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Universal Biquadratic Filter Employing Single Differential Voltage Current Controlled Conveyor Transconductance Amplifier

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Abstract—**This paper presents new realizations of second order voltage mode and current mode universal filters based on a recently reported active element, called the differential voltage current controlled conveyor transconductance amplifier (DVCCCTA). The proposed circuits do not use external resistor. The filter circuits provide all the responses without changing the circuit topology. All the capacitors are virtually grounded. The use of grounded capacitors makes the circuit suitable for monolithic implementation. The pole frequency and quality factor can be adjusted independently with the input bias currents. The non–ideal analysis and the sensitivity analysis have been included. Both the active and passive sensitivities are not more than unity. The filter performances are verified using the PSpice simulations which agree well with theoretical value.**

Index Terms—**universal Filter, differential voltage current controlled conveyor transconductance amplifier (DVCCCTA), voltage mode, current mode.**

I. INTRODUCTION

Analog filter is an important building block in the field of electrical engineering and widely used in many applications e.g., high–speed data communication systems, regulation, measurement and instrumentation, electro acoustics and control systems [1]. Current mode active building blocks have several distinct advantages such as, high speed, low power consumption at high frequency, high signal dynamic range, greater linearity, high slew rate, low cross–talk and switching noise [2]. In the last decades designing analog circuits that can operate in the voltage mode has been gaining increasing interests. Therefore, it is advantageous to implement voltage mode circuits using current mode active building blocks [3]. In recent years a filter working in the current mode technique is more suitable rather than the conventional voltage mode technique due to its advantages [4].

Several current mode active blocks have been reported in the literatures which includes second generation current conveyor (CCII) [5]–[7], current feedback amplifier (CFA) [8], [9], fully differential second generation current conveyor (FDCCII) [10], [11], differential voltage current conveyor (DVCC) [12], [13], differential difference current conveyor (DDCC) [14], current conveyor transconductance amplifier (CCTA) [2], [15] and current controlled current conveyor transconductance amplifier (CCCCTA) [16]–[18]. However, some filter topologies use two or more active blocks and three or more passive elements. Also in some cases electronic tuning as well as independently control of pole frequency and quality factor cannot be possible. For low power consumption and simplicity it is important to design a filter circuit using one active element and minimum number of passive elements.

In 2009, a new active element called the differential voltage current conveyor transconductance amplifier (DVCCTA) has been proposed [19]. It consists of differential voltage current conveyor (DVCC) and operational transconductance amplifier (OTA). Several realizations of voltage mode and current mode universal biquadratic filter using the DVCCTA and DVCCCTA have been proposed in the literature [20]–[22]. The realizations in [21], [22] are not controlled by the parasitic resistances. Unfortunately in each of these cases an external resistor is required. Due to this the power dissipation of this filter structure increases. The voltage mode biquadratic filters in [20], [22] cannot provide all standard filter responses.

This paper presents a resistorless biquadratic filter working in both voltage mode and current mode using a single DVCCCTA. The proposed three input and single output voltage mode filter has been transformed into equivalent single input and multiple output current mode structure by using the adjoint transformation method [23]. The proposed filter circuits provide all the responses without changing the circuit topology. The pole frequency and the quality factor can be controlled independently by the input bias currents. To validate the theoretical analysis the filter circuits are simulated using PSpice simulation.

II. DIFFERENTIAL VOLTAGE CURRENT CONTROLLED CONVEYOR TRANSCONDUCTANCE AMPLIFIER

The differential voltage current controlled conveyor transconductance amplifier (DVCCCTA) consists of a differential voltage current controlled conveyor (DVCCC) at the front end and operational transconductance amplifiers (OTAs) at the rear end [20]. The DVCCCTA possesses all the properties of DVCCC such as easy implementation of differential and floating inputs and the

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properties of OTA such as the electronic tuning of the parasitic resistance [21]. The schematic symbol and equivalent circuit of the DVCCCTA are shown in Fig. 1 and Fig. 2, respectively. The port relationship can be characterized by the following equations

