

A Universal Biquad Filter and a Quadrature Oscillator Using Only Two CDTAs

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Abstract— A new configuration for voltage-mode (VM) universal biquad filter using only two current differencing transconductance amplifiers (CDTAs) is proposed. The new configuration can realize all the five standard types of the filters, namely, low pass (LP), high pass (HP), band pass (BP), band stop (BS), and all pass (AP), from the same topology. The proposed configuration offers the tunability of the natural angular frequency (ω_o) and quality factor (Q) through the bias currents of the CDTAs. Moreover, the circuit has low input impedance to facilitate easy cascading without additional buffers. By a slight modification of the proposed configuration, a new CDTA-based sinusoidal quadrature oscillator can be easily obtained. The oscillation condition and the oscillation frequency are independently adjustable by adjusting different bias currents of the CDTAs. PSPICE simulation results have confirmed the practical workability of the new configuration.

Keywords—CDTA; electronically tunability; universal biquad filter; quadrature oscillator.

I. INTRODUCTION

Analog filters are widely used for continuous-time signal processing in communication, measurement, instrumentation, and control systems [1]. Universal biquadratic filters are particularly attractive since they can realize all the five standard types of the filters, namely, low pass (LP), high pass (HP), band pass (BP), band stop (BS), and all pass (AP), from the same topology. Whereas universal voltage-mode (VM) filters using current conveyors and other active elements have received considerable attention in the technical literature, many of the reported circuits suffer from the drawbacks of requiring a large number of active and/or passive components and/or non availability of tuning of filter parameters [2-4]. In general, the analog signal processing operations have been accomplished employing the voltage as signal variable. On the other hand, it has also been recognized that current-mode (CM) circuits can achieve significant improvement in bandwidth, simplification of circuitry, power consumption and dynamic range [5]. The current differencing transconductance amplifier (CDTA), a current active element [6], is suitable for IC implementation in both bipolar and CMOS technologies. Since a CDTA has the current differencing feature, it has been shown to offer a lot of flexibility in circuit design; for instance, see [6-8] and the references cited therein. Recently, an electronically tunable

current/voltage-mode universal biquad filter using current controlled current conveyor transconductance amplifier (CCCCTA) employing only two CCCCTAs and two grounded capacitors and realizing all the five standard filter functions is proposed [9]. However, a quadrature oscillator has not been obtained. Other new VM universal filters using current differencing buffered amplifiers (CDBAs) have been presented [10-11]. In addition to two capacitors, which are minimum number required, the presented filters use four resistors which is relatively a large number. More recently, CDTA-based multiple-input single-output (MISO) CM universal filter and a quadrature oscillator consisting of two CDTAs and two capacitors are presented in [12] in which the same circuit is used for the filter and the oscillator. However, the circuit is not suitable for operating in VM.

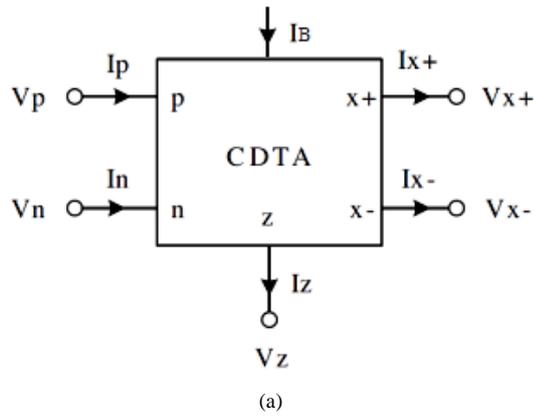
In this paper, a new CDTA-based VM universal filter and a quadrature oscillator using only two of CDTAs, two capacitors and only one resistor are proposed which provide a number of advantages over the previously reported VM circuits. The filter circuit realizes all the five standard filter functions. The workability of the proposed circuits has been demonstrated through PSPICE simulations.

