An Electronic Controllable Biquadratic Filter based on Single MO-CCCCTA

Abstract: This article presents a multi-input single-output (MISO) electronically controllable current-mode universal biquadratic filter. The proposed circuit is a simple construction consisting of a single multi-output current-controlled current conveyor transconductance amplifier (MO-CCCCTA), one resistor, and two grounded capacitors, which is well suited for integrated circuit fabrication. The highlight of the circuit is the response of five functions, including high-pass (HP), band-pass (BP), low-pass (LP), band-reject (BR), and all-pass (AP), which can be configured by correctly selecting input signals. In addition, the pole frequency can be independently adjusted from the quality factor by a bias current. Moreover, it is also convenient to be connected in current-mode due to its high-impedance output. The results of the simulation with the Pspice program to test the performance of the proposed universal filter circuit using an internal structure of MO-CCCCTA, BJT construction, were consistent with the theory as expected.

Keywords: MISO Filter, Current-mode, MO-CCCCTA.

Introduction
In electronic and electrical engineering, having been widely known that the analog filter is the most and widely applied for continuous time signal processing such as in medical instrument, telecommunications, and control system [1-2]. One of the popular filters is multi-input single-output (MISO), also known as a multi-purpose filter circuit [3]. The multi-function frequency filter circuit is characterized by its structure which is not complicating and its ability to respond to all types of frequencies [4].

Various techniques of using active buling block for designing the MISO within the CCTA and CCCCTA have been recently proposed [5,7-34]. The proposed filters current mode in [9, 10, 13, 14, 17-19, 21, 23, 25, 27-29, 34] contain excessive number of active elements (more than only ABB). The floating resistor is required for the proposed filter in [20, 32, 33]. In [20, 33], For the floating capacitor, the quality factor is not independently tuned from the natural frequency [5,11, 12, 31-32]. The advantages of MISO filter are shown in Table 1.

In the past decade, there were attempts to reduce the supply voltage and power consumption in electronic circuits due to the need to use with portable devices or wireless communication devices that use batteries as a power source. Therefore, a circuit has been developed to be able to perform multiple functions. Meanwhile, current mode techniques which have many advantages including wide dynamic range, are also applied. The circuit works well at low voltage, higher bandwidth, greater linearity, and lower power consumption [5-6].

The purpose of this paper is to introduce the current-mode filter using single MO-CCCCTA, two capacitors and one resistor which simultaneously provides HP,BP,LP,BR and AP without changing circuit topology. The feature is very simple. The possibility to electronically and independently adjust the quality factor and natural frequency is consummate which shows the PSpice simulation validate the workability of the filter circuits.

Streszczenie.
W artykule przedstawiono wielowejściowy jednowyjściowy (MISO) elektronicznie sterowany uniwersalny dwukwadratowy filtr w trybie prądowym. Proponowany obwód jest prostą konstrukcją składającą się z pojedynczego, wielowymiarowego, sterowanego prądowo wzmacniacza transkonduktacyjnego (MO-CCCCTA), jednego rezystora i dwóch uziemionych kondensatorów, co doskonale nadaje się do wytwarzania układów scalonych. Najważniejszym punktem obwodu jest odpowiedź pięciu funkcji, w tym górnoprzepustowy (HP), pasmowoprzepustowy (BP), dolnoprzepustowy (LP), pasmowy odrzucający (BR) i wszechprzepustowy (AP), które można skonfigurować poprzez prawidłowy wybór sygnałów wejściowych. Ponadto częstotliwość biegunów może być niezależnie regulowana od współczynnika jakości za pomocą prądu polarizacji. Co więcej, można go również wygodnie podłączyć w trybie prądowym ze względu na wyższe impedancje. Wyniki symulacji za pomocą programu Pspice do testowania wydajności proponowanego obwodu filtra uniwersalnego z wykorzystaniem wewnętrznej struktury MO-CCCCTA, konstrukcja BJT, były zgodne z oczekiwaną teorią (Elektronicznie sterowany filtr dwukwadratowy oparty на pojedynczym MO-CCCCTA)

Słowa kluczowe: MISO Filter, Current-mode, MO-CCCCTA.

