Integer-N Synthesizer with Integrated VCO Yields Top Notch PLL Performance in a 4mm × 5mm Package

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High data throughput requirements in high bandwidth communications systems make the phase purity of the local oscillator critical to reliable performance. One way to conserve space and cost in such systems is to use an IC that combines the PLL and the VCO without sacrificing signal quality. The LTC6946 does just that by integrating a world-class frequency synthesizer, a low phase noise VCO and top-shelf performance, allowing designers to meet stringent RF system performance goals.

LTC6946 SAVES TIME AND SPACE

In either an RF receiver or transmitter system, the local oscillator (LO) plays a key role in achieving the desired system specifications. The main goal in such systems is to maximize the signal-to-noise ratio (SNR) of the received or transmitted signal while limiting board space, power and cost.

There are several factors that limit the SNR in an RF system, including the linearity and noise figure of the receive or transmit chain, and the phase noise and spurs of the LO.

Proper component selection in the RF chain limits the linearity and noise figure degradation to a tolerable level. Similarly, careful design decisions must be made to attain the desired phase noise and spurious level of the LO.

High performance systems call for an LO source with high spectral purity, necessitating the use of a low in-band phase noise synthesizer with an external high end VCO. Such a solution requires a large amount of board space, an involved design process and is relatively expensive.

The LTC6946, in contrast, meets the requirements of high performance systems by integrating these components in a single 4mm × 5mm package. Specifically, it combines an industry-leading ultralow phase noise and spurious integer-N synthesizer with a low phase noise and broadband VCO. Overall costs are low compared to an external VCO system, and integrating the LTC6946 in an RF system is straightforward, as shown later in this article.

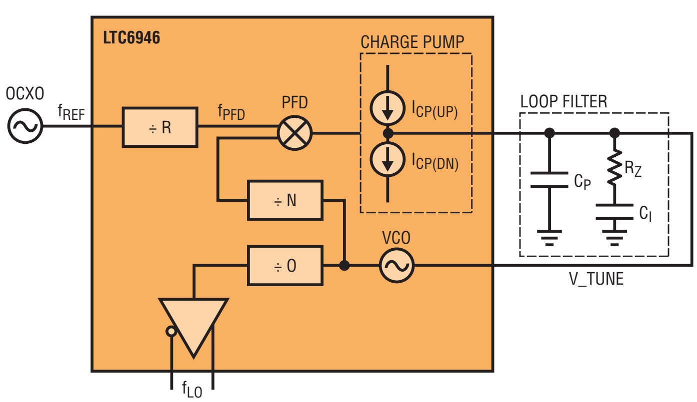
WHAT'S INSIDE THE LTC6946?

Figure 1 shows a simplified LTC6946 block diagram, along with the external reference clock (an OCXO, for example) and loop filter components.

In a nutshell, the phase/frequency detector (PFD) of Figure 1 compares the phase and frequency of the reference clock, f_{REF}, after its division by R to produce f_{PFD}, to those of the VCO following an integer division of N. The PFD then controls the current sources of the charge pump to ensure that the VCO runs at a rate such that when it is divided by N, its frequency is equal to f_{PFD} and its phase is in sync with the reference clock. This describes a negative feedback mechanism, with the external loop filter components stabilizing the loop and setting the control bandwidth. The O divider increases the output frequency range by dividing down the VCO output to create more frequency bands than just that of the VCO. The following equation relates the output frequency to f_{REF}.

$$f_{LO} = \frac{f_{REF}}{R} \bullet \frac{N}{O}$$

Figure 1. Simplified LTC6946 block diagram with external reference clock and loop filter



The LTC6946 meets the requirements of high performance systems by integrating components in a single 4mm × 5mm package. Specifically, it combines an industry-leading ultralow phase noise and spurious integer-N synthesizer with a low phase noise and broadband VCO. Overall costs are low compared to an external VCO system.

