

Research Article

Voltage-Mode All-Pass Filters Including Minimum Component Count Circuits

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This paper presents two new first-order voltage-mode all-pass filters using a single-current differencing buffered amplifier and four passive components. Each circuit is compatible to a current-controlled current differencing buffered amplifier with only two passive elements, thus resulting in two more circuits, which employ a capacitor, a resistor, and an active element, thus using a minimum of active and passive component counts. The proposed circuits possess low output impedance, and hence can be easily cascaded for voltage-mode systems. PSPICE simulation results are given to confirm the theory.

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1. INTRODUCTION

First-order all-pass filters have attracted the researchers worldwide for their utility in communication and instrumentation systems [1–9]. For instance, first-order all-pass filters find applications in correcting the phase of a signal; in delay equalization when transmitting data on cables; in design of highly selective band-pass filter and design of quadrature and multiphase oscillators. Thus numerous circuits employing second generation current conveyor “CCII” [1–5], current-controlled current conveyor “CCCII” [5], and differential difference current conveyor “DDCC” [6, 7] and FDCCII [8] have been reported in the technical literature. The cited circuits operate in voltage-mode, the topic of this paper; though a good number of current-mode all-pass filters [5] are also available in the literature. Amongst the available voltage-mode circuits, most of the works are based on a single active element and a number of passive (more than two) components. An all-pass section with minimum components is expected to use two passive components besides an active element. Some voltage-mode circuits enjoying this feature are available in literature [5–8], of which the circuit in [5] uses matching (in the form of external bias current adjustment to a specified value) whereas, the circuit of [6] requires no matching. However, the circuit of [6] does not exhibit low output impedance, a feature exhibited by another work with the same component count [7]. More

recently, a number of circuits using FDCCII were also reported, some of which enjoy a minimum component count, as well as low output impedance [8]. CDBA is a relatively new active element, which enjoys the current conveying property of second generation current conveyors (CCIIIs) and the voltage buffering property of current feedback amplifiers (CFAs). The CDBA has so far not been attempted for realizing voltage mode first-order all-pass filters in open literature. Recently, a tunable CDBA was also developed and called CCCDBA [10], however, CCCDBA-based first-order all-pass filters have not yet been attempted in the literature.

The motivation of this paper is to propose new first-order all-pass filters using a CDBA. The proposed circuit is also compatible with CCCDBA. The CCCDBA-based circuit requires minimum of passive component (two), thus resulting in a low cost structures. The proposed voltage-mode circuits possess low output impedance and thus are easy to cascade for realizing higher-order filters, quadrature oscillators, and so forth. PSPICE simulation results are also given to verify the proposed circuits.

2. PROPOSED CIRCUITS

A CDBA symbol (without I_o) is shown in Figure 1(a) and is characterized by the following relationship:

$$V_p = V_n = 0, \quad I_z = I_p - I_n, \quad V_w = V_z. \quad (1)$$

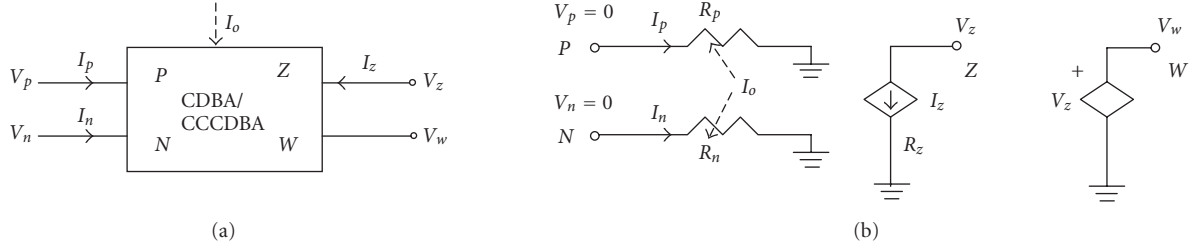


FIGURE 1: (a) CDBA/CCCDDBA symbol and (b) equivalent circuit of CDBA/CCCDDBA.

