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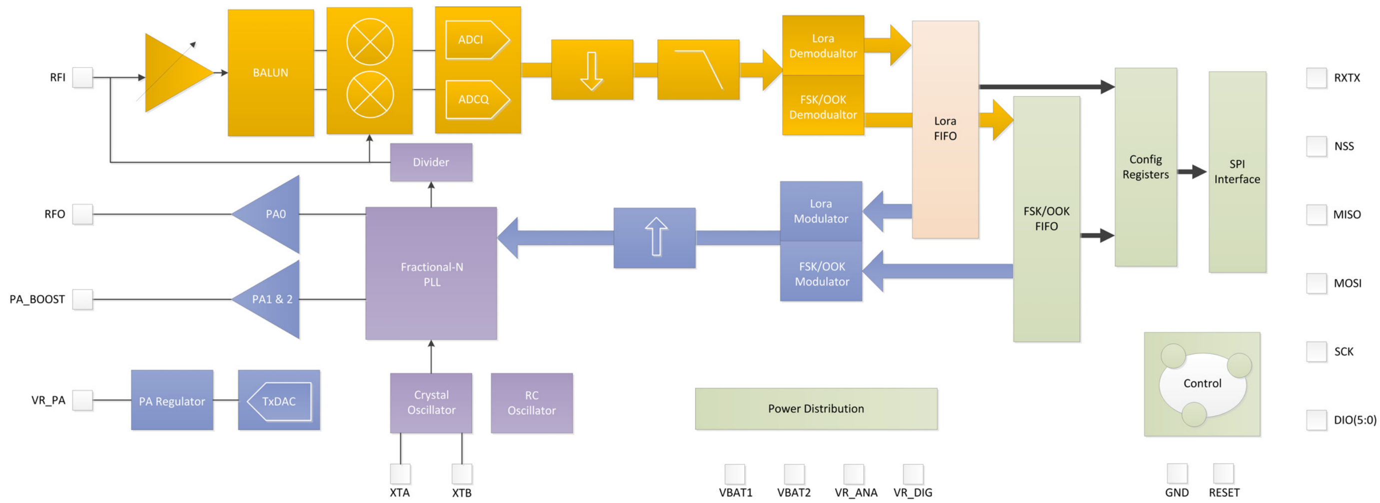
Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China

SX1272/73 - 860 MHz to 1020 MHz Low Power Long Range Transceiver



GENERAL DESCRIPTION

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

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

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

ORDERING INFORMATION

Part Number	Delivery	MOQ / Multiple
SX1272IMLTRT	T&R	3000 pieces
SX1273IMLTRT	T&R	3000 pieces

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

KEY PRODUCT FEATURES

- LoRa^{TM} Modem
- 157 dB maximum link budget
- +20 dBm at 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -137 dBm
- Bullet-proof front end: IIP3 = -12.5 dBm
- 89 dB blocking immunity
- Low RX current of 10 mA, 100 nA register retention
- Fully integrated synthesizer with a resolution of 61 Hz
- FSK, GFSK, MSK, GMSK, LoRa^{TM} and OOK modulation
- Built-in bit synchronizer for clock recovery
- Preamble detection
- 127 dB Dynamic Range RSSI
- Automatic RF Sense and CAD with ultra-fast AFC
- Packet engine up to 256 bytes with CRC
- Built-in temperature sensor and low battery indicator

