A Push-push Dual-band Cross-coupled VCO in 90-nm CMOS Technology

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Abstract. This paper presents a VHF dual-band cross-coupled voltage VCO with push-push structure. This is achieved by using the push-push structure and the binary-weighted capacitor. The circuit has been implemented in TSMC 90nm CMOS process with a core area about 800μm ×600μm. The measured fundamental and push-push output phase noise at 10MHz is -108.57 dBc/Hz and -98.43 dBc/Hz, with the tuning range covers 26.38 GHz~28.15 GHz and 52.76 GHz~56.30 GHz.

1. Introduction

There is a rapid growth of millimeter-wave chips applied in various communication system in recent years. The higher frequency bands offers lots advantages such as smaller chip size and low supply voltage. In these millimeter-wave systems, voltage-controlled oscillator must have low phase noise and enough tuning range to satisfy wireless communication protocol. One solution is to lower the production cost of chip by integrating different operating frequencies in millimeter-wave system. Therefore, Millimeter-wave VCOs with different oscillating frequency band should be realized. Push-push structure was used to obtain higher oscillation frequency. Cross-coupled LC-VCO has a wide tuning range and quite low phase. A low phase noise VCO with two structures combined seems very necessary for the GSM, and other millimeter-wave communication system.

It has been revealed that the shift of working state with frequency tuning is another handicap for tuning range besides the tuning range of the LC tank. On this discovery, a CMOS LC VCO was designed by using switchable parts in cross-coupled structure. In a GHz VCO, the tuning range of the LC tank plays the dominant role for the frequency coverage of the VCO. This paper proposes a wideband VCO with a tuning range of 2.2GHz, with -108.57 dBc/Hz in phase noise.

2. Circuit design: considerations and optimization

In GHz applications, a CMOS VCO always apply the LC tank structure. It combines of a single on-chip spiral inductor with fixed inductance bur low quality factor, and band-switching capacitors to adjust the
output frequency coarsely and a MOS varactor with continuous effective capacitance to cover the output frequency seamlessly. Combined with push-push structure, VCO can achieve higher frequency. In most push-push structures, the 2nd frequency signal is extracted from the middle node of the inductor, which is virtual ground. The even frequencies of oscillation can be counteracted by the anti-phase balanced structure. Therefore, combining the cross-couple pair with the push-push structure will extracted more easily. And using capacitor array to accomplish the required tuning range.

The schematic of VCO is shown below. The varactor array and inductors of the oscillation tank determines the tuning range and the oscillation frequency. The center of the inductor is where the 2nd frequency signal is extracted from. The cross-coupled VCO core is formed by NMOS Mn1 and Mn2. The output buffer Mn3 and Mn4 for differential fundamental signal, which is 27GHz, is connected to drain of cross-coupled core.

![Figure 1. Schematic of the dual-band VCO](image)

2.1 phase noise
An LC-VCO combines a lossy spiral inductor and an active cross-coupled pair to counteract the loss. In steady-state, phase noise condition near the fundamental frequency are shown by[1]:

\[ L\{\omega_m\} = \frac{4FKTR}{V_{RMS}^2} \]  

(1)

Where the Vrms is the root mean square of oscillation amplitude and the active circuit noise density is F-1 times the tank noise. While the VCO working in current–limited operation, the loss of the oscillation tank, the current source and cross-coupled differential pair constitute the factor \( F \): \[ F = \frac{4EI}{V_o} + \frac{8g_{mbias}}{g} + 1 \]  

(2)

where \( \gamma \) is the transistor noise factor, \( I \) in (2) represents the bias current, and \( g_{mbias} \) related to the transconductance of the current source. There are two important thing should be noticed from the equation.
First, the thermal noise from the cross-coupled pair is independent part in the phase noise analysis. Second, the frequency of the LC tank will be affected by the noise generated from the current source, which worsens the phase noise. Half of the noise around fundamental frequency and second harmonic signal will be translated to the oscillation tank.

The flick noise affects the phase noise performance near the frequency. And current source always causes the most part of it. It needs to be evaluated by simulation to understand the mechanism.

2.2 Design of tuning range

MOS transistor are used as a varactor in LC-VCO tank to provide a continuous capacity shift, so that the VCO’s frequency can be changing as the communication system required. But a single MOSFET with a limit capacity shift can’t cover the required frequency band. One practical solution is to divided the active circuit into capacitor array for the coarse-tuning and to adjust the varacotrs for fine-tuning. In this paper, varactor part includes four varactors and 4 assistant capacitors, and several control voltage. The tuning of capacity is achieved by changing the voltage between source and drain. The node voltage of varactors, which are Vcp and Vcn, determines the fine-tuning frequency. In order to steady the oscillation, fix voltage is applied to the node between the varactor $V_i$ ($i=1,2,3,4$) and assistant capacitor $C_i$ ($i=1,2,3,4$). The frequency range is not linear due to the varactor’s capacity changing ratio, causing smaller but steep tuning change. The oscillation frequency varies a lot eve if the control voltage changes only a bit. To avoid this, we design the value of 4 assistant capacitors close to the varactor. While the tuning range is maintained, it can slow the ratio of capacitor change to steady the oscillation. The control voltage is given by the supply source off the chip. To avoid the impact from source noise, Low-pass filters are added between the varactor part and the control voltage.

![Schematic of varactors](image)

3. Measured results

Figure 3 illustrates the frequency tuning range being measured of the designed circuit. The x-axis represents the differential control-voltage applied to the varactor, $V_{cp}$—$V_{cn}$. The tuning range of the oscillator can cover from 26.3 to 28 GHz by the capacitor array. As shown in the Fig.3, the ratio of the capacity change of varactor is more flat than the structure without assistant capacitor.
Figure 3. Measured frequency tuning characteristic
The output of fundamental signal is maintained between -17 dBm ~ -20 dBm. The push-push signal output is between -37 dBm ~ -40 dBm, shown in Fig. 4.

Figure 4. Outout of push-push signal
The phase noise at 30GHz carrier is shown in Fig 5.
4. Conclusion
A dual-band push-push LC-VCO fabricated in a standard TSMC 90nm CMOS process, using capacitor array technique topology for wideband and low phase noise. The fundamental signal can tuned from 26.38 GHz to 28.15 GHz with phase noise of —108.57 dBC/Hz at 10MHz and the second harmonic signal tuned from 52.76 GHz to 56.30 GHz with —98.43 dBC/Hz at 10MHz.

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