Electronically Controllable Grounded Capacitor Current-Mode Quadrature Oscillator Using Single MO-CCCDTA

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Abstract. *This paper presents an electronically controllable grounded capacitor quadrature oscillator using single multiple-output current controlled current differencing transconductance amplifier (MO-CCCDTA) as an active element. The proposed circuit employs a single MO-CCCDTA, two grounded capacitors and one grounded resistor and offers the advantages of (i) independent control of condition of oscillation (CO) and frequency of oscillation (FO), and (ii) low active and passive sensitivities. The workability of proposed configuration has been demonstrated by PSPICE simulation.*

Keywords

MO-CCCDTA, quadrature oscillator, current-mode circuits.

1. Introduction

Oscillator is an important basic building block, which is frequently employed in electrical engineering applications. Among several kinds of oscillators, the quadrature oscillator is widely used because it can offer sinusoidal signals with 90^0 phase difference, for example, in telecommunications for quadrature mixers and single-sideband modulators [1]. Among various modern active building blocks, the recently introduced current differencing transconductance amplifier (CDTA) is emerging as a very flexible and versatile building block for analog circuit design. CDTAs have been extensively used as building blocks in a number of current-mode (CM) and voltage-mode (VM) signal processing applications [2]-[14] and several implementations of oscillator employing CDTAs or CCCDTAs have been reported [15]-[24]. In [15], Keskin and Biolek presented a quadrature oscillator using two CDTAs and six passive elements. Tangsrirat and Tanjaroen proposed a CM multiphase sinusoidal oscillator using five CDTAs [19]. In [20], authors presented a single resistance controlled oscillator (SRCO) using a single CDTA and four passive elements. In [21], Jaikla, Siripruchyanun, Bajer and Biolek proposed a single Z copy Current Differencing Transconductance Amplifier (ZCDTA) based quadrature oscillator employing three passive components. In [22], Lahiri presented a VM/CM quadrature oscillator using two CDTAs and three passive elements. The advantages, applications and usefulness of recently introduced new active building block named multi-output current controlled current differencing transconductance amplifier (MO-CCCDTA) are now being recognized in literature [16], [17], [18], [23] and [24]. In [24], Lahiri proposed a quadrature oscillator using a single MO-CCCDTA and two grounded capacitors in which CO was established using the parasitic resistance (R_p) of the MO-CCCDTA employing bipolar technology. The purpose of this paper is, therefore, to propose a new electronically controllable grounded capacitor quadrature oscillator using a single MO-CCCDTA (employing CMOS technology), two grounded capacitors and one grounded resistor, in which CO is established by the grounded resistor. The proposed circuit offers (i) independent control of CO and FO and (ii) low active and passive sensitivities.

2. The Proposed New Configuration

The symbolic notation of MO-CCCDTA is shown in Fig. 1. The proposed new configuration is shown in Fig. 2. Assuming an ideal MO-CCCDTA is characterized by $V_p = V_n = 0$, $I_{Z1} = I_{Z2} = I_p - I_n$, $I_{x1}^+ = g_{m1}V_{z1}$, $I_{x1}^- = -g_{m1}V_{z1}$, $I_{x2}^+ = g_{m2}V_{z2}$, $I_{x2}^- = -g_{m2}V_{z2}$ where $V_z = I_z.Z_z$ and Z_z is the external impedance connected to the z-terminal of the CDTA. I_{B3} and I_{B4} indicated in Fig. 1 show the external bias currents which control the transconductances to make the circuit electronically controllable.

A routine circuit analysis yields the following characteristic equation

$$s^2 + \frac{s}{C_1}\left(\frac{1}{R_1} - 2g_{m_1}\right) + \frac{2g_{m_1}g_{m_2}}{C_1C_2} = 0\,. \tag{1}$$

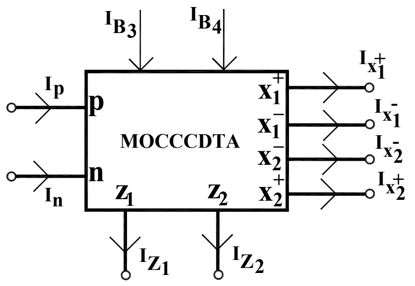


Fig. 1. Symbolic notation of MO-CCCDTA.