APPLICATIONS

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

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1. General Description

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

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

1.1. Simplified Block Diagram

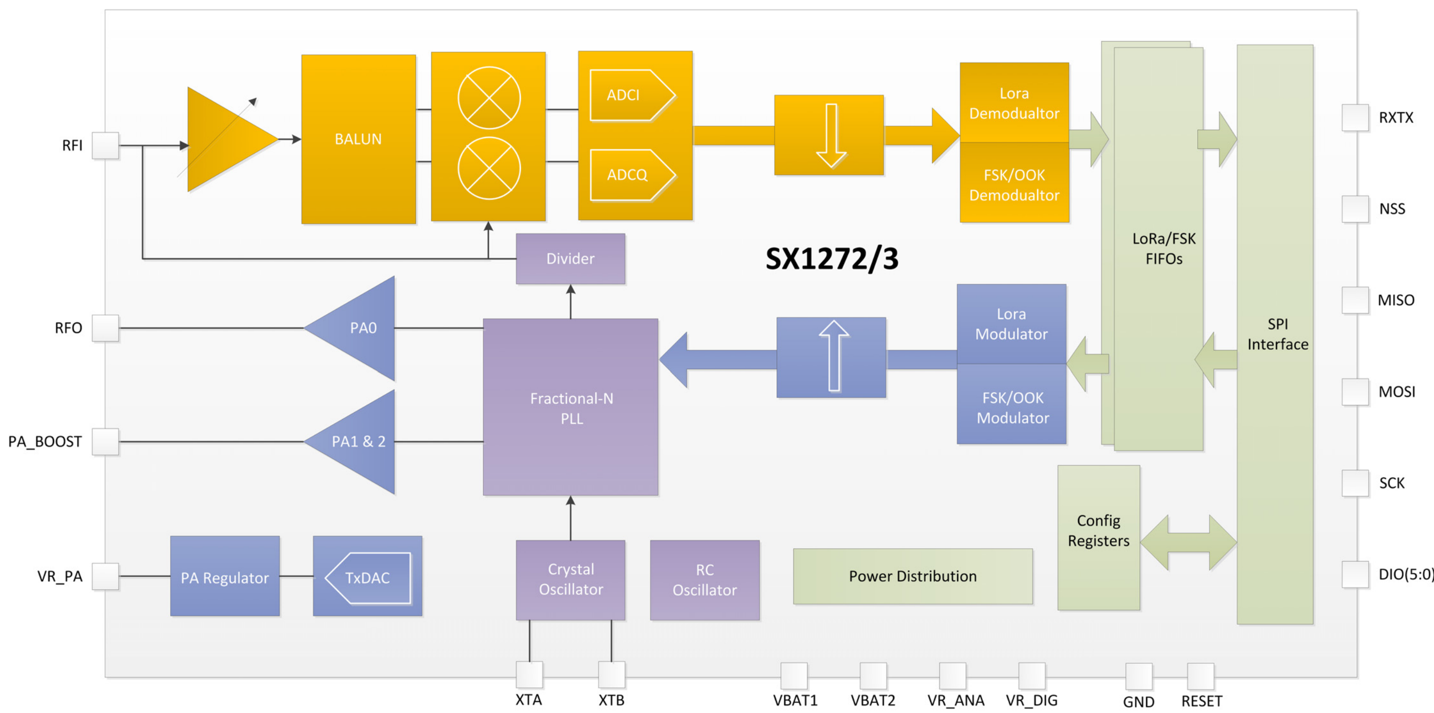


Figure 1. SX1272/73 Block Diagram

1.2. Product Versions

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

Table 1 SX1272/73 Device Variants and Key Parameters

Part Number	Frequency Range	LoRa™ Parameters			
		Spreading Factor	Bandwidth	Effective Bitrate	Sensitivity
SX1272	860 - 1020 MHz	6 - 12	125 - 500 kHz	0.24 - 37.5 kbps	-117 to -137 dBm
SX1273	860 - 1020 MHz	6 - 9	125 - 500 kHz	1.7 - 37.5 kbps	-117 to -130 dBm

