SX1272/3/6/7/8: LoRa Modem

Designer’s Guide

AN1200.13

TCo

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DISCLAIMER
The performance figures are for indication only. For definitive product performance data please refer to the datasheet.

1. Overview

This guide provides the basic information necessary for the designer to evaluate the suitability of the LoRa modem for their radio application. The design is split into two sections covering basic and advanced design topics.

2 Principles of LoRa Design

2.1 LoRa Modulation

LoRa is a spread spectrum modulation scheme that that uses wideband linear frequency modulated pulses whose frequency increases or decreases over a certain amount of time to encode information. The main advantages of this approach are twofold: a substantial increase in receiver sensitivity due to the processing gain of the spread spectrum technique and a high tolerance to frequency misalignment between receiver and transmitter.

To better understand how to implement a radio design using the LoRa modulation format it is necessary to briefly examine the factors influencing radio receiver sensitivity.

2.2 Receiver Sensitivity

The sensitivity of a radio receiver at room temperature is given by:

$$S = -174 + 10\ \log_{10} BW + NF + SNR \qquad \text{Eqn. 1}$$

The first term is due to thermal noise in 1 Hz of bandwidth and can only be influenced by changing the temperature of the receiver. The second term, *BW,* is the receiver bandwidth. *NF* Is the receiver noise figure and is fixed for a given hardware implementation. Finally, *SNR* represents the signal to noise ratio required by the underling modulation scheme. It is the signal to noise ratio and bandwidth that are available as design variables to the LoRa designer.

2.3 SNR and Spreading Factor

The basic premise of spread spectrum is that each bit of information is encoded as multiple chips. The relationship between the bit and chip rate for LoRa modulation, R_b and R_c respectively, is given by:

$$R_c = 2^{SF} R_b \qquad \text{Eqn. 2}$$

where *SF* is the spreading factor.

SNR Is the minimum ratio of wanted signal power to noise that can be demodulated. The performance of the LoRa modulation itself, forward error correction (FEC) techniques and the spread spectrum processing gain combine to allow significant SNR improvements. Some example SNRs for both conventional and LoRa modulation formats are shown in the table below. The lower this number the more sensitive the receiver will be. Negative numbers indicate the ability to receive signal powers below the receiver noise floor:

Table 1. SNR for Various Modulation Configurations

Modulation	Typical SNR
LoRa SF12	-20 dB
LoRa SF10	-15 dB
GMSK	9 dB

The substitution of one bit for multiple chips of information means that the spreading factor has a direct influence on the duration of the LoRa packet. The influence of the spreading factor on the sensitivity and the time on air are shown below for a fixed bandwidth of 250 kHz.

Table 2. Influence of SF on Time on Air and Sensitivity (CR=2, BW=250)

SF	Time on air [ms]	Sensitivity [dBm]
12	528.4	-134
10	132.1	-129
8	39.2	-124

2.4 BW and Chip Rate

One of the principle design compromises that the designer must manage in the selection of spreading factor is that of time on air (packet duration) versus occupied bandwidth. The representation of a single bit by many chips, implies that the chips must either be sent faster than the original bitrate – increasing the occupied bandwidth of the signal, or in the same bandwidth – increasing the time taken to transmit the information.

LoRa modulation sends the spread data stream at a chip rate equal to the programmed bandwidth in chips-per-second-per-Hertz. So a LoRa bandwidth of 125 kHz corresponds to a chip rate of 125 kcps.

Equation 1 shows us that an increase in bandwidth (*BW*) due to the integration of additional noise power in the channel, will desensitize the receiver. Meaning that for a given spreading factor the designer can either elect to use a narrow bandwidth, maximizing sensitivity but increasing time on air or increasing the bandwidth for faster transmission but reducing sensitivity.

Here we take the example of the SX1272, which has three programmable bandwidth settings 500 kHz, 250 kHz and 125 kHz (as shown below). (The SX1276 has bandwidths from 500 kHz to as low as 7.8 kHz).

