Low-Voltage CFOA with Bulk-Driven, Quasi-Floating-Gate and Bulk-Driven-Quasi-Floating-Gate MOS Transistors

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***Abstract*—In this work, the low-voltage current feedback operational amplifier (CFOA) with bulk-driven, quasi-floating-gate (QFG) transistor and bulk-driven-quasi-floating-gate (QFG) transistor techniques to operate under low supply voltage is proposed. The proposed circuits were design based on the voltage follower and current follower while the output stages are designed base on the voltage follower. The CFOA circuits are designed by using the 0.18 μm CMOS technology and supply voltage operated 1 V. Simulation results shows output impedance of CFOA with bulk-driven, quasi-floating-gate (QFG) MOS transistor and bulk-driven-quasi-floating-gate (BD-QFG) MOS transistor are 55.72 ΩdB, 43.88 ΩdB, and 41.63 ΩdB, respectively. Finally, the proposed BD, QFG and BD-QFG MOS transistors techniques can used before the ultra-low voltage and low-power CFOA circuits.**

***Keywords*—CFOA; low voltage; bulk-driven; quasi-floating-gate MOS transistor; bulk-driven-quasi-floating-gate MOS transistor.**

I. INTRODUCTION

A voltage feedback operational amplifier (VFOA) is a fundamental amplifier circuit which is commonly employed in a mixed-signal IC and a VLSI circuit for many years. Unfortunately, the VFOA application connected circuits are limitations in the slew rate and gain-bandwidth trade-off [1]. A current feedback operational amplifier (CFOA) is a transimpedance operational amplifier that can successfully replace in the electronics industry [1]–[7]. The CFOA most advantage the VFOA in high slew rate performance and gain-bandwidth independence. The application of CFOA like VFOA such as a sinusoidal oscillator, a universal biquad filter, and etc were proposed in [4, 5].

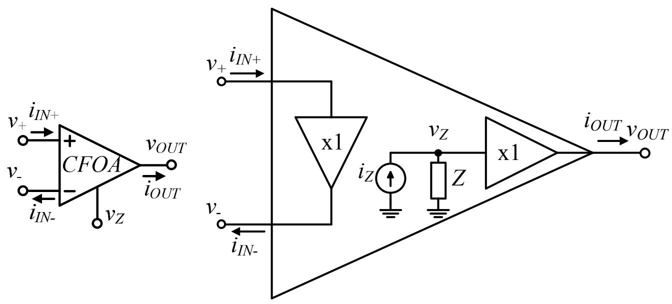
The high performance CFOA with rail-to-rail operation was designed base on the voltage follower and the transimpedance amplifier [6]. Unfortunately, the supply voltage of CFOA circuit equal to $4V_{DSAT} + 2V_{GS}$. The CFOA based on micropower class AB voltage buffer were proposed in [8]. The high current for large output capacitor is driven by the proposed circuit, but it required relatively high supply voltage. In addition, the output signal can't operated in the widely output swing. Since the increasing demand of portable equipments, the mixed-signal and VLSI circuits should be operated under low voltage and low power dissipation. The bulk-driven (BD), quasi-floating-gate (QFG), and bulk-driven-quasi-floating-gate (BD-QFG) MOS transistor have been reported in [8] – [10] that are low voltage and low power techniques design.

This paper presents a low voltage CFOA with bulk-driven (BD), quasi-floating-gate (QFG) and bulk-driven-quasi-floating-gate (BD-QFG) MOS transistors that are the novelty of the approach. The prototype of current feedback operational amplifier is presented in Section II. In Section III the proposed current feedback operational amplifier is explaining. Thereafter, the simulation results and discussions are presented in Section IV. Finally, conclusions are explained.

