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Enhancing the Slew rate and Gain Bandwidth of Single ended CMOS Operational Transconductance Amplifier using LCMFB Technique

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Abstract

Industry is continuously researching techniques to reduce power requirements, while increasing speed, to meet the demands of today's low (battery) powered wireless systems. The operational transconductance amplifier (OTA) is a fundamental building block in analog (mixed-signal) design and its performance characteristics are the foundation of system level characteristics. Improving the performance of the fundamental amplifier structure, while avoiding costly silicon area and static power increases, is critical to improving system performance. The application of Local Common Mode Feedback (LCMFB) to the conventional OTA structure provides significant increases in gain-bandwidth and slew rate performance without an increase in static power and limited additional silicon area. In the presented research, local common mode feedback technique has been applied to single ended differential operational transconductance amplifiers. LCMFB provides wide-range programming of amplifier characteristics and increases the versatility of the amplifier structure.

Keywords: **Slew rate, GBW, OTA, LCMFB**

1. Introduction

The operational transconductance amplifier (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 principle differences from standard op-amp are-

- Its output of a current contrasts to that of standard operational amplifier whose output is a voltage.
- It is usually used "open-loop"; without negative feedback in linear applications. This is possible because the magnitude of the resistance attached to its output controls its output voltage. Therefore a resistance can be chosen that keeps the output from going into saturation, even with high differential input voltages.

Improving the performance of the fundamental amplifier structure, while avoiding costly silicon area and static power increases, is critical to improving system performance. The application of Local Common Mode Feedback (LCMFB) to the conventional OTA structure provides significant increases in gain-bandwidth and slew rate performance without an increase in static power and limited additional silicon area. Both single ended and fully differential amplifier architectures are used in industry for modern design.

2. Circuit principle

As shown in Figure 2, the OTA employs a differential input pair and three current mirrors. The differential input pair is comprised of transistors M1, 2. The differential pair is biased by MB1, 2. Mirrors formed by M3, 5 and M4, 6 reflect currents generated in the differential pair to the output shell. The current generated by the mirror of M3, 5 is then reflected to the output via the mirror formed by M7, 8. The mirror gain factor, K, indicates the gain in mirrors formed by M3, 5 and M4, 6 with the following relations: β5=Kβ3, β6=Kβ4 where β=(KP/2)(W/L). Cascoding transistors M9, 10 are biased by V_{casn}/V_{casp}

and provide increased gain via increased (cascoded) output resistance.

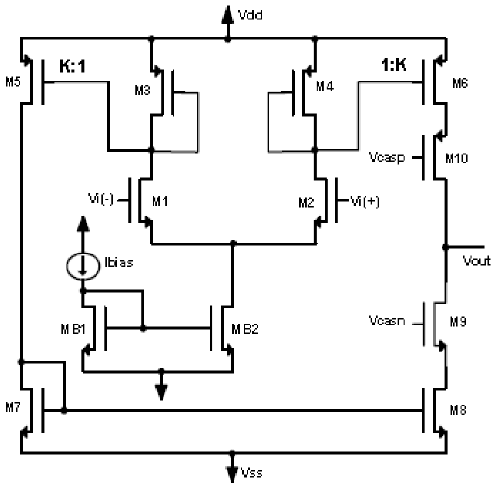


Figure.2. Conventional OTA architecture

The conventional OTA is differentiated from other amplifiers by the fact that its only high impedance node is located at the output terminal. The conventional OTA does not employ an output buffer and is therefore, only capable of driving capacitive loads. The gain of the OTA (G_mR_o) is dependent on the large output resistance of the shell (M5-M10) and is decreased to $G_mR_o//R_L \approx G_{mL}$ if a parallel resistive load R_L is applied. Industry is researching techniques to reduce power requirements, while increasing speed, to meet the demands of low (battery) powered wireless systems. These systems require amplifiers with low bias currents, capable of producing large dynamic currents. Application of Local Common Mode Feedback (LCMFB) [1-3] techniques to the conventional OTA architecture produces an efficient class AB amplifier with enhanced gain-bandwidth and slew rate. An OTA structure, with local common mode feedback, provided by R1, R2, is shown in Figure 2.1.

