SINGLE-CURRENT-CONTROLLED SINUSOIDAL OSCILLATOR WITH CURRENT AND VOLTAGE OUTPUTS USING SINGLE CURRENT-CONTROLLED CONVEYOR TRANSCONDUCTANCE AMPLIFIER AND GROUNDED PASSIVE ELEMENTS

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Key words: Current-controlled conveyor transconductance amplifier (CCCTA), Single-current-controlled (SCC), Sinusoidal oscillator.

This work presents a single-current-controlled (SCC) sinusoidal oscillator that explicitly generates both current and voltage outputs, and employing only a single current-controlled conveyor transconductance amplifier (CCCTA) as the active building block, and three passive components. The presented circuit provides the advantage features of independent electronic control of oscillation condition and oscillation frequency, and use of all grounded passive components. The circuit also exhibits low active and passive sensitivities and permits good frequency stability. Computer simulation results obtained from PSPICE program using 0.35-μm BiCMOS real process parameters are performed to confirm the excellent performance of the proposed oscillator circuit.

1. INTRODUCTION

Since an introduction of the newly defined active building block namely, the current conveyor transconductance amplifier (CCTA) in 2005 [1], this device has been gaining an increasing attention that led to a great number of analog function circuits. Basically, the CCTA device can be realized by cascading the second-generation current conveyor with the multi-output transconductance amplifier in monolithic form. By combining the advantages of both circuit topologies, the CCTA possesses wide bandwidth, high-slew rate, high dynamic range, and low power consumption. Considering these reasons, the CCTA is suitable for a class of

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Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **60**, *2*, p. 175–184, Bucarest, 2015

analog signal processing which can process in both current and voltage signals. Hence, a great number of numerous analog adjustable functions is available in technical literature [1–4]. In 2008, the current-controlled conveyor transconductance amplifier (CCCTA) which is a modified version of the CCTA, was introduced [5]. The parasitic resistance looking into the x-terminal (R_x) of the circuit is used to advantage in current-controlled circuit parameter, because it is easily adjusted by an external biasing current. This advantage allows the implementation of numerous electronically tunable circuits without requiring external passive resistors, which is especially important for integrated circuit implementation.

The sinusoidal oscillators constitute an essential circuit blocks of a typical information system, modern electronic or communication system. A great number of schemes based on modern active function blocks have been developed to realize sinusoidal oscillator [6–13]. However, the oscillator circuits reported in [6–12] are not minimal in a number of active and passive components. The works in [6–11] also do not provide electronic controllability to their important parameters. Moreover, all of them generate either voltage signal output or current signal output only.

This work describes a novel single-current-controlled (SCC) sinusoidal oscillator with current and voltage signal outputs, constructing one CCCTA, one grounded resistor and two grounded capacitors. The circuit provides the independent current controllability of the oscillation condition and oscillation frequency (ω_o), and suitability for integration due to employing only grounded passive components. Circuit analyses show that the circuit provides low component sensitivity, and good frequency stability. The presented oscillator circuit with dual-mode outputs is verified by the practical PSPICE model of the CCCTA. The simulation results using PSPICE program show an adequate agreement with the theoretical conclusions.

2. **CURRENT-CONTROLLED CONVEYOR TRANCONDUCTANCE AMPLIFIER (CCCTA)**

The CCCTA device is conceptually based on the combination of second generation current-controlled conveyor (CCCII) and transconductance amplifier. Its electrical symbol can be shown in Fig.1. As shown, the CCCTA device consists of two input terminals (y and x) and two output terminals (z and o). The x-terminal has a parasitic serial resistance (R_x), where its value usually depends on an external supplied current. The y-terminal is the high-input impedance terminal, while the z and o-terminals are two types of high-output impedance terminals. The property of the CCCTA can be described by the following matrix:

$$\begin{bmatrix} i_y \\ v_x \\ i_z \\ i_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & g_m & 0 \end{bmatrix} \cdot \begin{bmatrix} i_x \\ v_y \\ v_z \\ v_o \end{bmatrix} \tag{1}$$

where R_x and g_m are the finite parasitic resistance looking into the x-terminal, and the transconductance gain of the CCCTA, respectively. In addition, an auxiliary zc terminal provides a copy current of the current flowing out of the z-terminal, i.e., $i_{zc} = i_z$. Here, the values of R_x and g_m depend on the external dc bias currents I_A and I_B, respectively.