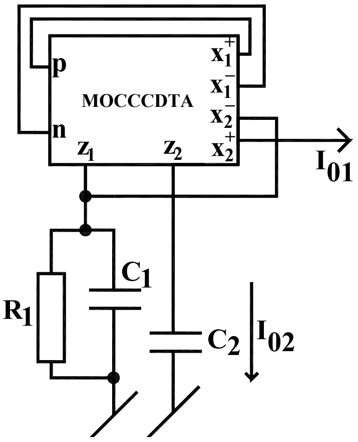


Fig. 2. Proposed quadrature oscillator.

Thus, the condition of oscillation (CO) and frequency of oscillation (FO) are given by

$$\left(\frac{1}{R_1}-2g_{m_1}\right)\leq 0 \tag{2}$$

and
$$\omega_0=\sqrt{\frac{2g_{m_1}g_{m_2}}{C_1C_2}}. \tag{3}$$

Therefore, it is seen that FO is independently controllable by transconductance g_{m2} of the MO-CCCDTA, whereas CO is independently established through the resistor R_1, FO can also be controlled independently by C_1 or C_2.

In fact, for maintaing the CO the minimum value of R_1 required is given by

$$R_{1_{\min}}>\frac{1}{2g_{m_1}}\cdot \tag{4}$$

However, on the other hand, there is an upper bound on the value of R_1 such that the starting frequency of oscillation is not zero, which can be deduced from equation (1) to be

$$(R_1)_{\max}<\left(\frac{1}{2(C_1\omega_0+g_{m_1})}\right)\cdot \tag{5}$$

Thus, for R_1 being between $R_{1\min}$ (from (4)) and $R_{1\max}$ as in (5), the roots of (1) will be complex and located in RHP, which ensures exponentially growing sinusoidal oscillations.

In view of the above, therefore, temperature dependence of g_{m1} posses no difficulty in maintaining oscillations. The same thing applies to some earlier works (such as those in [21], [22] and [26]).

The current transfer functions obtained from Fig. 2 are

$$\frac{I_{o1}(s)}{I_{o2}(s)}=\frac{g_{m_2}}{sC_2}. \tag{6}$$

For sinusoidal steady state, (4) becomes

$$\frac{I_{o1}(j\omega)}{I_{o2}(j\omega)}=\frac{g_{m_2}}{\omega C_2}e^{-j90^0}. \tag{7}$$

The phase difference ϕ between I_{o1} and I_{o2} is

$$\phi=-90^0 \tag{8}$$

hence, the currents I_{o1} and I_{o2} are in the quadrature form.

To extract the current I_{o2} explicitly another device with its input virtually grounded will be needed due to which although the capacitor C_2 will not physically be connected to ground but it will still be virtually grounded. However, in the context of implementation of the circuit as an IC chip, the configuration will have one floating capacitor.

3. Non-ideal Analysis

Taking into account the non-idealities of the MO-CCCDTA, namely $I_z = (\alpha_p I_p - \alpha_n I_n)$, $V_p = V_n = 0$, $I_{x+} = g_m V_z$ and $I_{x-} = -g_m V_z$, where $\alpha_p = 1-\varepsilon_p$ ($\varepsilon_p \ll 1$), $\alpha_n = 1-\varepsilon_n$ ($\varepsilon_n \ll 1$) denote the current tracking errors, then the condition of oscillation (CO) and frequency of oscillation (FO) can be given by

$$\left(\frac{1}{R_1}-g_{m_1}(\alpha_p+\alpha_n)\right)\leq 0, \tag{9}$$

$$\omega_0=\sqrt{\frac{g_{m_1}g_{m_2}(\alpha_p+\alpha_n)}{C_1C_2}}. \tag{10}$$

Its active and passive sensitivities can be found as

$$S_{g_{m_1}}^{\omega_0}=\frac{1}{2},\ S_{g_{m_2}}^{\omega_0}=\frac{1}{2},\ S_{C_1}^{\omega_0}=-\frac{1}{2},\ S_{C_2}^{\omega_0}=-\frac{1}{2},$$
$$S_{\alpha_p}^{\omega_0}=\frac{\alpha_p}{2(\alpha_p+\alpha_n)},\ \text{and}\ S_{\alpha_n}^{\omega_0}=\frac{\alpha_n}{2(\alpha_p+\alpha_n)} \tag{11}$$

which are all very low.