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_{Z+} \\ I_{Z-} \\ I_{O1+} \\ I_{O1-} \\ I_{O2+} \\ I_{O2-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ R_x & 1 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & +g_{m1} \\ 0 & 0 & 0 & -g_{m1} \\ 0 & 0 & 0 & +g_{m2} \\ 0 & 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_Z \end{bmatrix}. \quad (1)$$

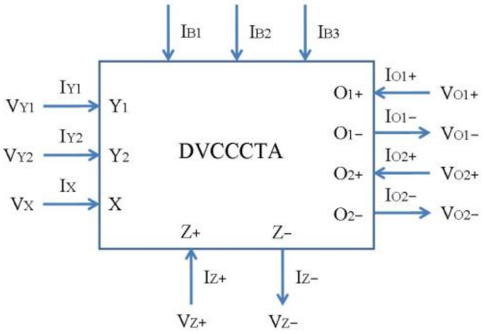


Figure 1. Schematic symbol of the DVCCCTA.

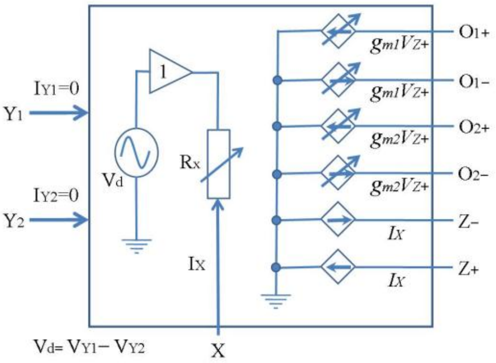


Figure 2. The equivalent circuit of DVCCCTA.

where R_x represent the finite parasitic resistance at the X input terminal, g_{m1} and g_{m2} represent the transconductance gains of the DVCCCTA. For bipolar implementation of the DVCCCTA as shown in the Fig. 3 the values of these parameters are

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

where I_{B1}, I_{B2} and I_{B3} are the bias currents and V_T is the thermal voltage.

III. PROPOSED FILTER CIRCUITS

In this section a three input and single output universal voltage mode filter based on single DVCCCTA is proposed. The proposed filter is illustrated in Fig. 4. The output voltage V_{out} of this filter is given as follows

$$V_{out} = \frac{(s^2C^2R_x + sCg_{m1}R_x)V_{in1} + g_{m2}V_{in2} - sCg_{m2}R_xV_{in3}}{s^2C^2R_x + sCg_{m1}R_x + g_{m2}} \quad (3)$$

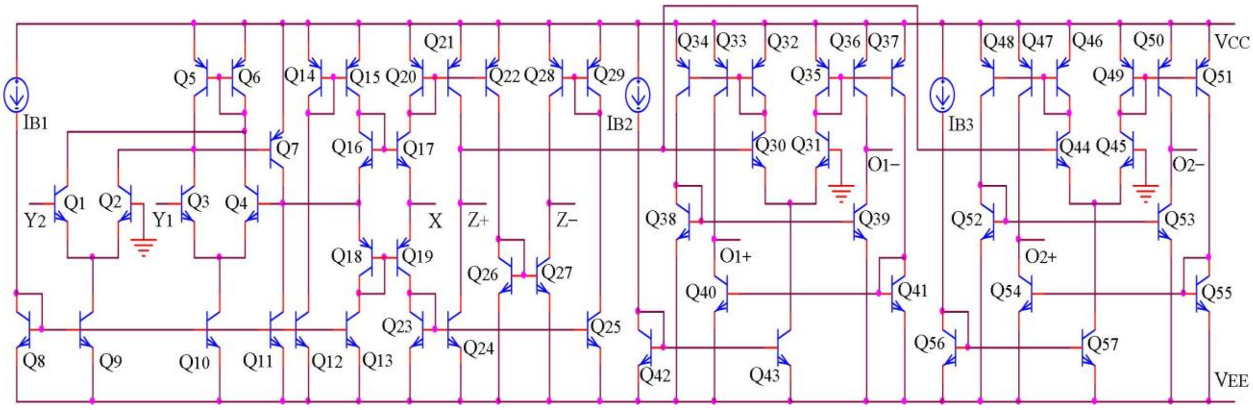


Figure 3. A possible bipolar implementation of the DVCCCTA.

