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# A Class-C Type Wideband Current-Reused VCO With Two-Step Automatic Amplitude Calibration Loop

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***Abstract*—This paper presents a wideband Current-Reused Voltage Controlled Oscillator (VCO) with 2-Step Automatic Amplitude Calibration (AAC). Tuning range of the proposed VCO is from 1.95 GHz to 3.15 GHz. The mismatch of differential voltage is within 0.6 %. At 2.423 GHz, the phase noise is -116.3 dBc/Hz at the 1 MHz offset frequency with the current consumption of 2.6 mA. The VCO is implemented 0.13 μm CMOS technology. The layout size is 720 × 580 μm$^2$.**

***Index Terms*—Current-reused VCO, Class-C type, AAC (Auto Amplitude Calibration)**

## I. INTRODUCTION

Voltage Controlled Oscillator (VCO) is the most important block for implementing wireless transceiver. Many VCOs constructed with the CMOS technology have been developed to achieve the characteristics of low power consumption, low phase noise, and high operation frequency [1]. Specially, low power designs for VCOs have drawn intensive researches recently. Several circuit techniques for reducing the current consumption of the VCO are reported including the current-reused technique. The current-reused VCO has a single current path from the supply voltage to ground during the one clock period [2]. Fig. 1(a) shows the operation of the current-reused VCO during the 1$^{st}$ half period. The current path from the supply voltage to ground is formed by the transistors, $M_1$ and $M_2$, depending on the differential outputs of the VCO. During the 2$^{nd}$ half period, the current path will be disabled and the current will flow through only the inductance and capacitance.

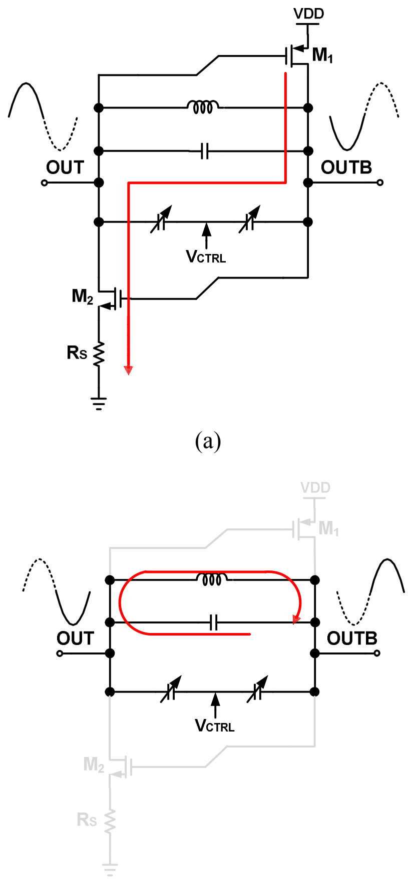


**Fig. 1.** Operation of current-reused VCO during (a) 1$^{st}$ half period, (b) 2$^{nd}$ half period

However, there is mismatch between the amplitudes of

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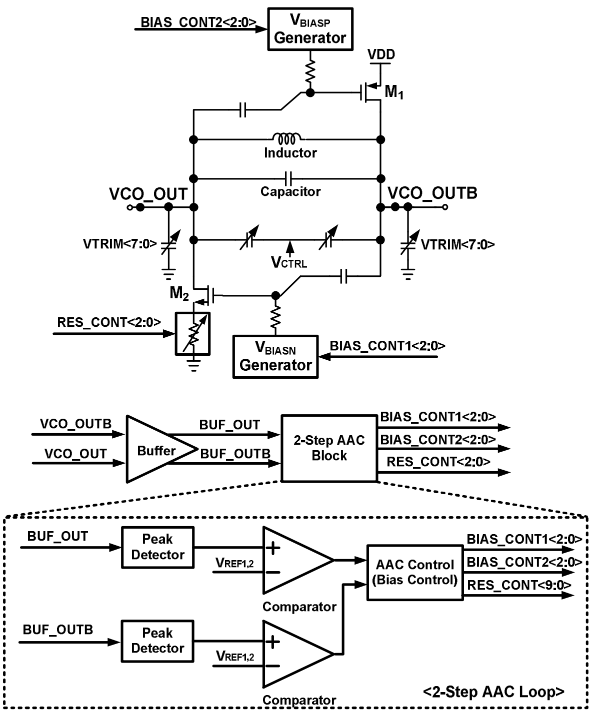


