A novel fully differential telescopic operational transconductance amplifier*

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Abstract: A novel fully differential telescopic operational transconductance amplifier (OTA) is proposed. An additional PMOS differential pair is introduced to improve the unit-gain bandwidth of the telescopic amplifier. At the same time, the slew rate is enhanced by the auxiliary slew rate boost circuits. The proposed OTA is designed in a 0.18 μm CMOS process. Simulation results show that there is a 49% improvement in the unit-gain bandwidth compared to that of a conventional OTA; moreover, the DC gain and the slew rate are also enhanced.

Key words: OTA; fully differential; unit-gain bandwidth; slew rate

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1. Introduction

The operational transconductance amplifier (OTA) is the block with the highest power consumption in analog integrated circuits in many applications. Low power consumption is becoming more important in handset devices, so it is a challenge to design a low power OTA. There is a tradeoff between speed, power, and gain for an OTA design because usually these parameters are contradicting parameters. There are three kinds of OTAs: two stage OTAs, folded-cascode OTAs, and telescopic OTAs. The telescopic amplifier consumes the least power compared with the other two amplifiers, so it is widely used in low power consumption applications[1, 2]. A conventional telescopic amplifier is shown in Fig. 1.

Recently, telescopic amplifier design research focused on improving the gain and the output swing[3, 4]. The unit-gain bandwidth of the conventional telescopic amplifier is $g_{m1}/(C_L + C_1)$, where C_L is the load capacitor and C_1 is the parasitic capacitor at the output node. The DC current of M7 is the same as that of M1 in Fig. 1. Only the current which flows in differential pair transistors helps to improve the bandwidth of the OTA. It is well known that a lower current can improve the small signal resistance of the transistors and improve the gain of the amplifier. This paper proposes a novel telescopic amplifier, which can reduce the current of load transistors M5–M7 by introducing an additional PMOS differential pair. The gain and bandwidth of the OTA are also effectively enhanced.

2. Proposed fully differential telescopic operational transconductor amplifier

The proposed fully differential telescopic OTA is shown in Fig. 2. The substrate of the PMOS transistors is connected to V_{DD}. The transistors M0–M8 use the same architecture as the conventional telescopic amplifier shown in Fig. 1. M9–M11 are newly introduced to improve the bandwidth of the amplifier, and Ma1–Ma16 are used to enhance the slew rate of the amplifier. With careful design, the transistors Ma1–Ma16 will be active only during the slewing period.

From Fig. 2, we can find that a PMOS differential pair is introduced as compared with the conventional telescopic amplifier. The PMOS differential pair injects current into nodes A and B, which helps to improve the bandwidth of the amplifier. Furthermore, the PMOS differential does not consume additional power, and the power consumption of the proposed design is the same as the conventional design. The small signal half equivalent circuits of the conventional telescopic amplifier and the proposed design are shown in Figs. 3 and 4, respectively. The DC gain of the conventional OTA in Fig. 3 can be shown as[4]

$$A_v = G_m R_{out}, \tag{1}$$

where G_m is g_{m1}, $R_{out} = r_1 \| (g_{m3} r_{ds3} r_{ds1} + r_{ds3} + r_{ds1}) \approx r_1 \| (g_{m3} r_{ds3} r_{ds1})$, r_1 is the PMOS current mirror small signal equivalent resistance, $r_1 = g_{m5} r_{ds5} r_{ds7}$, so

$$A_V = g_{m1} \left((g_{m5} r_{ds5} r_{ds7}) \middle\| (g_{m3} r_{ds3} r_{ds1}) \right). \tag{2}$$

The unit-gain bandwidth of the conventional design is

$$\omega_u = g_{m1}/(C_1 + C_L). \tag{3}$$

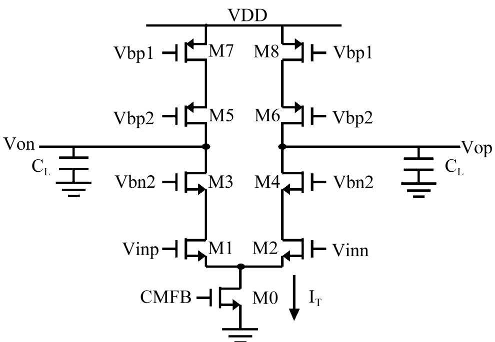

Fig. 1. Conventional telescopic amplifier.

