A Low-Power 2/5.8-GHz CMOS LC-VCO for Multi-band Wireless Communication Applications

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Abstract—A fully integrated dual-band LC voltage control oscillator designed in a 0.18-um CMOS technology for 5.8-GHz/2.0-GHz wireless communication applications is described. The frequency band switching is accomplished with switched-inductor technique. The dual-band oscillator can be operated in 5.38~6.23 GHz and 1.78~2.07 GHz with 15% frequency tuning range. Two different inductors are used for the frequency band switching. Frequency tuning is implemented by varying the capacitance of a MOS varactor. The measured phase noise is –109 dBc/Hz @1 MHz and -112 dBc/Hz @1 MHz for frequency at 5.8 GHz and 2 GHz, respectively. This oscillator is fabricated in UMC’s 0.18-um one-poly-six-metal 1.8 V process. The power dissipation of this dual-band VCO is 11.7 and 9.3 mW for oscillation frequency of 2 GHz and 5.8 GHz, respectively.

I. INTRODUCTION

Voltage Control Oscillator (VCO) [1] is widely used in communication system such as the local oscillator in a communication transmitter, and phase locked loop (PLL). A fully integrated and high frequency VCO is important for designing a radio frequency PLL and frequency synthesizer. Moreover, low voltage consumption is also an important consideration for developing portable RF products. Designing a fully integrated RF VCO is a big challenge. Several important issues must be considered. (1) Phase stability to reduce the phase noise. The ideal output signal spectrum of voltage control oscillator is as like an ideal impulse. (2) The tune range is designed as wider as possible to cover all application ranges. (3) The ideal VCO has a constant gain for optimum linearity. Other performance characteristics include operating frequency stability due to the temperature influence, the power consumption and the processor cost. These issues are importation considerations in VCO design. The LC tank oscillator [2][3] was chosen and implemented in the logic processor to provide lower power consumption, and high operating frequency.

There are increasing demands for circuits which can handle multiple frequency bands. In response to this, multi-band LC-VCOs have been reported [4][5]. However, to develop a multi-band VCO with easy and fast band switching capability is still a difficult and challenged problem. Basically, there are two major means to implement the multi-band VCOs. One is a switched-capacitor method. It is more frequently used in lower frequency than GHz-regime [6]. It use a capacitor with a series connected switch, which controls the capacitance of a LC tank. With this arrangement, the frequency tuning ability of the lower frequency band is greatly suppressed since frequency tuning is by a varactor. The parasitic resistance of the switch degrades the quality factor of the LC tank. While parasitic resistance decrease with larger switch, the parasitic capacitance of the switch also increases to reduce frequency switching range. The other is a regenerative multiplication method [7], in which a frequency multiplier (increasing frequency) or a divider (reducing frequency) is used obtain another frequency band. This method greatly increases the complexity and power consumption of VCO.

In this paper, a low-power and simple dual-wide-band VCO is designed. The dual-band operation is realized by using a combination of two inductors. As shown in Fig. 1, different inductors L1 and L2 form the switched inductors/variable LC-tank. The inductance can be reduced when the switch Ms is on. The switched inductors coarsely tune VCO to two operation bands: 2 and 5.8 GHz. Fine frequency tuning is implemented by varying the control voltage of a varactor. As compared with switched capacitor method which is bothered by parasitic capacitance and difficult frequency tuning control the switched inductance technique can achieve a more accurate oscillation frequency and easy frequency tuning control.

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II. CIRCUIT DESIGN

The quality value is infinity in an ideal LC tank oscillator circuit. However, the quality value is poor in an integrated circuit due to the poor quality of the integrated inductor. Here, we used a negative differential conductance circuit to compensate for the circuit quality and guarantee a stable resonance signal from the oscillator. The circuit shown in Fig. 1 consists of two stages. The first stage circuit, the NMOS M1 and M2, which is a cross-coupled pair forming a positive feedback loop that generates negative resistance. The second stage circuit is an output buffer circuit that includes Mb1, Mb2, and two inductors. This buffer stage can avoid the influence of other circuits in the system.

Changing the tuning voltage Vc to control the resonance frequency and obtain the fine tuning range. In this VCO design, inductors L1 and L2 have different inductance. When Va is 0 V, Lt is equal to L2. The oscillation frequency is in 2-GHz band. While we can switch the oscillation frequency to 5.8-GHz frequency band when Va is 1.5 V. The Lt is equal to L1 // L2 when transistor Ms is turned on. In each of the two frequency bands, the fine tune can be done by tuning the MIS varactors.

A. Frequency Tuning and Design Considerations

The actual frequency of oscillation fo is determined by

$$f_o = \frac{1}{2\pi \sqrt{L(C+\Delta C)}}$$

(1)

where delta C is the change in capacitance due to the varactor, L is the inductance. Hence, high Cv,max / Cv,min and Cv/Cparasitic ratio can reach a wider frequency tuning range [8]. Since

$$\text{Frequency Tuning} = \frac{Cv,max + C_{parasitic}}{Cv,min + C_{parasitic}}$$

(2)

where Cv is the capacitance of varactor and Cparasitic is the parasitic capacitance. This parasitic capacitance mainly comes from the gate capacitors of Mb1 and Mb2 and drain parasitic capacitors of M1-M4. To increase the frequency tuning range we need to increase the Cv/Cparasitic ratio. The parasitic capacitance can be reduced by properly choosing Mb1 and Mb2 sizes. A short channel length will lead to a lower equivalent series resistance and good quality factor. However, the value Cv,max / Cv,min will decrease with the channel length. For shorter channel length the weighting of overlap capacitance will increase. The devices parasitical characteristic degenerate the effective varactor tuning ability.

