A VOLTAGE-MODE FIRST ORDER ALLPASS FILTER BASED ON VDTA

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Abstract. *This article presents a new voltage-mode first order allpass filter (APF) employing voltage differencing transconductance amplifier (VDTA). The advantages of the circuit are that: the circuit description is very compact, consists of merely a VDTA and a capacitor: the phase shift can be electronically adjusted by current bias: it provides the lower THD of the output signal. Without any component matching conditions, the proposed circuit is very appropriate to further develop into an integrated circuit. Moreover, the proposed APF can provide the output current with high output impedance without modification of the circuit topology. The PSpice simulation results are depicted. The given results agree well with the theoretical anticipation. The maximum power consumption is $400\mu W$ at $\pm 1.25V$ power supplies.*

Keywords

Allpass filter, VDTA, voltage-mode.

1. Introduction

A phase shifter or first order allpass filter (APF) is widely employed in analog signal processing system such as, oscillators, high-Q band-pass filters and phase shifters [1], [2], [3], [4], [5], [6]. The literature surveys display that the first-order all-pass filter circuit using different high-performance active building blocks such as, current conveyors (CCIIs) [7], [8], [9], [10], [11], [12], OTAs [13], current controlled current conveyors (CCCIIs) [14], [15], [16], [17], differential voltage current conveyor (DVCC) [18], differential difference current conveyors (DDCCs) [19], [20], current differencing buffered amplifier (CDBA) [4], [21] and operational transresistance amplifiers (OTRAs) [22], [23], [24], voltage differencing-differential input buffered amplifier (VD-DIBA) [25], voltage differencing inverting buffered amplifier (VDIBA) [26], have been reported. However, these reported circuits suffer from one or more of the following weaknesses:

- use more one active element [9], [13],
- requirement of an external resistor [4], [7], [13], [18], [19], [20], [21], [22], [23], [24],
- absence of electronic adjustability [4], [7], [8], [9], [10], [11], [12], [18], [19], [20],
- absence of the output current with high output impedance in the same circuit topology [4], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26].

In 2011, the voltage differencing transconductance amplifier is presented [27]. It consists of 2 ports input voltage, 2 port output current and 2 external current bias. The voltage differencing of V_n with V_n is transferred to current at the terminal z by first transconductance gain and the voltage at z port is transferred to current at the seems to be a versatile component in the realisation of a class of analog signal processing circuits. The fact is that the device can operate in both current and voltage-modes, provides flexibility and enables a variety of circuit designs. In addition, output current of VDTA can be electronically adjusted. The aim of this paper is to propose a voltage-mode first order allpass filter, emphasizing on the use of the VDTA. The features of the proposed circuit are that: the phase shift can be tuned by current bias: the circuit description is very simple, it uses 1 VDTA and a capacitor as passive elements, which is suitable for fabricating in monolithic chip or off-the-shelf implementation: phase shift can be independently adjusted. The performances of proposed circuit are illustrated by PSpice simulations, they show good agreement as mentioned.

2. Theory and Principle

2.1. Basic Concept of VDTA

Since the proposed APF is based on VDTA, it is realized by CMOS technology, a brief review of VDTA is given in this Section. The characteristics of the ideal VDTA are presented by the following hybrid matrix:

$$\begin{bmatrix} I_z \\ I_{x+} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \end{bmatrix}, \quad (1)$$

g_{m1} and g_{m2} are the transconductances of the VDTA, I_{b1} and I_{b2} are currents bias employed to adjusted g_{m1} and g_{m2}, respectively. They can be found to be:

$$g_{m1} = \sqrt{I_{b1}\mu_i C_{ox}(W/L)}, \quad (2)$$

and

$$g_{m2} = \sqrt{I_{b2}\mu_i C_{ox}(W/L)}, \quad (3)$$

where μ_i is the mobility of the carrier for NMOS and PMOS transistors, C_{ox} is the gate-oxide capacitance/unit area, W and L are the effective channel width and length, respectively. The symbol of VDTA is shown in Fig. 1, where V_p and V_n are input terminals and z, $x+$ and x- are output terminals.