II. THE POTOTYPE OF CURRENT FEEDBACK OPERATIONAL AMPLIFIER

Fig. 1 shows the symbol and equivalent circuit of a conventional CFOA. Its characteristic can be described in the following matrix form:

$$\begin{bmatrix} i_{IN+} \\ v_{IN-} \\ i_Z \\ v_{OUT} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_{IN+} \\ i_{IN-} \\ v_Z \\ i_{OUT} \end{bmatrix} \tag{1}$$



(a) (b)

Fig. 1. (a) Symbol of CFOA and (b) equevalent circuit of CFOA

A CFOA is a four-port device where $i_{IN+} = 0$, $v_{IN-} = v_{IN+}$, $i_Z = i_{IN-}$, and $v_{OUT} = v_Z$. Parameters i_{IN+}, i_{IN-}, i_Z and v_{IN+}, v_{IN+}, v_Z are currents and voltages at non-inverting input, inverting input, port Z, and output voltage, respectively. The characteristics of CFOA are the high-impedance $v_{IN(+)}$ and Z node, the low input-impedance $v_{IN(-)}$. The very low input resistance is mandatory in order to maintain the CFOA bandwidth-constant.

CFOA consists of three basic elements stage: two voltage follower stages and a current follower stage. The first stage is the input stage of CFOA which is a pseudo voltage follower. It is connected between the non-inverting input and the inverting input of the CFOA. A differential voltage between the non-inverting input and the inverting input voltage is forced equal to zero voltage by the voltage follower circuit. In second stage, the current follower is employed to transfer current signal from i_{IN-} at v_{IN-} terminal to i_Z at v_Z terminal. The third stage is the output stage of CFOA which is a pseudo voltage follower

III. THE PROPOSED CURRENT FEEDBACK OPERATIONAL AMPLIFIER

A. CFOA with Bulk-Driven MOS transistor

Fig. 2 shows the proposed CFOA while the CFOA with bulk-driven MOS transistor is shown in Fig. 2(a). The input stage of CFOA consists of transistors M_1 – M_6 which is the pseudo voltage follower circuit, while the current follower consists of transistors M_5 –M_8. The transistors M_7 and M_8 are connected in parallel to the transistors M_5 and M_6, respectively. The quasi-floating gate techniques [10] are employed to provide the class AB current follower operation. The output stage consists of the transistors M_9 – M_{14} that is as circuitry as the input stage.

The class AB current follower, which is the QFG technique connecting, is employed to transfer from the input current i_{IN-} to the output current at node i_Z. The output stage, the pseudo voltage follower is employed to follow from the voltage node v_Z to the output node v_{OUT}. It is noted that M_{13} and M_{14} are also QFG transistors. The dc operating points at all-gate terminals are set by V_{B2} through the large resistors R_{G3}, R_{G4}, and R_{G7}. Resistor R_{C1} and R_{C2} and capacitor C_{C1}, C_{C2}, and C_{C3} are used to compensate the CFOA such that the circuit is always stable. A straightforward analysis shows the output resistance of is given by

$$R_{OUT} \cong \frac{1}{g_{mb9}(g_{m13}+g_{m14})(r_{O9} \parallel r_{O11})(r_{O13} \parallel r_{O14})} \quad (2)$$

where g_{mb9} is bulk-driven transconductance of M_9. g_{m13} and g_{m14} are gate-driven transconductance of M_{13}, and M_{14}, respectively. r_{O9}, r_{O11}, r_{O13} and r_{O14} are output resistance of M_9, M_{11}, M_{13}, and M_{14}, respectively.

In case of the current follower is connected to the pseudo voltage follower that is the transimpedance amplifier stage.

