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# A Low Phase Noise, Low Power and Wide Tuning Range VCO with Filtering Technique in ISM Band

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## Abstract

**In this paper, a novel voltage controlled oscillator (VCO) with low phase noise, low power consumption and wide tuning range in the industrial, scientific and medical (ISM) band is proposed for communication systems applications. For improving the phase noise, filtering technique is used and VCO is designed with TSMC CMOS 0.18 µm technology and the power supply is 1.5 V. The simulation results with advanced design system (ADS) shows that phase noise in 1 MHz offset frequency from the carrier is −122 dBc/Hz and tuning range is 2 to 2.8 GHz. The power consumption of the core is 2.49 mW.**

## Keywords

**Filtering Technique, Tuning Range, Phase Noise, Power Consumption, Voltage Controlled Oscillators (VCO)**

## 1. Introduction

One of the most important parts in transmitters is phase locked loop (PLL), and their performance is strongly influenced by the voltage controlled oscillators (VCO) [1]. VCO is one of the newest comparator types [2]-[4]. VCO-based comparator and quantizer are one of the most important sections of successive approximation ADC and delta-sigma, respectively [5]-[10]. The similarity between electrical oscillators and optical oscillators including lasers [11]-[20] and vertical-cavity surface-emitting lasers (VCSELs) [21]-[33] allows the processes

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used in optical spectroscopy to be applied. VCO is one of the most difficult circuits to integrate for the following reasons: 1) poor quality factor of the monolithic inductor; 2) limited tuning range of the varactor; and 3) poor flicker noise in CMOS technology compared with the other technologies such as SiGe HBT [34]. There are many methods to improve the phase noise, an example is the multigated transistor which is proposed in [35].

The important goals in designing of VCO are low power dissipation, low phase noise and wide tuning range. In this paper, with using the filtering technique and good selecting of the inductor and the varactor, a LC-VCO with low power (2.49 mW), low phase noise (−122 dBc/Hz) and wide band is proposed. The rest of this paper is as follows. In Section 2, the VCO design considering the conventional cross-coupled architecture is reviewed and the proposed VCO is introduced in order to reach low power consumption, low phase noise and wide tuning range. Section 3 presents the results and discussions. Finally, we conclude in Section 4.

## 2. Proposed Voltage-Controlled Oscillator

There are different structures for designing oscillators. As an example Ring oscillator and LC Tank structures can be noted. LC tank oscillators can be further divided to Colpits, Hartely and cross coupled oscillators. In this paper cross coupled structure which has a low phase noise is used This cross coupled structure is also suitable for integration. Cross coupled oscillators are one of the most commonly used structures [36]. In **Figure 1** the conventional cross coupled oscillator is shown.

The LC tank forms the most important part of the cross coupled oscillators. The integrated circuits oscillators like the other blocks of the transmitter, suffer from the low quality factor of the integrated inductors. Therefore a versatile design of the LC tank is very important. The resonator of the VCO consists of MOS varactors for continuous tuning and an on-chip inductor. MOS varactors ($C_{var}$) are employed to provide the frequency tuning capability. The capacitance of MOS varactors determines the oscillation frequency together with the inductance and other parasitic capacitances [37].

As power supply, PMOS current source is generally used because the PMOS transistors have less noise flicker [38]. Therefore in the proposed VCO this type of current source is used. **Figure 2** shows the PMOS current source that is used in the proposed circuit.

The most important parameter in a VCO is phase noise. To calculate the phase noise value, different relationships is presented [34]. The most famous of these relations is Leeson equation [39]. Leeson's model defines the phase noise at a given offset frequency, $\Delta\omega$, from the center frequency as bellow:

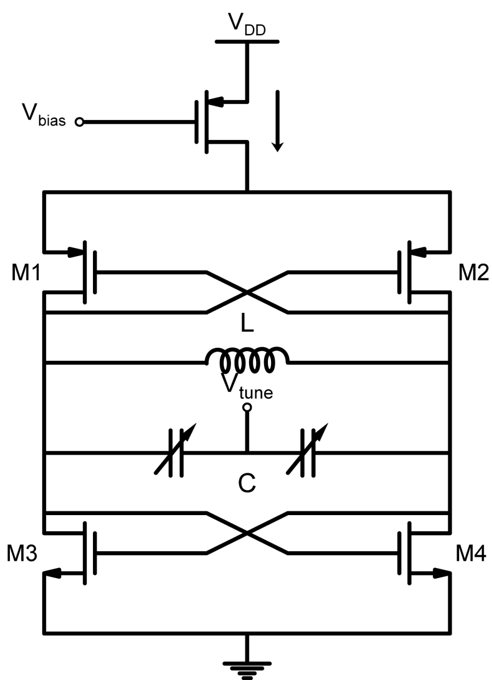


**Figure 1.** CMOS complementary voltage-controlled oscillator [36].

$$L[\Delta\omega] = 10Log\left[\frac{2FKT}{P_{sig}}\left[1+\left(\frac{\omega_0}{2Q\Delta\omega}\right)^2\right]\left(1+\frac{\Delta\omega_{1/f^3}}{|\Delta\omega|}\right)\right] \quad (1)$$

where L[$\Delta\omega$] is the phase noise at offset frequency $\Delta\omega$ from the operating frequency $\omega_0$, F is an empirical fitting factor, and Q is quality factor of the LC-tank. $\omega_0$ is the oscillation frequency as bellow:

$$\omega_0 = \frac{1}{\sqrt{LC}}. \quad (2)$$

Current source noise creates phase noise in the oscillator [40]. The filtering technique is an effective method for improving the phase noise. In this technique the second harmonic noises in the current source which are efficient in creating phase noise is blocked [38]. **Figure 3** shows the proposed VCO. In this scheme a high value capacitor is connected in parallel with the current source and shunts the second harmonic noises of the current to the ground. To further reduce the amplitude of the second harmonic of the current, an impedance boosting inductor is included at the common drain node in the design. The inductance ($L_2$), is selected for resonating at $2\omega_0$ with the total capacitance in the common mode.

## 3. Simulation Results

The proposed VCO is simulated by Advanced Design System (ADS) in TSMC 0.18 μm CMOS process. The tuning range of the VCO is from 2.04 to 2.79 GHz that is achieved by the tuning voltage from 0 to 1.5 V, as shown in **Figure 4**. **Figure 5** shows that the proposed VCO at 2.7 GHz central frequency has the phase noise of −122 dBc/Hz at 1 MHz offset. **Table 1** provides comparison of the proposed VCO and the most recently works. As seen, its phase noise is small compared to previous results. **Figure 6** shows the output power of the VCO versus tuning voltage, after connection to the output buffer. The power consumption of the circuit is 2.49 mW.

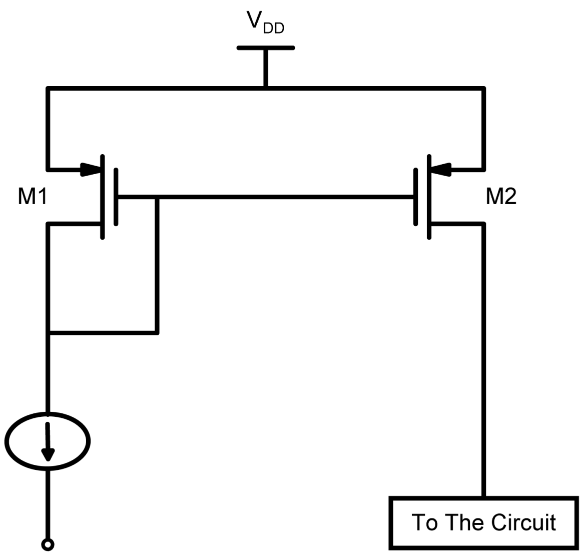


**Figure 2.** PMOS current source.

**Table 1.** Specification comparison of the proposed VCO and the other works.

| specification | This Work | [35] | [41] | [42] |
|---|---|---|---|---|
| Frequency (GHz) | 2.04 - 2.79 | 2.17 - 2.7 | 2.4 | 2.26 - 2.43 |
| Phase Noise | 122@1 MHz | 122@1 MHz | 131@3 MHz | 135@3 MHz |
| Power Consumption | 2.49 mW | 2.7 mW | 1.8 mW | 5.18 mW |
| Power Supply | 1.5 V | 0.9 V | 1.8 V | 0.7 V |