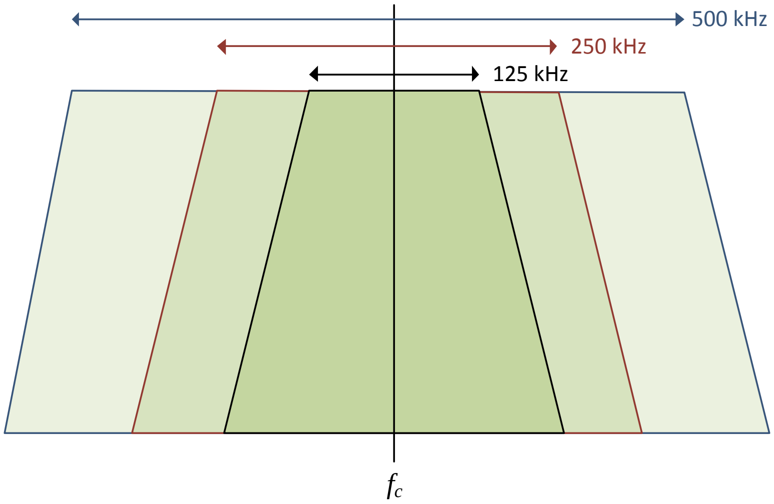


Figure 1. The LoRa Bandwidth Corresponds to the Double Sided Transmit Spectrum Bandwidth

For a fixed spreading factor the influence of bandwidth on the resulting time on air and sensitivity are shown in the table below for a 10 byte payload packet:

Table 3. Influence of BW on Time on Air and Sensitivity (CR=2, SF=10)

BW	Time on air [ms]	Sensitivity [dBm]
125	264.2	-132
250	132.1	-129
500	66	-126

Examination of the basic design criterion of bandwidth and spreading factor allow quick evaluation of the suitability of LoRa for a given application. However, to optimize design performance there are other design criteria that must also be considered.

3 Advanced LoRa Design Parameters

In addition to the use of spreading factor and bandwidth there are other design variables that the designer must consider when implementing a LoRa radio link. These are of particular importance when optimizing the robustness to interference and time on air of the LoRa transmission.

3.1 Forward Error Correction

The LoRa modem also employs a form of Forward Error Correction (FEC) that permits the recovery of bits of information due to corruption by interference. This requires a small overhead of additional encoding of the data in the transmitted packet. Depending upon the coding rate selected, the additional robustness attained in the presence of thermal noise alone is shown in the family of curves below.

