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A 3.8-GHz highly linear *LC*-VCO without a varactor device

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Abstract: A *LC*-VCO topology without a varactor device has been proposed. The oscillator includes a variable capacitance block for a frequency tuning. The block consists of two transistors and two capacitors. The *LC*-VCO has been fabricated in a 130-nm CMOS technology. The measured results show operation frequencies of 3.73 GHz to 3.94 GHz and a phase noise of −119.1 dBc/Hz at 1-MHz offset frequency. Power consumption is 5.9 mA from a 1.2 V supply.
Keywords: LC tank, oscillator, varactorless, VCO, VCO sensitivity
Classification: Integrated circuits

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1 Introduction

The VCO is one of the essential RF front-end building blocks in wireless/wired communication systems. The VCO performance often determines whether the system will meet the specifications or not. The phase noise and frequency tuning characteristics are important among the VCO parameters. Many papers discussed mainly about a low phase noise [1, 2, 3, 4, 5],

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but a linear tuning scheme is reported in only few papers. In addition, most of the VCOs have a nonlinear frequency tuning by using a varactor [1, 2, 3, 4], which degrades the settling behavior of a PLL. For this reason, it is desirable to have a linear tuning characteristic. In this paper, a novel VCO topology is proposed in order to realize a linear frequency tuning without a varactor device.

2 Circuit design

Figure 1 shows the schematic of the proposed *LC*-VCO which consists of a *LC* tank and a cross-coupled NMOS G_m–stage. The *LC* tank has a high *Q*-factor inductor and an MIM (metal-insulator-metal) capacitor. The G_m-stage synthesizes a negative resistance to compensate the loss of the *LC* tank. A differential cross-coupled NMOS topology has been preferred because it ensures lower parasitic capacitances and allows low-voltage operation. Additionally, a tail current source cannot be used for low-voltage and low noise performance.

