SEMTECH

WIRELESS & SENSING PRODUCTS

Application Note:
LoRa® Modulation
Crystal Oscillator Guidance

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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 to read this application note 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

The LoRa® 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, multi-path fading and Doppler effects.

3. LoRa® Modulation Crystal Specification

The crystal specification for LoRa® modulation is given 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 transceivers. Since the internal oscillator drive circuitry of Semtech transceivers are similar, no special IP is required to condition the oscillator.

Table 1: Typical Crystal Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
F_{XOSC}	Crystal Frequency		26	32	32	MHz
R_S	Crystal Series Resistance	For SX1272 [1] and SX1276	-	30	40	Ω
R_S	Crystal Series Resistance	For SX1276 [2] only	-	30	100	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		-	±10	±30	ppm
F_{TEMP}	Temp. Characteristics	Application specific	-	-	-	ppm
F_{AGING}	Aging Characteristics	Application specific	-	-	-	ppm
G_S	Acceleration Sensitivity	Application specific [3]	-	2	-	ppb/G

[1] Crystals with Rs (max) > 40 ohms are only to be used with SX1276 designs
[2] Crystals with Rs (max) < 40 ohms can be used with SX1272 and SX1276 designs
[3] Refer to *Section 4*

There are two crystal specifications that warrant further analysis:

- Frequency Tolerance
- G or Acceleration Sensitivity

3.1. Frequency Tolerance

The frequency or calibration tolerance, expressed in ppm, is typically an application-specific parameter.

Usually modulation techniques offering sensitivity performances similar to LoRa® such as narrow-band 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 previously highlighted, the LoRa® modulation technique is impervious to the relative initial frequency error (and subsequently symbol rate tolerance) between the transmitter and the receiver.

This immunity to both frequency and symbol tolerance is illustrated in Figure 1.