The active load transistors M3,4 are reconnected to have a common gate (node C) and matched resistors R1, R2 are used to connect the gate and drain terminals of M3, M4. Resistors R1, R2 can be implemented with PMOS transistors MR1, 2 operating in the triode region.

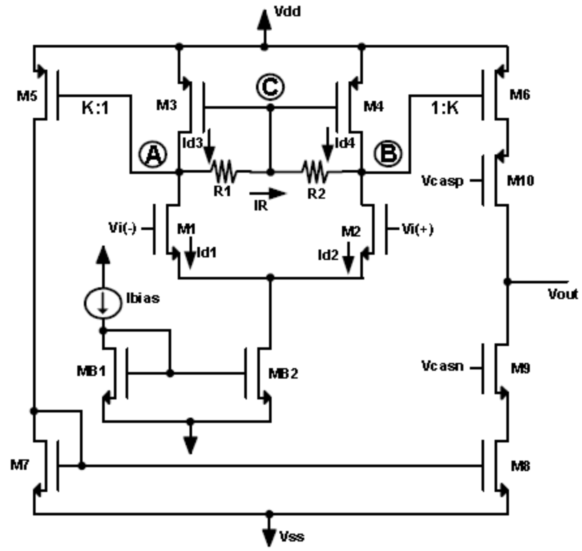


Figure.2.1 Proposed LCMFB OTA architecture

3. Circuit Structure

3.1 Input Stage for main OTA

The conventional OTA (Figure 3.1) uses a differential pair in conjunction with three current mirrors to convert an input voltage into an output current. Common mode signals (Vi(+)=Vi(-)) are, ideally, rejected. For a common mode input voltage, the currents are constant and will be: $i_{d1}=i_{d2}=I_{BIAS}/2$, and $i_{out}=0$. A differential input signal will generate an output current proportional to the applied differential voltage based on the transconductance of the differential pair. Although the output stage is a push-pull structure, the conventional OTA is only capable of producing an output current with a maximum amplitude equal to the bias current in the output shell ($K*I_{BIAS,OS}$). For this reason, the conventional OTA is a referenced as a class A structure capable of producing maximum signal currents equal to that of the bias current applied. Slew rate (SR) is directly proportional to the maximum output current and is defined as the maximum rate of change of the output voltage. For a single stage amplifier, the slew rate is the output current divided by the total load capacitance. The conventional OTA therefore suffers the consequence that high speed requires large bias currents which translates to large static power dissipation. Wireless and battery powered systems require high slew rate and gain bandwidth values with low static power dissipation. These requirements are difficult to achieve with class A structures such as the conventional OTA. The proposed class AB structure with Local Common Mode Feedback (LCMFB), can meet these requirements

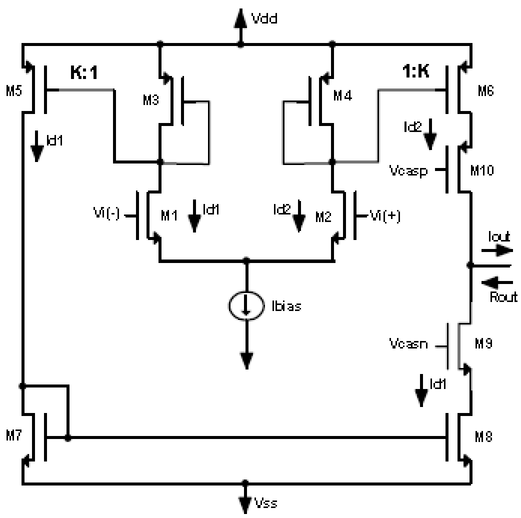


Figure 3.1 Conventional OTA open loop gain

The GBW and Slew Rate is given as,

$$GBW = Kgm_{1,2} / 2\pi C_L \quad \_ (3)$$

And

$$SR = KI_{Bias}/ C_L \quad \_ (4)$$

The slew rate and GBW, therefore, increases linearly with K.

