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DESIGN OF LOW POWER LOW VOLTAGE BULK DRIVEN OPERATIONAL TRANSCONDUCTANCE AMPLIFIER (BD-OTA)

Operational Transconductance Amplifier (OTA) is one of the most significant building-blocks in integrated continuous-time filters. Here we design Low Power Low Voltage Bulk Driven OTA with a new concept of high-linearity OTA with controllable Transconductance is proposed. The OTA is simulated in a standard TSMC 0.18 mm CMOS process with a 0.6 V supply voltage.

KEYWORDS: Bulk-Driven transistors, Low-voltage, Low-power OTA, PSPICE simulation

1. INTRODUCTON

Low-voltage (LV) and low-power (LP) CMOS circuits have received considerable attention recently due to several reasons:

a) Many of today's integrated circuit (IC) applications such as portable communication, remote computing and wireless communication systems require high performance IC's that operate under low supply voltage and consume low power.
b) With the increasing circuit density in VLSI, the requirement of low cost fabrication demands circuits with low power consumption [1].
c) The use of scaled down technologies has imposed a reduction of supply voltage.

The OTA is an amplifier whose differential input voltage produces an output current. Thus, it is a voltage controlled current source (VCCS). There is usually an additional input for a current to control the amplifier's transconductance. The OTA is similar to a standard operational amplifier in that it has a high impendence differential input stage and that it may be used with negative feedback. Portable electronics with low-voltage operation finds big markets [3]. However, the threshold voltage is not reduced proportionally with the supply voltage. Thus, the threshold voltage is becoming a restraint for many analog circuits. Some special techniques are used to overcome the size of the threshold voltage, e.g. floating gate

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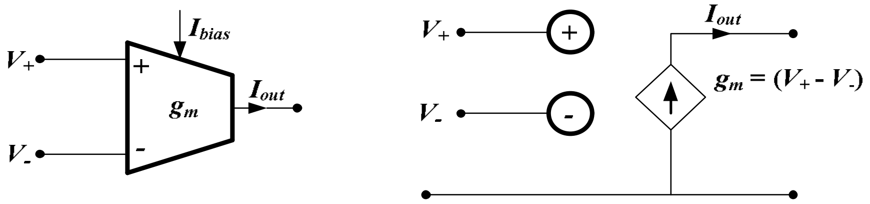
transistors [1], bulk-driven transistors [2], continuous-time filters [4] and low threshold transistors. They suffer from several drawbacks or need special fabrication steps, which increases the cost. It is preferred to implement low-voltage circuits using a standard CMOS technology.

OTA is the most important building block in analog circuits; the amplifier faces another difficulty in the low-voltage design, providing high gain and high output swing with low-power consumption.

2. THEORY AND PRINCIPLES

An ideal operational transconductance amplifier is a voltage-controlled current source, with infinite input and output impedances and frequency independent transconductance. OTA has two attractive features: 1) changing the external dc bias current or voltage can control its transconductance, and 2) It can work at high frequencies. This paper focus on the MOS implementations of the transconductance amplifiers.OTA is a voltage controlled current source [5 - 7].

More specifically, the term “operational" come from the fact that it takes the difference of two voltages as the input for the current conversion. The ideal OTA is a differential-input voltage-controlled current source (DVCCS). Its symbol is shown in Fig. 1 (a), and its operation is defined by the following equation (1). Both voltages *V*+ and *V*- are with reference to ground. The equivalent circuit of the ideal OTA is shown in Fig. 1 (b).



(a) (b)

Fig. 1. (a) OTA symbol, (b) ideal equivalent circuit

$$I_{out} = g_m(V_+ - V_-) \tag{1}$$

Bulk-driven CMOS implementation of OTA shown in Fig. 2 consists of two stage, the first which combined of the bulk-driven differential stage with pMOS input device M_1 and M_2 and the current mirror M_3 and M_4 acting as an active load [8]. The second stage is a simple CMOS inverter with M_6 as a driver and M_7 acting as an active load. Its output is connected to the output of the differential stage by means of compensation capacitance C_c and the resistance R_C since the compensation capacitance actually acts as a Miller capacitance in the last stage. By setting the gate-source voltage to a value sufficient to turn on the transistor, then the operation of the bulk-driven MOS transistor becomes a depletion type [8].

