IEEE International Conference On Recent Trends In Electronics Information Communication Technology, May 20-21, 2016, India

Design of High Gain Bulk-Driven Miller OTA Using 180nm CMOS Technology

Sushma P.S, Siddesh Gaonkar, K.S Gurumurthy, Amra Fathima

Abstract— **The Operational Transconductance Amplifier is an amplifier which uses the differential input voltages and generates the output current. Therefore, it is a voltage controlled current source. OTA is an important block in the design of analog filters. The continuous scaling down of the transistor size and reduction in power supply has added stringent design constraints in analog architecture. Here we design a bulk driven OTA with 0.4 V supply in 180nm CMOS technology using Cadence Virtuoso. The performance parameters such as gain, CMRR, Unity Gain Bandwidth, power, DC sweep error, Total Harmonic Distortion, output impedance and transconductance are analyzed. Further the Gm-C filter and Bi-Quad filter are designed using the proposed OTA.**

Keywords— ***biomedical, bulk-driven, CMOS, OTA, Ultra-low power, Weak Inversion.***

NOMENCLATURE

OTA: Operational Transconductance Amplifier
VLSI: Very Large Scale Integration
OPAMPs: Operational Amplifiers
NMOS: N-type Metal Oxide Semiconductor
PMOS: P-type Metal Oxide Semiconductor
MOSFET: Metal Oxide Semiconductor Field Effect Transistor
CMRR: Common Mode Rejection Ratio
CMOS: Complementary Metal Oxide Semiconductor
WI: Weak Inversion
$UGBW$: Unity Gain Bandwidth
THD: Total Harmonic Distortion

I. INTRODUCTION

The Operational Transconductance Amplifier is a significant block in analog circuit design, whose output current is a function of the differential input voltage. In view of sensor and biomedical applications, low voltage and high gain amplifiers are desired. Basically, bioelectrical signals are having range in µV to few mV and frequencies less than 200 Hz [1]. These bioelectrical signals are sensed by the amplifiers in biomedical devices and systems.

The success in analog architectures with high performance suffers mainly due to the reduction in supply, power consumption, and mainly because of reduction in size.

Sushma P.S ,Dept.of E&C ,NMAMIT , Nitte Research Scholar, Reva University, Bangalore, India (pssush@gmail.com)

Siddesh Gaonkar, PG Scholar, Dept.of E& C, NMAMIT, Nitte, India (siddeshgaonkar92@gmail.com)

Dr, K.S Gurumurthy, Professor, School of E & C Engineering, REVA University, Bangalore, India (drksgurumurthy@gmail.com)

Amra Fathima, PG Scholar, Dept.of E& C, NMAMIT, Nitte, India (amrafathima097@gmail.com)

These performances are now considered as the major constraints in designing of analog systems [2].

The main component of analog VLSI circuits such as OPAMPs requires a supply voltage of at least the sum of threshold voltages of NMOS and PMOS. This leads to a challenging task when designing of analog circuits with low supply using standard CMOS process [3]. Therefore, novel analog circuit design techniques are required to overcome these difficulties. Various low voltage design techniques [4] such as bulk-driven technique, floating-gate MOSFETs, and level shifting techniques etc have been used. Among these, bulk driven technique is the non-conventional technique where no change in the existing MOSFET structure is required.

For ultra-low power biomedical signal processing, low voltage OTAs are used which operates in weak inversion region. For low frequency applications the bias current required is less than 150 nA. The lower value of bias current decreases the power consumption, but affects the circuit bandwidth. For low frequency applications sub-threshold bulk OTAs are widely preferred. For analog filters, realization with the RC elements involves higher values, so Gm-C based analog filters are preferred. In Gm-C filters frequency tuning is done by varying either bias current of the MOSFET or by gate bias voltage [5].

The biomedical signals have weak amplitude and lower frequencies; therefore it is a difficult task to filter them so that only required information is processed. The recording probes pick up noise which could be due to power line interference, movement artifacts or measurement environment. Therefore, a high gain and high CMRR amplifier is required to amplify these signals in addition to lower noise contents [6]. The noise can be further reduced by using filters. Also, high output impedance is required to process biomedical signals. These design parameters are difficult to achieve when the technology scales down [1].

