Research Article

Transadmittance Type Universal Current-Mode Biquad Filter Using VDTAs

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A new resistorless single-input-multi-output (SIMO) universal transadmittance (TA) type filter employing two voltage differencing transconductance amplifiers (VDTA) and two grounded capacitors is proposed. The proposed topology realizes simultaneously low pass (LP), high pass (HP), and band pass (BP) filter functions. Band rejects (BR) and all pass (AP) filters are also realizable through appropriate connections of currents. The proposed configuration also offers independent control of natural angular frequency (ω_0) and bandwidth (BW) and low active and passive sensitivities. The workability of proposed configuration has been demonstrated through PSPICE simulations with TSMC CMOS 0.18 μm process parameters.

1. Introduction

Multifunction filters are getting significant attention in current analog IC design due to their versatility as the same configuration can be used for various filter responses. In the literature, SIMO type active filters employing different active building blocks/devices are available in both current mode (CM) and voltage mode (VM). The advantages and utility of TA type filters have been highlighted in [1]. There are few research publications which have been published dealing with the realisation of TA type filters [1–6].

VDTA is one of the active elements out of those introduced in [7]. Owing to its flexibility and versatility, compared to other active building blocks/devices, several VDTA-based applications have been reported in the literature [8–13]. In [8], Yeşil et al. proposed a simple CMOS realization of VDTA and its application as RF filter and double tuned amplifier. A SIMO VM biquad filter has been reported in [9]. In [11], an electronically controllable explicit current-mode sinusoidal oscillator using single VDTA and in [12] an electronically controllable fully uncoupled sinusoidal oscillator using two VDTAs have been presented. A universal current-mode

biquad filter using single VDTA has also been reported in [13] and grounded and floating inductance circuits using single/two VDTAs and one grounded capacitor have been proposed in [10].

In this communication, we present a new configuration for realizing TA universal biquadratic filter with one input and three outputs. The proposed new circuit offers various features such as employment of only two VDTAs, two grounded capacitors, simultaneous realization of LP, HP, and BP filtering responses without changing circuit topology, independent control of ω_0 and BW, and low active and passive sensitivities. BR and AP filter responses are also obtainable through proper connections of currents. The workability of the proposed TA filter has been verified by SPICE simulations with TSMC CMOS 0.18 μm process parameters.

2. The Proposed Transadmittance Filter

The symbolic notation of the VDTA is shown in Figure 1, where V_P and V_N are input terminals and Z , X^+ , and X^- are output terminals, having high impedance values [8]. The

FIGURE 1: The symbolic notation of VDTA.

FIGURE 2: The proposed TA biquad filter.

terminal equations can be described by the following set of equations:

$$\begin{bmatrix} I_Z \\ I_{X^+} \\ I_{X^-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_{V_P} \\ V_{V_N} \\ V_Z \end{bmatrix}. \quad (1)$$

The proposed TA filter configuration is shown in Figure 2.

Assuming ideal VDTAs, a routine analysis of the circuit shown in Figure 2 yields the following current transfer functions:

$$\begin{aligned} T_1(s)|_{BP} &= \frac{I_{o1}}{V_{in}} = -\frac{s((g_{m1}g_{m2})/C_1)}{D(s)} \\ T_2(s)|_{LP} &= \frac{I_{o2}}{V_{in}} = \frac{(g_{m1}g_{m3}g_{m4})/C_1C_2}{D(s)} \\ T_3(s)|_{HP} &= \frac{I_{o3}}{V_{in}} = \frac{s^2g_{m1}}{D(s)} \\ T_4(s)|_{NOTCH} &= \frac{(I_{o3} + I_{o2})}{V_{in}} = \frac{g_{m1}(s^2 + g_{m3}g_{m4}/C_1C_2)}{D(s)} \\ T_5(s)|_{AP} &= \frac{(I_{o3} + I_{o2} + I_{o1})}{I_{in}} \\ &= \frac{g_{m1}\{s^2 - s(g_{m2}/C_1) + g_{m3}g_{m4}/C_1C_2\}}{D(s)}, \end{aligned} \quad (2)$$

where

$$D(s) = s^2 + s\left(\frac{g_{m1}}{C_1}\right) + \frac{g_{m3}g_{m4}}{C_1C_2}. \quad (3)$$

The ω_0 , BW, and quality factor (Q_0) are given by

$$\omega_0 = \sqrt{\frac{g_{m3}g_{m4}}{C_1C_2}} \quad (4)$$

$$BW = \frac{g_{m1}}{C_1} \quad (5)$$

$$Q_0 = \sqrt{\frac{g_{m3}g_{m4}C_1}{(g_{m1})^2C_2}}. \quad (6)$$

From (4) and (5), it is seen that ω_0 and BW are independently controllable, the former through g_{m3} or g_{m4} or C_2 and the later through g_{m1} .