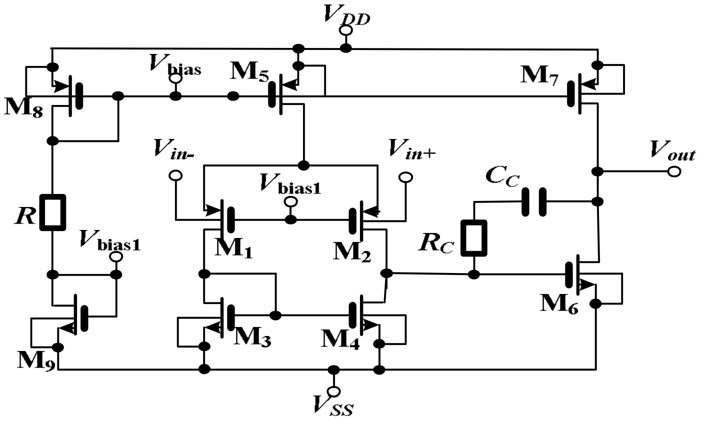


Fig. 2. Two stages Bulk-driven OTA

The simulation result of bulk driven OTA in Fig. 2 is shown in Table. 1.

Table 1. Simulation results of OTA

Characteristics	Simulation Result
Power consumption	30 μW
Open loop gain	70 dB
Bandwidth	4 MHz
Phase margin	70°
DC input voltage range	-400, 700 mV
Slow rate	SR_{LH} = 0.8 V/μs , SR_{HL} = 0.4 V/μs
Measurement condition: V_{DD} = 0.6 V, V_{SS} = 0.6 V, C_L = 1 pF	

3. BULK-DRIVEN OTA WITH g_m ADJUSTABLE VIA EXTERNAL *R*

The principle of g_m adjustable via a feedback resistor R_{adj} is show in Fig. 3. In this part, a high linearity, wideband OTA with tunable transconductance is presented according to Eq. (2).

The adjustable transconductance g_m, adjust depends on R_{adj} as follows:

$$g_m adjust = \frac{g_{m,core}}{1 + g_{m,core} R_{adj}} \tag{2}$$

Figs. 4 and 5 show circuit implementations of Fig.3, namely bulk-driven single input single output OTA (SISO) and a fully differential OTA (DIDO) based on voltage buffer and Current Conveyor of Second Generation CCII.