The static power dissipation (P_{STATIC}) is the product of the sum of the currents flowing through the current sources or sinks with the power supply voltages and is given by

$$P_{Static} = (V_{DD}- V_{SS})\, I_{Bias}\, (2+K) \quad \_ (5)$$

An increase in the mirror gain factor (K) will increase the SR and GB of the conventional OTA at the cost of increased area and static power dissipation and a decrease in phase margin.

3.2 Operation of Proposed Architecture

For quiescent (or common mode) operation, the drain currents of transistors M1-M10 have equal values (${ID_{1\text{-}10}}={I_{bias/2}}$) while the current i_R in transistors MR1, 2 is zero. The gate-source voltage of M3, 4 is the same as their drain-source voltage. For common mode signals, these transistors perform as low impedance (diode connected loads) with value:

$$R_L^{CM} = \frac{1}{gm_{3,4}} \quad \_ (6)$$

The SR and GBW are given as

$$GBW = \frac{gm_{1,2} R_{A,B}\left(gm_{5,6} R_{out}\right)}{2\pi C_L R_{out}} \quad \_ (7)$$

The GBW is dependent on the programmable resistance $R_{MR1,\ 2}$. As $R_{MR1,\ 2}$ increases, the GB increases. Class AB operation provides large non-symmetric currents in the output shell. These currents are created by the large gate-source voltage swings (generated at nodes A/B) applied to M5, M6. Maximum output current generation occurs when the maximum gate-source differential is applied to M6 (or M5) and M5 (or M6) is in cutoff.

$$SR = \frac{I_{Out}^{Max}}{C_L} = (V_{SD,Sat3,4}^{Q} + \Delta V_{GS5,6}^{Max})\hat{}2 \times \beta_{5,6} / C_L$$

$$P_{Static} = (V_{DD}- V_{SS})\, 3I_{bias} \quad \_ (9)$$

Class AB operation in the LCMFB OTA produces signal currents much larger than the bias current applied with the same static power dissipation as that of the conventional structure (K=1). The advantage of this operation is the capability to design high slew rate architectures with low static power dissipation.

4. Design and Implementation Issues

Table 4.1 Design specification and parameters

Parameter	Specification
Technology	AMI 0.18 µm CMOS

Lambda	1λ= 0.6 μm
Threshold Voltages	0.42 volts, 0.41 volts
Transconductance	171μA/V^2, 37μA/V^2
Power Supply	1.8 V
Bias Current	600 μA
GBW	100MHz
Load Capacitance	10.0 pF

Table 4.2 Comparative Analysis

PARAMETERS	SE-CONV	SE-PROPOSED
Slew Rate (V/μs)	**9.1**	**150**
Bandwidth (MHz)	**5.7**	**27**
Maximum O/P Current (mA)	**0.5**	**1.3**
Static Power Dissipation (mW)	**4.95**	**6.5**
Gain Margin (dB)	**25.2**	**35**
Phase Margin (Degree)	**88.3**	**55**

Table 4.3 W/L ratio for Design issues

TRANSISTORS	DIMENSIONS (W/L)	$V_{DS, Sat}$ (V)
M1=M2	**4.122/0.18 μm**	**0.25**
M3	**1.912/0.18 μm**	**0.28**
M4	**7.21/0.18 μm**	**0.28**
M5	**7.7/0.18 μm**	**0.28**
M6=M7=M8	**5.18/0.18 μm**	**0.23**
M9=M10, (L_{MIN})	**1.098/0.18 μm**	**0.24**
MB1	**1.098/0.18 μm**	**0.23**
MB2	**2.677/0.18 μm**	**0.23**

5. Simulation of circuit performances and implementation of circuit layout

The operational transconductance amplifier is designed with power voltage of 1.8V in 0.18um CMOS process. Figure 5.1 shows the layout of operational transconductance amplifier and bias circuit designed.