**Fig. 2.** Proposed current-reused VCO with 2-step AAC loop

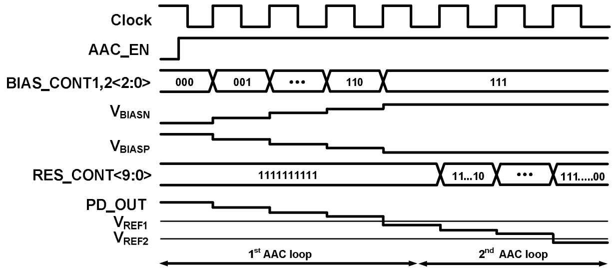


**Fig. 3.** Timing diagram of 2-step automatic amplitude calibration Loop

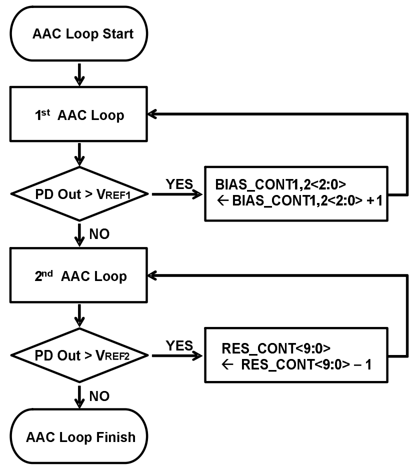


**Fig. 4.** Flow chart of 2-step automatic amplitude calibration Loop

differential outputs due to the asymmetric structure and operation. The overall system performance can be degraded due to the noise and distortion of the differential outputs. In this paper, the class-C type VCO [2] with 2-step automatic amplitude calibration (AAC) is proposed to compensate for the structural unbalance in addition to the unbalances due to the process variations.

## II. PROPOSED CURRENT-REUSED VCO

The most important issue of Current-reused VCO is voltage imbalance at outputs. Because the unbalanced outputs of the VCO will result in the imbalance of In-Phase and Quadrature-Phase Local Oscillator (LO) signals degrading the Error Vector Magnitude (EVM) performance of the receiver. To solve this problem, researchers have been studied how to reduce the voltage mismatch. The methods are forcing proper negative-Gm bias voltage for maximizing voltage swing or inserting the resistor at the source of NMOS to minimize voltage mismatch [4]. We propose 2-step AAC method to reduce the voltage mismatch and dynamic current. Fig. 2 shows proposed current-reused VCO with 2-Step AAC Loop. As shown in Fig. 2, the 2-step AAC loop consists of peak detector, comparator and Control logic. First, at 1st AAC loop, the peak detector senses the peak level of voltage outputs.

Fig. 3 and 4 show timing diagram and flow chart of 2-step AAC loop, respectively. After output of peak detector is compared with reference voltage ($V_{REF1}$) which is generated by a bias block. If the output level of peak detector is bigger than the reference voltage, the gate bias voltage control bits, BIAS_CONT1<2:0> and BIAS_CONT2<1:0>, are adjusted from “000” to “111 until the outputs of the Peak Detectors are less than the reference levels, $V_{REF1}$ and $V_{REF2}$, respectively. Result from this process, VBIASN or VBIASP which is negative-gm bias voltage can be changed as shown in Fig. 3. When the output of peak detector is smaller than the reference voltage, 1st AAC loop end and 2nd AAC loop start. Overall operation of 2nd AAC loop is similar with 1st AAC loop. At the 2nd AAC loop, RES_CONT<9:0> controls the resistor value instead of negative-gm bias voltage in 1st AAC loop. In the second stage, firstly the peak detector output is compared with the reference voltage ($V_{REF2}$) in the comparator. Depending on

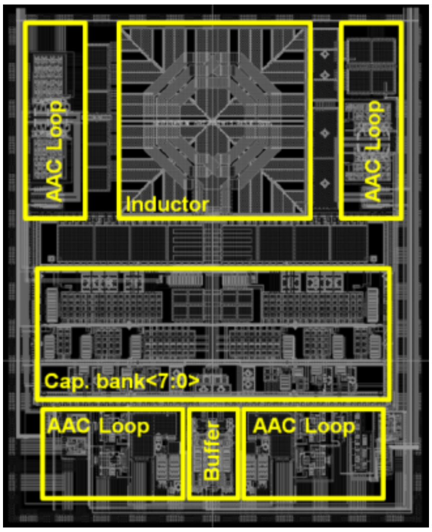


**Fig. 5.** The layout of proposed VCO

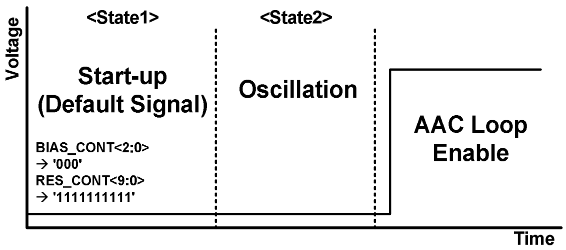


**Fig. 6.** Operation sequence of the proposed current-reused VCO

comparator output RES_CONT<9:0> is determined. This operation continues until the output of peak detector is lower than $V_{REF2}$. Through this process, resistor control bits (RES_CONT<9:0>) are changed by control logic block. According to resistor, dynamic current of VCO is controlled and the mismatch of differential outputs can be reduced.