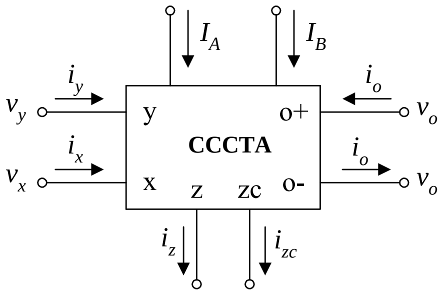


Fig. 1 – Circuit representation of the CCCTA.

Figure 2 shows the schematic BiCMOS realization of the CCCTA [14], which mainly consists of the CCCII (Q_1-Q_2, M_1-M_4, M_9-M_{12}) and transconductance amplifiers (Q_3-Q_6, M_5-M_8, M_{13}-M_{15}). Groups of transistors Q_1-Q_2, Q_3-Q_4 and Q_5-Q_6, which are assumed to be well matched, act as transconductance amplifiers to convert the voltage signal to the current signal. The current mirroring has been achieved by simple current mirror circuits (M_1-M_4), (M_5-M_6), (M_7-M_8), (M_9-M_{12}) and (M_{13}-M_{15}). The internal intrinsic resistance at the x-terminal (R_x) of the CCCTA can be derived as [14]:

$$R_x \cong \frac{2V_T}{I_A} \quad , \tag{2}$$

where $V_T \cong 26$ mV at 27 °C is the thermal voltage. It is clearly seen from eq.(2) that the resistance R_x is controllable electronically by adjusting the bias current I_A.

Similarly, the small-signal transconductance gain (g_m) of the CCCTA derived from the transconductor Q_3-Q_4 (Q_5-Q_6) can be expressed as [14]:

$$g_m = \frac{i_o}{v_z} = \frac{I_B}{2V_T} \quad . \tag{3}$$

Also note that the g_m-value can be controlled electronically and linearly by changing the I_B - value.

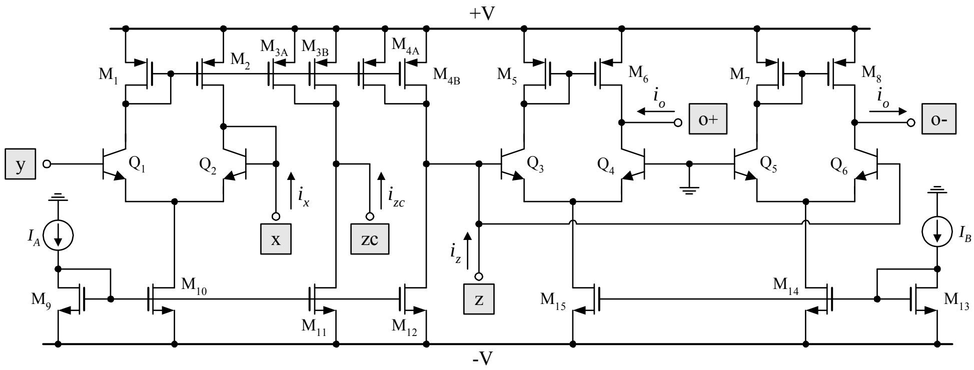


Fig. 2 – BiCMOS implementation of the CCCTA.

3. PROPOSED SCC DUAL-MODE SINUSOIDAL OSCILLATOR

Figure 3 shows the proposed SCC sinusoidal oscillator with current and voltage signal outputs, employing only one CCCTA, one resistor and two capacitors. This oscillator requires only grounded passive elements; it is a desirable feature for monolithic integration. The characteristic equation for the proposed oscillator in Fig. 3 can be expressed as:

$$s^2 + \frac{s}{C_2}\left(\frac{1}{R_1} - \frac{1}{R_x}\right) + \frac{g_m}{R_x C_1 C_2} = 0 \quad . \tag{4}$$

From Eq. (4), the condition of oscillation and the frequency of oscillation (ω_o) can be obtained by :

$$R_1 = R_x \tag{5}$$

and

$$\omega_o = \sqrt{\frac{g_m}{R_x C_1 C_2}} \quad . \tag{6}$$

Eq. (5) shows that the condition of oscillation can be controlled independently by a grounded resistor R_1. It is also clear from Eq. (6) that the ω_o is electronically controlled by the g_m value without affecting the condition of oscillation. Since the the g_m value is controlled by the external biasing circuit I_B of the CCCTA as given in eq. (3), the proposed circuit may be considered as a single-current-controlled variable frequency sinusoidal oscillator.

