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Low Power and Fast Transient High Swing CMOS Telescopic Operational Amplifier

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Abstract
CMOS telescopic operational amplifier with high-swing and high-performance is described in this paper. The swing is attained by using the tail and current source-transistors in deep-linear region. The resultant deprivation in parameters like differential gain, CMRR and added characteristics are recompensed by using regulated-cascode differential gain enhancement and a replica-tail feedback technique. Operating at power supply of 3.3V, the power consumption, slew rate and settling time are improved using transmission controlled pass circuitry and level amplifier. It is shown through simulations that the Op-Amp preserves its high CMRR and unity gain frequency.
Index Terms: CMOS feedback logic, transient response, op-amp, operational amplifier, telescopic**,** improved, low power.

I.   Introduction

Operational Amplifiers are the most important and basic integrated parts of the Analog and mixed-mode signal operations. The continuous work in the op-amp design provides developments from simple two stage op-amp to telescopic op-amp. Telescopic op-amps have lot of advantages over the remaining types, but the disadvantage is low output swing. Initially when we are using high supply voltages this was not a severe problem. As the developments in the VLSI technology making the supply voltages scaling down the output voltage swing drawing a more concern towards it, and it becomes an important parameter to be considered while designing the op-amps. To get a high-swing in the telescopic op-amp we need to compromise with the other parameters of the op-amp, such as speed, gain and power.

There are two types of telescopic op-amps, 1) Telescopic op-amp with tail and 2) Telescopic op-amp without tail. They are briefed below

1) Telescopic amplifier:

Fig 1 shows the tail telescopic cascode op-amp. It is a differential cascode amplifier. The gain of the telescopic op-amp is almost like two stage operational amplifier. It has high output impedance. Telescopic op-amp contains ability of higher frequency and they consume very low power when compared to the other types of op-amps.
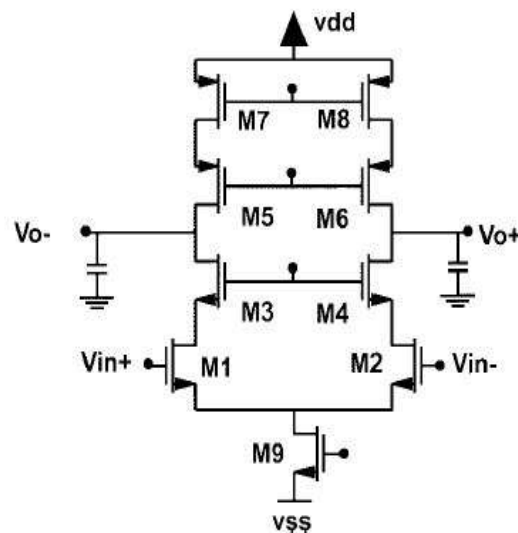

Fig 1: telescopic amplifier

Because the second pole of the source nodes of the n-channel cascode devices is obtained by the trans-conductance of n-channel devices as opposed to the p-channel devices, the high frequency response of the telescopic op-amps is possible.

The main drawback of the telescopic op-amp as we discussed earlier is that the output swing is limited when compared to the folded cascode, because of the voltage drop across the tail transistor reduces the voltage swing from both sides of the output. All the transistors must be placed in saturation. To get a considerable CMR, gain and high frequency response in telescopic op-amp, the input transistors M1 and M2, the load transistors M7 and M8, and tail transistor M9 should have at least

minimum drain to source saturation voltage $V_{ds,sat}$ across them. So the maximum output differential swing can be given by the equation $2V_{supply}$ - $10V_{ds,saturation}$ - $6V_{margin}$ [1].
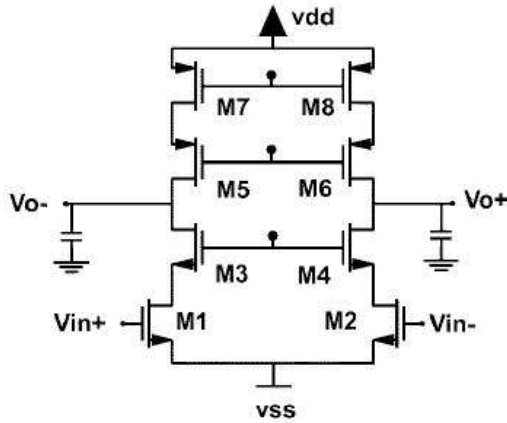
2) No-tail telescopic op-amp:

