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CCTA Based Current-mode First Order Filter and Its Application in Quadrature Oscillator

***Abstract**. This article presents a current-mode first order filter and application in quadrature oscillator circuit based on all-pass filter. The filter circuit using only single CCTA and single grounded capacitor. It is able to provide low-pass, high-pass and all-pass function. Morover, the proposed oscillator can provide two sinusoidal output currents with 90 degrees phase difference. The filter and oscillator circuits use only grounded capacitors without any external resistor and have high output impedance appropriate for cascade connection application in current mode which is capable to directly drive load. This qualification is very appropriate for further development into an integrated circuit. The results of PSPICE simulation program are corresponding to the theoretical analysis.*

***Streszczenie.** W artykule przedstawiono prądowy filtr pierwszego rzędu i jego zastosowanie w generatorze kwadraturowym. Układ filtru wykorzystuje uziemiony kondensator i układ CCTA (current conveyor transconductance amplifier). Generator umożliwia wytwarzanie dwóch prądów sinusoidalnych przesuniętych w fazie o 90^o. (**Filtr pierwszego rzędu wykorzystujący układ CCTA i jego zastosowanie do projektowania generatora**)*

Keywords: first order filter; quadrature oscillator; current-mode; CCTA.
Słowa kluczowe: filtr pierwszego rzędu, generator kwadraturowy, CCTA..

Introduction

The filter and oscillator circuit are important in electrical and electronic engineering. These circuits have been widely implemented in telecommunication system, measuring tool systems, and signal processing for instance. The filter is one of circuits providing appropriate qualifications for various kinds of application, such as, phase-lock loop, FM stereo demodulators and being used in three-way high fidelity loudspeakers in crossover networks [1]. On the other hand, quadrature oscillator (QO) is one of oscillator which provides two sinusoidal signals with 90 degrees phase difference. Some applications for quadrature signal are employed in telecommunications for single-sideband modulators and quadrature mixers [2]. In the last decade, a lot of papers in electronic circuit design have been presented in current-mode technique. It is stated that the circuit designed from current-mode technique can provide the advantages, such as, larger dynamic range, inherently wide bandwidth, higher slew-rate, greater linearity and low power consumption [3-4]. From literature survey, it is found that several implementations of first order filter [5-12] and quadrature oscillator based on all-pass filter [13-34], have been reported. Unfortunately, these reported circuits suffer from one more of weaknesses. For example, the circuits cannot be electronically controlled by adjusting the bias current [5-14, 17, 19, 23-28, 31, 34]. The proposed circuits use floating capacitor [6, 14-15, 17-18, 20, 24-25, 28-29, 32], which is not convenient for further fabrication in integrated circuits [35]. The external resistors are excessively used [5-21, 23-31, 34] and the proposed circuit consists of large number (more than four components) of passive components [6, 8, 14, 17, 19-21, 23-25, 28, 31, 34], which is not convenient for further fabrication in integrated circuits, as well as, the proposed circuits presented in voltage-mode technique [8, 9, 12-13, 17, 19, 22-23, 25-28, 31-32].

This paper presents the current-mode first order filter circuit based on CCTA. The filter circuit using single CCTA and single grounded capacitor. It can provide transfer functions which are high-pass filter (HP), low-pass filter (LP) and all-pass filter (AP). In addition, this paper presents the application of the all-pass filter circuit for the current-mode sinusoidal quadrature oscillator. The proposed quadrature oscillator circuit consists of two CCTAs and two grounded capacitors. The proposed filter and oscillator circuit have high output impedance which appropriate for cascade connection in current mode technique and capable to directly drive load. The proposed circuits use only grounded capacitor without additional external resistors. This qualification is convenient to for further fabrication in integrated circuits [36-37]. Accordingly, the PSPICE simulation program results are in correspondence with the theoretical analysis.