Let R_p and R_n denote the input resistances of the p and n terminals of the MO-CCCDTA respectively, C_Z and C_X denote the parasitic capacitances and R_Z and R_X denote the parasitic resistances of the Z and X terminals of the MO-CCCDTA respectively. Taking C_1, $C_2 \gg C_x$, C_z and $R_1 \ll R_x$, R_z then the condition of oscillation (CO) and frequency of oscillation (FO) can be given by

CO:

$$C_x R_p g_{m_1}[R_n(\frac{2g_{m_2}}{R_1}-\frac{2}{R_1R_z}-g_{m_1}g_{m_2}(1+\frac{R_p}{R_n}))$$
$$+C_1(1+\frac{R_n}{R_p})(3g_{m_2}-\frac{2}{R_z})-C_2(\frac{1}{R_1}-2g_{m_1})]+C_1C_2(\frac{1}{R_1}-2g_{m_1})\le 0 \tag{12}$$

and FO:

$$\omega_0=\left(\frac{2g_{m_1}g_{m_2}}{C_1C_2}\right)^{1/2}\left(\frac{1+\frac{(\frac{1}{R_1}-2g_{m_1})}{2g_{m_1}g_{m_2}R_z}+\frac{(R_p+R_n)}{2g_{m_2}R_x}(g_{m_2}-\frac{1}{R_z})}{1+\frac{(R_p+R_n)C_x}{C_1}(\frac{1}{R_1}-g_{m_1})+C_z(\frac{1}{C_1}+\frac{1}{C_2})}\right)^{1/2} \tag{13}$$

From (12) and (13), it is clear that CO and FO are not independent.

4. Simulation Results

To verify the theoretical analysis, the proposed circuit has been simulated using the CMOS-based MO-CCCDTA circuit as shown in Fig. 3. The component values used were C_1 = 0.5 nF, C_2 = 0.5 nF, and R_1 = 1.94 kΩ, the MO-CCCDTA was biased with ±1 V D.C. power supplies with $I_{B1} = I_{B2}$ = 25 µA and $I_{B3} = I_{B4}$ = 32 µA. I_{B1} and I_{B2} are the biasing currents for the devices to perform the current differencing operation, while MO-CCCDTA transconductances are controlled by I_{B3} and I_{B4}. PSPICE generated output waveforms indicating transient and steady state responses are shown in Fig. 4. From SPICE simulation the frequency of generated quadrature waves has been found to be 114.4 kHz. Fig. 5 shows the output spectrum, where the total harmonic distortion (THD) is found to be 0.6%. Fig. 5 does not represent any noise analysis. It is obtained by .FOUR analysis of SPICE and has been used to obtain percentage THD by looking into corresponding output file. These results, thus, confirm the validity of the proposed configuration.