Table 1. LTC6946 versions

	LTC6946-1	LTC6946-2	LTC6946-3
VCO Range (MHz)	2240 to 3740	3080 to 4910	3840 to 5790
f_{LO} (MHz) with O = 1	2240 to 3740	3080 to 4910	3840 to 5790
f_{LO} (MHz) with O = 2	1120 to 1870	1540 to 2455	1920 to 2895
f_{LO} (MHz) with O = 3	747 to 1247	1027 to 1637	1280 to 1930
f_{LO} (MHz) with O = 4	560 to 935	770 to 1228	960 to 1448
f_{LO} (MHz) with O = 5	448 to 748	616 to 982	768 to 1158
f_{LO} (MHz) with O = 6	373 to 623	513 to 818	640 to 965

LTC6946 VERSIONS

There are three different frequency range versions of the LTC6946, summarized in Table 1. All versions offer superior in-band phase noise, with industry-leading 1/f performance. The integrated VCOs achieve low phase performance and require no external components.

IMPORTANCE OF LOW PHASE NOISE

The impact of LO phase noise on a system can be illustrated with a simple down-converting receiver. Consider a perfect tone at a frequency f_{RF} downconverted by an ideal mixer with the use of a non-ideal LO source at f_{LO} as shown in Figure 2. The LO source is shown to have a practical phase noise profile illustrated by the surrounding skirts. As can be seen at the intermediate frequency (f_{IF}), the down-converted ideal tone is corrupted by the phase noise of the LO source.

The ideal tone present at the RF port of the mixer has infinite SNR, or a very large one as limited by the matching system. The mixer, being ideal, does not degrade the quality of the received signal. However, the IF output of the mixer has a much lower SNR compared to the received signal due to the phase noise of the LO. This example presents a simple way for describing the importance of low phase noise in preserving signal quality.

Effect of Phase Noise on Digitally Modulated Signals

Complex digital modulation schemes make efficient use of limited channel bandwidth in wireless communications, but tend to put pressure on the phase noise requirements used to generate the LO in these systems. To further clarify the effect of phase noise on such an approach, assume that the RF port of the mixer in Figure 2 receives a 64-quadrature amplitude-modulated (64-QAM) signal. Figure 3 shows the IF signal constellation diagram, a 2-dimensional scatter plot of the demodulated signal at symbol sampling instants, assuming both the mixer and the LO source are ideal. Because each of the dots is distinct and centered exactly within the decision boundary, a proper demodulation scheme will decipher the received message with zero errors.

Going back to the system given in Figure 2, and assuming the phase noise of the LO as the only non-ideal element in the system, the constellation of the IF signal becomes that shown in Figure 4.

The landing locations of the sampled symbols are skewed by the LO phase noise. Consequently, the symbols are not as easily intelligible by the demodulator. As such, phase noise alone is capable of making the demodulator's job tricky, causing errors in the interpreted message.

To put this into perspective, compare the effect of phase noise to that of white noise on the demodulator's ability to deduce the message correctly. Assume that the system and signals in Figure 2 are all ideal

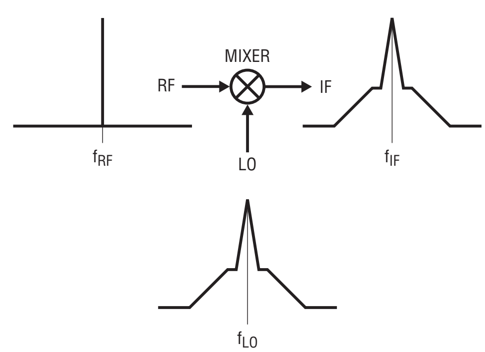


Figure 2. An ideal mixer downconverting an ideal tone with the use of a real-life LO

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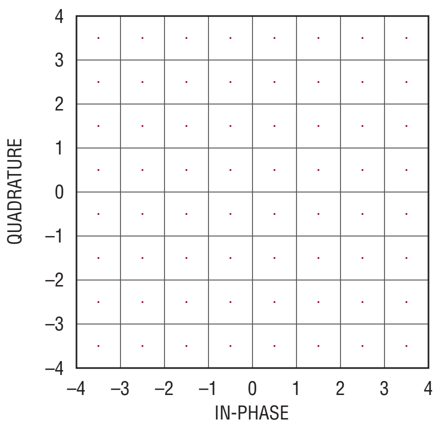

