Review: Phase Noise in Voltage Controlled Oscillator

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Abstract

In this work, the review of phase noise in voltage controlled oscillator (VCO) which is very important system in all kinds of wireless communication system is presented. Such kinds of VCOs can be fabricated by hybrid method using PCB substrate or by semiconductor technology using silicon, GaAs, InP, complementary metal oxide semiconductor (CMOS), micro-electromechanical sytems (MEMS) and so on. Recently there are many kinds of design tools like ADS, AWAR etc. for RF system design. Especially, the phase noise is essential parameter to be considered during the design and simulation process. Optimization of such parameter is also important in simulation because phase noise cannot be totally eliminated but it can be reduced using different techniques. If phase noise is maximum in the signal, spectrum purity cannot be expected, eventually, the system will be failed to extract the real signal. That means, the performance of the overall system will not be degraded by improving the VCO phase noise performance

Keywords: Voltage controlled oscillator; phase noise; VCO; resonator.

1. Introduction

A phase noise of voltage controlled oscillator (VCO) is very important parameter in both wired and wireless communication system, especially in transmitter and receiver part of RF system. Such VCO can be fabricated using semiconductor technologies like silicon, GaAs, InP, complementary metal oxide semiconductor (CMOS), micro-electromechanical sytems (MEMS) etc. However, we have to consider before design and simulation that which technology is suitable to achieve a low noise.

There are many RF researchers who are trying to reduce the phase noise in VCO. The VCO can be designed by using various RF system design tools at different frequencies. However, theoretically, there is no any spectrum except signal as shown in Figure 1 (a). When it is mixed with other frequencies, it generates harmonics resulting sideband noise like in Figure 1 (b). If the short term stability of an oscillator is examined using a spectrum analyzer, it shows a spectrum consisting of random and discrete frequency components causing a broad skirt and spurious peaks. If the oscillator was noise free the spectrum would consist of a single spectral line. The broadening of the spectrum is caused by various noise sources including thermal noise, shot noise or flicker noise in active and passive devices. This broadening is due to the phenomenon of phase noise. We can define phase noise as a ratio of signal power to noise power measured in 1 Hz bandwidth at a given offset from the wanted signal. The definition of phase noise is shown in Figure 2.

VCO can be used as frequency synthesizers in various systems like radio receivers, transmitters and RF signal generators and phase noise of VCO is a main parameter for applications. The effect of VCO phase noise affects the overall performance of the system. Poor levels of VCO phase noise can manifest themselves in different ways. A weak performance of oscillator may result in weak reciprocal mixing performance for an analogue radio receiver. The noise floor of the receiver can also be raised. In the process of phase modulation in the RF system, the bit error rate is also degraded with band phase
noise performance.

In the case of transmitter, a poor level of phase noise performance will result in noise being transmitted beyond the required transmit band, causing interference to users on other frequencies. Again it can result in poor levels of bit error rate in a radio communications system. Additional RF signal generators will look for as ‘pure’ a signal as possible. Design parameters, phase noise in frequency domain and time domain will be explained in the next section and finally it will be concluded [1-4].

Figure 1. The ideal (a) and (b) practical VCO output in frequency domain.

![Figure 1](image1.png)

Figure 2. The phase noise characteristics.

![Figure 2](image2.png)

2. Design Considerations

The optimum phase noise of VCO is very important for which we have a number of key parameters to be considered in the process of design and simulations. For the best performance for the system using VCO, the optimization of phase noise parameter is required. Some parameters are explained below which play essential role in the RF system

2.1. High quality factor (Q) resonator
High Q-resonator network is essential one of the major factor in determining the VCO phase noise performance. If the Q of resonator is high, we can achieve a low phase noise performance of VCO and for this purpose, we can use high Q-inductor and capacitor to build resonance circuit. To get variable frequencies, we can use varactor diode in the resonance circuit having a lower Q than capacitors. Typically high Q tuned circuits do not have the tuning range of lower Q circuits. This means that when wide tuning ranges are required, it becomes more difficult to obtain a high level of Q and hence the optimum phase noise. As an illustration of the effect of having a high Q resonant circuit in an oscillator, crystal oscillators exhibit very low levels of phase noise as a result of the fact that the crystals used in them possess very high levels of Q. The implementation of varactor diode can be used in the circuit as shown in the Figure 3. In this Figure, varactor diode with periphery components like filters, RF choke, inductor, DC block capacitor etc are shown. The harmonic filter passes the desired harmonic, say the 3rd, to the output, f3. The capacitor at the bottom of the inductor is a large value, low reactance, to block DC but ground the inductor for RF. The varactor diode in parallel with the inductor constitutes a parallel resonant network. It is tuned to the desired harmonic. Here, the reverse bias voltage, Vbias, is fixed [5].

