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A new multi-input single-output voltage-mode universal biquadratic filter with grounded passive elements and orthogonally adjustable filter parameters

Topraklanmış pasif elemanlar ve dikey olarak ayarlanabilir filtre parametrelerine sahip yeni bir çok-girişli tek-çıkışlı gerilim modlu evrensel bikuadratik filtre

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Abstract

A novel multiple-input, single-output (MISO) Voltage-Mode (VM) analog filter configuration composed of two plus-type differential voltage current conveyors (DVCC+) as active components moreover two capacitors and three resistors as passive elements is proposed in this paper. By selecting input voltage nodes in different orders, it is able to provide all five standard second-order filter responses in one topology. Also, it does not need any passive element matching condition; so the proposed filter is suitable for integrated circuit (IC) design. Further, it offers orthogonal control of quality factor (Q) and angular frequency (ω_0), can be adjusted electronically. Further, to confirm the theoretical analysis, simulation results are investigated. TSMC 0.13 µm process parameters is applied to the circuit and voltage sources are selected as ±0.75 V and 0.2 V for V_B, in this case the power consumption is found as 0.65 mW.

Keywords: DVCC+, Analog filter, Voltage-Mode, Multiple input-single output filter, Universal biquadratic filter.

Öz

Bu çalışmada, yalnızca iki artı tipli gerilim farkı alan akım taşıyıcı (DVCC+), iki kapasitör ve üç direnç kullanarak, tek bir topolojide ikinci derece filternin standart beş farklı tepkisinin tamamını sağlayabilecek çok girişli, tek çıkışlı gerilim modlu evrensel biquadratic filtre devresi önerilmiştir. Önerilen devre, pasif eleman eşleştirme şartından bağımsızdır. Bu nedenle, Entegre Devre Teknolojisi (IC) için uygundur. Ayrıca, kalite faktörü (Q) ve açısal frekansın (ω_0) dikey olarak kontrol edilmesi mümkün olup, elektronik olarak ayarlanabilirdir. Ayrıca, teorik analizleri doğrulamak amacıyla benzetim PSPICE simülasyon sonuçları incelenmiştir. Devre, TSMC 0.13 µm işlem parametreleri kullanılarak gerçekleştirilmiş ve gerilim kaynakları ±0.75 V ile VB için 0.2 V olarak seçilmiştir. Bu durumda güç tüketimi 0.65 mW olarak bulunmuştur

Anahtar kelimeler: DVCC+, Analog filtre, Gerilim-Modlu, Çok girişli- tek çıkışlı filtre, Evrensel bikuadratik filtre.

1 Introduction

Analog filters are widely utilized for applications like as continuous-time analog signal processing, communication systems, signal generators, as well as in measurement instrumentations, power electronic, and control systems [1]-[3].

According to the feature of transferring the desired range of frequency from input to the output, analog filters are extensively used in signal processing. In a multiple-input, single-output (MISO) second-order universal filter, several output responses of the filter can be attained easily by properly selecting the input voltage source(s). Also, this selection can be applied digitally to the circuit by employing a microcontroller or microcomputer. Numerous universal Voltage-Mode (VM) filter implementations have been presented in [3]-[24]. However, many of them have the following disadvantages:

I. lack of orthogonally control of central frequency (ω_0) and quality factor (Q) [3],[7],[12],[15],[21],[22],

II. All conventional second-order functions, cannot be obtained in one circuit topology [11],

III. Capacitor connection to the X terminal of the active element, which cause restrictions at high frequencies [8]-[10],

IV. Redundant number of active devices [8],[11],[17],[21],[22],

V. Employing excessive number of passive components [8],

VI. Requirement for floating capacitor(s), these circuits are not suitable for IC design [9],[10],[20]. According to using only grounded capacitors in the structure of proposed LP and BP filters, these topologies are suitable for IC technology implementations,

VII. Requirement of matching condition for obtaining All pass filter [13],[23],[24].

A novel plus-type differential voltage current conveyors (DVCC+) based MISO universal biquadratic filter is presented in this work. The recently proposed filter performs all conventional second-order responses, namely Low-Pass (LP), High-Pass (HP), Band-Pass (BP), Band-Stop (BS) and All-Pass (AP) in only one circuit topology. In the structure of the filter two DVCC+s, two capacitors and three resistors are employed.

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The proposed filter does not require any component matching condition. Also, the angular frequency (ω_0) and quality factor (Q) parameters can be adjusted orthogonally.

