AN1200.14
LoRa Modulation: Crystal Oscillator Guidance

1 Introduction

The purpose of this application note is to assist the engineer with the selection of a suitable crystal oscillator for the LoRa modulation family of long-range wireless ISM transceiver devices.

It is recommended that this application note be read in conjunction with Semtech Application Note AN1200.07, "Improving the Accuracy of a Crystal Oscillator" [1], for further information on crystal oscillator specifications and parameters.

2 LoRa Modulation

LoRa, Semtech's proprietary modulation is a spread spectrum technique that uses wideband linear frequency modulated pulses to encode information, whose frequency increases or decreases over a certain amount of time.

As with other spread spectrum modulation techniques LoRa uses the entire channel bandwidth to broadcast a signal, making it robust to channel noise. In addition, because LoRa modulation uses a broad band of the spectrum it is also resistant to long term relative frequency error and multi-path fading and Doppler effects.

3 LoRa Modulation Crystal Specification

The Crystal specification for LoRa modulation is tabulated below in Table 1.

It can be observed that the crystal specification for Semtech's family of LoRa modulation transceivers is similar to those of existing Semtech FSK ISM transceiver range. Since the internal oscillator drive circuitry of Semtech transceivers are similar it can be seen that no special IP is required to condition the oscillator.

Symbol	Description	Conditions	Min	Typ	Max	Unit
F_{XOSC}	Crystal Frequency		26	32	32	MHz
R_S	Crystal Series Resistance		-	30	40	Ω
C_0	Crystal Shunt Capacitance		-	2.8	7	pF
C_{FOOT}	External Foot Capacitance	On each pin XTA and XTB	8	15	22	pF
C_{LOAD}	Crystal Load Capacitance		6	-	12	pF
F_{TOL}	Initial Frequency Tolerance		-	-	±30	ppm
F_{TEMP}	*Temp. Characteristics*	*Application specific*	-	-	-	*ppm*
F_{AGING}	*Aging Characteristics*	*Application specific*	-	-	-	*ppm*
G_S	*Acceleration Sensitivity*	*Application specific*[1] *[2]*	-	*2*	-	*ppb/G*

Table 1: Typical Crystal Specification

There are two crystal specifications that warrant further analysis which are discussed below:

- Frequency Tolerance
- G or Acceleration Sensitivity

3.1 Frequency Tolerance

Frequency or calibration tolerance (expressed in ppm) is typically an application specific parameter.

Generally modulation techniques offering similar sensitivity performance to LoRa, such as narrowband FHSS or high spreading factor DSSS, typically require a crystal oscillator tolerance of only a few ppm to ensure both frequency and symbol rate accuracy.

As noted, the LoRa modulation technique is relatively impervious to the relative initial frequency error (and subsequently symbol rate tolerance) between the transmitter and receiver.

This immunity to both frequency and symbol tolerance is illustrated below in Figure 1. This indicates that frequency tolerances of typically ±25% of the LoRa modulation bandwidth can be withstood and still maintain a 10% PER link[2].

This compares favorably with current high link budget systems.

