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DVCCTAs-based current-mode MISO filters with separate adjustments for pole frequency, quality factor and amplitude

***Abstract**. The current-mode multi-input single-output filters design on a differential voltage current conveyor transconductance amplifier (DVCCTA) are the topic of this article. The multi-input single-output filters that are presented in this paper provide two DVCCTAs, two resistors, and two capacitors connected to ground, all of which are appropriate for the manufacture of integrated circuits. By choosing the appropriate input signals, it is possible to react the all five typical filter functions, including low-pass, high-pass, band-pass, band-reject, and all-pass response. An external resistor allows for proportional and independent tune of the quality factor in relation to the pole frequency. In addition, the adjustment independent of the pole frequency can be modified by the use of external capacitors. The output signal amplitude can be individually modified without affecting its quality factor or pole frequency. In addition, the output has a high impedance, which makes it appropriate as a setup of a current-mode design. A simulation with the PSPICE software demonstrated that the efficiency of the circuit is completely consistent with the theoretical analysis.*

Streszczenie.** Tematem tego artykułu jest projekt wielowejściowych filtrów jednowyjściowych w trybie prądowym na wzmacniaczu transkonduktancji przenośnika prądu różnicowego napięcia (DVCCTA). Przedstawione w tym artykule filtry wielowejściowe i jednowyjściowe zawierają dwa DVCCTA, dwa rezystory i dwa kondensatory połączone z masą, z których wszystkie są odpowiednie do produkcji układów scalonych. Wybierając odpowiednie sygnały wejściowe, możliwe jest reagowanie na wszystkie pięć typowych funkcji filtra, w tym odpowiedź dolnoprzepustową, górnoprzepustową, środkowoprzepustową, pasmową i wszechprzepustową. Zewnętrzny rezystor pozwala na proporcjonalne i niezależne dostrojenie współczynnika jakości w stosunku do częstotliwości biegunów. Ponadto regulację niezależną od częstotliwości biegunów można modyfikować za pomocą zewnętrznych kondensatorów. Amplituda sygnału wyjściowego może być indywidualnie modyfikowana bez wpływu na jego współczynnik jakości lub częstotliwość biegunów. Ponadto wyjście ma wysoką impedancję, co sprawia, że jest odpowiednie jako konfiguracja projektu w trybie prądowym. Symulacja za pomocą oprogramowania PSPICE wykazała, że wydajność obwodu jest całkowicie zgodna z analizą teoretyczną.* (Oparte na DVCCTA filtry MISO w trybie prądowym z oddzielnymi regulacjami częstotliwości biegunowej, współczynnika jakości i amplitudy***)

Keywords: current-mode, multi-input single-output, grounded capacitor, DVCCTA.
Słowa kluczowe: tryb prądowy, wielowejściowe jednowyjściowe, uziemiony kondensator, DVCCTA

Introduction

Analog filters have become a part of electrical and electronics engineering and are an important component widely used in many fields, such as communication systems, instrumentation systems, and biomedical systems, and are used for teaching in electronic and electrical laboratories [1], and high-frequency signal processing applications using analog filters in the receiver/transmitter parts of a mobile cellular telephones [2], and other systems [3-4]. From a literature survey of the design of filter circuits, many types have been used, but it was found that they can be classified by their number of input and output ports. They use terms like single-input, single-output (SISO), single-input, multiple-output (SIMO), multiple-input, single-output (MISO), and multiple-input, multiple-output (MIMO) to describe the many filter types. The multi-input-single-output (MISO) filter is one of the most frequently utilized filters, which provides five different output standard response filters. It consists of a low-pass filter (LPF), a high-pass filter (HPF), a band-pass filter (BPF), a band-reject filter (BRF), and an all-pass filter (APF), which can be easily implemented by turning on or off different input signals. Selection can be made digitally using a microcontroller or microcomputer in the same configuration or circuit topology.

As can be seen in Table 1, they were also designed using high-performance, active building blocks [5-22]. The current-mode technique is used to set them up because the different active buildings have to meet certain performance requirements, such as a large bandwidth, a high slew rate, and a wide dynamic range etc. In addition, the current-mode technique is simple to develop and configure and it has low power consumption. The following are some of the benefits offered by the various MISOs: all of the circuits in Table 1 have a high output impedance, making them suitable for connecting or driving to load get rid of the use of additional current buffers. There are only a small number of active building blocks in use [5, 7, 10, 17, 19-22], which makes it easy to assemble for simulations and an implementation circuit. The passive elements that have been used in small numbers in the references [5, 7 - 12, 14 -16, 19 - 20, 22] and [5 - 17, 20, 22] are all connected to ground, where a grounded capacitor is attractive for integrated circuit (IC) implementation. The quality factor can be modified independently of the pole frequency in the proposed MISOs in [6, 8, 12-15, 17-18, 21-22], and the amplitude can be adjusted independently of the quality factor and pole frequency in the proposed circuit in [20]. Table 1 presents a comparison of several MISOs, and although this is useful for learning about the strengths of each, it also reveals certain limitations, as discussed below. There are a large number of active construction blocks used, which may increase with power use in references [6, 8-9, 11-13, 16]. A significant number of resistors and capacitors are used, which increases the footprint of the IC, as seen in the proposed circuits of [13], [18], and [21]. Floating capacitors have been used in MISO filters [19, 21], but they are not suitable for making an integrated circuit [23]. The designs in references [5, 7, 9-11, 16, 19-20] cannot be modified without changing the quality factor, which in turn affects the pole frequency. The amplitude of the output signals in references [5–19, 21–22] cannot be adjusted to be independent of the quality factor and pole frequency.