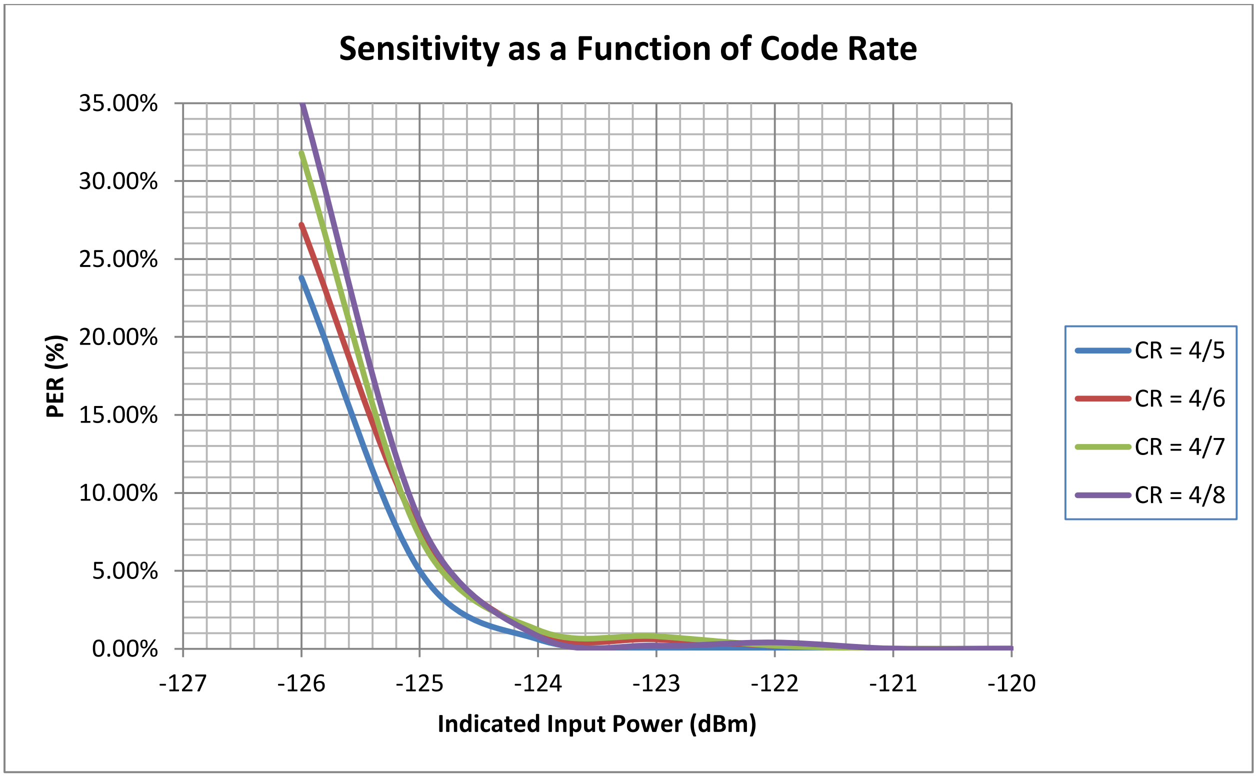


Figure 2. Influence of Coding Rate on Sensitivity (SF = 7, BW = 125 kHz, 13 Byte Payload)

The real performance gain of FEC, however, is in the presence of bursts of interference. If the radio link is likely to be subject to such interference, the use of FEC should be evaluated.

The table below then shows how the increase in coding rate influences time on air for a fixed bandwidth of 250 kHz at SF = 10.

Table 4. Influence of CR on Time on Air (SF=10, BW=250 kHz)

CR	Time on air [ms]
1	123.9
2	132.1
4	148.5

3.2 Hardware Implementation

The receiver RF connection method will further influence the receiver sensitivity and the header mode has an impact on the time on air. The effect of the header mode is discussed in Section 4.

Two receiver input connection, RFI, configurations are possible with the SX1272/3/3/6/7/8. The image below shows both configurations. Optimal sensitivity performance (by reduction of noise figure, NF, of Equation 2) is possible by employing individual RF and Tx paths, using separate antennas or an RF switch for single antenna operation.

Figure 3. Individual RF transmit and receive paths (left) provides better sensitivity than the single shared TRx path (right).

3.3 Low Data Rate Optimisation Mode & Header Mode

The final two factors that influence the time on air of the packet are two operational modes connected to the modem and packet settings of the modem. To understand their influence it is necessary to examine the format of the LoRa packet.

4 The LoRa Packet Format & Time On Air

To effectively manage the regulatory and system level design constraints of time on air and receiver sensitivity, it is hence necessary to be able to calculate the time on air of a given modem configuration. The precise formulae are given below.

For calculation of the time on air it is convenient to define symbol duration, T_{sym}. This is the time taken to send 2^{SF} chips at the chip rate so, recalling that the bandwidth defines the chip rate, it is given by:

$$T_{sym} = \frac{2^{SF}}{BW}$$

The packet comprises several elements, as shown in the following image.