1.3. Pin Diagram

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

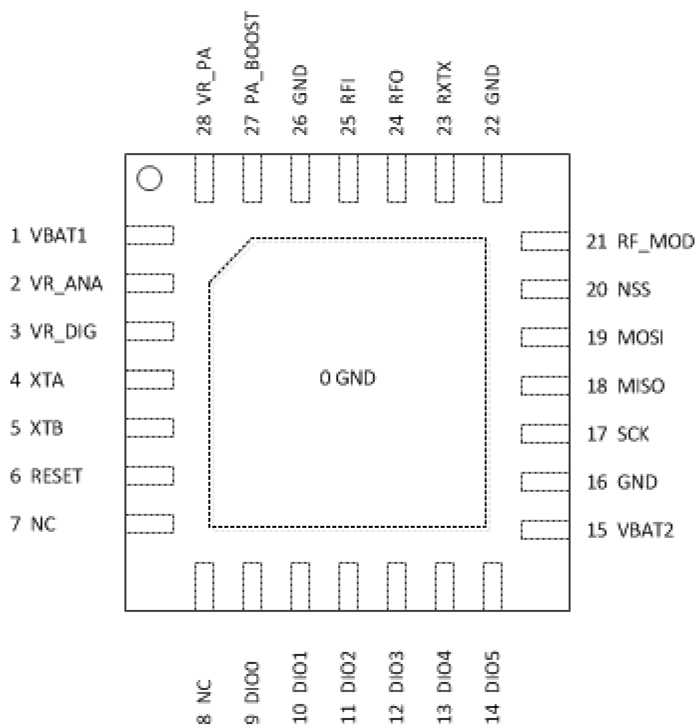


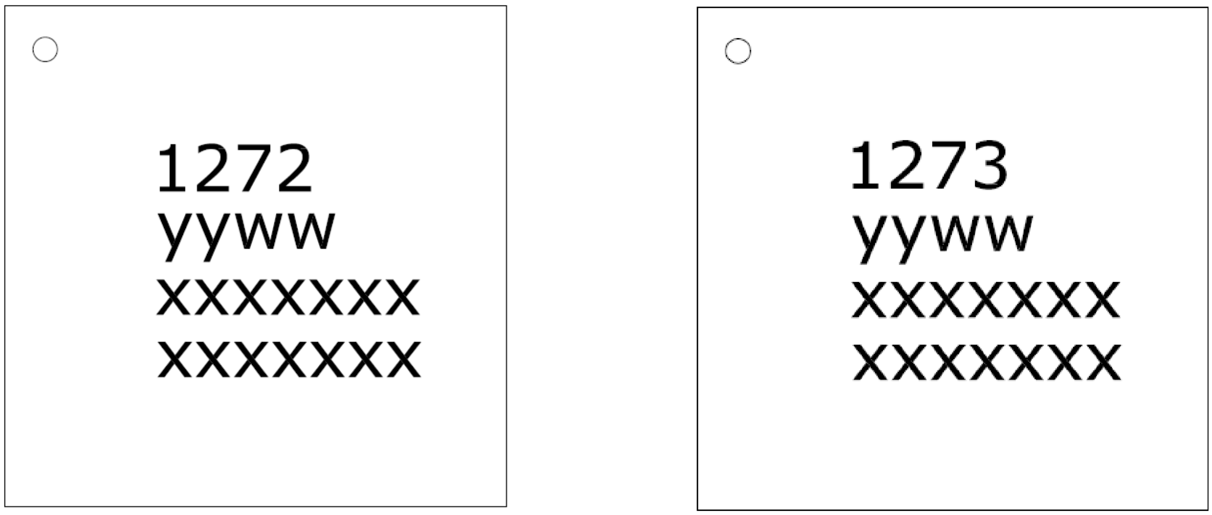
Figure 2. Pin Diagram

1.4. Pin Description

Table 2 Pin Description

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

1.5. Package Marking



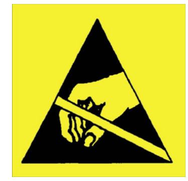
TOP MARK	
CHAR	ROWS
7/7/7/7/7	5

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

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

Figure 3. Package Marking

2. Electrical Characteristics



2.1. ESD Notice

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

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

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

2.2. Absolute Maximum Ratings

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

Table 3 Absolute Maximum Ratings

Symbol	Description	Min	Max	Unit
VDDmr	Supply Voltage	-0.5	3.9	V
Tmr	Temperature	-55	+115	° C
Tj	Junction temperature	-	+125	° C
Pmr	RF Input Level	-	+10	dBm

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

2.3. Operating Range

Table 4 Operating Range

Symbol	Description	Min	Max	Unit
VDDop	Supply voltage	1.8	3.7	V
Top	Operational temperature range	-40	+85	°C
Clop	Load capacitance on digital ports	-	25	pF
ML	RF Input Level	-	+10	dBm