Proposed Circuit

Basic Concept of CCTA

In 2005, a new active building block namely current conveyor transconductance amplifier (CCTA) is presented for analog signal processing [38], which is suitable for a class of analog signal processing for voltage-mode and current-mode technique. CCTA has been widely applied in current-mode circuit, for example, filter and oscillator circuits. The characteristic of the ideal current conveyor transconductance amplifier are represented by the following hybrid matrix:

$$\begin{bmatrix} I_y \\ V_x \\ I_{z,z_c} \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}. \tag{1}$$

Where g_m is the transconductance of the CCTA. This g_m can be adjusted by external input bias current I_B. In some applications, the z terminal of CCTA can be extended to utilize the current through z terminal which is called z_c (z-copy). For bipolar junction transistor CCTA, the transconductance can be shown in Eq. (2). The symbol and the equivalent circuit of the CCTA are illustrated in Fig. 1 and Fig. 2, respectively.

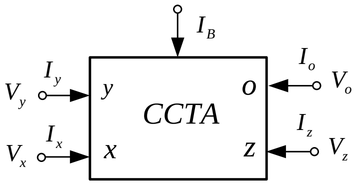

Fig. 1. Symbol of the CCTA

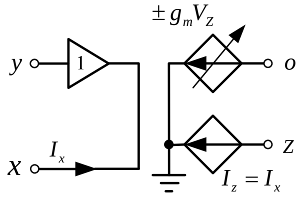

Fig. 2. Equivalent circuit of the CCTA

$$g_m = \frac{I_B}{2V_T}. \tag{2}$$

V_T is the thermal voltag. The bipolar junction transistor implementation of the internal construction of CCTA can be shown in Fig. 7.

Proposed Current-mode First Order Filter

The proposed current-mode filter can be shown in Fig. 3. It consists of single CCTA and grounded capacitor. The circuit can provide low-pass, high-pass and all-pass function. The current transferring functions of proposed circuit can be written as

$$\frac{I_{LP}}{I_{in}} = \frac{g_m}{sC_1 + g_m}, \tag{3}$$

$$\frac{I_{HP}}{I_{in}} = -\frac{sC_1}{sC_1 + g_m}, \tag{4}$$

and

$$\frac{I_{AP}}{I_{in}} = \frac{g_m - sC_1}{g_m + sC_1}. \tag{5}$$

From Eqs. (3)-(5), the pole frequency (ω_o) of the proposed filter and phase response of the all-pass function $(\phi(\omega))$ can be expressed as

$$\omega_o = \frac{g_m}{C_1}, \tag{6}$$

and

$$\phi(\omega) = -2\tan^{-1}\left(\frac{\omega C_1}{g_m}\right). \tag{7}$$

Substituting the transconductance as depicted in Eq. (2), the pole frequency and phase response can be written as

$$\omega_o = \frac{I_B}{2V_T C_1}, \tag{8}$$

and

$$\phi(\omega) = -2\tan^{-1}\left(\frac{2V_T \omega C_1}{I_B}\right). \tag{9}$$

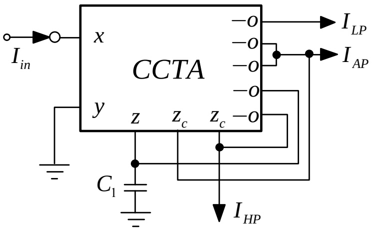

Fig. 3. Proposed current-mode first order filter

Sensitivities of the pole frequency can be written as

$$S_{g_m}^{\omega_o} = 1, \quad S_{C_1}^{\omega_o} = -1. \tag{10}$$

Proposed Current-mode Quadrature Oscillator

The proposed quadrature oscillator was designed using block diagram, shown in Fig. 4. The proposed circuit consists of 2 CDTAs and 2 grounded capacitors. The circuit is shown in Fig. 5 and the characteristic equation of the proposed circuit can be written as in Eq. (11).

$$s^2 + s\frac{g_{m1}C_2 - g_{m2}C_1}{C_1C_2} + \frac{g_{m1}g_{m2}}{C_1C_2} = 0. \tag{11}$$

