Ultra Low-Power OTA for Biomedical Applications

Shahram H. Hesari, Ava Hedayatipour, and Shaghayegh Aslanzadeh
Department of Electrical Engineering and Computer Science, The University of Tennessee, Knoxville, TN, USA
E-mail: hesari@vols.utk.edu

Syed K. Islam
Department of Electrical Engineering and Computer Science, University of Missouri, Columbia, MO 65211, USA
Email: islams@missouri.edu

Abstract—This paper presents a design of an ultra low-power operational transconductance amplifier (OTA) intended for biomedical applications and realized in a 0.18 µm CMOS technology. The proposed OTA take advantages of bulk-driven (OTA) scheme to reduce power consumption. The OTA uses a single 0.8 V supply and dissipates 5.5 pW of power and provides 70 dB gain which makes it suitable for use as a main block of many biomedical applications including implantable and wearable sensors. The simulation results are compared with conventional OTA structures and some recent works and indicate significant increase in gain while indicating a reduction in power consumption.

I. INTRODUCTION

Low voltage and low frequency operating ranges are the main characteristic of human physiological signals. The need for detecting these signals and enormous demand for portable biomedical devices, have resulted in the rapid development of low-voltage, low-power analogue circuit schemes. In the analogue biomedical circuits, OTAs are the most power-hungry analogue blocks. In this work the primary goal is to reduce power dissipation of an OTA. Typically reducing the operating current, or power supply voltage leads to a reduction in power consumption. In order to reduce the operating current and hence reduce the power consumption, the MOSFET is needed to be biased in subthreshold or weak inversion region [1]-[2]. In weak inversion region, the drain current (I_D) of a MOSFET can be calculated by the following equation;

$$I_D = I_0 \frac{W}{L}\left[\exp\left(\frac{-[V_{GS}+(\eta-1)V_{BS}]}{\eta V_t}\right)\right]\left[1-\exp\left(\frac{V_{DS}}{V_t}\right)\right] \quad (1)$$

In equation (1), I_0 is a characteristic current in weak inversion, η is slope factor in weak inversion region and V_t is thermal voltage [3]-[5]. There are several approaches dealing with maintaining MOSFET in weak inversion condition. These approaches such as floating gate schemes, level shifting and bulk-driven techniques allow enhancement of circuit performances in low voltage conditions while preserving acceptable signal swing. Among them, bulk driven technique is the non-conventional technique where no change in the existing MOSFET structure is required [6]. Also compared to other approaches, it is less complex and cheaper to implement [7]. It should be mentioned that bulk-driven technique requires each bulk to be accessible, hence, in standard CMOS technologies, only p-channel transistors can be driven from the bulk [8]. In this paper we take the advantage of bulk-driven approach to design a low-power OTA. The applied gate voltage of a bulk-driven MOSFET can be negative, zero, or slightly positive to control the current flow in the channel between the drain and the source

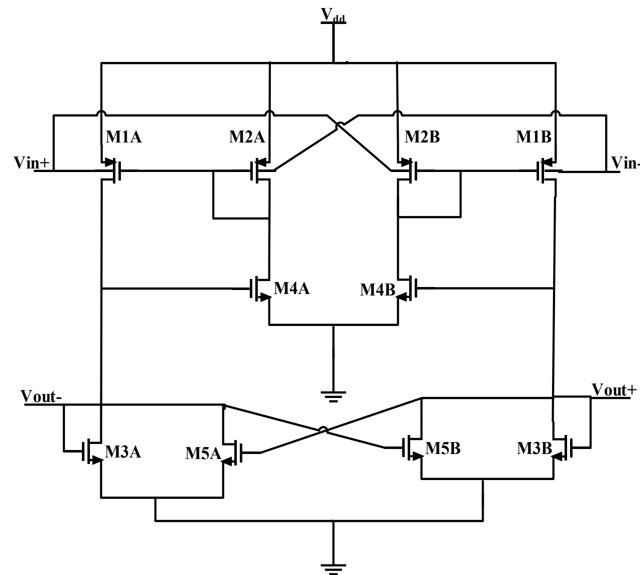

Fig. 1. Transistor-level implementation of the proposed bulk-driven OTA in a 0.18 µm CMOS technology.

