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Electronically Tunable Voltage-mode Universal Biquadratic Filter with One Input and Five Outputs Using DDCCTAs

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Abstract

An electronically tunable voltage-mode universal biquadratic filter with one input and five output terminals employing differential difference current conveyor transconductance amplifiers (DDCCTAs) has been proposed. The proposed circuit uses only two DDCCTAs, two grounded resistors and two grounded capacitors. It can realize all the five standard biquadratic filter functions, namely lowpass, bandpass, highpass, bandstop and allpass, simultaneously, without changing the circuit configuration and the passive elements. The proposed circuit provides the advantage features of high-input impedance, independent electronic control of natural angular frequency (ω0) and quality factor (Q), using only grounded passive elements as well as low sensitivity performance. The workability of the circuit is established through computer simulation.

Keywords : Differential Difference Current Conveyor Transconductance Amplifier (DDCCTA), universal biquadratic filter, voltage-mode circuit

1. Introduction

In 2011, a relatively new active building block, the so-called differential difference current conveyor transconductance amplifier (DDCCTA), was introduced [1]. The DDCCTA device is conceptually combination conveyor transconductance amplifier (DDCCTA), was introduced [1]. The DDCCTA device is conceptually combination of the differential difference current conveyor (DDCC) [2] and the transconductance amplifier (TA) in monolithic chip for compact implementation of analog function circuits. This device provides the possibility of in built electronic tuning of the parameters of the analog function circuits to be implemented, and also has all the good properties of the DDCC, such as high-input impedance, employs fewer active and passive components, and easy implementation of differential and floating input circuits. Moreover, the differential voltage current conveyor transconductance amplifier (DVCCTA) can easily be implemented from DDCCTA by connecting the Y3-terminal to ground. Hence, the applications and advantages in realizing various signal processing circuits using DDCCTAs/DVCCTAs have been proposed, particularly from the area of frequency active filters [1], [3]–[6].

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In this paper, an electronically controllable voltage-mode biquadraric universal filter with one input and five output terminals using three DDCCTAs, two grounded resistors and two grounded capacitors. With respect to similar type of the previously published single-input five-output voltage-mode universal filters in [7]–[20], the proposed circuit offers the following advantageous features :

i) simultaneous realization of all the five standard biquadratic filtering functions, namely, lowpass (LP), bandpass (BP), highpass (HP), bandstop (BS) and allpass (AP) responses from the same topology;

ii) the employment of all grounded passive elements, which is suitable for integrated circuit implementation, and attractive for absorbing shunt parasitic impedances;

iii) the natural angular frequency (ω_0) and the quality factor (Q) are electronically controllable through the transconductance parameter (g_m) of the DDCCTA;

iv) no need to impose component choice, except BS response realization;

v) low active and passive sensitivity performance.

The proposed circuit has been implemented using 0.5 µm MIETEC CMOS technology, and is simulated with PSPICE to confirm the theory.

2. Circuit Description

The DDCCTA is a versatile analog active building block, which can be shown in Fig.1. The port relations of the DDCCTA can be defined by the following matrix expression :

$$\begin{bmatrix} i_{Y1} \\ i_{Y2} \\ i_{Y3} \\ v_X \\ i_Z \\ i_O \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} v_{Y1} \\ v_{Y2} \\ v_{Y3} \\ i_X \\ v_Z \\ v_O \end{bmatrix} \tag{1}$$

where g_m is the transconductance parameter of the DDCCTA.