The sensitivity analysis shows that the various active and passive sensitivities of the parameter ω_o are all low and obtained as :

$$S_{g_m}^{\omega_o} = -S_{R_x}^{\omega_o} = -S_{C_1,C_2}^{\omega_o} = \frac{1}{2} \quad . \tag{7}$$

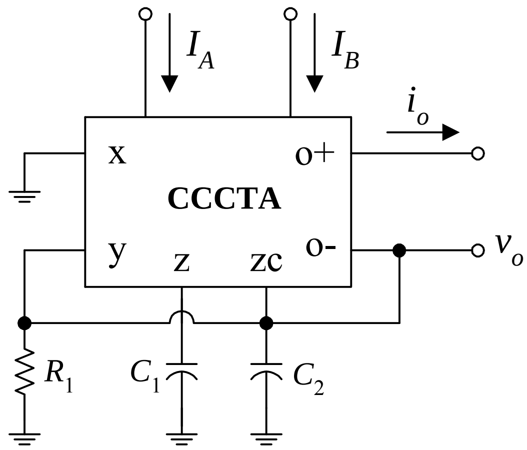


Fig. 3 – Proposed SCC dual-mode sinusoidal oscillator using single CCCTA.

4. FREQUENCY STABILITY

The classical frequency stability factor (S_F) can be defined as [6]:

$$S_F = \left. \frac{\mathrm{d}\varphi(u)}{\mathrm{d}u} \right|_{u=1} \quad , \tag{8}$$

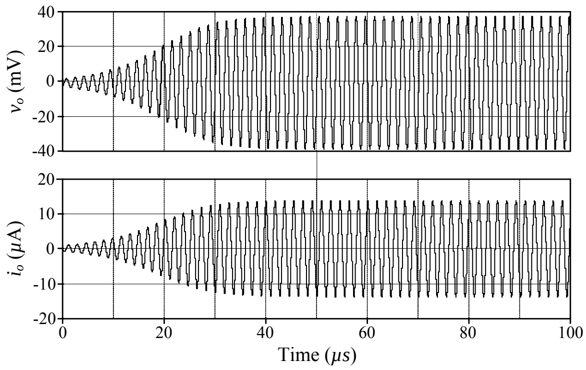
where $u = \omega/\omega_o$ and $\phi(u)$ is the phase function of the open-loop transfer function of the oscillator in Fig. 3. With $C_1 = C_2$, $R_x = R_1 = R$ and $g_m = R/n$, the S_F factor of Fig. 3 is derived as

$$S_F = \frac{2n\sqrt{n}}{n+1} \quad . \tag{9}$$

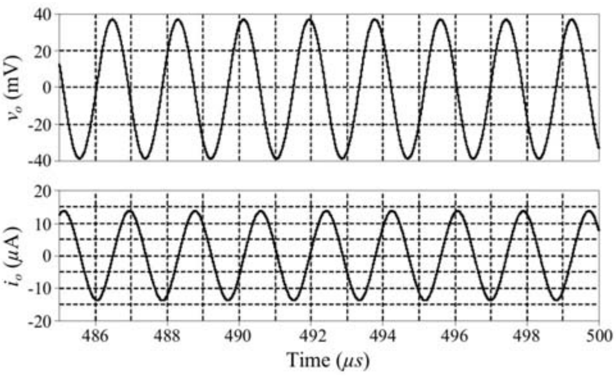
If $n >> 1$ is satisfied, the value of S_F can be made quite high. It reveals that this sinusoidal oscillator has good frequency stability.

5. COMPUTER VERIFICATION AND DISCUSSION

To verify the theory, the proposed SCC dual-mode sinusoidal oscillator of Fig. 3 has been simulated with PSPICE simulation program. In simulations, the CCCTA structure depicted in Fig. 2 was perfomed using standard 0.35 μm BiCMOS process parameters [14]. The dc supply voltages were selected as: +V = – V = 1V. The transistor aspect ratios (W/L in μm/μm) were chosen as: 7/0.7 and 8.5/0.7 for all the PMOS and NMOS transistors respectively. The following component values were chosen as: I_A = 10 μA, I_B = 35 μA and $C_1 = C_2$ = 0.1 nF, resulting in $R_x \cong 5$ kΩ, $g_m \cong 0.67$ mA/V and $f_o = \omega_o/2\pi \cong 584$ kHz, respectively. The value of $R_1 \cong 5.2$ kΩ was chosen to be slightly larger than R_x, in order to ensure that the oscillation will occur.



a)



b)

Fig. 4 – Simulated output waveforms for v_o and i_o of the proposed oscillator circuit in Fig. 3: a) during initial state; b) during steady-state.