The aim of this paper is to propose the use of MISO filters using two differential voltage current conveyor transconductance amplifiers (DVCCTA), two resistors, and two capacitors, and to make use of all the grounded passive elements which are suitable for integrated circuit implementation. The MISO circuits are able to operate with standard filter functions, such as BPF, BRF, LPF, HPF, and APF, with input signals determining the filter type. The quality factor can be non-interactively tuned to the pole frequency. In addition, the output amplitude of the signal can be non-interactively tuned by the quality factor and the pole frequency. The output port of the proposed MISOs has a high impedance that can be cascaded directly without the use of an external current buffer and without the need for passive element matching conditions. In addition, the proposed MISO filters show simulation results with the PSPICE program.

Table 1 Comparison between various MISOs current-mode filters.

Ref.	Active element	No. of active elements	No. of R+C	All grounded passive elements	Electronic control	Independent tune of Q_p	Amplitude adjustable independent	High output impedance	Matching Condition
[5]	MCDTA	1	0+2	Yes	Yes	No	No	Yes	No
[6]	DOCCII, MO-CCCA	2+1	2+2	Yes	Yes	Yes	No	Yes	No
[7]	CFCTA	1	0+2	Yes	Yes	No	No	Yes	No
[8]	CCCII	4	0+2	Yes	Yes	Yes	No	Yes	No
[9]	ZC-CFTA	2	0+2	Yes	Yes	No	No	Yes	No
[10]	VDTA	1	0+2	Yes	Yes	No	No	Yes	Yes
[11]	MCDU, MO-CF	2+1	0+2	Yes	Yes	No	No	Yes	Yes
[12]	CCCDTA	3	0+2	Yes	Yes	Yes	No	Yes	No
[13]	ICCII	3	4+2	Yes	No	Yes	No	Yes	No
[14]	CCCTA	2	0+2	Yes	Yes	Yes	No	Yes	No
[15]	CCCDTA	2	0+2	Yes	Yes	Yes	No	Yes	No
[16]	OTA-C	3	0+2	Yes	Yes	No	No	Yes	No
[17]	VD-DXCC	1	2+2	Yes	Yes	Yes	No	Yes	No
[18]	EXCCTA	2	4+2	No	Yes	Yes	No	Yes	Yes
[19]	FTFNTA	1	1+2	No	Yes	No	No	Yes	Yes
[20]	MO-CCCCTA	1	1+2	Yes	Yes	No	Yes	Yes	No
[21]	VD-EXCCII	1	3+2	No	Yes	Yes	No	Yes	Yes
[22]	MO-CCCCTA	1	1+2	Yes	Yes	Yes	No	Yes	No
Proposed MISOs	DVCCTA	2	2+2	Yes	Yes	Yes	Yes	Yes	No

Principle and operation

This topic presents the electrical characteristics of the differential voltage current conveyor transconductance amplifier as an active building block. It was used as the basis for the design of the proposed MISOs. Next is an analysis of the various working operations of MISOs and, lastly, is a non-ideal case analysis of the proposed circuits.

a)

b)

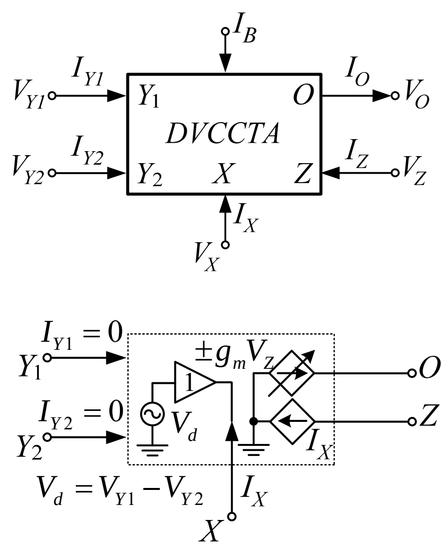


Fig.1 DVCCTA (a) schematic symbol (b) equivalent circuit

Descriptions of DVCCTA

The proposed MISO filters were designed and synthesized using the active building blocks named as a differential voltage current conveyor transconductance amplifier (DVCCTA) [24]. It was developed with CCTA, which added the input part so that is was able to accept the differential voltage. The details of the electrical symbols and equivalent circuits can be seen in Fig. 1 which has five-terminals (Y_1, Y_2, X, Z, and O) for work and one external bias current terminal (I_B). The x terminal is the only one with a low impedance, while the others are all high impedance. The characteristics of DVCCTA in terms of current and voltage are shown in the following equation:

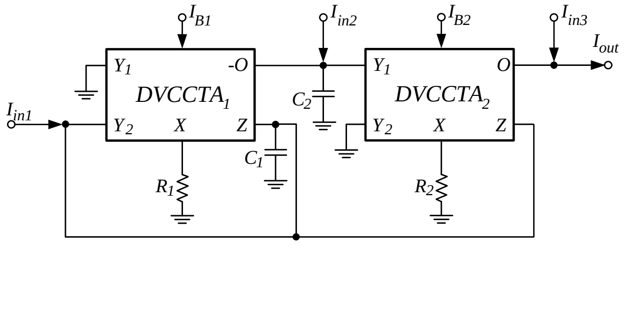
(1) $$\begin{vmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_Z \\ I_O \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \pm g_m & 0 \end{vmatrix} \begin{vmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_Z \\ V_O \end{vmatrix}$$

The proposed circuit uses BJT technology to construct the DVCCTA, for which the transconductance (g_m) can be written as

(2) $$g_m = \frac{I_B}{2V_T}.$$

From equation (2), the g_m can be adjusted using the DC bias current (I_B), also known as the electronic method. The thermal voltage (V_T) is equal to 26 mV at room temperature.

a)



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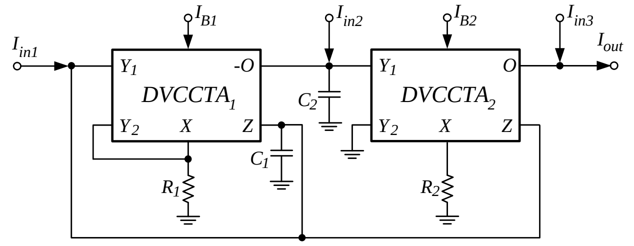

c)

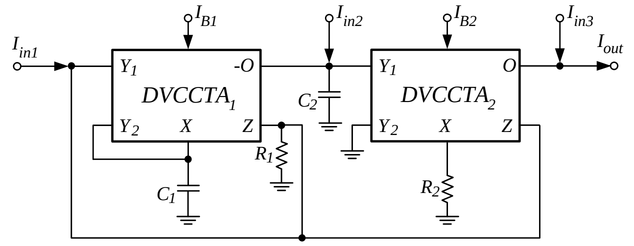

Fig. 2 The proposed MISO filters

The Proposed Multi-Input Single-Output Filter

DVCCTA was used to design the proposed circuits of MISO filters shown in Figs. 2 (a), (b), and (c). Two DVCCTAs, two resistors, and two capacitors connect to ground each circuit. A grounded capacitor connection is useful in integrated circuit implementation because it reduces the area of ICs and compensates for parasitic capacitance at the nodes and terminals of the circuit. The lossless and lossy integrators in [25] are utilized for their design. In particular, the transfer functions (3a), (3b), and (3c) illustrate the current output characteristics of the filter circuits in Figs. 2 (a), (b), and (c), respectively.

(3a)

$$I_{out} = \frac{I_{in3}s^2R_1R_2C_1C_2 + \left(I_{in3} - I_{in1}k_2\right)sR_2C_2 + I_{in3}k_1 - I_{in2}k_2}{s^2R_1R_2C_1C_2 + sR_2C_2 + k_1},$$

(3b)

$$I_{out} = \frac{I_{in3}s^2 2R_1R_2C_1C_2 + \left(I_{in3} - I_{in1}2k_2\right)sR_2C_2 + I_{in3}2k_1 - I_{in2}2k_2}{s^2 2R_1R_2C_1C_2 + sR_2C_2 + 2k_1},$$

and

(3c)

$$I_{out} = \frac{I_{in3}s^2\frac{R_1R_2C_1C_2}{2} + \left(I_{in3} - I_{in1}k_2\right)sR_2C_2 + I_{in3}k_1 - I_{in2}k_2}{s^2\frac{R_1R_2C_1C_2}{2} + sR_2C_2 + k_1}.$$

The transfer functions (3a), (3b), and (3c) allow the output current of the MISO filters to support the five standard second-order filter functions: HPF, BPF, BRF, inverting LPF, non-inverting LPF, and APF. It depends on the selection of the three input currents, I_{in1}, I_{in2}, and I_{in3}, as shown in detail in Table 2. In addition, the circuit's output current at high impedance is simple to connect directly to a load or cascade to a high-order filter without the use of current buffer devices, making it ideal for use in current-mode configuration.