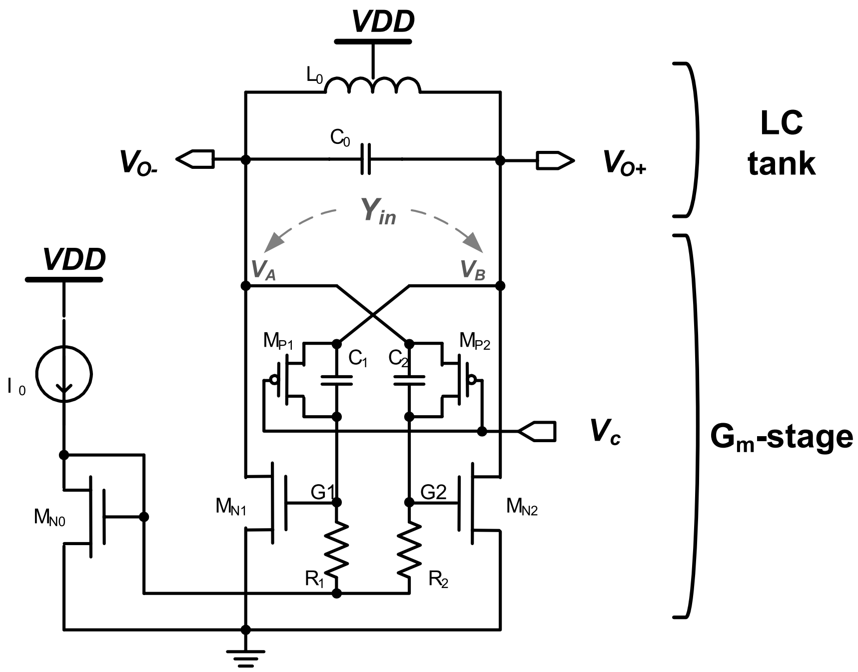

Fig. 1. LC-VCO circuit without a varactor device

As mentioned earlier, a varactor is used for tuning the frequency of the VCO. The use of a varactor, however, has disadvantages such as low *Q*-factor, nonlinear characteristic, and narrow tuning range. To mitigate these difficulties, a variable capacitance block should be inserted in the G_m-stage as alternative of the varactor device, as shown in Fig. 1. The variable capacitance block consists of the p-type transistors $M_{P1,P2}$ and capacitors $C_{1,2}$. The operation mode of the transistors $M_{P1,P2}$ changes according to the control voltage V_c and the capacitance characteristic is also varied. As V_c is increased, the transistors $M_{P1,P2}$ operate in the triode, saturation, and cutoff region. More specifically, the control voltage range can be divided into three regions. First, when $0\,\mathrm{V} \leq V_c < 0.48\,\mathrm{V}$, the transistors $M_{P1,P2}$ operate in triode region. Therefore, the transistors are like a resistor of which value is well-known as $R_P = [\mu_p C_{ox}(W/L)(V_{GS}\text{-}V_{TH})]^{-1}$ [6]. The equivalent small-

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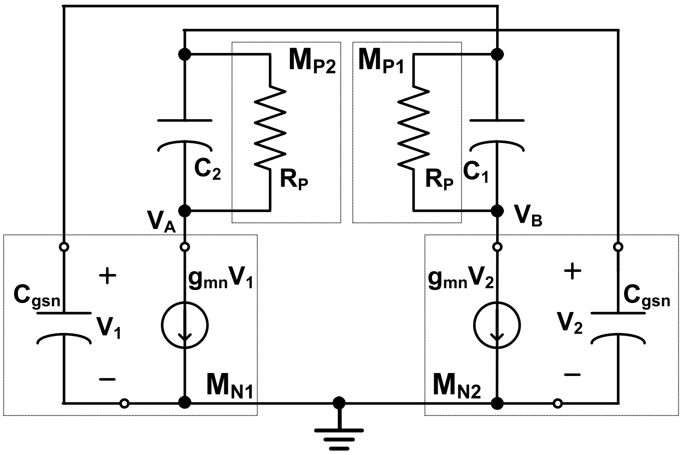
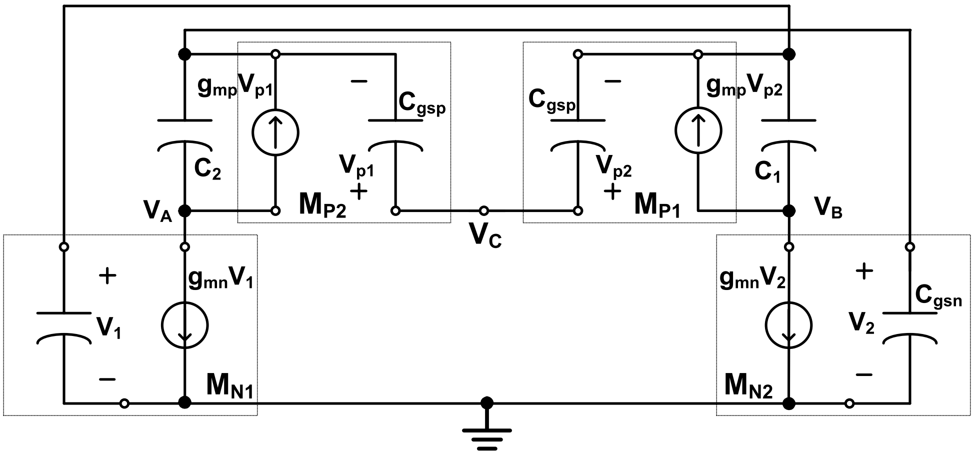


(a)



(b)

Fig. 2. Small-signal equivalent circuit for the G_m-stage; (a) when $M_{P1,P2}$ are in a triode region, and (b) when $M_{P1,P2}$ are in a saturation region

signal circuit for the G_m–stage in triode region is shown in Fig. 2(a), where g_{mn} and C_{gsn} are the transconductance and the gate-source capacitance of $M_{N1,N2}$, respectively. Second, when $0.48\,V < V_c \leq 0.88\,V$, the $M_{P1,P2}$ operate in saturation region. The equivalent circuit for the G_m–stage in saturation region is given in Fig. 2(b), where g_{mp} and C_{gsp} are the transconductance and the gate-source capacitance of $M_{P1,\ P2}$, respectively. Third, when $0.88\,V <$ $V_c \leq 1.2\,V$, the transistors $M_{P1,P2}$ turn off and enter the cutoff region. In this case, the resistive component R_P in Fig. 2(a) is large enough to ignore. Therefore, the capacitor C_1 and C_{gsn} may be series-connected.