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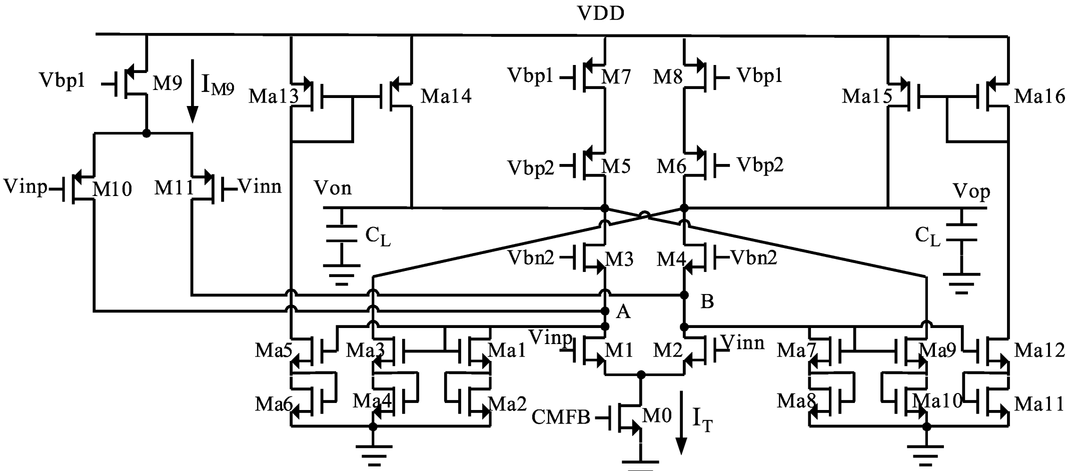

Fig. 2. The proposed telescopic amplifier.

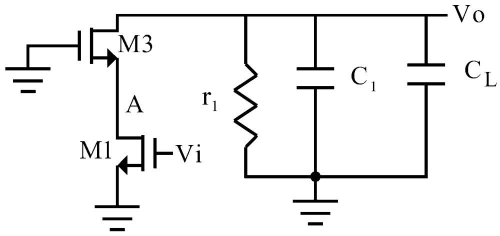

Fig. 3. Small signal half-equivalent circuits of the conventional telescopic amplifier.

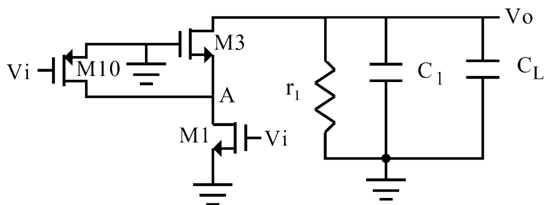

Fig. 4. Small signal half-equivalent circuits of the proposed telescopic amplifier.

Compared with Fig. 3, there is an additional PMOS transistor contributing to G_m in Fig. 4. It is easy to derive the DC gain and the unit-gain bandwidth from Fig. 4. The DC gain of the proposed OTA is

$$A_V = (g_{m1} + g_{m10})\left((g_{m5}r_{ds5}r_{ds7})\,\middle|\middle|\,\left(g_{m3}r_{ds3}(r_{ds1}\,||\,r_{ds10})\right)\right). \quad (4)$$

The unit-gain bandwidth of the proposed design is

$$\omega_u = (g_{m1} + g_{m10})/(C_1 + C_L). \quad (5)$$

Comparing Eq. (2) with Eq. (4), we can find that the equivalent small signal resistor r_1 of the PMOS current load in the proposed design is increased due to the current reduction of these transistors. The G_m of the new design is $g_{m1} + g_{m10}$, which is bigger than for the conventional design (g_{m1}). So, the DC gain is increased.