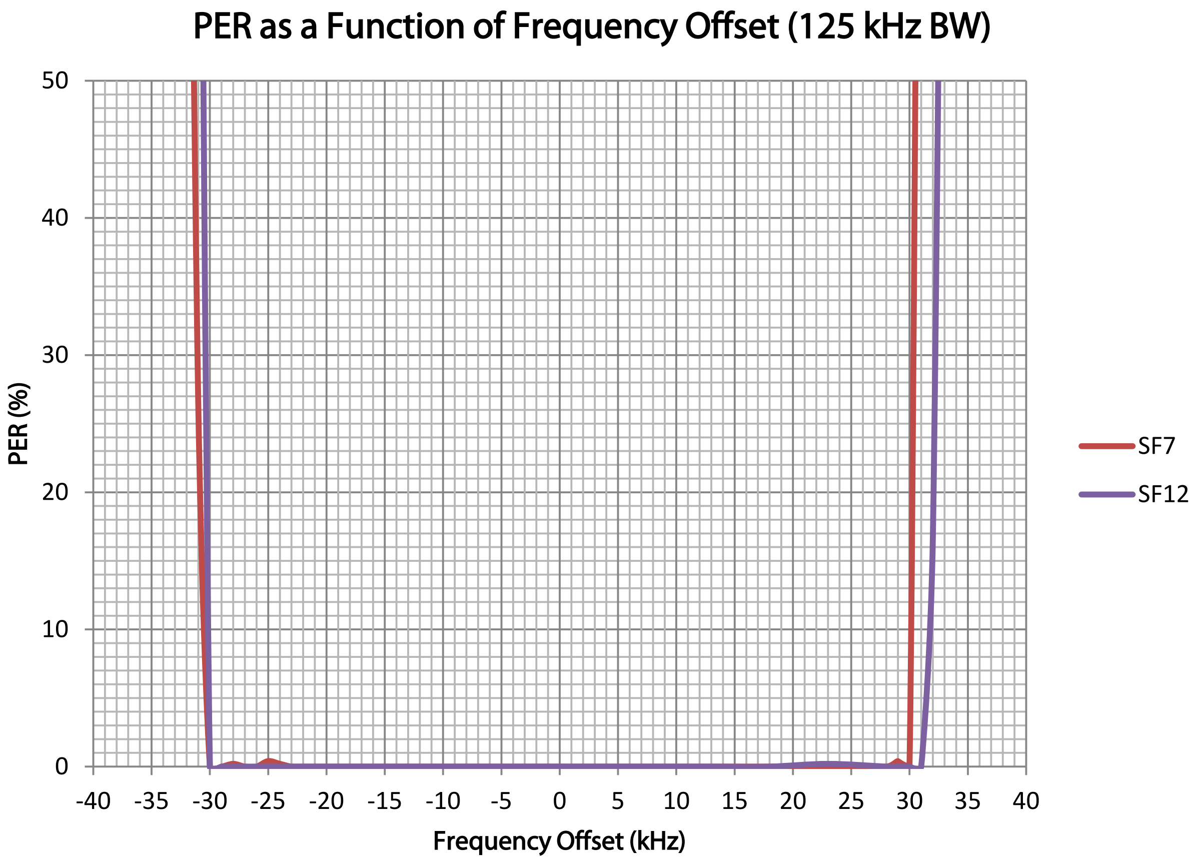

Figure 1: LoRa® PER versus Relative Crystal Oscillator Frequency Offset

The figure indicates that frequency tolerances of typically ±25% of the LoRa® modulation bandwidth can be withstood and still maintain a 10% PER link. This compares favorably with current high-link budget systems.

3.2. G – Acceleration Sensitivity

G or acceleration sensitivity is a measurement 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 no 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 subject to a cycle of acceleration at a rate of f_V:

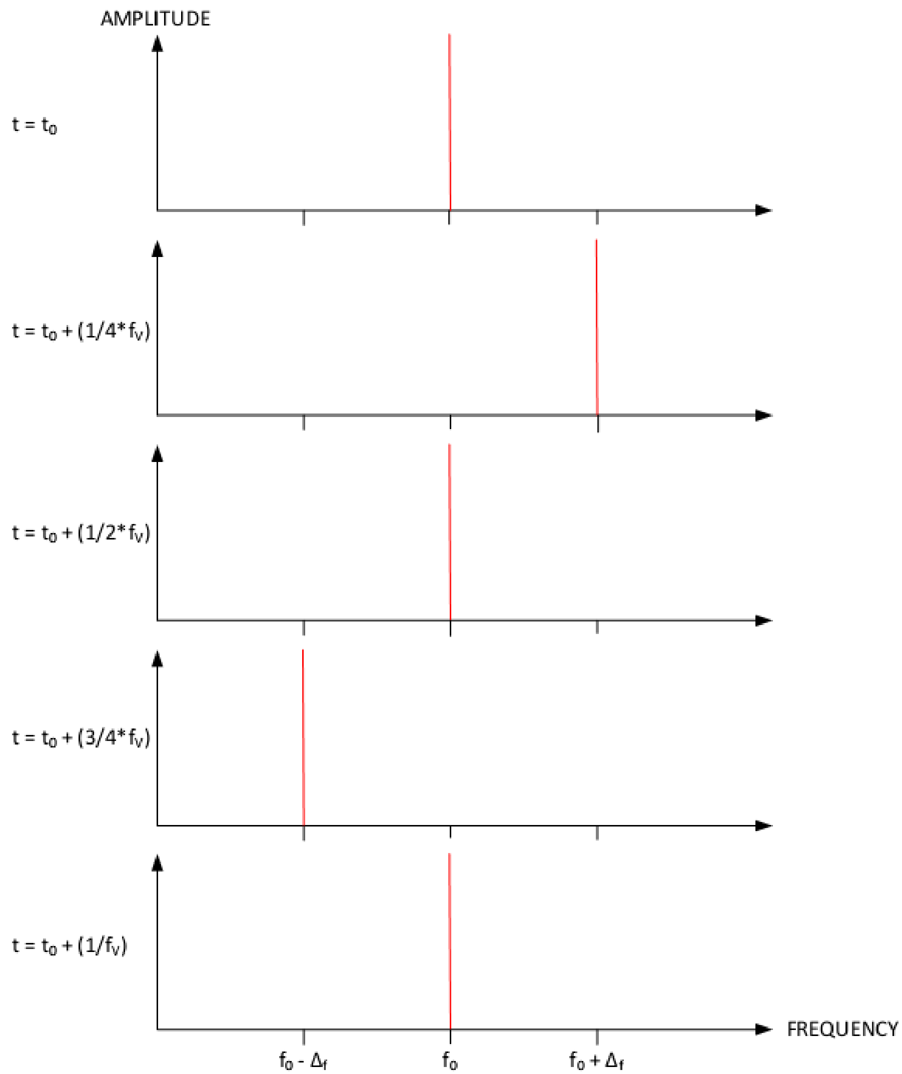

Figure 2: Instantaneous Frequency during one Vibration Cycle

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 observed that the instantaneous frequency deviation occurs at the crest and trough of the applied sinusoidal force.