From Eq. (11), the condition of oscillations and frequency of oscillation are written as

$$g_{m1} = g_{m2}, \quad C_2 = C_1, \tag{12}$$

and

$$\omega_{osc} = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}. \tag{13}$$

It is found from Eq. (12) and Eq. (13) that if $g_m = \frac{I_B}{2V_T}$, the condition of oscillation and frequency of oscillation are as follows:

$$I_{B1} = I_{B2}, \quad C_1 = C_2, \tag{14}$$

and

$$\omega_{osc} = \sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}}. \tag{15}$$

From circuit in Fig. 6, the current transfer function of I_{o1} and I_{o2} is

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{g_{m2}}{sC_2}. \tag{16}$$

For sinusoidal steady state, Eq. (16) becomes

$$\frac{I_{o2}(j\omega)}{I_{o1}(j\omega)} = \frac{g_{m2}}{\omega_{osc}C_2}e^{-j90^0}. \tag{17}$$

From Eq. (17), the phase difference ϕ between I_{o1} and I_{o2} can be written as

$$\phi = -90^0. \tag{18}$$

It is seen from Eq. (18) that the proposed current-mode quadrature oscillator can provide 2 sinusoidal signal output currents with 90^0 phase difference. Sensitivities of the active and passive of oscillator circuit is shown in Eq. (19).

$$S_{C_1,C_2}^{\omega_{osc}} = -\frac{1}{2}, \quad S_{g_{m1},g_{m2}}^{\omega_{osc}} = \frac{1}{2}. \tag{19}$$

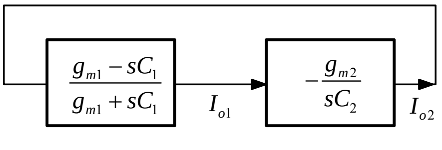

Fig. 4. Block diagram of the quadrature oscillator

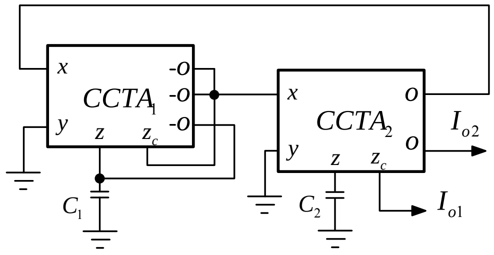

Fig. 5. Proposed quadrature oscillator based on all-pass filter

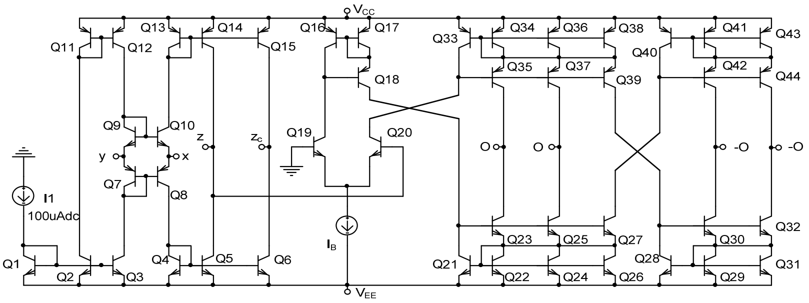

Fig. 6. Internal construction of CCTA

Analysis of Non-ideal Case

For non-idealities case, the characteristic equation of current conveyor transconductance amplifier in Eq. (1) is written as

$$\begin{bmatrix} I_y \\ V_x \\ I_{z,z_c} \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \beta & 0 & 0 \\ \alpha & 0 & 0 & 0 \\ 0 & 0 & \pm\gamma g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}. \tag{20}$$