Table 2 selection of input to obtain output filter response

Filter Responses	Input selections		
I_{out}	I_{in1}	I_{in2}	I_{in3}
LPF	0	1	0
HPF	1	1	1
BPF	1	0	0
BRF	1	0	1
APF	2	0	1

The transfer functions (3a), (3b), and (3c) can be successfully analyzed for pole frequency (ω_p), which is expressed by (4a), (4b), and (4c), respectively, as shown below:

(4a) $$\omega_p = \sqrt{\frac{g_{m1}}{R_2C_1C_2}},$$

(4b) $$\omega_p = \sqrt{\frac{g_{m1}}{R_2C_1C_2}},$$

and

(4c) $$\omega_p = \sqrt{\frac{2g_{m1}}{R_2C_1C_2}}.$$

It is possible to provide the quality factor (Q_p) by

(5a) $$Q_p = R_1\sqrt{\frac{g_{m1}C_1}{R_2C_2}},$$

(5b) $$Q_p = 2R_1\sqrt{\frac{g_{m1}C_1}{R_2C_2}},$$

and

(5c) $$Q_p = R_1\sqrt{\frac{g_{m1}C_1}{2R_2C_2}}.$$

In addition, the Q_p of Figs. 2(a), (b), and (c) are adjusted according to (5a), (5b), and (5c) accordingly, and all Q_p have the same independence and proportionate adjustment capability utilizing external R_1. The expressions for ω_p and Q_p are as follows when the transconductance gains $g_{m1} = I_{B1}/2V_T$ and $g_{m2} = I_{B2}/2V_T$ are inserted into (4) and (5), so that they are modified to

(6a) $$\omega_p = \sqrt{\frac{I_{B1}}{2V_TR_2C_1C_2}},$$

(6b) $$\omega_p = \sqrt{\frac{I_{B1}}{2V_TR_2C_1C_2}},$$

and

(6c) $$\omega_p = \sqrt{\frac{I_{B1}}{V_TR_2C_1C_2}}.$$

Then the Q_p of all the MISOs is represented in (7a), (7b) and (7c), respectively.

(7a) $$Q_p = R_1\sqrt{\frac{I_{B1}C_1}{2V_TR_2C_2}},$$

(7b) $$Q_p = R_1\sqrt{\frac{I_{B1}C_1}{2V_TR_2C_2}},$$

and

(7c) $$Q_p = \frac{R_1}{2}\sqrt{\frac{I_{B1}C_1}{V_TR_2C_2}}.$$

It is interesting that the output function of BRF and APF can be modified in amplitude by adjusting the current gain k_1 with g_{m1} and R_1 in (8) in light of the output current of the MISOs (3a), (3b), and (3c).

(8) $$k_1 = g_{m1}R_1.$$

The output amplitude of function BPF can also be freely adjusted by k_2 to adjust the current gain which is g_{m2} and R_1 without impacted of ω_p and Q_p

(9) $$k_2 = g_{m2}R_1.$$

The MISO filters clearly show that ω_p and Q_p can be electronically adjusted by tuning the DC bias current I_{B1} with the passive elements R_2, C_1, and C_2, respectively. By setting external capacitors like $C_1 = C_2 = C$ and concurrently adjusting them, the ω_p can be tuned separately. Likewise, the adjustment of Q_p can be made separately and directly with the passive element by adjusting R_1 without an alert to ω_p. Also, the output current amplitude of BRF and APF can be controlled separately from ω_p and Q_p by adjusting g_{m1} as well as the amplitude of the BPF which can be independently adjusted by g_{m2} with the DC bias current.

Sensitivity characteristics of proposed MISO filters

Because of the tolerances in the passive elements, the response of the actually assembled filter will deviate from the ideal response [26]. Therefore, the sensitivities of the elements as active and passive of the proposed circuits are shown in Figs. 2 (a), (b), and (c) that can be calculated in Table 3.

Table 3 The relative sensitivities of the proposed MISOs filters

Figs.	ω_p	Q_p
2 (a)	$S^{\omega_p}_{I_{B1}}=\frac{1}{2}, S^{\omega_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$	$S^{Q_p}_{R_1}=1,\ S^{Q_p}_{I_{B1},C_1}=\frac{1}{2},$ $S^{Q_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$
2 (b)	$S^{\omega_p}_{I_{B1}}=\frac{1}{2}, S^{\omega_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$	$S^{Q_p}_{R_1}=1,\ S^{Q_p}_{I_{B1},C_1}=\frac{1}{2},$ $S^{Q_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$
2 (c)	$S^{\omega_p}_{I_{B1}}=\frac{1}{2}, S^{\omega_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$	$S^{Q_p}_{R_1}=1,\ S^{Q_p}_{I_{B1},C_1}=\frac{1}{2},$ $S^{Q_p}_{R_2,C_1,C_2,V_T}=-\frac{1}{2}$

The proposed circuits have relative sensitivities that are either equal to one or less than one.

The analysis of the proposed circuits under non-ideal conditions

It is necessary to perform a non-ideal analysis of the proposed filter circuits to account for the DVCCTA non-idealities, which include the tracking errors of voltage and current and the impacts of parasitic elements, as follows:

a) The tracking errors of voltage and current

The impact analysis from the voltage and current tracking errors using DVCCTA can be written according to following equation:

(10)
$$\begin{vmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_Z \\ I_O \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma_1 & -\gamma_2 & 0 & 0 \\ \alpha & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \pm\beta g_m & 0 \end{vmatrix} \begin{vmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_Z \\ V_O \end{vmatrix}$$

where the voltage tracking errors from Y_1 and Y_2 terminals to the X-terminal are γ_1 and γ_2. The current tracking error from X-terminal to Z-terminal is α and the voltage tracking error from the Z-terminal for transfer to the O terminal is the β. The ideal values of the parameters α, β, and γ are equal to unity. However, the influence of the voltage and current tracking errors of the proposed MISO in Figs. 2 (a), (b), and (c) can be analyzed for the ω_p and Q_p as shown in Table 4.