2.2. Proposed Voltage-Mode First-Order All-Pass Filter

The proposed voltage-mode first-order APF is illustrated in Fig. 2. The proposed circuit consists of only one VDTA and a capacitor. Not only the output voltage is achieved, the output current with high output impedance is also achieved which is well-known as transconductance-mode. Considering the circuit in Fig. 2, the current of z terminal can be found to be:

$$0 = I_c + I_z + I_{x-}. \quad (4)$$

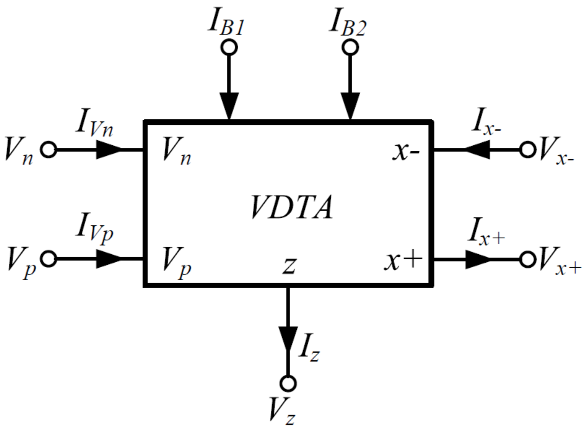

Fig. 1: Symbol of VDTA.

From the properties of VDTA, Eq. (4) can be rewritten as:

$$0 = sC(V_{in} - V_0) - g_{m1}V_{in} - V_0 g_{m2}. \quad (5)$$

From Eq. (5), the voltage and transconductanc transfer functions can be express to be:

$$\frac{V_0}{V_{in}} = \frac{sC - g_{m1}}{sC + g_{m2}}, \quad (6)$$

and

$$\frac{I_0}{V_{in}} = g_{m2}\left(\frac{sC - g_{m1}}{sC + g_{m2}}\right). \quad (7)$$

For easy consideration, if g_{m2}=g_{m1}=g_m, the transfer functions can be rewritten to:

$$\frac{V_0}{V_{in}} = \frac{sC - g_m}{sC + g_m}, \quad (8)$$

and

$$\frac{I_0}{V_{in}} = g_m\left(\frac{sC - g_m}{sC + g_m}\right). \quad (9)$$

From Eq. (8), the pole frequency, voltage gain and phase response of the proposed circuit are:

$$\omega_p = \frac{g_m}{C}, \quad (10)$$

$$\left|\frac{V_0}{V_{in}}\right| = 1, \quad (11)$$

and

$$\phi(\omega_p) = \pi - 2\tan^{-1}\left(\frac{\omega_p C}{g_m}\right). \quad (12)$$

For transconductance-mode, the pole frequency and phase response are same to the voltage-mode APF. But the transconductance-gain is written as:

$$\left|\frac{I_0}{V_{in}}\right| = g_m. \quad (13)$$

From properties of VDTA as shown in Eq. (2) and Eq. (3), the pole frequency and phase response for both mode can be modified to be:

$$\omega_p = \frac{C}{\sqrt{I_B \mu_i C_{ox}(W/L)}}, \tag{14}$$

and

$$\phi(\omega_p) = \pi - 2\tan^{-1}\left[\frac{\omega_p C}{\sqrt{I_B \mu_i C_{ox}(W/L)}}\right]. \tag{15}$$

It can be seen that the circuit gives a phase shift from 180° −0°. Moreover, the angle pole frequency can be electronically controlled by I_B. For transconductance-mode, the transconductance gain is rewritten as:

$$\left|\frac{I_0}{V_{in}}\right| = \sqrt{I_B \mu_i C_{ox}(W/L)}. \tag{16}$$

The ω_p sensitivities of the filter can be written to:

$$S_C^{\omega_p} = -1, S_{I_B}^{\omega_p} = 1.5. \tag{17}$$

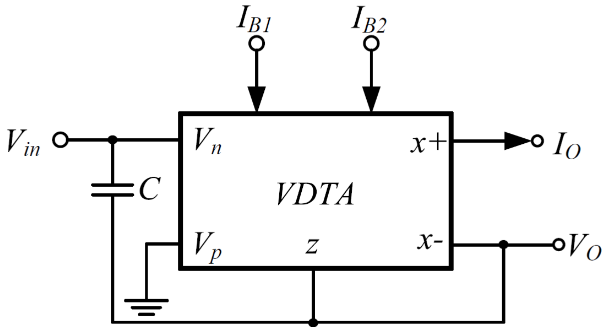

Fig. 2: Proposed voltage-mode first-order APF.