To confirm the above analysis, the capacitances were extracted by the Agilent ADS simulation. Figure 3 shows the capacitance (C_{gsp}, C_{gsn}, C_1, and C_{gm}) curves with respect to the control voltage, where C_{gm} means the imaginary part of the admittance Y_{in} in Fig. 1. Ideally, the C_{gm} should be proportional to $-C_f^{3/2}$ to have linear characteristics, where C_f means a constant capacitance. However, C_{gm} is monotonically decreased, as shown in Fig. 3. Because VCO operates with a large signal in real situation, C_{gm} tendency can be confirmed by the small-signal and the size of p-type transistors should be finally optimized for the linearity. In our work, the capacitance C_0 in LC-bank is as large as 317 fF. If the ratio of C_{gm}/C_0 is

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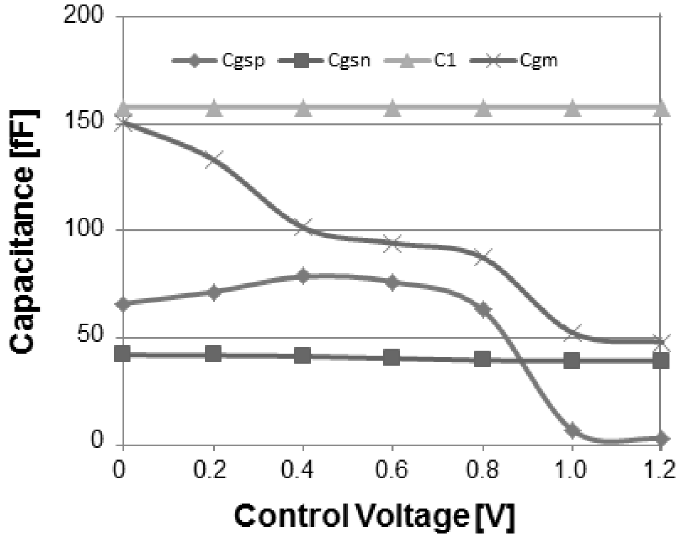

Fig. 3. Simulated capacitance characteristics for the VCO circuit

increased, the VCO may have the more wide frequency range.

3 Measurement results

To verify the performance of the VCO, the proposed VCO was fabricated in 130-nm CMOS technology. Figure 4 shows the die photograph of the prototype that occupies an active area of 0.162 mm^2. The VCO drew 5.9 mA current from a 1.2 V supply voltage including a VCO output buffer. The frequency curve and tuning sensitivity of the VCO are given in Fig. 5(a) and 5(b). The measured results show a tuning range of 210 MHz, from 3.73 GHz to 3.94 GHz. The VCO sensitivity changes from 150 MHz/V to 210 MHz/V, which is fairly constant on the whole tuning range. The ratio of the maximum sensitivity to the minimum one in the proposed VCO is 1.4. The measured phase noise at an offset frequency of 1-MHz is –119.1 dBc/Hz and below –115.1 dBc/Hz on the whole control range.