It can be shown 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 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.

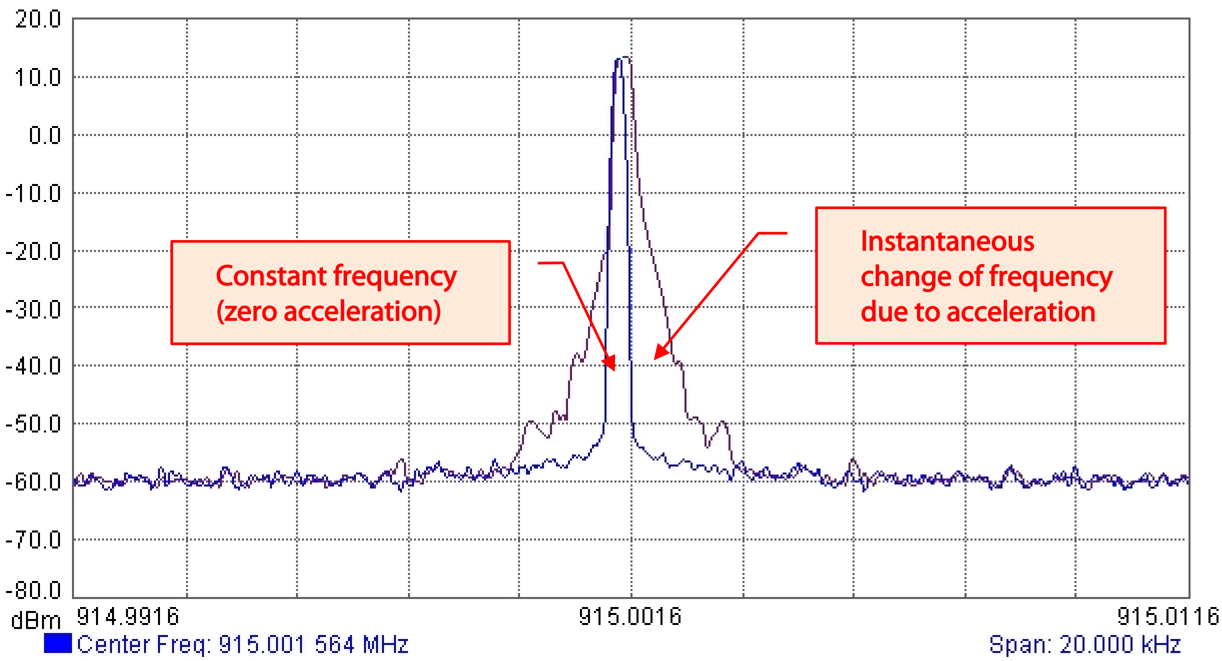

Figure 3: Effect of Acceleration due to Shock on a Crystal-Referenced PLL Transmitted Carrier

As it 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 observed that the resultant acceleration vector is proportional to both the magnitude of the acceleration, Γ_G, and relative angle (Θ, Φ) applied. [4]