2.3. Non Ideal Case

In practice, the influences of voltage and current tracking errors and also the parasitic terminal impedances of VDTA will affect the filter performance. In this Section, these parameters will be taken into account. For non-ideal the VDTA can be respectively characterized with the following equations:

$$\begin{bmatrix} I_z \\ I_{x+} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} \alpha_P g_{m1} & \alpha_N g_{m1} & 0 \\ 0 & 0 & \beta g_{m2} \\ 0 & 0 & -\beta g_{m2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix}, \tag{18}$$

where α_P and α_N are the transconductance error gains from P and N ports to z port. β is the transconductance error gain from z port to x port. The influences of parasitic impedances are resistive and capacitive parts affecting the P, N, Z and X ports of VDTA. Let us denote them R_P, C_P, R_N, C_N, R_z, C_Z, and R_X, C_X, respectively. Considering into these effects, the voltage and transconductane transfer functions will be modified to the more general forms:

$$\frac{V_0}{V_{in}} = \frac{sC - \alpha_N g_{m1}}{s(C + C^*) + G^* + \beta g_{m2}}, \tag{19}$$

and

$$\frac{I_0}{V_{in}} = \beta g_{m2}\left(\frac{sC - \alpha_N g_{m1}}{s(C + C^*) + G^* + \beta g_{m2}}\right), \tag{20}$$

where C*= C_N+ C_Z+ C_X and G*= G_N+ G_Z+ G_X. In this case, the pole frequency, voltage gain and phase response are modified to:

$$\omega_p = \frac{G^* + \alpha_N g_m}{C + C^*}, \tag{21}$$

$$\left|\frac{V_0}{V_{in}}\right| = \frac{\sqrt{(\omega_p C)^2 - (\alpha_N g_{m1})^2}}{\sqrt{[\omega_p(C + C^*)]^2 + (G^* + \beta g_{m2})^2}}, \tag{22}$$

and

$$\begin{aligned} \phi(\omega_p) &= \pi - \tan^{-1}\left(\frac{\omega_p C}{\alpha_N g_{m1}}\right) \\ &- \tan^{-1}\left[\frac{\omega_p(C + C^*)}{G^* + \beta g_{m2}}\right]. \end{aligned} \tag{23}$$

The transconductance-gain from Eq. (20) is written as:

$$\left|\frac{I_0}{V_{in}}\right| = \beta g_{m2}\frac{\sqrt{(\omega_p C)^2 - (\alpha_N g_{m1})^2}}{\sqrt{[\omega_p(C + C^*)]^2 + (G^* + \beta g_{m2})^2}}. \tag{24}$$

It should be mentioned that the non-ideal parameters of the VDTA affect the pole frequency, voltage gain and phase response.

3. Simulation Results

The performances of the proposed voltage-mode first order allpass filter have been tested by PSpice simulation. This work employed a VDTA realized by a CMOS technology. The NMOS and PMOS transistors employed in the proposed circuit as shown in Fig. 2, were simulated by respectively using the parameters of the 0.25 μm TSMC CMOS technology (level 7) with ±1.25 V supply voltages. Fig. 3 depicts the schematic description of VDTA used in the simulations. The aspect ratios of PMOS and NMOS transistor are W/L = 8 μm/0.25 μm and W/L = 5 μm/0.25 μm, respectively. C = 10 pF, I_B = 80 μA. Simulated gain and phase responses of the APF are given in Fig. 4. It can be found that the simulated gain is slightly deviated from ideal responses due to the error terms as expressed in Eq. (22). Phase response for different I_B is shown in Fig. 5. This result confirms that the angle natural frequency can be electronically controlled by setting IB as shown in Eq. (15). The time-domain response of the proposed APF is shown in Fig. 6, where a sine wave of 150 mV/5 MHz was applied as the input to the filter. Fig. 7 shows the total harmonic distortion (THD) variation with respect to amplitude of the applied sinusoidal input voltage at the pole frequency of the all-pass filter. The tuning of pole frequency by I_B is confirmed by the result in Fig. 8.

