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A 1.2V operation 5 GHz CMOS VCO with series varactor bank

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Abstract. This paper presents the design of a voltage controlled oscillator (VCO) with small VCO gain (K_{vco}) variation. To compensate large K_{vco} variation, a series varactor bank has been added to the conventional LC-tank with parallel capacitor bank array. Implemented in a 0.13□m CMOS RF technology, the proposed VCO can be tuned from 4.6GH to 5.5GHz with the K_{vco} variation of less than 9.6%. While consuming 3.1mA from a 1.2V supply, the VCO has -120dBc/Hz phase noise at 1MHz offset from the carrier.

Keywords: CMOS (Complementary Metal Oxide Semiconductor), VCO (Voltage controlled oscillator), AMOS(Accumulation MOS) varactor, Series varactor bank

1 Introduction

Among The VCO gain (K_{vco}) of conventional structure is variable across the entire tuning range, which increases the phase noise but is useful for widening the tuning range of the VCOs, and this essentially nonlinear characteristic will deteriorate the phase noise performance of VCO and phase locked loop[1,2]. To cover such a wideband frequency range, switching capacitor array is usually used in LC voltage-controlled-oscillator (VCO) to extend the tuning range with low VCO tuning gain (K_{vco}), which avoids degrading the phase noise performance. For low phase noise, it is desirable to have as small a K_{vco} as possible, but small K_{vco} means narrow frequency locking range. To extend the frequency locking range with small K_{vco}, the LC-tank VCO may employ a switchable capacitor bank [3–6]. The oscillation frequency of the LC-tank VCO is given as

$$f_{osc} = \frac{1}{2\pi\sqrt{L(C_v + C_{Cap.bank})}} \qquad (1)$$

Where C_v and $C_{Cap.bank}$ are the capacitance of the varactor and switchable capacitor bank, respectively. The oscillation frequency f_{osc} coarsely controlled by $C_{Cap.bank}$ and finely tuned by C_v whose value is determined by V_{tune}. The VCO gain, K_{vco}, can be derived as given by Eq. (2)

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$$K_{VCO} = \frac{\partial f_{osc}}{\partial V_{tune}} = -\frac{1}{4\pi\sqrt{L}(C_v + C_{Cap.bank})^{1.5}} \cdot \frac{\partial C_v}{\partial V_{tune}} \quad (2)$$

This paper proposes a series-varactor, parallel capacitor bank structure which minimizes the VCO gain variation. Section 2 describes AMOS varactor and the proposed VCO circuit. Results of the VCO implemented in a 0.13 m CMOS technology are given in Section 3.
The conclusion follows in Section 4.

2 Voltage-Controlled Oscillator with Small VCO Gain Variation

The oscillation frequency of the proposed VCO shown in Figure 1 is given as

$$f_{osc} = \frac{1}{2\pi\sqrt{L(C_v \| C_{ser.Var} + C_{par.Cap})}} \quad (3)$$

and the VCO gain K_{vco} is Eq. (4), shown below, where α = $C_{ser.Var}/C_{par.Cap}$. We can find the design parameters such as α and $C_{ser.Var}$ (Series varactor bank) which minimize the variation of K_{vco}. To obtain right above parameters, $C_{par.Cap(}$(Parallel capacitor bank)$_{)}$, V_{tune} are actually fixed in this simulation.

$$K_{VCO} = -\frac{(C_{ser.Var}/C_{par.Cap})^2 \cdot C_{ser.Var}}{4\pi\sqrt{L(C_v + (C_{ser.Var}/C_{par.Cap}) \cdot C_{ser.Var})}\left\{C_v(1 + C_{ser.Var}/C_{par.Cap}) + C_{ser.Var}\right\}^{1.5}} \cdot \frac{\partial C_v}{\partial V_{tune}} \quad (4)$$

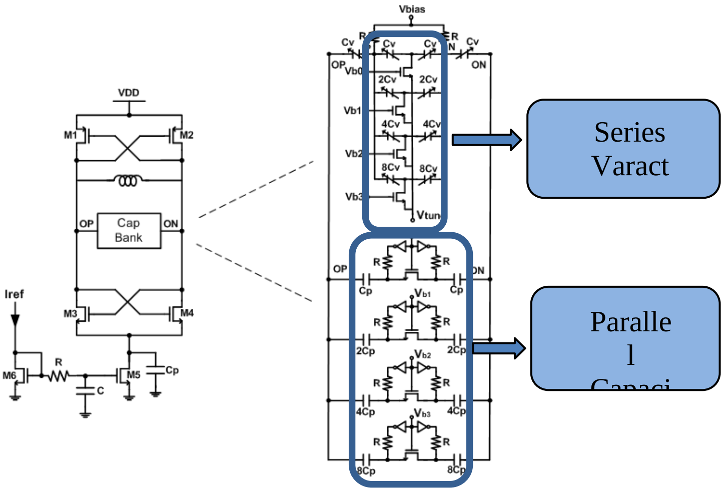

Fig. 1. Proposed LC-tank VCO with Series Varactor bank

3 Measurement Results

The wide band VCO with small K_{vco} variation has been implemented in a 0.13□m 1-poly, 6-metal CMOS RF technology. Fig. 2 shows the microphotograph of the fabricated chip.