Figure 4 illustrates the simulated time domain responses for the sinusoidal output signals v_o and i_o of the proposed oscillator circuit of Fig. 3. The simulated f_o obtained from the results was measured as : $f_o \cong 556$ kHz. Fig.5 shows the simulated frequency spectrums for both outputs, giving the total harmonic distortion (THD) equal to 4.28%.

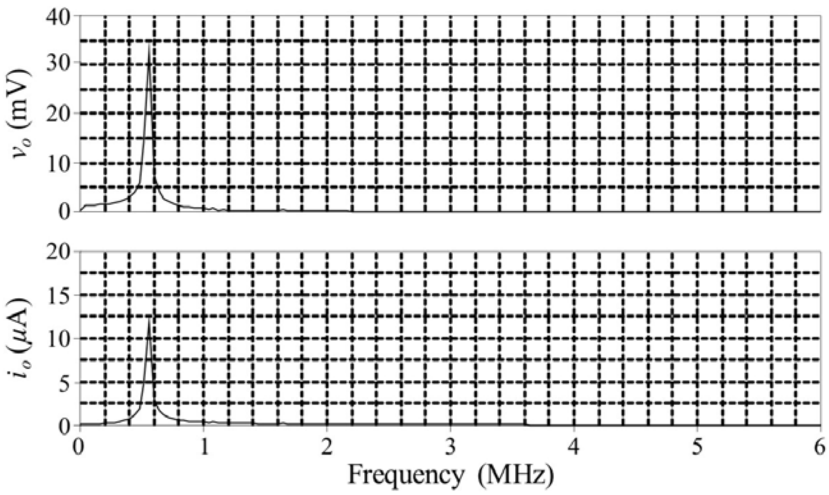


Fig. 5 – Simulated frequency spectrums for v_o and i_o of the proposed oscillator circuit in Fig.3.

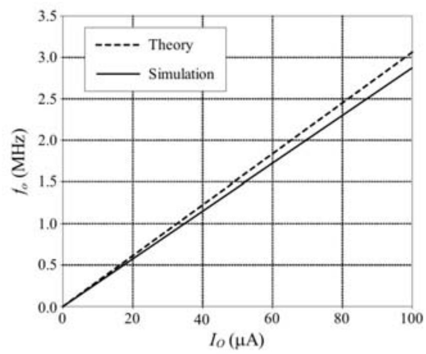


Fig. 6 – Variation of f_o as a function of the bias current I_O.

Figure 6 shows the variability of f_o against the bias current (I_O), where $I_O = I_A = I_B$. As can be seen, the difference between the theory and the simulated plots especially in high bias current value region is mainly attributed to the deviation of the values of R_x and g_m that differ from the calculation values. Since the expressions of R_x and g_m for the proposed oscillator configuration in Figure 3 include voltage equivalent of temperature, i.e., V_T term, the circuit is prone to thermal influence, needing measures to counteract. Figure 7 displays the simulated

f_o of the proposed oscillator versus ambient temperature (T). As calculated from the results, the relative sensitivity of f_o with respect to T, which is defined by $S_T^{f_o} = (\partial f_o / f_o)/(\partial T/T)$, is around 11.17×10^{-3}.

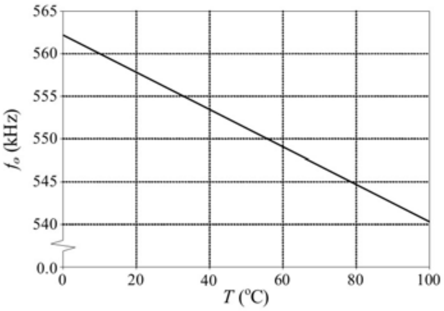


Fig. 7 – Variation of f_o as a function of the ambient temperature T.