## III. Experimental Results

Fig. 5 is the layout of proposed VCO. The size is 720 x 580 $\mu m^2$. Fig. 6 shows the operation sequence of the proposed current-reused VCO. After starting the oscillation (State2) of the VCO by a Start-up signal, (State 1), the two-step AAC calibration loop is enabled.

Fig. 7 shows the simulation results about two-step AAC loop. When the peak detector out is higher than comparator bias voltage, so BIAS_CONT1,2 <2:0> is changed from LSB. Therefore negative-Gm bias voltages (VBIASN, VBIASP) are moved separately. Because the

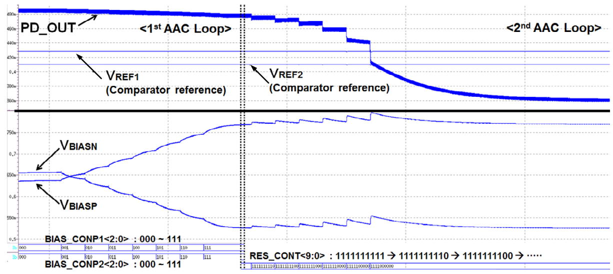


**Fig. 7.** Two-step AAC loop simulation results

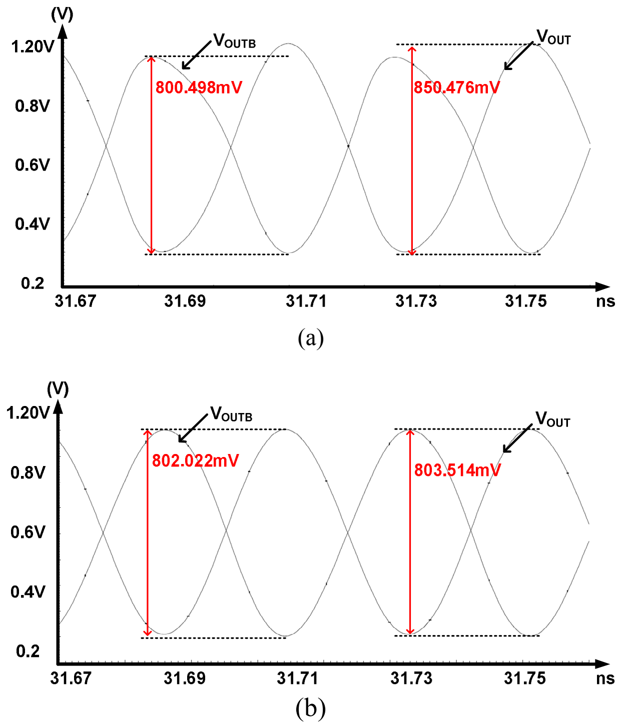


**Fig. 8.** Transient simulation result of VCO (a) without calibration loop, (b) with 2-step AAC loop

output of peak detector output is still lager than $V_{REF1}$, the 2nd AAC loop starts to operate. Similar to 1st AAC loop, at 2nd AAC loop, RES_CONT<9:0> can control the VCO output swing by adjusting the entire dynamic current of VCO. The 2nd AAC loop operates until the output of the peak detector is smaller than $V_{REF2}$.

Fig. 8(a) and (b) show the transient simulation result of VCO without the calibration loop and with two-step AAC loop. As shown in Fig. 7(a), when the two-step AAC calibration loop is disabled, the difference between differential outputs is about 50 mV. Also, they show the distorted waveforms with the phase difference of about 5% (18°). As shown in Fig. 7(b), by operating the two-step AAC calibration loop, the difference between the

