A Low Voltage Bulk Driven Feed Forward OTA

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Abstract

A low voltage,highswing, pseudo differential OperationalTransconductance Amplifier(OTA) is proposed in this paper.This OTA enhances the common mode rejection ratio(CMRR) by using common mode feed forward(CMFF) technique.The design is simulatedusing Cadence Spectre simulator in 180nm CMOS technology.The OTA can operate at a supply voltage of 0.5V and provides a gain of 49.4 dB, unity gain frequency of 1.3MHz with output swing of 0.44 V and consumes a power of 3.5µW.

1. Introduction

As the world is advancing to the new heights of development and the need for analog circuits in modern mixed signal VLSI chips for multimedia, control, instrumentation, medical, electronics and communication is increasing, so new technologies are being developed that enable the designers to create faster, complex, portable and battery operated systems within the permissible limit of power consumption.Low power supply analog circuits demand reduction in their supply voltage but the reduction in supply voltage will cause many problems as the threshold voltage(V_T) of the analog circuits has been reduced at a slower rate than their supply voltage which causes reduction in the available signal swing.So for reducing the threshold voltage (V_T) many techniques have been used[1, 2].

[3, 4] proposed bulk-driven which is used in the input stage proves to be useful alternative for designing the amplifiers able to operate with a low supply voltage which is in the order of threshold voltage.The input voltage applied to bulk and the gate voltage is tied to some bias which reduces the threshold voltage of the transistor.So, thethreshold voltage can be removed from the signal path and enabling the circuit to operate at a low supply voltage.The expression for the threshold voltage in bulk driven MOS[5] can be given as in (1)

$$V_T = V_{TO} + \gamma\left(\sqrt{|2\emptyset_F - V_{SB}|} - \sqrt{|2\emptyset_F|}\right) \quad (1)$$

whereγ is the body effect coefficient,Φ_F is the Fermi potential and V_{SB} is the source to bulk potential difference.The main drawback of bulk driven technique is the bulk transconductance (g_{mb}) is 4 to 5 times smaller than the gate transconductance (g_m) which results in low DC gain. Another approach for low power,low voltage design is to utilize subthreshold region for operating the circuit [6].

The Operational Transconductance Amplifier (OTA) is one of the most important and frequently used analog building blocks as OTA finds many applications in many analog circuits such as comparators, ADCs and so on.Several approaches have been proposed for realizing OTA[7-9] using both fully-differential (FD) and pseudo-differential (PD) topologies.The main difference between FD and PD is that FD is typically based on differential pair with a tail current source while PD is based on two independent inverters without tail current source.Advantage of using PD is that it avoids the voltage drop across the tail current source which allows wider input and output ranges and makes circuit attractive for low power applications.However, for suppressing common-mode signal,PD structure requires an extra common-mode feedback(CMFB) circuit,thus degrading the performance as CMFB behaves like an additional load.Furthermore,CMFB circuit has to be carefully designed to avoid stability problems,resulting in complex circuitry and more power consumption. So an alternative is to use common-modefeed forward(CMFF) technique.[10] shows that the CMFF performs better in terms of induced nonlinear,signal distortion,speed and output signal swing and feed-

forward approach results very attractive for low-voltage applications.

In this work,a low voltage pseudo-differential OTA using bulk-driven technique is proposed.The circuit uses a feed forward technique to suppress common mode signals and enhances the differential-mode signals, and operates in the subthreshold region.

2. Proposed pseudo differential OTA

A. Bulk input pseudo differential OTA

A basic low voltage bulk driven PD-OTA is shown in Fig.1. The circuit consists of two independent bulk input PMOS ($M_{1a,b}$) and two active load NMOS transistors($M_{2a,b}$).The gate voltages for PMOS and NMOS are biased to a constant voltage V_{b1} and V_{b2} respectively for operating in subthreshold region.

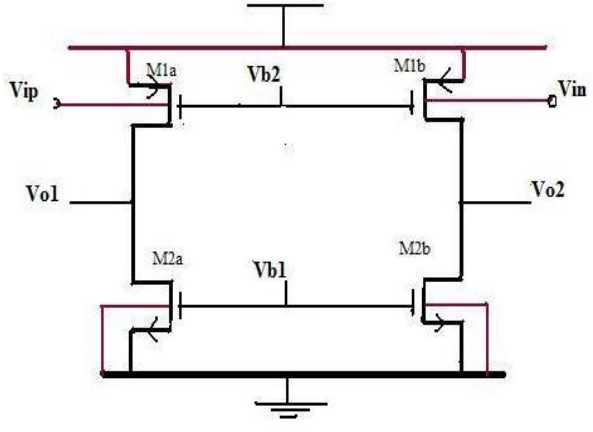

Fig.1 Bulk input PD-OTA.