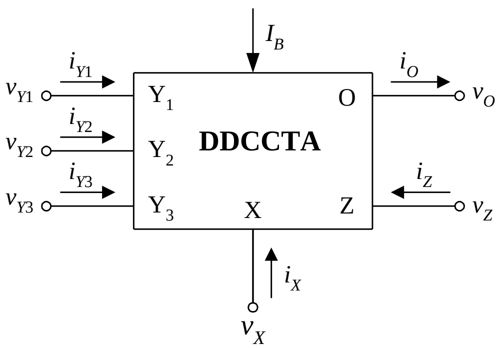


Fig. 1. Electrical symbol of the DDCCTA

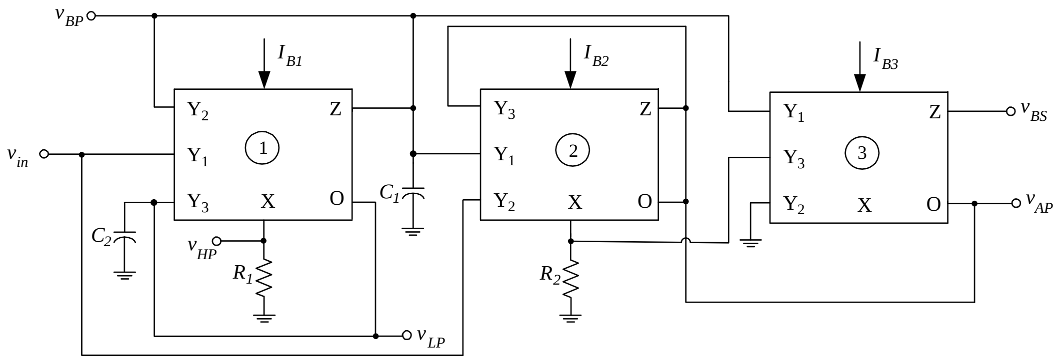


Fig. 2. Proposed voltage-mode universal biquadratic filter

The proposed voltage-mode universal filter with one input terminal and five output terminals employing three DDCCTAs and four grounded passive elements is shown in Fig.2. Since all the passive components are grounded, it is therefore suitable for integrated circuit implementation point of view. By routine circuit analysis using equation (1), the voltage transfer functions of the proposed filter in Fig.2 can be given by :

$$LP(s) = \frac{V_{LP}}{V_{in}} = -\frac{g_{m1}}{s^2 R_1 C_1 C_2 + sC_2 + g_{m1}} \tag{2}$$

$$BP(s) = \frac{V_{BP}}{V_{in}} = \frac{sC_2}{s^2 R_1 C_1 C_2 + sC_2 + g_{m1}} \tag{3}$$

$$HP(s) = \frac{V_{HP}}{V_{in}} = \frac{s^2 R_1 C_1 C_2}{s^2 R_1 C_1 C_2 + sC_2 + g_{m1}} \tag{4}$$

and

$$AP(s) = \frac{V_{AP}}{V_{in}} = \frac{s^2 R_1 C_1 C_2 - sC_2 + g_{m1}}{s^2 R_1 C_1 C_2 + sC_2 + g_{m1}} . \tag{5}$$

Moreover, by selecting $g_{m2} = 1/R_2$, the BS response can be obtained as :

$$BS(s) = \frac{V_{BS}}{V_{in}} = -\left[\frac{1}{g_{m3} R_2}\right]\left[\frac{s^2 R_1 C_1 C_2 + g_{m1}}{s^2 R_1 C_1 C_2 + sC_2 + g_{m1}}\right] . \tag{6}$$

From equations (2)-(6), all the five basic biquadratic filter functions are simultaneously obtained from the proposed circuit configuration. Note that there is no need of any component-matching constraints for filter response realizations, except the BS response. Also, from equations (2)-(6), the natural angular frequency (ω_0), bandwidth (BW) and quality factor (Q) of the proposed filter can be found as :

$$\omega_0 = \sqrt{\frac{g_{m1}}{R_1 C_1 C_2}} \tag{7}$$

$$BW = \frac{1}{R_1 C_1} \quad (8)$$

and

$$Q = \sqrt{\frac{g_{m1} R_1 C_1}{C_2}} \quad (9)$$

Equations (7)-(9) show that the parameters ω_0 and Q for all the filter responses can electronically be tuned by varying g_m. For the fix-valued capacitors, the ω_0 can be adjusted arbitrarily without disturbing Q by simultaneously changing g_m and R_1 and keeping the product $g_m R_1$ constant. On the other hand, the parameter Q can be tuned without disturbing ω_0 by simultaneously increasing g_m and R_1 and keeping g_m/R_1 constant.