Figure 3. Ideal constellation of a 64-QAM signal

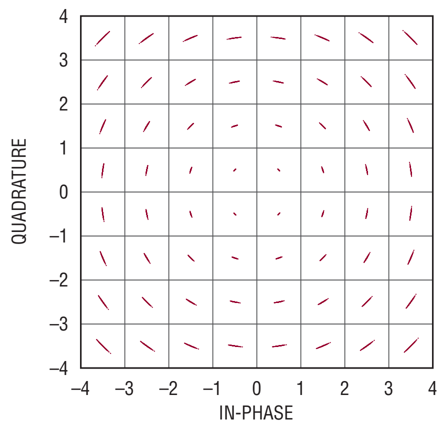

Figure 4. 64-QAM constellation corrupted by phase noise

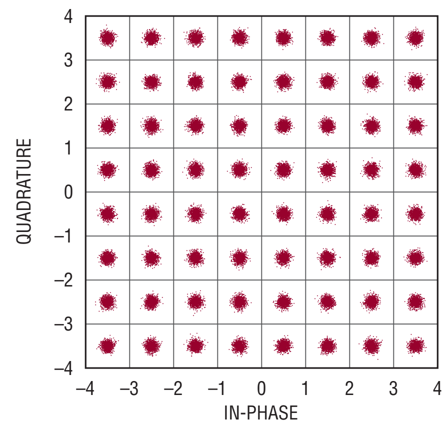

Figure 5. 64-QAM constellation corrupted by white noise

except that the mixer has a non-zero noise figure, such that it adds white noise to the received signal. The constellation of the IF signal in this case is shown in Figure 5.

Once again, the symbols are offset from their ideal spots, causing errors in the received signal. The ultimate consequence of white noise on the system is very similar to that of phase noise.

In a practical situation, the received signal at the RF port of the mixer has a limited SNR, which is already inadequate for error-free demodulation at the IF port. A real mixer worsens the situation due to its own impairments. The phase noise of the LO further harms the SNR if it is not carefully designed. Accordingly, the phase noise must stay at or below the level of SNR degradation acceptable in the system.

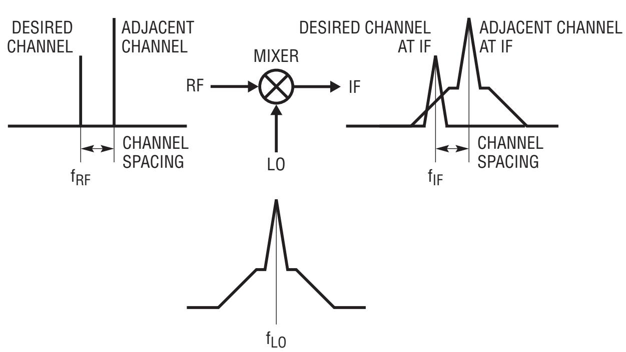

Figure 6. Reciprocal mixing due to LO phase noise

Effect of Phase Noise on Adjacent Channel

Another reason for requesting low phase noise is to avoid or reduce the effects of reciprocal mixing. It is common in communications systems with multiple channels in a certain band to have large variations in signal strength between two adjacent channels. If a weak signal located next to a much stronger adjacent channel is to be properly downconverted and demodulated, the LO used with the mixer must have low phase noise. It must be low enough to prevent the spectral leakage from the larger signal from seriously degrading the desired channel's SNR.

Assume that in Figure 2 two ideal tones are received at the RF port of the mixer and that the LO has the phase noise profile shown in the same figure. Figure 6 depicts the new system and illustrates reciprocal mixing.

As seen at the IF, the phase noise of the LO makes the stronger adjacent channel

The LTC6946 has an industry leading –274dBc/Hz normalized in-band 1/f noise specification, which is equivalent to a –134dBc/Hz phase noise level for a 100MHz reference clock at an offset of 100Hz. This number challenges the best 100MHz crystal oscillators available on the market.

"leak" into the weaker desired one and severely limit its SNR. The same concepts apply whether the mixer is used to downconvert or upconvert the incoming signal.