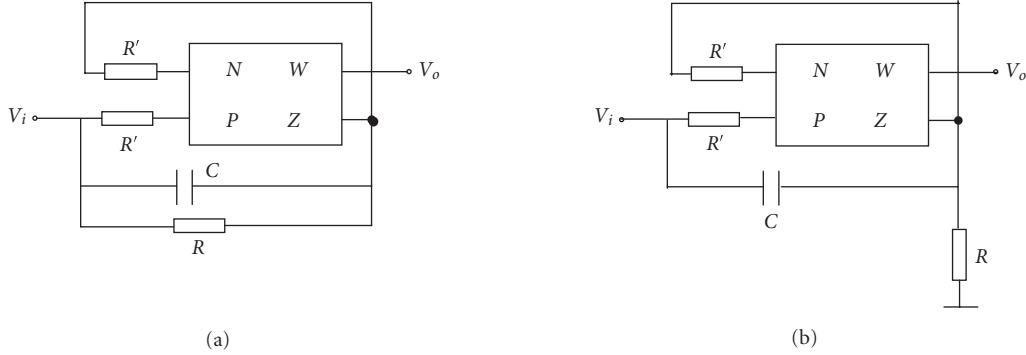


FIGURE 2: (a) Proposed all-pass filter Circuit-1 using CDBA and (b) proposed all-pass filter Circuit-2 using CDBA.

Currents entering the ports are taken to be positive as shown in Figure 1(a). The CDBA conveys the difference of input currents (I_p and I_n), which are at desirable low impedance to the high impedance output (Z) terminal. Besides, the voltage developed at the Z terminal (depending upon the terminated impedance at it) is buffered to the low impedance output (W) terminal. Therefore, CDBA enjoys the current conveying property of CCII and the voltage buffering property of current CFA (AD844 is one example of available ICs). On the other hand, a current-controlled current differencing buffered amplifier (CCCDDBA), whose symbol is given in Figure 1(a) (with I_o), was introduced very recently [10]. Besides satisfying (1), The CCCDDBA possesses current controllable P and N terminal internal resistances $R_p = R_n = V_T/2I_o$, where I_o is the bias current of the CCCDDBA [10]. The equivalent circuit model of the CDBA (without control I_o)/CCCDDBA (with controlling current I_o) is shown in Figure 1(b). The two proposed circuits using a single CDBA and passive components are shown in Figures 2(a) and 2(b). The Circuit-1 using CDBA is given in Figure 2(a), whereas, the Circuit-2 using CDBA is shown in Figure 2(b). It is to be noted that both the circuits of Figure 2 are canonical by employing a single capacitor necessary for first-order sections. The two circuits are characterized by the following voltage transfer functions, respectively:

$$\frac{V_o}{V_i} = \frac{s - (1/C)(1/R' - 1/R)}{s + 1/RC}, \quad \text{see Figure 2(a),} \quad (2)$$

$$\frac{V_o}{V_i} = \frac{s - 1/R'C}{s + 1/RC}, \quad \text{see Figure 2(b).} \quad (3)$$

The circuit of Figure 2(a) realizes an all-pass filter with $R' = R/2$, whereas the circuit of Figure 2(b) realizes all-pass filter with $R' = R$. Since both circuits use equal valued resistors at P and N terminals, they are easily compatible to a CCCDDBA. The resulting circuits employing CCCDDBA are shown in Figure 3. Besides being canonical, the CCCDDBA-based Circuit-1 of Figure 3(a) and Circuit-2 of Figure 3(b) use a minimum component count by employing a single capacitor, single resistor, and an active element. The circuit of Figure 3(a) is also characterized by the transfer function of (2), and that of Figure 3(b) by (3). Here R' is replaced by the intrinsic P or N terminal resistance of the CCCDDBA. The matching condition for realizing all-pass filter can be conveniently met by adjusting the bias current of CCCDDBA so as to make R' (here $R_p = R_n$) equal to $R/2$ for Figure 2(a) and $R' = R$ for the circuit of Figure 3(b).

