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doi:10.15199/48.2022.05.25

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 multiple-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.*

Streszczenie. *W artykule przedstawiono wielowejściowy jednowyjściowy (MISO) elektronicznie sterowany uniwersalny dwukwadratowy filtr w trybie prądowym. Proponowany obwód jest prostą konstrukcją składającą się z pojedynczego, wielowyjściowego, sterowanego prądowo wzmacniacza transkonduktancyjnego (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 polaryzacji. Co więcej, można go również wygodnie podłączyć w trybie prądowym ze względu na wyjście o wysokiej impedancji. 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 na pojedynczym MO-CCCCTA***)

Keywords: MISO Filter, Current-mode, MO-CCCCTA.
Słowa kluczowe: filtr dwukwadratowy, wzmacniacz transkonduktancyjkny

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 inTable 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 posibility to electronically and independenlty adjust the quality factor and natural frequency is consummate which shows the PSpice simulation validate the workability of the filter circuits.

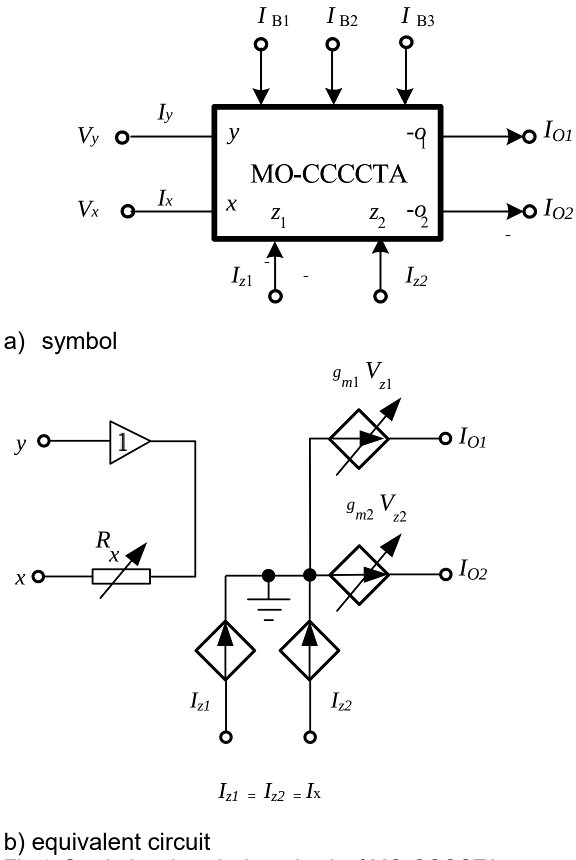


Fig.1. Symbol and equivalent circuit of MO-CCCCTA

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

o_1 and o_2. 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 parasitic resistance R_x is electronically tuned. 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

(1) $$\begin{bmatrix} I_y \\ V_x \\ I_{z1}, I_{z2}, I_{zc} \\ I_{o1} \\ I_{o2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \pm g_{m1} & 0 \\ 0 & 0 & 0 & 0 & \pm g_{m2} \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_{z1} \\ V_{o1} \\ V_{o2} \end{bmatrix}$$

Where

(2) $V_x = I_x R_x + V_y$, $I_{z1} = I_{z2} = I_{zc} = I_x$

$$I_{o1} = g_{m1} V_{Z1} \quad , \ I_{o2} = g_{m2} V_{Z2}$$

$$R_x = \frac{V_T}{2 I_{B1}}, g_{m1} = \frac{I_{B2}}{2V_T}, g_{m2} = \frac{I_{B3}}{2V_T}$$

V_T is the thermal voltage equal to 26 mV. From Eq.(2), the g_m is transconductance gain lineally controlled by I_{B2} and I_{B3}, and the parameter R_x is controlled by I_{B1}. The BJT internal construction of MO-CCCCTA is illustrated in Fig.2.

Table 2. Input selection to output filter response.