This paper describes a method to design a low voltage, high gain, ultra-low power transconductance amplifier. A very low operating voltage of 0.4V has been achieved by bulk driven MOSFETs. This technique allows lower threshold voltages for the MOSFETs and is suitable for low voltage and ultra-low power applications. The low frequency operation also makes it suitable for biomedical applications.

II. BRIEF OVERVIEW OF BULK DRIVEN TECHNIQUE

The MOSFET has four terminals i.e. drain “D”, gate “G”, source “S” and bulk “B” as shown in Fig. 1(a) and its cross section is shown in Fig.1 (b) along with the substrate terminal “Sub”. For the gate driven MOSFET, the bulk terminal is tied to the source terminal, hence in many applications bulk connection is overlooked [7], [8]. Among many techniques used for designing of low power analog

978-1-5090-0774-5/16/$31.00 © 2016 IEEE

circuits, the Bulk/body driven approach can be used instead of gate driven approach due to its simplicity and it does not require changing the overall structure of the MOSFET's. For bulk driven MOSFET depending on the technology (i.e. N-well, P-well or twin-tub) the gate terminal is connected to positive or negative supply for NMOS or PMOS transistor respectively. This provides sufficient gate to source voltage to form a weak inversion region. An input voltage is fed to the bulk or body terminal of the MOSFET's. The drain current of the MOSFET can be varied by varying the input voltage applied to the bulk terminal [3], [7], [8].

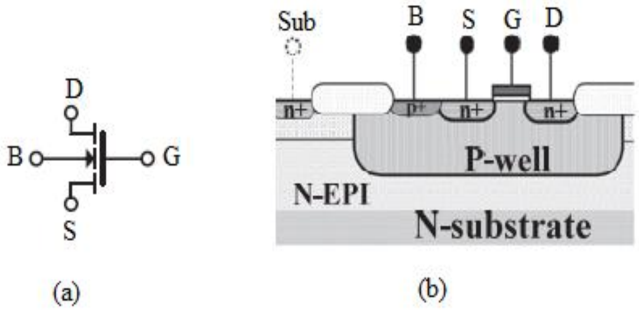

Fig.1: Bulk-driven N-MOSFET: (a) symbol and (b) cross-section

For a gate driven MOSFET, it is compulsory to meet the requirement of $V_{GS} > V_{TH}$ to operate the MOSFET in the saturation or triode region. The threshold voltage of the MOSFET decreases with bulk voltage as given in equation (1). Therefore, the bulk-driven technique permits much smaller voltages to be applied at the input and still generates the saturation voltage at the output.

$$V_T = V_{T0} + \gamma[\sqrt{2\phi_F + V_{BS}} - \sqrt{2\phi_F}] \quad (1)$$

where, γ is the body bias factor, V_{BS} is bulk to source voltage and ϕ_F is the surface potential

The P and T wave are detected using windowing technique. The search window starts at 200 ms before and ends 70 ms before the location of R peak. Then to find onset and off set of P wave, a backward and forward search is made to find the minima from the point of maximum of P wave with suitable search window. T wave is detected in the same way

III. Proposed Miller OTA

The low output impedance of an OPAMP makes it power hungry [9], while for biomedical applications high output impedance and low power blocks are required. The important characteristics of an OTA are high input-output impedance and high bandwidth. Therefore bulk OTA based circuits are more attractive in such applications. The proposed miller bulk OTA is shown in Fig.2.

The MOSFETs (*M3, M4*) form current mirror load and (*M5, M7* and *M8*) is a current mirror circuit to provide the bias current to the amplifier. The resistor R_C and capacitor C_C form the miller compensation circuitry to improve the phase margin of the OTA. The miller capacitor is in the feed forward path introduces a zero in right half of the plane that destroys the phase shift of the OTA and causes instability at high frequency. Hence to reduce the zero effect a nulling resistor is introduced in series with a capacitor. The series resistor moves

