

General Description

The SX1213 is a low cost single-chip receiver operating in the frequency ranges from 300MHz to 510MHz. The SX1213 is optimized for very low power consumption (3mA). It incorporates a baseband demodulator with data rates up to 200 kb/s. Data handling features include a sixty-four byte FIFO, packet handling, CRC and data whitening processing. 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 15.247 and 15.249) regulatory standards.

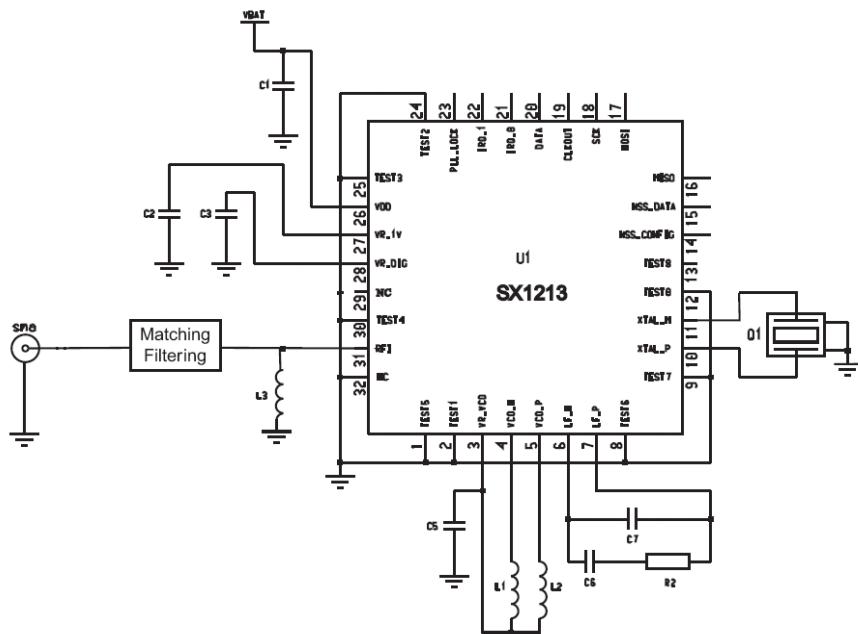
Ordering Information

Table 1: Ordering Information

Part number	Delivery	Minimum Order Quantity / Multiple
SX1213IWLTRT	Tape & Reel	3000 pieces

- TQFN-32 package – Operating range [-40;+85°C]
- T refers to Lead Free packaging
- This device is WEEE and RoHS compliant

Application Circuit Schematic



Features

- Low Rx power consumption: 3mA
- Good reception sensitivity: down to -104 dBm at 25 kb/s in FSK, -110 dBm at 2kb/s in OOK
- Packet handling feature with data whitening and CRC processing
- RSSI (Received Signal Strength Indicator) range from Rx noise floor to 0 dBm
- Bit rates up to 200 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
- Optimized Circuit Configuration for Low-cost applications
- Pin to pin compatible with SX1212 Transceiver

Applications

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

Table of Contents

1. General Description	5	5.3.1. General Description	36
1.1. Simplified Block Diagram.....	5	5.3.2. Rx Processing	37
1.2. Pin Diagram.....	6	5.3.3. Interrupt Signals Mapping	37
1.3. Pin Description.....	7	5.3.4. uC Connections.....	38
2. Electrical Characteristics.....	8	5.3.5. Continuous Mode Example	38
2.1. ESD Notice	8	5.4. Buffered Mode	39
2.2. Absolute Maximum Ratings	8	5.4.1. General Description	39
2.3. Operating Range	8	5.4.2. Rx Processing	39
2.4. Chip Specification	8	5.4.3. Interrupt Signals Mapping	40
2.4.1. Power Consumption	8	5.4.4. uC Connections.....	41
2.4.2. Frequency Synthesis	9	5.4.5. Buffered Mode Example.....	41
2.4.3. Receiver	10	5.5. Packet Mode.....	42
2.4.4. Digital Specification	11	5.5.1. General Description	42
3. Architecture Description.....	12	5.5.2. Packet Format	42
3.1. Power Supply Strategy	12	5.5.3. Rx Processing	44
3.2. Frequency Synthesis Description	13	5.5.4. Packet Filtering	44
3.2.1. Reference Oscillator	13	5.5.5. DC-Free Data Mechanisms	46
3.2.2. CLKOUT Output.....	13	5.5.6. Interrupt Signal Mapping	47
3.2.3. PLL Architecture.....	14	5.5.7. uC Connections.....	47
3.2.4. PLL Tradeoffs.....	14	5.5.8. Packet Mode Example	48
3.2.5. Voltage Controlled Oscillator.....	15	5.5.9. Additional Information	48
3.2.6. PLL Loop Filter	16	6. Configuration and Status Registers	49
3.2.7. PLL Lock Detection Indicator	16	6.1. General Description	49
3.2.8. Frequency Calculation	16	6.2. Main Configuration Register - MCPParam.....	49
3.3. Receiver Description.....	18	6.3. Interrupt Configuration Parameters - IRQParam	51
3.3.1. Architecture	18	6.4. Receiver Configuration parameters - RXParam	53
3.3.2. LNA and First Mixer	19	6.5. Sync Word Parameters - SYNCParam.....	54
3.3.3. IF Gain and Second I/Q Mixer.....	19	6.6. Oscillator Parameters - OSCParam	55
3.3.4. Channel Filters	19	6.7. Packet Handling Parameters – PKTParam	56
3.3.5. Channel Filters Setting in FSK Mode	20	7. Application Information	57
3.3.6. Channel Filters Setting in OOK Mode	21	7.1. Crystal Resonator Specification	57
3.3.7. RSSI	21	7.2. Software for Frequency Calculation	57
3.3.8. Fdev Setting in Receive Mode	23	7.2.1. GUI	57
3.3.9. FSK Demodulator.....	23	7.2.2. .dll for Automatic Production Bench	57
3.3.10. OOK Demodulator	23	7.3. Switching Times and Procedures	57
3.3.11. Bit Synchronizer	26	7.3.1. Optimized Receive Cycle	58
3.3.12. Alternative Settings	27	7.3.2. Receiver Frequency Hop Optimized Cycle	59
3.3.13. Data Output	27	7.4. Reset of the Chip	60
4. Operating Modes.....	28	7.4.1. POR	60
4.1. Modes of Operation	28	7.4.2. Manual Reset	60
4.2. Digital Pin Configuration vs. Chip Mode	28	7.5. Reference Design	61
5. Data Processing.....	29	7.5.1. Application Schematic	61
5.1. Overview	29	7.5.2. PCB Layout	61
5.1.1. Block Diagram	29	7.5.3. Bill Of Material	62
5.1.2. Data Operation Modes	29	7.5.4. Ordering Information for Tools	63
5.2. Control Block Description	30	8. Packaging Information	63
5.2.1. SPI Interface	30	8.1. Package Outline Drawing	63
5.2.2. FIFO	32	8.2. PCB Land Pattern	64
5.2.3. Sync Word Recognition	34	8.3. Tape & Reel Specification	64
5.2.4. Packet Handler.....	35	9. Revision History	65
5.2.5. Control	35	10. Contact Information	65
5.3. Continuous Mode	36		

Index of Figures

Figure 1: SX1213 Simplified Block Diagram	5	Figure 27: Continuous Mode Conceptual View.....	36
Figure 2: SX1213 Pin Diagram	6	Figure 28: Rx Processing in Continuous Mode.....	37
Figure 3: SX1213 Detailed Block Diagram	12	Figure 29: uC Connections in Continuous Mode	38
Figure 4: Power Supply Breakdown.....	13	Figure 30: Buffered Mode Conceptual View	39
Figure 5: Frequency Synthesizer Description.....	14	Figure 31: Rx Processing in Buffered Mode (FIFO size=16, Fifo_fill_method=0).....	40
Figure 6: LO Generator	14	Figure 32: uC Connections in Buffered Mode.....	41
Figure 7: Loop Filter	16	Figure 33: Packet Mode Conceptual View.....	42
Figure 8: Receiver Architecture	18	Figure 34: Fixed Length Packet Format.....	43
Figure 9: FSK Receiver Setting	18	Figure 35: Variable Length Packet Format	44
Figure 10: OOK Receiver Setting	18	Figure 36: CRC Implementation	46
Figure 11: Active Channel Filter Description.....	19	Figure 37: Manchester Decoding	46
Figure 12: Butterworth Filter's Actual BW	21	Figure 38: Data Whitening Implementation.....	47
Figure 13: Polyphase Filter's Actual BW	21	Figure 39: uC Connections in Packet Mode	47
Figure 14: RSSI Dynamic Range.....	22	Figure 40: Optimized Rx Cycle	58
Figure 15: RSSI IRQ Timings	23	Figure 41: Rx Hop Cycle	59
Figure 16: OOK Demodulator Description	24	Figure 42: POR Timing Diagram.....	60
Figure 17: Floor Threshold Optimization.....	25	Figure 43: Manual Reset Timing Diagram	60
Figure 18: BitSync Description.....	26	Figure 44: Reference Design Circuit Schematic	61
Figure 19: SX1213's Data Processing Conceptual View	29	Figure 45: Reference Design's Stackup	62
Figure 20: SPI Interface Overview and uC Connections	30	Figure 46: Reference Design Layout (top view).....	62
Figure 21: Write Register Sequence.....	31	Figure 47: Package Outline Drawing	63
Figure 22: Read Register Sequence.....	32	Figure 48: PCB Land Pattern.....	64
Figure 23: Read Bytes Sequence (ex: 2 bytes)	32	Figure 49: Tape & Reel Dimensions	64
Figure 24: FIFO and Shift Register (SR).....	33		
Figure 25: FIFO Threshold IRQ Source Behavior.....	34		
Figure 26: Sync Word Recognition	34		

Index of Tables

Table 1: Ordering Information	1
Table 2: SX1213 Pinouts	7
Table 3: Absolute Maximum Ratings	8
Table 4: Operating Range	8
Table 5: Power Consumption Specification	8
Table 6: Frequency Synthesizer Specification	9
Table 7: Receiver Specification	10
Table 8: Digital Specification (1)	11
Table 9: MCPParam_Freq_band and MCPParam_Subband Setting	15
Table 10: Operating Modes	28
Table 11: Pin Configuration vs. Chip Mode	28
Table 12: Data Operation Mode Selection	30
Table 13: Config vs. Data SPI Interface Selection	31
Table 14: Status of FIFO when Switching Between Different Modes of the Chip	34
Table 15: Interrupt Mapping in Continuous Rx Mode	37

Table 16: Relevant Configuration Registers in Continuous Mode (data processing related only)	38
Table 17: Interrupt Mapping in Buffered Rx and Stby Modes	40
Table 18: Relevant Configuration Registers in Buffered Mode (data processing related only)	41
Table 19: Interrupt Mapping in Rx and Stby in Packet Mode	47
Table 20: Relevant Configuration Registers in Packet Mode (data processing related only)	48
Table 21: Registers List	49
Table 22: MCPParam Register Description	49
Table 23: IRQParam Register Description	51
Table 24: RXParam Register Description	53
Table 25: SYNCParam Register Description	54
Table 26: OSCParam Register Description	55
Table 27: PKTParam Register Description	56
Table 28: Crystal Resonator Specification	57
Table 29: Reference Design BOM	62
Table 30: Tools Ordering Information	63

Acronyms

BOM	Bill Of Materials
BR	Bit Rate
BW	Bandwidth
CCITT	Comité Consultatif International Téléphonique et Télégraphique - ITU
CP	Charge Pump
CRC	Cyclic Redundancy Check
DAC	Digital to Analog Converter
DDS	Direct Digital Synthesis
DLL	Dynamically Linked Library
ERP	Equivalent Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
Fdev	Frequency Deviation
FIFO	First In First Out
FS	Frequency Synthesizer
FSK	Frequency Shift Keying
GUI	Graphical User Interface
IC	Integrated Circuit
ID	IDentifier
IF	Intermediate Frequency
IRQ	Interrupt ReQuest
ITU	International Telecommunication Union
LFSR	Linear Feedback Shift Register
LNA	Low Noise Amplifier

LO	Local Oscillator
LSB	Least Significant Bit
MSB	Most Significant Bit
NRZ	Non Return to Zero
NZIF	Near Zero Intermediate Frequency
OOK	On Off Keying
PA	Power Amplifier
PCB	Printed Circuit Board
PFD	Phase Frequency Detector
PLL	Phase-Locked Loop
POR	Power On Reset
RBW	Resolution BandWidth
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
Rx	Receiver
SAW	Surface Acoustic Wave
SPI	Serial Peripheral Interface
SR	Shift Register
Stby	Standby
Tx	Transmitter
uC	Microcontroller
VCO	Voltage Controlled Oscillator
XO	Crystal Oscillator
XOR	eXclusive OR

This product datasheet contains a detailed description of the SX1213 performance and functionality. Please consult the Semtech website for the latest updates or errata.

1. General Description

The SX1213 is a single chip FSK and OOK receiver capable of operation in the 300 to 510 MHz license free ISM frequency bands. It complies with both the relevant 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 full active mode of only 3mA (typ). The SX1213 is available in a 5x5 mm TQFN-32 package.

1.1. Simplified Block Diagram

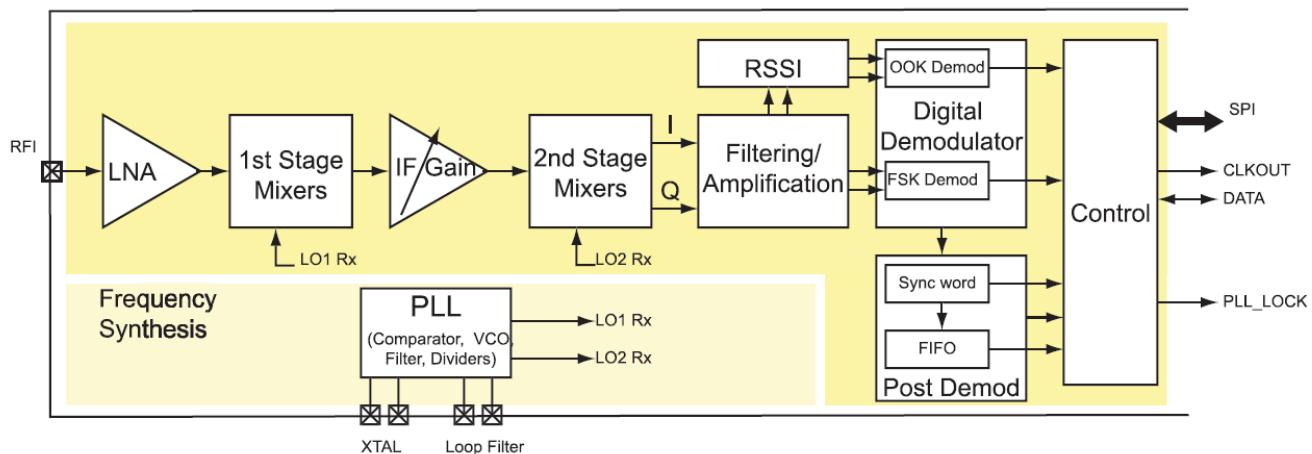


Figure 1: SX1213 Simplified Block Diagram

1.2. Pin Diagram

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

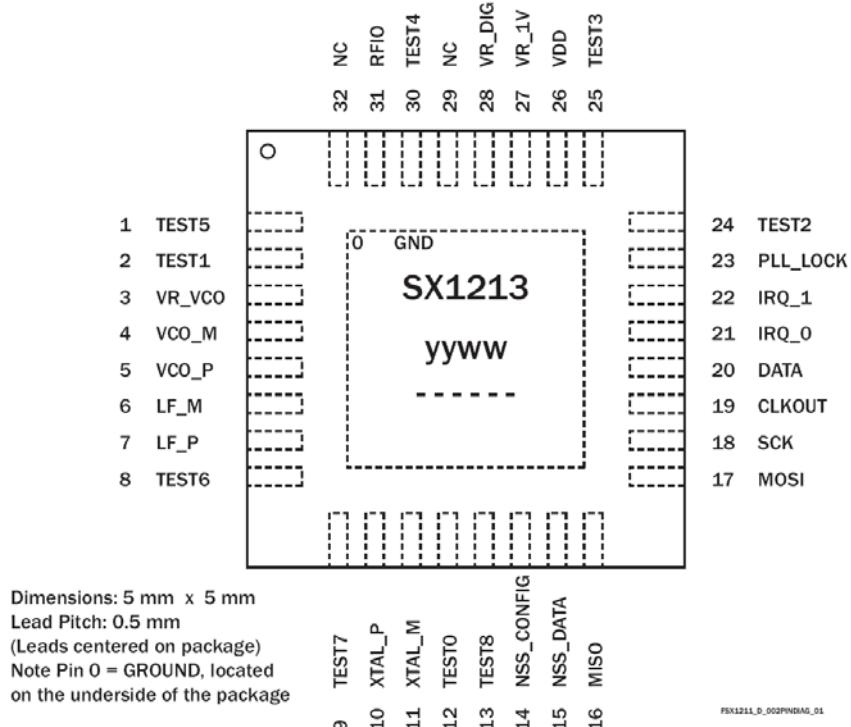


Figure 2: SX1213 Pin Diagram

Notes:

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

1.3. Pin Description

Table 2: SX1213 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	I/O	POR. Do not connect if unused
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	O	NRZ data 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	NC	-	Connect to GND
30	TEST4	I/O	Connect to GND
31	RFI	I	RF input
32	NC	-	Connect to GND

Note: pin 13 (Test 8) can be used as a manual reset trigger. See section 7.4.2 for details on its use.