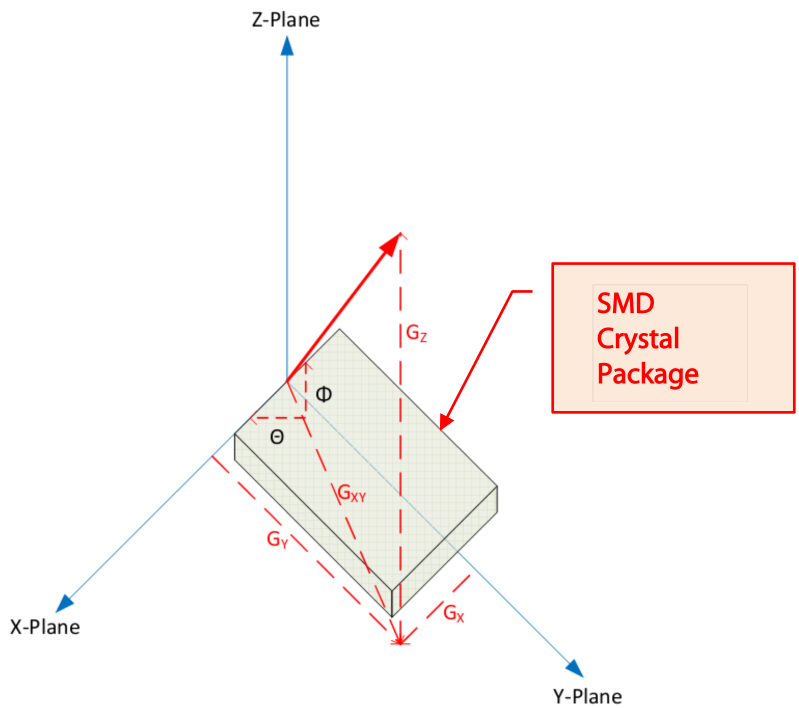

Figure 4: Magnitude of Acceleration Relative to Crystal Package

4. Conclusion

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 subject to acceleration forces, such as shock or vibration, for example where the SX1272 transceiver is implemented in a mobile link (such as a hand-held or vehicle mounted 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 to ensure that both crystal and PCB orientation minimize the acceleration vector.

If in doubt, contact your crystal vendor or Semtech representative.

5. Recommended Crystal Manufacturers

Crystal manufacturers familiar with the requirements for GPS receiver designs are able to recommend a suitable crystal for a given application and can also advise as to orientation.

Loading capacitance must be applied externally and adapted to the actual *Cload* specifications of the crystal, to center the LO frequency. Load capacitors value can slightly vary depending on the selected crystal part number and PCB design.

Currently Semtech LoRa® transceiver reference designs use only 32 MHz low-G sensitivity crystals from the following manufacturers below. Contact directly a crystal manufacturer sales representative for more details and specifications by selecting the desired part number below:

Table 2: LoRa® Modulation Recommended Crystal Manufacturers

Manufacturer	Website	Package Size	Model / Reference Part Number
Rakon	http://temexpress.com/en/index	3.2x2.5mm	FTR5092-A3 [2]
		2.0x1.6mm	FTR5123-B0 [2]
NDK	http://www.ndk.com/en/products/search/crystal/index.html	2.5x2.0mm	NX2520SA / EXS00A-CS00131 [1]
		2.0x1.6mm	NX2016SA / EX500A-CS06465 [1]
Epson	http://www5.epsondevice.com/en/ic_partners/info.html	2.0x1.6mm	FA-128 / Q22FA1280053000 [1] FA-128 / Q22FA1280058900 [2]
Taitien	http://www.taitien.com/crystal-oscillator	3.2x2.5mm	S0197-X-002-3 [2]
KDS	http://www.kds.info/product/	2.0x1.6mm	DSX211SH-32MHz 1ZZHAE32000AA0B [2]
		3.2x2.5mm	DSX321G-32MHz 1C232000AA0Q [2]
Murata	http://www.murata.com/en-global/products/quartzdevice/	2.0x1.6mm	XRCGB32M000F1H50R0 [1]
			XRCGB32M000F1H83R0 [1]
Kyocera	http://www.kyocera-crystal.jp/eng/prdct/list/xtal/#02	2.0x1.6mm	CX2016DB32000F0FFFC2 [1]
NSK	http://www.nsk.com.tw/product.asp?lv=0&id=2	2.0x1.6mm	NXN32.000AG10F-DKAB12 [2]

[1] Crystals with Rs (max) > 40 ohms are only to be used with SX1276 designs
[2] Crystals with Rs (max) < 40 ohms can be used with SX1272 and SX1276 designs

6. Recommended 32 MHz TCXO Manufacturers for Specific Applications if Required

Table 3: LoRa® Modulation Recommended TCXO Manufacturers

Manufacturer	Website	Package Size	Model / Reference Part Number
NDK	http://www.ndk.com/en/products/search/tcxo/index.html	2.0x1.6mm	NT2016SA / END4263A
		2.0x1.6mm	NT2016SB / END4329A
Rakon	http://temexpress.com/en/index	3.2x2.5mm	IT3205CE 32.000MHz
		2.0x1.6mm	IT2105 32.000MHz
Taitien	http://www.taitien.com/vctcxo-tcxo	3.2x2.5mm	S0197-T-004-3
KDS	http://www.kds.info/product/	2.0x1.6mm	T16-0626A-DSB211SDN-32MHz-1XXD32000PCA
Kyocera	http://www.kyocera-crystal.jp/eng/prdct/list/tcxo/	2.0x1.6mm	KT2016K32000ACW18YAS

7. References

[1] Semtech Application Note AN1200.07, "Improving the Accuracy of a Crystal Oscillator" http://www.semtech.com/apps/filedown/down.php?file=xo_precision_std.pdf

[2] "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)

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

Important Notice

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