An Electronically Tunable Digitally Controlled Current Mode Quadrature Oscillator Using DC-VDTA

Ruchin Sharma, Dinesh Prasad, and Ravendra Singh

Abstract An electronically tunable digitally controlled current mode quadrature oscillator is designed employing one new digitally controlled voltage differencing transconductance amplifier (DC-VDTA), two grounded capacitors, and one grounded resistor. The condition of oscillation and frequency of oscillation can be adjusted independently and electronically. Also, the FO can also be controlled through an n-bit digital input. By introducing the digital control technique, the proposed oscillator can produce 2^n different oscillating frequencies without altering the circuit topology. The functioning of the proposed design is validated through Pspice simulation using 180 nm technologies.

Keywords Quadrature oscillator · VDTA · Digital control unit (DCU)

1 Introduction

The oscillator is a closed loop system with positive feedback which follows the Barkhausen criteria to get a sustained oscillation. If the oscillator circuit can generate two outputs with 90º phase difference, then it is known as a quadrature oscillator (QO). Oscillators are very important and integral part of the various communications and control systems [1, 2]. An enormous variety of quadrature oscillators using different active building blocks (ABB) were already reported in [3–29]. Oscillators reported in [3–10] are able to generate current-mode outputs while voltage mode outputs are obtained in [11–23]. Also, among these oscillators, none is able to generate both voltage mode (VM) and current mode (CM) signals at the same time. This issue is compensated in the circuits reported in [24–27]. In [28], a digitally programmable VMQO was firstly introduced. But, these oscillators have one or more than one of the following drawbacks

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A. Rani et al. (eds.), *Signals, Machines and Automation*, Lecture Notes in Electrical Engineering 1023, https://doi.org/10.1007/978-981-99-0969-8_48

(i) Require two or more ABBs [25–27];
(ii) Require four or more passive components [24, 26, 27];
(iii) Require floating passive components for realization [26];
(iv) Lack of electronic tuning [24, 26]
(v) Except [28] no other circuits can provide digital control feature.

So in this manuscript, an electronically tunable, digitally controlled CM QO is designed to overcome all the drawbacks mentioned above. The proposed QO topology requires one DC-VDTA with three grounded passive elements. As this circuit utilizes only passive elements, so the presented design is acceptable for IC realization. The functioning of DC-VDTA is explained in the next section.

2 DC-VDTA

The DC-VDTA is a modified version of VDTA [29] as shown in Fig. 1. The aspect ratio of all the transistors utilized in realization of DC-VDTA is defined in Table 1. In VDTA, the digital controllability is achieved by adding an n-bit DCU between first and second stage

$$I_x = \mathrm{K} g_{m2} V_Z \quad \text{where } K = \frac{\beta N}{2^n} \tag{1}$$

where K is the n-bit digital control input, n is number of control lines in DCU, and N is the digital control word.

The other port characteristics of DC-VDTA is given as

$$I_N = I_P = 0, \quad I_Z = g_{m1}\left(V_N - V_p\right) \tag{2}$$

where g_{m1} and g_{m2} are the transconductances of DC-VDTA.

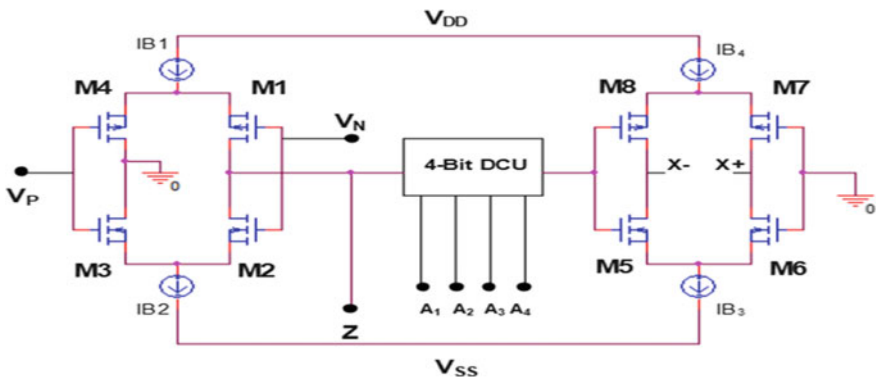


Fig. 1. CMOS structure of DC-VDTA

Table 1 Aspect ratio

Transistor	Width (μm)	Length (μm)
M2,M3	3.6	0.36
M1,M4	16.64	0.36
M5,M6	3.6	0.36
M7,M8	16.64	0.36