B. CFOA with Quasi-Floating Gate MOS Transistor

The CFOA with quasi-floating gate MOS transistor is illustrated in Fig. 2(b) that is a modification of the CFOA with bulk-driven MOS transistors in Fig. 2(a). The QFG MOS transistor is the low voltage analog building block and the widely dynamic range. The QFG MOS transistor has become so popular like the BD MOS transistor that can successfully replace gate-driven MOS transistor. In addition, the transconductance of the QFG MOS transistor is 2 to 5 times larger than the transconductance of the bulk-driven MOS transistor. As a result, the output resistance of CFOA in Fig. 2(b) is lower than the output resistance of CFOA in Fig. 2(a). The input terminal of the input stage and the output stage of the pseudo voltage follower are capacitively coupled to the QFG terminals of the transistors M_1, M_2, M_9, and M_{10}. The dc operating points at both gate terminals are set by V_{B3} through the large resistors R_{G1}, R_{G2}, R_{G5} and R_{G6}. In this design, V_{B3} is set equal to 0.5 V, thus allowing the input stage to operate under the supply voltage. The current follower stage and output stage of the voltage follower output stage of the CFOA are connected by using QFG technique in order to the class AB operation. The CFOA with QFG MOS transistor can be operating as same as the CFOA with BD MOS transistor. The output resistance of the CFOA with QFG MOS transistor in Fig. 2(b) is given by

$$R_{OUT} \cong \frac{1}{g_{m9}(g_{m13}+g_{m14})(r_{O9} \parallel r_{O11})(r_{O13} \parallel r_{O14})} \quad (3)$$

where g_{m9} is gate-driven transconductance of M_9.

C. CFOA with Bulk-Driven-Quasi-Floating Gate MOS Transistor

As shown in Fig. 2(c), the input stage and the output stage are the pseudo bulk-driven-quasi-floating gate (BD-QFG) MOS transistor voltage follower. Recently, the BD-QFG MOS transistor is a new low voltage and low power analog building block that was presented in [10]. Since the input v_{IN+} and v_{IN-} are connected to the bulk terminals and the capacitor terminals, the total transconductance of BD-QFG MOS transistor is larger than the transconductance of BD MOS transistor and QFG MOS transistor. The capacitors are coupled to the QFG terminals of the transistors M_1, M_2, M_9, and M_{10}. Since the proposed circuit is improve the BD CFOA and QFG CFOA, the BD-QFG CFOA can be operating as same as the BD CFOA and QFG CFOA. A straightforward analysis of the CFOA with BD-QFG MOS transistor in Fig. 2(c) shows that impedance at the output node as

$$R_{OUT} \cong \frac{1}{(g_{m9}+g_{mb9})(g_{m13}+g_{m14})(r_{O9} \parallel r_{O11})(r_{O13} \parallel r_{O14})} \quad (4)$$