2. Electrical Characteristics

2.1. ESD Notice

The SX1213 is a high performance radio frequency device. It satisfies:

- Class 2 of the JEDEC standard JESD22-A114-B (Human Body Model), except on pins 3-4-5-27-28-31-where it satisfies Class 1A.
- Class III of the JEDEC standard JESD22-C101C (Charged Device Model) on all pins.

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

2.2. Absolute Maximum Ratings

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

Table 3: Absolute Maximum Ratings

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

2.4. Chip Specification

Conditions: Temp = 25 °C, VDD = 3.3 V, crystal frequency = 12.8 MHz, carrier frequency = 315 or 434 MHz, modulation FSK, data rate = 25 kb/s, Fdev = 50 kHz, fc = 100 kHz, unless otherwise specified.

2.4.1. Power Consumption

Table 5: Power Consumption Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSSL	Supply current in sleep mode		-	0.1	2	µA
IDDST	Supply current in standby mode, CLKOUT disabled	Crystal oscillator running	-	65	95	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

⁽¹⁾ Information from design and characterization

2.4.2. Frequency Synthesis

Table 6: Frequency Synthesizer Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
FR	Frequency ranges	Programmable (may require specific BOM)	300	-	330	MHz
			320	-	350	MHz
			350	-	390	MHz
			390	-	430	MHz
			430	-	470	MHz
			470	-	510	MHz
BR_F	Bit rate (FSK)	NRZ	1.56	-	200	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		9	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⁾	-	1.5	5	ms
TS_FS	Frequency synthesizer wake-up time at most 10 kHz away from the target	From Stby mode	-	500	800	μs
TS_HOP	Frequency synthesizer hop time at most 10 kHz away from the target	200 kHz step	-	180	-	μs
		1 MHz step	-	200	-	μs
		5 MHz step	-	250	-	μs
		7 MHz step	-	260	-	μs
		12 MHz step	-	290	-	μs
		20 MHz step	-	320	-	μs
		27 MHz step	-	340	-	μs

⁽¹⁾Information from design and characterization

2.4.3. Receiver

- On the following table, fc and fo describe the bandwidth of the active channel filters as described in section 3.3.4.2. All sensitivities are measured receiving a PN15 sequence, for a BER of 0.1.%

Table 7: Receiver Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
RFS_F	Sensitivity (FSK)	434 MHz, BR=25 kb/s, Fdev =50 kHz, fc=100 kHz	-	-104	-	dBm
RFS_O	Sensitivity (OOK)	434 MHz, 2kb/s NRZ fc-fo=50 kHz, fo=50 kHz	-	-110	-	dBm
CCR	Co-channel rejection	Modulation as wanted signal	-	-12	-	dBc
ACR	Adjacent channel rejection	Offset = 300 kHz, unwanted tone is not modulated	-	27	-	dB
		Offset = 600 kHz, unwanted tone is not modulated	-	52	-	dB
		Offset = 1.2 MHz, unwanted tone is not modulated	-	57	-	dB
BI	Blocking immunity	Offset = 1 MHz, unmodulated	-	-48	-	dBm
		Offset = 2 MHz, unmodulated, no SAW	-	-37	-	dBm
		Offset = 10 MHz, unmodulated, no SAW	-	-33	-	dBm
RXBW_F ^(1,2)	Receiver bandwidth in FSK mode	Single side BW Polyphase Off	50	-	250	kHz
RXBW_O ^(1,2)	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 ⁽¹⁾	Receiver wake-up time	From FS to Rx ready	-	280	500	μs
TS_RE2 ⁽¹⁾	Receiver wake-up time	From Stby to Rx ready	-	600	900	μs
TS_RE_HOP	Receiver hop time from Rx ready to Rx ready with a frequency hop	200 kHz step	-	400	-	μs
		1MHz step	-	400	-	μs
		5MHz step	-	460	-	μs
		7MHz step	-	480	-	μs
		12MHz step	-	520	-	μs
		20MHz step	-	550	-	μs
		27MHz step	-	600	-	μs
TS_RSSI	RSSI sampling time	From Rx ready	-	-	1/Fdev	s
DR_RSSI	RSSI dynamic Range	Ranging from sensitivity	-	70	-	dB

⁽¹⁾ Information from design and characterization

⁽²⁾ This reflects the whole receiver bandwidth, as described in sections 3.3.4.1 and 3.3.4.2

2.4.4. Digital Specification

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

Table 8: Digital Specification (1)

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		-	-	6	MHz
SCK_DATA	SPI data clock frequency		-	-	1	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

⁽¹⁾ Information from design and characterization

Note: on pin 10 (XTAL_P) and 11 (XTAL_N), maximum voltages of 1.8V can be applied.

3. Architecture Description

This section describes in depth the architecture of this ultra low-power receiver:

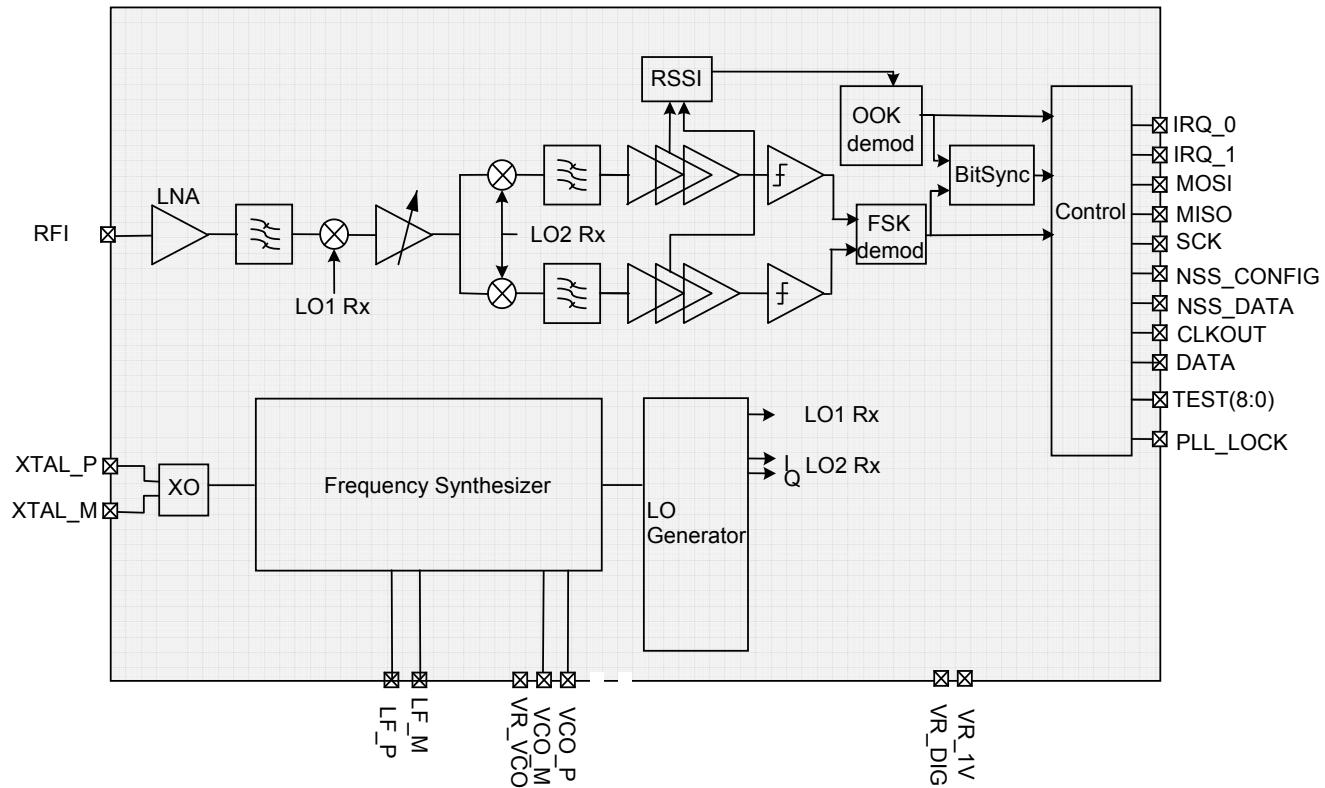


Figure 3: SX1213 Detailed Block Diagram

3.1. Power Supply Strategy

To provide stable sensitivity and linearity characteristics over a wide supply range, the SX1213 is internally regulated. This internal regulated power supply structure is described below:

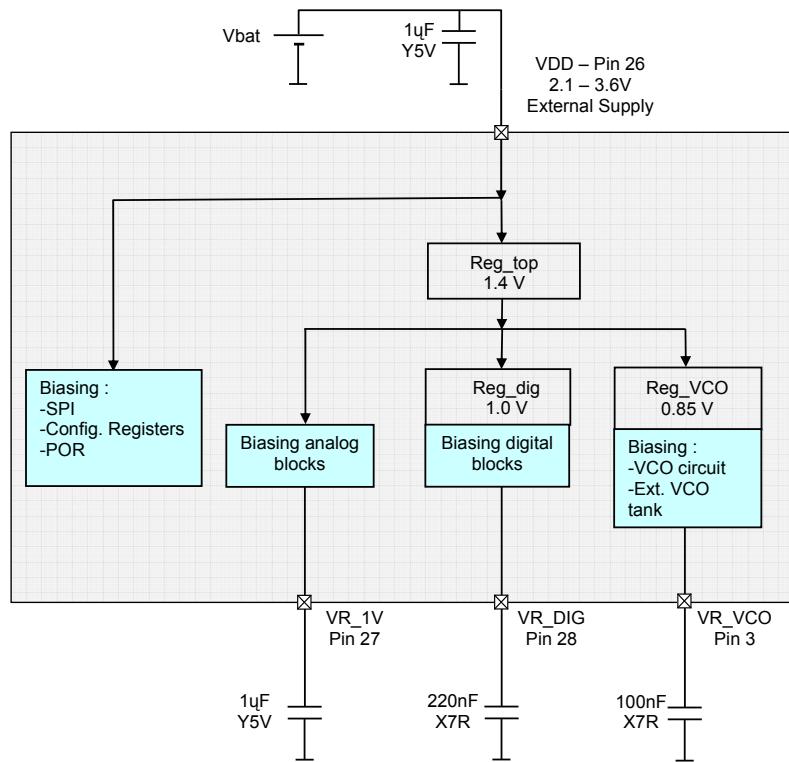


Figure 4: Power Supply Breakdown

To ensure correct operation of the regulator circuit, the decoupling capacitor connection shown in Figure 4 is required. These decoupling components are recommended for any design.

3.2. Frequency Synthesis Description

The frequency synthesizer of the SX1213 is a fully integrated integer-N type PLL. The PLL circuit requires only five external components for the PLL loop filter and the VCO tank circuit.

3.2.1. Reference Oscillator

The SX1213 embeds a crystal oscillator, which provides the reference frequency for the PLL. The recommended crystal specification is given in section 7.1.

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 OSCPParam_Clkout_on. The division ratio is programmed through bits OSCPParam_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 SX1213, 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 5 shows a block schematic of the SX1213 PLL. Here the crystal reference frequency and the software controlled dividers R, P and S determine the output frequency of the PLL.

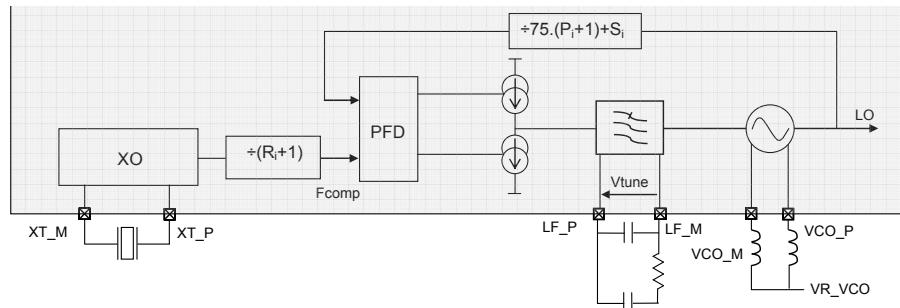


Figure 5: Frequency Synthesizer Description

The VCO tank inductors are connected on an external differential input. Similarly, the loop filter is also located externally. However, there is an internal 8pF 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 6. The VCO frequency is subdivided and used in a series of up (down) conversions for transmission (reception).

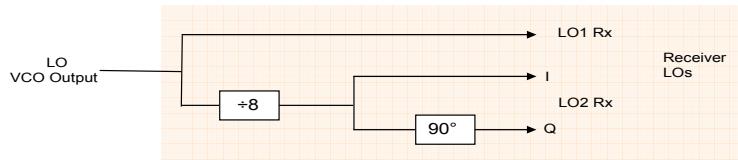


Figure 6: LO Generator

3.2.4. PLL Tradeoffs

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

- The comparison frequency, Fcomp, 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 Fcomp. This is expressed in the inequality:

$$PLLBW \leq \frac{Fcomp}{6}$$

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

With the recommended Bill Of Materials (BOM) of the reference design of section 7.5.3, 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, the two inductors should have the same nominal value. The performance of these components is important for both the phase noise and the power consumption of the PLL. It is recommended that a pair of high Q factor inductors is selected. These should be mounted orthogonally to other inductors (in particular the LNA biasing inductor) to reduce spurious coupling between the LNA input and VCO.

For best performance wound type inductors, with tight tolerance, should be used as described in section 7.5.3.

3.2.5.1. SW Settings of the VCO

To guarantee the optimum operation of the VCO over the SX1213's frequency and temperature ranges, the following settings should be programmed into the SX1213:

Freq_band [MHz]	300MHz - 330MHz				320MHz - 350MHz			
L1 and L2	39nH				33 nH			
Subbband	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter
fo [MHz]	303.75MHz	311.25MHz	318.75MHz	326.25MHz	323.75MHz	331.25MHz	338.75MHz	346.25MHz

Freq_band [MHz]	350MHz - 390MHz				390MHz - 430MHz			
L1 and L2	27nH				22nH			
Subbband	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter
fo [MHz]	355.00MHz	365.00MHz	375.00MHz	385.00MHz	395.00MHz	405.00MHz	415.00MHz	425.00MHz

Freq_band [MHz]	430MHz - 470MHz				470MHz - 510MHz			
L1 and L2	18nH				15nH			
Subbband	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter	1 st quarter	2 nd quarter	3 rd quarter	4 th quarter
fo [MHz]	435.00MHz	445.00MHz	455.00MHz	465.00MHz	475.00MHz	485.00MHz	495.00MHz	505.00MHz

Table 9: MCPParam_Freq_band and MCPParam_Subband Setting

3.2.5.2. Trimming the VCO Tank by Hardware and Software

To ensure that the frequency band of operation 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 7.5) no centering is necessary. However, any deviation from the reference design may require the optimization procedure, outlined below, to be implemented. This procedure is simplified thanks to the built-in VCO trimming feature which is controlled over the SPI interface. This tuning does not require any RF test equipment, and can be achieved by simply measuring Vtune, the voltage between pins 6 (LFM) and 7 (LFP).

The VCO is centered if the voltage is within the range:

$$50 \leq Vtune(mV) \leq 150mV$$

If this inequality is not satisfied then adjust the Trim_band bits from 11 (default value) to 00 whilst monitoring Vtune. This allows the VCO voltage to be trimmed by adding additional capacitance to the VCO tank. Should the desired voltage range be inaccessible, the voltage may be adjusted further by changing the tank circuit inductance value. Note that an increase in capacitance will result in a decrease of Vtune (approximately ~60 mV per step).

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 100 mV.