The parameters α, β and γ are the voltage/current transfer which is deviating from one, depending on the value of intrinsic impedances and temperatures. Considering this fact and make it possible in practice, these deviations are very small and can be ignored in theory. In non-ideal case the current transferring functions from Eqs. (3)-(5) become

$$\frac{I_{LP}}{I_{in}} = -\frac{\gamma\alpha g_m}{sC_1 + \gamma g_m}, \tag{21}$$

$$\frac{I_{HP}}{I_{in}} = \frac{s\alpha C_1}{sC_1 + \gamma g_m}, \tag{22}$$

and

$$\frac{I_{AP}}{I_{in}} = \alpha\frac{sC_1 - \gamma g_m}{sC_1 + \gamma g_m}. \tag{23}$$

In this case, the (ω_o) and $(\phi(\omega))$ can be expressed as

$$\omega_o = \frac{\gamma g_m}{C_1}, \tag{24}$$

and

$$\phi(\omega) = -2\tan^{-1}\left(\frac{\omega C_1}{\gamma g_m}\right). \tag{25}$$

Additionally, in non-ideal case for the current-mode quadrature oscillator, the characteristic equation, the condition of oscillation and the frequency of oscillation from Eqs. (11) - (13) are as follows

$$s^2 + s\frac{\gamma_1 g_{m1}C_2 - \alpha_1\alpha_2 g_{m2}C_1}{C_1C_2} + \frac{\gamma_1\gamma_2\alpha_1\alpha_1 g_{m1}g_{m2}}{C_1C_2} = 0, \tag{26}$$

$$\gamma_1 g_{m1}C_2 = \alpha_1\alpha_2 g_{m2}C_1, \tag{27}$$

and

$$\omega_{osc} = \sqrt{\frac{\gamma_1\gamma_2\alpha_1\alpha_1 g_{m1}g_{m2}}{C_1C_2}}. \tag{28}$$

Analysis of the Parasitic Resistances and Capacitances

The parasitic resistances and capacitances of the CCTA can be shown in Fig. 7. If the parasitic resistances at the z and o terminals are much greater than the parasitic resistance at x terminal $(R_z, R_o \gg R_x)$. In this case, the current transferring functions from Eqs. (3)-(5) of the filter circuit become

$$\frac{I_{LP}}{I_{in}} = -\frac{g_m}{s(C_1 + C_z + C_o) + g_m}, \tag{29}$$

$$\frac{I_{HP}}{I_{in}} = \frac{s(C_1 + C_z + C_o)}{s(C_1 + C_z + C_o) + g_m}, \tag{30}$$

and

$$\frac{I_{AP}}{I_{in}} = \frac{s(C_1 + C_z + C_o) - g_m}{s(C_1 + C_z + C_o) + g_m}. \tag{31}$$

The the (ω_o) and $(\phi(\omega))$ can be expressed as

$$\omega_o = \frac{g_m}{(C_1 + C_z + C_o)}, \tag{32}$$

and

$$\phi(\omega) = -2\tan^{-1}\left(\frac{\omega(C_1 + C_z + C_{o1})}{\gamma g_m}\right). \tag{33}$$

Accordingly, the characteristic equation, condition of oscillation and the frequency of oscillation of the current-mode quadrature oscillator, from Eqs. (11)-(13) are presented as follows:

$$\left\{\begin{array}{l} s^2 + s\dfrac{g_{m1}(C_2 + C_{z2}) - g_{m2}(C_1 + C_{z1} + C_{o1})}{(C_1 + C_{z1} + C_{o1})(C_2 + C_{z2})} \\ + \dfrac{g_{m1}g_{m2}}{(C_1 + C_{z1} + C_{o1})(C_2 + C_{z2})} \end{array}\right\} = 0, \tag{34}$$

$$g_{m1}(C_2 + C_{z2}) = g_{m2}(C_1 + C_{z1} + C_{o1}), \tag{35}$$

and

$$\omega_{osc} = \sqrt{\frac{g_{m1}g_{m2}}{(C_1 + C_{z1} + C_{o1})(C_2 + C_{z2})}}. \tag{36}$$