I_{o1} and I_{o2} are explicit current outputs but I_{o3} is taken through grounded capacitor C_1 . To extract this current (I_{o3}) explicitly another device with its input virtually grounded will be needed due to which the capacitor C_1 will not be physically connected to ground but it will still be virtually grounded [11].

3. Nonideal Analysis and Sensitivity Performance

Taking into account the various VDTA parasitics such as the finite P -terminal parasitic impedance consisting of a resistance R_P in parallel with capacitance C_P , the finite N -terminal parasitic impedance consisting of a resistance R_N in parallel with capacitance C_N , the finite X -terminal parasitic impedance consisting of a resistance R_X in parallel with capacitance C_X , and the parasitic impedance at the Z -terminal consisting of a resistance R_Z in parallel with capacitance C_Z , then the ω_0 and Q_0 including the influence of parasitic are given by

$$\begin{aligned} \omega_0 &= \left(\left(\frac{2}{R_ZR_n} + \frac{1}{R_xR_z} + \frac{1}{R_z^2} + \frac{g_{m1}}{R_z} + g_{m3}g_{m4} \right) \right. \\ &\quad \times (C_1C_2 + 2C_nC_2 + C_xC_2 + C_zC_2 + C_1C_z \\ &\quad \left. + C_xC_z + 2C_nC_z + C_z^2)^{-1} \right)^{1/2} \\ Q_0 &= \sqrt{\left(\frac{2}{R_ZR_n} + \frac{1}{R_xR_z} + \frac{1}{R_z^2} + \frac{g_{m1}}{R_z} + g_{m3}g_{m4} \right)} \\ &\quad \times (C_1C_2 + 2C_nC_2 + C_xC_2 + C_zC_2 + C_1C_z \\ &\quad + C_xC_z + 2C_nC_z + C_z^2)^{1/2} \\ &\quad \times \left(2\frac{C_2}{R_n} + \frac{C_2}{R_x} + \frac{C_2}{R_z} + C_2g_{m1} + 2\frac{C_z}{R_n} + \frac{C_z}{R_x} \right. \\ &\quad \left. + 2\frac{C_z}{R_z} + C_zg_{m1} + \frac{C_1}{R_z} + 2\frac{C_n}{R_z} + \frac{C_x}{R_z} \right)^{-1}. \end{aligned} \quad (7)$$

TABLE 1

Reference	Active elements used	Number of resistors	Number of capacitors	Number of simultaneously realized filters
[3]	1	2 (1G + 1F)	1G	BP, LP
[2]	3	2 (1G + 1F)	2F	BP, LP, HP
[1]	3	3 (1G + 2F)	2F	BP, LP, HP
Proposed	2	0	2G	BP, LP, HP

*G: grounded, F: floating.

FIGURE 3: Frequency response of proposed TA filter.

Using the classical definition of the sensitivity coefficient, that is,

$$S_x^F = \frac{x}{F} \frac{\partial F}{\partial x}, \quad (8)$$

where “ F ” may represent the parameters of the elements and “ x ” may represent passive elements as well as the active elements with respect to which the sensitivity is to be evaluated and by taking $C_1 = 0.05$ nF, $C_2 = 0.1$ nF, $R_p = R_z = \infty$, $C_p = C_x = C_z = 0$, $g_{m1} = g_{m2} = g_{m3} = g_{m4} = 631.702$ μ A/V, the sensitivities of ω_0 and Q_0 are found to be either 0 or 0.5. Thus, all the active and passive sensitivities of ω_0 and Q_0 are low.

4. Simulation Results

To confirm theoretical analysis, the proposed configuration was simulated using CMOS VDTA as given in [8]. The passive elements of the configuration were selected as $C_1 = 0.05$ nF and $C_2 = 0.1$ nF. The power supplies used for CMOS VDTA were ± 0.9 V. The transconductances of VDTA were controlled by bias currents. Figure 3 shows the simulated filter responses of LP, BP, HP, BR, and AP. A comparison with previously published TA biquad is shown in Table 1. These results, thus, confirm the validity of the proposed configuration.

5. Conclusion

A new Transadmittance-mode biquad filter has been proposed which employs only two VDTAs and two grounded

capacitors. The proposed filter can realize the second-order LP, BP, and HP responses simultaneously without changing the circuit topology and without any matching condition. The notch and AP filter responses are also obtainable through proper connections of the currents. The filter circuit offers (i) independent control of ω_0 and BW and (ii) low active and passive sensitivities. SPICE simulations have established the workability of the proposed formulation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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