From (3), it is seen that:

(i). If $V_{in1}=V_{in3}=0$ and $R_x=1/g_{m1}=1/g_{m2}$, a second–order low pass filter (LP) can be obtained with V_{out}/V_{in2};

(ii). If $V_{in2}=0$, $V_{in1}=V_{in3}=V_{in}$ and $R_x=1/g_{m1}=1/g_{m2}$, a second–order high pass filter (HP) can be obtained with V_{out}/V_{in};

(iii). If $V_{in1}=V_{in2}=0$ and $R_x=1/g_{m1}=1/g_{m2}$, a second–order inverted band pass filter (Inv. BP) can be obtained with V_{out}/V_{in3};

(iv). If $V_{in1}=V_{in2}=V_{in3}=V_{in}$ and $R_x=1/g_{m1}=1/g_{m2}$, a second–order notch filter can be obtained with V_{out}/V_{in};

(v). If $V_{in1}=V_{in2}=V_{in3}=V_{in}$ and $R_x=1/g_{m1}=2/g_{m2}$, a second–order all pass filter (AP) can be obtained with V_{out}/V_{in}.

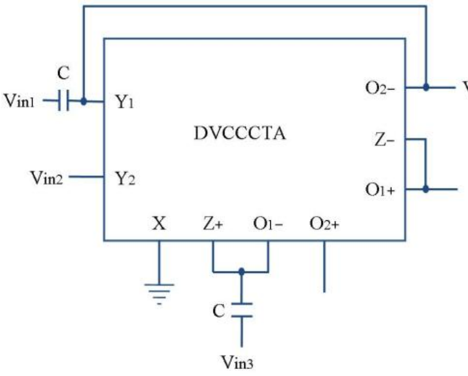


Figure 4. DVCCCTA based voltage mode filter.

Therefore by choosing the input voltages V_{in1}, V_{in2} and V_{in3} in appropriate way the standard filter functions of the second order network can be obtained.

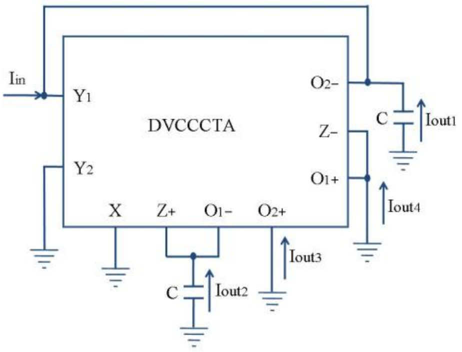


Figure 5. DVCCCTA based filter working in current mode.

The proposed three input and single output voltage mode biquadratic filter can be transformed into the equivalent single input and multiple output multifunction current mode filter, by using the adjoint transformation method [23]. The proposed current mode filter is shown in Fig. 5. By routine circuit analysis the current transfer functions are given by

$$\frac{I_{out1}}{I_{in}}=-\frac{\left(s^2C^2R_x+sC\right)}{s^2C^2R_x+sC+g_{m2}} \tag{4}$$

$$\frac{I_{out2}}{I_{in}}=-\frac{sC}{s^2C^2R_x+sC+g_{m2}}=K_{BP} \tag{5}$$

$$\frac{I_{out3}}{I_{in}}=-\frac{g_{m2}}{s^2C^2R_x+sC+g_{m2}}=K_{LP} \tag{6}$$

$$\frac{I_{out4}}{I_{in}}=\frac{sC}{s^2C^2R_x+sC+g_{m2}}=K_{Inv.BP} \tag{7}$$

By adding the inverted band pass response (I_{out4}) to I_{out1} the high pass response can be obtained i.e.,

$$\frac{I_{out1}}{I_{in}}+\frac{I_{out4}}{I_{in}}=-\frac{s^2C^2R_x}{s^2C^2R_x+sC+g_{m2}}=K_{HP} \tag{8}$$

Similarly,

$$\frac{I_{out1}}{I_{in}}+\frac{I_{out3}}{I_{in}}+\frac{I_{out4}}{I_{in}}=-\frac{s^2C^2R_x+g_{m2}}{s^2C^2R_x+sC+g_{m2}}=K_{Notch} \tag{9}$$

$$\frac{I_{out1}}{I_{in}}+\frac{I_{out3}}{I_{in}}+2\left(\frac{I_{out4}}{I_{in}}\right)=-\frac{s^2C^2R_x-sC+g_{m2}}{s^2C^2R_x+sC+g_{m2}}=K_{AP} \tag{10}$$

In all these cases R_x is equal to $1/g_{m1}$.

