | Bits | Address (d) | RW | Description |
|-------------------|------|-------------|-----|---|
| Sync_value(31:24) | 7-0 | 22 | r/w | Sync word's 1 st byte (d): "00000000" |
| Sync_value(23:16) | 7-0 | 23 | | Sync word's 2 nd byte (only used if Sync_size ≠ 00) (d): "00000000" |
| Sync_value(15:8) | 7-0 | 24 | | Sync word's 3 rd byte (only used if Sync_size = 1x) (d): "00000000" |
| Sync_value(7:0) | 7-0 | 25 | | Sync word's 4 th byte (only used if Sync_size = 11) (d): "00000000" |

6.6. Transmitter Parameters - TXParam

The detailed description of the TXParam register is given in Table 32.

Table 32: TXParam Register Description

| Name | Bits | Address (d) | RW | Description |
|------------|------|-------------|-----|--|
| InterpFilt | 7-4 | 26 | r/w | Interpolation filter cut off frequency: $f_c = 200\text{kHz} \cdot \frac{F_{xtal}\text{MHz}}{12.8\text{MHz}} \cdot \frac{1 + \text{Val}(\text{InterpFiltTx})}{8}$ (d): "0111" => $f_c = 200\text{ kHz}$ |
| Pout | 3-1 | 26 | r/w | Tx output power (1 step \approx 3 dB): 000 \rightarrow 13 dBm 001 \rightarrow 13 dBm -1 step (d) 010 \rightarrow 13 dBm - 2 steps 011 \rightarrow 13 dBm - 3 steps 100 \rightarrow 13 dBm - 4 steps 101 \rightarrow 13 dBm - 5 steps 110 \rightarrow 13 dBm - 6 steps 111 \rightarrow 13 dBm - 7 steps |
| Res | 0 | 26 | r/w | Reserved (d): "0" |

6.7. Oscillator Parameters - OSCParam

The detailed description of the OSCParam register is given in Table 33.

Table 33: OSCParam Register Description

| Name | Bits | Address (dec) | RW | Description |
|-------------|------|---------------|-----|--|
| Clkout_on | 7 | 27 | r/w | Clkout control 0 \rightarrow off 1 \rightarrow on, frequency given by Clkout_freq (d) |
| Clkout_freq | 6-2 | 27 | r/w | Frequency of the signal provided on CLKOUT: $f_{clkout} = f_{xtal}$ if Clkout_freq = "00000" $f_{clkout} = \frac{f_{xtal}}{2 \cdot \text{Clkout_freq}}$ otherwise (d): 01111 (= 427 kHz) |
| Res | 1-0 | 27 | r/w | Reserved (d): "00" |

6.8. Packet Handling Parameters – PKTParam

The detailed description of the PKTParam register is given in Table 34.

Table 34: PKTParam Register Description

| Name | Bits | Address (dec) | RW | Description |
|------------------|------|---------------|-----|--|
| Manchester_on | 7 | 28 | r/w | Enable Manchester encoding/decoding: 0 → off (d) 1 → on |
| Payload_length | 6-0 | 28 | r/w | If Pkt_format=0, payload length. If Pkt_format=1, max length in Rx, not used in Tx. (d): "000000" |
| Node_adrs | 7-0 | 29 | r/w | Node's local address for filtering of received packets. (d): 00h |
| Pkt_format | 7 | 30 | r/w | Packet format: 0 → fixed length (d) 1 → variable length |
| Preamble_size | 6-5 | 30 | r/w | Size of the preamble to be transmitted: 00 → 1 byte 01 → 2 bytes 10 → 3 bytes (d) 11 → 4 bytes |
| Whitening_on | 4 | 30 | r/w | Whitening/dewhitening process: 0 → off (d) 1 → on |
| CRC_on | 3 | 30 | r/w | CRC calculation/check: 0 → off 1 → on (d) |
| Adrs_filt | 2-1 | 30 | r/w | Address filtering of received packets: 00 → off (d) 01 → Node_adrs accepted, else rejected. 10 → Node_adrs & 0x00 accepted, else rejected. 11 → Node_adrs & 0x00 & 0xFF accepted, else rejected. |
| CRC_status | 0 | 30 | r | CRC check result for current packet: 0 → failed 1 → ok |
| CRC_autoclr | 7 | 31 | r/w | FIFO auto clear if CRC failed for current packet: 0 → on (d) 1 → off |
| Fifo_stby_access | 6 | 31 | r/w | FIFO access in standby mode: 0 → Write (d) 1 → Read |
| Res | 5-0 | 31 | r/w | Reserved (d): "000000" |

7. Reference Design

The SX1211 results presented in the preceding sections have been measured on the SM1211 two-layer reference design detailed below.