Table 4 The ω_p and Q_p of MISOs affected by tracking errors

Figs.	ω_p	Q_p
2 (a)	$\sqrt{\frac{\alpha_1\beta_1\gamma_{21}I_{B1}}{2V_T R_2 C_1 C_2}}$	$\frac{R_1}{\alpha_1\gamma_{12}}\sqrt{\frac{\alpha_1\beta_1\gamma_{21}I_{B1}C_1}{2V_T R_2 C_2}}$
2 (b)	$\sqrt{\frac{\beta_1\gamma_{11}\gamma_{21}I_{B1}}{2V_T R_2 C_1 C_2}}$	$\frac{2R_1}{\gamma_{12}\alpha_2}\sqrt{\frac{\gamma_{11}\gamma_{21}\beta_1 I_{B1}C_1}{2V_T R_2 C_2}}$
2 (c)	$\sqrt{\frac{\beta_1\gamma_{11}\gamma_{21}I_{B1}}{V_T R_2 C_1 C_2}}$	$\frac{R_1}{\gamma_{12}\alpha_2 2}\sqrt{\frac{\beta_1\gamma_{11}\gamma_{21}I_{B1}C_1}{V_T R_2 C_2}}$

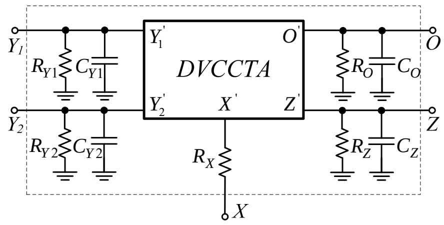

Fig. 3 Non-ideal DVCCTA model

Table 5 The ω_p and Q_p of MISOs affected by the parasitic elements

Figs.	ω_p	Q_p	Settings of parasitic elements
2 (a)	$\sqrt{\frac{g_{m1}G_{R2}}{Y_{T1}Y_{T2}}}$	$\frac{1}{G_{R1}}\sqrt{\frac{g_{m1}G_{R2}Y_{T1}}{Y_{T2}}}$	$G_{Y2}=\frac{1}{R_{Y2}}, G_{Z1}=\frac{1}{R_{Z1}}, G_{Z2}=\frac{1}{R_{Z2}},\ G_{R1}=\frac{1}{R_1},\ G_{T1}=G_{Z1}+G_{Z2}+G_{Y2},$ $sC_{T1}=s\left(C_{Z1}+C_{Z2}+C_{Y2}+C_1\right), Y_{T1}=G_{T1}+sC_T,\ G_{Y12}=\frac{1}{R_{Y12}},$ $sC_{T2}=s\left(C_{y22}+C_2\right), Y_{T2}=G_{Y12}+sC_{T2}, G_{R2}=\frac{1}{R_2}$
2 (b)	$\sqrt{\frac{g_{m1}G_{R2}}{Y_{T1}Y_{T2}}}$	$\frac{2}{Y_{R1}}\sqrt{\frac{2g_{m1}G_{R2}Y_{T1}}{Y_{T2}}}$	$G_{Y2}=\frac{1}{R_{Y2}}, G_{R1}=\frac{1}{R_1},\ sC_{Y2}, Y_{R1}=G_{Y2}+G_{R1}+sC_{Y2}, G_{Y1}=\frac{1}{R_{Y1}},\ G_{Z1}=\frac{1}{R_{Z1}},$ $G_{Z2}=\frac{1}{R_{Z2}},\ G_{T1}=G_{Y1}+G_{Z1}+G_{Z2}, sC_{T1}=s\left(C_{Y1}+C_{Z1}+C_{Z2}+C_1\right),\ Y_{T1}=G_{T1}+sC_{T1},$ $G_{Y12}=\frac{1}{R_{Y12}},\ G_{O1}=\frac{1}{R_{O1}}\ sC_{T2}=s\left(C_{y22}+C_2+C_{O1}\right), Y_{T2}=G_{Y12}+G_{O1}+sC_{T2}, G_{R2}=\frac{1}{R_2}$
2 (c)	$\sqrt{\frac{2g_{m1}G_{R2}}{Y_{C1}Y_{T2}}}$	$\frac{1}{Y_{T1}}\sqrt{\frac{g_{m1}G_{R2}Y_{C1}}{2Y_{T2}}}$	$G_{Y2}=\frac{1}{R_{Y2}},\ sC_{Y2}, sC_1, Y_{C1}=G_{Y2}+sC_{Y2}+sC_1,\ G_{Y1}=\frac{1}{R_{Y1}},\ G_{Z1}=\frac{1}{R_{Z1}}, G_{Z2}=\frac{1}{R_{Z2}}, G_{R1}=\frac{1}{R_1}$ $G_{T1}=G_{Y1}+G_{Z1}+G_{Z2}+G_{R1},\ sC_{T1}=s\left(C_{Y1}+C_{Z1}+C_{Z2}\right),\ Y_{T1}=G_{T1}+sC_{T1},\ G_{Y12}=\frac{1}{R_{Y12}},$ $G_{O1}=\frac{1}{R_{O1}},\ sC_{T2}=s\left(C_{y22}+C_2+C_{O1}\right), Y_{T2}=G_{Y12}+G_{O1}+sC_{T2}, G_{R2}=\frac{1}{R_2}$