THE ANATOMY OF PHASE NOISE AND LTC6946 PERFORMANCE

So how does the LTC6946 stack up against synthesizer performance metrics? To illustrate this, the phase noise profile of a given LO is subdivided into four approximate regions as one of the LO sidebands shows in Figure 7. It is assumed that this LO source is produced by a PLL IC that locks a high frequency VCO to a lower frequency reference clock. The performance of the LTC6946 in each distinct region is discussed.

Close-In

Close-in phase noise is ideally dominated by the phase noise profile of the reference clock. However, the flicker (or 1/f) noise of the PLL IC usually worsens the noise here. This region typically extends to 100s or 1000s of Hz from the LO. Close-in phase noise degrades the performance of complex communications schemes especially if they have long burst durations.

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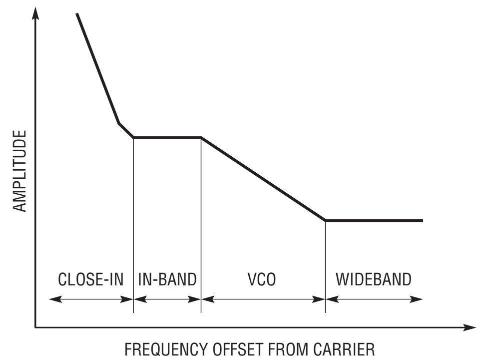


Figure 7. Single-sideband phase noise anatomy

In-Band

In-band phase noise is usually dictated by the PLL IC and any noisy components in the loop filter. The reference clock might also elevate the noise in this region if it is not properly chosen. The in-band phase noise region typically extends to around the loop bandwidth of the PLL. Depending on several factors, such as channel bandwidth and phase noise levels in the other regions, in-band phase noise is often the most significant contributer to signal SNR degradation due to phase noise.

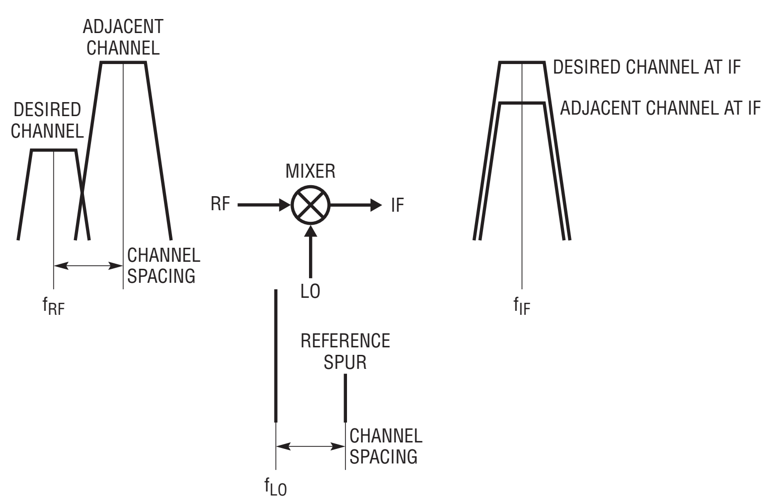
The LTC6946 boasts an impressive –226dBc/Hz normalized in-band phase noise floor that keeps the "plateau" area as low as possible. This figure allows the LTC6946 to be used in the most demanding applications.

VCO

VCO phase noise, as the name implies, is mainly contributed by the VCO. Depending on the PLL loop bandwidth and channel width, the VCO phase noise can be a significant contributor to signal SNR degradation due to phase noise. And, depending on the channel spacing, VCO phase noise might give birth to reciprocal mixing.

The VCOs integrated into the LTC6946 have competitive phase noise compared to standalone broadband VCOs, ensuring excellent overall performance.

Figure 8. Adjacent channel interference due to reference spurs



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Wideband

Wideband phase noise is dominated by the buffering present at the output of the VCO. Like VCO noise, and due to reciprocal mixing, wideband phase noise affects adjacent channels. Even far out channels experience a rise in their noise floor due to a distant strong channel, commonly referred to as a blocker.

The LTC6946 has a superior –157dBc/Hz wideband phase noise floor that matches the performance of standalone broadband VCOs, thus minimizng blocking effects.

THE IMPORTANCE OF LOW SPURS

An integer-N PLL produces spurs around the LO offset at its PFD update rate (f_{PFD}) and at the harmonics of this rate. These are commonly referred to as reference spurs.