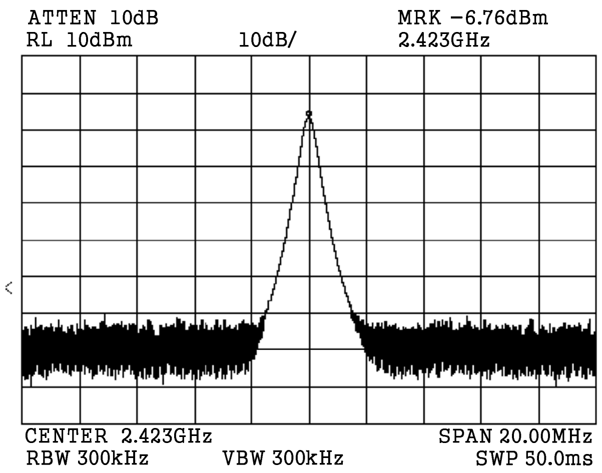


**Fig. 9.** The output spectrum of the proposed current-reused VCO

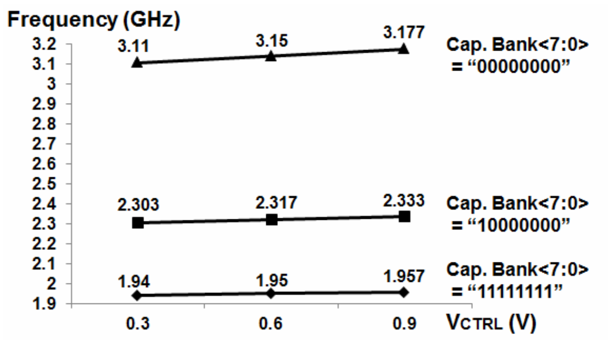


**Fig. 10.** The output frequency range of proposed current-reused VCO

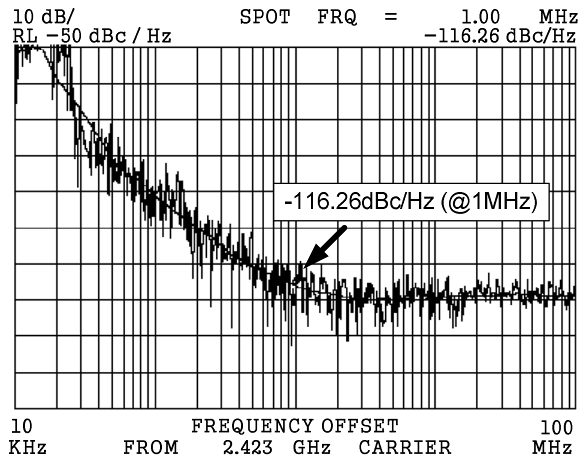


**Fig. 11.** Measured phase noise of proposed current-reused VCO

**Table 1.** Performance comparison with previous works

| | [1] | [4] | [5] | [6] | [7] | This Work |
|---|---|---|---|---|---|---|
| Technology (μm) | 0.18 | 0.18 | 0.18 | 0.18 | 0.13 | 0.13 |
| Frequency (GHz) | 16 | 3.5 | 2.26 | 1.96 | 0.83 | 2.5 |
| Supply Voltage (V) | 1.8 | 1.5 | 1.8 | 1.8 | 1.2 | 1.2 |
| Tuning Range (%) | 5.6 | 21 | 8.5 | 56 | 127 | 47 |
| Phase noise @ 1MHz (dBc/Hz) | -111 | -122 | -121.66 | -118.3 | -109 | -116.3 |
| Power (mW) | 8.1 | 2.475 | 1.62 | 14.4 | 13 | 3.12 |
| FoMT (dBc/Hz) | -186.8 | -195.7 | -187 | -190 | -186 | -192.3 |

differential outputs can be reduced to approximately 1.5 mV ~ 4.5 mV around the oscillation range.

Fig. 9 shows the measured spectrum of the proposed VCO. The output power is −6.76 dBm.

Fig. 10 shows the frequency ranges of the proposed current-reused VCO. In this paper, 8-bit Capacitor bank connected to the output s of VCO is designed to have a wide range from 1.9 GHz to 3.1 GHz.

Fig. 11 shows the measured phase noise for the proposed current-reused VCO at the oscillation frequency of 2.423 GHz. The measured values for the proposed VCOs are -116 dBc/Hz at 1 MHz offset when the current consumption is 2.6 mA. The noise floor is relatively high due to the noises from the measurement environments and test board. Table 1 represents the summary of the VCO performance compared with other papers. Overall frequency tuning range is from 1.95 GHz to 3.15 GHz and mismatch between VCO outputs is within 4.5 mV (< 0.6%). Table 1 summarizes the VCO performance and comparison with other published wideband VCOs. The figure of merit including tuning range (FOMT) in Eq. (1) is used to make fair comparison.

$$FoM_T = L(\Delta F) - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mW}\right) - 20\log\left(\frac{FTR}{10\%}\right) \quad (1)$$

## IV. CONCLUSIONS

The paper proposes the Class-C type Current-Reused VCO with Two-Step AAC Loop. The tuning range of the proposed VCO is from 1.95 GHz to 3.15 GHz. The mismatch of differential voltage is within 0.6 %. At 2.423 GHz, the phase noise is -116.3 dBc/Hz at the 1 MHz offset frequency with the current consumption of

2.6 mA. The VCO is implemented 0.13 μm CMOS technology. The layout size is 720 × 580 $\mu m^2$.


## ACKNOWLEDGMENTS

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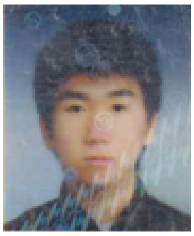

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