[1] Refer to Section 4

[2] Refer to the SX1272 Datasheet for further information

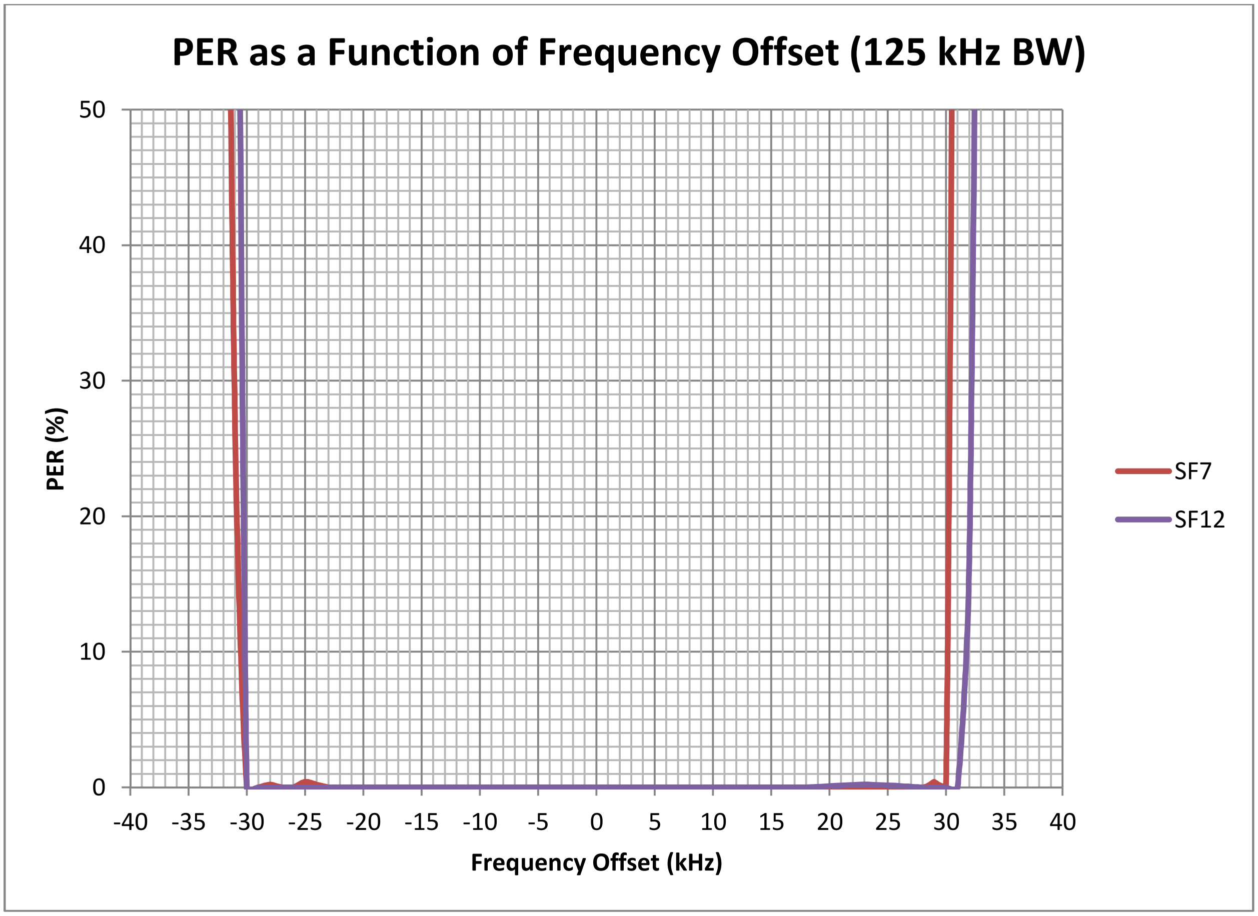

Figure 1: LoRa PER versus Relative Crystal Oscillator Offset

3.2 G Sensitivity

G or acceleration sensitivity is a measure of the sensitivity of a crystal oscillator to acceleration, and describes a short-term or instantaneous frequency error.

A crystal oscillator subject to acceleration (or mechanical shock) has a slightly different series resonant frequency than the same oscillator experiencing zero acceleration. It has been observed that the magnitude of the frequency shift is proportional to both the magnitude and the direction of the acceleration relative to a coordinate system applied to the crystal. [3]

A representation of this effect can be considered in the case of a crystal subjected to a cycle of acceleration at a rate of f_V:

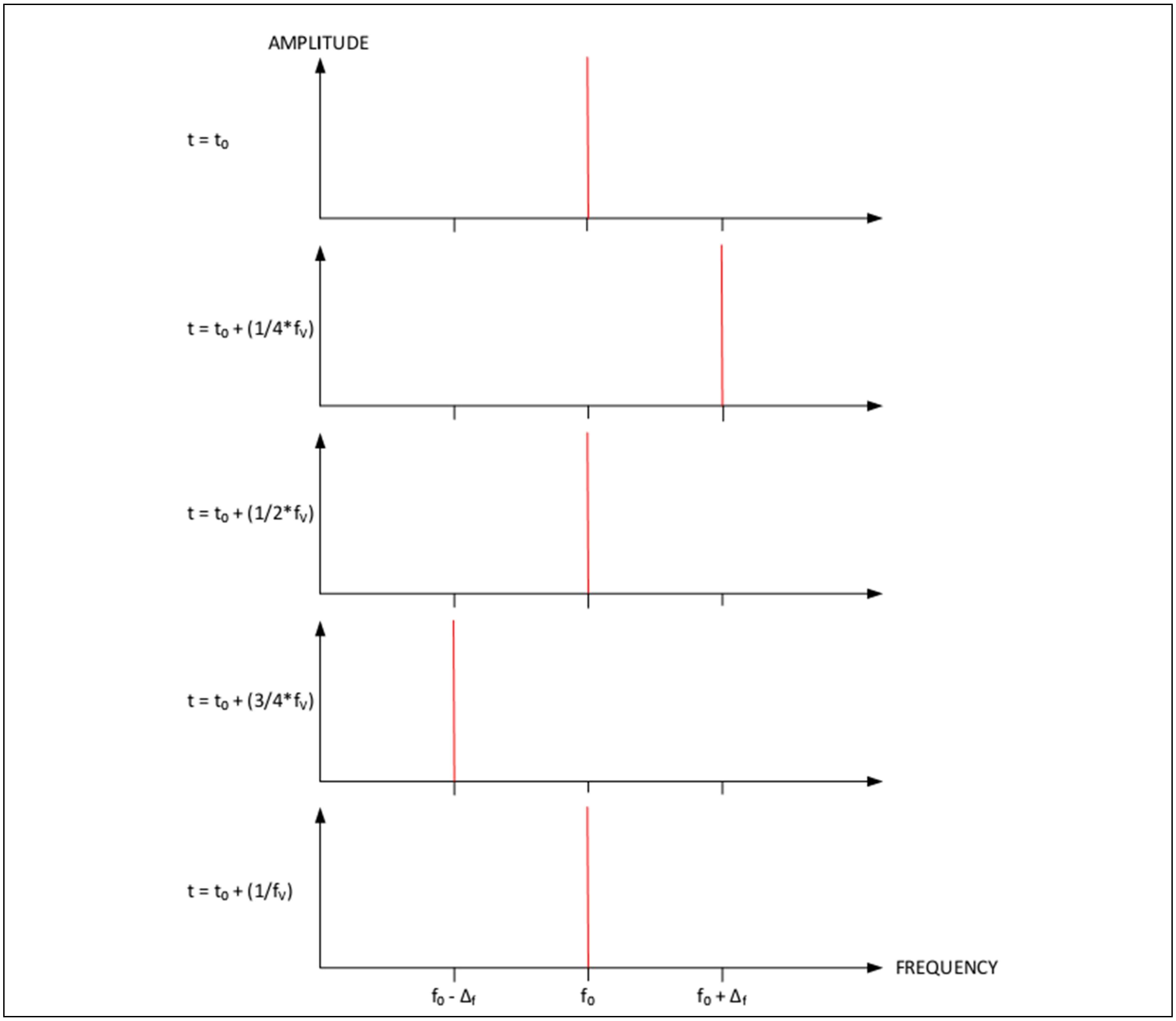

Figure 2: Instantaneous Frequency during one Vibration Cycle

Each plot shows the instantaneous output frequency sampled at a time period $n/4*f_V$. If we consider the rate of acceleration to be sinusoidal, it can be seen that the instantaneous frequency deviation occurs at the peak and trough of the applied sinusoidal force.

It can be shown that that the magnitude of the instantaneous frequency deviation is proportional to the instantaneous amplitude of the acceleration. [3]

This can be viewed practically by observing the effect of acceleration or shock on the spectrum of a phase-locked loop carrier implemented with a crystal oscillator that does not have a low-G sensitivity crystal specified, as illustrated below in Figure 3.

Applying an acceleration force to the crystal causes an instantaneous change in frequency. The apparent amplitude of the instantaneous frequency is limited only by the measurement instrumentation.