3.2.6. PLL Loop Filter

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

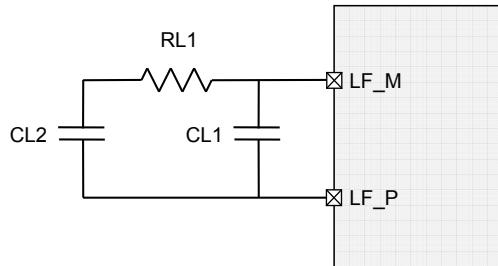


Figure 7: Loop Filter

Following the recommendations made in section 3.2.4, the loop filter proposed in the reference design's bill of material on section 7.5.3 should be used. The loop filter settings are frequency band independent and are hence relevant to all implementations of the SX1213.

3.2.7. PLL Lock Detection Indicator

The SX1213 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 5 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.

$$Fr_{f, fsk} = \frac{9}{8} Flo$$

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

3.2.8.2. OOK Mode

Due to the low intermediate frequency (Low-IF) architecture of the SX1213 the frequency should be configured so as to ensure the correct low-IF receiver baseband center frequency, IF2.

$$Fr_{f,ook} = \frac{9}{8} Flo - IF2$$
$$Fr_{f,ook} = \frac{9}{8} \frac{Extal}{R+1} [75(P+1) + S] - IF2$$

Note that from Section 3.3.4, it is recommended that IF2 be set to 100 kHz.

3.3. Receiver Description

The SX1213 is set to receive mode when MCPParam_Chip_mode = 011.

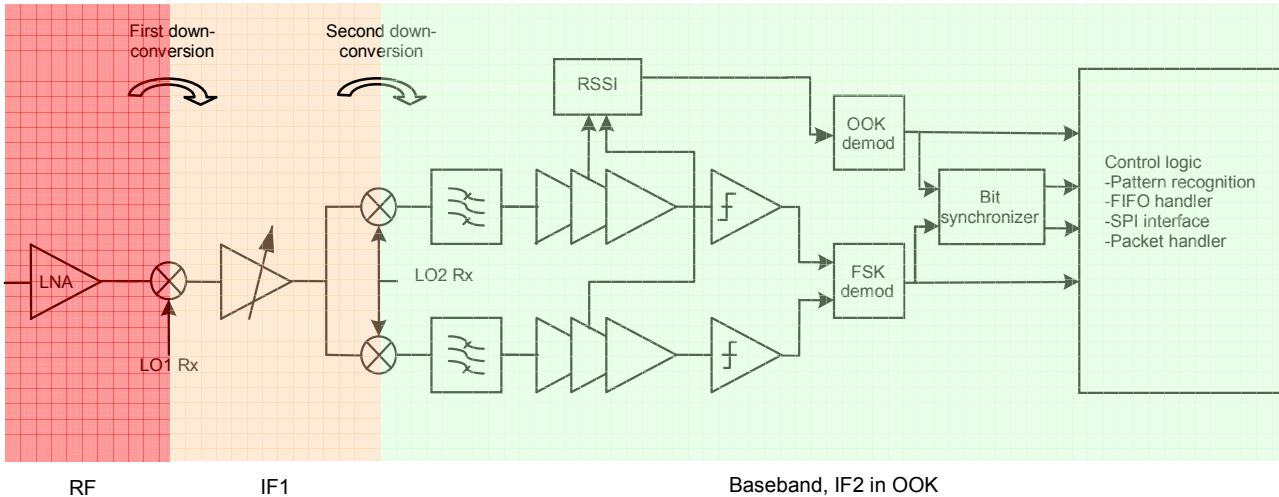


Figure 8: Receiver Architecture

3.3.1. Architecture

The SX1213 receiver employs a super-heterodyne architecture. Here, the first IF is $1/9^{\text{th}}$ of the RF frequency (approximately 100MHz). The second down-conversion down-converts 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.

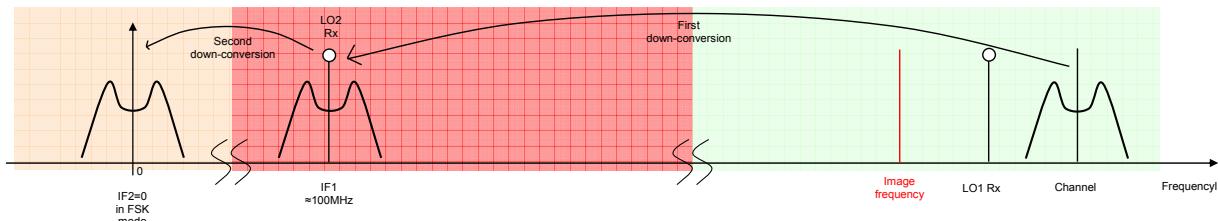


Figure 9: FSK Receiver Setting

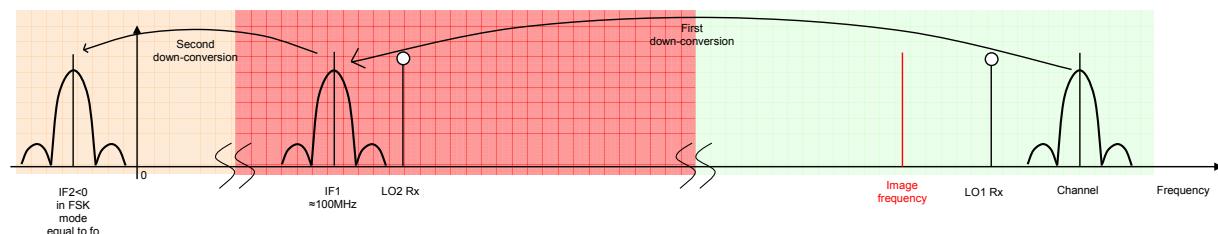


Figure 10: OOK Receiver Setting

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: Image rejection is achieved by the SAW filter.

3.3.2. LNA and First Mixer

The performance of this amplifier is such that the Noise Figure (NF) of the receiver can be estimated to be ≈ 7 dB.

3.3.3. 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 3.3.7 for additional information.

3.3.4. 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.

3.3.4.1. 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 optimum performance it should be set to 3 to 4 times the cutoff frequency of the active Butterworth (or polyphase) filter described in the next section.

$$3 * Fc_{\text{Butterfilt}} \leq BW_{\text{passive,filter}} \leq 4 * Fc_{\text{Butterfilt}}$$

3.3.4.2. 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 polyphase filter for the Low-IF (OOK) configuration. The `RXParam_Polyfilt_on` bit enables/disables the polyphase filter.

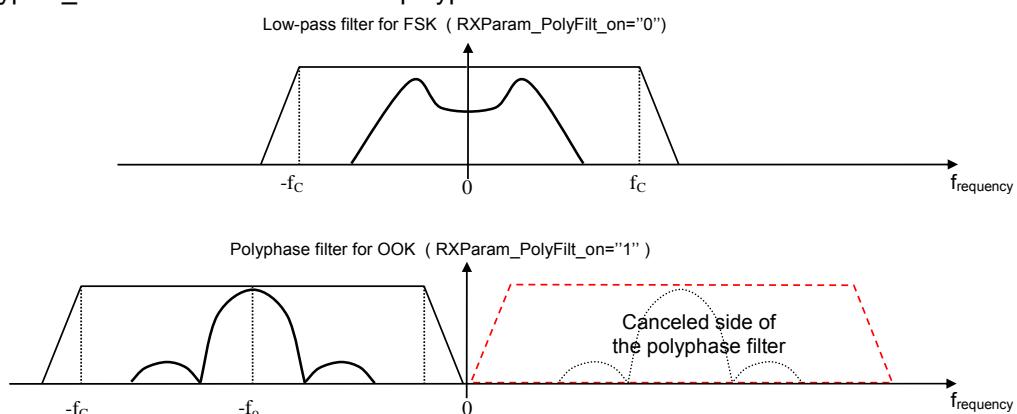


Figure 11: Active Channel Filter Description

As can be seen from Figure 11, 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:

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

The bits RXParam_ButterFilt set fc, 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 fc should be such that the modulated signal falls in the filter bandwidth, anticipating the Local Oscillator frequency drift over the operating temperature and aging of the device:

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

Please refer to the charts in section 3.3.5 for an accurate overview of the filter bandwidth vs. setting.

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

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

The bits RXParam_PolyPfilt_center set fo, the center frequency of the polyphase filter when activated. fo should always be chosen to be equal to the low Intermediate Frequency of the receiver (IF2). This is why, in the GUI described in section 7.2.1 of this document, the low IF frequency of the OOK receiver denoted IF2 has been replaced by fo.

The following setting is recommended:

$$fo = 100kHz$$

$$RXParam_PolyPfilt = "0011"$$

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

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

Again, fc as a function of RXParam_ButterFilt is given in the section 3.3.6.

3.3.5. Channel Filters Setting in FSK Mode

Fc, 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:

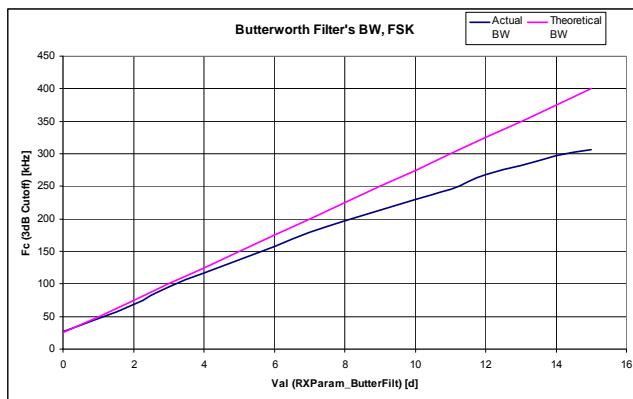


Figure 12: Butterworth Filter's Actual BW

Error! Reference source not found. suggests filter settings in FSK mode, along with the corresponding passive filter bandwidth and the accepted tolerance on the crystal reference.

3.3.6. Channel Filters Setting in OOK Mode

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

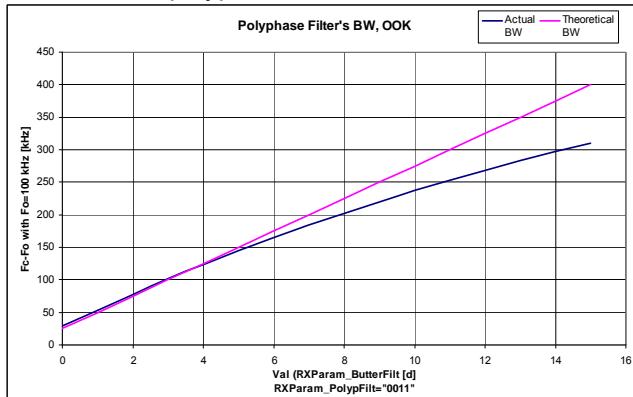


Figure 13: Polyphase Filter's Actual BW

Error! Reference source not found. suggests a few filter settings in OOK mode, along with the corresponding passive filter bandwidth and the accepted tolerance on the crystal reference.

3.3.7. RSSI

After filtering, the In-phase and Quadrature signals are amplified by a chain of 11 amplifiers, each with 6dB gain. The outputs of these amplifiers are used to evaluate the Received Signal Strength (RSSI).

3.3.7.1. Resolution and Accuracy

Whilst the RSSI resolution is 0.5 dB, the absolute accuracy is not expected to be better than +/- 3dB due to process and external component variation. Higher accuracy whilst performing absolute RSSI measurements will require additional calibration.

3.3.7.2. Acquisition Time

In OOK mode, the RSSI evaluates the signal strength by sampling I(t) and Q(t) signals 16 times in each period of the chosen IF2 frequency (refer to section 3.3.1). In FSK mode, the signals are sampled 16 times in each Fdev period, Fdev being the frequency deviation of the companion transmitter. An average is then performed over a sliding window of 16 samples. Hence, the RSSI output register RXParam_RSSI is updated 16 times in each Fdev or IF2 period.

The following settings should be respected:

- FSK Mode: Ensure that the Fdev parameter (as described in MCPParam_Fdev) remains consistent with the actual frequency deviation of the companion transmitter.
- OOK reception: Ensure that the Fdev parameter (as described in MCPParam_Fdev) is equal with the frequency of I(t) and Q(t) signals, i.e. the second Intermediate Frequency, IF2, of the receiver (Note that this equals F_0 , the center frequency of the polyphase filter).

3.3.7.3. Dynamic Range

The dynamic range of the RSSI is over 70 dB, extending from the nominal sensitivity level. The IF gain setting available in MCPParam_IF_gain is used to achieve this dynamic range:

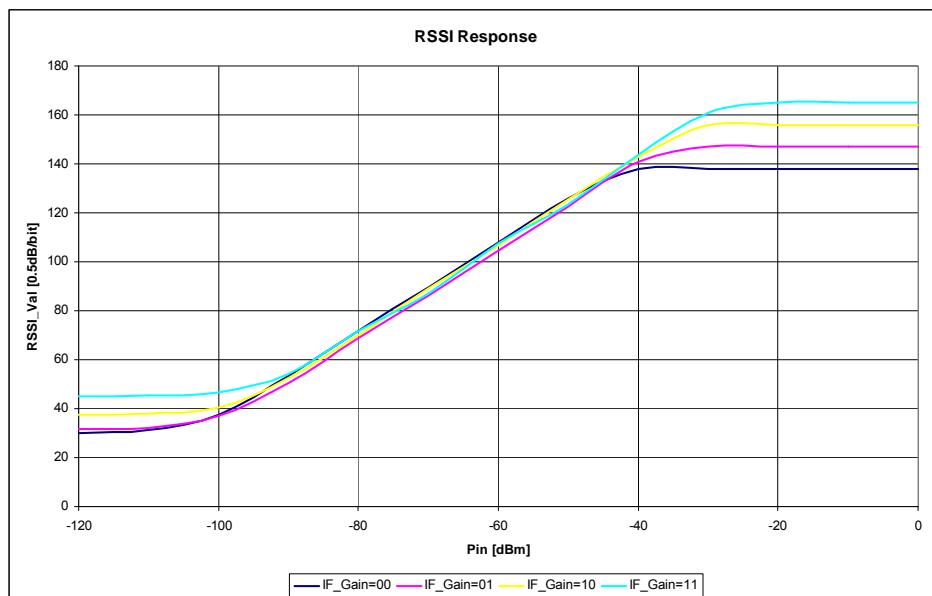


Figure 14: RSSI Dynamic Range

The RSSI response versus input signal is independent of the receiver filter bandwidth. However in the absence of any input signal, the minimum value directly reflects upon the noise floor of the receiver, which is dependant on the filter bandwidth of the receiver.

3.3.7.4. RSSI IRQ Source

The SX1213 can also be used to detect a RSSI level above a pre-configured threshold. The threshold is set in IRQParam_RSSI_irq_thresh and the IRQ status stored in IRQParam_RSSI_irq (cleared by writing a "1").

An interrupt can be mapped to the IRQ0 or IRQ1 pins via bits IRQParam_Rx_stby_irq0 or IRQParam_Rx_stby_irq1. Figure 15 shows the timing diagram of the RSSI interrupt source, with IRQParam_RSSI_irq_thresh set to 28.

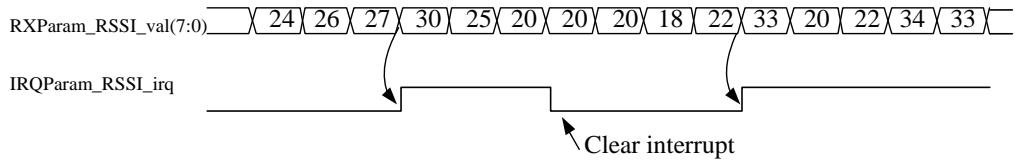


Figure 15: RSSI IRQ Timings

3.3.8. Fdev Setting in Receive Mode

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

3.3.8.1. FSK Rx Mode

In FSK mode the Fdev setting, as configured by MCPParam_Freq_Dev, sets sampling frequencies on the receiver. The user should make it consistent with the frequency deviation of the FSK signal that is received.