Principle Characteristics of MO-CCCCTA
The structure multiple output current-controlled current conveyor transconductance amplifier (MO-CCCCTA) is a six-terminal analogue active element. The names of the input and output terminal are represented as $x, y, z_1, z_2$.

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The $y$ terminal is the voltage input port with high impedance. The $x$ terminal contains controllable parasitic resistance ($R_x$) is the current input port. The high impedance $z_1$, $z_2$, $o_1$ and $o_2$ terminals are the current output port. Ideally, the current at $z$ terminal is equal to current at $x$ terminal. The symbol and equivalent circuit of the MO-CCCCTA are presented by Fig. 1. The characteristics of idea MO-CCCCTA can be following matrix:

$$
\begin{bmatrix}
I_1 & R_x & 0 \\
I_y & 1 & 0 \\
I_{z1} & 0 & 0 \\
I_{z2} & 0 & 0 \\
i_o & 0 & 0 \\
i_2 & 0 & 0 \\
i_3 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
I_y \\
i_{z1} \\
i_{z2} \\
i_1 \\
i_2 \\
i_o
\end{bmatrix} = \begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
$$

Where

$$V_x = I_x R_x + V_y $$

$$I_{z1} = I_{z2} = I_o = I_x$$

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<th>Table1. Comparison between various MISO filters using CCTA and CCCCTA</th>
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<td>Proposed filter</td>
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![Fig.2. Internal Construction of MO-CCCCTA](image-url)
Proposed MISO filter.

The proposed MISO filter is shown in Fig.3 and it uses the MO-CCCCTA properties to transfer function output to be

\[
I_{\text{out}} = \frac{g_{\text{m}} R I_{\text{in1}} - g_{\text{m}} I_{\text{in2}} + \left[ s + \frac{g_{\text{m}} R}{R C_1} + \frac{g_{\text{m}}}{R C_2} \right] I_{\text{in3}}}{s^2 + \frac{g_{\text{m}} R}{R C_1} + \frac{g_{\text{m}}}{R C_2}}
\]

From Eq.(3), \( I_{\text{out}}, I_{\text{in1}}, I_{\text{in2}} \) and \( I_{\text{in3}} \) can be chosen as in Table 2 to achieve transfer function. The pole frequency \( (\omega_p) \) and quality factor \( (Q_o) \) are given by

\[
\omega_p = \frac{1}{2\pi \frac{g_{\text{m}} R}{R C_2}}
\]

\[
Q_o = \frac{1}{g_{\text{m}} R \sqrt{C_1 C_2}}
\]

Substituting the parasitic resistance \( R_1 = V_i / 2I_{\text{in1}} \) transconductance gain \( g_{\text{m}} = I_{\text{in1}} / 2V_i \) and \( g_{\text{m}} = I_{\text{in2}} / 2V_i \) into Eq.(4) and Eq.(5) can be expressed as

\[
\omega_p : f_o = \frac{1}{2\pi V_i} \sqrt{\frac{I_{\text{in1}}}{C_2}}
\]

\[
Q_o = \frac{1}{g_{\text{m}} R \sqrt{C_1 C_2}}
\]

The current-mode MISO filters have the same ability and the \( \omega_p \) and \( Q_o \) can be electronically tuned by adjusting the external bias current of the MO-CCCCTA. Moreover, the quality factor can be independently tuned with bias current \( I_{\text{in1}} \) without any effect on the pole frequency.

Sensitivities of proposed MISO filters.