II. DESIGN OF BULK-DRIVEN OTA

In this paper we have combined the ideas of bulk-driven transistors and weak operation region to design an OTA suitable for biomedical implantable or wearable applications which need very low power consumption to make the circuit operate as long as possible. Fig. 1 illustrates the transistor-level implementation of the proposed bulk-driven OTA. From the figure it can be seen that the OTA input voltages drive the substrate/bulk-body terminals of the MOSFETs M1A, M2B and M1B, M2A. In the proposed design, transistors M1A and M1B serve as differential input while forming current mirrors with M2A and M2B to supply current. The first stage amplification is performed through M4A and M4B. M3A, M3B, M5A, and M5B increase the gain by means of having g_m values that are close together. The bulk-driven sub-threshold OTA of Fig. 1 was simulated using a 0.18µm CMOS Technology. The power supply voltages V_{dd} were set to 0.8V. Table I shows the aspect ratio of transistors constituting the OTA.

TABLE I. SPECIFICATION OF PROPOSED OTA.

MOSFET	W/L
M1A, M2A, M1B, M2B	8 µm/0.18 µm
M3A, M3B, M5A, M5B	1 µm/0.18 µm
M4A,M4B	3 µm/3 µm

III. SIMULATION RESULTS

Simulation is carried out using 0.8V power supply. Power dissipation in the circuit is below 5.5 pW. Gain and phase plots of the proposed design are shown in Fig. 2. Result shows that gain, unity gain band width and phase margin of proposed design are 70dB, 108.3MHz, and 85.8°, respectively. These results are compared to other OTAs reported in [1-5] and show significant improvement in gain and power consumption. This makes it ideal candidate to use as a main block of many biomedical applications such as charge amplifier needed for apnea detection [9].

The variation of phase margin (PM) with load capacitor of proposed design in Fig. 3 shows that load of 25 pF can be used with our proposed design. Figs. 4 and 5 show input and output waveforms, respectively for slew rate and current consumption of power supply of the proposed design.

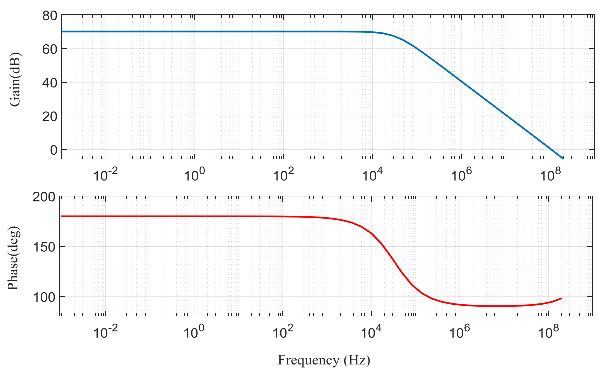

Fig. 2. Gain and phase plot of the proposed design.

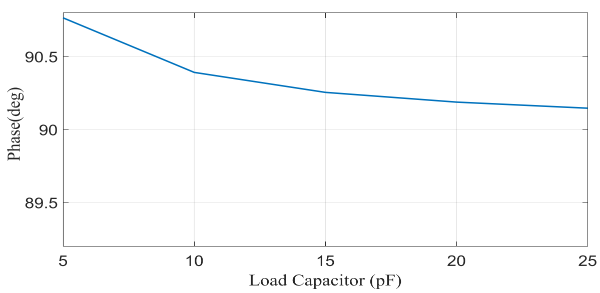

Fig. 3. Variation of phase margin with load (proposed design).

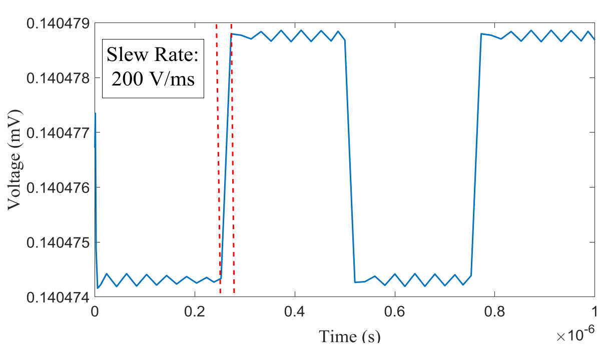

Fig. 4. Output waveform illustrating slew rate of the proposed OTA.