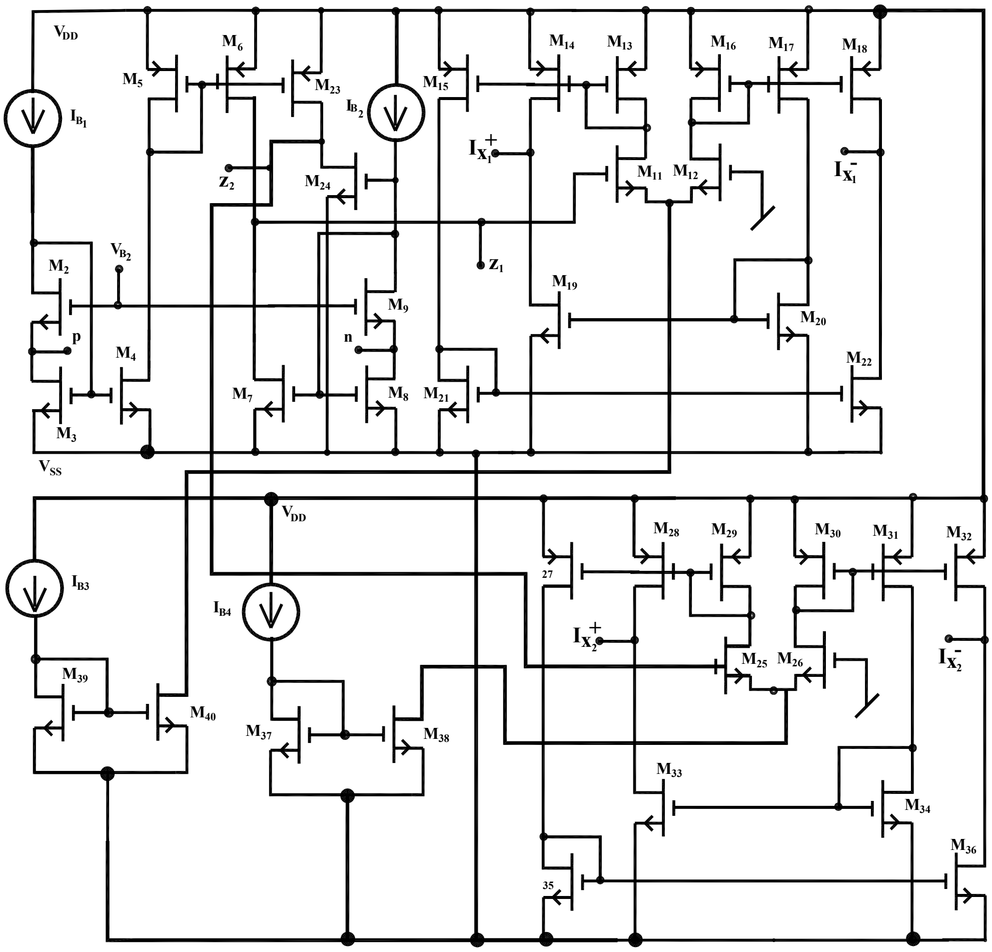


Fig. 3. CMOS-based MO-CCCDTA.

For this purpose, the parameters of the 0.5µm MIETEC real transistor model are implemented for all MOSFETs in the circuit, which are given below:

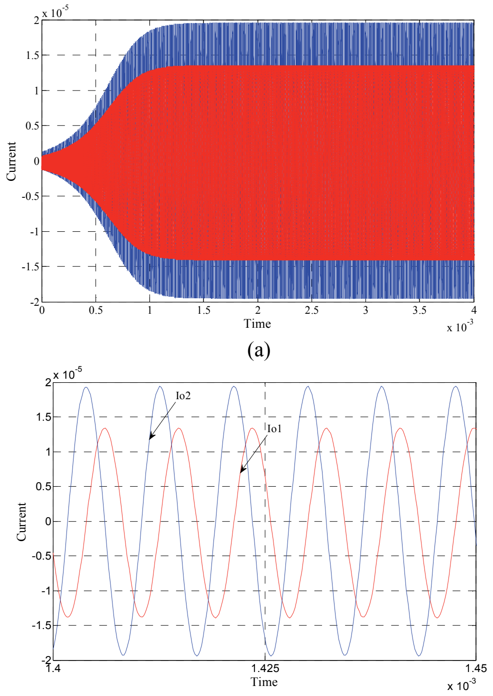
.model n nmos (LEVEL=3 TOX=1E-8 TPG=1 VTO=0.62 JS=1.08E-6 XJ=0.15U RS=417 RSH=2.73 LD=0.04U VMAX=130E3 NSUB=1.71E17 PB=0.761 ETA=0.00 THETA=0.129 PHI=0.905 GAMMA=0.69 KAPPA=0.10 CJ=76.4E-5 MJ=0.357 CJSW=5.68E-10 MJSW=0.302 CGSO=1.38E-10 CGDO=1.38E-10 CGBO=3.45E-10 KF=3.07E-28 AF=1 WD=0.11U DELTA=0.42 NFS=1.2E11)

.model p pmos (LEVEL=3 TOX=1E-8 TPG=1 VTO=-0.58 JS=0.38E-6 XJ=0.10U RS=886 RSH=1.81 LD=0.03U VMAX=113E3 NSUB=2.08E17 PB=0.911 ETA=0.00 THETA=0.12 PHI=0.905 GAMMA=0.76 KAPPA=2 CJ=85E-5 MJ=0.429 CJSW=4.67E-10 MJSW=0.631 CGSO=1.38E-10 CGDO=1.38E-10 CGBO=3.45E-10 KF=1.08E-29 AF=1 WD=0.14U DELTA=0.81 NFS=0.52E11)

Transistor aspect ratios are indicated in Tab. 1.