This article proceeds in the following order: a brief introduction is given in Section 1, the newly designed second-order VM universal filter with its mathematical descriptions, calculated ω_0 and Q and passive component sensitivity analysis are given in Section 2. In Section 3, the effects of non-idealities on transfer functions are investigated. In Section 4, to verify the performance of proposed filter some simulation outcomes are given. Finally, Section 5 brings the paper to a close.

2 Proposed voltage mode filter

The schematic block diagram and the non-ideal ports definition of DVCC+ are given in Figure 1 and (1) respectively,

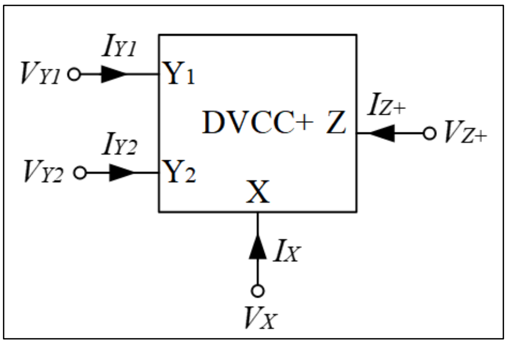

Figure 1. The schematic block diagram of DVCC+.

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_{Z+} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \alpha & -\beta & 0 \\ 0 & 0 & \gamma \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ I_X \end{bmatrix} \tag{1}$$

In (1), α, γ and β are the non-ideal current and voltage gains.

The non-ideal current and voltage gains are expressed in (2-4),

$$\alpha(s) = \frac{\alpha_0}{1 + \frac{s}{\omega_\alpha}} \tag{2}$$

$$\beta(s) = \frac{\beta_0}{1 + \frac{s}{\omega_\beta}} \tag{3}$$

$$\gamma(s) = \frac{\gamma_0}{1 + \frac{s}{\omega_\gamma}} \tag{4}$$

ω_α, ω_β and ω_γ parameters are ideally infinity. α_0, β_0 and γ_0 are DC gains and ideally are equal to unity.

In non-ideal cases DC gains are expressed in (5-7),

$$\alpha_0 = 1 + \varepsilon_\alpha \tag{5}$$

$$\beta_0 = 1 + \varepsilon_\beta \tag{6}$$

$$\gamma_0 = 1 + \varepsilon_\gamma \tag{7}$$

ε_α, ε_β and ε_γ are tracking errors which are defined as $|\varepsilon_\alpha|<<1$, $|\varepsilon_\beta|<<1$ and $|\varepsilon_\gamma|<<1$. So in ideal case the α, β and γ coefficients are equal to unity and the ideal definition of DVCC+ becomes as,

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_{Z+} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ I_X \end{bmatrix} \tag{8}$$

The newly recommended MISO voltage mode biquadratic universal filter configuration is depicted in Figure 2.

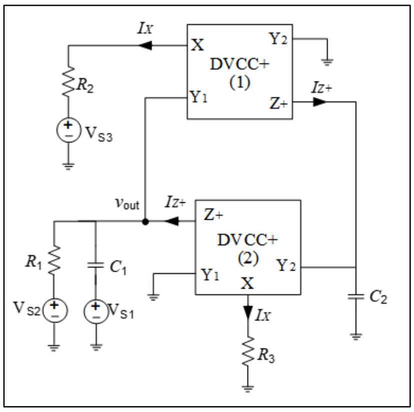

Figure 2. Proposed DVCC+ based MISO universal biquadratic filter.

The output voltage (V_{out}) in terms of input voltages V_{S1}, V_{S2}, and V_{S3} is,

$$V_{out}(s) = \frac{s^2 C_1 C_2 R_1 R_2 R_3 V_{S1} + s C_2 R_3 R_2 V_{S2} + R_1 V_{S3}}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_3 R_2 + R_1} \tag{9}$$

As shown in Table 1, by properly selection of different voltage source(s), various filter functions will be achieved. The realization of five conventional filter functions can be expressed as demonstrated in Table 2.

Table 1. Filter types according to the selection of source (s).

Realization	V_{S1}	V_{S2}	V_{S3}	Filter Type
# I	V_{in}	*0*	*0*	High-Pass
# II	*0*	*0*	V_{in}	Low-Pass
# III	*0*	V_{in}	*0*	Band-Pass
# IV	V_{in}	*0*	V_{in}	Band-Stop
# V	V_{in}	$-V_{in}$	V_{in}	All-Pass

Table 2. Transfer functions of different filter types.