Therefore the current mode structure will be used as a universal filter of equivalent properties to those of voltage mode filter of Fig. 4. For all these responses the pole frequency (ω_o), quality factor (Q) and bandwidth (BW) can be expressed as

$$\omega_o=\frac{1}{C}\sqrt{\frac{g_{m2}}{R_x}},\ Q=\sqrt{g_{m2}R_x},\ BW=\frac{1}{CR_x} \tag{11}$$

The above equations reveal that the pole frequency (ω_o) can be adjusted independently of the quality factor (Q) with simultaneously changing R_x and g_{m2} such that the product $g_{m2}R_x$ remains constant and g_{m2}/R_x varies and vice versa.

IV. NON–IDEAL ANALYSIS AND SENSITIVITY ANALYSIS

To see the non ideal effect, the proposed filter circuits are characterized with the following equations [24]

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_{Z+} \\ I_{Z-} \\ I_{O1+} \\ I_{O1-} \\ I_{O2+} \\ I_{O2-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ R_x & \alpha_1 & -\alpha_2 & 0 \\ \beta_1 & 0 & 0 & 0 \\ -\beta_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & +\gamma_1 g_{m1} \\ 0 & 0 & 0 & -\gamma_2 g_{m1} \\ 0 & 0 & 0 & +\gamma_3 g_{m2} \\ 0 & 0 & 0 & -\gamma_4 g_{m2} \end{bmatrix} \begin{bmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_Z \end{bmatrix}. \tag{12}$$

where α_1 and α_2 represent the voltage transferred errors, β_1, β_2, γ_1, γ_2, γ_3 and γ_4 represent the current transferred gains, deviated from one. Re–analyzing the proposed filter circuits for the following non–ideal values the expression of the denominator of the transfer functions become

$$D=s^2C^2R_x+sC\gamma_2+\alpha_1\beta_1\gamma_4 g_{m2} \tag{13}$$

In this case, the pole frequency (ω_o), quality factor (Q) and bandwidth (BW) are changed to

$$\omega_o=\frac{1}{C}\sqrt{\frac{\alpha_1\beta_1\gamma_4 g_{m2}}{R_x}},\ Q=\frac{1}{\gamma_2}\sqrt{\alpha_1\beta_1\gamma_4 g_{m2}R_x},$$

$$BW=\frac{\gamma_2}{CR_x} \tag{14}$$

The sensitivity of any active network is given as

$$S_e^F = \frac{e}{F}\frac{\partial F}{\partial e} \tag{15}$$

where *F* represents a network function and *e* represents element of variation of the filter. A sensitivity study of the filter parameters is analyzed here. The non–ideal sensitivities of the pole frequency (ω_o), quality factor (Q) and bandwidth (BW) are given by

$$S_{\alpha_1}^{\omega_o} = S_{\beta_1}^{\omega_o} = S_{\gamma_4}^{\omega_o} = S_{g_{m2}}^{\omega_o} = \frac{1}{2},\ S_{R_x}^{\omega_o} = -\frac{1}{2},\ S_C^{\omega_o} = -1 \tag{16}$$