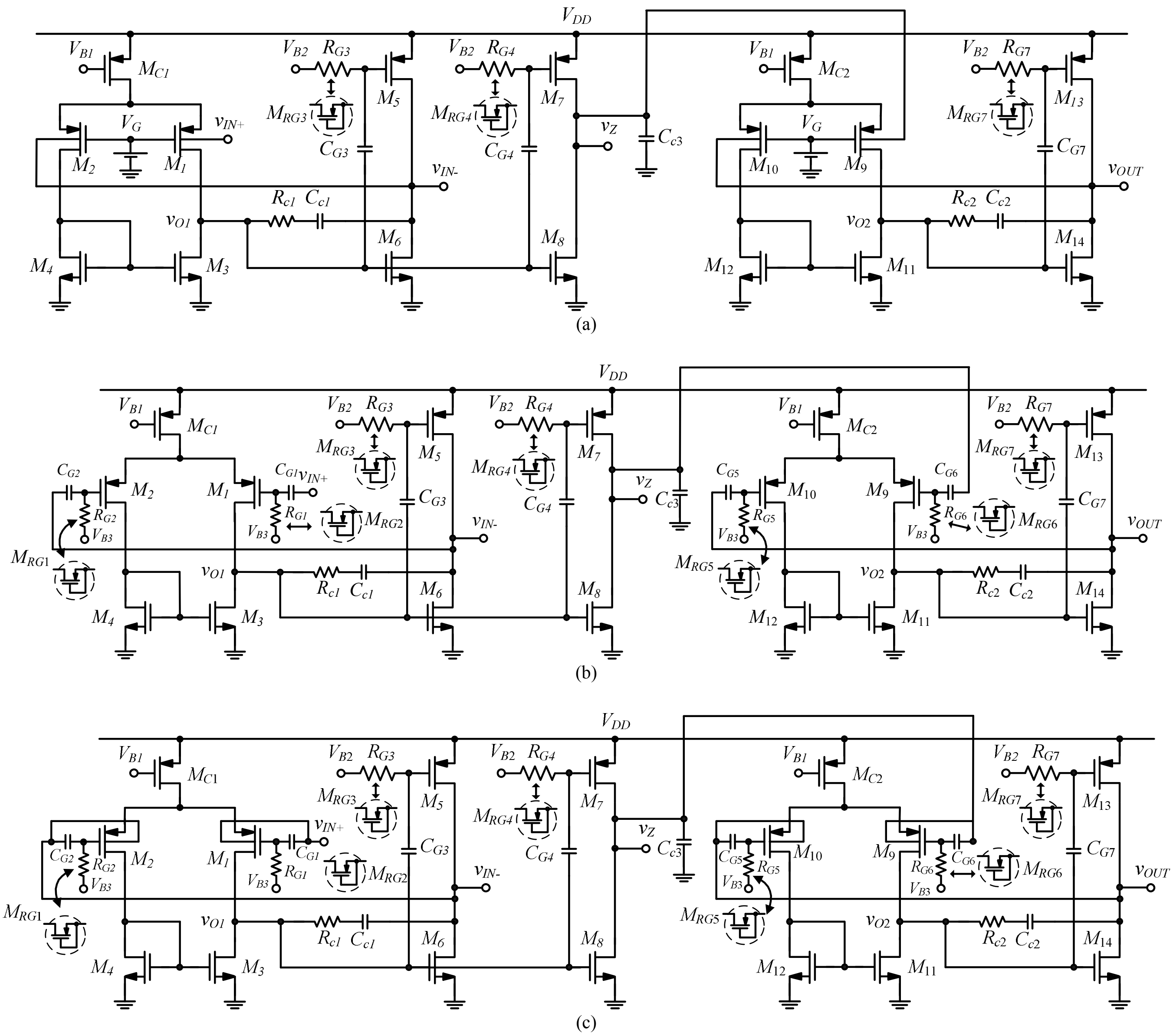


Fig. 2. The proposed CFOA (a) bulk-driven MOS transistor, (b) quasi-floating-gate MOS transistor, and (c) bulk-driven-quasi-floating-gate MOS transistor.

IV. The Simulation Results and Discussions

The current feedback operational amplifier with BD, QFG, and BD-QFG MOS transistors in Fig. 3 was designed based on the circuit in Fig. 2 and simulated using HSPICE with Level 49 models and 0.18 μm CMOS technology. Fig. 3 shows the DC transfer characteristic between v_{IN+} and v_{IN-} input. As seen, the inverting input terminal v_{IN-} following the signal at the non-inverting input terminal v_{IN+} of BD (dotted line), QFG (dash line) and BD-QFG (dash-dot-dot line) MOS transistors input that are a wide common mode range while GD (solid line) MOS transistor input is limited the high level input swing. The limitation of rail-to-rail operation, when input v_{IN+} of GD MOS transistor input is connected to the high level signal swing, the pMOS differential pair input enter into the cut off region.

The output impedances of the proposed CFOA circuits are illustrated in Fig. 4. The output impedance of CFOA with bulk-driven, quasi-floating-gate (QFG) MOS transistor and bulk-driven-quasi-floating-gate (QFG) MOS transistor are 55.72 ΩdB, 43.88 ΩdB, and 41.63 ΩdB, at 10 kHz, respectively. The output impedance can be decreased by increasing of the DC gain of first stage of voltage follower stage. Fig. 5 shows the time-domain response of the proposed CFOA with non-inverting amplifier configuration for the gain of 14 dB. A 100 mV_{pp} sine wave at 100 kHz is applied to CFOA input of a non-inverting amplifier circuit. As a result, the proposed CFOA circuits are a good transient response while of the conventional CFOA circuit (GD MOS transistor) has been distortion.