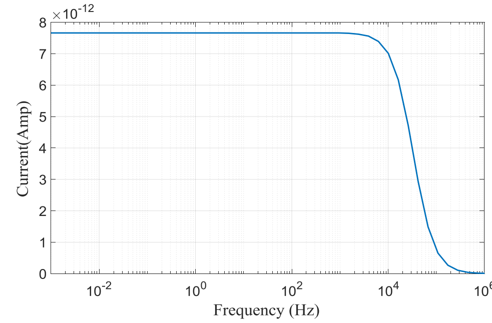

Fig. 5. Current consumption of power supply as a function of the signal frequency.

Table II presents different OTA performances indicators and its comparison with other OTAs reported in literature.

TABLE II. PERFORMANCE COMPARISON WITH OTHER WORKS.

	This work	**[2]**	**[3]**	**[4]**	**[5]**
Process (µm)	0.18	65 nm	0.18	0.18	0.18
Supply (V)	0.8	0.35	0.4	0.5	0.7
Gain (dB)	70	60	60	38	61
GBW (MHz)	108.3	0.032	0.347	0.0506	3.6
PM (°)	85.8	83.2	57	56.30	60
SR (V/ms)	200	24.6	-	200	2000
CMRR (dB)	74.9	71.5	82.3	76.5	46.7
Power (W)	5.5 p	40 n	281 n	32 n	22.4 µ

REFERENCES

[1] M.S. Ansari, R. Sinha, and S. Khot, “Ultra-low power 50/60Hz notch filter for biomedical signal acquisition using 32nm±0.15 V Bulk-Driven subthreshold CMOS OTAs,” *IEEE 4th International Conference on Electrical and Electronic Engineering (ICEEE),* pp. 309-313, 2017.

[2] Y. Wang, X. Zhao, Q.Zhang, and X. Lv “Adjustably transconductance enhanced bulk-driven OTA with the CMOS technologies scaling. ” *Electronics Letters 54, no. 5,* pp.276-278, 2018.

[3] A. Shrivastava, AP. Gangwar, R. Kumar, and R. Dhiman, “A 60 dB Bulk-Driven Rail-to-Rail Input/Output OTA,” *IEEE International Symposium on Nanoelectronic and Information Systems (iNIS)*, pp. 139-143, 2016.

[4] LHC. Ferreira, and SR. Sonkusale. “A 60-dB gain OTA operating at 0.25-V power supply in 130-nm digital CMOS process, ” *IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 1881-1884, 2014.

[5] LHC. Ferreira, and SR. Sonkusale. “Gm enhancement for bulk-driven sub-threshold differential pair in nanometer CMOS process.” *IEEE Conference on Subthreshold Microelectronics (SubVT),* , pp. 1-3, 2012.

[6] PS. Sushma, S. Gaonkar, K.S. Gurumurthy, and A. Fathima, “Design of high gain bulk-driven miller OTA using 180nm CMOS technology,” *IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, pp. 1774-1777, 2016.

[7] T. Sharan, and V. Bhadauria, “Ultra low-power bulk and gate-driven, class AB, sub-threshold transconductor,” *2nd International Conference on Signal Processing and Integrated Networks (SPIN)*, pp. 921-926, 2015.

[8] E. Cabrera-Bernal, S. Pennisi, and A.D. Grasso, “0.7-V bulk-driven three-stage class-AB OTA,” *IEEE 13th International Conference on New Circuits and Systems Conference (NEWCAS)*, pp. 1-4, 2015.

[9] I. Mahbub, S. A. Pullano, H. Wang, S. K. Islam, A. S. Fiorillo, G. To, and M. R. Mahfouz, “A Low-Power Wireless Piezoelectric Sensor-Based Respiration Monitoring System Realized in CMOS Process” *IEEE Sensors Journal*, vol. 17, no. 6, pp. 1858-1864, 2017.