3. Simulation Results

To verify theoretical analysis, the proposed single DDCCTA-based voltage-mode universal filter of Fig.2 has been simulated with PSPICE program using MIETEC 0.5 μm CMOS technology process parameters. The DDCCTA was performed by the CMOS structure given in Fig.3 with supply voltages of $+V_{DD} = -V_{SS} = 2$ V, and $V_B = -1.22$ V. The aspect ratios of CMOS transistors are given in Table 1. In Fig.3, the scheme is based on the internal circuit of the DDCC [2], which is followed by a TA [21]. In this case, the transconductance gain (g_m) of the DDCCTA can be given by :

$$g_m = \sqrt{\mu C_{ox} \frac{W}{L} I_B} \quad (10)$$

where I_B is an external DC bias current, μ is the effective channel mobility, C_{ox} is the gate-oxide capacitance per unit area, W and L are channel width and length, respectively. It should be noted that the g_m-value of the DDCCTA can be adjustable electronically by I_B.

The filter of Fig.2 was designed to realize LP, BP and HP responses with $f_0 \cong \omega_0/2\pi = 1.6$ MHz and $Q = 1$. For this purpose, the active and passive components were chosen as : $g_{m1} \cong 100$ μA/V ($I_{B1} = 16$ μA), $R_1 = 10$ kΩ and $C_1 = C_2 = 10$ pF. The simulated responses comparing with the theoretical values are shown in Fig.4. In addition, the ideal and simulated frequency responses of BS and AP filters are drawn in Figs.5 and 6, respectively. From the results, it can be observed that the proposed circuit is capable of realizing all the five standard biquadratic filter functions as expected.

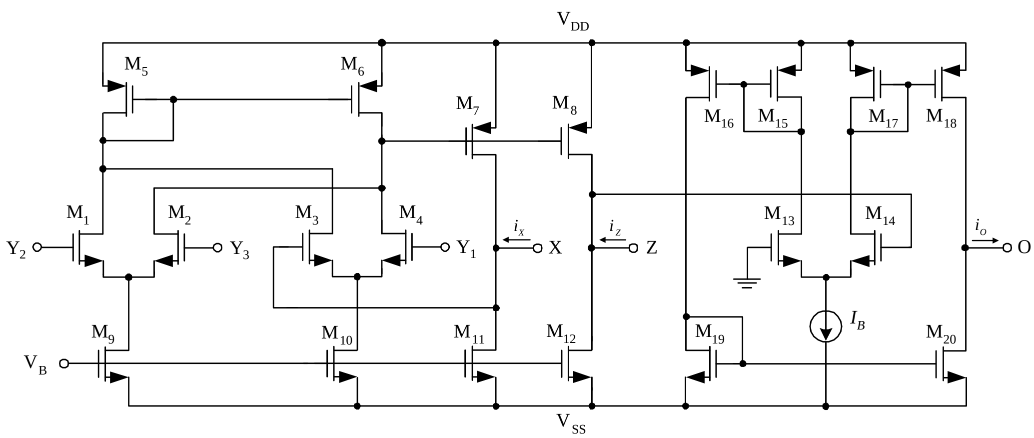


Fig.3. Internal structure of the DDCCTA using MOS transistors

Table 1. Dimensions of MOS transistors of the DDCCTA circuit shown in Fig.3.

Transistors	W (μm)	L (μm)
$M_1 – M_4$	1.8	0.7
$M_5 – M_6$	5.2	0.7
$M_7 – M_{10}$	20	0.7
M_{11} - M_{12}	58	1.0
M_{13} - M_{20}	4	0.7