Sensitivities of the active and passive of filter circuit were illustrated in Eq.(8) and (9)

\[
S_{\omega p}^{\omega p} = S_{\omega p}^{f_o} = \frac{1}{2}, S_{Q_o}^{C_{11}} = S_{Q_o}^{C_{22}} = \frac{1}{2}, S_{\omega p}^{V_i} = -1
\]

\[
S_{\omega p}^{g_{\text{m}}} = S_{\omega p}^{I_{\text{in1}}} = -1, S_{Q_o}^{R_1} = S_{Q_o}^{C_1} = S_{Q_o}^{C_2} = \frac{1}{2}, S_{\omega p}^{R_1} = S_{\omega p}^{C_1} = -1
\]

It can be obviously seen that all the sensitivities of the proposed filter were lower, equal to or less than the unity in magnitude.

Effect error non-idea

Analysis of voltage and current transfer

The performance of circuit was deviated from the idea because of deviations of internal current and voltage transfer of MO-CCCCTA. These parameters include the voltage tracking error \( (\beta) \) and the current tracking error \( (\gamma, \alpha) \). The MO-CCCCTA properties form Eq.(1) were changed in order that it can be rewritten as

\[
\begin{bmatrix}
I_y \\
V_x \\
I_{\text{in1}}, I_{\text{in2}}, I_{\text{in3}} \\
I_{\text{in1}} \\
I_{\text{out}} \\
I_{\text{in2}}
\end{bmatrix}
= \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
R_1 & \beta & 0 & 0 & 0 & 0 \\
\alpha & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \pm \gamma g_{\text{m1}} & 0 & V_y \\
0 & 0 & 0 & \pm \gamma g_{\text{m2}} & 0 & V_y \\
0 & 0 & 0 & \pm \gamma g_{\text{m3}} & 0 & V_y
\end{bmatrix}
\begin{bmatrix}
I_y \\
V_x \\
I_{\text{in1}}, I_{\text{in2}}, I_{\text{in3}} \\
I_{\text{in1}} \\
I_{\text{out}} \\
I_{\text{in2}}
\end{bmatrix}
\]

From Eq.(10), the case of non-idea and reanalysis of proposed filter circuit in Fig. 3, the output current can be written as:

\[
I_{\text{out}} = \frac{\beta A}{R C_1} I_{\text{in1}} - \frac{B}{R C_2} I_{\text{in2}} + \left( s^2 + \frac{\beta A}{R C_1} + \frac{\beta B}{R C_2} \right) I_{\text{in3}}
\]

where \( A = \alpha_m g_{\text{m}} R_1, B = \gamma m g_{\text{m}} R_1 \)

\[
F(s) = \left( s^2 + \frac{\alpha_m g_{\text{m}} R_1}{R C_2} + \frac{\gamma \alpha_m g_{\text{m}} C R_1}{C_2} \right)
\]

In this case, the \( \omega_p \) and quality factor \( Q_o \) in Eq.(4) and Eq.(5) are changed to

\[
\omega_p : f_o = \frac{1}{2\pi \sqrt{g_{\text{m}} R C_2}}
\]

\[
Q_o = \frac{1}{g_{\text{m}} R \sqrt{C_1 C_2}}
\]

Analysis of the parasitic resistances and capacitances

The parasitic resistances and capacitances of MO-CCCCTA, \( R_1 \) \( R_2 \), and \( C_1 \) \( C_2 \) are the parasitic resistances of \( y \) at the input terminals. In addition, the output \( z \) and \( o \) terminals consist of parasitic resistances and capacitances \( R_{z1}, R_{z2}, C_{z1}, C_{z2} \) and \( R_{o1}, R_{o2}, C_{o1}, C_{o2} \) from terminals to ground. The parasitic resistances and capacitances of the MO-CCCCTA can be shown in Fig. 4, the transfer function of the proposed circuits becomes

\[
I_{\text{out}} = -\frac{g_{\text{m2}} \left( C \right) I_{\text{in1}} - g_{\text{m1}} \left( R + C \right) I_{\text{in2}} - F_i(s) I_{\text{in3}}}{F_i(s)}
\]

where

\[
F_i(s) = s^2 + s \left[ \frac{C}{RC} \right] + s \left[ \frac{g_{\text{m2}} C + g_{\text{m1}} C}{RC C} \right] + \frac{g_{\text{m1}}}{R C C}
\]