Input Selection			Filter Response
I_{in1}	I_{in2}	I_{in3}	I_{out}
0	1	0	LP
1	0	0	BP
2	0	1	AP
1	1	1	HP
1	0	1	BR

Table1. Comparison between various MISO filters using CCTA and CCCCTA

Ref.	Active element	No.of active element	No.of input signals	No.of R +C	Floating C connector	Independent tune of ω_0 and Q_o	Current mode
[5]	CCCTA Fig.8	1	3	0+1	No	No	Yes
[7]	CCCCTA	1	3	0+2	No	Yes	Yes
[8]	DO-CCCDTA	1	3	0+2	No	Yes	Yes
[9]	CCCCTA	2	3	0+2	No	Yes	Yes
[10]	CCCDTA	3	3	0+2	No	Yes	Yes
[11]	MO-CCTA	1	3	1+2	No	No	Yes
[12]	MO-CCCCTA	1	3	1+2	No	No	Yes
[13]	CCCCTA,OP-AMP	2,2	3	0+0	No	Yes	Yes
[14]	DO-CCTAs	2	3	0+0	No	Yes	Yes
[15]	CCCCTA	1	3	0+2	No	Yes	No
[16]	CCTA Fig.14	1	3	2+1	Yes	Yes	No
[17]	MO-CCCCTA	2	3	0+2	No	Yes	No
[18]	CCTAs	2	3	0+2	No	Yes	Yes
[19]	CCCCTA	2	3	0+2	No	Yes	Yes
[20]	CCCCTA	1	3	1+2	Yes	Yes	No
[21]	CCCCTAs	2	3	0+2	No	Yes	Yes
[22]	DV- CCCCTA	1	3	0+2	Yes	Yes	No
[23]	CCCCTA,DP-CCCII	2	3	0+2	No	Yes	No
[24]	CCDDCCTA	1	3	0+2	No	Yes	No
[25]	CCTA	2	3	1+2	No	Yes	No
[26]	DV- CCCCTA Fig.4	1	3	0+2	Yes	Yes	No
[27]	EXCCTA	2	3	3+2	No	Yes	VM/CM
[28]	CCCTAs	2	3	0+2	No	Yes	Yes
[29]	CCTAs	2	3	0+2	No	Yes	Yes
[30]	CCCTA	1	3	0+2	No	Yes	Yes
[31]	CCCTA	1	3	0+2	No	No	Yes
[32]	CCTA	1	3	3+2	No	No	No
[33]	MDVCCTA	1	3	2+2	Yes	Yes	No
[34]	CCCCTAs	2	3	0+2	Yes	Yes	No
Proposed filter	MO-CCCCTA	1	3	1+2	No	Yes	Yes

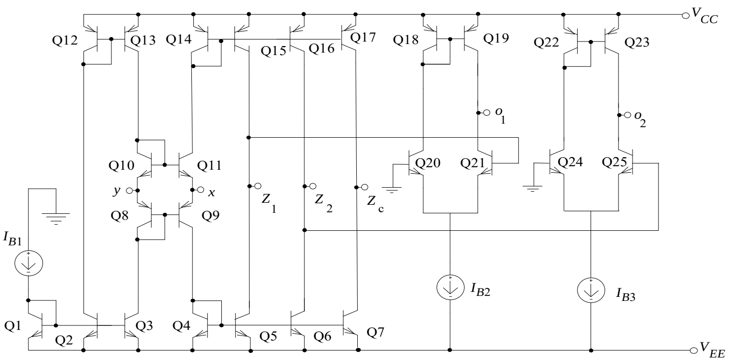


Fig.2. Internal Construction of MO-CCCCTA

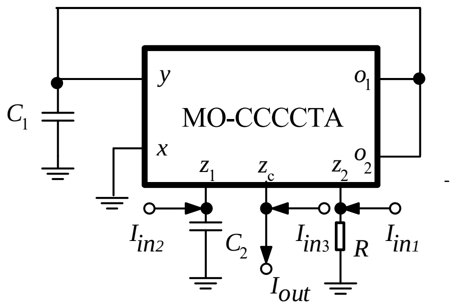


Fig.3. Proposed filter of MO-CCCCTA

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

$$(3) I_{out} = -\frac{s\dfrac{g_{m2}R}{R_xC_1}I_{in1} - \dfrac{g_{m1}}{R_xC_1C_2}I_{in2} + \left[s^2 + s\dfrac{g_{m2}R}{R_xC_1} + \dfrac{g_{m1}}{R_xC_1C_2}\right]I_{in3}}{s^2 + s\dfrac{g_{m2}R}{R_xC_1} + \dfrac{g_{m1}}{R_xC_1C_2}}$$