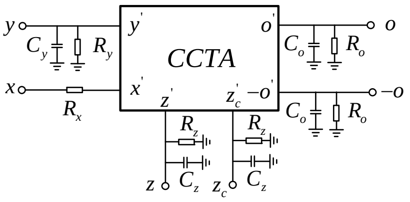

Fig. 7. The parasitic resistances and capacitances of the CCTA

Results of Computer Simulation

To verify the theoretical prediction of the proposed first order filter in Fig. 3, the PSPICE simulation was built with $C_1 = 1\text{nF}$, $I_B = 100\mu A$. The BJT implementation of the internal construction of CCTA used in simulation is shown in Fig. 6. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [39]. The circuit was biased with

$\pm 1.7V$ supply voltages. This yields pole frequency of 284.446 kHz, where the calculated value of this parameter from Eq. (8) yields 306.067 kHz (deviated by 7.064%). In this case, value of the parameter changed because the BJT implementation used in the circuit deviated from the non-ideal properties and the effect of parasitic elements. Figure 8 shows the function responses of the first order filter obtained from Fig. 3. It shows that the gain responses of the filter circuit, low-pass, high-pass and all-pass function. Figure 9 shows the phase response of the all-pass function.

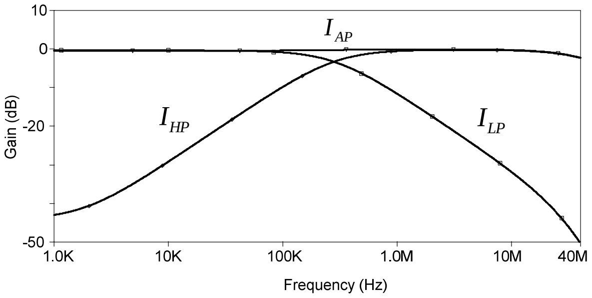

Fig. 8. Gain responses of the first order filter

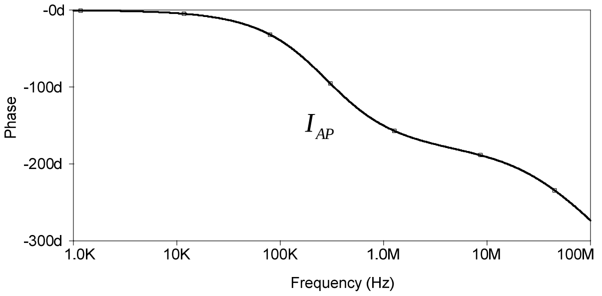

Fig. 9. Phase responses of the all-pass function

In addition, to verify the theoretical prediction of the proposed current-mode quarature oscillator in Fig. 5, the PSPICE simulation was built with $C_1 = C_2 = 1nF$, and $I_{B1} = I_{B2} = 250\mu A$. The circuit was biased with $\pm 1.7V$ supply voltages. This yields oscillation frequency of 660.330 kHz, where the calculated value of this parameter from Eq. (15) yields 765.167 kHz (deviated by 13.701%). Figures 10 and 11 show the simulated quadrature output waveforms during initial state and steady state, respectively. Figure 12 shows the simulation result of output spectrum. The results of the harmonics distortion analysis are shown in Tables 1 and 2, where the total harmonic distortion (THD) of I_{o1} and I_{o2} are about 1.394% and 0.965%, respectively. Additionally, Tables 1 and 2 can be shown, the phase difference of the output current I_{o1} and I_{o2} are about 90.1 degrees.