The CCCDDBA-based circuits fall in the category of available voltage-mode all-pass sections with this component count [5, 6], but with the added feature of low output impedance [7, 8]. However, the feature of low output impedance is exhibited by some of the circuits of [3, 4] when implemented using IC AD844, but these works employ larger passive component count. It is therefore to be realized that the proposed circuits not only add to the rich repertoire of literature on the subject but also provide a practical and minimum component low-cost structure for first-order voltage-mode all-pass filters.

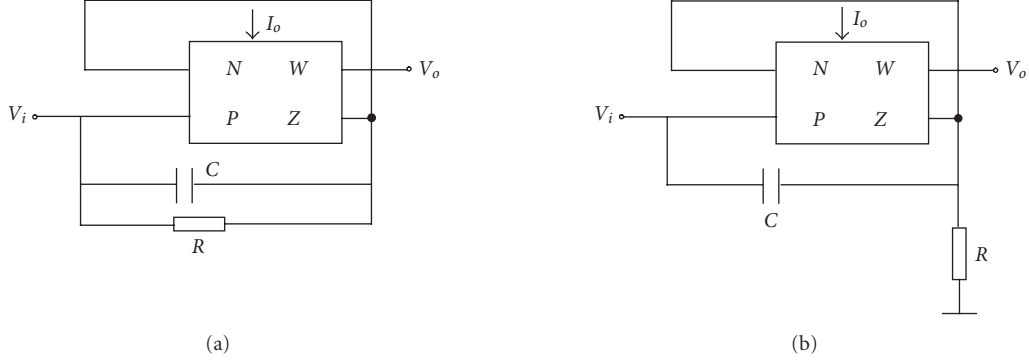


FIGURE 3: (a) Proposed all-pass filter Circuit-1 using CCCDBA and (b) proposed all-pass filter Circuit-2 using CCCDBA.

3. NONIDEAL STUDY

A nonideal current differencing buffered amplifier is characterized by the following relationship [11]:

$$V_p = V_n = 0, \quad (\alpha_p I_p - \alpha_n I_n) = I_z, \quad V_w = \beta V_z. \quad (4)$$

Here, α_p and α_n are the current transfer gains from P and N terminals to Z terminal, respectively. β is the voltage transfer gain from Z to W terminal. These gains differ from unity by the transfer errors. Using the above equation, the proposed circuits are reanalyzed so as to yield the following voltage transfer functions for Figures 2(a) and 2(b), respectively:

$$\frac{V_o}{V_i} = \beta \frac{s - (2\alpha_p - 1)/RC}{s + (3 - 2\alpha_n)/RC}, \quad (5)$$

$$\frac{V_o}{V_i} = \beta \frac{s - \alpha_p/RC}{s + (2 - \alpha_n)/RC}. \quad (6)$$

The pole- ω_o sensitivity to the nonidealities as well as external components is analyzed for (5) and found as

$$S_{R,C}^{\omega_o} = -1, \quad S_{\alpha_p}^{\omega_o} = 0, \quad S_{\alpha_n}^{\omega_o} = \frac{-2\alpha_n}{3 - 2\alpha_n}. \quad (7)$$

The same for (6) is found as

$$S_{R,C}^{\omega_o} = -1, \quad S_{\alpha_p}^{\omega_o} = 0, \quad S_{\alpha_n}^{\omega_o} = \frac{-1}{2 - \alpha_n}. \quad (8)$$

Next, the sensitivity of all-pass filter gain (H) to the nonidealities and passive components for both circuits of Figure 2 is also analyzed as

$$S_{\alpha_p, \alpha_n, R, C}^H = 0, \quad S_{\beta}^H = 1. \quad (9)$$

Equations (7)–(9) show that all the sensitivity values are within unity, which implies good sensitivity performance, with the exception of pole- ω_o sensitivity of Figure 2(a) (see (7)) to α_n , implying that pole- ω_o is highly sensitive to this particular nonideality. It is to be noted that the current and voltage transfer gains α and β are frequency-dependent with a first order-low-pass roll-off, with the cutoff frequency dependent on the devices and the technology used in implementing the active element. Therefore, high frequency performance would be limited by the actual circuit parameters and the technology used.