3.3.8.2. 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 low-IF frequency, IF2, of 100 kHz:

$$Fdev = IF2 = 100\text{kHz}$$

MCPParam_Freq_dev = "00000011"

3.3.9. FSK Demodulator

The FSK demodulator provides data polarity information, based on the relative phase of the input I and Q signals at the 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 SX1213 operates most effectively for FSK signals with a modulation index greater than or equal to two:

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

3.3.10. OOK Demodulator

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

The recommended mode of operation is the “Peak” threshold mode, illustrated below in Figure 16:

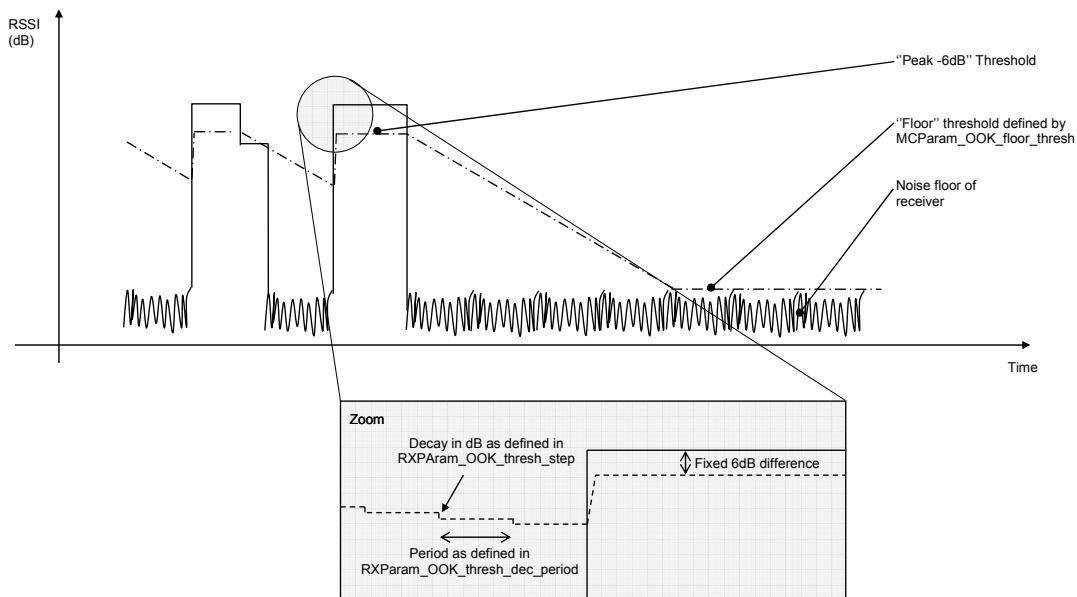


Figure 16: OOK Demodulator Description

In peak threshold mode the comparison threshold level is the peak value of the RSSI, reduced by 6dB. In the absence of an input signal or 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.

3.3.10.1. Optimizing the Floor Threshold

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

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

- The noise figure of the receiver.
- The gain of the receive chain from antenna to base band.
- The matching - including SAW filter.
- 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 recommended to optimize MCPParam_OOK_floor_thresh.

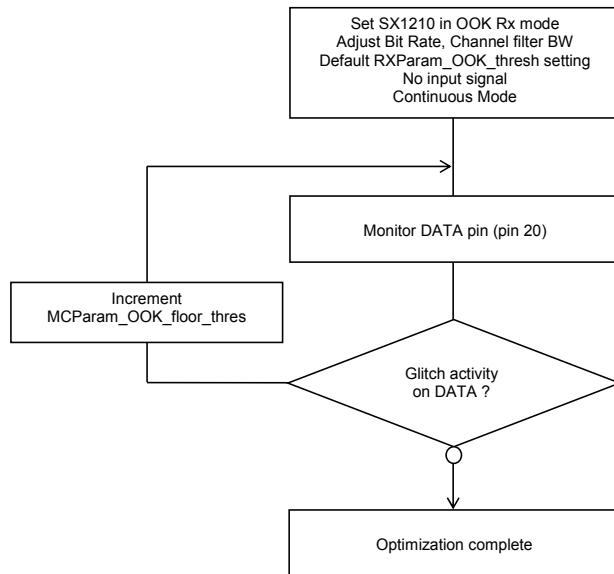


Figure 17: Floor Threshold Optimization

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

Note that if the output signal on DATA is logic “1”, the value of MCPParam_OOK_floor_thres is below the noise floor of the receiver chain. Conversely, if the output signal on DATA is logic “1”, the value of MAPParam_floor_thres is several dB above the noise floor.

3.3.10.2. Optimizing OOK Demodulator Response for Fast Fading Signals

A sudden drop in signal strength can cause the bit error rate to increase. For applications where the expected signal drop can be estimated the following OOK demodulator parameters RXParam_OOK_thresh_step and RXParam_OOK_thresh_dec_period can be optimized as described below for a given number of threshold decrements per bit RXParam_OOK_thresh_dec_period:

- 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

For each decrement of RXParam_OOK_thresh_step:

- 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

3.3.10.3. Alternative OOK Demodulator Threshold Modes

In addition to the Peak OOK threshold mode, the user can alternatively select two other types of threshold detectors:

- Fixed threshold: The value is selected through the `MCParam_OOK_floor_thresh` register (refer to section 3.3.10.1 for further information concerning optimization of the floor threshold).
- Average threshold: Data supplied by the RSSI block is averaged with the following cutoff frequency:

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

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

In the first example, the higher cut-off frequency enables a sequence of up to 8 consecutive “0” or “1” to be supported, whilst the lower cut-off frequency presented in the second example allows for the correct reception of up to 32 consecutive “0” or “1”.

3.3.11. Bit Synchronizer

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

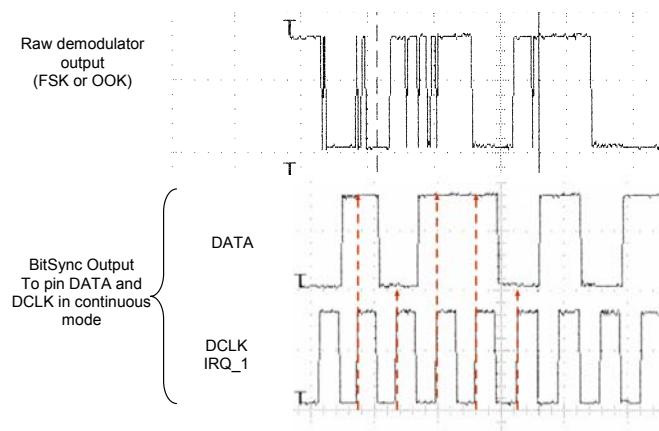


Figure 18: BitSync Description

The BitSync can be disabled through the bits `RXParam_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`.

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

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

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 SX1213 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:

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

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).

3.3.12. Alternative Settings

Bit Synchronizer and Active channel filter settings are a function of the reference oscillator crystal frequency, F_{XTAL} . Settings other than those programmable with a 12.8 MHz crystal can be obtained by selection of the correct reference oscillator frequency. Please contact your local Semtech representative for further details.

3.3.13. 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 is retrieved from the FIFO through the SPI interface.

4. Operating Modes

This section summarizes the settings for each operating mode of the SX1213, and explains the functionality available and the timing requirements for switching between modes.

4.1. Modes of Operation

Table 10: Operating Modes

Mode	MCPParam_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

4.2. Digital Pin Configuration vs. Chip Mode

Table 11 describes the state of the digital IOs in each of the above described modes of operation, regardless of the data operating mode.

Table 11: Pin Configuration vs. Chip Mode

Pin	Chip Mode	Sleep mode	Standby mode	FS mode	Receive mode	Comment
NSS_CONFIG	Input	Input	Input	Input	Input	NSS_CONFIG has the priority over NSS_DATA
NSS_DATA	Input	Input	Input	Input	Input	
MISO	Input	Input	Input	Input	Input	Output only if NSS_CONFIG or NSSDATA='0'
MOSI	Input	Input	Input	Input	Input	
SCK	Input	Input	Input	Input	Input	
IRQ_0	High-Z	Output (1)	Output (1)	Output (1)	Output	
IRQ_1	High-Z	Output (1)	Output (1)	Output (1)	Output	
DATA (3)	High-Z	High-Z	High-Z	High-Z	Output	
CLKOUT	High-Z	Output	Output	Output	Output	
PLL_LOCK	High-Z	Output (4)	Output (4)	Output (4)	Output (4)	

Notes:

- (1): High-Z if Continuous mode is activated, else Output
- (2): Valid logic states must be applied to inputs at all times to avoid unwanted leakage currents
- (3): Tie to Vss (or Vdd) when not in active receive mode.
- (4): Output if PLL_lock_en = 1, else High-Z

5. Data Processing

5.1. Overview

5.1.1. Block Diagram

Figure 19, illustrates the SX1213 data processing circuit. Its role is to interface the data from the demodulator and the uC access points (SPI, IRQ and DATA pins). It also controls all the configuration registers.

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

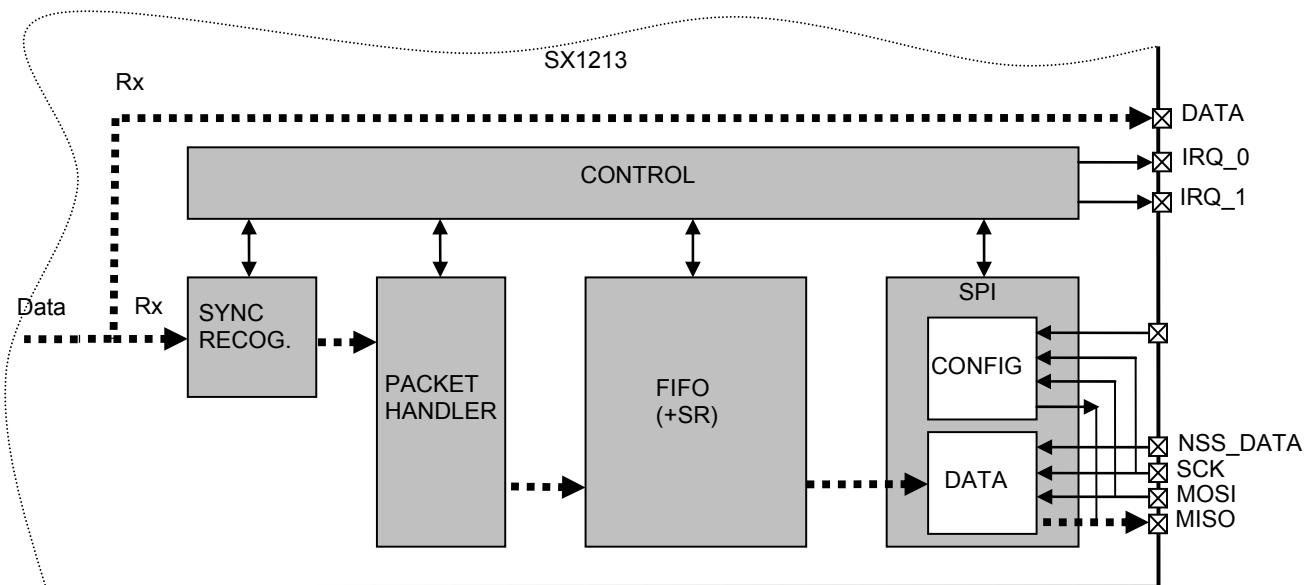


Figure 19: SX1213's Data Processing Conceptual View

The SX1213 implements several data operation modes, each with their own data path through the data processing section. Depending on the data operation mode selected, some control blocks are active whilst others remain disabled.

5.1.2. Data Operation Modes

The SX1213 has three different data operation modes selectable by the user:

- Continuous mode: each bit 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 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 retrieves payload bytes to/from the FIFO. Sync word is automatically detected and stripped off while optional CRC check and DC free data decoding can be performed. The uC processing overhead is hence reduced further compared to Buffered mode. The maximum payload length is limited to the maximum FIFO limit of 64 bytes

Table 12: 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.

5.2. Control Block Description

5.2.1. SPI Interface

5.2.1.1. Overview

As illustrated in the Figure 20 below, the SX1213's SPI interface consists 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 read data bytes from the FIFO. (FIFO interrupts can be used to manage the FIFO content.)

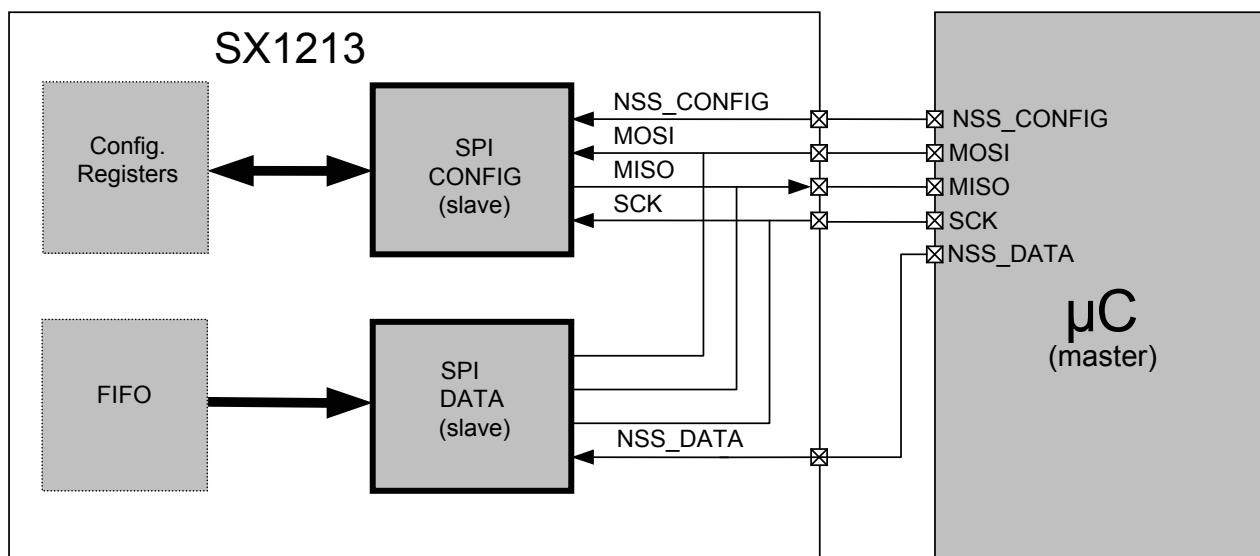


Figure 20: SPI Interface Overview and uC Connections

Both interfaces are configured in slave mode whilst the uC is configured as 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 SX1213

As described below, only one interface can be selected at a time with NSS_CONFIG having the priority:

Table 13: Config vs. Data SPI Interface Selection

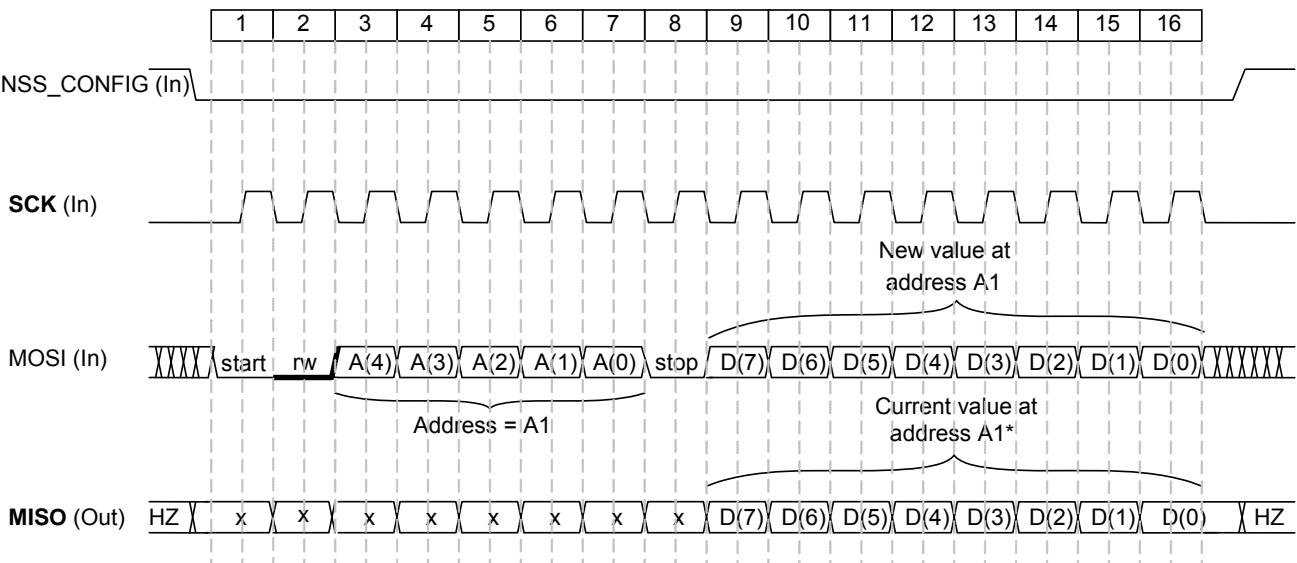
NSS_DATA	NSS_CONFIG	SPI Interface
0	0	Config
0	1	Data
1	0	Config
1	1	None

The following paragraphs describe how to use each of these interfaces.

5.2.1.2. 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 SX1210 side

Figure 21: 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.