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

$$(4) \qquad \omega_o : f_o = \frac{1}{2\pi}\left(\frac{g_{m1}}{R_xC_1C_2}\right)$$

$$(5) \qquad Q_o = \frac{1}{g_{m2}R}\sqrt{\frac{g_{m1}C_1R_x}{C_2}}$$

Substituting the parasitic resistance $R_x = V_T/2I_{B1}$ transconductance gain $g_{m1} = I_{B2}/2V_T$ and $g_{m2} = I_{B3}/2V_T$ into Eq.(4) and Eq.(5) can be expressed as

$$(6) \qquad \omega_o : f_o = \frac{1}{2\pi V_T}\sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}}$$

$$(7) \qquad Q_o = \frac{V_T}{I_{B3}R}\sqrt{\frac{I_{B2}C_1}{I_{B1}C_2}}$$

The current-mode MISO filters have the same ability and the ω_o and the 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_{B3} 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)

$$(8) \qquad S_{I_{B1}}^{\omega_o} = S_{I_{B2}}^{\omega_o} = \frac{1}{2}, S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -\frac{1}{2}, S_{V_T}^{\omega_o} = -1$$

$$(9) \qquad S_{I_{B1}}^{Q_o} = S_{C_2}^{Q_o} = -\frac{1}{2}, S_{I_{B2}}^{Q_o} = S_{C_1}^{Q_o} = \frac{1}{2}, S_{I_{B3}}^{Q_o} = S_{R}^{Q_o} = -1$$

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 (β) and the current tracking error (γ, α). The MO-CCCCTA properties form Eq.(1) were changed in order that it can be rewritten as

$$(10) \qquad \begin{bmatrix} I_y \\ V_x \\ I_{z1}, I_{z2}, I_{zc} \\ I_{o1} \\ I_{o2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ R_x & \beta & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \pm\gamma_1 g_{m1} & 0 \\ 0 & 0 & 0 & 0 & \pm\gamma_2 g_{m2} \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_{z1} \\ V_{o1} \\ V_{o2} \end{bmatrix}$$

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

$$(11) I_{out} = \frac{\beta\left(-\dfrac{A}{R_xC_1}I_{in1} - \dfrac{B}{R_xC_1C_2}I_{in2}\right) + \left(s^2 + s\dfrac{\beta A}{R_xC_1} + \dfrac{\beta B}{R_xC_1C_2}\right)I_{in3}}{F(s)}$$

where $A = \alpha_2\gamma_2 g_{m2}R$, $B = \alpha_1\gamma_1 g_{m1}$

$$F(s) = \left\{s^2 + s\frac{\alpha_2\gamma_2\beta g_{m2}R}{R_xC_1} + \frac{\alpha_1\gamma_1\beta g_{m1}}{R_xC_1C_2}\right\}$$

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

$$(12) \qquad \omega_o : f_o = \frac{1}{2\pi}\sqrt{\frac{\alpha_1\gamma_1\beta g_{m1}}{R_xC_1C_2}}$$

$$(13) \qquad Q_o = \frac{1}{\alpha_2\gamma_2 g_{m2}R}\sqrt{\frac{\alpha_1\gamma_1 g_{m1}C_1R_x}{C_2}}$$

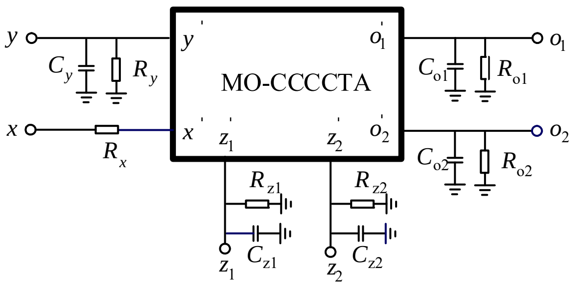


Fig.4. Parasitic of MO-CCCCTA

Analysis of the parasitic resistances and capacitances

The parasitic resistances and capacitances of MO-CCCCTA, R_y and C_y 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

$$(14) I_{out} = -\frac{g_{m2}\left(C''\right)sI_{in1} - g_{m1}\left(\dfrac{1}{R} + C_{z2}\right)I_{in2} - F_1(s)I_{in3}}{F_1(s)}$$

where

$$F_1(s) = s^3 + s^2\left[\frac{C'''}{RC''}\right] + s\left[\frac{g_{m1}C_{z2} + g_{m2}C'''}{R_xC''C'}\right] + \frac{g_{m1}}{R_xC_1C''C'}$$

