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New MOS-C Biquad Filter Using the Current Feedback Operational Amplifier

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***Abstract*— A new MOS-C bandpass-low-pass filter using the current feedback operational amplifier (CFOA) is presented. The filter employs two CFOA’s, eight MOS transistors operating in the nonsaturation region, and two grounded capacitors. The proposed MOS-C filter has the advantage of independent control of Q and ω_o. PSpice simulation results for the proposed filter are given.**

***Index Terms*—Current feedback operational amplifiers, filters.**

I. Introduction

The current feedback operational amplifier (CFOA) is a very versatile building block and is now commercially available from several manufacturers [1], [2]. The CFOA has the advantages of constant bandwidth, which is independent of the closed loop gain and its high slew rate, which is typically around 2000 V μs^{-1}. It is well known that the MOS-C filters using the conventional op-amp [3]–[7] suffer from the finite gain bandwidth of the op-amps. Recently, the realization of MOS-C filters using the CFOA has received considerable attention [8]–[10]. The CFOA-based Tow–Thomas biquad, introduced in [9], uses two CFOA’s, four MOS resistor cells (MRC) [11], and six grounded capacitors with the constraint that every three capacitors must be equal. Therefore, any error resulting from the fabrication process will introduce distortion in the output signals.

The purpose of this paper is to introduce a new MOS-C bandpass-low-pass filter based on a new MOS-C lossy integrator, using the CFOA requiring only two grounded capacitors, one (MRC) and four MOS transistors operating in the nonsaturation region. The proposed filter has the advantage of independent control of Q and ω_o. In Section II, the proposed MOS-C-CFOA lossy integrator and the MOS-C-CFOA filter are introduced. In Section III, PSpice simulation results of the proposed filter using a 1.2-μm technology file (Vendor: ORBIT Semiconductor) are given.

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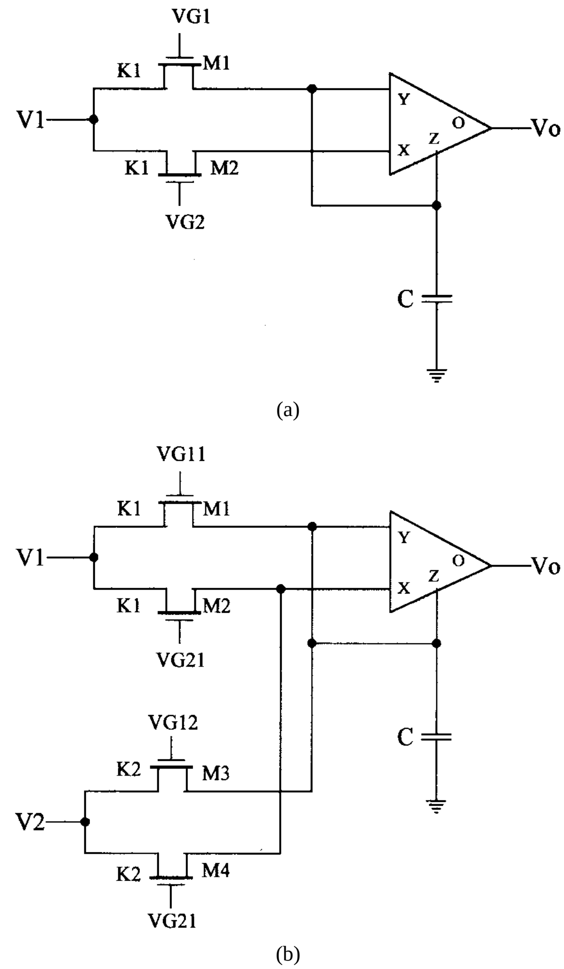

Fig. 1. (a) The proposed MOS-C-CFOA lossy integrator. (b) The MOS-C-CFOA lossy summer integrator.

II. The MOS-C CFOA Based Bandpass-Lowpass Filter

Fig. 1(a) shows the basic MOS-C-CFOA lossy integrator. The proposed integrator circuit employs two matched transistors (M_1, M_2) and a grounded capacitor. The output voltage of the integrator is given by

$$V_o = \frac{G}{s + G} V_1 \tag{1}$$

where

$$G = K_1(V_{G1} - V_{G2}) \quad \text{for } V_{Gi} - V_T > \max(V_1, V_o), \quad \text{for } i = 1, 2 \tag{2}$$

and K_1 is the transconductor parameter of each of M_1 and M_2 and is given by

$$K_1 = \mu_n C_{ox}\left(\frac{W_1}{L_1}\right) \tag{3}$$

where (W_1/L_1) is the transistor aspect ratio, C_{ox} is the gate oxide capacitance per unit area, and μ_n is the electron mobility. The