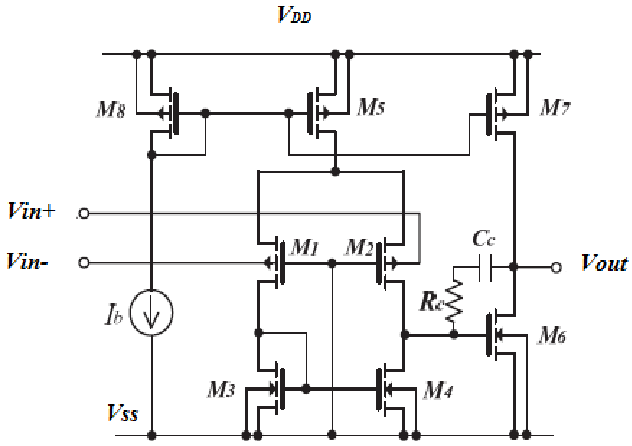

Fig. 2: Circuit diagram of proposed bulk Miller OTA

the zero from the right half plane to the left half plane [10], [11]. Compared to gate driven OTA, the bulk driven OTA consume less power, however has poor gain and low bandwidth. This is because; the bulk transconductance is less than the gate transconductance [5], [11] as given in equation (2). The gain can be enhanced by optimizing the various performance parameters of the OTA.

$$g_{mb} = (0.2 \rightarrow 0.4)g_m \quad (2)$$

If the MOSFET is bulk driven then the drain current ($I_{DS}(WI)$)is given as

$$I_{DS}(WI) = 2nk\frac{W}{L}U_T{}^2 \exp\left\{\frac{V_{gs} - V_t + (n-1)V_{BS}}{nU_T}\right\} \quad (3)$$

The Weak Inversion transconductance ($g_m(WI)$) is given by

$$g_m(WI) = \frac{\partial I_{DS}}{\partial V_{gs}} = \frac{I_{DS}}{nU_T} \quad (4)$$

The output resistance (r_0)in weak inversion is given as

$$r_0 = \frac{1}{\lambda I_D} \quad (5)$$

IV. Filter Design

The Gm-C filter designed using the proposed bulk OTA structure with 0.4 V supply voltage is shown in Fig.3.

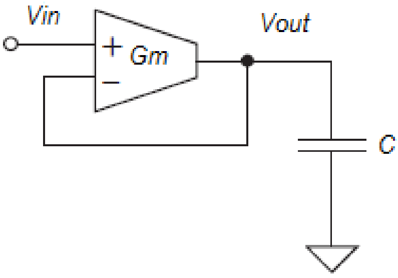

Fig. 3: Gm-C filter using bulk driven OTA

The "Bi-Quad filter" is designed for low frequency biomedical application in unity gain mode for 0.4 V supply and is shown in Fig.4.

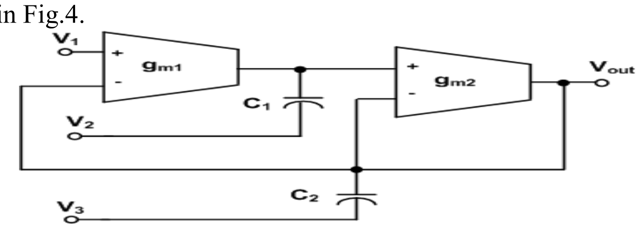

Fig. 4: Bi-Quad filter circuit

For "Low pass filter", input conditions are V_1=V_{in} when V_2 and V_3 are grounded.
For "High pass filter", input conditions is V_3=V_{in} when V_1 and V_2 are grounded.
For "Band pass filter", input conditions is V_2=V_{in} when V_1 and V_3 is grounded.
For "Band reject filter", input conditions is V_1, V_3 =V_{in} when V_2 is grounded

V. Simulation Results

The simulation results for the proposed OTA implemented in Cadence Virtuoso using 180nm CMOS technology. The AC response of bulk OTA with 0.4 V supply for differential input signals is shown in Fig.5. The DC gain of this OTA is obtained to be 60 dB and the phase margin is 57°. With common mode input, the gain obtained is -23.33 dB. The calculated CMRR of this OTA is 82.38 dB.