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

2.4. Thermal Properties

Table 5 Operating Range

Symbol	Description	Min	Typ	Max	Unit
THETA_JA	Package θ_{ja} (Junction to ambient)	-	22.185	-	°C/W
THETA_JC	Package θ_{jc} (Junction to case ground paddle)	-	0.757	-	°C/W

2.5. Chip Specification

The tables below give the electrical specifications of the transceiver under the following conditions: Supply voltage VBAT1 = VBAT2 = VDD = 3.3 V, temperature = 25 °C, *FXOSC* = 32 MHz, F_{RF} = 915 MHz, Pout = +13 dBm, 2 level FSK modulation without pre-filtering, FDA = 5 kHz, Bit Rate = 4.8 kbps and terminated in a matched 50 Ohm impedance, unless otherwise specified. Shared Rx and Tx path matching.

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

2.5.1. Power Consumption

Table 6 Power Consumption Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSL	Supply current in Sleep mode		-	0.1	1	uA
IDDIDLE	Supply current in Idle mode	RC oscillator enabled	-	1.5	-	uA
IDDST	Supply current in Standby mode	Crystal oscillator enabled	-	1.4	1.6	mA
IDDFS	Supply current in Synthesizer mode	FSRx	-	4.5	-	mA
IDDR	Supply current in Receive mode	*LnaBoost* Off *LnaBoost* On	- -	10.5 11.2	- -	mA
IDDT	Supply current in Transmit mode with impedance matching	RFOP = +20 dBm on PA_BOOST RFOP = +17 dBm on PA_BOOST RFOP = +13 dBm on RFO pin RFOP = + 7 dBm on RFO pin	- - - -	125 90 28 18	- - - -	mA mA mA mA

2.5.2. Frequency Synthesis

Table 7 Frequency Synthesizer Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
FRF	Synthesizer frequency range	Programmable	860	-	1020	MHz
FXOSC	Crystal oscillator frequency		-	32	-	MHz
TS_OSC	Crystal oscillator wake-up time		-	250	-	us
TS_FS	Frequency synthesizer wake-up time to PllLock signal	From Standby mode	-	60	-	us
TS_HOP	Frequency synthesizer hop time at most 10 kHz away from the target frequency	200 kHz step 1 MHz step 5 MHz step 7 MHz step 12 MHz step 20 MHz step 25 MHz step	- - - - - - -	20 20 50 50 50 50 50	- - - - - - -	us us us us us us us
FSTEP	Frequency synthesizer step	$FSTEP = FXOSC/2^{19}$	-	61.0	-	Hz
FRC	RC Oscillator frequency	After calibration	-	62.5	-	kHz

BRF	Bit rate, FSK	Programmable values (1)	1.2	-	300	kbps
BRO	Bit rate, OOK	Programmable	1.2	-	32.768	kbps
BRA	Bit Rate Accuracy	ABS(wanted BR - available BR)	-	-	250	ppm
FDA	Frequency deviation, FSK (1)	Programmable FDA + BRF/2 =< 250 kHz	0.6	-	200	kHz

Note For Maximum Bit Rate the maximum modulation index is 0.5.