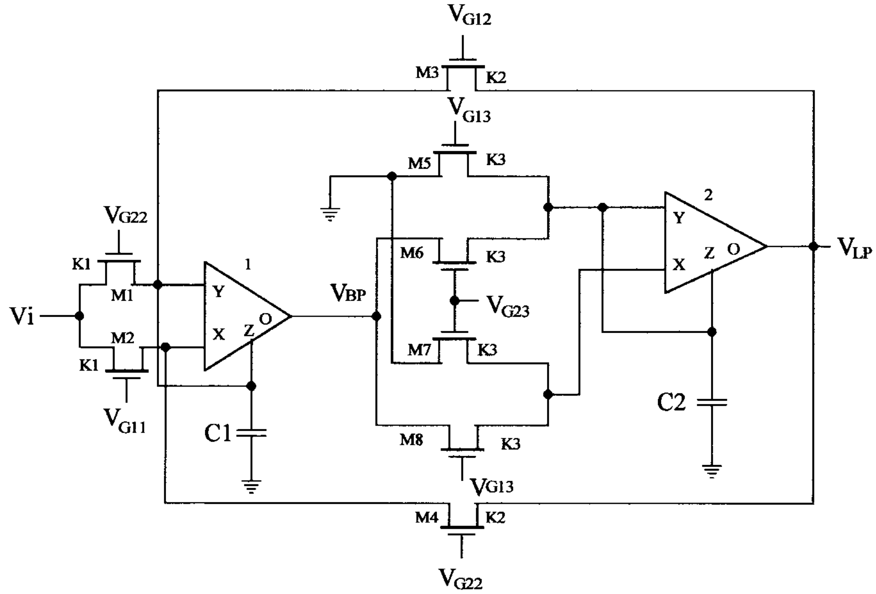

Fig. 2. The proposed MOS-C CFOA bandpass-low-pass filter.

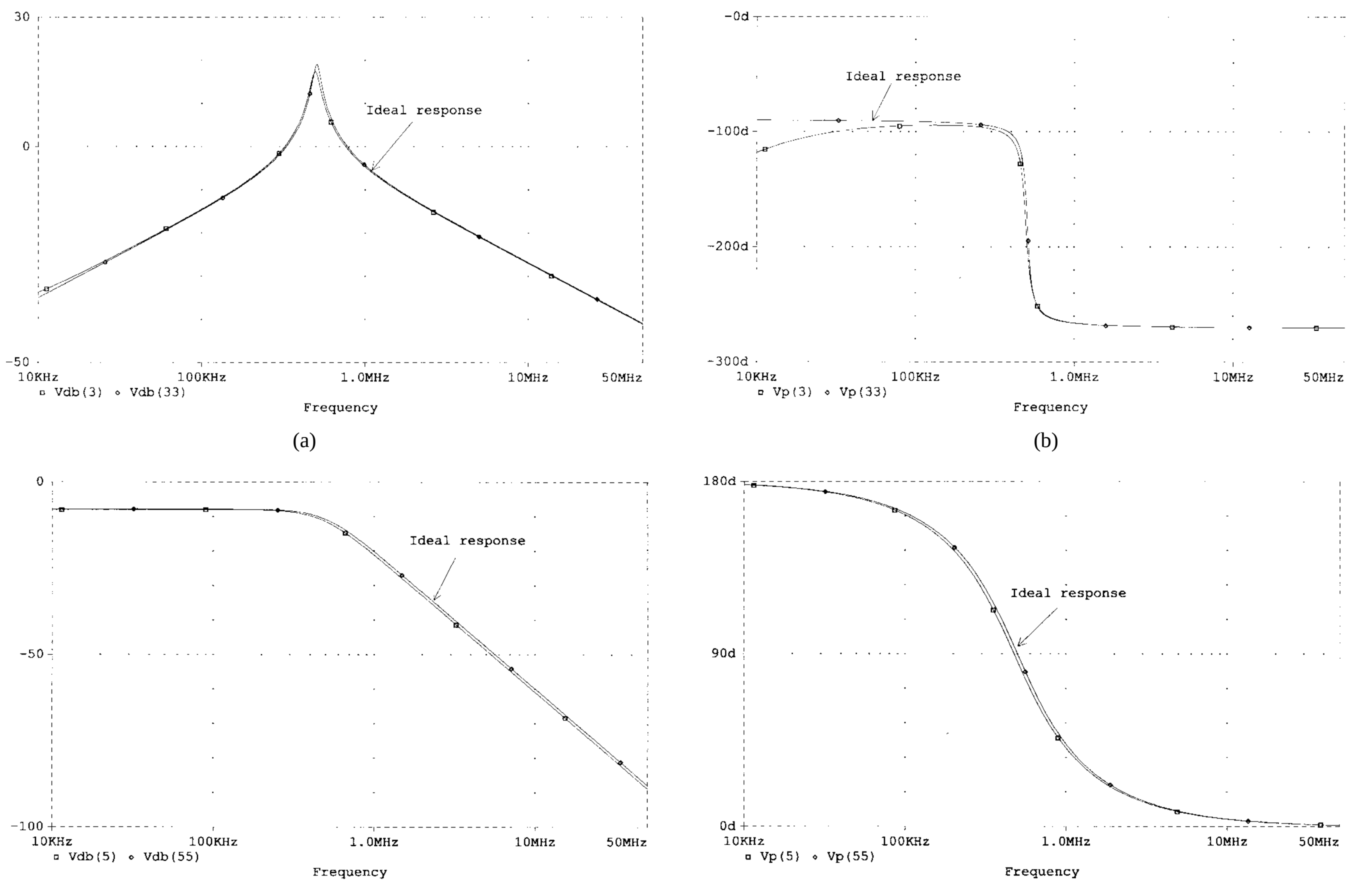

Fig. 3. (a) The magnitude response of the bandpass filter. (b) The phase response of the bandpass filter. (c) The magnitude response of the low-pass filter. (d) The phase response of the low-pass filter.