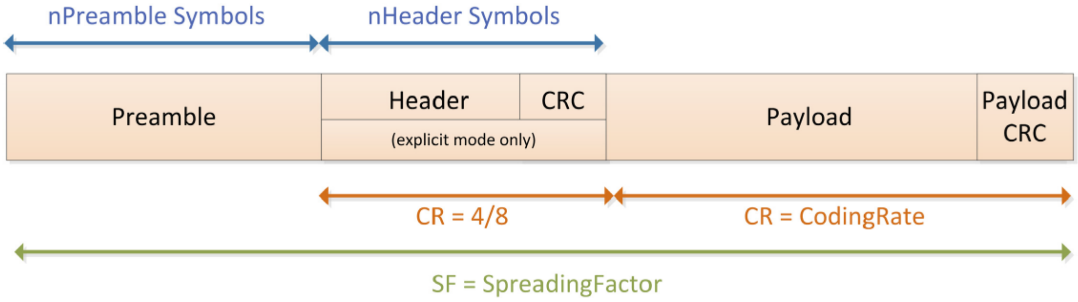


Figure 4. LoRa Modem Packet formatting.

Common to all modem configurations is a sequence of preamble, whose duration is given by:

$$T_{preamble} = \left(n_{preamble} + 4.25\right) Tsym$$

Where $n_{preamble}$ is the number of programmed preamble symbols. The number of symbols that make up the packet payload and header is given by:

$$payloadSymbNb = 8 + max\left(ceil\left(\frac{8PL - 4SF + 28 + 16 - 20H}{4(SF - 2DE)}\right)(CR + 4)\,, 0\right)$$

With the following dependencies:

- PL Is the number of payload bytes.
- SF The spreading factor
- H = 0 when the header is enabled and H = 1 when no header is present.
- DE = 1 when the low data rate optimization is enabled , DE = 0 for disabled.
- CR Is the coding rate from 1 to 4

It follows that if the time on air requires reduction, and the packet length is known in advance, then the header information can be removed. The payload duration is then the symbol period multiplied by the number of payload symbols.

$$T_{payload} = payloadSymbNb\ \ Tsym$$

The time on air, or packet duration, is simply then the sum of the preamble and payload duration:

$$T_{packet} = T_{preamble} + T_{payload}$$

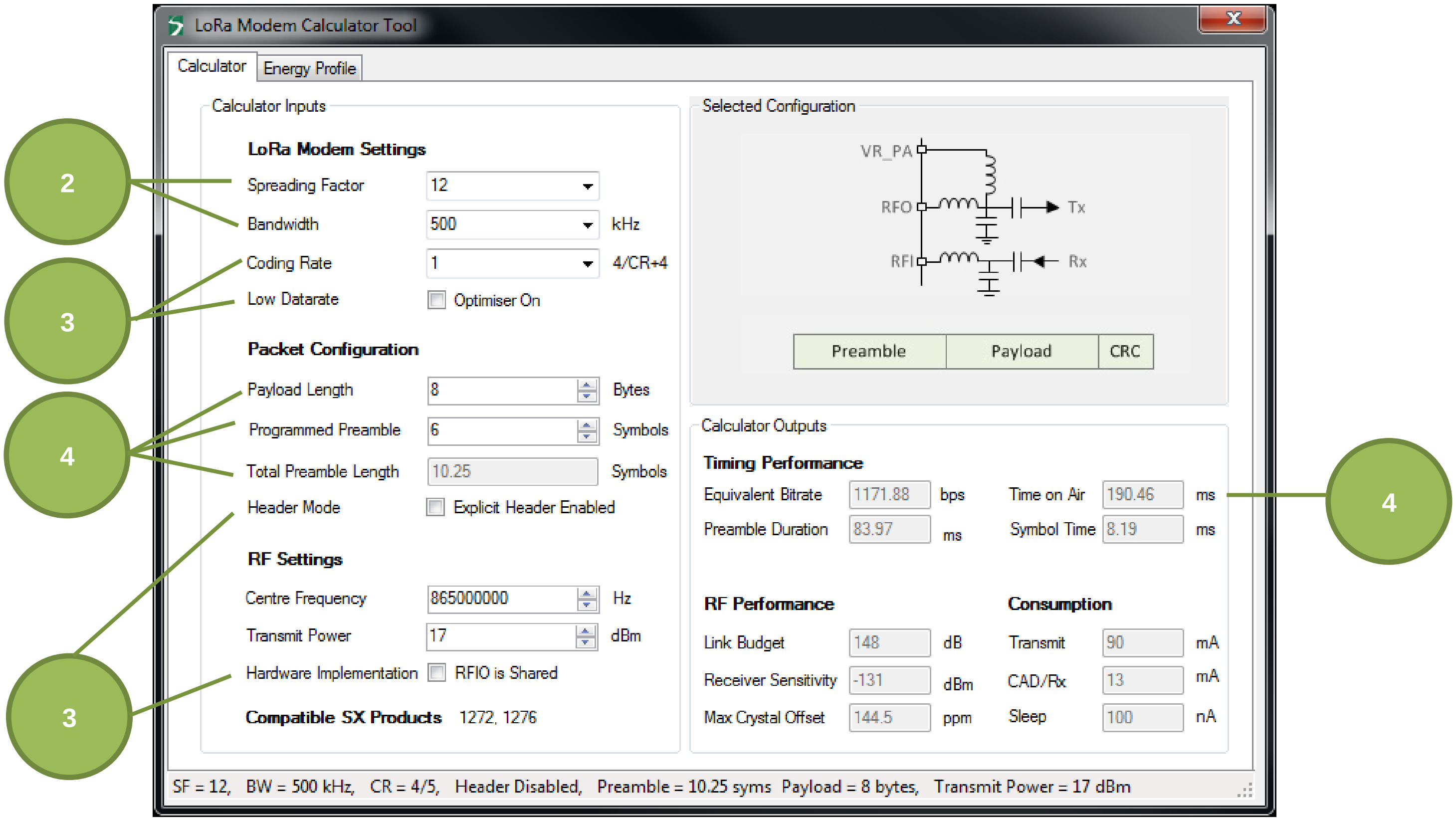
Here we can see that, in the narrow band regime, the LoRa packet can have a significant duration. To avoid issues surrounding drift of the crystal reference oscillator due to either temperature change or motion, the low data rate optimization bit is used. Specifically for 125 kHz bandwidth and SF = 11 and 12, this adds a small overhead to increase robustness to reference frequency variations over the timescale of the LoRa packet.