It is strongly recommended that this reference design (i.e. schematics, placement, layout, BOM,) is copied *verbatim* in the final application board to guarantee optimum performance, short development time and the least design effort.

7.1. Schematics

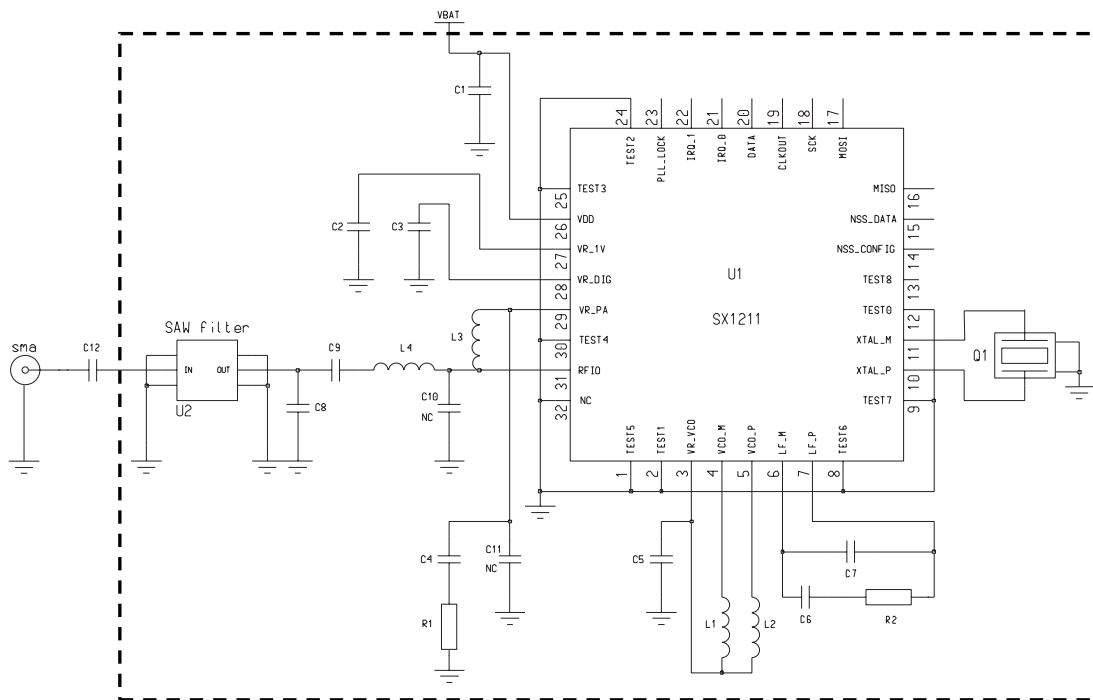


Figure 54: Reference Design's Schematics

The reference design area is represented by the dashed rectangle. C12 is a DC blocking capacitor which protects the SAW filter. It has been added for debug purposes only so is not required for a direct antenna connection. Please note that C10 and C11 are not used.

7.2. PCB Layout

As illustrated in figures below, the layout has the following characteristics:

- very compact (9x19mm) => can be easily inserted even on very small PCBs
- standard PCB technology (2 layers, 1.6mm, std via & clearance) => low cost
- Its performance is quasi-insensitive to dielectric thickness => quasi-zero effort portability to other PCB technology (thickness, # of layers, etc...)

The layers description is illustrated in Figure 55:

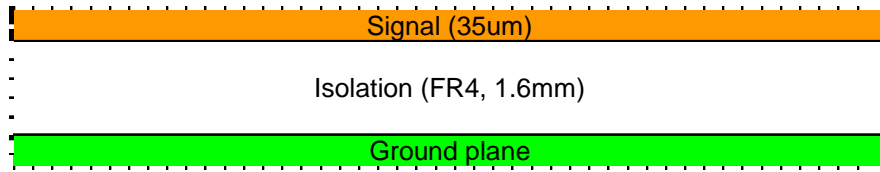


Figure 55: Reference Design's Stackup

The layout itself is illustrated in Figure 56. Please contact Semtech for gerber files.