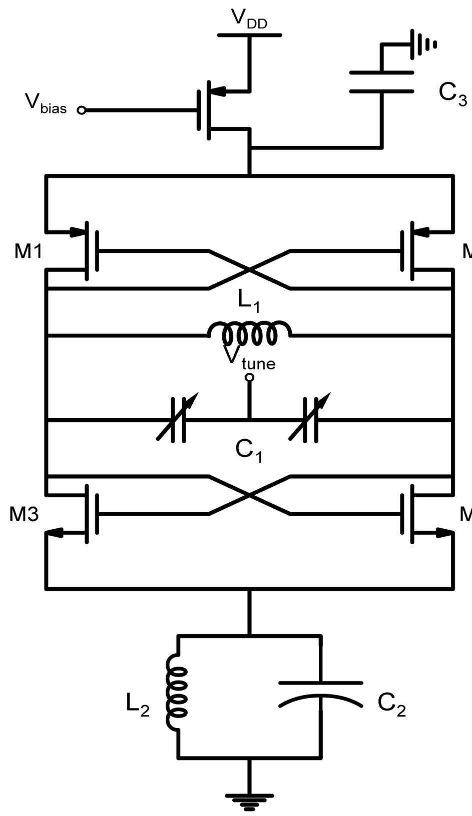


**Figure 3.** Proposed VCO scheme with the PMOS current source.

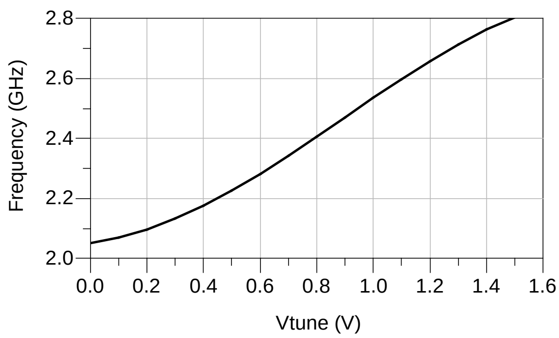


**Figure 4.** Oscillation frequency versus control voltage.

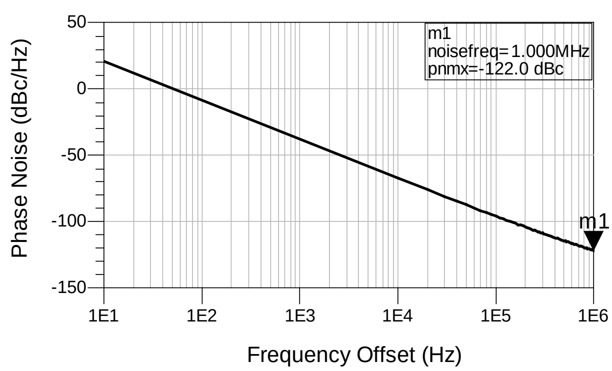


**Figure 5.** Phase noise of the VCO in the 1 MHz offset.

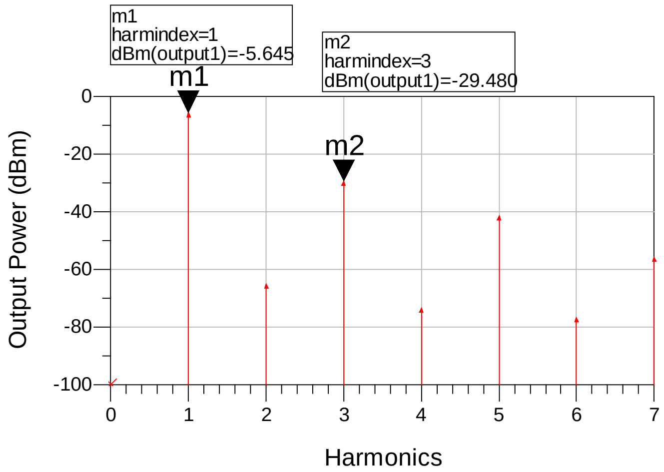


**Figure 6.** Output power of the VCO.

## 4. Conclusion

A novel voltage controlled oscillator design using filtering technique is presented. The simulation results show that the proposed VCO at 2.7 GHz central frequency has the phase noise of −122 dBc\Hz at 1 MHz offset. The power consumption of the VCO core is 2.49 mW and the tuning range is 2.04 to 2.8 GHz with 0 to 1.5 V voltage control.

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