In PD structure,removing the tail current source results in larger common-mode gain (A_{CM}) where as in FD structure the common-mode gain is increased by increasing the output resistance of the bias current source. However for PD shown in Fig.1, the common-mode gain (A_{CM}) is equal to the differential-gain (A_{DM}).

The differential-mode gain for the above circuit is given in (2)

$$A_{DM}= g_{mb1a,b}(r_{o1}\|r_{o2}) \qquad (2)$$

The CMRR calculated for the above circuit is given in (3)

$$\text{CMRR} = A_{DM}/\ A_{CM} = 1 \qquad (3)$$

which results in unity.This large A_{CM},in PD structure results in huge common-mode variations at the OTA output.

B.Common mode Feed Forward

The CMRR problem can be solved by using common-mode feed forward technique.Fig 2 shows the CMFF topology for bulk driven circuit.This method reduces the common-mode signal at the input nodes by feeding them inversely through another path forward to the output nodes.The common-mode signals which come from both the paths would be cancelled at the output node by superposition addition which results in the increase of CMRR while the common-mode gain is decreased.

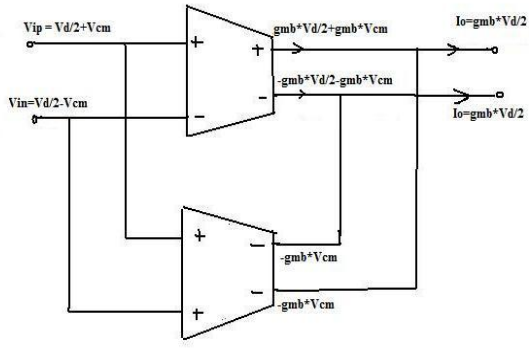

Fig.2. Common mode Feed Forward Method

C. Bulk driven Feed Forward OTA

A bulk driven OTA with common-mode feed forward technique is shown in Fig.3.The common feed forward circuit concept is taken from[9], but this circuit operates in the subthreshold region.For operating the circuit near moderate inversion or weak inversion side of moderate inversion regiona large voltage can be applied as a gate bias and the signal can be applied to the body of the device in order to attain a relatively large body transconductance.The input is applied to the body of PMOS transistors M_1 and M_2, and their g_{mb} provides the input transconductance.For an input common-mode voltage of $V_{DD}/2$ the resulting small body-source forward bias lowers the V_T and further increases the inversion level.The body inputs of M_3 and M_4 form cross coupled pair that boosts the differential DC gain by adding negative resistance to the output.The current equation for the subthreshold region operating in weak inversion is given by (4)

$$I_d = \frac{W}{L}\mu\left(\frac{KT}{q}\right)^2\sqrt{\frac{q\varepsilon_{Si}N_{Ch}}{4\emptyset_F}}\exp\left(\frac{V_{GS}-V_T}{nKT/q}\right) \qquad (4)$$

where$\emptyset_F$ is the Fermi potential,N_{ch} is the channel doping,V_{GS} is the gate to source potential,K is the Boltzmann constant and q is the electron charge.For

bulk driven circuit the current expression is given by (5)

$$I_d=\frac{W}{L}\mu\left(\frac{KT}{q}\right)^2\sqrt{\frac{q\varepsilon_{Si}N_{ch}}{4\emptyset_F}}*\exp\left(\frac{V_{GS}-V_{TO}-\gamma\sqrt{2\emptyset_F-V_{BS}}+\gamma\sqrt{2\emptyset_F}}{nKT/q}\right) \quad (5)$$

where V_{BS} is the bulk to source potential, V_{TO} is the threshold voltage when bulk-source is at 0V and n is the subthreshold slope factor.

The bulk transconductance g_{mb} can be obtained by differentiating (5) with respect to V_{BS} and is given as in (6)

$$g_{mb} = I_d\frac{\gamma}{nKT/q\sqrt{2\emptyset_F-V_{BS}}} \quad (6)$$

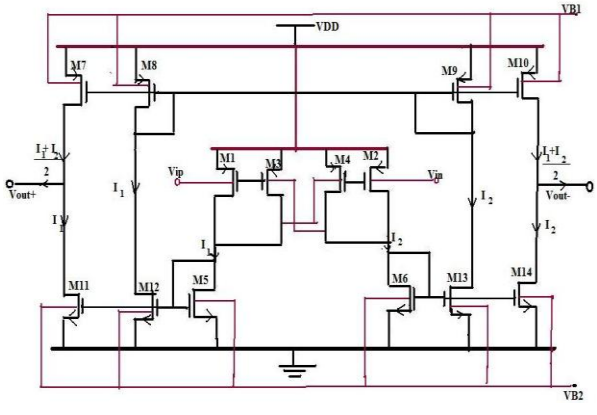

Fig. 3 Bulk driven Feed Forward OTA

The common-mode signal is strongly suppressed as a result of $g_{m1,2}$ being larger than $g_{mb1,2}$ and is intrinsically less than 1.