![Figure 3. The schematic showing varactor diode with periphery circuits.](image)

The tuning range of high Q resonator incorporated with VCO is very narrow. If we need wide tuning range, the Q of resonator should be lower but this gives poor phase noise performance and it is not easy to get a low phase noise characteristics. Therefore, we have to optimize these factors to get required results. For example, the effect of having a high Q resonant circuit in crystal oscillators, it exhibits very low levels of phase noise due to the fact that the crystals possess very high levels of Q.

### 2.2. Device Selection

Both bipolar junction transistors (BJTs) and field effect transistors (FETs) are possible to use in the RF VCO. It can be implemented in the basic circuit topologies. However, we have to choose the low noise device that results low phase noise performance. The bipolar transistor has a low input impedance and is current driven, while the FET has a high input impedance and is voltage driven. The high input impedance of the FET is able to better maintain the Q of the tuned circuit and this should give a better level of performance in terms of the phase noise performance where the maintenance of the Q of the tuned circuit is a key factor in the reduction
of phase noise. That said, many bipolar transistor designs are able to offer excellent phase noise performance.

Another major factor is the flicker noise generated by the devices. Oscillators are highly non-linear circuits and as a result the flicker noise is modulated onto the oscillation as sidebands. This manifests itself as VCO phase noise. In general bipolar transistors offer a lower level of flicker noise and as a result oscillators based around them often offer a superior phase noise performance.

2.3. Feedback Circuit

A critical feature in any oscillator design is to ensure that the correct level of feedback is maintained. There should be sufficient to ensure that oscillation is maintained over the frequency range, over the envisaged temperature range and to accommodate the gain and parameter variations between the devices used. However if the level of feedback is too high, then the level of VCO phase noise will also be increased. Thus the circuit should be designed to provide sufficient feedback for reliable operation and little more.

2.4. VCO Output:

It is found that the noise floor of an oscillator is reasonably constant in absolute terms despite the level of the output signal. In some designs there can be improvements in the overall signal to noise floor level to be made by using a high level signal and applying this directly to the mixer or other circuit where it may be required. Accordingly some low noise circuits may use surprisingly high oscillator power levels.

2.5. Elimination of VCO Power Line:

It is necessary to ensure that any supply line or other extraneous noise is not presented to the oscillator. Supply line ripple, or other unwanted pickup can seriously degrade the performance of the oscillator. To overcome this, good supply smoothing and regulation is absolutely necessary. Additionally it may be advisable to place the oscillator within a screened environment so that it does not pick up any stray noise. It is worth remembering that the oscillator acts as a high gain amplifier, especially close to the resonant frequency. Any noise picked up can be amplified and will manifest itself as VCO phase noise.

3. Phase Noise and Jitter

The phase noise and jitter are both the expression of describing the stability of an oscillator or VCO. The first one describes the stability in the frequency domain and the later expresses the stability in the time domain. These both cases are shown in Figure 4 in which the upper one shows the phase in time domain for an oscillator and the second one depicts the case of phase noise in VCO. In most cases, frequency domain result of phase noise is interested by RF designers who work in radar, satellite communication, base stations, and wireless communications systems etc. They used those characteristics in up-converter and down converter observing phase noise performance in the system. On the other hand, time domain result of phase noise, jitter is interested by digital circuit designers who work in telecommunication infrastructure, especially in time division multiplexing.

There are some boundaries in specifying noise characteristics in the measurement process. Simply we can express the phase noise from 10 Hz to 3 MHz (normally) from the DC offset. However in jitter measurement process, we need sampling periods and its bandwidths. This is a bit complicated.
The measurement equipment for the phase noise measurement should be considered. In the case of phase noise measurement. It can be achieved by quadrature locking the VCO under test to a reference VCO. The purpose of quadrature locking is to eliminate the carrier frequency leaving only non-phase noise components. The second harmonics can be removed by this method since lowpass filter is not used. The mixer generates the sum and difference frequency but we are only interested in the difference frequency. The LNA can be switched in or out depending on the resolution of the low frequency spectrum analyzer. Eventually we can use spectrum analyzer to measure phase noise performance of VCO which are seems like in Figure 4 (a).

However, in order to measure jitter (time domain), we can use a digital storage oscilloscope and trigger on one leading edge then look at the position in time of next edge. But this approach has some problems because we don’t know the bandwidth of oscilloscope, number of samples and sampling time which lead the uncertainty of the triggering point [6]. The generation of jitter is shown in Figure 4 (b).

(a) Phase noise in frequency domain

(b) Jitter in time domain
3. Conclusion

In this work, we reviewed the basic parameters for VCO and its characteristics. VCO can be fabricated using both hybrid and MMIC technologies like HBT, CMOS, MEMS etc. However, the important thing is the applications or purpose of VCOs. There are some important parameters like high Q resonator, device selection, feedback network, and power line. These parameters should be considered during design and simulation. Additionally we can characterize the VCO with spectrum analyzer to measure phase noise performance which is very important and is should be a low phase noise characteristics. The phase noise can be measured in frequency and time domain to analyze its characteristics.

References

[6] https://www.maximintegrated.com/ (online)