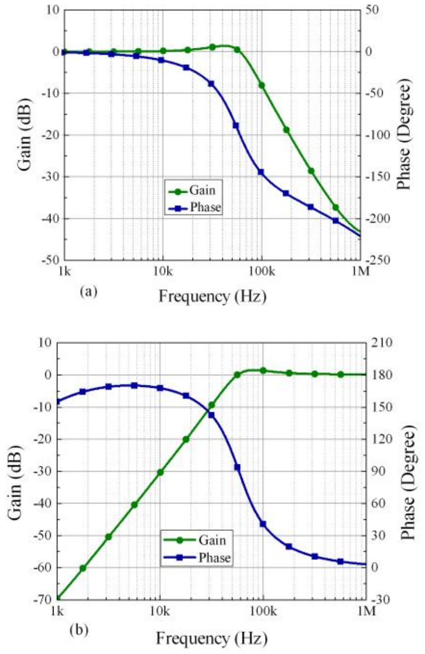
$$S_{\alpha_1}^{Q} = S_{\beta_1}^{Q} = S_{\gamma_4}^{Q} = S_{g_{m2}}^{Q} = S_{R_x}^{Q} = \frac{1}{2},\ S_{\gamma_2}^{Q} = -1 \tag{17}$$

$$S_{\gamma_2}^{BW} = +1,\ S_C^{BW} = S_{R_x}^{BW} = -1 \tag{18}$$

Therefore the filter circuits provide low active and passive sensitivities.

V. RESULTS AND DISCUSSIONS

The proposed voltage mode and current mode filter circuits as in Fig. 4 and Fig. 5 have been simulated in PSpice using the bipolar implementation of the DVCCCTA as shown in Fig. 3 using the bipolar transistors Q2N2907 (PNP) and Q2N2222 (NPN). The circuit is biased with ±1.5V supply voltages. The circuits have been designed for the oscillation frequency f_{osc}=61.24 kHz and the quality factor Q=1. For this the passive components were chosen as C=10 nF, R_x=260 Ω (I_{B1}=50 μA), g_{m1}=g_{m2}=3.846 mS (I_{B2}=I_{B3}=200 μA). Fig. 6 shows the simulated gain and phase responses of the proposed biquad filter as shown in Fig. 4. This indicates that the circuit can provide low pass, high pass, band pass, notch and all pass responses depending on the appropriate selection of the input voltages. Fig. 7 shows the gain and phase responses of the low pass, high pass, band pass, notch and all pass responses in current mode filter as shown in Fig. 5, without modifying circuit topology.



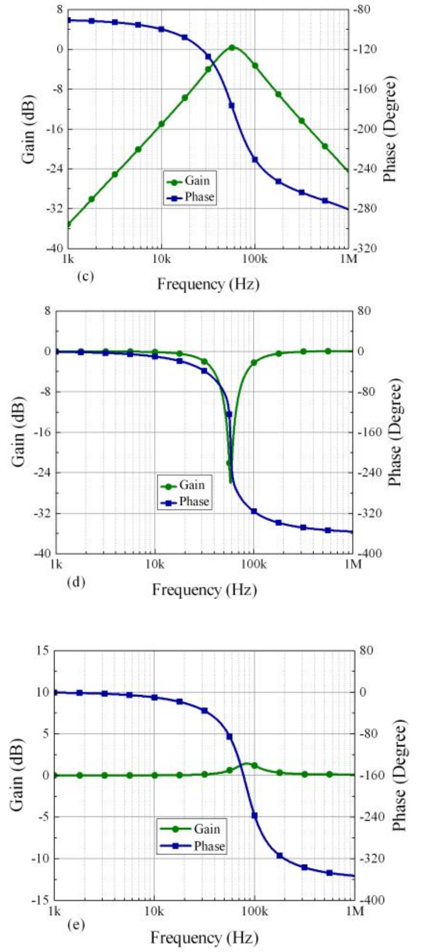
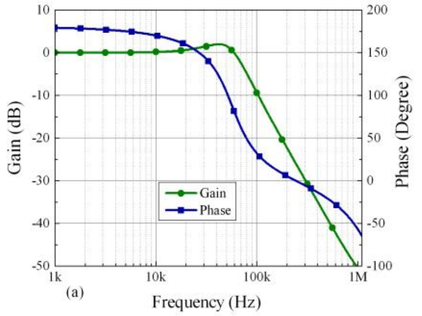


Figure 6. Gain and phase responses of the voltage mode filter (a) LP, (b) HP, (c) Inv. BP, (d) Notch, (e) AP.