In this design the differential gain A_{DM} can be increased by cascading two identical gain blocks to form a two-stage OTA as shown in Fig. 4.To increase the stability Miller compensation capacitors C_C with series resistors R_C was added to move the right half-plane zero to left half-plane zero.The unity gain-bandwidth product is given by (7) and the second pole frequency is given by (8) as in[3, 4].

$$GBW=\frac{g_{mb1,2}}{2\pi C_C} \quad (7)$$

$$GBW=\frac{g_{mb1,2}''}{2\pi C_L} \quad (8)$$

where $g_{mb1,2}$and $g_{mb1,2}$" are the input transconductance of the first and the second stage.

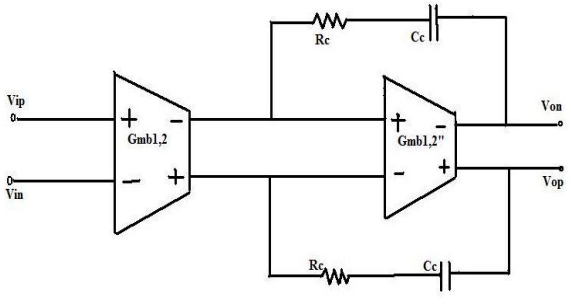

Fig. 4Two Stage OTA

The aspect ratios of all the transistors are shown in Table 1.

TABLE I
ASPECT RATIOS OF TRANSISTORS

FIRST STAGE(PARAMETER)	VALUE
$(W/L)_{1-2}$	10.01µ/180n
$(W/L)_{3-4}$	500n/475n
$(W/L)_{5-6}$	400n/180n
$(W/L)_{7-8-9-10}$	12 µ /950n
$(W/L)_{11-12-13-14}$	9.95 µ/1.25 µ
SECOND STAGE	
$(W/L)'_{1-2}$	10.01µ/180n
$(W/L)'_{3-4}$	500n/475n
$(W/L)'_{5-6}$	400n/180n
$(W/L)'_{7-8-9-10}$	12 µ /950n
$(W/L)'_{11-12-13-14}$	9.95 µ/1.25 µ

4. Simulation results

The designed OTA was simulated with Cadence Spectre simulator using 180nm CMOS technology with threshold voltage less than 0.45V for both PMOS and NMOS to operate under supply voltage. The aspect ratios of all the transistors are shown in Table 1.

Fig.5 shows the frequency response of the simple bulk driven PD-OTA.The differential gain and the common-mode gain of the circuit is found to be 14 dB which makes CMRR value equal to unity.Fig. 6 shows the differential gain and phase plot for the two stageBulk driven Feed Forward OTA,the differential gain is found to be 49.4 dB while the unity gain frequency is 1.3MHz.The phase margin of the circuit is 22.6°.

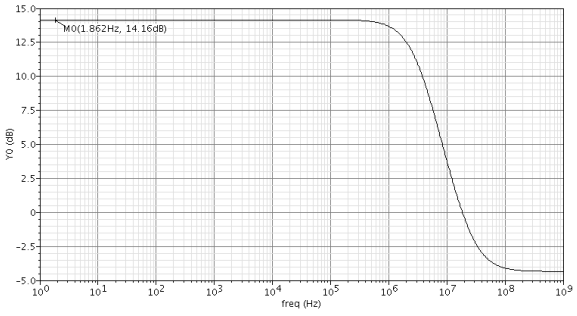

Fig. 5 Gain plot of Bulk input PD-OTA

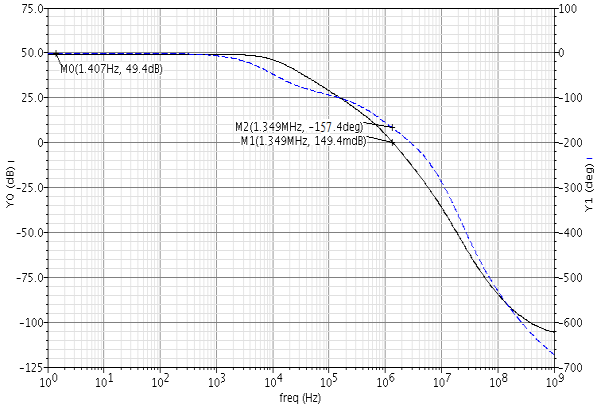

Fig.6. Gain and phase plot for Bulk driven Feed Forward OTA.