Fig 2: No-tail telescopic op-amp

No-tail telescopic op-amp is shown in above fig 2. Because there is no need of voltage drop across the tail transistor, in the no-tail telescopic op-amp the output voltage swing will be improved. The amount of voltage swing improved in no-tail op-amp will be equal to $2V_{ds,saturation} + 2V_{margine}$. To get this improved output swing in the telescopic op-amp we have to compromise with the CMRR, PSRR of the telescopic op-amp. In addition to that the parameters like settling time and unity gain frequency of the telescopic op-amp are sensitive to the input common-mode and variations in the supply voltage.

II. High-swing Op-amp
A) why high-swing op-amps?
The relationship among the parameters of op-amp is given by

$$\frac{(SNR).(speed)}{P} = \frac{swing^2}{\gamma(\frac{kT}{C})} \cdot \frac{\beta(\frac{gm}{C})}{V_{supply}.(\lambda I)} \qquad .....(1)$$

Where SNR is signal to noise ratio, P is power, β is the feedback factor of the closed loop op-amp, λ is the ratio of total current consumption of the operational amplifier to the current flowing through one of the input devices, γ is the number of kT/C noise contributions at the output of the amplifier. kT/C is the thermal noise which is dominant in the analog circuits.
The equation (1) can be represented in the simplified form as

$$\frac{(SNR).(speed)}{P} \alpha \frac{swing^2}{V_{supply}} \qquad .... (2)$$

From the above equation we can incur that if the swing is high then either SNR is high or power consumption P is low. Here the speed will be determined by the location of the dominant pole of the operational amplifier. So the overall performance of the op-amp will be improved.
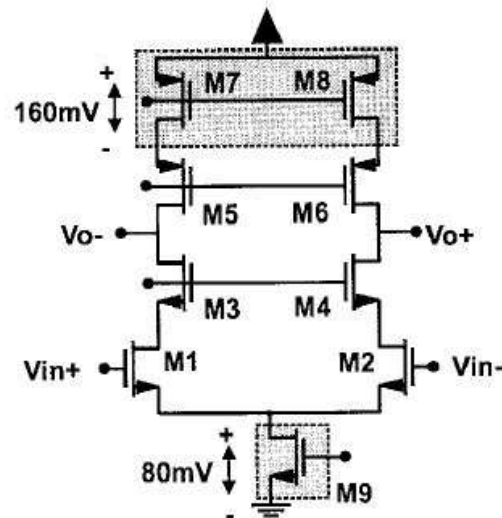
B. Procedure to improve the swing:

Fig 3: procedure for improving swing

If we want to improve the output swing we need to reduce the voltage drop across the tail and the load transistors. To reduce the voltage drop across these transistors, we need to drive the tail transistor M9, and load transistors M7 and M8 into deep linear region[2]. As these transistors or operating in the triode region the marginal voltage V_{margin} need not to be considered. The output swing equation is given by $2V_{supply}$ - $2V_{margin}$ - $6V_{ds,saturation}$ - $2V_{ds,linear-tail}$ - $2V_{ds,linear-load}$, where $V_{ds,linear-tail}$ is the voltage drop across the drain and source of the tail transistor in the linear region and $V_{ds,linear-load}$ is the voltage drop across the drain to source of the load transistors in the linear region. The swing obtained in this method is not only superior to the telescopic op-amp but also superior to the regular folded cascode amplifier. The improvement in the swing is because of i. no longer we need marginal voltage, ii. difference between $V_{ds,sat}$ and the voltage across the devices in the linear region. Any voltage reduction in across the tail transistor M9 will improve the voltage swing by twofold of the reduction, because the tail transistor is connected to the both sides of the output of the op-amp.