2.5.3. FSK/OOK Mode Receiver

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

Table 8 Receiver Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
RFS_F	Direct tie of RFI and RFO pins, shared Rx, Tx paths FSK sensitivity, highest LNA gain.	FDA = 5 kHz, BR = 1.2 kbps FDA = 5 kHz, BR = 4.8 kbps FDA = 40 kHz, BR = 38.4 kbps* FDA = 20 kHz, BR = 38.4 kbps** FDA = 62.5 kHz, BR = 250 kbps***	- - - - -	-119 -115 -105 -106 -92	- - - - -	dBm dBm dBm dBm dBm
	Split RF paths, LnaBoost is turned on, the RF switch insertion loss is not accounted for.	FDA = 5 kHz, BR = 1.2 kbps FDA = 5 kHz, BR = 4.8 kbps FDA = 40 kHz, BR = 38.4 kbps* FDA = 20 kHz, BR = 38.4 kbps** FDA = 62.5 kHz, BR = 250 kbps***	- - - - -	-123 -119 -110 -110 -97	- - - - -	dBm dBm dBm dBm dBm
RFS_O	OOK sensitivity, highest LNA gain shared Rx, Tx paths	BR = 4.8 kbps BR = 32 kbps	- -	-117 -108	- -	dBm dBm
CCR	Co-Channel Rejection		-	-9	-	dB
ACR	Adjacent Channel Rejection	FDA = 2 kHz, BR = 1.2 kbps, RxBw = 5.2 kHz Offset = +/- 25 kHz	-	54	-	dB
		FDA = 5 kHz, BR=4.8kbps Offset = +/- 25 kHz Offset = +/- 50 kHz	- -	50 50	- -	dB dB
BI	Blocking Immunity	Offset = +/- 1 MHz Offset = +/- 2 MHz Offset = +/- 10 MHz	- - -	73 78 87	- - -	dB dB dB
AMR	AM Rejection, AM modulated interferer with 100% modulation depth, fm = 1 kHz, square	Offset = +/- 1 MHz Offset = +/- 2 MHz Offset = +/- 10 MHz	- - -	73 78 87	- - -	dB dB dB

IIP2	2nd Order input intercept point unwanted tones are 20 MHz above the LO	Highest LNA gain	-	+57	-	dBm
IIP3	3rd Order input intercept point unwanted tones are 1 MHz and 1.995 MHz above the LO	Highest LNA gain G1 LNA gain G2, 4dB sensitivity reduction.	- -	-12.5 -8.5	- -	dBm dBm
BW_SSB	Single Side channel filter BW	Programmable	2.7	-	250	kHz
IMR	Image Rejection	Wanted signal power sensitivity +3 dB BER = 0.1%	-	48	-	dB
IMA	Image Attenuation		-	57	-	dB
DR_RSSI	RSSI Dynamic Range	AGC enabled Min Max	- -	-127 0	- -	dBm dBm

* *RxBw = 83 kHz (Single Side Bandwidth)*

** *RxBw = 50 kHz (Single Side Bandwidth)*

*** *RxBw = 250 kHz (Single Side Bandwidth)*

2.5.4. FSK/OOK Mode Transmitter

Table 9 Transmitter Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
RF_OP	RF output power in 50 ohms on RFO pin (High efficiency PA).	Programmable with steps Max Min	+11 -	+14 -1	- -	dBm dBm
ΔRF_OP_V	RF output power stability on RFO pin versus voltage supply	VDD = 2.5 V to 3.3 V VDD = 1.8 V to 3.7 V	- -	3 8	- -	dB dB
RF_OPH	RF output power in 50 ohms, on PA_BOOST pin (Regulated PA)	Programmable with 1dB steps Max Min	- -	+17 +2	- -	dBm dBm
RF_OPH_MAX	Max RF output power, on PA_BOOST pin	High power mode	-	+20	-	dBm
ΔRF_OPH_V	RF output power stability on PA_-BOOST pin versus voltage supply.	VDD = 2.4 V to 3.7 V	-	+/-1	-	dB
ΔRF_T	RF output power stability versus temperature on both RF pins.	From T = -40 °C to +85 °C	-	+/-1	-	dB
PHN	Transmitter Phase Noise	Low Consumption PLL, 915 MHz 50 kHz offset 400 kHz offset 1 MHz offset	- - -	-102 -114 -120	- - -	dBc/Hz
		Low Phase Noise PLL, 915 MHz 50 kHz offset 400 kHz offset 1 MHz offset	- - -	-106 -117 -122	- - -	dBc/Hz

ACP	Transmitter adjacent channel power (measured at 25 kHz offset)	BT = 1. Measurement conditions as defined by EN 300 220-1 V2.3.1	-	-	-37	dBm
TS_TR	Transmitter wake up time, to the first rising edge of DCLK	Frequency Synthesizer enabled, *PaRamp* = 10 us, BR = 4.8 kbps	-	120	-	us