Consider a typical scenario in a multichannel wireless communications system that carries a stronger channel adjacent to the desired but weaker channel as shown in Figure 8. Only one of the LO reference spurs is shown.

In an integer-N PLL, f_{PFD} is usually chosen to be equal to the channel spacing, which means that the reference spurs are positioned at channel spacing from the LO. These spurs translate all adjacent and nearby channels to the center of the IF, along with the LO translating the desired channel to the same exact frequency.

These undesired channels, being uncorrelated to the signal in the desired channel, appear as an elevated noise floor to the desired signal and limit its SNR. Hence, it is important to keep reference spurs at bay.

LTC6946 DESIGN EXAMPLE

To appreciate the simplicity of the design process with the LTC6946, a complete design example for the LO of a wideband point-to-point radio for wireless access is shown here. The design assumes the following frequency plan.

- LO frequency band: 4700MHz to 5700MHz
- Frequency step size (channel-to-channel spacing): 5MHz
- Reference clock frequency: 100MHz

Based on the frequency ranges in Table 1, the LTC6946-3 is suitable for covering the requested frequency band. All further design choices can be made using the PLLWizard™ free PLL design and simulation tool found at www.linear.com/designtools/software.

Entering the given frequency information in PLLWizard and picking the approximate noise optimized loop bandwidth suggested by the PLLWizard tool produces the loop filter values needed to modify a DC1705A-C demo board. Since the LTC6946 VCO gain is nearly constant as a percentage of the frequency, the loop filter designed at any frequency within the band works for all other frequencies. Figure 9 shows a snapshot of PLLWizard used in completing this design.

The DC1705A-C is updated with the loop filter components as found above and its schematic is shown in Figure 10.

Figure 11 verifies that the achieved phase noise matches that predicted by PLLWizard. Double-sideband integrated noise from 100Hz to 40MHz allows for

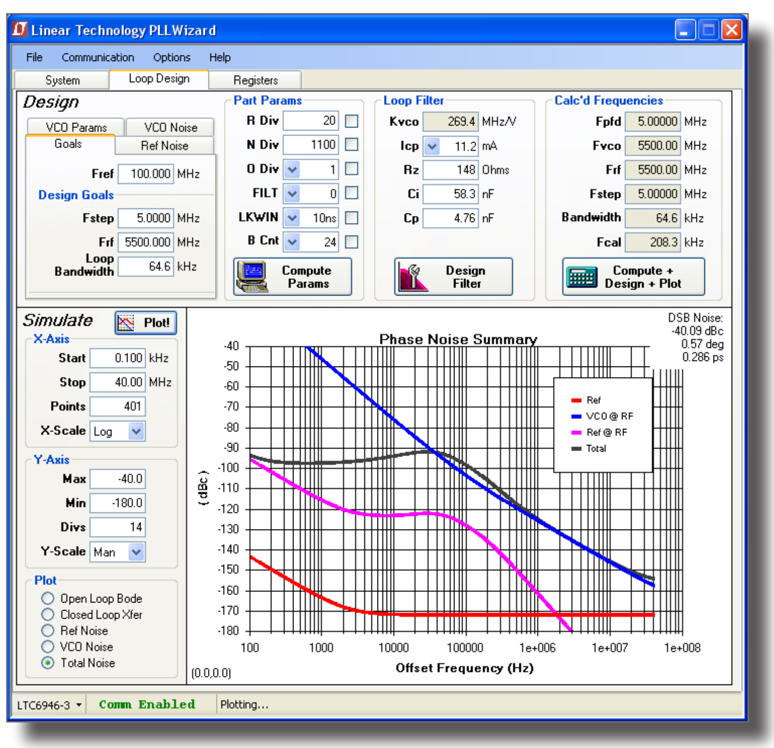

Figure 9. Snapshot of the PLLWizard software tool used in designing a broadband LO from 4700MHz to 5700MHz with 5MHz channel spacing

Spurious performance at 5500MHz is impressive, with the tallest reference spurs around –97dBc, which is phenomenal at an LO frequency this high. These spurs are unlikely to contribute to any noticeable adjacent channel interference.

close to 40dB of SNR, sufficient to meet most demanding application requirements.