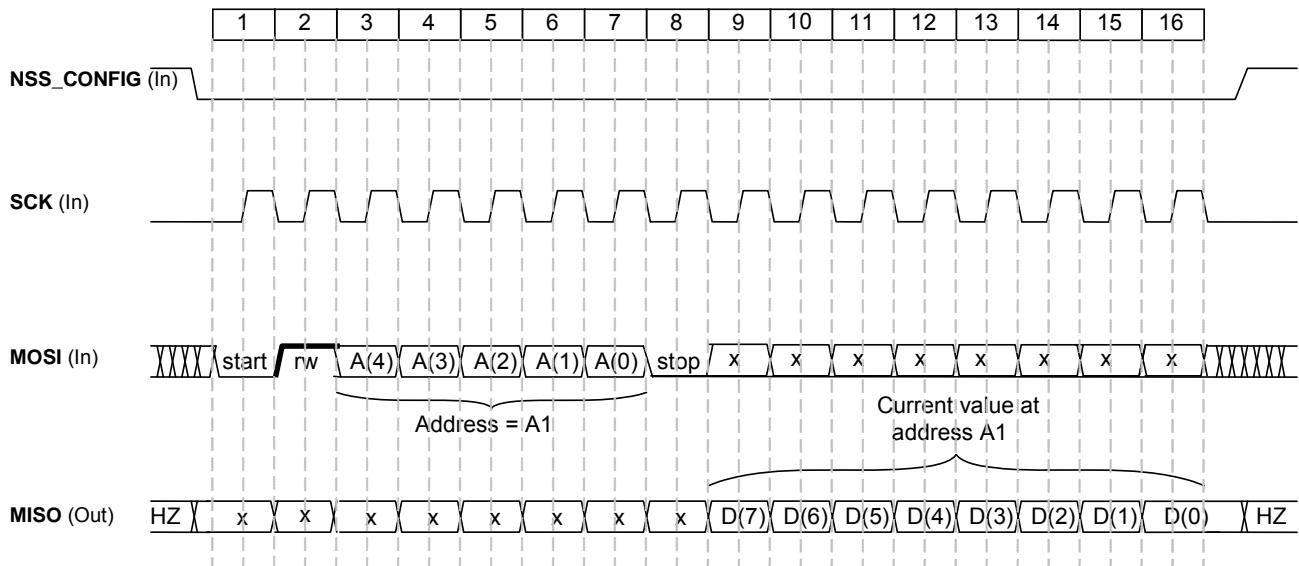


Figure 22: Read Register Sequence

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.

5.2.1.3. SPI Data

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

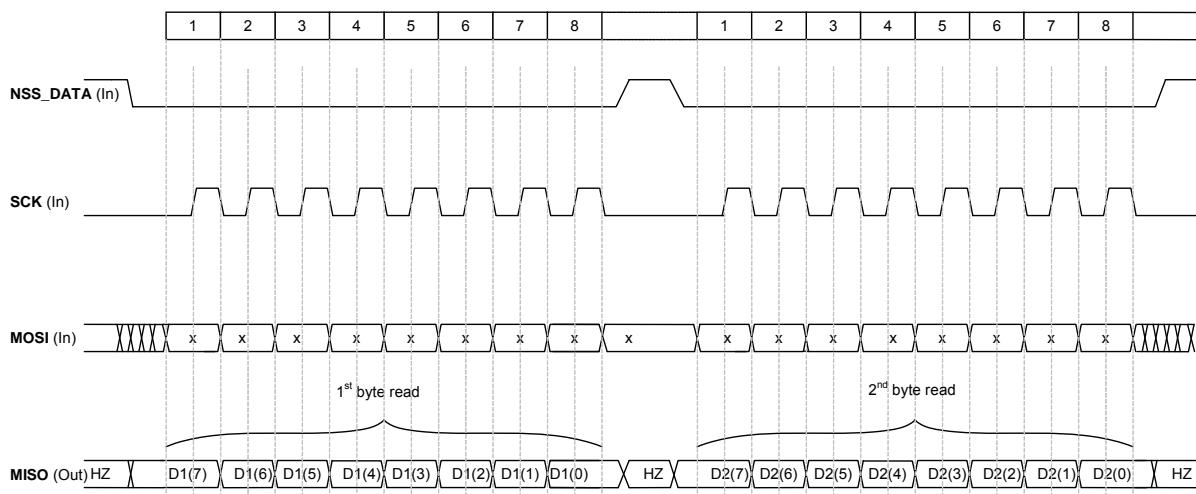


Figure 23: Read Bytes Sequence (ex: 2 bytes)

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

5.2.2. FIFO

5.2.2.1. Overview and Shift Register (SR)

In Buffered and Packet modes of operation, data that have been received are stored in a configurable FIFO (First In First Out) device. 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 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.

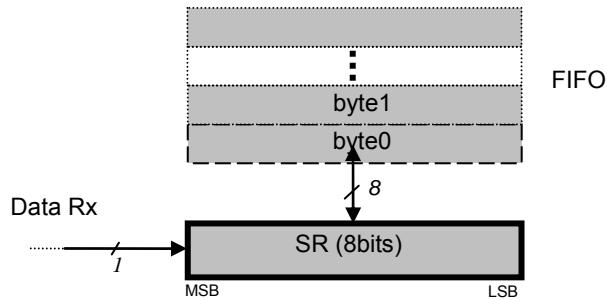


Figure 24: FIFO and Shift Register (SR)

5.2.2.2. Size Selection

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

5.2.2.3. Interrupt Sources and Flags

All interrupt sources and flags are configured in the IRQParam section of the configuration register, with the exception of Fifo_threshold :

- /Fifoempty: /Fifoempty interrupt source is low when byte 0, i.e. whole FIFO, is empty. Otherwise it is high. Note that when retrieving data from the FIFO, /Fifoempty is updated on NSS_DATA falling edge, i.e. when /Fifoempty is updated to low state the currently started read operation must be completed. In other words, /Fifoempty state must be checked **after** each read operation for a decision on the next one (/Fifoempty = 1: more byte(s) to read; /Fifoempty = 0: no more byte to read).
- 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 SR 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.
- Fifo_threshold: Fifo_threshold interrupt source's behavior can be programmed via MCPParam_Fifo_thresh (B value). This behavior is illustrated in Figure 25.

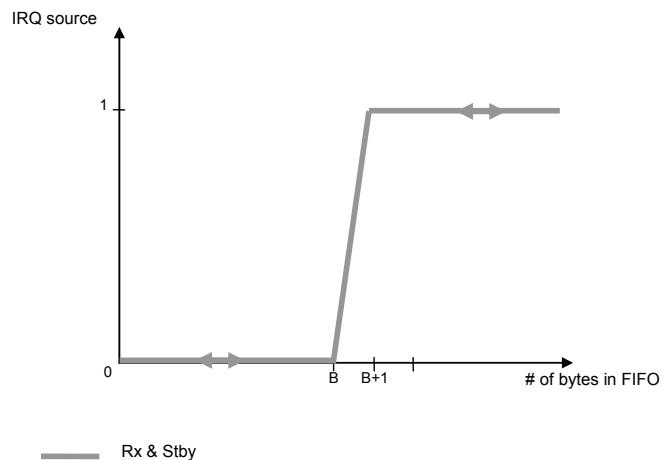


Figure 25: FIFO Threshold IRQ Source Behavior

5.2.2.4. FIFO Clearing

Table 14 below summarizes the status of the FIFO when switching between different modes

Table 14: Status of FIFO when Switching Between Different Modes of the Chip

From	To	FIFO Status	Comments
Stby	Rx	Cleared	
Rx	Stby	Not cleared	In Packet & Buffered modes FIFO can be read in Stby after Rx
Any	Sleep	Cleared	

5.2.3. Sync Word Recognition

5.2.3.1. 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 on each occasion that a match is detected. This is illustrated in Figure 26.

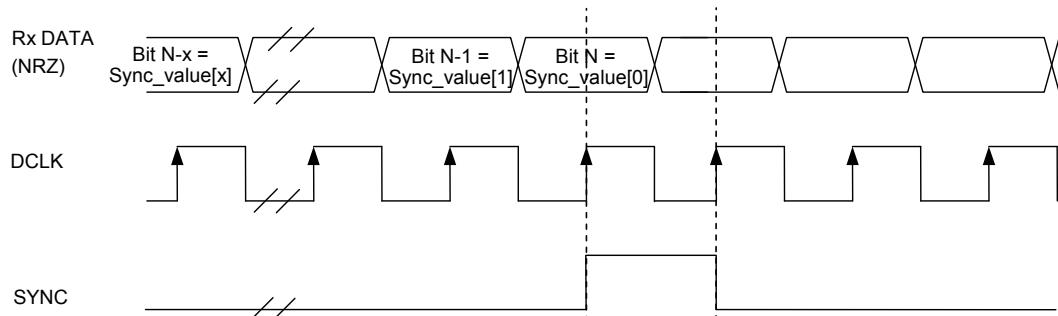


Figure 26: Sync Word Recognition

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 the node and can be processed accordingly.

5.2.3.2. Configuration

- **Size:** Sync word size can be set to 8, 16, 24 or 32 bits via RXParam_Sync_size.
- **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 SYNCParam_Sync_value.

5.2.4. Packet Handler

The packet handler is the block used in Packet mode. Its functionality is fully described in section 5.5.

5.2.5. Control

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

5.3. Continuous Mode

5.3.1. General Description

As illustrated in Figure 27, in Continuous mode the NRZ data from the demodulator is directly accessed by the uC on the DATA pin (20). The SPI Data, FIFO and packet handler are thus inactive.

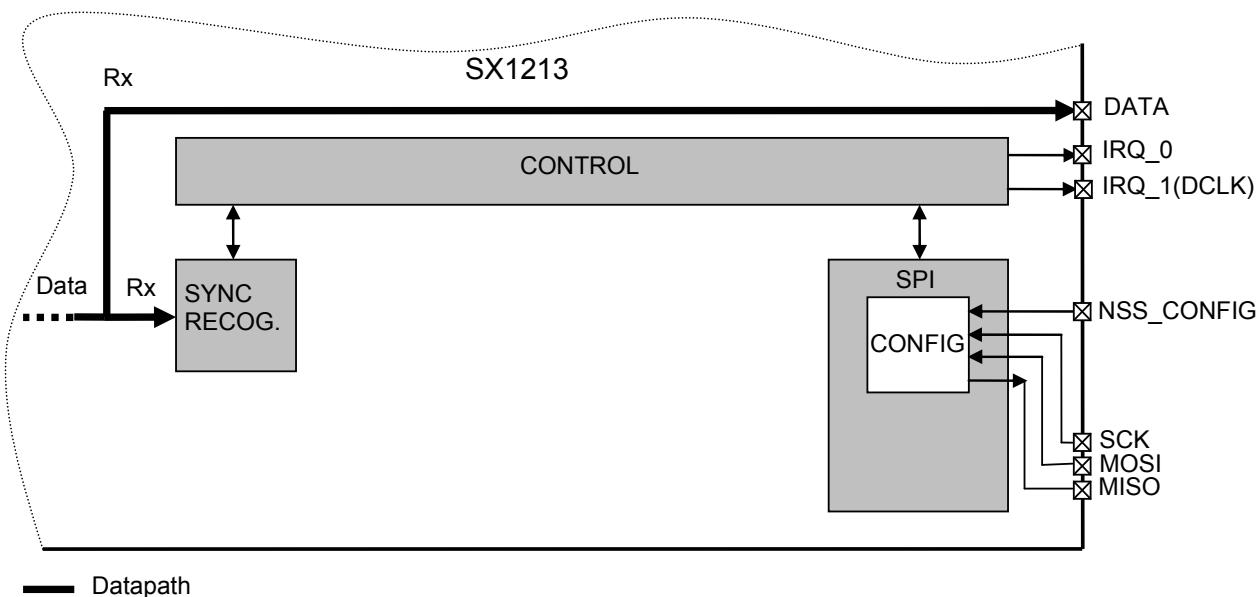


Figure 27: Continuous Mode Conceptual View

5.3.2. 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 sampled on the rising edge of DCLK and updated on the falling edge as illustrated in Figure 28.

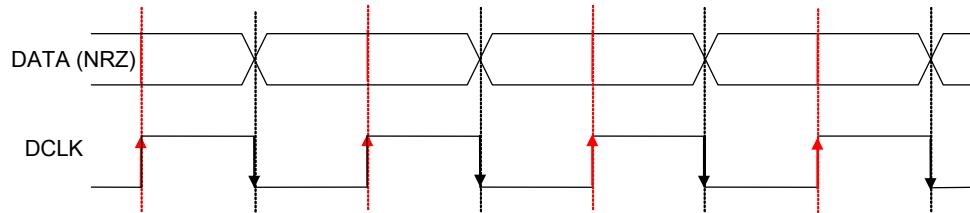


Figure 28: Rx Processing in Continuous Mode

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).

5.3.3. 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 15: Interrupt Mapping in Continuous Rx Mode

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

5.3.4. uC Connections

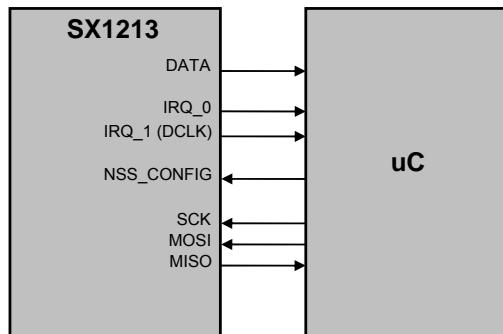


Figure 29: uC Connections in Continuous Mode

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

- IRQ_0: if Sync and RSSI interrupts are not used. In this case, leave floating.
- IRQ_1: DCLK connection is not compulsory. In this case, leave floating.
- MISO: if no read register access is needed. In this case, pull-up to VDD through a 100 kΩ resistor.

In addition, NSS_DATA pin (unused in continuous mode) should be pulled-up to VDD through a 100 kΩ resistor. Please refer to Table 11 for SX1213's pins configuration

5.3.5. Continuous Mode Example

- 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 16: Relevant Configuration Registers in Continuous Mode (data processing related only)

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

- 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 40)
- Wait for Sync interrupt
- Get all packet bits on DATA pin synchronously with DCLK signal provided on IRQ_1
- Go to Sleep mode

5.4. Buffered Mode

5.4.1. General Description

As illustrated in Figure 30, for Buffered mode operation the NRZ data from the demodulator 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 SX1213, 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.

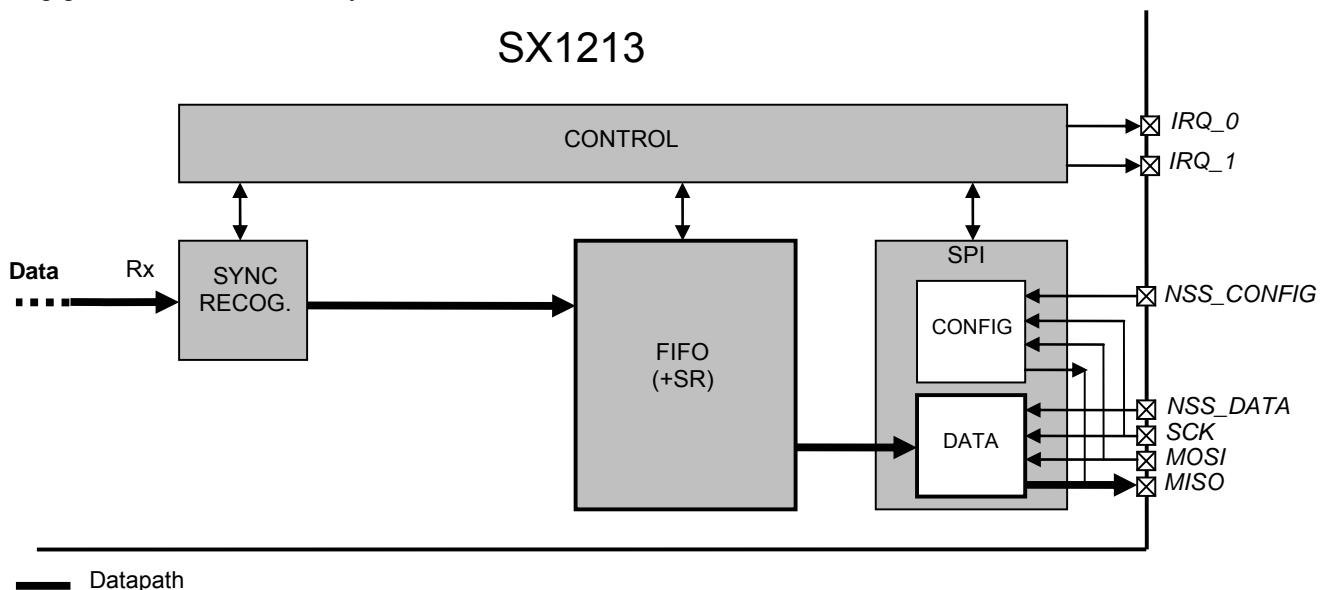


Figure 30: Buffered Mode Conceptual View

Note that Bit Synchronizer is automatically enabled in Buffered mode. The Sync word recognition must be enabled (RXParam_Sync_on=1) independently of the FIFO filling method selected (IRQParam_Fifo_fill_method).