2.5.5. Electrical specification for LoRa™ modulation

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

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

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

Table 10 Electrical specifications: Lora™ mode

Symbol	Description	Conditions	Min.	Typ	Max	Unit
IIP2_L	2nd order input intercept point, highest LNA gain, FRF = 868 MHz, CW interferer.	F1 = FRF + 20 MHz F2 = FRF+ 20 MHz + Δf	-	57	-	dBm
BR_L	Bit rate, Long-Range Mode	From SF6, CR = 4/5, BW = 500 kHz to SF12, CR = 4/8, BW = 125 kHz	0.24	-	37.5	kbps
RFS_L125	RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 125 kHz bandwidth using split Rx/Tx path	SF = 6 SF = 7 SF = 8 SF = 9 SF = 10 SF = 11 SF = 12	- - - - - - -	-121 -124 -127 -130 -133 -135 -137	- - - - - - -	dBm dBm dBm dBm dBm dBm dBm
RFS_L250	RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 250 kHz bandwidth using split Rx/Tx path	SF = 6 SF = 7 SF = 8 SF = 9 SF = 10 SF = 11 SF = 12	- - - - - - -	-118 -122 -125 -128 -130 -132 -135	- - - - - - -	dBm dBm dBm dBm dBm dBm dBm
RFS_L500	RF sensitivity, Long-Range Mode, highest LNA gain, LNA boost, 500 kHz bandwidth using split Rx/Tx path	SF = 6 SF = 7 SF = 8 SF = 9 SF = 10 SF = 11 SF = 12	- - - - - - -	-111 -116 -119 -122 -125 -128 -129	- - - - - - -	dBm dBm dBm dBm dBm dBm dBm
CCR_LCW	Co-channel rejection Single CW tone = Sens +6 dB 1% PER	SF = 7 SF = 8 SF = 9 SF = 10 SF = 11 SF = 12	- - - - - -	5 9.5 12 14.4 17 19.5	- - - - - -	dB dB dB dB dB dB
CCR_LL	Co-channel rejection	Interferer is a LoRa™ signal using same BW and same SF. Pw = Sensitivity +3 dB		-6		dB
ACR_LCW	Adjacent channel rejection FRF = 868 MHz	Interferer is 1.5*BW_L from the wanted signal center frequency 1% PER, Single CW tone = Sensitivity + 3 dB SF = 7 SF = 12	- -	60 72	- -	dB dB
IMR_LCW	Image rejection after calibration	1% PER, Single CW tone = Sens +3 dB	-	66	-	dB
FERR_L	Maximum tolerated frequency offset between transmitter and receiver, no sensitivity degradation	BW_L = 125 kHz BW_L = 250 kHz BW_L = 500 kHz	-30 -60 -120	- - -	30 60 120	kHz kHz kHz

Table 10 Electrical specifications: Lora™ mode

2.5.6. Digital Specification

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

Table 11 Digital Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
V_{IH}	Digital input level high		0.8	-	-	VDD
V_{IL}	Digital input level low		-	-	0.2	VDD
V_{OH}	Digital output level high	Imax = 1 mA	0.9	-	-	VDD
V_{OL}	Digital output level low	Imax = -1 mA	-	-	0.1	VDD
F_{SCK}	SCK frequency		-	-	10	MHz
t_{ch}	SCK high time		50	-	-	ns
t_{cl}	SCK low time		50	-	-	ns
t_{rise}	SCK rise time		-	5	-	ns
t_{fall}	SCK fall time		-	5	-	ns
t_{setup}	MOSI setup time	From MOSI change to SCK rising edge	30	-	-	ns
t_{hold}	MOSI hold time	From SCK rising edge to MOSI change	20	-	-	ns
t_{nsetup}	NSS setup time	From NSS falling edge to SCK rising edge	30	-	-	ns
t_{nhold}	NSS hold time	From SCK falling edge to NSS rising edge, normal mode	100	-	-	ns
t_{nhigh}	NSS high time between SPI accesses		20	-	-	ns
T_DATA	DATA hold and setup time		250	-	-	ns