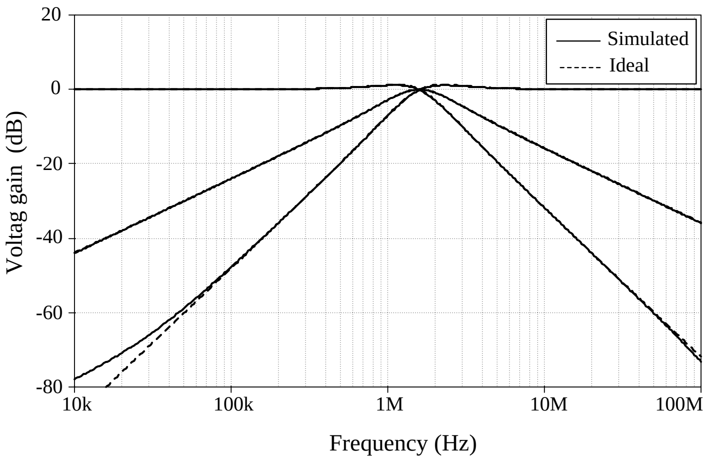
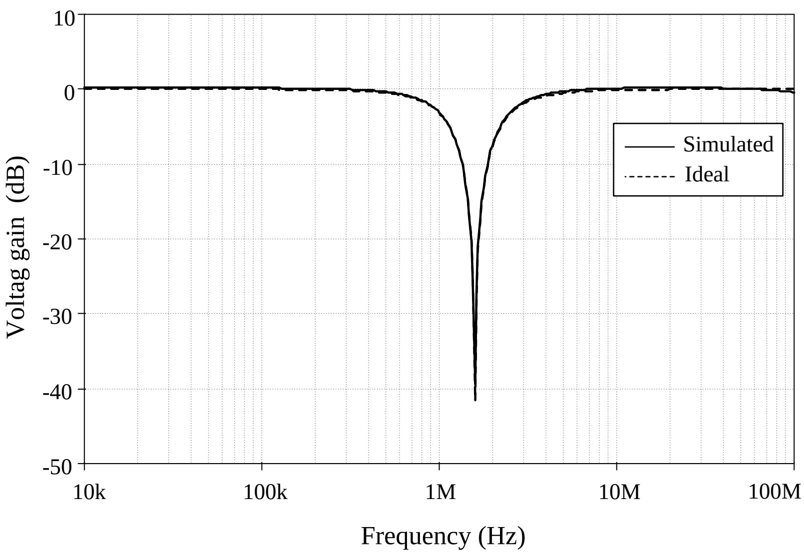
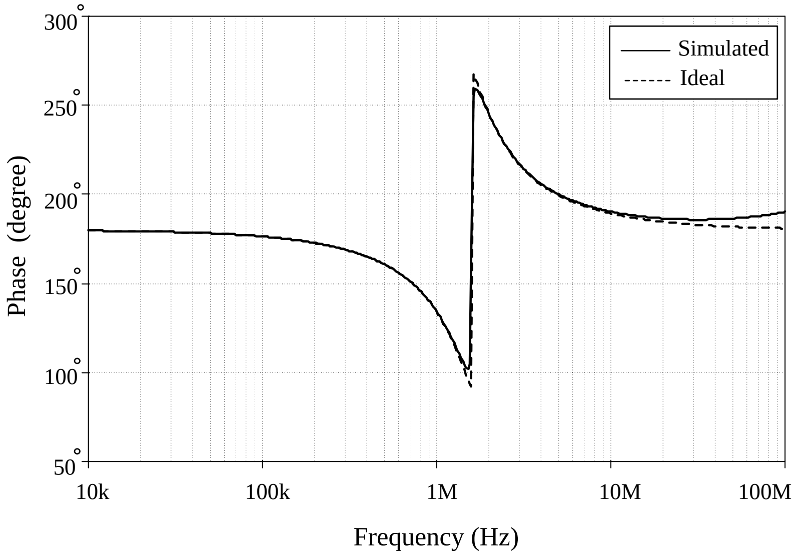


Fig. 4. Simulated frequency responses of LP, BP and HP for the proposed filter in Fig.2



(a)



(b)

Fig. 5. Ideal and simulated frequency responses for the proposed BS filter. (a) gain characteristic (b) phase characteristic

In order to investigate a time-domain response of the proposed voltage-mode universal filter, a 1.6 MHz sinusoidal input voltage with 200 mV peak is applied to the filter. The results obtained are shown in Fig.7. It can be measured from simulations that in case of BP response the total harmonic distortion (THD) of about 0.40% is obtained. Besides, the variation of the THD versus the applied sinusoidal input voltage for the BP response at f_0 = 1.6 MHz is also depicted in Fig.8. The THD values of the circuit remain below 1.5% for sinusoidal input signals up to 900 mV peak.