5.4.2. 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 manage 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 31 illustrates an Rx processing with a 16 bytes FIFO size and Fifo_fill_method=0. Please note that in the illustrative example of section 5.4.5, the uC does not retrieve any byte from the FIFO through SPI Data, causing overrun.

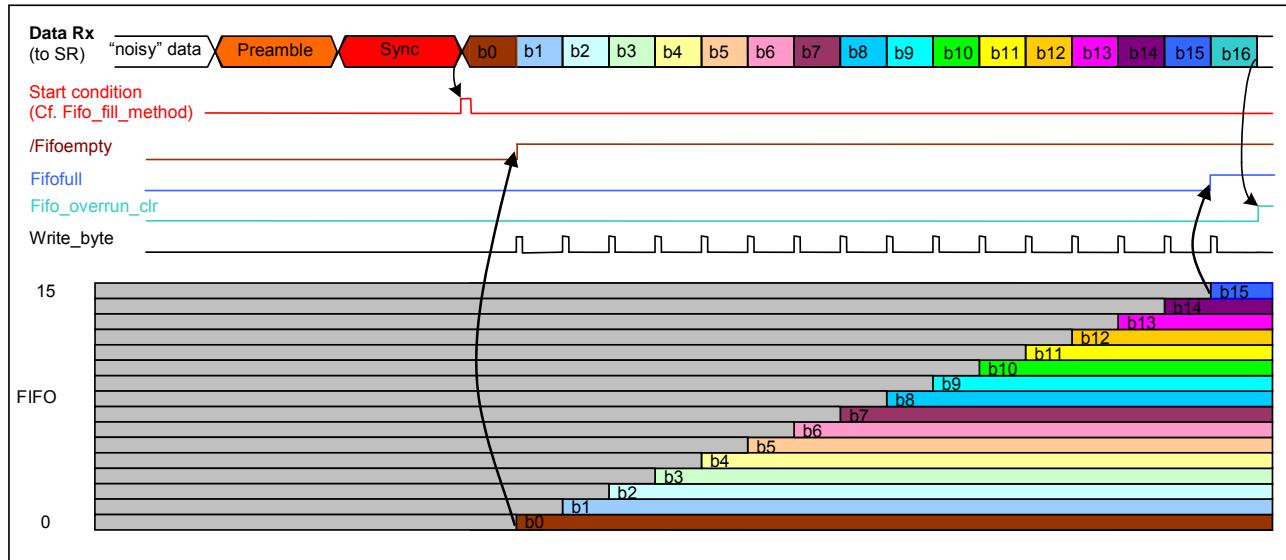


Figure 31: Rx Processing in Buffered Mode (FIFO size=16, Fifo_fill_method=0)

5.4.3. 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 17: Interrupt Mapping in Buffered Rx and Stby Modes

5.4.4. uC Connections

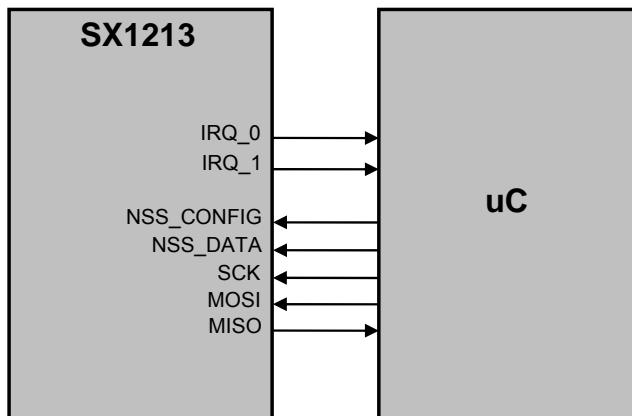


Figure 32: uC Connections in Buffered Mode

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

- IRQ_0: if none of the relevant IRQ sources are used. In this case, leave floating.
- IRQ_1: if none of the relevant IRQ sources are used. In this case, leave floating.

In addition, DATA pin (unused in buffered mode) should be pulled-up to VDD through a 100 kΩ resistor. Please refer to Table 11 for the SX1213's pin configuration.

5.4.5. Buffered Mode Example

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

		Description
MCParam	Data_mode_x	Defines data operation mode (→Buffered)
	Fifo_size	Defines FIFO size
	Fifo_thresh	Defines FIFO threshold
IRQParam	Rx_stby_irq_0	Defines IRQ_0 source in Rx & Stby modes
	Rx_stby_irq_1	Defines IRQ_1 source in Rx & Stby modes
	Fifo_fill_method	Defines FIFO filling method
	Fifo_fill	Controls FIFO filling status
RXParam	Sync_size	Defines Sync word size
	Sync_tol	Defines the error tolerance on Sync word detection
SYNCParam	Sync_value	Defines Sync word value

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

- 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 7.3.1).
- 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.

5.5. Packet Mode

5.5.1. General Description

Similar to Buffered mode operation, in Packet mode the NRZ data from the demodulator is not directly accessed by the uC but stored in the FIFO and accessed via the SPI Data interface.

In addition, the SX1213's packet handler performs several packet oriented tasks such as Preamble and Sync word extraction, CRC check, dewhitening of data, address filtering, etc. This simplifies still further software and reduces uC overhead by performing these repetitive tasks within the RF chip itself.

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

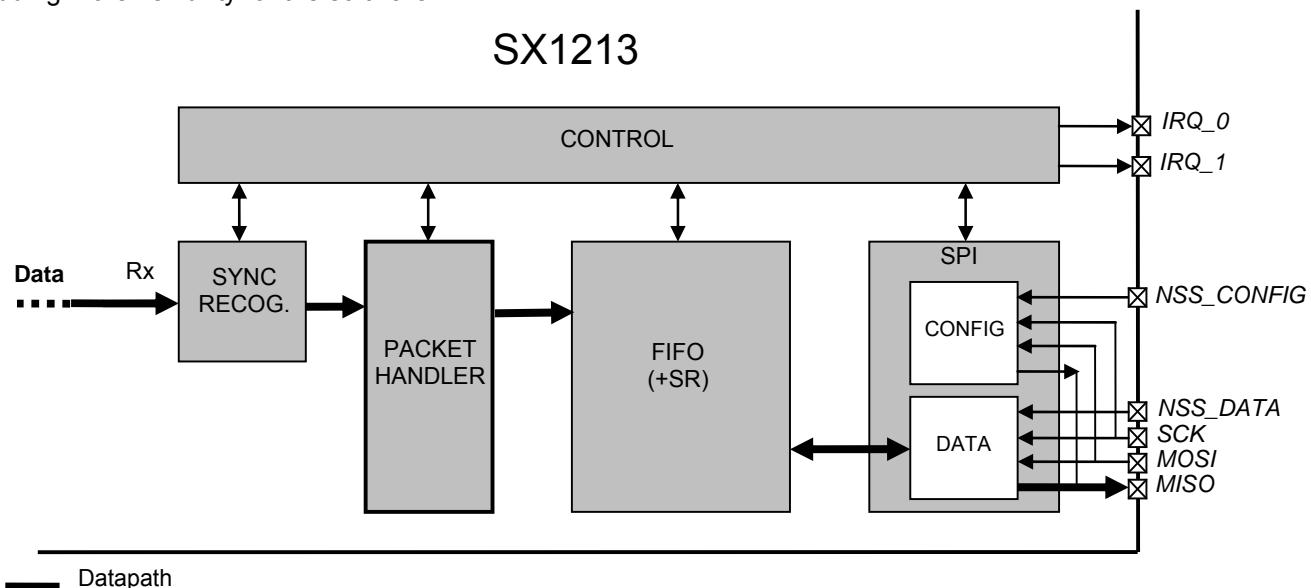


Figure 33: Packet Mode Conceptual View

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

5.5.2. 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).

5.5.2.1. Fixed Length Packet Format

In applications where the packet length is fixed in advance, this mode of operation may be of interest to minimize RF overhead (no length byte field is required). All nodes 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 34. It contains the following fields:

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

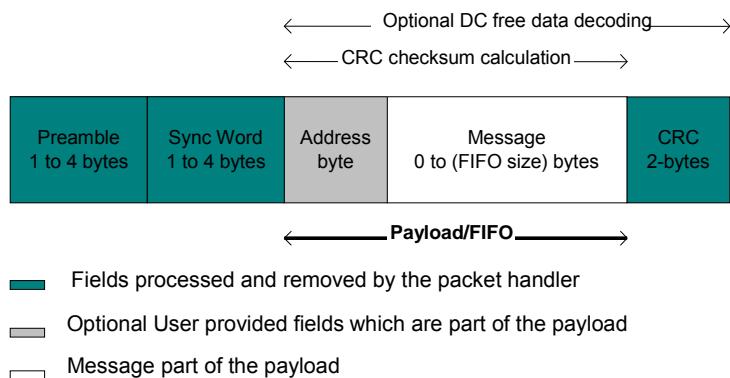


Figure 34: Fixed Length Packet Format

5.5.2.2. Variable Length Packet Format

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 in Figure 35, is given by the first byte of the FIFO and is limited only by the size (width of 8bits) of the FIFO selected. Note that the length byte itself is not included in its calculation. In this mode, the payload must contain at least 2 bytes, i.e. length + address or message byte.

An illustration of a variable length packet is shown in Figure 35. It contains the following fields:

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

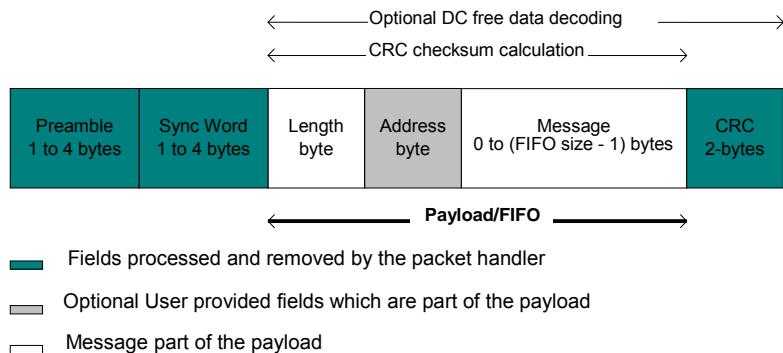


Figure 35: Variable Length Packet Format

5.5.3. 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). FIFO must be empty for a new packet reception to start.

5.5.4. Packet Filtering

SX1213'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.

5.5.4.1. 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 to filter 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.

5.5.4.2. 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.

5.5.4.3. 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.

5.5.4.4. CRC Based

The CRC check is enabled by setting bit PKTParam_CRC_on. It is used for checking the integrity of the message.

- On your Tx side a two byte CRC checksum should be calculated on the payload part of the packet and appended to the end of the message.
- On SX1213 (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 36. This implementation also detects errors due to leading and trailing zeros.

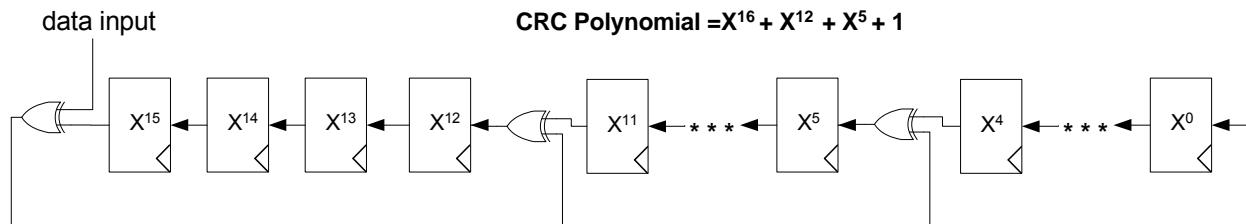


Figure 36: CRC Implementation

5.5.5. DC-Free Data Mechanisms

Two techniques are supported by the SX1213 packet handler: Manchester decoding and data whitening. Please note that only one of the two methods should be enabled at a time.

5.5.5.1. Manchester Decoding

Manchester decoding is enabled by setting bit PKTParam_Manchester_on and can only be used in Packet mode.

The NRZ data to Manchester codes '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 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 decoding is thus made transparent for the user, who still retrieves NRZ data from the FIFO.

RF chips @ BR	1/BR ...Sync								1/BR Payload...										
	...	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	0	0	1	1	0	1	1	...

Figure 37: Manchester Decoding

5.5.5.2. Data Dewhitening

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 SX1213 (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.

SX1213 supported whitening algorithm is given in Figure 38. This figure provides you with the random sequence to be X-ORed with the actual payload.

The de-whitening process is enabled by setting bit PKTParam_Whitening_on. The data is de-whitened by the SX1213 receiver side by XORing with the same random sequence as the Tx.

Payload de-whitening is thus made transparent for the user, who still retrieves NRZ data from the FIFO.

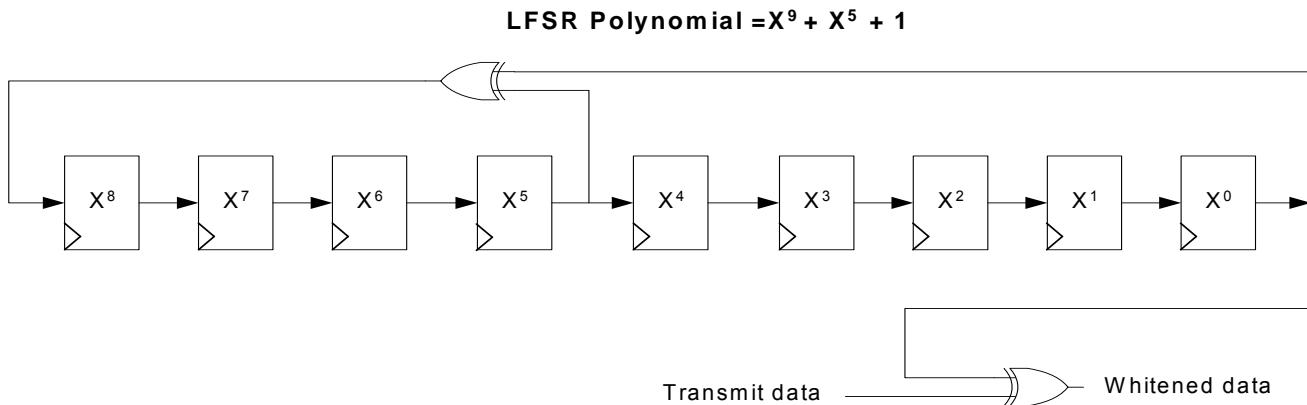


Figure 38: Data Whitening Implementation

5.5.6. Interrupt Signal Mapping

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

Table 19: 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

5.5.7. uC Connections

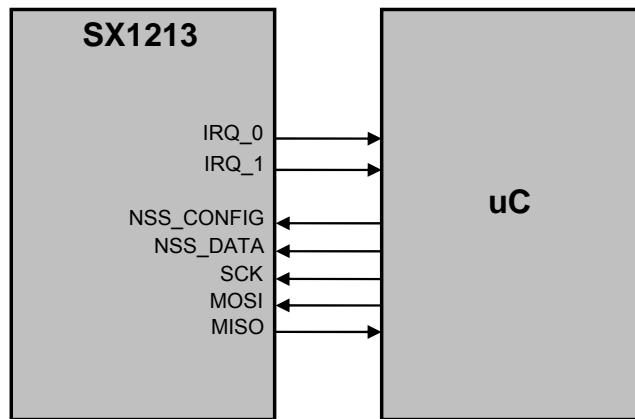


Figure 39: uC Connections in Packet Mode

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

- IRQ_0: if none of the relevant IRQ sources are used. In this case, leave floating.

- IRQ_1: if none of the relevant IRQ sources are used. In this case, leave floating. In addition, DATA pin (unused in packet mode) should be pulled-up to VDD through a 100 kΩ resistor. Please refer to Table 11 for the SX1213's pin configuration.