Another form of nonideality (parasitics) can also be studied, that is, the effect of finite parasitic input resistances at P and N terminals. For CDBA-based circuits, these finite resistances (R_p and R_n) merge with external R' , whereas for CCCDBA-based circuits, these resistances are actually used as one of the parameters for circuit functioning, therefore not posing any performance deterioration. Another nonideal effect (parasitic) to be considered is the Z terminal parasitic capacitance, say C_z . Analysis of all the circuits show that this capacitance effect does affect the pole-frequency by adding up with external C , thus a slight deviation (decrement) in pole-frequency can be expected with reference to the designed value.

4. SIMULATION RESULTS

The proposed circuits were simulated using PSPICE simulations using the CCCDBA of [10] (shown in Figure 4) with a supply voltage of ± 2.5 V and transistor parameters as listed in Table 1 [12]. The CCCDBA-based circuit of Figure 3(a) was designed with $C = 10$ nF, $R = 268$ ohms, and $I_o = 100$ μ A. The designed pole-frequency was as 59 KHz. The V_T is taken to be 26 mV, the value at room temperature. The design would vary with the change in operating temperature. However, it should not be seen as a drawback, as the designer has a control over the circuit's parameters through the bias current (I_o). The simulation results are shown in Figure 5, which show the pole-frequency as 56 KHz. Next the circuit of Figure 3(b) was designed with $C = 10$ nF, $R = 135$ ohms, and $I_o = 100$ μ A so as to yield a pole frequency

TABLE 1: NR100N and PR100N transistor parameters.

NR100N NPN ($IS = 121E-18$ $BF = 137.5$ $VA_F = 159.4$ $IKF = 6.974E-3$ $ISE = 36E-16$ $NE = 1.713$ $BR = 0.7258$ $VAR = 10.73$ $IKR = 2.198E-3$ $RE = 1$ $RB = 524.6$ $RBM = 25$ $RC = 50$ $CJE = 0.214E-12$ $VJE = 0.5$ $MJE = 0.28$ $CJC = 0.983E-13$ $VJC = 0.5$ $MJC = 0.3$ $XCJC = 0.034$ $CJS = 0.913E-12$ $VJS = 0.64$ $MJS = 0.4$ $FC = 0.5$ $TF = 0.425E-8$ $TR = 0.5E-8$ $EG = 1.206$ $XTB = 1.538$ $XT1 = 2$)
PR100N PNP ($IS = 73.5E-18$ $BF = 110$ $VA_F = 51.8$ $IKF = 2.359E-3$ $ISE = 25.1E-16$ $NE = 1.650$ $BR = 0.4745$ $VAR = 9.96$ $IKR = 6.478E-3$ $RE = 3$ $RB = 327$ $RBM = 24.55$ $RC = 50$ $CJE = 0.18E-12$ $VJE = 0.5$ $MJE = 0.28$ $CJC = 0.164E-12$ $VJC = 0.8$ $MJC = 0.4$ $XCJC = 0.037$ $CJS = 1.03E-12$ $VJS = 0.55$ $MJS = 0.35$ $FC = 0.5$ $TF = 0.610E-9$ $TR = 0.610E-8$ $EG = 1.206$ $XTB = 1.866$ $XT1 = 1.7$)

