A 2.4 GHz CMOS LC VCO with Phase Noise Optimization

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Abstract

A 2.4 GHz low phase noise fully integrated LC voltage-controlled oscillator (VCO) in 0.18 μm CMOS technology is presented in this paper. The VCO is optimized based on phase noise reduction. The design of the VCO uses differential varactors which are adopted for symmetry of the circuit, and consider AM-PM conversion due to a cross-coupled pair. The VCO is designed to draw 3 mA from 1.8 V supply voltage. Simulated phase noise is -137.3 dBc/Hz at 3 MHz offset. The tuning range is found to be 300 MHz range from 2.3 GHz to 2.6 GHz.

I. Introduction

The integrated LC VCOs play an important role in frequency translation in RF transceivers. The VCOs are used to generate the local oscillator (LO) carrier signal used to mix with the RF signal to the target frequency, so that the phase noise performance of the LO affects the conversion process between RF and IF band seriously. Hence, a low phase noise VCO is strongly desired.

As published by Leeson in 1966 [1], the phase noise of an LC VCO can be described as Eq. (1):

(1)

Eq. (1) suggests that the most effective way to lower the phase noise level while maintaining the same bias current is to improve the loaded quality factor of the LC tank. Also, due to the existence of AM-PM conversion, the AM noise is potentially converted to PM noise [2]. Thus, reducing the AM-PM conversion factor can suppress the noise converted into phase noise.

The organization of the paper is as follows: Section II presnets the design of a VCO shown in Fig. 1; Section III gives the simulation results which are compared with those of other VCOs, and conclusion is presented in Section Ⅳ.

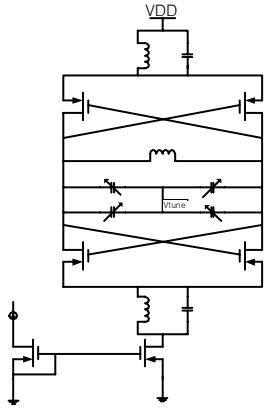

Figure 1. Circuit schematic of the VCO

II. Design of the VCO

In LC tank, noise is produced due to the existence of resistors in inductors and varactors. We can write them as $i_n^2=4k_BT/R$, where R is the parallel resistance. Also due to the R, a quality factor Q of the tank will be reduced. So when we design the LC tank, we keep Q high. Also differential varactors

can keep the symmetry of the circuit and hence realize lower phase noise well.

As to the cross-coupled pair transistor, this is a special part, because it controls an oscillation-start of the VCO, AM-PM conversion factor, also it is a noise source with parasitic capacitors. These parasitic capacitors will reduce the tuning range, and even due to their nonlinearity, result in AM-PM conversion. To reduce the noise, we can increase the width of transistor. However, there is a trade-off between noise and AM-PM conversion factor, so the width of the transistors should be adjusted properly.

The tail bias current source is an important noise contributor, which includes thermal noise and low frequency flicker noise. Thermal noise will be upconverted into $1/f^2$ and, the flicker noise is upconverted into $1/f^3$ region, due to the switching mechanism of the cross-coupled pair as a single balanced mixer and AM-PM conversion.

Also, from Fig. 1, we can see that a filter is used between the tail current source and cross-coupled pair, as being known, to stop the noise of tail current source be up-converted into phase noise. And it can prevent that the MOS transistors are loaded into the LC tank to result in lowering Q.

$$Q_{Load} = \frac{Q_{Unload} R_L}{Q_{Unload} \omega_0 L + R_L} \qquad (2)$$

Ⅲ. Simulation results

For simulation results, phase noise is found to be -137.3 dBc/Hz at 3 MHz offset, shown in Fig. 2. The tuning range is from 2.3 GHz to 2.6 GHz, shown in Fig. 3. And the current in VCO core is 3mA.

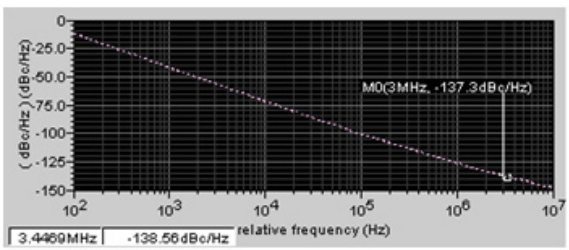

Figure 2. The phase noise of the VCO

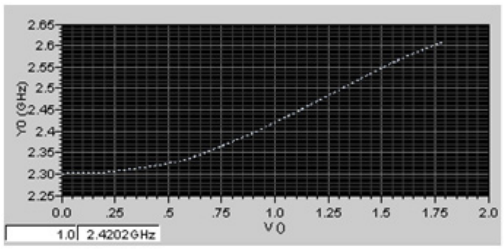

Figure 3. The tuning range of the VCO

The Figure of Merit (FOM) of each design is defined as follows, and compared to those of other published designs as shown in Table 1.

(3)

TABLE 1. Performance comparison of the VCOs

Reference	(GHz)	(Hz)	P (mW)	dBc/Hz	FOM
[3]	2.4	3M	1.8	-131.4	-187.7
[4]	2.5	3M	2.6	-131	-186
This work	2.4	3M	5.4	-137.3	-188.1

Ⅳ. Conclusion

The 2.4 GHz VCO is designed using differential varactors, with AM-PM conversion considered, in which, 3 mA current flows though the VCO core from the 1.8 V power supply. The tuning range is simulated to be from 2.3 GHz to 2.6 GHz with 0-1.8V tuning voltage. The phase noise is found to be -137.3 dBc/Hz at 3 MHz offset with 2.4 GHz oscillation frequency.

References

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