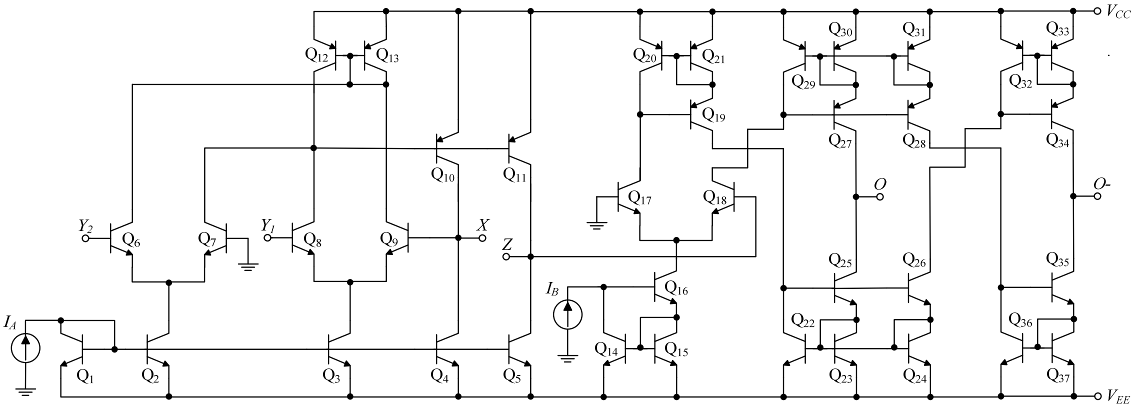

Fig. 4 The internal construction of DVCCTA

b) The influence of the parasitic elements

An analysis of the influence caused by the parasitic elements is shown in Fig. 3. The terminals Y_1, Y_2, Z, and O are high impedance, which consist of parasitic resistances (R_{Y1}, R_{Y2}, R_Z, and R_O) and parasitic capacitances (C_{Y1}, C_{Y2}, C_Z, and C_O) connected to the ground. But at the X terminal there is low impedance, which has parasitic resistance (R_X) connected in series.

The details of DVCCTA with parasitic elements is shown in Fig. 3. The ω_p and Q_p of the three circuits are obtained as in Table 5. Table 5 shows the parasitic elements at the terminals (Y_1, Y_2, Z, O, and X) that affect ω_p and Q_p. Clearly, these parasitic elements have degraded the performance of the proposed MISOs.

Results of simulation

In order to verify the accuracy of the theoretical analysis, the proposed circuits of current-mode MISO filter in Fig. 2 (a) was chosen to be simulated by the PSPICE program. The PR200N and NR200N bipolar transistors of AT&T's ALA400 transistor array provide the parameters for the PNP and NPN transistors that make up the DVCCTA's internal structure [27], for which the supply voltage is set to ±1.5 V and I_{A1} = I_{A2} = 55 µA. The simulation is configured for Q_p = 1 with I_{B1} = I_{B2} = 50 µA, and the values of the capacitors and resistors in the circuit are C_1 = C_2 = 1 nF and R_1 = R_2 = 1 kΩ, respectively. The gain response of the output-current of LPF, HPF, BPF, and BRF of the proposed filter, which provides an input connection as shown in Table 3, is shown in Fig. 5 (a). In addition, simulations of the gain and phase responses of the APF filter are illustrated in Fig. 5 (b). The calculated value of ω_p is approximately 159.15 kHz. However, the simulated pole frequency was found to be 147.91 kHz (with a deviation of 7.06%), in which the deviation is caused by the voltage and current tracking errors and the effects of the parasitic elements. A separate adjustment of Q_p is shown with the gain responses of the band-pass function in Fig. 6, which demonstrates the change of Q_p to 1, 2, and 4 when the resisters R_1 are values of 1 kΩ, 2 kΩ, and 4 kΩ, respectively. Moreover, it was shown that the ω_p can be adjusted separately from Q_p by changing the values of the capacitors C_1= C_2=C to 0.5 nF, 1 nF, and 2 nF concurrently. Fig. 7 is a simulation of these results and it shows the outcome, which proves the theory that was analyzed in (6). It is clear that ω_p was changed to the different frequencies of 288.40kHz, 147.91kHz, and 74.13kHz, respectively. Also, the amplitude of the BPF responses can be changed by adjusting g_{m2} with the bias current I_{B2}, as shown in the gain response in Fig. 8, where the bias current I_{B2} is changed by 50 µA, 100 µA, and 200 µA. Fig. 9 demonstrates the adjustment of the amplitude of the BPF responses for the time-domain response by feeding only I_{in1} to a sinusoidal signal at a frequency of 147.91 kHz and then adjusting I_{B2} to 50 µA, 100 µA, and 200 µA, respectively. It is obvious that the bias current I_{B2}, denoted in (9), can be used to adjust the amplitude of the output signal separately.