5 LoRa Calculator

Note that in order to simplify design decisions using the LoRa modem there is a software planning tool that allows the quick evaluation of the LoRa modem configuration and the resulting time on air and sensitivity performance. This can be downloaded from www.semtech.com.

The image below shows the main display of the LoRa calculator. Here we see that all of the design variables of this guide can be modified and the resultant RF and time on air performances are calculated without the need to manually calculate the quantities of the design equations of both this guide and the datasheet.

For convenience the image is indexed with the Section number of this guide that discusses that feature. For information on other parameters, please consult the product datasheet.



Calculator Inputs

LoRa Modem Settings

Spreading Factor: 12
Bandwidth: 500 kHz
Coding Rate: 1 4/CR+4
Low Datarate: ☐ Optimiser On

Packet Configuration

Payload Length: 8 Bytes
Programmed Preamble: 6 Symbols
Total Preamble Length: 10.25 Symbols
Header Mode: ☐ Explicit Header Enabled

RF Settings

Centre Frequency: 865000000 Hz
Transmit Power: 17 dBm
Hardware Implementation: ☐ RFIO is Shared

Compatible SX Products 1272, 1276

Selected Configuration

Calculator Outputs

Timing Performance

Equivalent Bitrate: 1171.88 bps
Preamble Duration: 83.97 ms
Time on Air: 190.46 ms
Symbol Time: 8.19 ms

RF Performance

Link Budget: 148 dB
Receiver Sensitivity: -131 dBm
Max Crystal Offset: 144.5 ppm

Consumption

Transmit: 90 mA
CAD/Rx: 13 mA
Sleep: 100 nA

SF = 12, BW = 500 kHz, CR = 4/5, Header Disabled, Preamble = 10.25 syms Payload = 8 bytes, Transmit Power = 17 dBm

Figure 5. The LoRa Calculator Interface.

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