5.5.8. Packet Mode Example

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

Table 20: Relevant Configuration Registers in Packet Mode (data processing related only)

		Description
MCPParam	Data_mode_x	Defines data operation mode (→Packet)
	Fifo_size	Defines FIFO size
	Fifo_thresh	Defines FIFO threshold
IRQParam	Rx_stby_irq_0	Defines IRQ_0 source in Rx & Stby modes
	Rx_stby_irq_1	Defines IRQ_1 source in Rx & Stby modes
RXParam	Sync_size	Defines Sync word size
	Sync_tol	Defines the error tolerance on Sync word detection
SYNCParam	Sync_value	Defines Sync word value
PKTParam	Manchester_on	Enables Manchester decoding
	Payload_length	Length in fixed format, max length in variable format
	Node_adrs	Defines node address for address filtering
	Pkt_format	Defines packet format (fixed or variable length)
	Whitening_on	Enables de-whitening process
	CRC_on	Enables CRC calculation/check
	Adrs_filt	Enables and defines address filtering
	CRC_autoclr	Enables FIFO autoclear if CRC failed

Rx Mode:

- 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 7.3.1)
- Wait for CRC_OK interrupt
- Go to Stby
- Read payload bytes from FIFO until /Fifoempty goes low.
- Go to Sleep mode

5.5.9. Additional Information

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.

6. Configuration and Status Registers

6.1. General Description

Table 21 sums-up the control and status registers of the SX1213:

Table 21: Registers List

Name	Size	Address	Description
MCPParam	12 x 8	0 - 11	Main parameters
IRQParam	4 x 8	12 - 15	Interrupt registers
RXParam	6 x 8	16 - 21	Receiver parameters
SYNCParam	4 x 8	22 - 25	Pattern
Reserved	1 x 8	26	Do not change default value : "01111110"
OSCParam	1 x 8	27	Crystal oscillator parameters
PKTParam	4 x 8	28 - 31	Packet handler parameters

6.2. Main Configuration Register - MCPParam

The detailed description of the MCPParam register is given in Table 22.

Table 22: MCPParam Register Description

Name	Bits	Address (d)	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
Freq_band	4-2	0	r/w	Frequency band: 000 → 300-330 MHz 001 → 320-350 MHz 010 → 350-390 MHz 011 → 390-430 MHz 100 → 430-470 MHz (d) 101 → 470-510 MHz
Subbband	1-0	0	r/w	Frequency Sub-band: 00 -> 1st quarter of the selected band (d) 01 -> 2nd quarter of the selected band 10 -> 3rd quarter of the selected band 11 -> 4th quarter of the selected band
Data_mode	7-6	1	r/w	Data operation mode: 00 -> continuous mode (d) 01 -> buffered mode 1X -> packet handling mode
FSK_OOK_ctrl	5-4	1	r/w	RxTx modulation scheme: 00 -> Reset 01 -> OOK 10 -> FSK (d) 11 -> Direct mode of transmitter (internal). Reserved (external)
OOK_thresh_type	3-2	1	r/w	OOK demodulator threshold type: 00 → fixed threshold mode 01 → peak mode (d) 10 → average mode 11 → reserved

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 in FSK Transmit mode: Refer to sections Error! Reference source not found. and Error! Reference source not found. $F_{dev} = \frac{f_{XTAL}}{32 \cdot (D+1)}, 0 \leq D \leq 255$, where D is the value in the register. (d): D = "00000011" => Fdev = 100 kHz
BR_C	7-0	3	r/w	C coefficient of the bit rate $\text{Bit Rate} = \frac{f_{XTAL}}{2 \cdot (C+1) \cdot (D+1)}, 0 \leq C \leq 255$, where C is the value in the register. (d): C = "0000111" => Bit Rate = 25 kb/s NRZ
BR_D	7-0	4	r/w	D coefficient of the bit rate $\text{Bit Rate} = \frac{f_{XTAL}}{2 \cdot (C+1) \cdot (D+1)}, 15 \leq D \leq 255$, where D is the value in the register. (d): D = "0001111" => Bit Rate = 25 kb/s NRZ
Res	7-6	5	r/w	Reserved (d): "0"
Low_power_rx	5	5	r/w	Enables the low power mode of the receiver by reducing the bias current of the LNA. 0 -> Low power mode disabled (d) 1 -> Low power mode enabled
Trim_band	2-1	5	r/w	VCO trimming: 00 -> Add VCO trimming capacitor of weight 3 01 -> Add VCO trimming capacitor of weight 2 10 -> Add VCO trimming capacitor of weight 1 11 -> No additional VCO trimming capacitor (d)
RF_frequency	0	5	r/w	Selection between the two RF frequencies defined by the SynthRi, SynthPi, and SynthSi registers: 0 -> frequency 1 for R1,P1,S1 (d) 1 -> frequency 2 for R2,P2,S2
R1	7-0	6	r/w	R counter, active when RPS_select="0" (d): 6Bh; default values of R1, P1, S1 generate 434.0 MHz in FSK mode
P1	7-0	7	r/w	P counter, active when RPS_select="0" (d): 2Ah; default values of R1, P1, S1 generate 434.0 MHz in FSK mode
S1	7-0	8	r/w	S counter, active when RPS_select="0" (d): 1Eh; default values of R1, P1, S1 generate 434.0 MHz in FSK mode
R2	7-0	9	r/w	R counter, active when RPS_select="1" (d): 77h; default values of R2, P2, S2 generate 435.0 MHz in FSK mode
P2	7-0	10	r/w	P counter, active when RPS_select="1" (d): 2Fh; default values of R2, P2, S2 generate 435.0 MHz in FSK mode
S2	7-0	11	r/w	S counter, active when RPS_select="1" (d): 19h; default values of R2, P2, S2 generate 435.0 MHz in FSK mode

6.3. Interrupt Configuration Parameters - IRQParam

The detailed description of the IRQParam register is given in Table 23.

Table 23: IRQParam Register Description

Name	Bits	Address (d)	RW	Description
Fifo_size	7-6	12	r/w	Configures the size of the FIFO: 00 -> 16 bytes (d) 01 -> 32 bytes 10 -> 48 bytes 11 -> 64 bytes
Fifo_thresh	5-0	12	r/w	Number of bytes to be written in the FIFO to activate the Fifo_threshold interrupts Actual number of bytes = B + 1, where B is the value in the register. (d): B = 001111 => Number of bytes = 16
Rx_stby_irq_0	7-6	13	r/w	IRQ_0 source in Rx and Standby modes: If Data_mode(1:0) = 00 (Continuous mode): 00 → Sync (d) 01 → RSSI 10 → Sync 11 → Sync If Data_mode(1:0) = 01 (Buffered mode): 00 → - (d) 01 → Write_byte 10 → /Fifoempty* 11 → Sync 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) *also available in Standby mode (Cf sections 5.4.3 and 5.5.6)
Rx_stby_irq_1	5-4	13	r/w	IRQ_1 source in Rx and Standby modes: If Data_mode(1:0) = 00 (Continuous mode): xx → DCLK If Data_mode(1:0) = 01 (Buffered mode): 00 → - (d) 01 → Fifofull* 10 → RSSI 11 → Fifo_threshold* If Data_mode(1:0) = 1x (Packet mode): 00 → CRC_ok (d) 01 → Fifofull* 10 → RSSI 11 → Fifo_threshold* *also available in Standby mode (Cf sections 5.4.3 and 5.5.6)
Res	3-2	13		Reserved default 0d
Fifofull	1	13	r	Fifofull IRQ source Goes high when FIFO is full.
/Fifoempty	0	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 <u>Fifo_fill</u>
Fifo_fill	6	14	r/w/c	FIFO filling status/control (Buffered mode only): <ul style="list-style-type: none"> ▪ If <u>Fifo_fill_method</u> = '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 <u>Fifo_overrun_clr</u> =0) <ul style="list-style-type: none"> ▪ If <u>Fifo_fill_method</u> = '1': 0 → Stop filling the FIFO 1 → Start filling the 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 <u>Fifo_fill</u>
Fifo_fill	6	14	r/w/c	FIFO filling status/control (Buffered mode only): <ul style="list-style-type: none"> ▪ If <u>Fifo_fill_method</u> = '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 <u>Fifo_overrun_clr</u> =0) <ul style="list-style-type: none"> ▪ If <u>Fifo_fill_method</u> = '1': 0 → Stop filling the FIFO 1 → Start filling the FIFO
Res	5	14	r	reserved
Fifo_overrun_clr	4	13	r/w/c	Goes high when an overrun error occurred. Writing a 1 anytime clears flag (if set) and launches a new Rx or Tx process
Res	3	14	r/w	(d): "0", should be set to "1". Note: "0" disables the RSSI IRQ source. It can be left enabled at any time, and the user can choose to map this interrupt to IRQ0/IRQ1 or not.
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

6.4. Receiver Configuration parameters - RXParam

The detailed description of the RXParam register is given in Table 24.

Table 24: RXParam Register Description

Name	Bits	Address (d)	RW	Description
PassiveFilt	7-4	16	r/w	Typical single sideband 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 3.3.5 (FSK) and 3.3.6 (OOK). $f_c = f_0 + 200\text{kHz} \cdot \frac{f_{xtal}\text{MHz}}{12.8\text{MHz}} \cdot \frac{1 + \text{Val(ButterFilt)}}{8}$ (d): "0011" => $f_c = 200 \text{ kHz}$
PolypFilt_center	7-4	17	r/w	Central frequency of the polyphase filter (100kHz recommended): $f_0 = 200\text{kHz} \cdot \frac{f_{xtal}\text{MHz}}{12.8\text{MHz}} \cdot \frac{1 + \text{Val(PolypFilt_center)}}{8}$ (d): "0011" => $f_0 = 100 \text{ kHz}$
Res	3-0	17	r/w	Reserved (d): "1000"
PolypFilt_on	7	18	r/w	Enable of 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"

Name	Bits	Address (d)	RW	Description
Res	7-0	19	r/w	Reserved (d): "00000111"
RSSI_val	7-0	20	r	RSSI output, 0.5 dB / bit Note: READ-ONLY (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 25.

Table 25: SYNCParam Register Description

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

6.6. Oscillator Parameters - OSCParam

The detailed description of the OSCParam register is given in Table 26.

Table 26: OSCParam Register Description

Name	Bits	Address (d)	RW	Description
Clkout_on	7	27	r/w	Clkout control 0 → Disabled 1 → Enabled, Clk frequency set 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" $f_{clkout} = \frac{f_{xtal}}{2 \cdot Clkout_freq}$ otherwise (d): 01111 (= 427 kHz)
Res	1-0	27	r/w	Reserved (d): "00"

6.7. Packet Handling Parameters – PKTParam

The detailed description of the PKTParam register is given in Table 27.

Table 27: PKTParam Register Description

Name	Bits	Address (d)	RW	Description
Manchester_on	7	28	r/w	Enable Manchester 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 (d): “0000000”
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
Res	6-5	30	r/w	(d) : “10”
Whitening_on	4	30	r/w	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 (READ ONLY): 0 → Fail 1 → Pass
CRC_autoclr	7	31	r/w	FIFO auto clear if CRC failed for current packet: 0 → on (d) 1 → off
Res	6-0	31	r/w	Reserved (d): “0000000” recommended to set to “1000000”

7. Application Information

7.1. Crystal Resonator Specification

Table 28 shows the crystal resonator specification for the crystal reference oscillator circuit of the SX1213. This specification covers the full range of operation of the SX1213 and is employed in the reference design (see section 7.5.3).

Table 28: Crystal Resonator Specification

Name	Description	Min.	Typ.	Max.	Unit
Fxtal	Nominal frequency	9	12.800	15	MHz
Cload	Load capacitance for Fxtal	10	15	16.5	pF
Rm	Motional resistance	-	-	100	ohms
Co	Shunt capacitance	1	-	7	pF
ΔFxtal	Calibration tolerance at 25+/-3°C	-15	-	+15	ppm
ΔFxtal(ΔT)	Stability over temperature range [-40°C ; +85°C]	-20	-	+20	ppm
ΔFxtal(Δt)	Ageing tolerance in first 5 years	-2	-	+2	ppm/year

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.

7.2. Software for Frequency Calculation

The R1, P1, 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.

7.2.1. GUI

To aid the user with calculating appropriate R, P and S values, software is available to perform the frequency calculation. The SX1213 PLL frequency Calculator Software can be downloaded from the Semtech website.

7.2.2. .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 SX1213) 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 oscillator frequency.

7.3. Switching Times and Procedures

As an ultra-low power device, the SX1213 can be configured for low minimum average power consumption. To minimize consumption the following optimized transitions between modes are shown.

7.3.1. Optimized Receive Cycle

The lowest-power Rx cycle is the following:

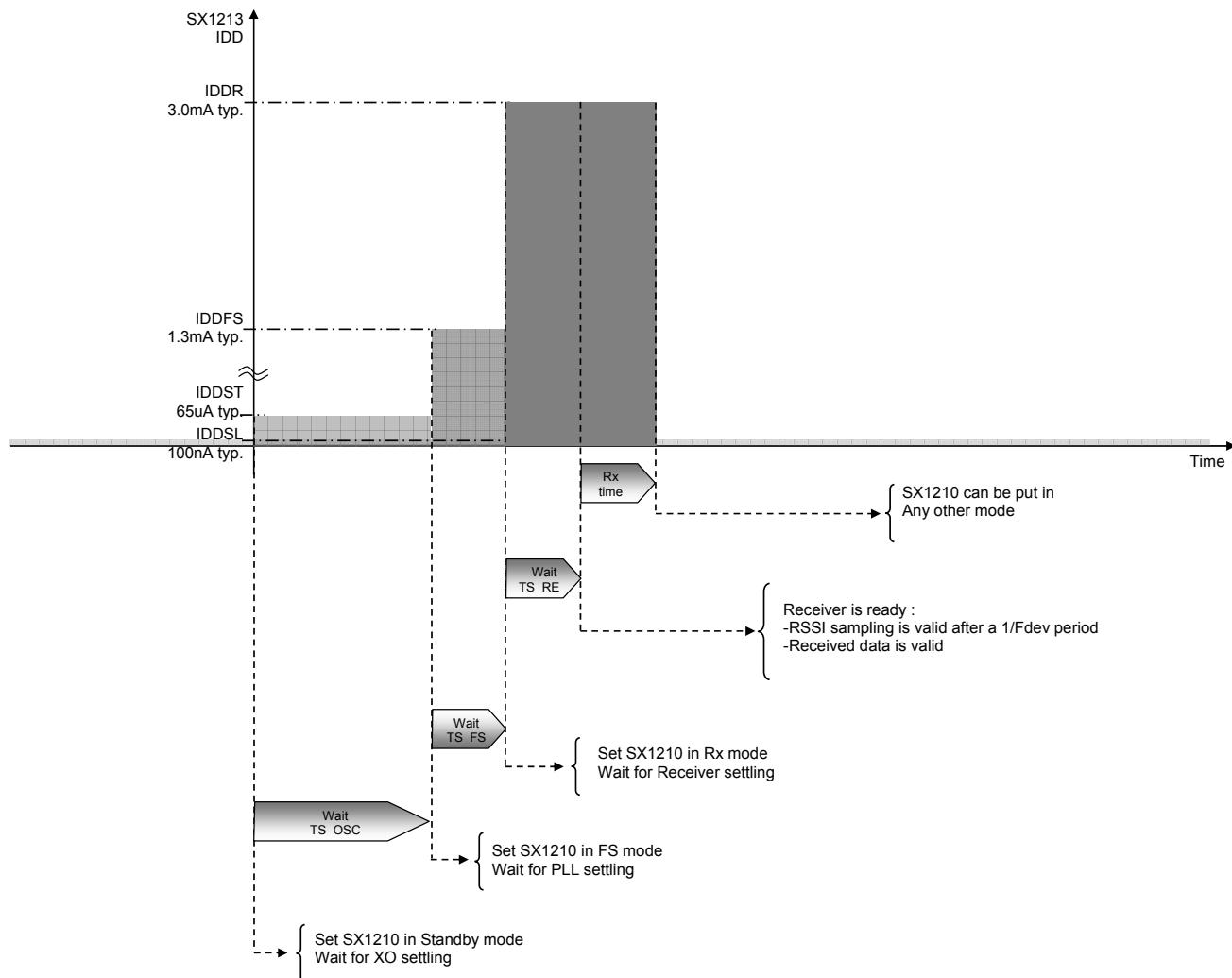


Figure 40: Optimized Rx Cycle

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.