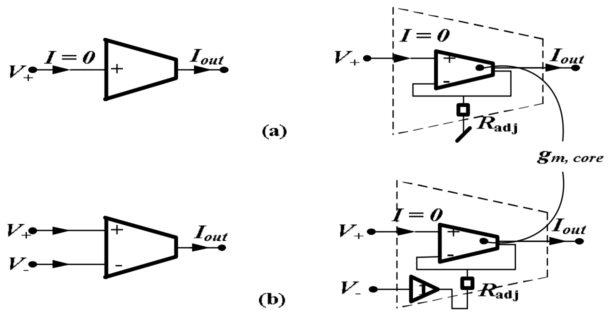


Fig. 3. (a) SISO OTA with gm adjustable, (b) DISO OTA with gm adjustable

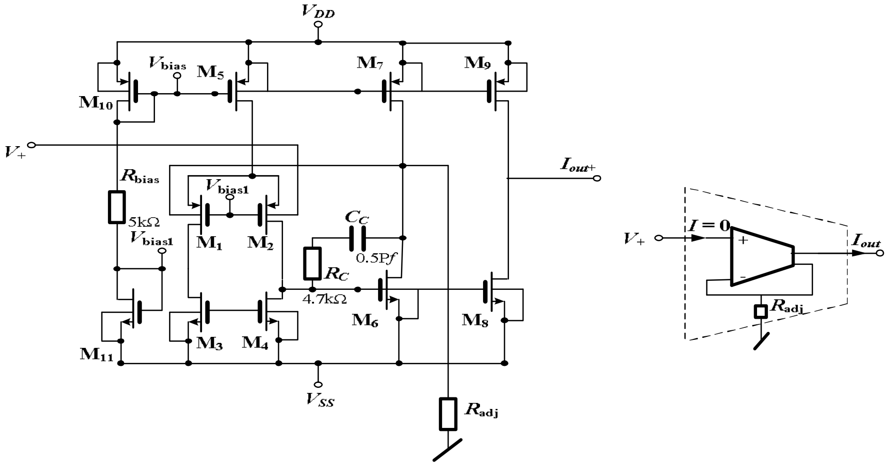


Fig. 4. Bulk-driven single input single output OTA (SISO) based on CCII

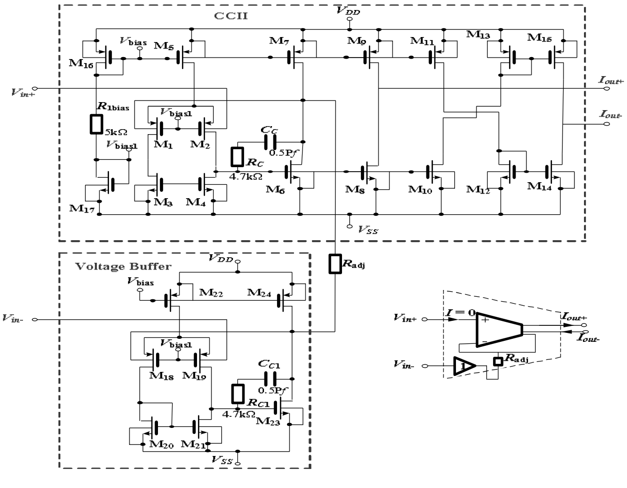


Fig. 5. Bulk-driven fully differential OTA (DIDO) based on CCII and voltage buffer

The aspect ratios of each of the transistors used the CCII and voltage buffer in Fig. 5 are listed in Tables 2 and 3, respectively.

Table 2. Aspect ratios of the transistors used in the CCII in Fig. 5

Transistor	Length (μm)	Width (μm)
M_1, M_2	2	30
M_3, M_4	2	4
M_5, M_{16}	3	20
M_6,M_8,M_{10},M_{12}, M_{14}	2	16
M_7,M_9,M_{11},M_{13}, M_{15}	3	40
M_{17}	3	10

Table 3. Aspect ratios of the transistors used in the Voltage buffer in Fig. 5

Transistor	Length (μm)	Width (μm)
M_{18}, M_{19}	2	30
M_{20},M_{21}	2	4
M_{22}	3	20
M_{23}	2	16
M_{24}	3	40

4. SIMULATION RESULTS

The performance of the proposed OTA in Fig. 5 was verified via PSPICE simulation. All the balanced CMOS OTA was simulated by using CMOS structure and MIETEC 0.18 μm. The dimensions of transistors were used from Tables 2 and 3 and the power supply voltages were set $V_{DD} = -V_{SS} = \pm 0.6$ V.

Fig. 6 shows the simulated transfer characteristics of the OTA in Fig. 5.The plots of the output current I_{out} versus the input voltage V_{in} show that, for R_{adj} values of 1 Ω, 10 Ω, 100 Ω, 1 kΩ. 2 kΩ, 5 kΩ, 10 kΩ, 20 kΩ, 50 kΩ, 100 kΩ, 200 kΩ, 500 kΩ, and 1 MΩ, the g_{m} is controlled accordingly.

It is shown that the transconductance gain g_m can be linearly tuned when R_{adj} is increased. But for R_{adj} bigger than 50 kΩ it causes distortion. The linear range is very good for R_{adj} of about 10 kΩ.

The AC analysis of the bulk-driven OTA in Fig. 5 is shown in Fig. 7. The frequency dependence of I_{out} is measured by fixing AC value of V_{in} at 1 V.

The responses are plotted for R_{adj} of 1 Ω, 10 Ω, 100 Ω, 1 kΩ, 2 kΩ, 5 kΩ, 10 kΩ, 20 kΩ, 50 kΩ, 100 kΩ, 200 kΩ, 500 kΩ, and 1 MΩ. The corresponding values of g_{m} are shown in Table. 4.