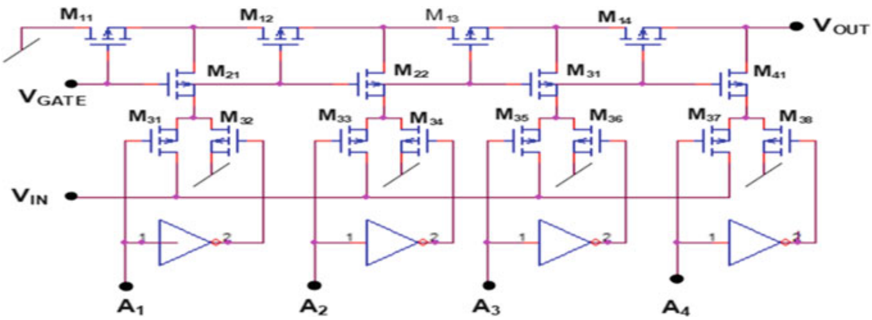


Fig.2. 4-bit DCU

3 Digital Control Unit (DCU)

In this manuscript, a 4-bit DCU is utilized. The CMOS structure of DCU is illustrated in Fig. 2. The output of DCU is determined as

$$V_{\text{out}} = \frac{V_{\text{in}}}{2^4}\left(A_1 + 2A_2 + 2^2 A_3 + 2^3 A_4\right) = K V_{\text{in}} \quad (3)$$

where A_1, A_2, A_3 and A_4 are the bit values of digital control word.

4 Proposed QO

The proposed structure of QO using DC-VDTA is illustrated in Fig. 3. Subsequent by applying KCL at different node, we get the characteristic equation,

$$s^2 + \frac{s}{C_1}\left(\frac{1}{R_1} - g_{m1}\right) + \frac{\beta N g_{m1} g_{m2}}{2^n C_1 C_2} = 0 \quad (4)$$

The CO and FO are determined from Eq. (4)

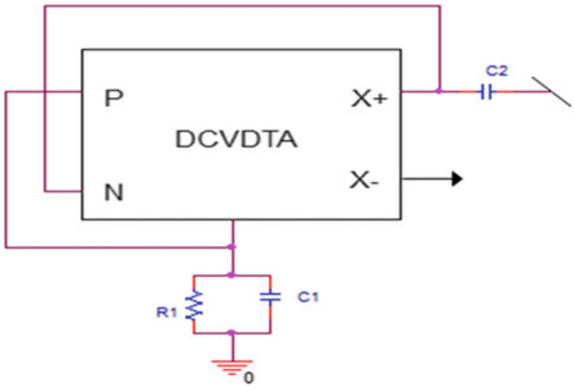


Fig. 3 Proposed QO

$$\mathrm{CO}: \quad \frac{1}{R_1} - g_{m1} \leq 0 \quad \text{and} \quad \mathrm{FO}: \quad \omega = \sqrt{\frac{\beta N g_{m1} g_{m2}}{2^n C_1 C_2}} \tag{5}$$

The proposed circuit is able to provide the quadrature current signal, and their amplitude ratio is mentioned in Eq. (6)

$$\frac{I_{C2}(j\omega)}{I_{C1}(j\omega)} = K \frac{g_{m2}}{\omega C_2} \angle - 90^{\circ}, \quad \left| \frac{I_{C2}(j\omega)}{I_{C1}(j\omega)} \right| = \sqrt{\frac{2^n g_{m2}}{\beta N g_{m1}}} \tag{6}$$

5 Non-ideal and Sensitivity Analysis

A non-ideal analysis of the proposed DC-VDTA is also investigated with considering the parasitic port element. A DCVDTA with parasitic element is shown in the Fig. 4. By considering the parasitic elements, the characteristic equation will be given as

$$\begin{aligned} & s^2\big(C_1 + C_{p1}\big)(C_2 + C_{p2}) + s\left\{\big(C_1 + C_{p1}\big)\frac{1}{R_{p2}} \right. \\ & \left. + \ (C_2 + C_{p2})\left(\frac{1}{R_1} + \frac{1}{R_2} - g_{m1}\right)\right\} + \frac{1}{R_1 R_{p2}} + \frac{1}{R_{p1} R_{p2}} \\ & - \frac{g_{m1}}{R_{p2}} + K g_{m1} g_{m2} = 0 \end{aligned} \tag{8}$$

As $C_1 \gg C_{p1}$ and $C_2 \gg C_{p2}$ then the capacitance C_1 and C_2 will eliminate the effect of C_{p1} and C_{p2} respectively. So, the parasitic capacitance does not affect the functioning of QO, but the parasitic resistance will affect its functioning.