III. Implementation of op-amp :
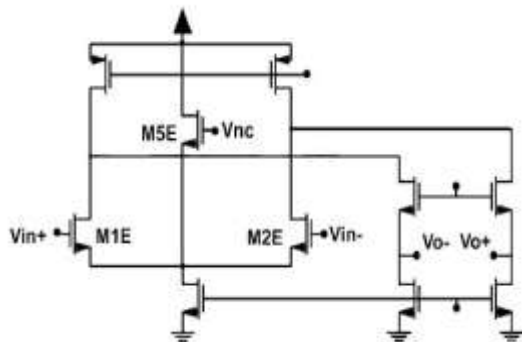Description of the circuit:

Fig 4: gain amplification across p-channel

The op-amp architecture will be determined by the requirements in the application such as speed, SNR, or power. The amplifier shown in fig 4 uses standard folded-cascode amplifier architecture. The input applied at the gate of the transistor named as the M5E sets the drain voltage of the M7 and M8 in the main amplifier.

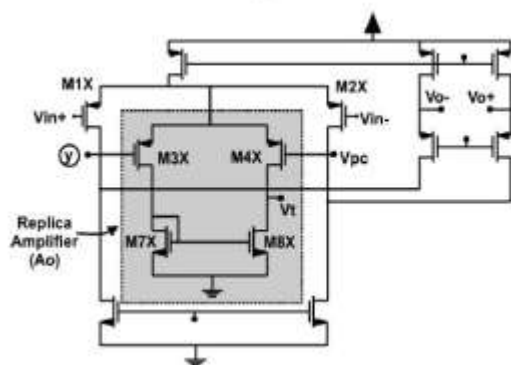The modified amplifier is shown in shown in fig 5 below

Fig 5: gain amp across n-channel

The transistors in shaded region M3X, M4X, M7X and M8X act as active load. This amplifier serves as replica amplifier without V_t.

This amplifier has many advantages, i) the current through the single third input transistor will be reused in the new differential pair and it will reduce the additional power required to construct amplifier, ii) the common voltage at the inputs of this enhancement amplifier equals the common-mode voltage of inputs of amplifier iii) ensures good replica matching, which improves the performance of the replica-tail feedback technique, iv) this implementation allows simultaneous setting of the dc levels of the common-mode voltage at the drains of the input devices[3]
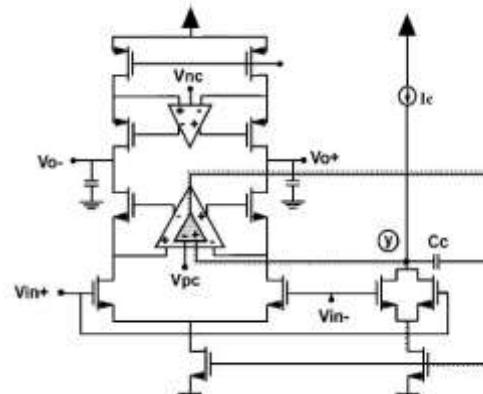
The overall implementation is shown in below fig 6.

Fig 6: overall implementation

Capacitance C_c can be used to push the second stage pole to a higher frequency. The ratio of the transcondance of the duplication amplifier to the capacitance C_c establishes the unity gain frequency of the replica loop. The gain amps, on the other hand, are stabilized by the arrangement of an explicit capacitance and parasitic capacitance at the gate of the cascoded devices. A cascode current-mirror is used to supply the current to the replica circuitry. For the common-mode feedback, the typical switched capacitor circuit is used [5].