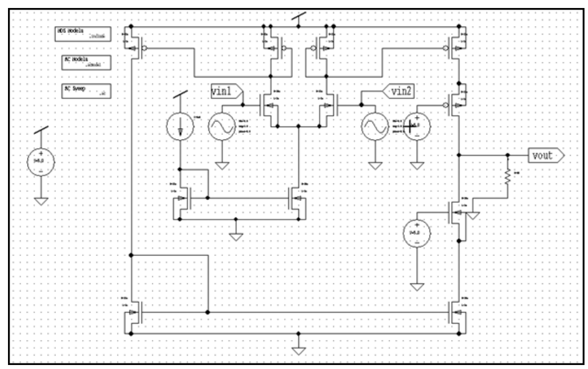


Figure 5.1.1 Conventional OTA layout

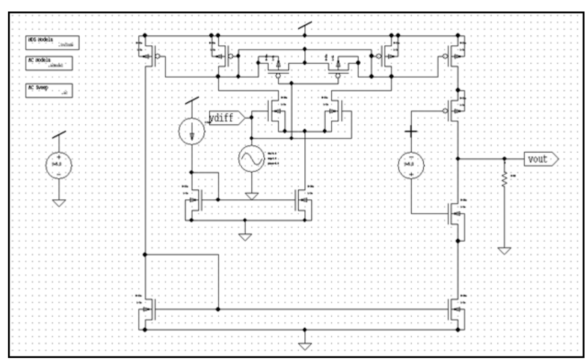


Figure 5.1.2 Proposed OTA layout

The waveforms of Frequency response simulation and output setting time simulation are shown in Figures 5.2 and 5.3.

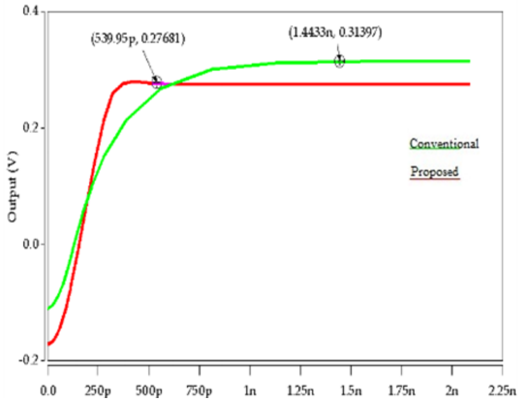


Figure 5.2 Output Setting Time simulations

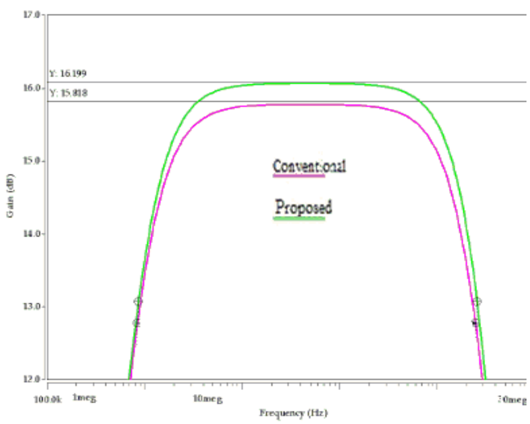
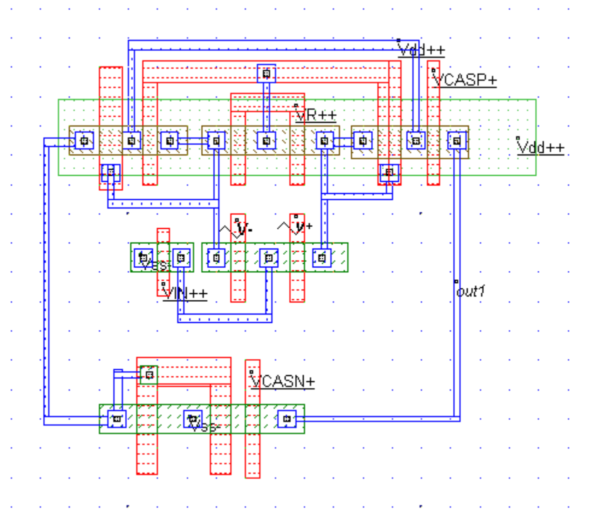


Figure 5.3 Frequency Response simulations

Silicon Area Dimensions for proposed architecture



6. Conclusion

In this study, a local common mode feedback technology has been adopted. As a result, the operational transconductance amplifier has greater slew rate and GBW as well as quick output signal setting time.

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