Transfer Function of Filter	Filter Type
$\frac{s^2 C_1 C_2 R_1 R_2 R_3}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + R_1}$	High-Pass
$\frac{R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + R_1}$	Low-Pass
$\frac{s C_2 R_3 R_2}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + R_1}$	Band-Pass
$\frac{s^2 C_1 C_2 R_1 R_2 R_3 + R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + R_1}$	Band-Stop
$\frac{s^2 C_1 C_2 R_1 R_2 R_3 - s C_2 R_2 R_3 + R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + R_1}$	All-Pass

According to (9), filter parameters ω_0 and Q are found as (10-11).

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_2 R_3}} \quad (10)$$

$$Q = R_1 \sqrt{\frac{C_1}{C_2 R_2 R_3}} \quad (11)$$

The Band-Width (BW) of the filters is calculated as,

$$BW = \frac{\omega_0}{Q} = \frac{1}{R_1 C_1} \quad (12)$$

From (10) and (11) it can be easily understanding that the Q can be set, through resistor R_1, without influencing ω_0. So, Q and ω_0 parameters are orthogonal and the filters are biquadratic filters. In the special case, $C_1 = C_2 = C$, $R_1 = R_2 = R_3 = R$ the $\omega_0 = \frac{1}{RC}$ and Q=1.

The ideal passive component sensitivities of ω_0, Q and BW are found as,

$$S^{\omega_0}_{R_2,R_3} = S^{\omega_0}_{C_1,C_2} = -\frac{1}{2} \quad (13)$$

$$S^{Q}_{R_1} = 1, S^{Q}_{R_2,R_3,C_2} = -S^{Q}_{C_1} = -\frac{1}{2} \quad (14)$$

$$S^{BW}_{R_1} = S^{BW}_{C_1} = -1 \quad (15)$$

By performing a simple inspection in (13-15) it can be concluded that as magnitude of sensitivities are less than one, the proposed topology has suitable performance in term of passive component changing.

3 Effect of non-ideal DVCC+

According to (1) with regard to the non-ideal gains of the DVCC+s in proposed filter, the general transfer function in (9) turns to,

$$V_{out}(s) = \frac{s^2 C_1 C_2 R_1 R_2 R_3 V_{s1} + s C_2 R_2 R_3 V_{s2} + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1 V_{s3}}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1} \quad (16)$$

In non-ideal case the ω_0 and Q are calculated as,

$$\omega_0 = \sqrt{\frac{\alpha_1 \beta_2 \gamma_1 \gamma_2}{C_1 C_2 R_2 R_3}} \quad (17)$$

$$Q = R_1 \sqrt{\frac{\alpha_1 \beta_2 \gamma_1 \gamma_2 C_1}{C_2 R_2 R_3}} \quad (18)$$

The transfer functions of all types of filters in non-ideal case are demonstrated in Table 3.

According to Table 3, it can be easily seen that non-ideal gains are shaped as multiplier for only one of the coefficients of the transfer functions.

In this case the passive component sensitivities can be found as,

$$S^{\omega_0}_{\alpha_1,\gamma_1,\gamma_2,\beta_2} = -S^{\omega_0}_{C_1,C_2,R_2,R_3} = \frac{1}{2} \quad (19)$$

$$S^{Q}_{R_1} = 1,\ S^{Q}_{\alpha_1,\beta_2,\gamma_1,\gamma_2,C_1} = -S^{Q}_{C_2,R_2,R_3} = \frac{1}{2} \quad (20)$$

Table 3. Transfer functions of different filter types in non-ideal case.

Transfer Function of Filter	Filter Type
$\frac{s^2 C_1 C_2 R_1 R_2 R_3}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}$	High-Pass
$\frac{\alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}$	Low-Pass
$\frac{s C_2 R_2 R_3}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}$	Band-Pass
$\frac{s^2 C_1 C_2 R_1 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}$	Band-Stop
$\frac{s^2 C_1 C_2 R_1 R_2 R_3 - s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}{s^2 C_1 C_2 R_1 R_2 R_3 + s C_2 R_2 R_3 + \alpha_1 \beta_2 \gamma_1 \gamma_2 R_1}$	All-Pass

4 Simulation results of the universal filter

In this part the simulation outcomes of the recommended VM biquadratic universal filter are exposed. The simulations are done by applying an AC voltage source with amplitude of 1 V to all inputs of the filters according to Table 3. Capacitors and resistors are chosen as $C_1 = C_2 = 100\,pF$ and $R_1 = R_2 = R_3 = 400\Omega$. In this situation, the center frequency (f_0) and Q of filters are calculated as $f_0 = \frac{\omega_0}{2\pi} \cong 3.98\,MHz$ and Q=1.