In general, we desire to have a large on-chip inductor for the resonator. Large on-chip inductor has better Q value and phase-noise performance. Due to CMOS process the on-chip inductor is not tunable. Large inductor will need a small Cv to reach the high oscillation frequency. However, this small Cv will reduce the frequency tuning range. This effect imposes a design tradeoff between frequency tuning and phase noise. Several considerations are employed to design the VCO: 1) for low-power low-phase noise VCO optimization, the inductance value needs to be increased and, therefore, the varactors must be scaled down [8][9]. 2) large Cv/Cparasitic and Cv,max/Cv,min ratios must be considered for getting better frequency tuning. 3) process variations in the capacitor and in the inductors must be compensated to obtain the desired oscillation frequency.

III. SIMULATION RESULTS

The VCO circuit is designed and fabricated in UMC’s 0.18-μm CMOS process. The process offers six metal layers for interconnect, and various kinds of RF inductors and varactors. The physical dimensions of the dual-band VCO chip is 1.2 × 1 mm² including pads. The VCO die photo is shown in Fig. 2. The VCO performance is measured on wafer by using the Agilent E4407B spectrum analyzer.
Figure 3. Oscillation frequency transition from 2 GHz to 5.4 GHz.

A. Output waveform
We show the simulated output waveform in Fig. 3. In this figure we can see the transition of oscillation frequency from 2-GHz to 5.4-GHz when the transition enable voltage is enabled. The frequency switch between these two bands is quite quick and smooth. The peak-to-peak voltages are 0.91 V and 0.73 V for oscillation frequency at 2 GHz and 5.4 GHz, respectively. Fig. 4 (a) (b) shows the measured VCO output frequency spectrum at 1.8 GHz and 5.4 GHz. The corresponding output power is about -17 and -34 dBm, respectively.

B. Tuning range
The simulated and measured frequency tuning range for 2-GHz and 5.8-GHz bands are shown in Fig. 5 and 6, respectively. The measured resonance frequency output can be adjusted from 1.78 GHz to 2.08 GHz and from 5.38 MHz to 6.23 MHz. The tuning ranges for both bands are 300 MHz and 850 MHz, respectively. It reaches a 15% frequency tuning range for both frequency bands. The simulated VCO oscillation frequency and frequency tuning range in lower frequency band agree well with measurement results. While there is about 3% discrepancy between simulation and measurement results in 5.8-GHz frequency band. This discrepancy mainly comes from the over estimated inductance. The practical inductance is lower than the theoretical inductance value.

C. Phase noise
The phase noise is one of the most important performance characteristics in the oscillator. It will influence the jitter from the output waveform in the time domain. From the simulation results, the phase noise is -115 dBc/Hz @1 MHz and -109 dBc/Hz @1 MHz at 2 GHz and 5.8 GHz, respectively. While the measured phase noise is -112 dBc/Hz @1 MHz and -109 dBc/Hz @1 MHz at 2 GHz and 5.8 GHz, respectively. The VCO characteristics comparison between simulation and measurement results are listed in Table I.
Figure 6. Simulated and measured frequency tuning range at 5.8-GHz frequency band.

TABLE I. MAJOR CHARACTERISTICS OF DUAL-BAND VCO

<table>
<thead>
<tr>
<th>VCO</th>
<th>2-GHz Band</th>
<th>5.8-GHz Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>1.5V</td>
<td></td>
</tr>
<tr>
<td>Simulated Phase Noise @ 1 MHz offset</td>
<td>-115 dBc / Hz</td>
<td>-113 dBc / Hz</td>
</tr>
<tr>
<td>Measured Phase Noise @ 1 MHz offset</td>
<td>-112 dBc / Hz</td>
<td>-109 dBc / Hz</td>
</tr>
<tr>
<td>Simulated Tuning Range</td>
<td>1.73 - 2.06 GHz</td>
<td>5.13 - 6.05 GHz</td>
</tr>
<tr>
<td>Measured Tuning Range</td>
<td>1.78 - 2.08 GHz</td>
<td>5.38 - 6.23 GHz</td>
</tr>
<tr>
<td>Measured Power Dissipation</td>
<td>11.7 mW</td>
<td>9.3 mW</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

This paper presented a 1.5 V, dual-band 2.6/5.2 GHz CMOS RF VCO design. It utilizes the inductor-switched technique for changing the oscillation frequency band. This method provides wide frequency change with simple voltage control. The power consumption is 9.14 mW for VCO operated in 5.8-GHz band. It will increase to 10.14 mW for VCO switched to 2-GHz. The dual-band VCO shows phase noises performances of -109 and -112 dBc/Hz at 1-MHz offset frequency for 5.8 and 2 GHz, respectively. The VCO can have a wide 15% frequency tuning range in both frequency bands. Table II summarizes the performance of the VCO and compares it with recently published VCOs.

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REFERENCES