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

$$(15) \; I_{out} = s^3 + \omega_o\left(1 + \frac{1}{Q_o}\right)s^2 + \omega_o^2\left(1 + \frac{1}{Q_o}\right)s + \omega_o^3$$

By comparing Eq. (14) with Eq. (15), can be found that

$$\omega_o^3 = \frac{g_{m1}}{R_x C' C'' C'''} \quad (16)$$

$$\omega_o^2\left[1+\frac{1}{Q_o}\right] = \left[\frac{g_{m1}C_{z2} + g_{m2}C'''}{R_x C' C''}\right] \quad (17)$$

$$\omega_o\left[1+\frac{1}{Q_o}\right] = \left[\frac{C'''}{RC''}\right] \quad (18)$$

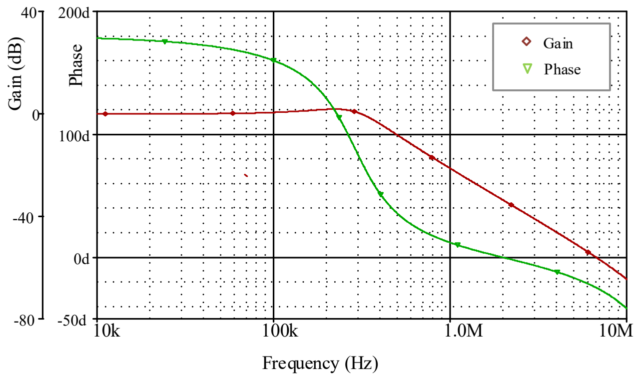
where $C' = C_1 + C_{y1} + C_{o1} + C_{o2}$, $C'' = C_{z1}C_{z2} + C_1C_{z2}$ and $C''' = C_{z1} + C_2$

The ω_o and the Q_o in Eq.(4) and Eq.(5) were changed to

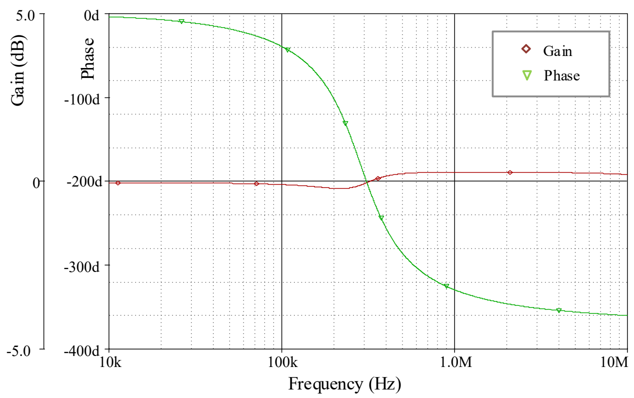
$$\omega_o : f_o = \frac{1}{2}\sqrt[3]{\frac{g_{m1}}{R_x C' C'' C'''}} \quad (19)$$