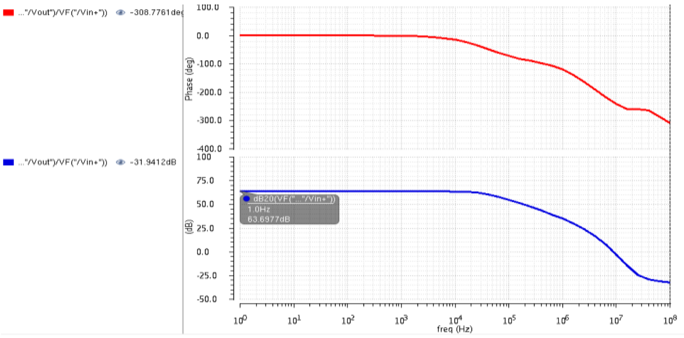

Fig. 5: Differential gain and phase plot for Bulk OTA

The DC sweep error shown in Fig.6 in unity gain configuration of bulk OTA at 180nm technology shows a very close tracking of input and output voltage.

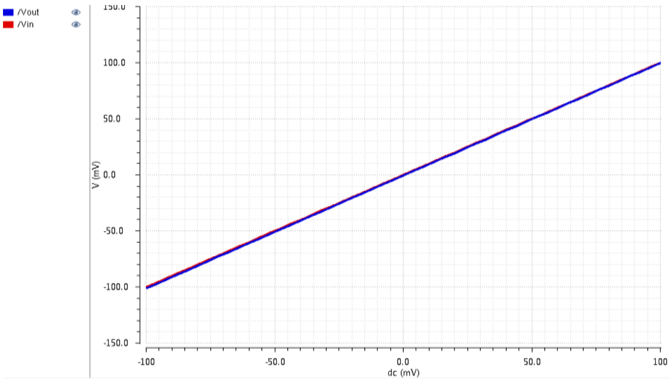

Fig. 6: DC sweep error of an OTA

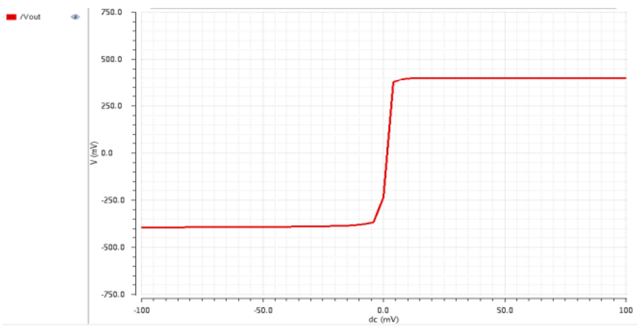

Fig. 7: Open loop analysis of bulk driven OTA

Fig.7 shows the simulation result for open loop configuration of bulk OTA with 0.4 V supply. It shows output voltage swing from -400 mV to +400 mV, which is rail-to-rail voltage swing.

The Total Harmonic Distortion (THD) for a bulk OTA at 0.4 V, 200 mV_{p-p} sine wave is shown in Fig.8. The THD is obtained to be 0.057%.

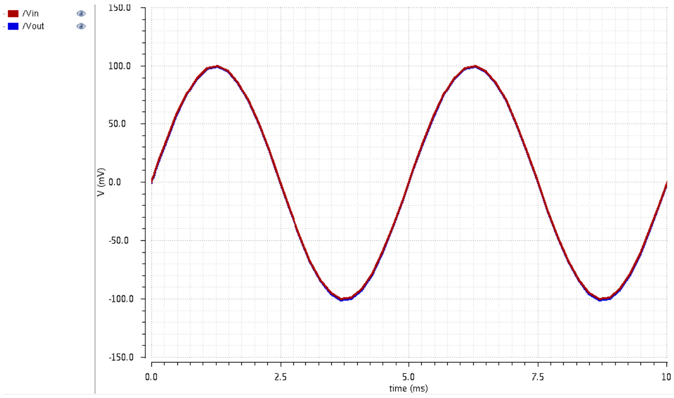

Fig. 8: Total harmonic distortion of an OTA
For 200mVp-p Sine wave

Fig.9 shows the frequency response of Gm-C filter implemented using the proposed bulk OTA with 0.4 V supply. The capacitor of the filter is varied from 1 nF to 10 nF. The average transconductance of the filter is 96.12 µS.