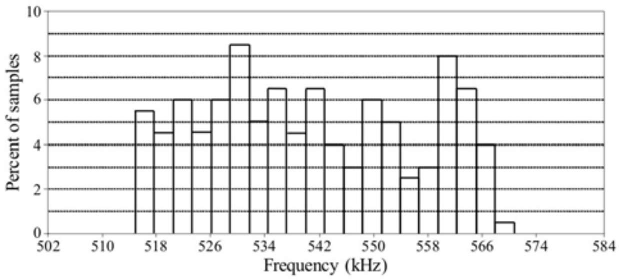


Fig. 8 – Monte-Carlo analysis for f_o when 10% deviation in R_x and R_1 values.

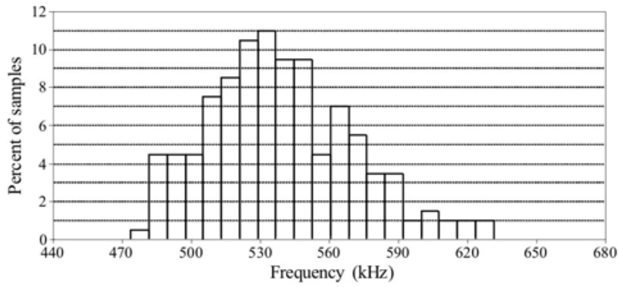


Fig. 9 – Monte-Carlo analysis for f_o when 10% deviation in C_1 and C_2 values.

In addition, the impact of the component mismatching on the oscillator's response has been evaluated through Monte-Carlo statistical analysis. In this study, the Monte-Carlo simulations with 10% Gaussion deviation on the values of R_x, R_1, C_1 and C_2 were performed for the proposed oscillator circuit. The derived statistical histograms of f_o variation in percent are given in Figs.8 and 9. Both graph were generated from the same 200 simulation runs. In Fig.8, a standard deviation of f_o was 2.78%, and maximum and minimum f_o were 571 kHz and 515 kHz, respectively. Likewise, the plots of Fig.9 also indicate that the standard deviation, and maximum and minimum f_o were obtained as : 5.75%, 631 kHz and 474 kHz, respectively. These results reveal that the proposed oscillator has reasonable sensitivity performance. In conclusion, a comparative study of performance specifications of the proposed oscillator circuit with some of the earlier reported oscillators has been summarized in Table 1.

Table 1
Comparison of the proposed SCC dual-mode sinusoidal oscillator of Fig. 3 to the earlier reported oscillator circuits [6–13]

Circuits [Ref]	No. of active components	No. of passive components	All grounded passive components	Electronic tunability	Voltage and current outputs	Technology	Supply voltages
[6]	CCII = 1, buffer = 1	R = 3, C = 2	no	no	no	CA3096, LF356	±12V
[7]	CCII = 1, buffer = 2	R = 3, C = 2	no	no	no	CA3096, OA741	±12V
	CCII = 1, buffer = 1						
[8]	FTFN = 1	R = 4, C = 2	no	no	no	AD844	±10V
[9]	OTRA = 1	R = 3, C = 2	no	no	no	0.8 µm AMS	±2.5V
[10]	AD844 = 2	R = 4, C = 2	yes	no	no	AD844	±12V
[11]	CCII = 2	R = 2, C = 2	no	no	no	AD844	±5V
	CCCII = 2	C = 2	yes	yes	no	ALA400	±5V
[12]	CDTA = 3	R = 1, C = 2	no	yes	no	0.5 µm MIETEC	±2.5V
[13]	CCCTA = 1	R = 1, C = 2	yes	yes	no	0.25 µm TSMC	±1.25V
Proposed	CCCTA = 1	R = 1, C = 2	yes	yes	yes	0.35µm BiCMOS	±1V

6. **CONCLUSION**

This paper describes a single-current-controlled sinusoidal oscillator employing a single CCCTA along with three grouded passive elements, i.e. one resistor and two capacitors. The proposed oscillator circuit provides voltage-mode as well as current-mode outputs simultaneously from the same configuration. The circuit enjoys the non-interactive current controls for both oscillation condition and oscillation frequency, which can be used as a current-controlled variable frequency sinusoidal oscillator. The simulation results have been performed for the realized sinusoidal oscillator circuit to verify the theoretical expectation.

ACKNOWLEDGEMENTS

This work was supported by Faculty of Engineering, Rajamangala University of Technology Iran, Khon Kaen Campus. The support in part by Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL) with the project code 2558-01-01034 is also gratefully acknowledged.

Received on May 20, 2014

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