a)

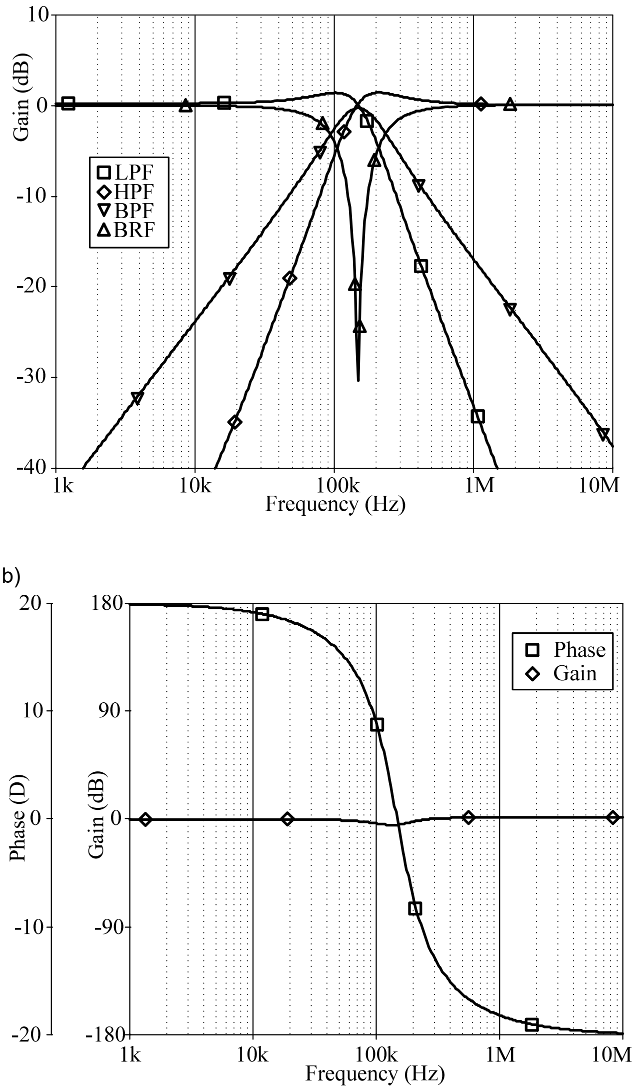

Fig. 5 The simulated frequency response a) LPF, HPF, BPF, and BRF, b) APF

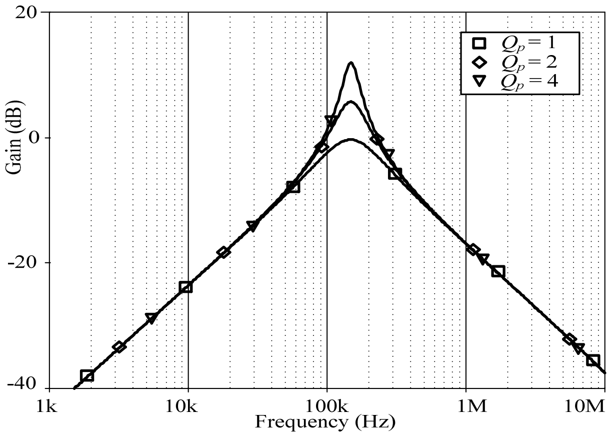

Fig. 6 The BPF response with a different Q_p

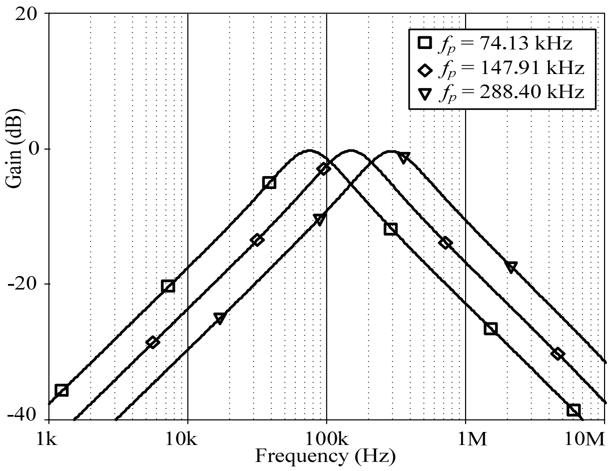

Fig. 7 The adjustment of ω_p

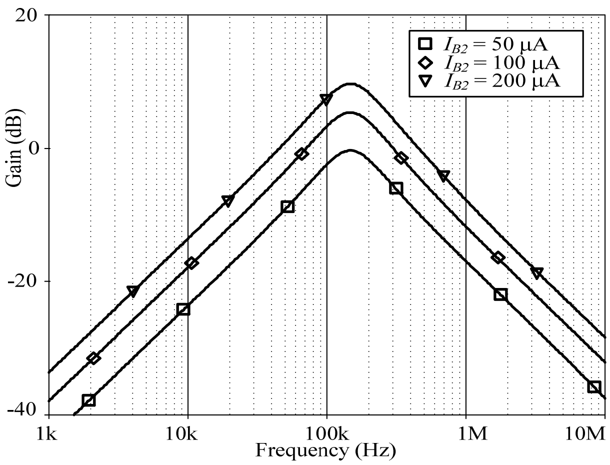

Fig. 8 Amplitude adjustment of BPF by varying the values of I_{B2}

Implementation of the proposed MISO resulted in a deviation of ω_p due to the tolerances of passive elements. The Monte Carlo Analysis is used to evaluate deviations from the tolerances. The BPF response after 100 trials with a 1% tolerance error for resistors and a 10% tolerance error for capacitors is depicted in Fig. 10. Fig. 11 depicts the histograms of the conceivable distribution of ω_p. It can be seen that the minimum and maximum ω_p are 135.211 kHz and 184.549 kHz, and the median and mean of ω_p are 162.536 kHz and 164.187 kHz, respectively.

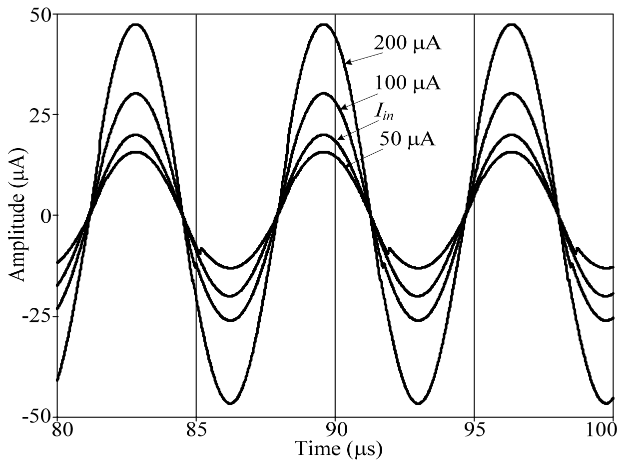

Fig. 9 The simulated BPF response in time-domain with different I_{B2}

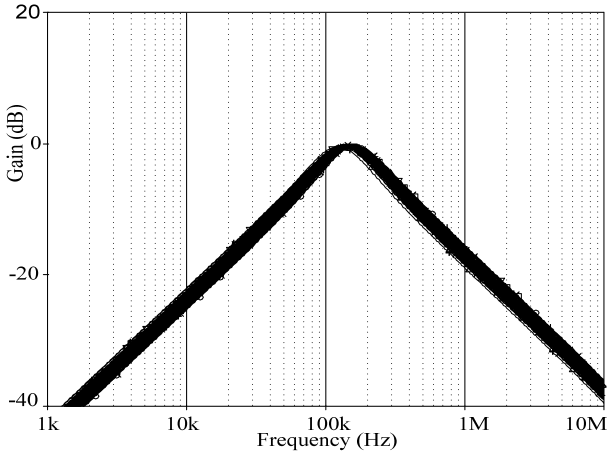

Fig. 10 The BPF response using a Monte Carlo Analysis