IV.   Modified Circuit and Description
As we can see from the results of Base design, the power dissipation is controlled differentially by the input supplies only. Here in order to prevent leakage from supply, transmission controlled circuitry is added which helps to improvise the previously obtained results. Also improvisation in current flowing through tail transistor is also done by increasing the gate voltage across the tail transistor by employing level change amplifier, which in turn increases the gate-to-source voltage for tail transistor. Due to this added circuitry, settling time and slew rate restored their base values, which were initially degraded due to transmission controlled circuitry. CMMR and internal gain of the amplifier remained legitimately constant. A very small increase in output offset voltage resulted due to very small leakages in amplifier gain circuitry. The schematic diagram of proposed design is shown in the fig given below. The added circuit components transmission controller and level change amplifier are also shown below:
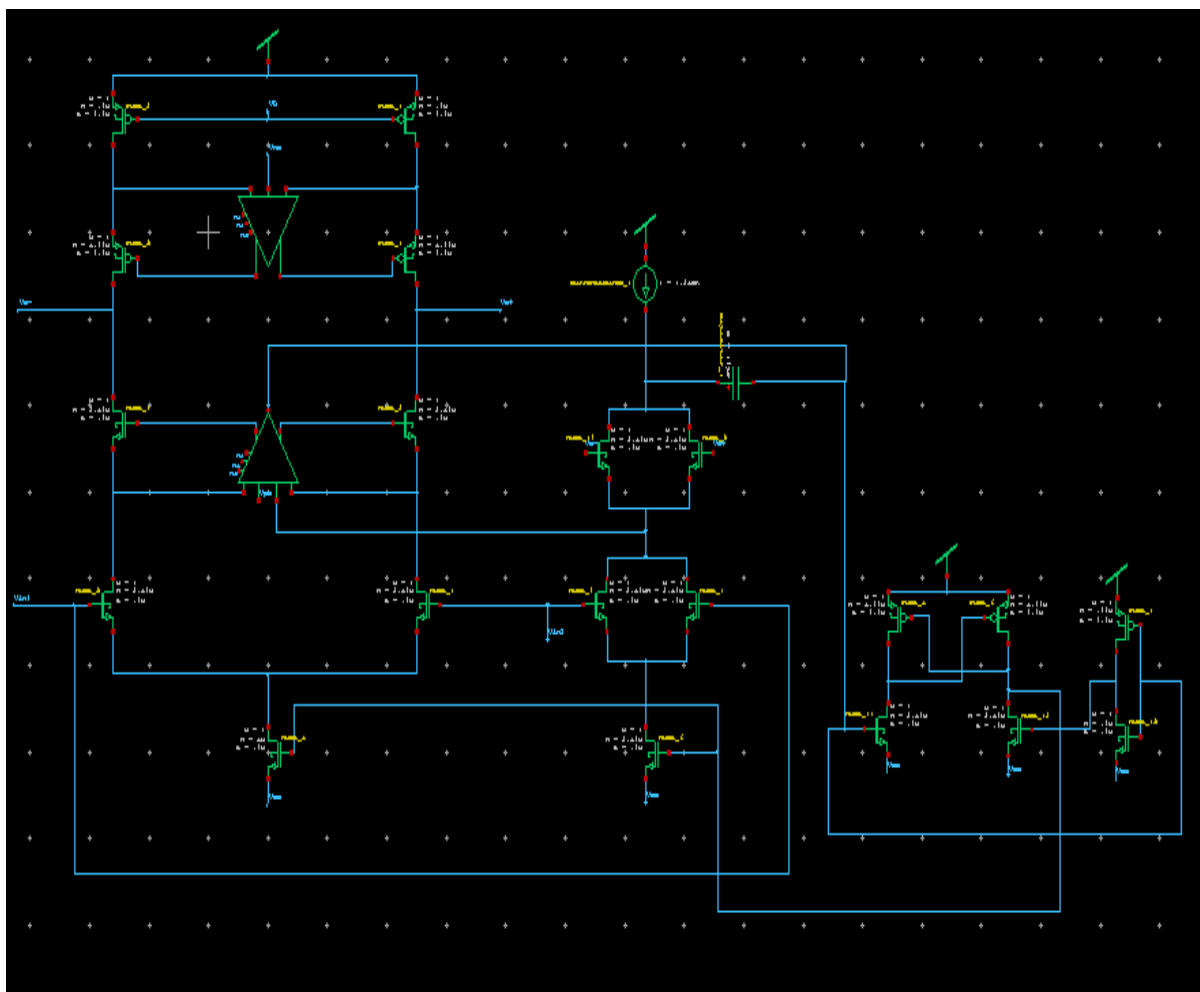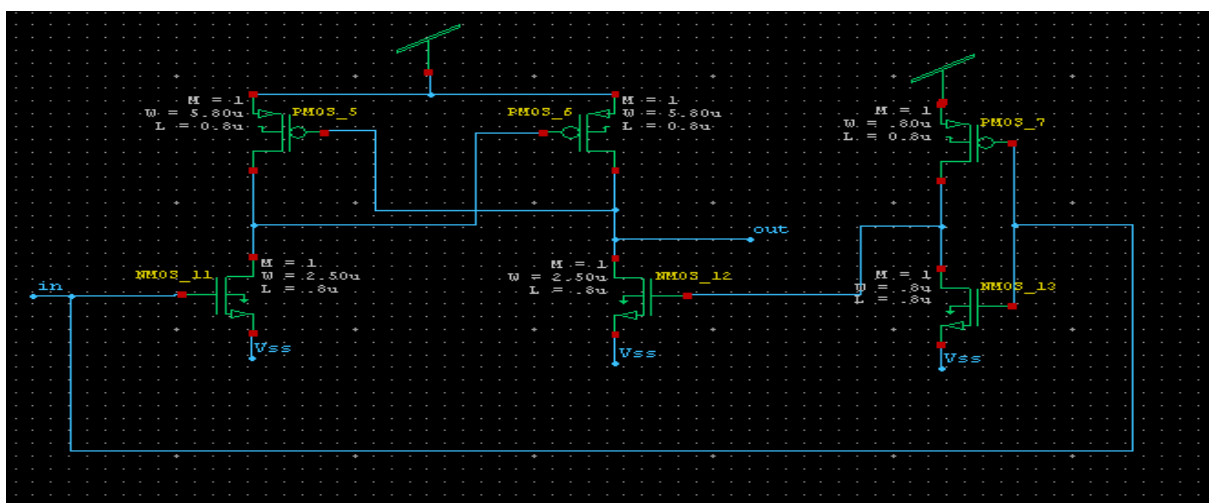
Fig 7: Modified implementation