Transistor	W/L (µm)
M1-M2	30/0.7
M3-M4	90/2.1
M5-M6, M23	150/3.5
M7-M8, M24	90/2.1
M9-M10	30/0.7
M11, M12, M25, M26	16/1
M13-M18, M27-M32	6/1
M19-M22, M33-40	4/1

Tab. 1. Transistor aspect ratios.



(a)

(b)

Fig. 4. **(a)** Transient output waveform, **(b)** Steady state responses of the quadrature outputs.

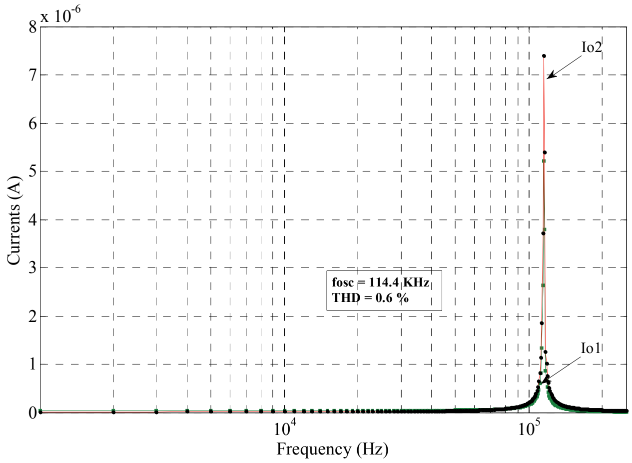


Fig. 5. Simulation result of the output spectrum.

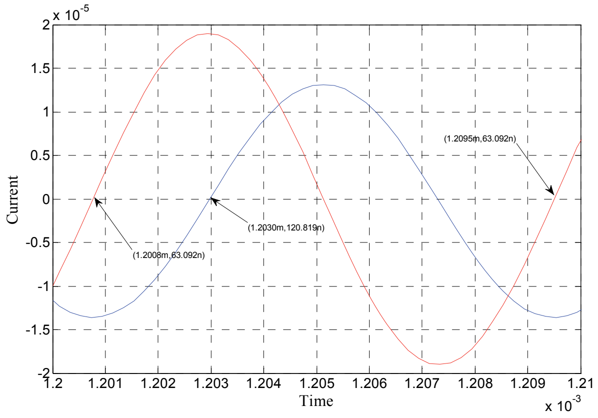


Fig. 6. Currents.

From Fig. 6 it is clear that the two currents are in quadrature and the measured value of phase shift between two waveforms is 89.91°.

Ref.	Active elements	Passive elements	Grounded capacitors	CO	FO
[21]	1	3	1	$(1-g_mR)\le 0$	$\omega_0=\sqrt{\frac{g_m}{C_1C_2R}}$
[22]	2	3	2	$(1-g_{m_1}R_1)\le 0$	$\omega_0=\sqrt{\frac{g_{m_1}g_{m_2}}{C_1C_2}}$
[25]	1	4	2	$(R_1-R_2)\le 0$	$\omega_0=\sqrt{\frac{g_m}{C_1C_2R_1}}$
[26]	2	4	2	$(1-g_mR_1)\le 0$	$\omega_0=\sqrt{\frac{g_m}{C_1C_2R_2}}$
Proposed	1	3	2	$(1-2g_{m_1}R_1)\le 0$	$\omega_0=\sqrt{\frac{2g_{m_1}g_{m_2}}{C_1C_2}}$

Tab. 2. Comparison.

5. Concluding Remarks

An electronically controllable grounded capacitor CM quadrature oscillator using single MO-CCCDTA has been presented. The proposed configuration offers independent control of both CO and FO (the former through resistor R_1 and the latter through g_{m2}). The active and passive sensitivities are low. The workability of the proposed configuration has been verified using PSPICE simulation.

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