For DVCC+s, the transistor-based circuit is given in Figure 3 with 0.13 μm CMOS technology and aspect ratio values given in Table 4. is being used. The input stage of DVCC+ is realized with two differential stages (M_5-M_6 and M_7-M_8) with active load M_9-M_{10}. The second stage applying negative feedback from the output node (drain of M_7) to the terminal X is composed of M_{11}. The current through the terminal X is conveyed to the Z terminal with the help of transistors M_3-M_4, and M_{11}-M_{12}. It can be easily seen that I_X and I_Z flow in the same direction towards or away from the DVCC+. The applied voltage sources are selected as ±0.75 V and the V_B is chosen as 0.2 V.

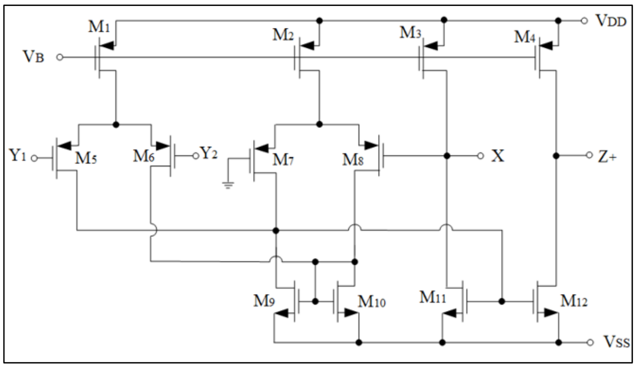

Figure 3. CMOS realization of DVCC+ [19].

Table 4. Aspect ratio of transistors in Figure 3.

PMOS transistors	$W(\mu m)/L(\mu m)$
$M_1 - M_8$	39 /0.39
NMOS transistors	**$W(\mu m)/L(\mu m)$**
$M_9 - M_{12}$	13 /0.39

For examining the functionality of the proposed filter all of the realizations in Table 1 are applied to the proposed circuit. Realizations #1, #2 and #3 are applied to the proposed circuit and the obtained gain characteristics of HP, LP and BP in terms of frequency are shown in Figure 4.

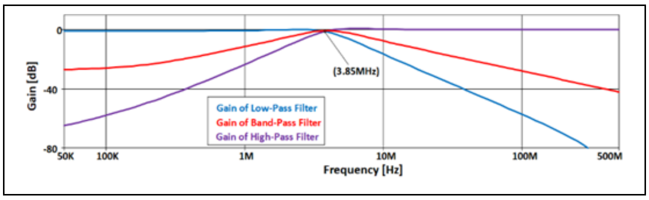

Figure 4. Gain characteristics of HP, LP and BP filters versus frequency.

Realization #4 is applied to the proposed circuit and the obtained AC response of BS filter with respect to frequency is demonstrated in Figure 5.

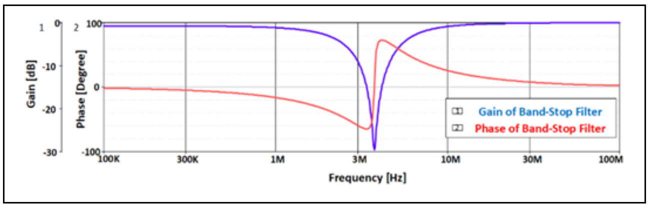

Figure 5. Characteristics of BS filter versus frequency.

Realization #5 is applied to the proposed circuit and the obtained AC response of AP filter with respect to frequency is demonstrated in Figure 6, in this case the obtained gain for all frequencies is approximately equal to 0 *dB*.

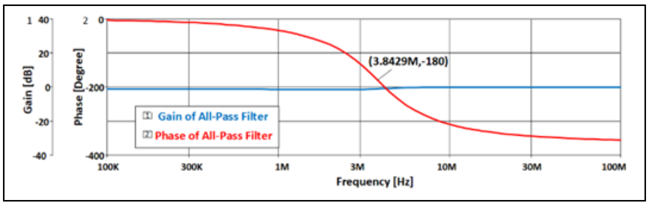

Figure 6. Characteristics of AP filter versus frequency.