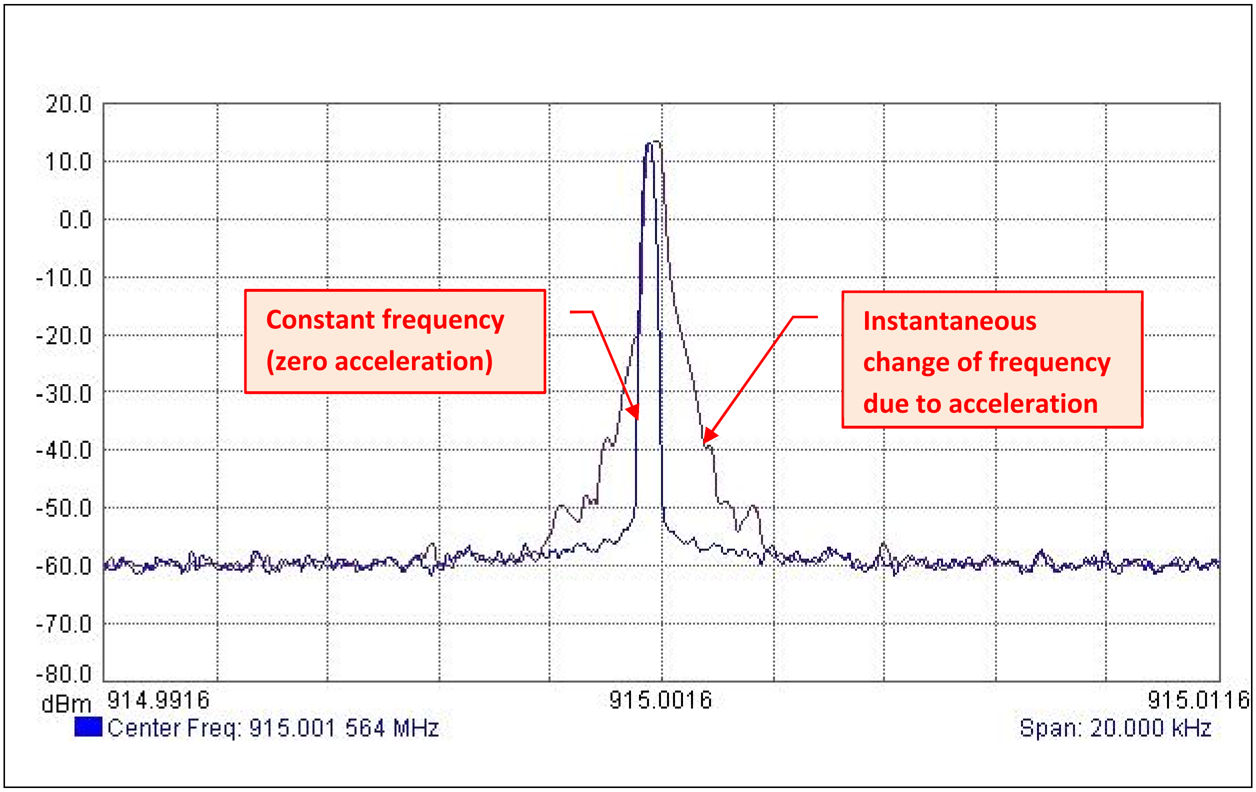

Figure 3: Effect of Acceleration due to Shock on a Crystal-Referenced PLL Transmitted Carrier

As has been noted, the magnitude of the instantaneous frequency shift is also proportional to the direction of the acceleration relative to a coordinate system applied to the crystal. As illustrated in Figure 4 it can be seen that the resultant acceleration vector is proportional to both the magnitude of the acceleration, Γ_G, and relative angle (Θ, Φ) applied. [4]