II. CIRCUIT DESCRIPTION

The proposed circuit is based on CDTAs. An ideal CDTA, whose symbol and equivalent circuit are shown in Fig. 1, can be described by the following matrix equation [7]

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \end{bmatrix} \quad (1)$$

According to the above equation and the equivalent circuit of Fig. 1(b), the current through z-terminal follows the difference of the currents through the terminals p and n ($I_p - I_n$) and the voltage drop at z-terminal is transferred to a current at x-terminal (I_x) by a transconductance gain (g_m), which is electronically controllable by a bias current (I_B). For such a CDTA given in Fig. 1, $I_x = g_m V_z$ and $I_x = -g_m V_z$ where $V_z = I_z Z_z$ and Z_z is the external impedance that is considered to be connected to the z-terminal of the CDTA.



$$\frac{V_o}{V_1} = \frac{\frac{g_{m1}}{RC_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (3)$$

For HP response $V_1=V_2=0$ and $V_3=V_1$ are selected to obtain:

$$\frac{V_o}{V_3} = \frac{s^2}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (4)$$

For BP response $V_1=V_3=0$ and $V_2=V_1$ are selected to obtain:

$$\frac{V_o}{V_2} = -\frac{\frac{g_{m1}}{C_2}s}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (5)$$

For BS response $V_1=V_3=V_1$ and $V_2=0$ are selected to obtain:

$$\frac{V_o}{V_1} = \frac{s^2 + \frac{g_{m1}}{RC_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (\text{for } R = 1/g_{m2}) \quad (6)$$

For AP response $V_1=V_2=V_3=V_1$ is selected to obtain:

$$\frac{V_o}{V_i} = \frac{s^2 - \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (\text{for } R = 1/g_{m2} \text{ \& } g_{m1} = g_{m2}) \quad (7)$$

The central angular frequency ω_o and the quality factor Q of the filter can be expressed as:

$$\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}, \quad Q = \sqrt{\frac{g_{m1}C_2}{g_{m2}C_1}} \quad (8)$$

The sensitivity analysis of the proposed circuit shows that

$$S_{g_{m1}}^{\omega_o} = S_{g_{m2}}^{\omega_o} = -S_{C_1}^{\omega_o} = -S_{C_2}^{\omega_o} = S_{C_2}^Q = -S_{g_{m2}}^Q = S_{g_{m1}}^Q = -S_{C_1}^Q = \frac{1}{2}$$

Thus, the entire sensitivities are low.

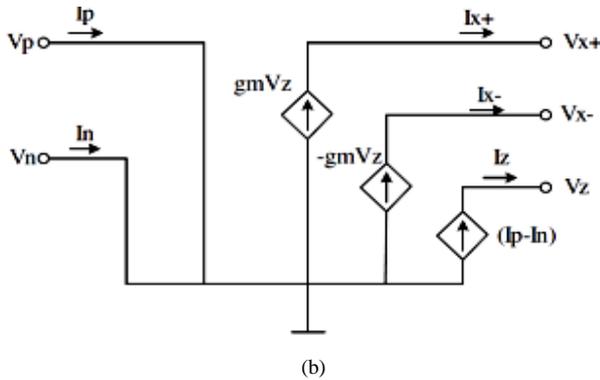


Figure 1. CDTA: (a) symbol and (b) equivalent circuit

The proposed VM universal filter based on CDTAs is shown in Fig. 2. The nodal analysis of the circuit shown in Fig. 2 yields the following transfer functions:

$$V_o = \frac{s^2V_3 - sV_2 \frac{g_{m1}}{C_2} + V_1 \frac{g_{m1}}{RC_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (2)$$

For LP response $V_3=V_2=0$ and $V_1=V_i$ are selected to obtain:

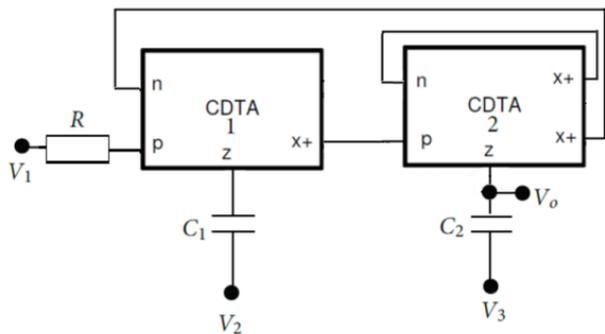


Figure 2. The proposed universal biquad filter

III. PROPOSED CDTA-BASED QUADRATURE OSCILLATOR

From the configuration of Fig. 2, by setting $V_2 = V_3 = 0$ V (grounded), open circuiting V_1 and connecting an additional $x+$ output current to the terminal p of the CDTA2, the proposed CDTA-based sinusoidal quadrature oscillator can be obtained [11] as shown in Fig. 3. It is worth noting that since V_{o2} is $(V_{o1} \times 1/s)$, i.e., V_{o2} is the integration of V_{o1} there will be a 90° phase difference between them. In this case, the characteristic equation of the second proposed configuration can be given by

$$s^2 + \frac{g_{m2} - g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2} = 0 \Rightarrow s^2 + \frac{g_{m1}g_{m2}}{C_1C_2} = 0 \quad (9)$$

The oscillation frequency (ω_o) of this configuration can be obtained, as

$$\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (10)$$

Note from (9) that the oscillation condition of the proposed oscillator of Fig. 3 can be satisfied directly without affecting the oscillation frequency ω_o . The ω_o can be adjusted by g_{m1} or/and g_{m2} . From the configuration of Fig. 3, the relationship between two quadrature output voltages V_{o1} and V_{o2} can be expressed as

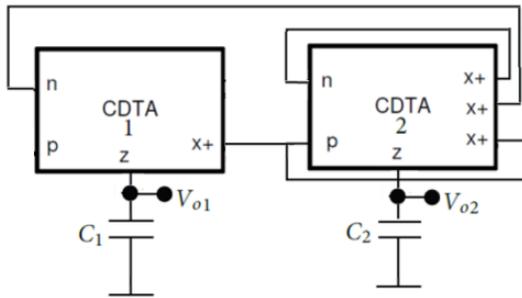


Figure 3. The quadrature oscillator based on the biquad filter

$$\frac{V_{o2}}{V_{o1}} = -\frac{g_{m2}}{sC_1} \quad (11)$$

where the phase shift is $\varphi = 90^\circ$. This guarantees that the proposed oscillator circuit provides the quadrature outputs V_{o1} and V_{o2} .

IV. SIMULATION RESULTS

The proposed universal filter circuit has been simulated using PSPICE program to verify the given theoretical analysis. The CDTAs have been simulated using the model given in Fig. 1(b) with $g_m=1$ mA/V. Simulated gain (V_o/V_i) responses of the basic filter functions (HP, LP, BP, AP and BS) of the proposed universal filter circuit are given in Fig. 4. For the simulation, the capacitance values of $C_1=C_2=40$ pF for a central frequency of $f_o \approx 5.6$ MHz and a quality factor of $Q=0.707$ are chosen. From Fig. 4 it can be realized that the simulation results agree well with the theoretical analysis.

As an example to demonstrate the workability of the proposed CDTA-based quadrature oscillator circuit in Fig. 3, the following transconductance values are chosen as $g_{m1} = g_{m2} = 0.1$ mA/V and $C_1 = C_2 = 1$ nF. The simulated quadrature output waveforms V_{o1} and V_{o2} of the oscillator are illustrated in Fig. 5.