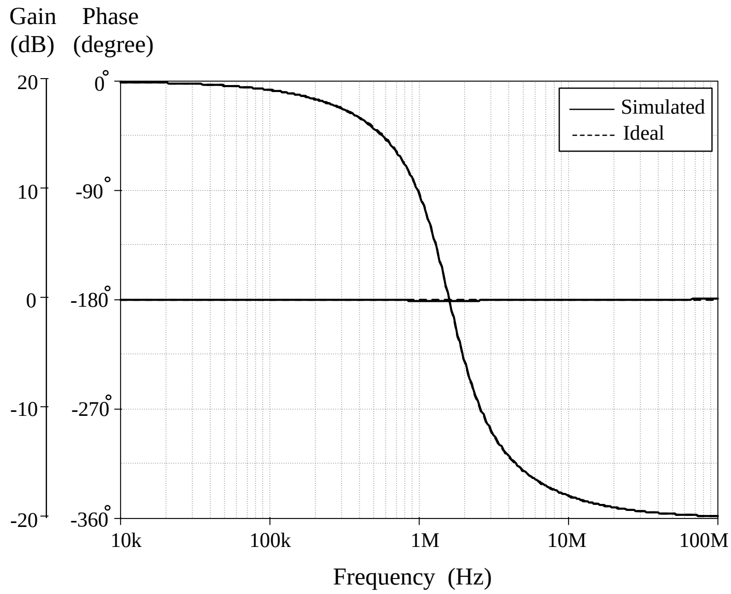


Fig. 6. Ideal and simulated frequency responses for the proposed AP filter

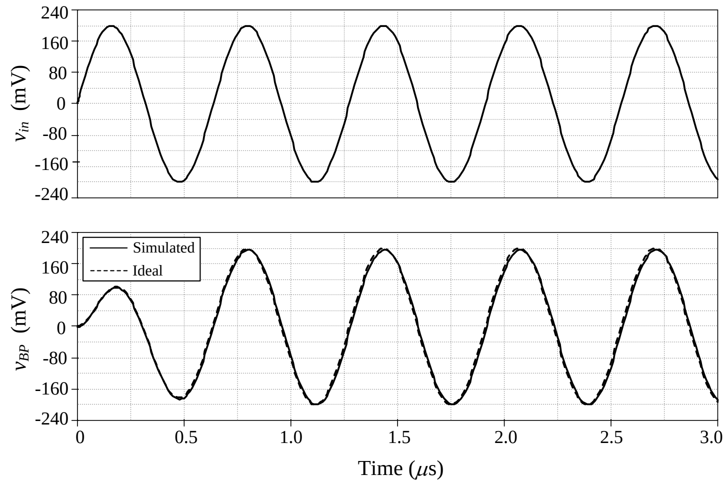


Fig. 7. Input and output waveforms of the BP responses for a 1.6-MHz sinusoidal input voltage of 200 mV (peak)

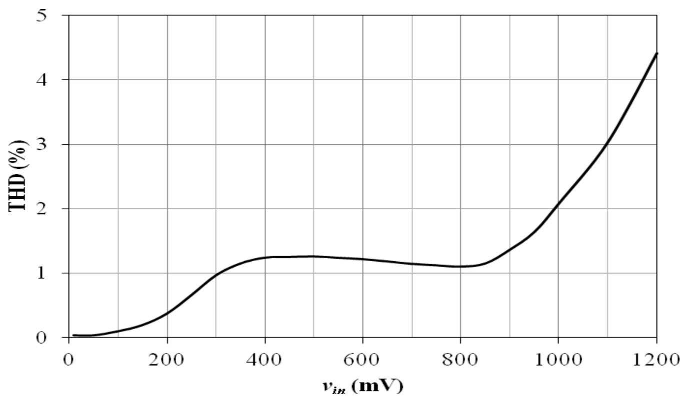


Fig. 8. THD variation of the BP response against applied input voltage amplitude

4. Conclusion

In this paper, a single-input five-output voltage-mode universal filter for simultaneously realize LP, BP, HP, BS and AP responses without changing the configuration and requiring extra active component has been presented. The presented circuit uses one DDCCTA and four grounded passive elements, which is attractive for integration. It has high-input impedance, and exhibits electronic controllability of its important parameters via the bias current of the DDCCTA. Also, no critical component matching conditions are required, except BS realization. Both its active and passive sensitivities are low.

Acknowledgements

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