From Eqs. (3) and (5), it is easy to find that the unit-gain bandwidth of the proposed design is higher than that of the conventional one. Moreover, the bandwidth and gain enhancement do not need additional power; so the power efficiency of the proposed design is improved greatly.

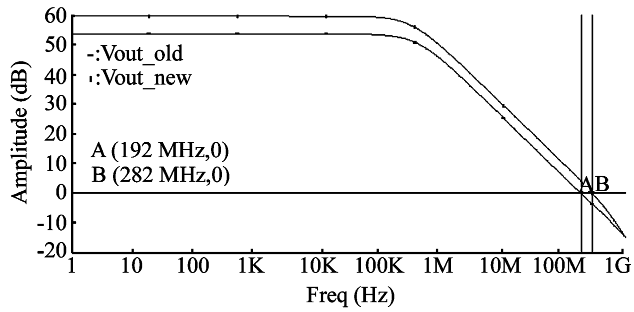

Fig. 5. Frequency responses of the conventional OTA and proposed design.

In the proposed design, the current flowing in the PMOS current load is smaller than in the conventional design. In a switch capacitor application, the slew rate is important. In Ref. [5], a slew rate enhancement method is proposed for a folded-cascode amplifier, and it can be modified to improve our proposed telescopic OTA. The transistors Ma1–Ma16 in Fig. 2 are used to improve the slew rate of the new design. These transistors consume about 0.3 μA at small signal work conditions. When the amplifier enters into the slew mode, the node voltages A or B will be high enough to make transistors Ma1, Ma2, Ma7, Ma8 conduct current. Then Ma3, Ma4 or Ma9, Ma10 will begin to sink current, and Ma14 or Ma15 will source current at the same time. Additional current is injected into the output node. It improves the slew rate of the proposed design. With the slew rate enhancement circuit, the slew rate of the proposed amplifier is faster than that of the conventional amplifier.

3. Simulation results

Both the conventional and the proposed telescopic amplifier are designed and simulated in a 0.18-μm CMOS process. To compare the power efficiency of the proposed design with the conventional telescopic amplifier, an ideal CMFB architecture is used. The AC frequency responses of the two amplifiers are shown in Fig. 5. It is found that the DC gain of the proposed design is 6 dB higher than that of the conventional telescopic

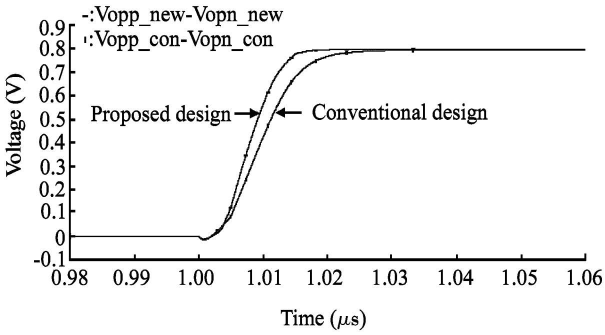

Fig. 6. Setting behavior of the conventional OTA and the proposed design.

amplifier. The unit-gain bandwidth of the proposed design is 286 MHz, about 49% higher than that of the conventional design of 192 MHz.

A similar capacitor gain stage to that of Ref. [5] is used to test the setting behavior of the conventional telescopic and proposed design. The transient responses of both designed OTAs are shown in Fig. 6.

As can be seen, the slew rate of the proposed telescopic amplifier is higher than that of the conventional design. The performance of both designs is listed in Table 1.

4. Conclusion

A novel telescopic operational amplifier is presented in this paper. The bandwidth is improved by introducing the PMOS differential pair, and the slew rate is enhanced by the auxiliary slew boost circuits. Compared to Refs. [3, 5], the proposed design is a good choice for low power analog circuit designs.

Table 1. Performance comparison of the conventional OTA and the proposed design.

Parameter	Conventional OTA	Proposed OTA
UGBW (MHz)	192	286
Power (μA)	360	360
Gain (dB)	53	59
PM (°)	87	66
SR (V/μs)	66	87
Supply voltage	1.8	1.8
Technology	0.18 μm CMOS	0.18 μm CMOS

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