Fig 8: Level Amplifier

V.   Simulation Results

The op-amp shown in Fig. 5(d) has been implemented in a standard 0.8 um, single-poly, double metal CMOS process. It consumes a total power of 4.8 mW at a 3.3-V supply. The slew rate obtained at 1V peak-to-peak voltage is improvised to 170mV/ns. The settling time measured is 12.70ns with a very fast transient response.

The CMMR at 500MHz is 48dB and the unity gain frequency at load capacitance of 3.52pF turned out to 97Mhz.The comparison with previous design is shown in the table below.
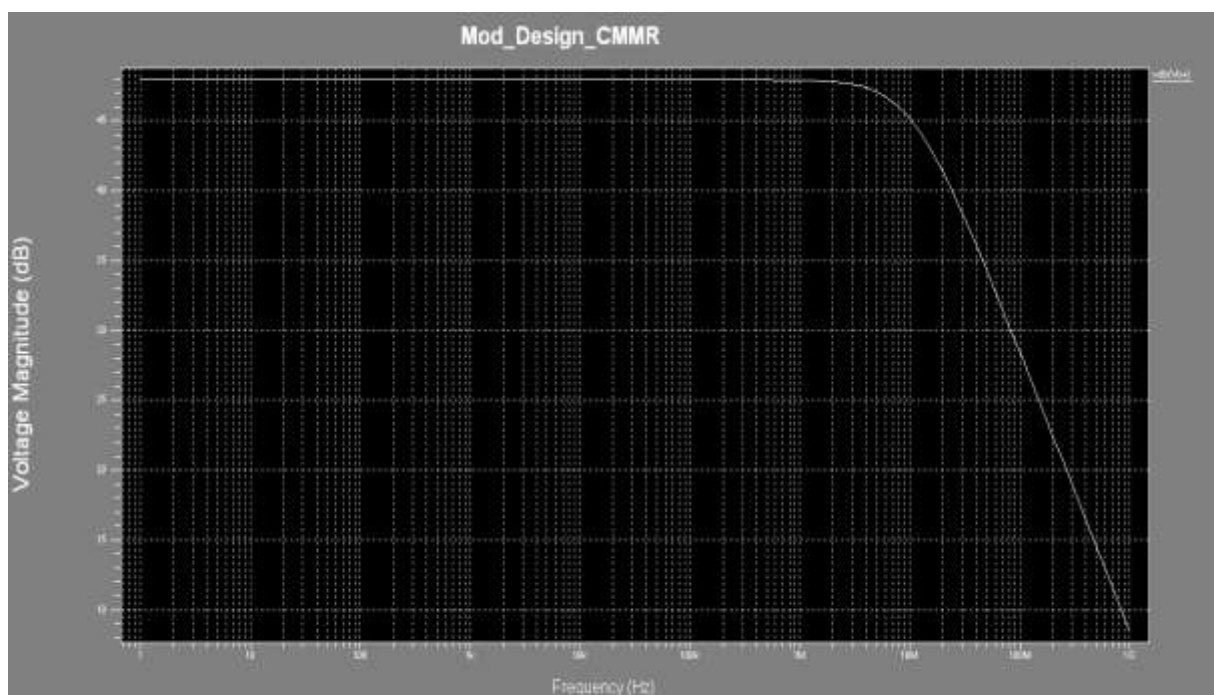
Fig 9: Slew rate for proposed telescopic Op-Amp

Fig 10: CMMR for proposed telescopic Op-Amp

VI. Comparison

Parameter	Base Design	Modified Design
Power	4.8mW	4.3mW
Settling Time	17.3ns	12.7ns
Slew Rate	133 mV/ns	170mV/ns
CMMR (at 500 Hz)	57dB	48dB
Unity Gain frequency	93 MHz	97 MHz
Offset Voltage	9.5mV	16mV
Swing	±2.4V	±2.4V

VII. Conclusion

With the supply voltages becoming more restricted, output swing of Op-Amp becomes an extremely crucial parameter. For the telescopic architectures, high speed and power consumption accompanies with partial output swing. The proposed strategy pools the high-speed, low-power telescopic architecture which can be suitable for implementation of Switched Capacitor filters. Further improvements can be expected for high capacitive load requirement.

References

[1] G. Nicollini, F. Moretti, and M. Conti, "High-frequency fully differential filter using operational amplifiers without common-mode feedback," *IEEE J. Solid-State Circuits*, vol. 24, pp. 803–813, June 1989.

[2] P. W. Li, M. J. Chin, P. R. Gray, and R. Castello, "A ratio-independent algorithmic analog-to-digital conversion technique," *IEEE J. Solid-State Circuits*, vol. SC-19, pp. 1138–1143, Dec. 1984.

[3] J. N. Babanezad, "A low-output-impedance fully differential op amp with large output swing and continuous-time common-mode feedback," *IEEE J. Solid-State Circuits*, vol. 26, pp. 1825–1833, Dec. 1991.

[4] K. Bult and G. J. G. M. Geelen, "A fast-settling CMOS op amp for SC circuits with 90-dB DC gain," *IEEE J. Solid-State Circuits*, vol. 25, pp. 1379–1384, Dec. 1990.

[5] J. Yang and H.-S. Lee, "A CMOS 12-bit 4 MHz pipelined A/D converter with commutative feedback capacitor," in *Proc. IEEE Custom Integrated Circuits Conf.*, 1996, pp. 427–430.

[6] W. Krenik, J. Hellums, W.-C. Hsu, R. Nail, and L. Izzi, "High dynamic range CMOS amplifier design in reduced supply voltage environment," *Tech. Dig. Midwest Symp. Circuits and Systems*, 1988, pp. 368–370.