For current-mode biquad filter, the transfer function with general third order transfer functions was given by

\[
I_{\text{out}} = s^2 + \omega_p \left( 1 + \frac{1}{Q_o} \right) s + \omega_p^2
\]
By comparing Eq. (14) with Eq. (15), can be found that

\[ \omega_2 = \frac{g_m}{RCC} \quad (16) \]
\[ \omega_2 \left[ 1 + \frac{1}{Q_0} \right] = \left[ \frac{g_m}{RCC} \right] \quad (17) \]
\[ \omega_2 \left[ 1 + \frac{1}{Q_0} \right] = \left[ \frac{C}{RC} \right] \quad (18) \]

where \( C = C_1 + C_{s1} + C_{s2} \), \( C' = C_1C_{s1} + C_1C_{s2} \) and \( C'' = C_1 + C_2 \).

The \( \omega_2 \) and the \( Q_0 \) in Eq. (4) and Eq. (5) were changed to

\[ \omega_2 = \frac{1}{2} \sqrt{\frac{g_m}{RCC}} \quad (19) \]
\[ Q_0 = \frac{\omega_2 RC}{C'' - \omega_2 RC} \quad (20) \]

Simulation Results

To verify the theoretical analysis of the proposed circuit as shown in Fig. 3, it was simulated using the PNP and NPN transistors by the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T. Internal construction of MO-CCCCTA used in simulation was shown in Fig. 2. The power supply voltage was taken as ±1.5 V and the capacitors of the configuration values were chosen as \( C_1 = 1 \text{nF}, R = 250 \text{ohms} \). The simulation set for \( Q_0 = 1 \) and \( f_0 = 293.765 \text{kHz} \) with \( I_{B1} = 50 \mu A \), \( I_{B2} = 100 \mu A \), and \( I_{B3} = 200 \mu A \). Fig. 5 presents gain response of proposed circuit output-current, gain of the LP, BP, AP, HP, and BR depending on the selection as illustrated in Table 2 without modifying circuit topology.

The simulated pole frequency of the proposed circuit was obtained as 293.765 kHz while the calculated value from Eq. (4) was about 306.067 kHz (deviated about 4.019%). The deviation was affected by error of current, current transfer gains and parasitic elements of the MO-CCCCTA. The results in Fig. 6 present the tuning of \( Q_0 \) for the BP response by electronics adjusting at \( Q_0 = 2, 1, 0.6 \) and 0.5 when kept to be \( I_{B1} = I_{B2} = 50 \mu A \) and varied \( I_{B3} \) as 50, 100, 150, and 200 \( \mu A \), respectively. These results confirmed that \( Q_0 \) can be electronically adjusted without affecting of pole frequency Fig. 7 shows the gain responses of the band-pass function while setting \( I_{B1} = I_{B2} = 50 \mu A \), \( I_{B1} = I_{B2} = 100 \mu A \), \( I_{B1} = I_{B2} = 200 \mu A \) respectively. This result showed that the pole frequency of the BP response at 293.765 kHz, 578.096 kHz and 1.097 MHz can be adjusted without affecting the quality factor, as described in Eq.(6) and Eq.(7)
The current-mode multifunction biquadratic filter circuit shown in this article is based on a single MO-CCCCTA. The proposed circuit has a simple construction since it is composed of a single MO-CCCCTA and three grounded passive components, which makes it ideal for fabrication into an integrated circuit. The designed circuit provides five functions of filter, which are high-pass (HP), band-pass (BP), low-pass (LP), band-reject (BR), and all-pass (AP) responses by selecting input conditions. The results of the simulation with the Pspice program showed that the circuit works in accordance with the analyzed theory. Consequently, the designed circuit is suitable for developing integrated circuits used in wireless communication systems.

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