The active and passive sensitivities of proposed oscillator are given as

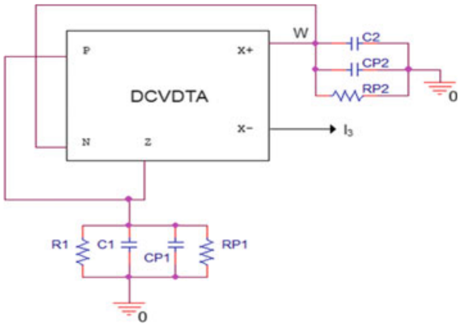


Fig. 4 Non-ideal model of DC-VDTA

$$S^{\omega}_{C_1,C_2} = -0.5, \quad S^{\omega}_{g_{m1},g_{m2}} = 0.5 \tag{9}$$

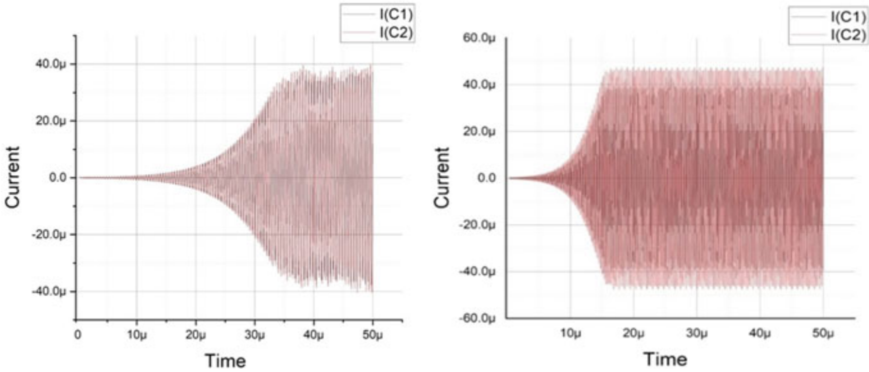
So, the sensitivity values are low and lie within the specified range.

6 Simulation Results

To observe the functionality of proposed QO, the Pspice simulation is carried out using 180nm technology. To design the QO 4-bit DCU is used with the components values are $C_1 = C_2 = 50$pF, $R_1 = 1.7$KΩ, $V_{DD} = 0.9$V, $V_{SS} =$ -0.9V, and for $I_{B1} = I_{B2} = I_{B3} = I_{B4} = 150\mu$A the value of $g_{m1} = g_{m2} = 611\mu$A/V. The 4-bit DCU will help to generate sixteen different frequency signals. The transient response of designed QO for control words $N = 1$ and 6 are demonstrated in Fig. 5. The steady state characteristic is also been shown in Fig. 6. The quadrature outputs I_{C1} and I_{C2} are having a phase shift of 89.3°. The variation in calculated and measured frequency is also shown in Fig. 7 that indicates that the both values are closely related.

7 Conclusion

A digitally controlled VDTA (DC-VDTA) and its application as digitally controllable QO have been reported for the first time. The proposed QO requires only one DC-VDTA and three grounded passive elements that make the circuit suitable for fabrication. The 4-bit DCU can generate sixteen different frequencies of quadrature output for different combinations of control word. The FO and CO can be controlled electronically and independently. The FO can also be modulated through the both grounded capacitors. The functioning of the circuit is validated through the Pspice simulations.



(a)N=0001 (b)N=0110

Fig. 5 Steady state response of the QO for **a** $N = 1$ **b** $N = 6$

Fig. 6 Steady state response

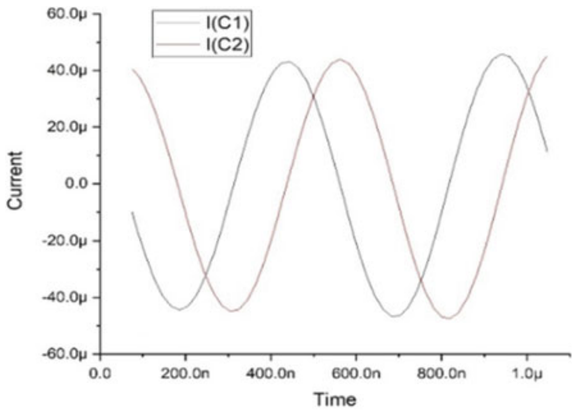
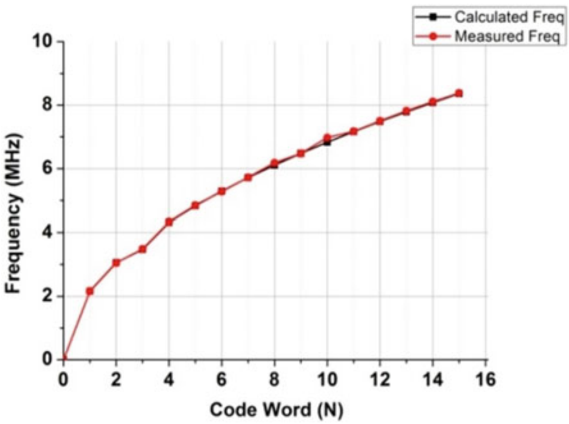


Fig. 7 Frequency Deviation



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