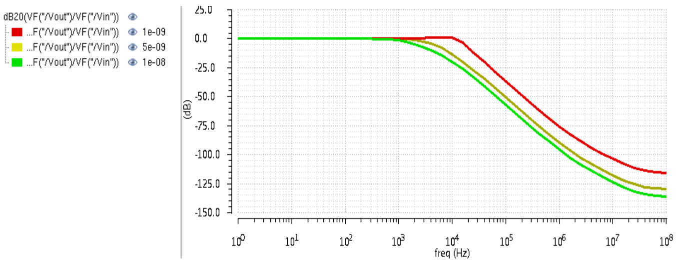

Fig. 9: Frequency response of Gm-C filter using the bulk OTA

A. "Low Pass Filter"using Bulk OTA with 0.4 V Supply

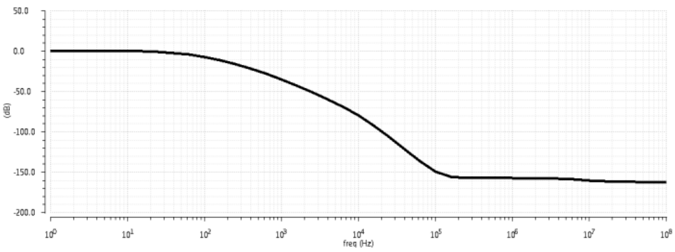

Fig. 10: Low pass filter using bulk OTA with 0.4 V supply

Fig.10 shows the "low pass filter" implemented using bulk OTA with 0.4 V supply in unity gain mode.

B. "High Pass Filter"using Bulk OTA with 0.4 V Supply

Fig.11 shows the "high pass filter" implemented using bulk OTA with 0.4 V supply in unity gain mode.

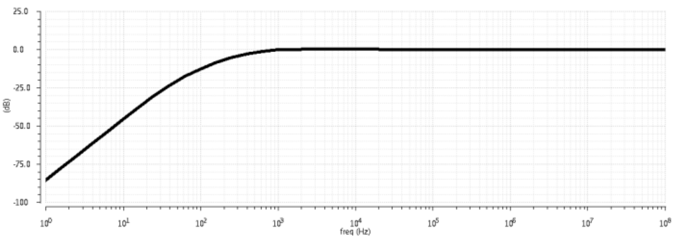

Fig. 11: High pass filter using bulk OTA with 0.4 V supply

C. "Band Pass Filter " using Bulk OTA with 0.4 V Supply

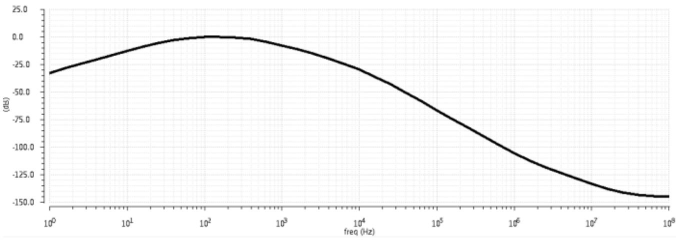

Fig. 12: Band pass filter using bulk OTA with 0.4 V supply

Fig.12 shows the "band pass filter" implemented using bulk OTA with 0.4 V supply in unity gain mode.

D. "Band Reject Filter" using Bulk OTA with 0.4 V Supply

Fig.13 shows the "band reject filter" implemented using bulk OTA with 0.4 V supply in unity gain mode.

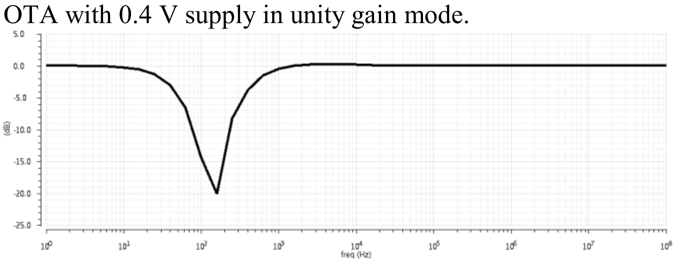

Fig. 13: Band reject filter using bulk OTA with 0.4 V supply

The Gm-C filter result is shown in TABLE I.

TABLE I: SUMMARY OF GM-C FILTER RESULT

Capacitor	Corner Frequency	Transconductance
1 nF	15.5 kHz	94.24 µS
5 nF	3.18 kHz	99.99 µS
10 nF	1.5 kHz	94.24 µS
Average Transconductance		96.12 µS

TABLE II shows the summary of Bi-Quad filter result.