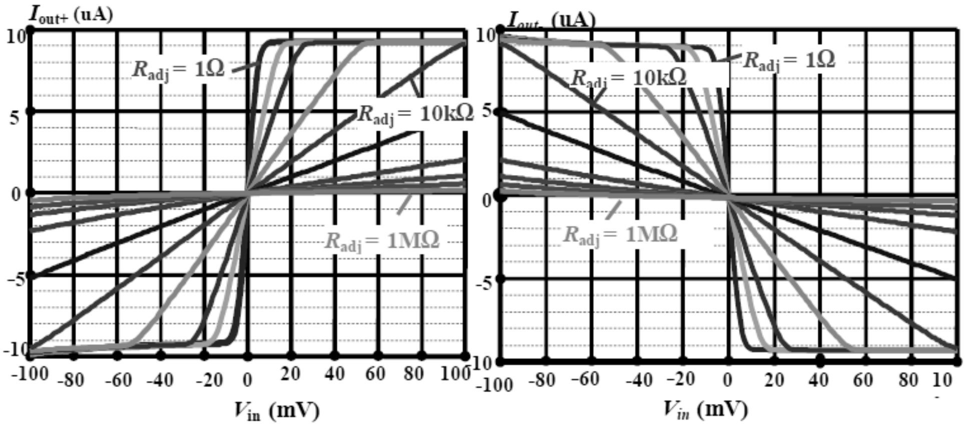


Fig. 6. DC transfer characteristics of bulk-driven fully differential OTA

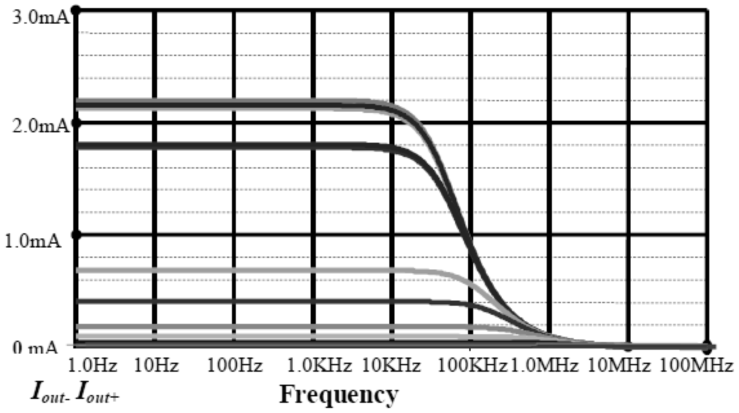


Fig. 7. AC transfer characteristics of bulk-driven fully differential OTA

Table 4. Variations of g_m by R_{adj}

R_{adj}	g_{m}
1 Ω	2.2 ms
10 Ω	2.16 ms
100 Ω	1.8 ms
1 kΩ	688.7 µs
2 kΩ	408.5 µs
50 kΩ	184.45 µs
100 kΩ	96.82 µs
200 kΩ	50.1 µs
500 kΩ	21.04 µs
1 MΩ	11.2 µs

5. CONCLUSION

The Bulk-driven Operational Transconductance Amplifier (OTA) principle which is suitable for Low Voltage LV Low Power LP circuit design is presented in this paper and the unique with the Bulk-driven MOSTs is that, it could be used in ultra-LV ultra-LP design where the voltage supply could be even below 600 mV and power consumption below 30 μW.

This circuit is designed for low frequency application. SPICE simulation of the circuit confirms the theoretical conclusions.

REFERENCES

[1] J. Ramrez-Angulo, S. C. Choi, and G. Gonzlez-AltamiranoG, “Low-voltage circuits building blocks using multiple-input floating-gate transistors”, IEEE Transactions on Circuits and Systems—Part I: Fundamental Theory and Applications, 29:971 – 974, November 1995.

[2] B. J. Blalock and P. E. Allen, “A One-Volt, 120-μW, 1-MHz OTA for Standard CMOS Technology”, In Proceedings IEEE International Symposium on Circuits and Systems (ISCAS), pages 305 – 307, May 1996.

[3] Libin Yao, Michiel Steyaert and Willey Sassen “Low Power Low Voltage Sigma Delta Modulators In Nanometer Cmos” Springer, 2006.

[4] E. Seevinck, M. du Plessis, T.-H. Joubert, and A. E. Theron, “Active bootstrapped gain-enhancement technique for low voltage circuits”, IEEE Transactions on Circuits and Systems—Part II: Analog and Digital Signal Processing, 45:1250 – 1254, September 1998.

[5] P. Yu and H. Lee, “A high-swing 2-V CMOS operational amplifier with replica-amp gain enhancement”, IEEE Journal of Solid-State Circuits, 28:1265–1272, December 1993.

[6] W. Jaikla and M. Siripruchyanun, "Floating positive and negative inductance simulators based on OTAs", Proc. Inter. Symp. On Communications and Information Technologies 2006 (ISCIT 2006), Bangkok, Thailand, 18-20 October 2006.

[7] Senani R. A simple approach of deriving single-input multiple-output current-mode biquad filters. Electron Lett 1989; 25:19–21.

[8] M. Shaktour, “Unconventional circuit elements for ladder filter design,” Ph.D. Theses, Brno University of Technology, 2011, p. 104.