The process, voltage, and temperature (PVT) analysis is also applied to AP filter. The variation of f_0 for gain characteristic with respect to different values of V_{DD} and V_{SS} are given in Figure 7. By investigating the f_0 and gain variation of AP filter with respect to V_{DD} and V_{SS}, one can understand that the voltages between 0.5V and 1.5V are acceptable voltage ranges for good operation of newly proposed VM filter.

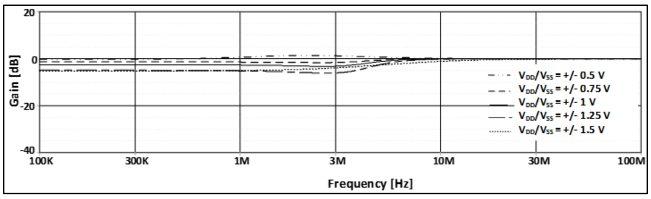

Figure 7. Variation of f_0 for gain characteristic with respect to different values of V_{DD} and V_{SS}.

The temperature analysis applied to AP filter. The variation of f_0 for gain characteristics with respect to temperature are given in Figure 8.

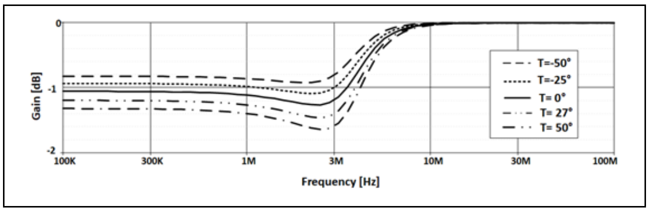

Figure 8. Gain characteristic variation of all-pass filter with respect to temperature.

By investigating the variation in gain characteristic of AP filter with respect to temperature, one can understand that the newly designed circuit is durable to temperature changing and exhibits negligible deviation in results. The newly designed filter is compared with previously DVCC based universal filters in Table 5.

5 Conclusion

A newly designed inductor-less MISO-VM universal biquadratic filter configuration, using two DVCC+s, two capacitors, and three resistors is introduced in this article. The advantages of designed filter are as following:

- Is able to provide simultaneously all conventional VM filter responses by applying the appropriate input(s) to the proposed circuit without requiring any passive element matching conditions,
- Is able to adjust Q from ω_0 independently by selecting different values for R_1 only, which is valuable superiority due to tuning flexibility in different applications,
- In cases of LP and BP it consists of only grounded capacitors; therefore, it is appropriate for IC technology implementation,
- The designed filter very low sensitivity to all active and passive components.

Table 5. A comparison between DVCC+ based universal filters.

Features	Proposed	[22] Fig. 4	[21] Fig. 2	[21] Fig. 3	[23]	[24] Fig. 2	[24] Fig. 3
Number of DVCC(s)	2	3	3	3	3	2	2
CMOS Realization (μm)	0.13	0.18	0.13	0.13	0.25	0.13	0.13
Number of passive devices	2C, 3R	2C, 4R	2C, 2R	2C, 2R	2C, 3R	2C, 4R	2C, 4R
Type of filter	MISO	SIMO	SIMO	SIMO	SIMO	SIMO	SIMO
Orthogonal control of ω_0 and Q	Yes	No	No	No	Yes	Yes	Yes
All passive devices grounded	No	Yes	Yes	No	No	No	No
Matching condition (s)	No	No	No	No	Yes	Yes	Yes
Power supply (V)	±0.75	±1.25	±0.75	±0.75	±1.25	±0.75	±0.75
Power dissipation (mW)	0.65	8.47	4.36	4.36	NA	1.25	1.26

The feasibility of the recommended filter has been examined by applying PSPICE simulations and found that, the simulation and theoretical results match well. Also, applying PVT and temperature analysis proved that the proposed VM filter has a good performance with respect to voltage sources and temperature variation.

6 Author contribution statement

In this article the Elham Minayi contributed to the stages of structure, introduction, materials and methods and general evaluation of the results.

7 Ethics committee approval and conflict of interest statement

"There is no need to obtain permission from the ethics committee for the article prepared".

"There is no conflict of interest with any person/institution in the article prepared".

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