This yields the simulated pole frequency of 58.21 kHz. The simulation results agree quite well with theoretical value as expected. The difference between the theoretical and simulated value arises from non–idealities such as non ideal gain and parasitic elements of the proposed circuits. Next, the frequency tuning aspect is verified for the band pass response in voltage mode for constant Q value (Q=1). The bias currents I_{B1} and I_{B3} are varied simultaneously. The oscillation frequency variation is shown in Fig. 8. For I_{B1}= 25 μA, 50 μA, 75 μA and 100 μA the oscillation frequency is found to vary as 29.11 kHz, 58.21 kHz, 87.90 kHz and 117.49 kHz respectively. This indicates that the pole frequency can be adjusted without affecting the quality factor. The power dissipation of the proposed circuit is 4.12 mW which is quite low.



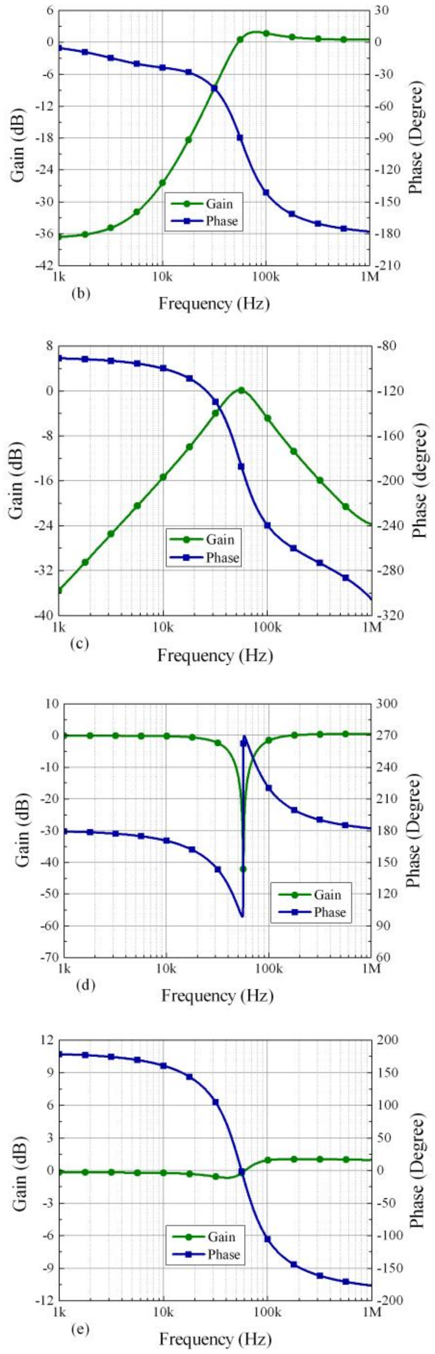


Figure 7. Gain and phase responses of the current mode filter (a) LP, (b) HP, (c) BP, (d) Notch, (e) AP.

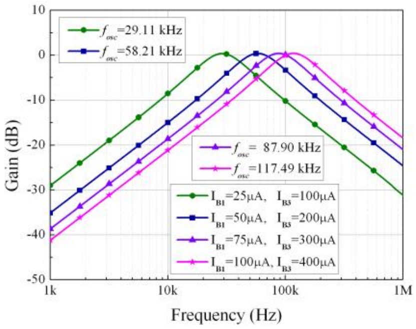


Figure 8. Band pass responses in voltage mode for different I_{B1}.

VI. CONCLUSIONS

This paper presents an electronically tunable dual-mode universal biquadratic filter based on single DVCCCTA. The advantages of the proposed circuits are: the circuits require minimum number of passive components which are virtually grounded in the structure, it performs low pass, high pass, band pass, notch and all pass functions in voltage mode as well as in current mode without changing the circuit topology, the pole frequency and the quality factor can be electronically controlled orthogonally via corresponding input bias currents, it is easily modified to use in control systems using a microcontroller, it offers low active and passive sensitivity figures and low power consumptions, the circuit description comprises only one DVCCCTA and two virtually grounded capacitors. With these features, it is suitable to realize the proposed circuits in monolithic chip for use in battery powered, portable electronic equipments such as wireless communication system devices.

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