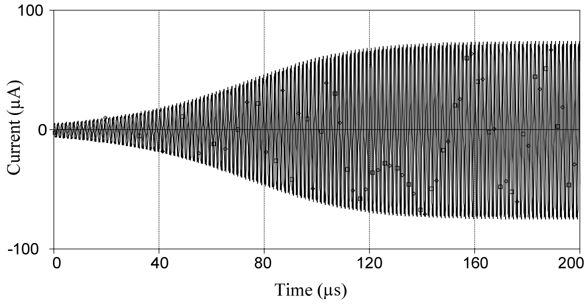

Fig. 10. The simulation result of output waveforms during initial state

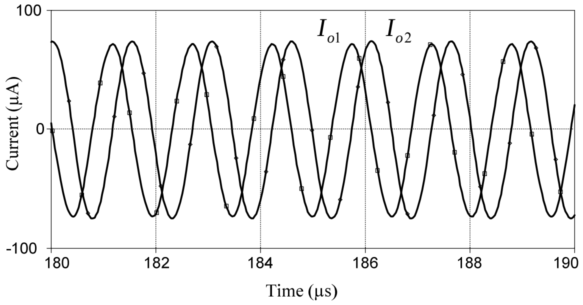

Fig. 11. The quadrature output waveforms in steady state

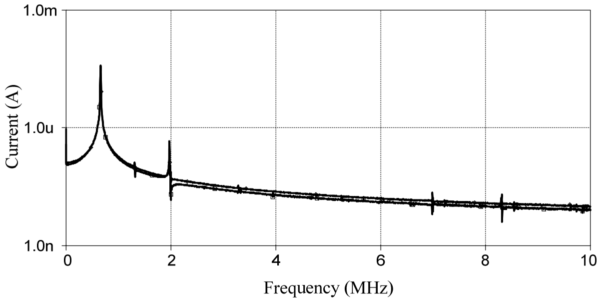

Fig.12. The output frequency spectrum

Table 1. Total harmonic distortion analysis of I_{o1}

Harmonic no.	Frequency (Hz)	Fourier Component (A)	Phase (Degrees)
1	6.603×10^5	7.210×10^{-5}	-1.395×10^2
2	1.321×10^6	3.833×10^{-7}	-1.543×10^2
3	1.981×10^6	8.744×10^{-7}	6.538×10^1
4	2.641×10^6	1.842×10^{-7}	-1.659×10^2
5	3.302×10^6	1.606×10^{-7}	-1.537×10^2
6	3.962×10^6	1.072×10^{-7}	-1.580×10^2
7	4.622×10^6	8.694×10^{-8}	-1.621×10^2
8	5.283×10^6	9.306×10^{-8}	-1.604×10^2
9	5.943×10^6	8.431×10^{-8}	-1.528×10^2
10	6.603×10^6	6.344×10^{-8}	-1.526×10^2
DC component = -7.211052×10^{-7}			
Total harmonic distortion = 1.394055%			

Table 2. Total harmonic distortion analysis of I_{o2}

Harmonic no.	Frequency (Hz)	Fourier Component (A)	Phase (Degrees)
1	6.603×10^5	7.509×10^{-5}	1.304×10^2
2	1.321×10^6	3.419×10^{-7}	1.528×10^2
3	1.981×10^6	5.912×10^{-7}	1.526×10^1
4	2.641×10^6	1.283×10^{-7}	1.677×10^2
5	3.302×10^6	1.188×10^{-7}	1.673×10^2
6	3.962×10^6	1.091×10^{-7}	1.763×10^2
7	4.622×10^6	7.814×10^{-8}	-1.735×10^2
8	5.283×10^6	5.935×10^{-8}	1.787×10^2
9	5.943×10^6	5.834×10^{-8}	-1.797×10^2
10	6.603×10^6	6.086×10^{-8}	-1.739×10^2
DC component = 1.162620×10^{-6}			
Total harmonic distortion = 0.9655245%			

Conclusion

The first order current-mode filter has been presented. It can provide low-pass, high-pass and all-pass function. The filter circuit is simple construction using only single active element. In addition,the proposed quadrature oscillator consists of two CCTAs and two grounded capacitors. Morover, the proposed current-mode filter and quadrature circuits use only grounded capacitors without addition external resistor which is very appropriate to further develop into an integrated circuit. PSPICE simulations are included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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