As shown been in Fig. 2, microphotograph of the proposed VCO occupies less than 0.24mm^2. The output frequency of the proposed VCO can be tuned from 4.6 GHz 5.5 GHz as shown in Fig. 3. The VCO gain, K_{vco}, and phase noise of the proposed VCO are measured as a function of the control code of the switchable capacitor bank while the analog varactor control voltage V_{tune} is fixed at 0.6 V and the result is shown Figure 4. The variation of VCO gain is less than 9.6% while the previously reported LC-tank VCOs show larger than 25.3% variation in the VCO gain as summarized in Table I [7–10]. The VCO consumes 3.1 mA from a 1.2 V supply voltage. To compare the performance of the proposed VCO with that of some prior works, the well known figure-of-merit (FoM) of the VCO defined as Eq. (5) is used.

$$FoM = 10\log\left(\left(\frac{\omega_0}{\Delta\omega}\right)^2 \cdot \frac{1}{L\{\Delta\omega\}P}\right) \qquad (5)$$

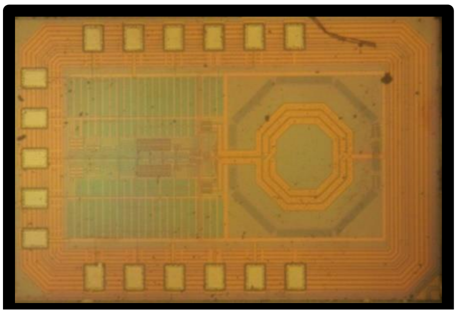

Fig. 2. Chip Microphotograph of Proposed VCO

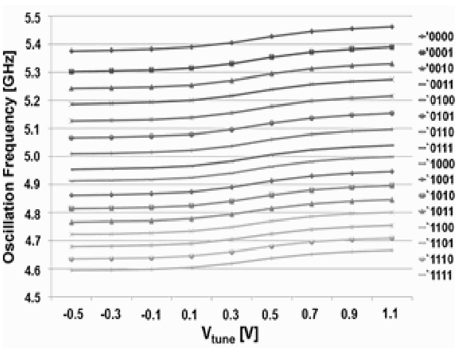

Fig. 3. Frequency tuning range of the Proposed LC-tank VCO with Series Varactor bank

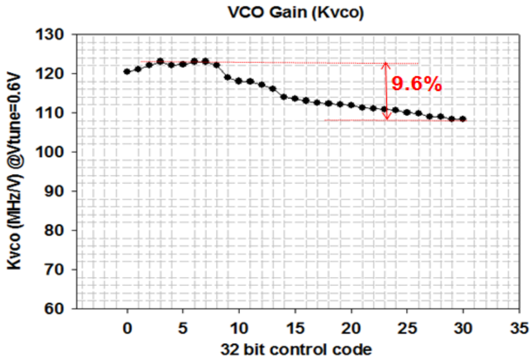

Fig. 4. VCO gain as a function of Varactor and Cap bank

Table 1. Comparison of the Performance of Other VCOs

Ref.	fosc [GHz]	ΔKVCO [%]	Tuning Range [%]	Phase Noise [dBc/Hz]	Power [mW]	FoM [dBc]	Tech [μm]
[7]	6.0	57.5	5.1	-115.2@1M	12.5	179.8	0.13
[8]	1.7	69.5	63.1	-128.0@1M	14.0	179.2	0.18
[9]	1.8	27.2	66.7	-130.0@1M	41.4	175.7	0.18
[10]	2	25.3	52	-124.0@1M	18	176	0.18
This Work	**5.5**	**9.6**	**18.5**	**-120@1M**	**3.72**	**180**	**0.13**

4 Conclusion

For small variation of VCO gain, series varactor banks and parallel capacitor banks are used together in a wide band LC-tank voltage controlled oscillator (VCO). Implemented in a 0.13 μm CMOS RF technology, the proposed VCO shows less than 9.6% variation in the VCO gain while the frequency tuning range is from 4.6 GHz to 5.5 GHz. The VCO consumes 3.1mA from a 1.2V supply and the phase noise is 120dBc/Hz at 1 MHz offset from the carrier.

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