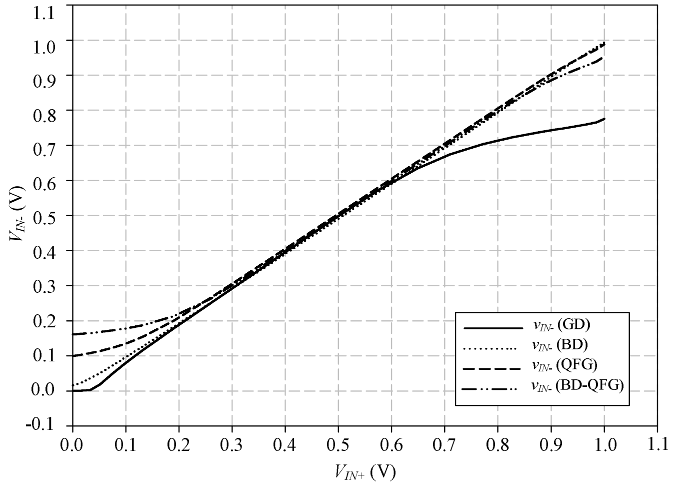


Fig. 3. DC transfer characteristic of the CFOA between v_{IN+} and v_{IN-} input.

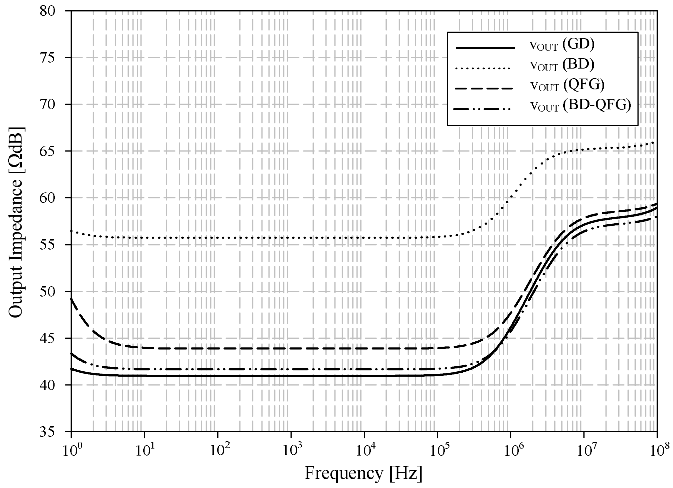


Fig. 4. Frequency response of the output impedance.

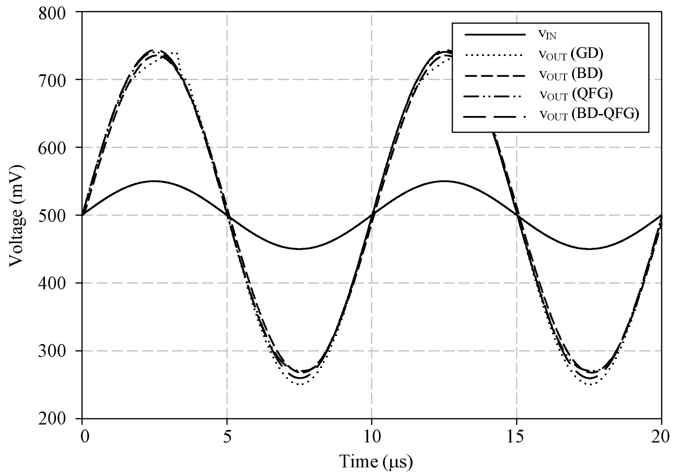


Fig. 5. Time-domain response with a gain of 14 dB.

V. CONCLUSSIONS

The low voltage CFOA circuits have been proposed with bulk-driven quasi-floating gate and bulk-driven-quasi-floating-gate MOS Transistor. Simulation results show that the proposed CFOA circuits with BD and QFG MOS transistors input are wide input signal swing while GD and BD-QFG MOS transistors input are limited input signal swing. The power dissipation the proposed CFOAs are 80 μW. Finally, the BD, QFG and BD-QFG MOS transistors input techniques have been used before the ultra-low-voltage and low-power CFOA circuits and its applications design.

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