proposed integrator has many advantages over the classical op-amp MOS-C lossy integrator. The proposed integrator has a lower component count (only two MOS transistors and one grounded capacitor) and therefore more relaxed matching requirements for nonlinearity cancellation. This integrator is realized only using the CFOA and cannot be realized using the classical op-amp because the realization of this integrator depends on the use of the Z terminal of the CFOA that does not exist in the op-amp. In addition, the CFOA has the advantages of constant bandwidth and a high slew rate.

Fig. 1(b) shows the MOS-C-CFOA-based lossy summer integrator. The integrator circuit employs a pair of matched transistors (M_1, M_2) and (M_3, M_4). The output voltage of the integrator is given by

$$V_o = \frac{G_1 V_1 + G_2 V_2}{s + G_1 + G_2} \tag{4}$$

where

$$G_1 = K_1(V_{G11} - V_{G12}), \qquad \text{for } V_{G1i} - V_T > \max(V_1, V_o), \quad i = 1, 2 \tag{5}$$

$$G_2 = K_2(V_{G21} - V_{G22}), \qquad \text{for } V_{G2i} - V_T > \max(V_2, V_o), \quad i = 1, 2. \tag{6}$$

Fig. 2 shows the MOS-C-CFOA bandpass-low-pass filter. The first CFOA with the MOS transistors $M_1, M_2, M_3,$ and M_4 is the summer lossy integrator described above and the second CFOA, with the four MOS transistor cell [11] formed from M_5 to M_8, is a lossless integrator. All MOS transistors are assumed to be operating in the nonsaturation region. The filter has the following voltage transfer functions:

$$\frac{V_{BP}}{V_i} = \frac{-\dfrac{sG_1}{C_1}}{s^2 + s\dfrac{(G_2 - G_1)}{C_1} + \dfrac{G_2 G_3}{C_1 C_2}} \tag{7}$$

$$\frac{V_{LP}}{V_i} = \frac{\dfrac{G_1 G_3}{C_1 C_2}}{s^2 + s\dfrac{(G_2 - G_1)}{C_1} + \dfrac{G_2 G_3}{C_1 C_2}} \tag{8}$$

where

$$\omega_o = \sqrt{\frac{G_2 G_3}{C_1 C_2}}, \quad Q = \sqrt{\frac{C_1}{C_2}\,\frac{G_2 G_3}{(G_2 - G_1)^2}} \tag{9}$$

$$G_i = K_i(V_{G1i} - V_{G2i}) = K_i V_{G12i}, \qquad \text{for } i = 1, 2, \text{ and } 3 \tag{10}$$

where

$$K_i = \mu_n C_{ox}\left(\frac{W}{L}\right)i, \qquad \text{for } i = 1, 2, \text{ and } 3. \tag{11}$$

It is seen that the transconductor G_1 controls the Q of the filter without affecting ω_o. Large Q can be obtained by making the transconductance value of G_1 near to the transconductance value of G_2 through its control voltages V_{G11} and V_{G21}. To simplify the design, take $G_2 = G_3 = G$, $C_1 = C_2 = C$. Therefore

$$\omega_o = \frac{G}{C} \quad \text{and} \quad Q = \frac{G}{G - G_1}. \tag{12}$$

III. Simulation Results

PSpice simulation results for the filter circuit shown in Fig. 2 using the CFOA given in [10] with $C_1 = C_2 = 12.75$ pF, $G_2 = G_3 = 40\ \mu$A/V ($K_2 = K_3 = 40\ \mu$A/V^2 and $V_{G122} = V_{G123} = 1$ V) and $G_1 = 36\ \mu$A/V ($K_1 = 40\ \mu$A/V^2 and $V_{G121} = 0.9$ V) to obtain a bandpass filter with center frequency of $f_o = 500$ kHz, $Q = 10$, and $|T_{BP}(\omega_o)| = (G_1/G - G_1) = 9$ is shown in Fig. 3(a) and (b), indicating both the magnitude and the phase of the bandpass output.

Simulation results for the same circuit but with $G_1 = -16.6\ \mu$A/V ($K_1 = 40\ \mu$A/V^2 and $V_{G121} = -0.4143$ V) to obtain a maximally flat low-pass response, with f_o equal to 500 kHz as shown in Fig. 3(c) and (d), indicating both the magnitude and the phase of the low-pass output.

IV. Conclusions

A new MOS-C CFOA-based bandpass-low-pass filter has been introduced. The proposed filter offers two basic advantages, namely, that it requires two grounded capacitors and has independent control of Q and ω_o. The PSpice simulation results confirm the theoretical analysis.

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