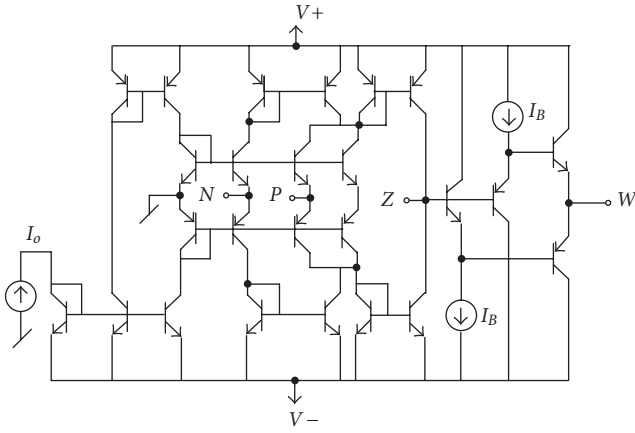


FIGURE 4: Circuit schematic of CCCDBA [10].

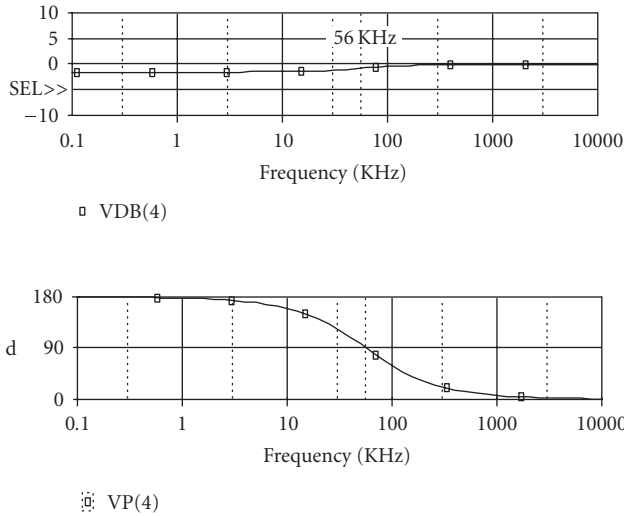


FIGURE 5: Frequency response of Circuit-1 using CCCDBA.

of 115 KHz as shown in Figure 6, as against the designed value of 119 KHz. Thus the proposed all-pass filter circuits are verified.

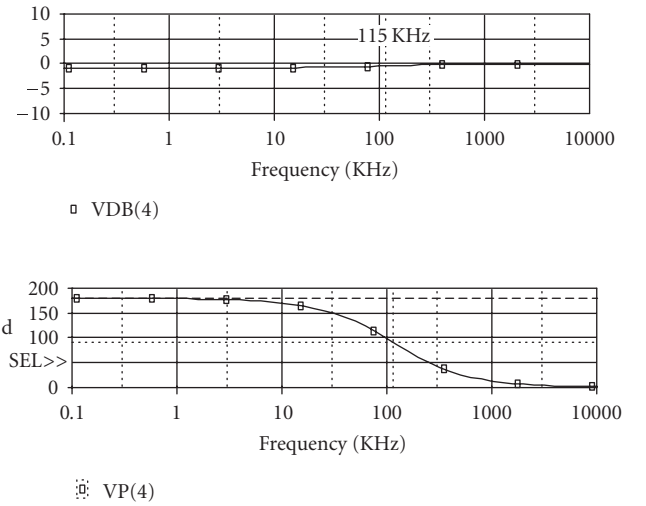


FIGURE 6: Frequency response of Circuit-2 using CCCDBA.

5. CONCLUSION

New voltage-mode first-order all-pass filters using CDBA and CCCDBA are proposed which possess low output impedance and hence are suited for cascading without additional voltage buffers. The CCCDBA-based circuits with a capacitor, a resistor, and an active element are minimum component count circuits and hence provide a low-cost solution. Nonideal analysis and sensitivity performance is also given. PSPICE simulation results are given to verify the proposed circuits. The integration of the proposed circuits in modern IC technologies is an area open for further research.

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