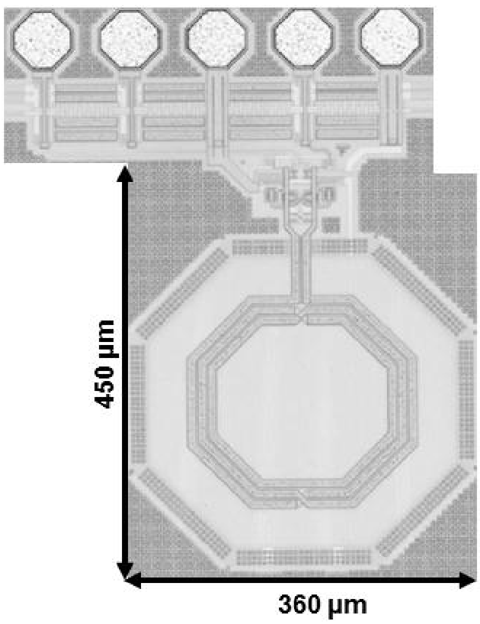

Fig. 4. Chip photograph

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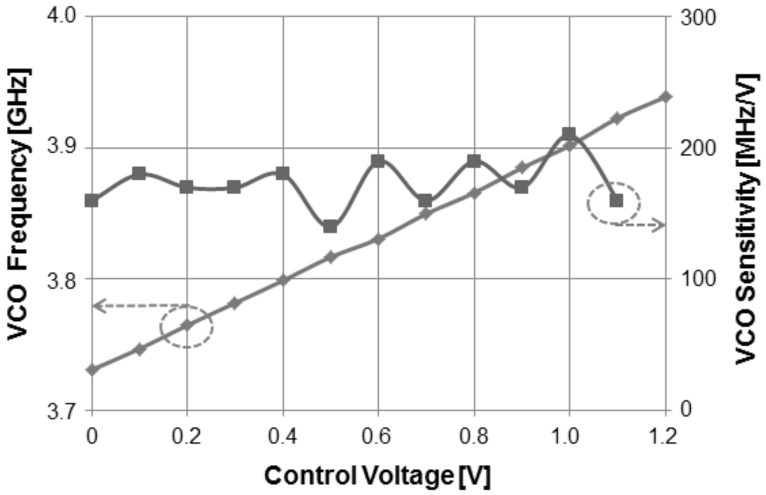
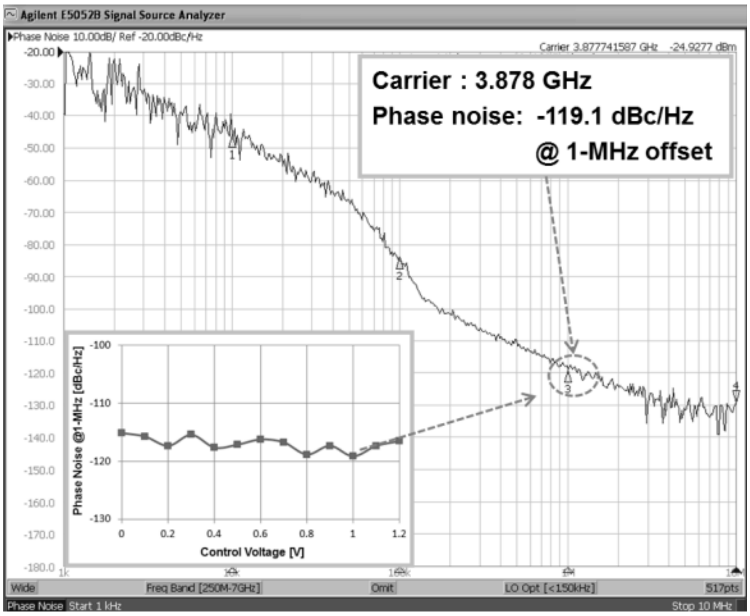


(a)



(b)

Fig. 5. Measured characteristics; (a) VCO frequency and VCO sensitivity, (b) phase noise curve @ 1-MHz offset

To show comparative performance, a FOM [4] extracted in the measured results is −182.4 dBc/Hz (at a 3.878 GHz carrier). These measured results demonstrate the validity for the proposed varactor-less VCO

Table I. Summary of measured VCO performances

Parameter	Measurement results
Technology	130-nm 1P8M CMOS
Supply voltage	1.2 V
Control voltage range	0 V ~ 1.2 V
Oscillation frequency range	3.73 GHz ~ 3.94 GHz
VCO gain	150 MHz/V ~ 210 MHz/V
Phase noise @1-MHz offset	-119.1 dBc/Hz ~ -115.1 dBc/Hz
Power consumption including output buffer	7.1 mW
Active chip area	360 μm × 450 μm

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topology. The measured VCO performance is summarized in Table I.

4 Conclusion

An *LC*-VCO with a novel frequency tuning technique has been presented. The *LC*-VCO adapts a negative-impedance transconductance stage that simultaneously realizes a negative resistance, a current biasing and a frequency tuning. This tuning scheme eliminates the use of a varactor device. The variable capacitance is achieved by the combination of two transistors and two capacitors. The VCO exhibits a highly linear frequency tuning range from 3.73 GHz to 3.94 GHz with the small VCO sensitivity variation.

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