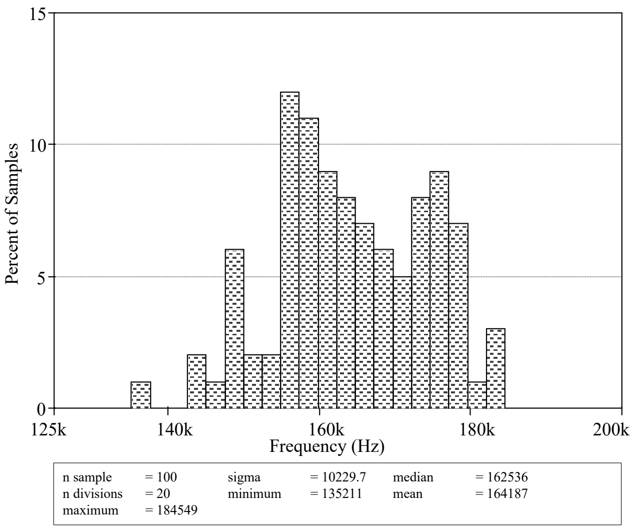

Fig. 11 The histograms of the possible spread of ω_p

Conclusion

The DVCCTA-based current-mode MISO filters are shown. These filters include two DVCCTAs, two grounded resistors, and two grounded capacitors. The capacitors connected to ground can be scaled down based on the size of the integrated circuit to eliminate the parasitic capacitance in the circuits at nodes or ports, which simplifies the implementation of the proposed filters in ICs.

The proposed MISO filters can perform five distinct functions: LPF, HPF, BPF, BRF, and APF. The Q_p can also be modified using R_1, without changing the pole frequency. Additionally, the pole frequency can be independently tuned by modifying the external capacitors. Regardless of ω_p and Q_p, the amplitude is altered by adjusting the DC bias current I_{B2}. The filter has a high output impedance, making it easier to connect or drive circuits or loads. To verify the correctness of the proposed MISO filters theory, it has been simulated using the PSPICE software which demonstrates that the simulated results are very consistent with the theory.

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