The common-mode signal is suppressed using Feed Forward technique as the common mode gain is found to be -182.4 dB which is obtained by applying a common mode input signal of 10mV and shown as in Fig.7. The CMRR is obtained above 200 dB which is calculated by(9).

$$\text{CMRR} = A_{DM} / A_{CM} \quad (9)$$

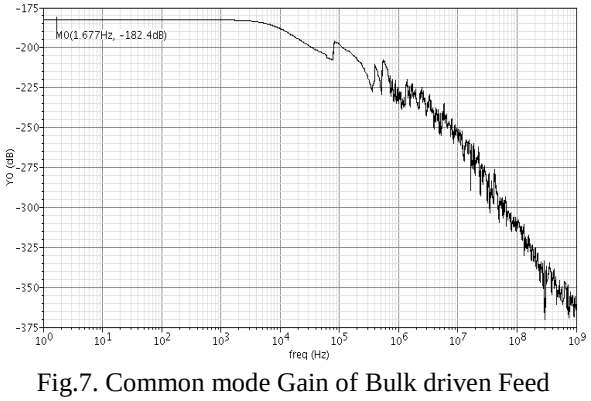

Fig.7. Common mode Gain of Bulk driven Feed Forward OTA.

To calculate the PSRR, an a.c. signal of 10mV, 50Hz is superimposed on V_{DD} with no input applied at inverting and non-inverting terminals and the gain w.r.t. supply voltage (A_{PS}) is plotted with frequency as shown in Fig. 8.The power supply gain obtained is -153.8 dB.

The PSRR is given by

$$PSRR = A_{DM}/A_{PS}$$

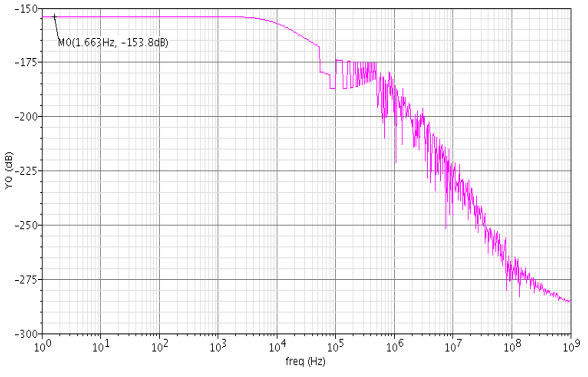

Fig. 8.Power supply Gain.

Fig.9 shows the transient responses of the output voltages for differential mode (V_{01},V_{02}) when the inputs are differential mode voltages with amplitude of 10 mV at 1kHz.The output swing obtained is 0.44V.

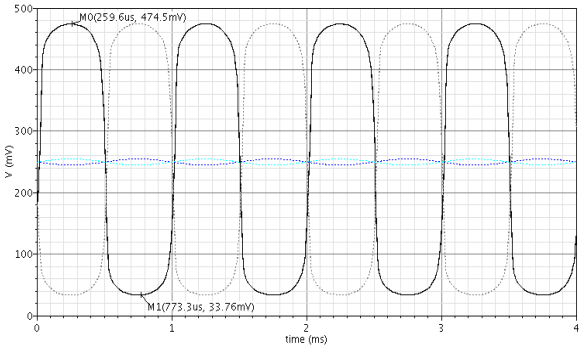

Fig. 9. Differential output voltages.

The simulation results are summarised in Table 2.

TABLE II
SIMULATION RESULTS

PARAMETER	VALUE
Supply Voltage	0.5V
Gain	49.4dB
Unity Gain frequency	1.3MHz

Phase margin	22.6˚
Output Swing	0.44V
Power Dissipation	3.5 µW
Technology	180nm
CMRR	231.4dB
PSRR	203.2dB
Load Capacitance	2.5pF

5. Conclusion

In this paper, a bulk driven CMOS pseudo differential OTA is proposed.The design incorporates the feed forward technique which suppresses the common mode gain and gives a differential gain of 49.4 dB with unity gain frequency of 1.3MHz for a phase margin of 22.6°.The circuit gives high output swing with a power dissipation of 3.5μW.

6. References

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