TABLE II: SUMMARY OF BI-QUAD FILTER RESULT

Filter Type	Cut-off frequency (Theoretical)	Cut-off frequency (simulated)
Low pass	50 Hz	47.32 Hz
High Pass	500 Hz	373.7 Hz
Band Pass	50 Hz-500Hz	39.6 Hz-480.62Hz
Band Reject	50 Hz-500Hz	40 Hz-463.1 Hz

TABLE III shows the summary of simulation results of the bulk OTA in 180nm CMOS technology.

TABLE III: SUMMARY OF OTA SIMULATED RESULTS

Sl. No	Performance Parameters	180nm Technology
1	Supply (V)	0.4
2	Differential gain (dB)	60
3	Common mode gain (dB)	-23.33
4	CMRR (dB)	82.38
5	Power (nW)	281.5
6	UGBW (Hz)	347.13 k
7	Phase Margin	57°
8	THD (%)	0.057
9	Output impedance (Ω)	12.058 M
10	Transconductance (S)	96.12 µ

VI. CONCLUSION AND FUTURE SCOPE

This paper has presented an OTA using bulk driven MOSFETs, a non-conventional design technique. The supply voltage to this OTA is as low as 0.4 V, hence useful for low voltage, ultra-low power biomedical applications. The OTA consumes 281.5 nW of power, has good stability, high gain and high CMRR. The gain can be further enhanced by employing gain boosting techniques as the technology scales down. Since the output impedance of the OTA is large it can be also used in implantable, biosensor circuits.

REFERENCES

[1]. Kavita Bhange, Pravin Zode and Pradnya Zode, "Design of Bulk Driven Miller Operational Transcondu tance Amplifier", IEEE International Conference on Industrial Instrumentation and Control, 2015, pp. 1567-1570.

[2]. INTISSAR Toihria and TIXIER Thierry, "Modeling and Design of a Folded Cascode Bulk Driven OTA", IEEE International Conference on Design & Technology of Integrated Systems in Nanoscale Era, 2012, pp. 1-5.

[3]. Yasutaka Haga, Hashem Zare- Hoseini, Laurence Berkovi, and Izzet Kale, "Design of a 0.8 Volt Fully Differential CMOS OTA Using the Bulk-Driven Technique", IEEE International Symposium of Circuits and Systems, 2005, pp. 220-223.

[4]. Abhishek Tiwari and Sheetal U. Bhandari, " Improvement in Noise Performance and Transconductance Using Positive Feedback in Bulk Driven Operational Amplifier", IEEE International Conference on Computing Communication Control and Automation, 2015, PP. 979-983

[5]. Tripurari Sharan and Vijaya Bhadauria, "Ultra Low-power Rail-to-Rail Linear Sub-threshold Bulk driven Transconductor", IEEE Conference on Power, Control and Embedded Systems, 2014, pp. 1-6.

[6]. Himadri Singh Raghav, B.P. Singh and Sachin Maheshwari, "Design of Low Voltage OTA for Biomedical Application", IEEE International Conference on Microelectronics, Communication and Renewable Energy, 2013.

[7]. Fabian KHATEB, Salma BAY ABO DABBOUS and Spyridon VLASSIS, "A Survey of Non-conventional Techniques for Low-voltage Low-power Analog Circuit Design", Radio Engineering Journal, 2013, vol. 22, pp. 415-425.

[8]. Neha Gupta, Sapna Singh, Meenakshi Suthar and Priyanka Soni, "Low Power Low Voltage Bulk Driven Balanced Ota", International Journal of VLSI design & Communication Systems (VLSICS), 2011, Vol.2, No.4,PP. 131-140.

[9]. Rekha S. and Laxminidhi T., "Low power fully differential, feed-forward compensated bulk driven OTA", The 8th Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology, Association of Thailand – Conference, 2011, pp. 90-92.

[10]. Shouri Chatterjee, Yannis Tsividis and Peter Kinget, "0.5 V Analog Circuit Techniques and Their Application in OTA and Filter Design", IEEE Journal of Solid State Circuits, 2005, vol. 40, No.12, pp. 2373-2387.

[11]. Nikhil Raj and Anil Kumar Gupta, "Multifunction Filter Design Using BDQFG Miller OTA", International Journal of Electrical and Electronics Engineering, 2015, vol. 4, pp. 55-65.