3. SX1272/73 Features

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

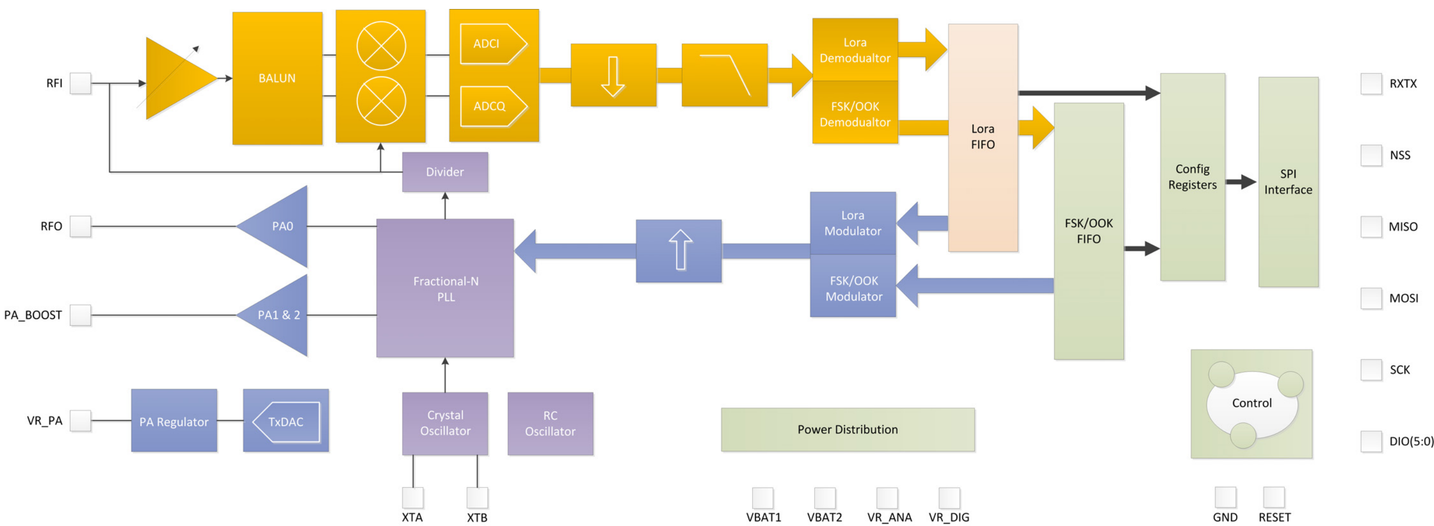


Figure 4. Simplified SX1272 Block Schematic Diagram

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

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

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

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

All major parameters of the RF front end and digital state machine are fully configurable via an SPI interface which gives access to SX1272/73's configuration registers. This includes a mode auto sequencer that oversees the transition and calibration of the SX1272/73 between intermediate modes of operation in the fastest time possible.

The SX1272/73 are equipped with both standard FSK and long range spread spectrum (LoRa^{TM}) modems. Depending upon the mode selected either conventional OOK or FSK modulation may be employed or the LoRa^{TM} spread spectrum modem.

3.1. LoRa^{TM} Modem

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

3.2. FSK/OOK Modem

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

4. SX1272/73 Digital Electronics

4.1. The LoRa^{TM} Modem

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

Table 12 Example LoRa^{TM} Modem Performances

Bandwidth (kHz)	Spreading Factor	Nominal Rb (bps)	Sensitivity (dBm)
125	6	9380	-122
125	12	293	-137
250	6	18750	-119
250	12	586	-134
500	6	37500	-116
500	12	1172	-131