$$Q_o = \frac{\omega_o RC''}{C''' - \omega_o RC''} \quad (20)$$

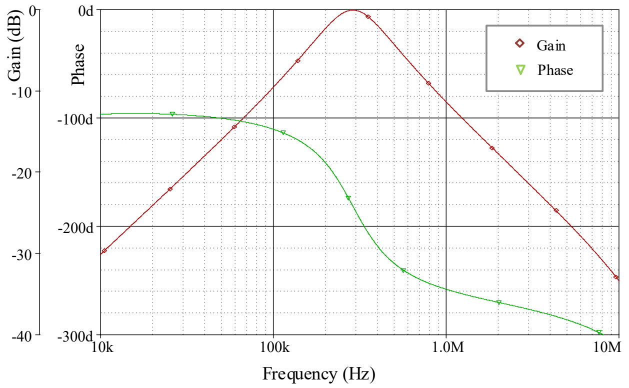
a) LP



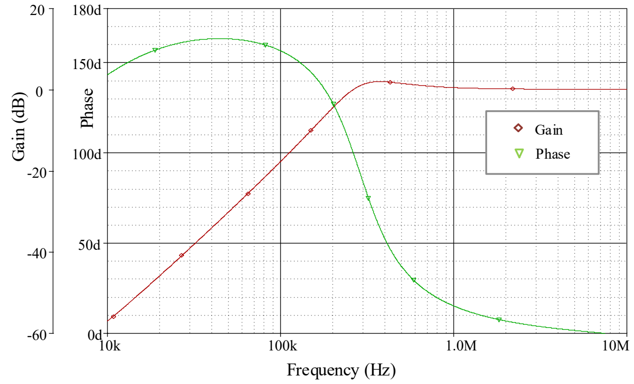
b) AP



c) BP



d) HP



e) BR

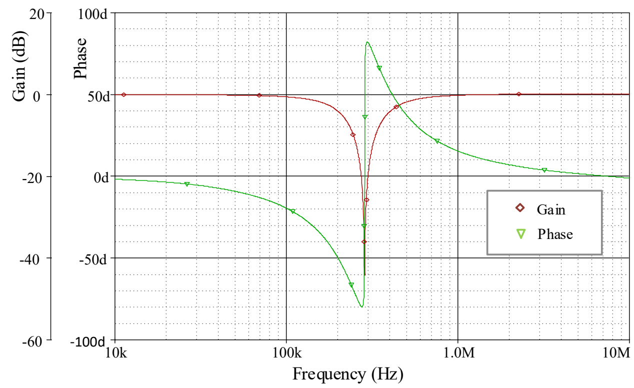


Fig.5. shows gain response of proposed circuit output-current gain of the LP, BP, AP,HP and BR

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 = C_2= 1 nF, R =250 ohms. The simulation set for Q_o =1 and f_o =293.765 kHz with $I_{B1} = I_{B2}$ =50μA, I_{B3} = 100μA, 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_o for the BP response by electronics adjusting at Q_o = 2, 1, 0.6 and 0.5 when kept to be $I_{B1} = I_{B2}$ =50μA and varied I_{B3} as 50, 100,150 and 200 μA, respectively. These results confirmed that Q_o can be electronically adjusted without affecting of pole frequency Fig. 7 shows the gain responses of the band-pass function while setting I_{B3} = 50μA constantly change according to the settings I_{B1} = I_{B2} =50μA, I_{B1} = I_{B2} 100μA, I_{B1} = I_{B2} =200μA 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)

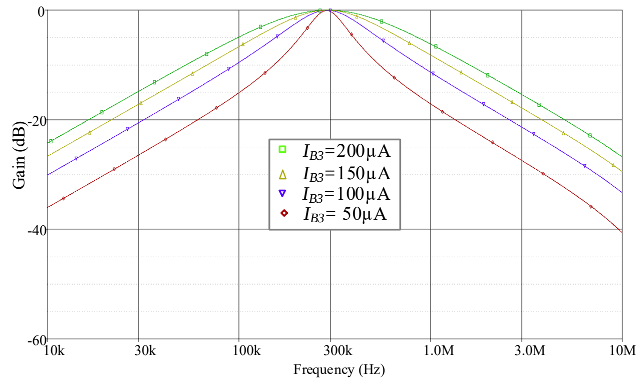


Fig.6. Bandpass responses by changing the bias current I_{B3}

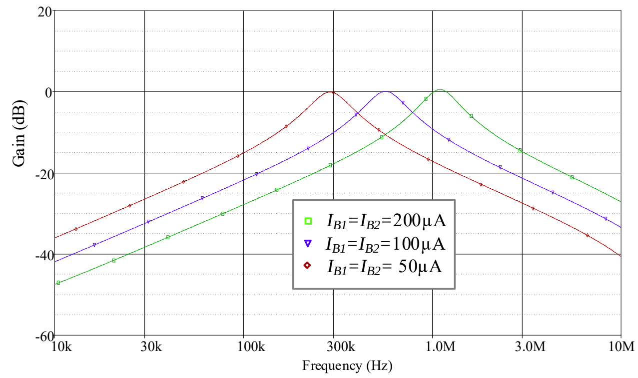


Fig.7. Bandpass responses by changing the bias currents $I_{B1} = I_{B2}$

Conclusion

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.

Acknowledgments

This research project is supported by Faculty of Engineering, Rajamangala University of Technology Isan, Khonkaen Campus, Khonkaen, Thailand.

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