7.3.2. Receiver Frequency Hop Optimized Cycle

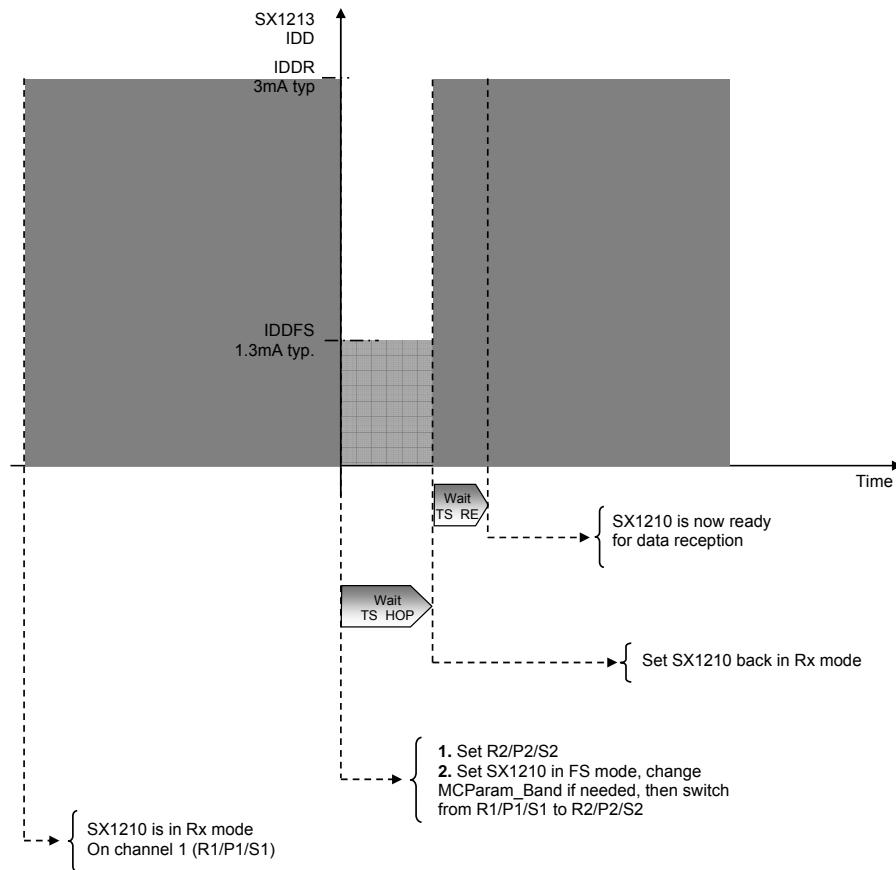


Figure 41: Rx Hop Cycle

Note: it is also possible to move from one channel to the other one without having to switch off the receiver. This method is faster, and overall draws more current. For timing information, please refer to TS_RE_HOP on Table 7.

7.4. Reset of the Chip

A power-on reset of the SX1213 is triggered at power up. Additionally, a manual reset can be issued by controlling pin 13.

7.4.1. POR

If the application requires the disconnection of VDD from the SX1213, despite of the extremely low Sleep Mode current, the user should wait for 10 ms from the end of the POR cycle before commencing communications over the SPI bus. Pin 13 (TEST8) should be left floating during the POR sequence.

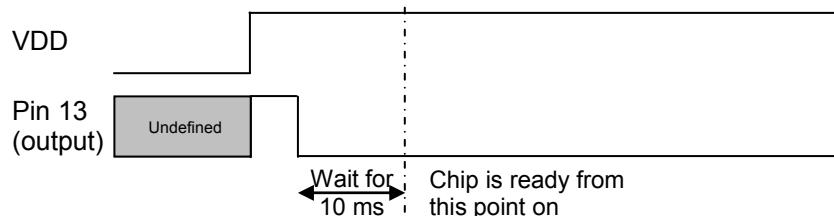


Figure 42: POR Timing Diagram

Please note that any CLKOUT activity can also be used to detect that the chip is ready.

7.4.2. Manual Reset

A manual reset of the SX1213 is possible even for applications in which VDD cannot be physically disconnected. Pin 13 should be pulled high for a hundred microseconds, and then released. The user should then wait for 5 ms before using the chip.

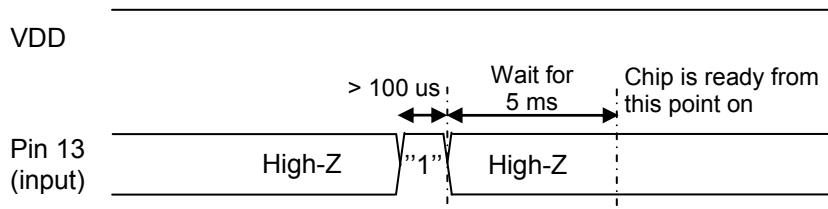


Figure 43: Manual Reset Timing Diagram

Please note that while pin 13 is driven high, an over current consumption of up to ten millamps can be seen on VDD.

7.5. Reference Design

SX1212 Transceiver module is provided to perform the SX1213 evaluation, it is the receiver part of SX1212 Transceiver with compatible pinout and same receiver performances. SX1212 reference design is given as an example below. However it is possible to reduce the BOM on SX1213 (refer to Table 29: Reference Design BOM).

7.5.1. Application Schematic

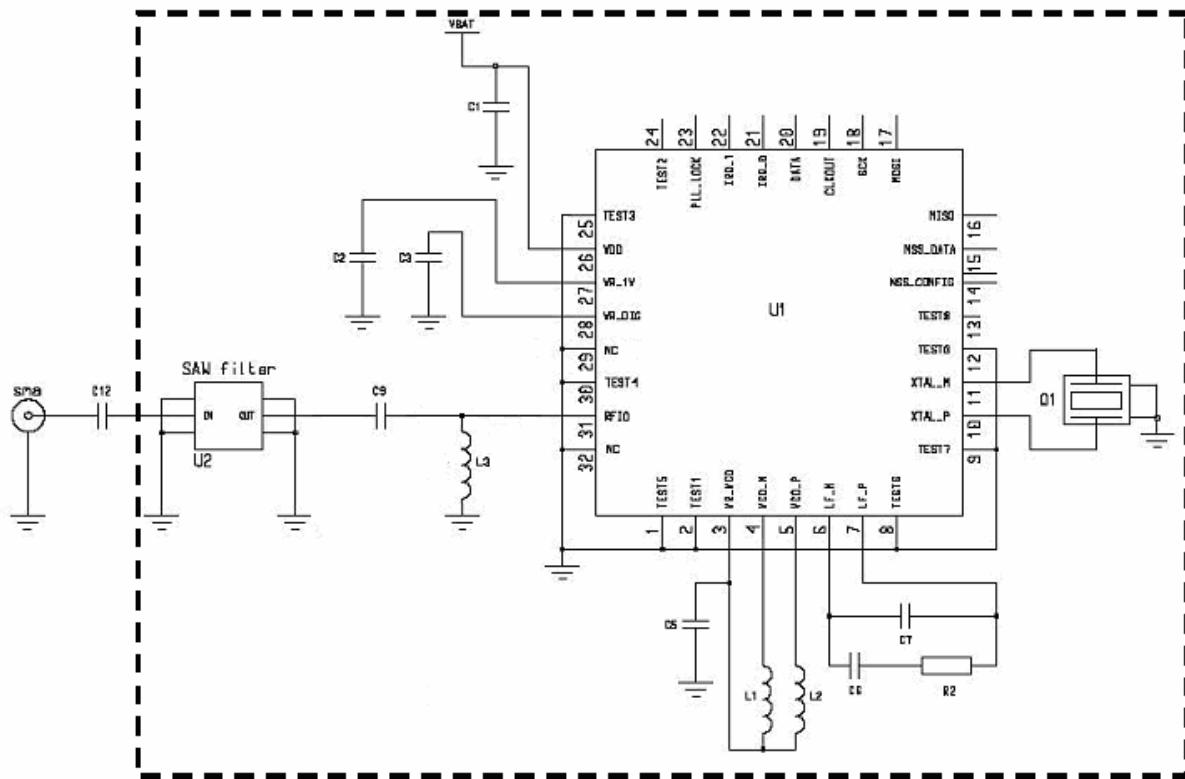


Figure 44: Reference Design Circuit Schematic

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 could be removed for a direct antenna connection if there is no DC bias is expected at the antenna port. Please note that for SX1213 C10 can be replaced a 5.4nH inductor, L4 by a 0Ohm, L3, C4, R1, C8 and C11 are not used. SAW filter is optional on most application (refer to Table 29: Reference Design BOM)

7.5.2. 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 => minimal design effort to transfer to other PCB technologies (thickness, # of layers, etc...)

The layers description is illustrated in Figure 45:

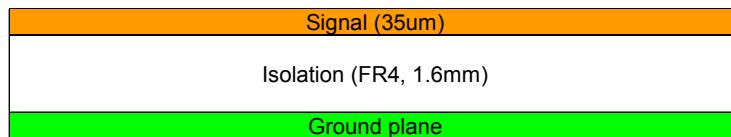


Figure 45: Reference Design's Stackup

The layout itself is illustrated in Figure 46. Please contact Semtech for Gerber files.

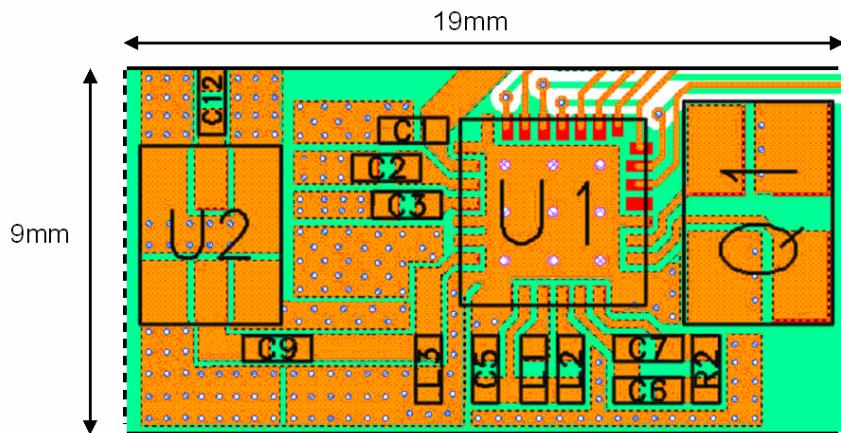


Figure 46: Reference Design Layout (top view)

7.5.3. Bill Of Material

Ref	Value		Tol (+/-)	Techno	Size	Comment
	315MHz	433MHz				
U1	SX1213		-	Transceiver IC	TQFN-32	-
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
R2	6k8		1%	-	0402	Loop filter
C1	1uF		15%	X5R	0402	VDD decoupling
C2	100 nF		10%	X7R	0402	Top regulator decoupling
C3	100 nF		10%	X7R	0402	Digital 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
C9	22 pF		5%	NPO	0402	DC block
L1, L2	39 nH	18 nH	2%	Wire wound	0402	VCO tank inductors
L3	47 nH		5%	Monolithic	0402	LNA bias inductor
U2	315 MHz	434 MHz	-	SAW Filter	3.8*3.8 mm	Optional
C12*	47pF		5%	NPO	0402	DC block

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

Table 29: Reference Design BOM

Note: for battery powered applications, a high value capacitance should be implemented in parallel with C1 (typically 10 μ F) to offer a low impedance voltage source during startup sequences.

7.5.4. Ordering Information for Tools

The modules described in section 7.5 can be ordered through your Semtech representative for evaluation purpose:

Table 30: Tools Ordering Information

Part Number	Description
SM1212E433	2 layer RF module, 433 MHz band (Transceiver is used to evaluate the receiver)
SM1212E315	2 layer RF module, 315 MHz band (Transceiver is used to evaluate the receiver)
SX1212SKA315	USB evaluation kit, including antennas
SX1212SKA433	USB evaluation kit, including antennas

8. Packaging Information

8.1. Package Outline Drawing

SX1213 is available in a 32-lead TQFN package as shown in Figure 47 below.

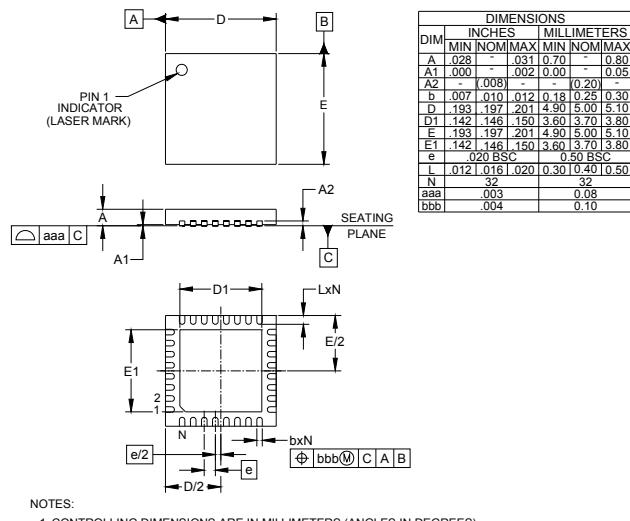
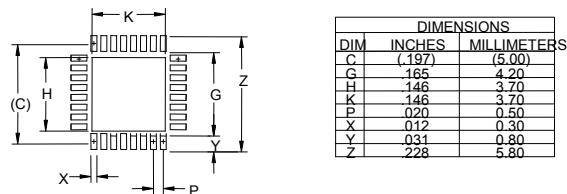


Figure 47: Package Outline Drawing

8.2. PCB Land Pattern

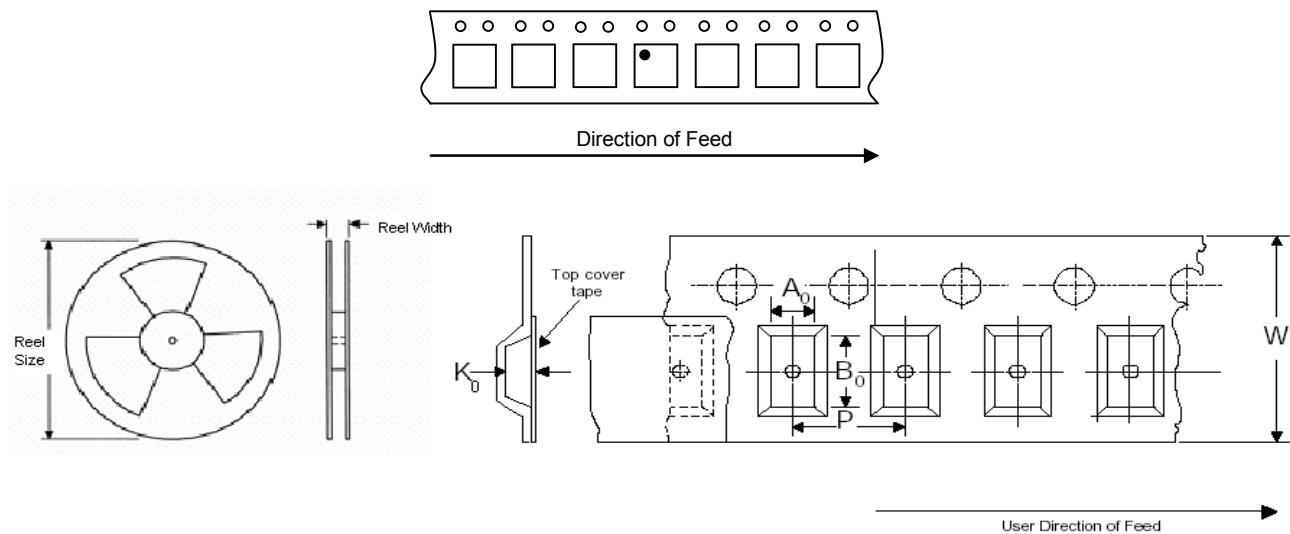


NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. THIS LAND PATTERN IS FOR REFERENCE PURPOSES ONLY. CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR COMPANY'S MANUFACTURING GUIDELINES ARE MET.
3. THERMAL VIAS IN THE LAND PATTERN OF THE EXPOSED PAD SHALL BE CONNECTED TO A SYSTEM GROUND PLANE. FAILURE TO DO SO MAY COMPROMISE THE THERMAL AND/OR FUNCTIONAL PERFORMANCE OF THE DEVICE.
4. SQUARE PACKAGE - DIMENSIONS APPLY IN BOTH "X" AND "Y" DIRECTIONS.

Figure 48: PCB Land Pattern

8.3. Tape & Reel Specification



Carrier Tape				Reel				
Tape Width(W)	Pocket Pitch (P)	Ao/Bo	Ko	Reel Size	Reel Width	Min. Trail er Length	Min. Leader Length	QTY per Reel
12 +/-0.3	8 +/-0.1	5.25 +/-0.2	1.10 +/-0.1	330.2	12.4	400	400	3000

Notes:

*all dimensions in mm

*single sprocket holes

Figure 49: Tape & Reel Dimensions

9. Revision History

- Revision 2.0: Final datasheet supersedes preliminary.

10. Contact Information

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