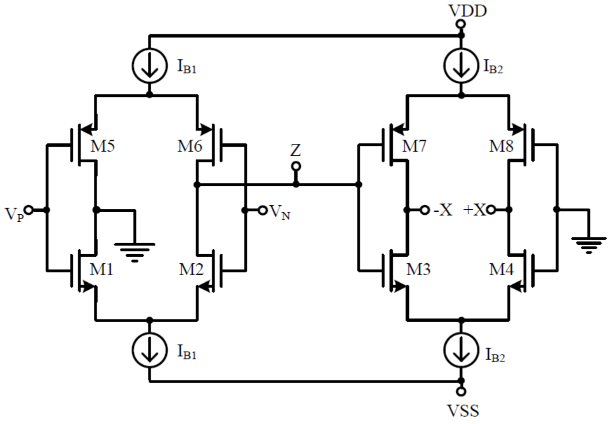

Fig. 3: Internal construction of VDTA.

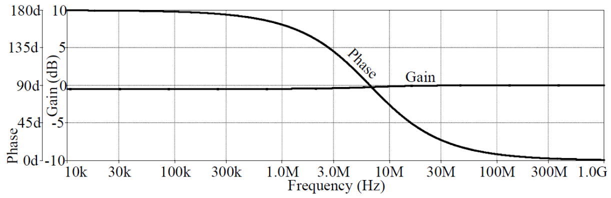

Fig. 4: Output phase and gain response.

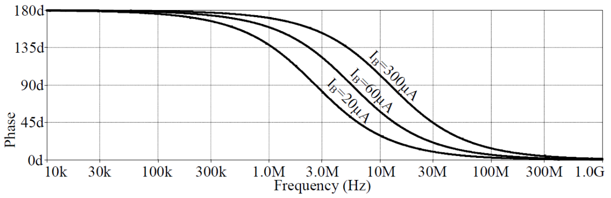

Fig. 5: Output phase and gain responses.

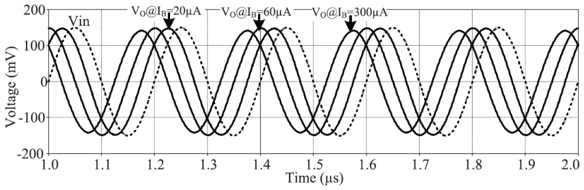

Fig. 6: Time domain response of the circuit in Fig. 2.

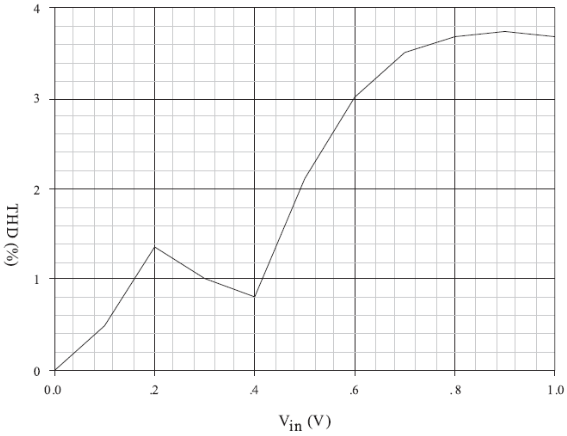

Fig. 7: THD variations versus amplitudes of the applied sinusoidal input voltages at f_0= 6.75 MHz.

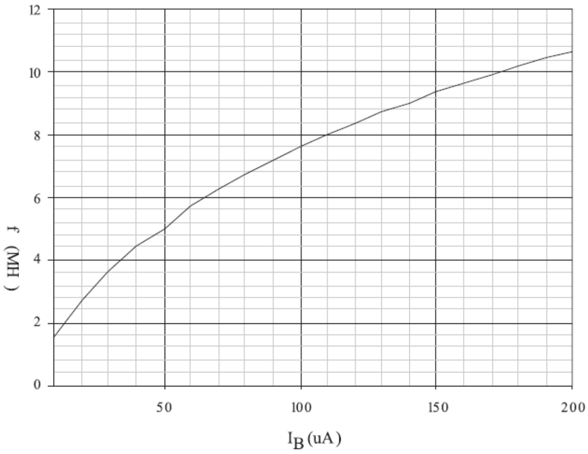

Fig. 8: Pole frequency vs I_B.

4. Conclusion

An electronically tunable voltage-mode first-order all-pass filter has been introduced via this paper. The proposed configuration is very simple and can be electronically controlled. It consists of single VDTA and single capacitor. So it is easy to fabricate in IC form to use in battery-powered or portable electronic equipments such as wireless communication devices. In addition, the output current with high output impdenace is achieved. The PSpice simulation results were depicted, and agree well with the theoretical anticipation.

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