Figure 12 shows the spurious performance at 5500MHz. The tallest reference spurs are about –97dBc, which is phenomenal at an LO frequency this high, and are unlikely to contribute to any noticeable adjacent channel interference.

After following the quick and straightforward steps summarized above, the circuitry is ready to be deployed in a real-life point-to-point radio application.

CONCLUSION

The LTC6946 simplifies frequency synthesis by integrating an integer-N synthesizer with a VCO without sacrificing performance. It is ideal for many demanding applications where low phase noise is essential. To top it off, designing with the LTC6946 is a breeze when combined with the PLLWizard tool, available at www.linear.com/designtools/software. ■

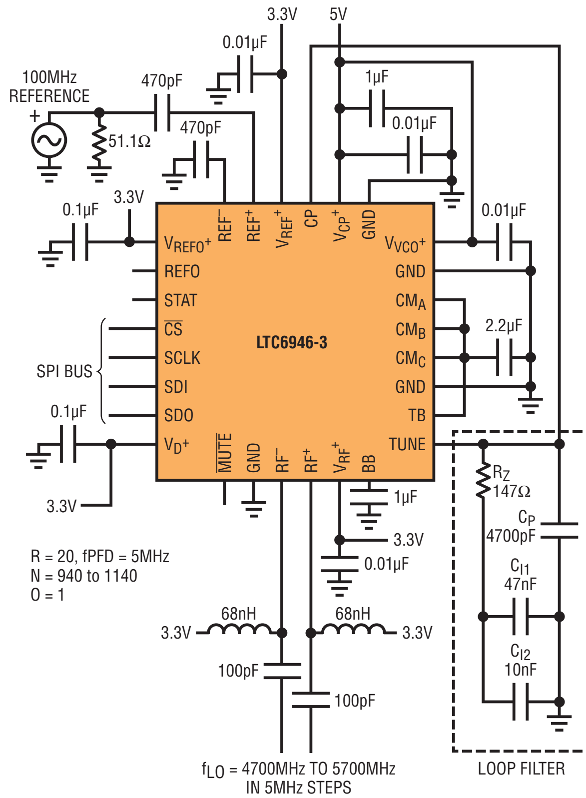

Figure 10. Schematic of the 4700MHz to 5700MHz LO synthesizer circuit

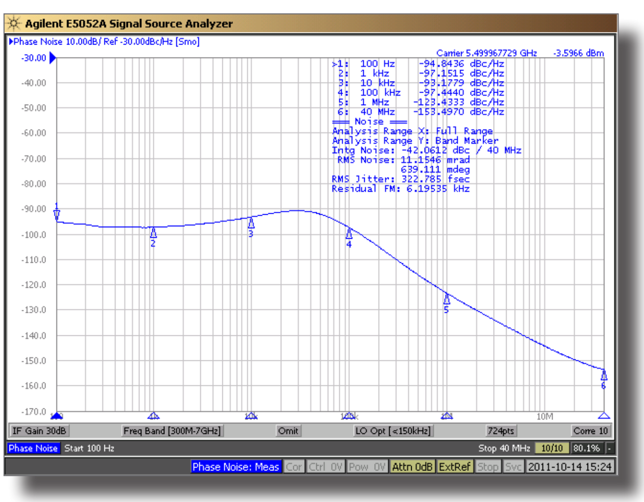

Figure 11. Phase noise at 5500MHz

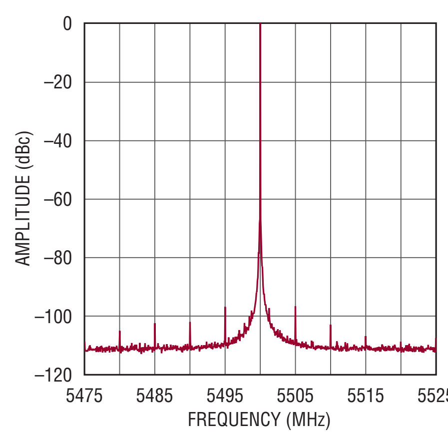

Figure 12. Spectrum at 5500MHz