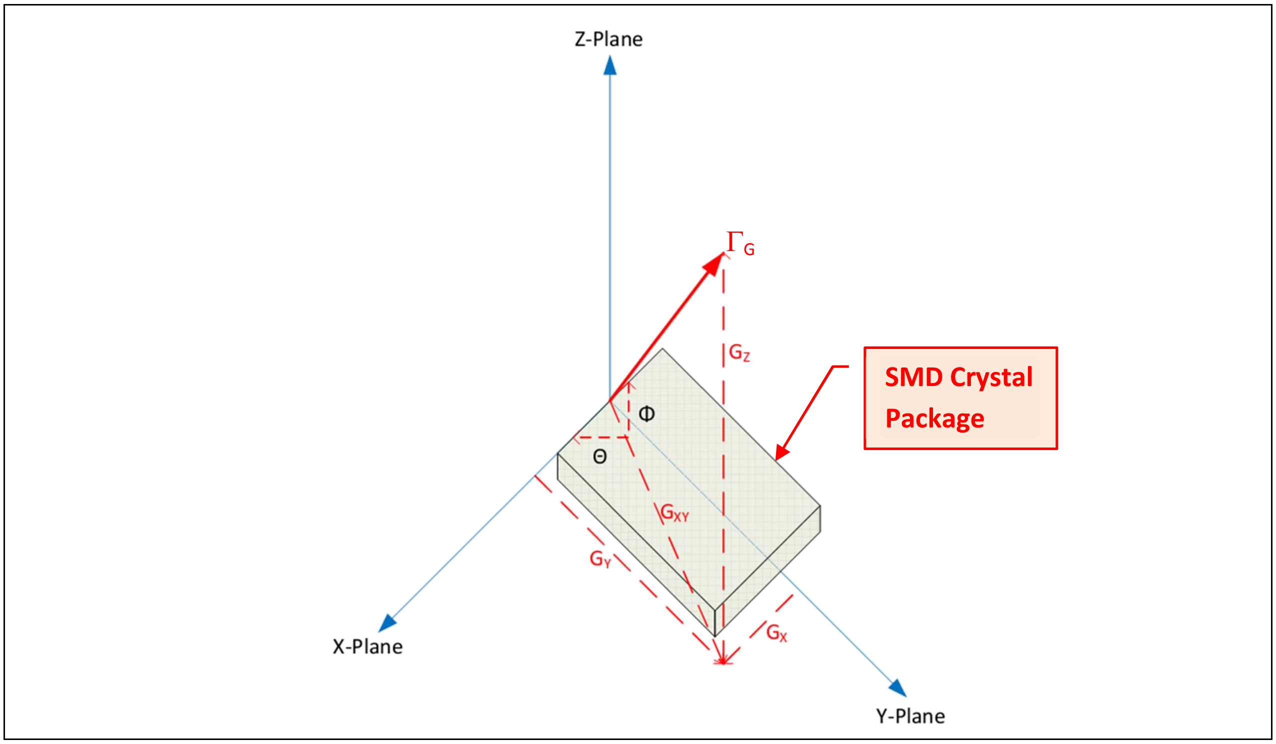

Figure 4: Magnitude of Acceleration Relative to Crystal Package

4 Conclusions

Since LoRa modulation contains both relative time and frequency information it can be deduced that any short term frequency variance could lead to incorrect detection of encoded data.

Thus it is recommended that for those applications which may be subjected to acceleration forces, such as shock or vibration, for example where the SX1272 is implemented in a mobile link (such as a hand-held or vehicle mount application, a low-g crystal is used as the reference oscillator.

In addition, since the resultant acceleration vector has both magnitude and angle components, care should be taken ensure that both crystal and PCB orientation minimize the acceleration vector.

If in doubt, contact your crystal vendor or Semtech representative

5 Recommended Crystal Vendors

Crystal vendors familiar with the requirements for GPS receiver designs should be able to recommend a suitable crystal for a given application and can also advise as to orientation, etc…

Currently Semtech LoRa transceiver reference designs use 32 MHz low-g sensitivity crystals from the following vendor(s):

Vendor	Website	Model / Part No.
NDK	https://www.ndk.com/en/products/search/crystal/index.html	NX2520SA 32 MHz EXS00A-CS00131
		NX2016SA 32 MHz EX500A-CS06465
Rakon	http://temexpress.com/en/index	FTR5092-A2-32 MHz
Taitien	http://www.taitien.com.tw/en/index.aspx	S0197-X-002-3

Table 2: LoRa Modulation Recommended Crystal Vendors

6 References

[1]Semtech Application Note AN1200.07, "Improving the Accuracy of a Crystal Oscillator"

[2] Rakon #FTR5092-A1-32 MHz Datasheet, Taitien #S0197-X-0023 Datasheet, NDK # NX2520SA 32MHz EXS00A-CS00131 Datasheet, NDK # NX2016SA 32 MHz EX500A-CS06465 Datasheet

[3] "The Acceleration Sensitivity of Quartz Crystal Oscillators: A Review", Raymond L Filler (IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol 35, No.3 May 1988)

[4] Greenway Industries Application Note, "Acceleration Sensitivity of Characteristics of Quartz Crystal Oscillators"

Contact Information

Semtech Corporation
Wireless and Sensing Products Division
200 Flynn Road, Camarillo, CA 93012
Phone: (805) 498-2111 Fax: (805) 498-3804
E-mail: E-mail Support
Internet: http://www.semtech.com