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

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

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

4.1.1. Link Design Using the LoRa™ Modem

4.1.1.1. Overview

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

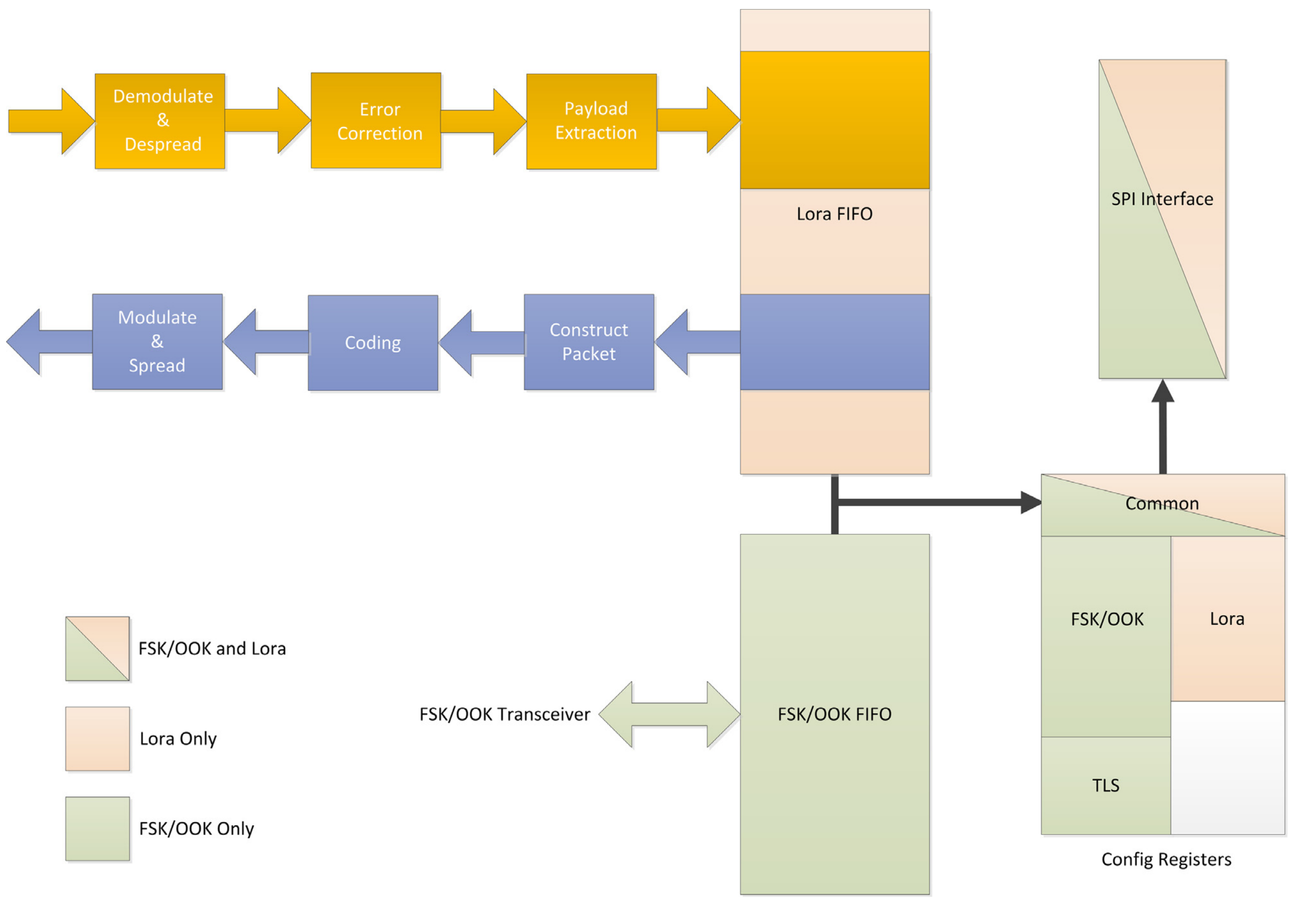


Figure 5. LoRa™ Modem Connectivity

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

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

4.1.1.2. Spreading Factor

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

Table 13 Range of Spreading Factors

SpreadingFactor (RegModemConfig2)	Spreading Factor (Chips / symbol)	LoRa Demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

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

Spreading Factor 6

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

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

4.1.1.3. Coding Rate

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

Table 14 Cyclic Coding Overhead

CodingRate (RegModemConfig1)	Cyclic Coding Rate	Overhead Ratio
1	4/5	1.25
2	4/6	1.5
3	4/7	1.75
4	4/8	2