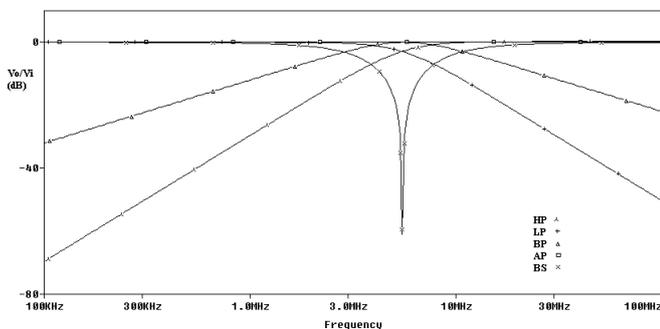


Figure 4. The simulation results for the proposed VM universal biquad filter

To show the electronically tunability of the proposed universal filter, different values of the bias currents of the CDTAs producing different transconductance gain (g_m) values

of 0.5 mA/V, 0.75 mA/V and 1.2 mA/V are selected for equal transconductance values of $g_{m1}=g_{m2}$ and capacitor values of $C_1=2C_2=0.2$ nF are chosen resulting in filter responses with a quality factor of $Q=0.707$ and natural frequencies of $f_o=2.81$ MHz, 4.26 MHz and 6.76 MHz, respectively. The magnitude response of the BP response as an example is shown in Fig. 6.

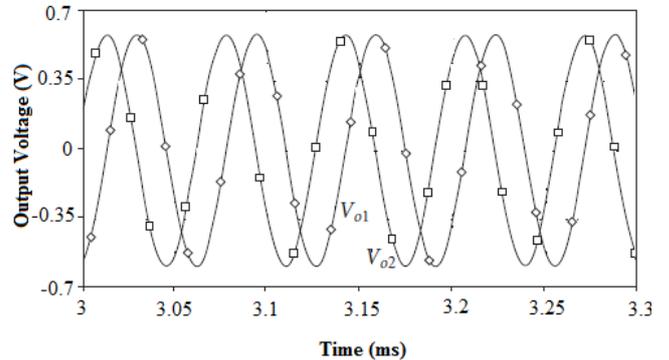


Figure 5. Simulated output signals V_{o1} and V_{o2} of the proposed quadrature oscillator based on the proposed universal biquad filter

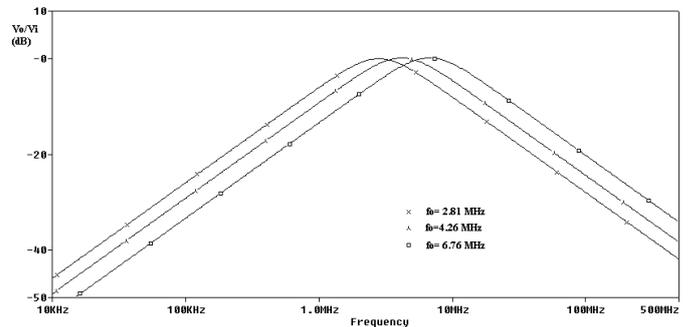


Figure 6. Magnitude response of the BP filter for different values of transconductance gains of the CDTAs

V. CONCLUSION

A new three-input single-output VM universal filter using two CDTAs has been proposed which can realize all the five standard types filter functions with only two capacitors and one resistor to enable sequential tuning of various filter parameters. The proposed circuit has one external resistor going to the input terminal of the first CDTA and the other input terminals are going to x-terminals of the CDTAs, due to which the parasitic input resistances of the CDTAs can be easily merged in the external resistor and the transconductance (g_m) of the CDTAs. In the proposed circuit, any additional voltage inversion is not required to realize all pass function, thus resulting in the saving of one active element. Furthermore, a CDTA-based quadrature oscillator can be obtained easily by slightly modifying the proposed CDTA-based biquad filter. Its oscillation condition is satisfied directly and its oscillation frequency can be controlled via CDTA biasing currents. In addition, the sensitivities of the proposed circuit are shown to be low. PSPICE simulations have verified the workability of the proposed circuits.

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