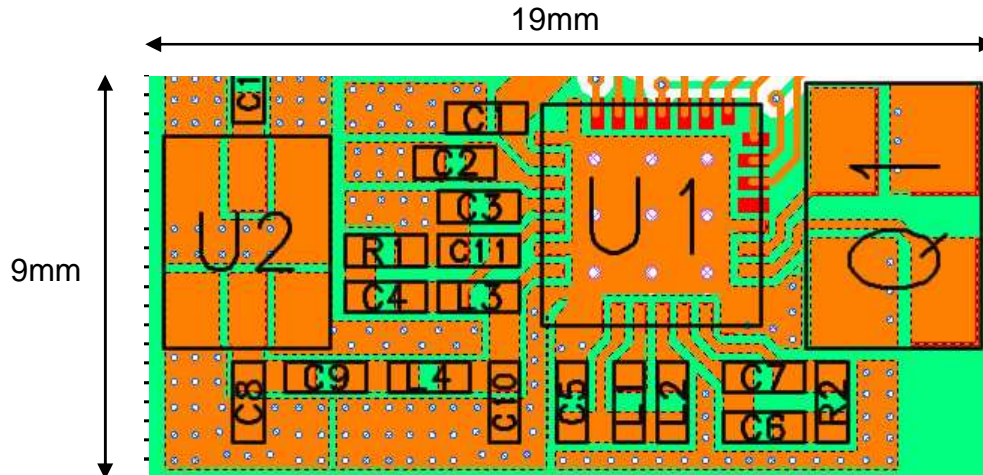


Figure 56: Reference Design's Layout (top view)

7.3. Bill Of Material

Table 35: Reference Design's BOM

| Ref | Value | | Tol (+/-) | Techno | Size | Comment |
|---------|----------|---------|--|----------------|------------|------------------------------|
| | 868MHz | 915MHz | | | | |
| U1 | SX1211 | | - | Transceiver IC | TQFN-32 | - |
| U2 | 869 MHz | 915 MHz | - | SAW Filter | 3.8*3.8 mm | Plotted in section 6.4 |
| Q1 | 12.8 MHz | | 15 ppm at 25°C 20 ppm over -40/+85°C 2ppm/year max | AT-cut | 5.0*3.2 mm | Fundamental, Cload=15 pF |
| R1 | 1Ω | | 1% | - | 0402 | PA regulator |
| R2 | 6.8 kΩ | | 1% | - | 0402 | Loop filter |
| C1 | 1uF | | 15% | X5R | 0402 | VDD decoupling |
| C2 | 1uF | | 15% | X5R | 0402 | Top regulator decoupling |
| C3 | 220 nF | | 10% | X7R | 0402 | Digital regulator decoupling |
| C4 | 47 nF | | 10% | X7R | 0402 | PA regulator decoupling |
| C5 | 100 nF | | 10% | X7R | 0402 | VCO regulator decoupling |
| C6 | 10 nF | | 10% | X7R | 0402 | Loop Filter |
| C7 | 680 pF | | 5% | NPO | 0402 | Loop Filter |
| C8 | 1.8 pF | | 0.25 pF | NPO | 0402 | Matching |
| C9 | 22 pF | | 5% | NPO | 0402 | DC block and L4 adjust |
| L1, L2 | 8.2 nH | 6.8 nH | 0.2 nH | Wire wound | 0402 | VCO tank inductors |
| L3 | 100 nH | | 5% | Wire wound | 0402 | PA Choke |
| L4 | 8.2 nH | | 5% | Multilayer | 0402 | Matching |
| C10,C11 | NC | | - | - | 0402 | - |
| C12* | 47pF | | 5% | NPO | 0402 | DC block |

*Not part of the ref. design (not required for direct antenna connection).

7.4. SAW Filter Plot

The following screenshot shows the plot of the SAW filter used on the reference design:

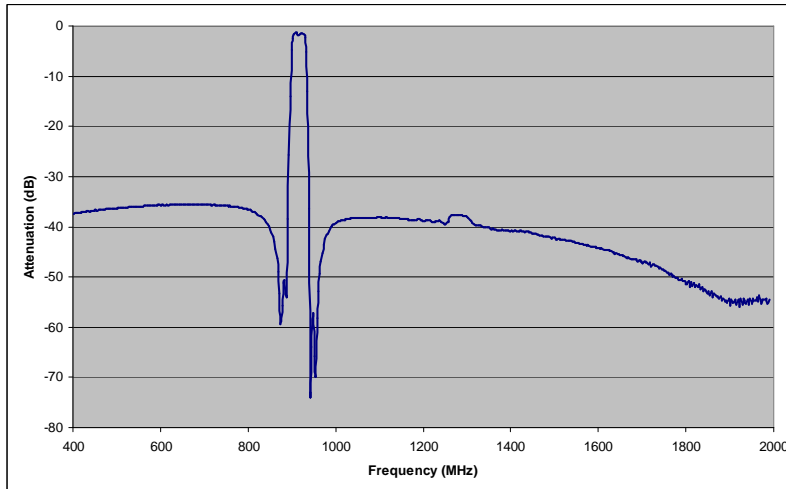


Figure 57: 915 MHz SAW Filter Plot

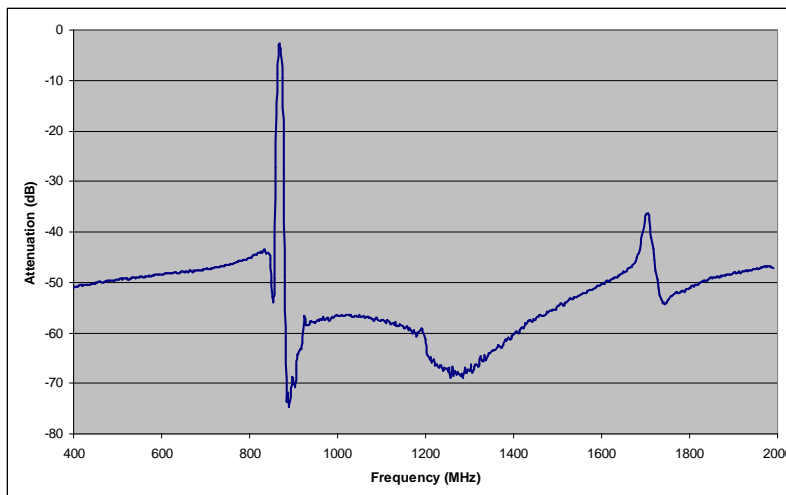


Figure 58: 869 MHz SAW Filter Plot

8. Packaging Information

SX1211 is available in a 32-lead TQFN package as shown in Figure 59 below.

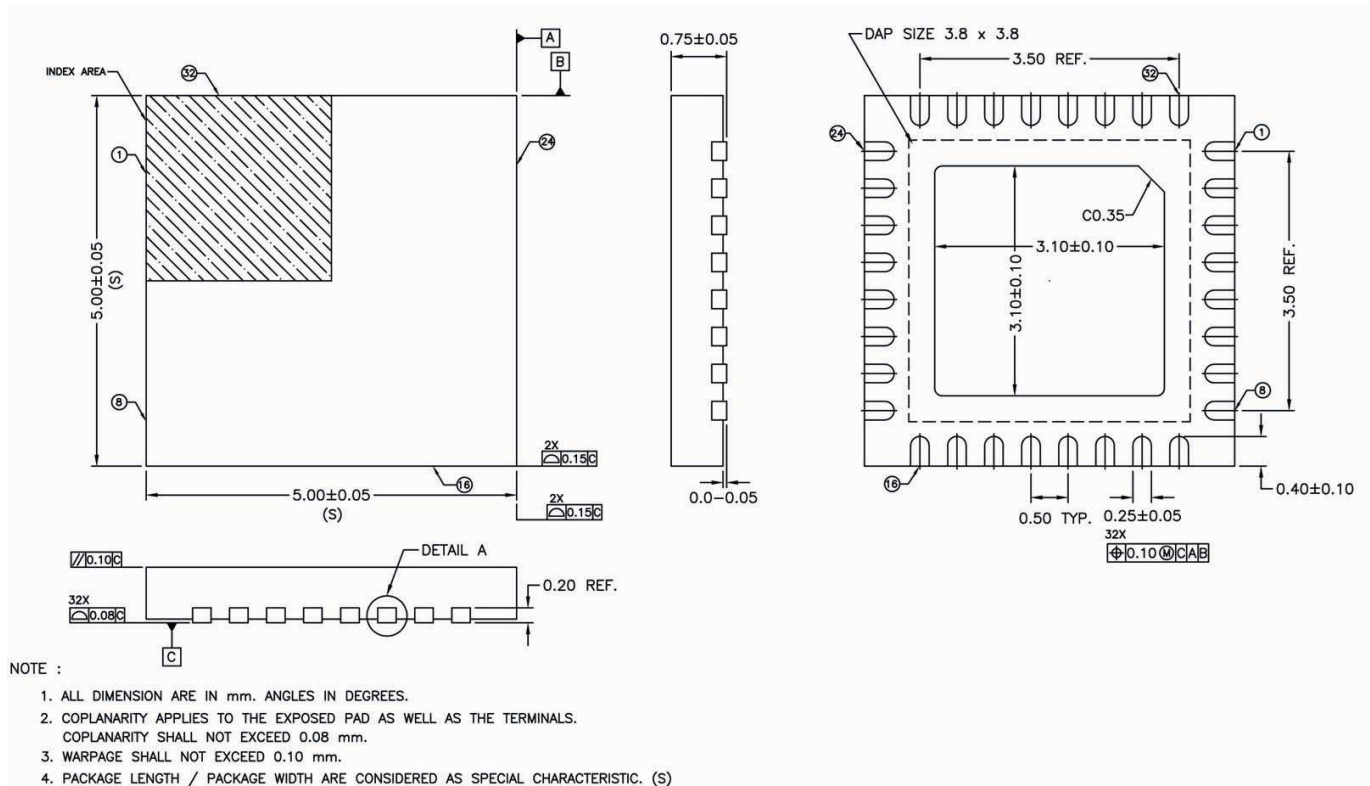


Figure 59: Package Information

9. Contact Information

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