Comparative Study on Telescopic Differential Amplifier and Folded-Cascode Operational Transconductance Amplifier (OTA) design using 50 nm BSIM4 Technology

Muhamad Aiman Aisar bin Mohd Amin
Faculty of Electrical Engineering
UniversitiTeknologi Mara
Shah Alam, 40450, Selangor, Malaysia
Email: caca_aisar86@yahoo.co.uk

Abstract—**Thispaper presents the comparison between telescopic differential amplifier and folded-cascode OTA design using 50nm BSIM4 Technology. The objective of this project is to compare the parameters of gain and power dissipation between these two design models. Implementation has been done in 50nm BSIM4 technology using LTSpice simulation tools, and use 1.0V voltage supply. The telescopic differential op-amp has gain of 70.5dB and power dissipation of 23.92mV. The folded-cascode OTA has 52dB of gain and 60.8mV of power dissipation. From the simulation results, the Telescopic structure is better in gain and power dissipation than folded-cascode structure.**

Keywords-component; Differential op-amp; Telescopic; Folded-Cascode; power dissipation; gain.

I. INTRODUCTION

With the development of CMOS process technologies and the increasing popularity of battery-powered mobile electronic systems comes the demand for lower-voltage analog circuit designs. Op-amps are among today's most widely used circuit blocks. They can be used as summers, integrators, differentiators, comparators, attenuators and much more. Nowadays, a lot of analog design techniques and methodologies have been advised to enable high performance analog signal processing. Two basic differential amplifier topologies that are going to be used are telescopic differential amplifier and folded-cascode differential amplifier. There are two architectures can be considered to design differential op amp which are differential folded cascode OTA and differential telescopic OTA. They are usually called Operational Transconductance Amplifier (OTA) because of the importance of their transconductance value. Instead of using a Miller compensation capacitor as in two-stage op-amp design, OTAs use the load capacitor to achieve compensation. Both topologies amplifier need a biasing circuit to operate in saturation region, designing a biasing circuit is difficult. This project is to compare the parameters of gain and power dissipation between these two models, Telescopic and Folded-Cascode Differential Op-Amp design. Both amplifier are designed in single stage op-amp by using 50nm BSIM4 Technology and characterized the parameters by comparing between these two models of op-amp.

II. METHODOLOGY

Using the LTSpice Tools, differential op-amp topologies are designed based on 50nm BSIM4 technology as shown in Table 1.

TABLE 1: CMOS TRANSISTOR PARAMETER

	PMOS	NMOS
Width	5µm	2.5µm
Length	100nm	100nm
Threshold Voltage	280mV	280mV

Figure 1 show the flowchart of this whole project.

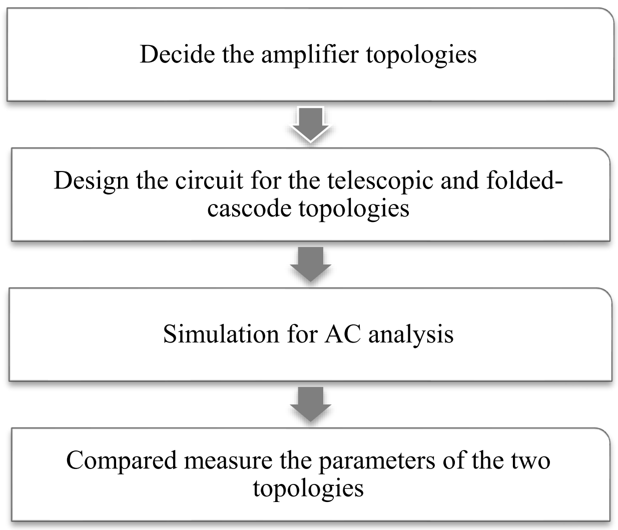

Figure 1: The design and simulation flowchart.

After output (waveform) from both differential op-amps was obtained, the measurements will be compared on gain and power dissipation.

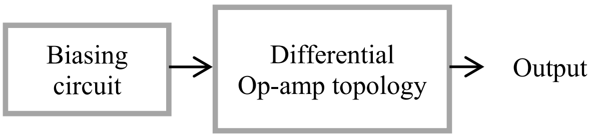

Figure 2: The block diagram of the differential op-amp.

A. Biasing circuit

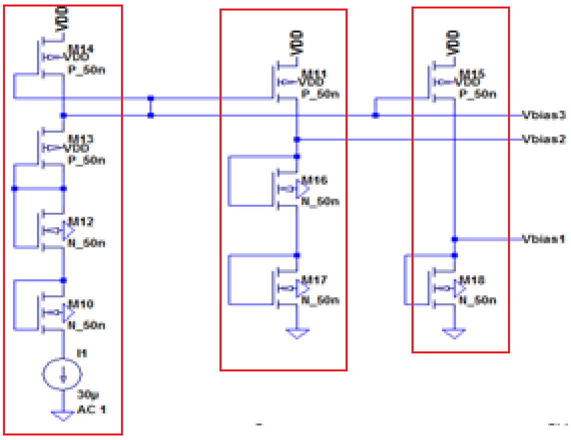

Figure 3: Biasing circuit.

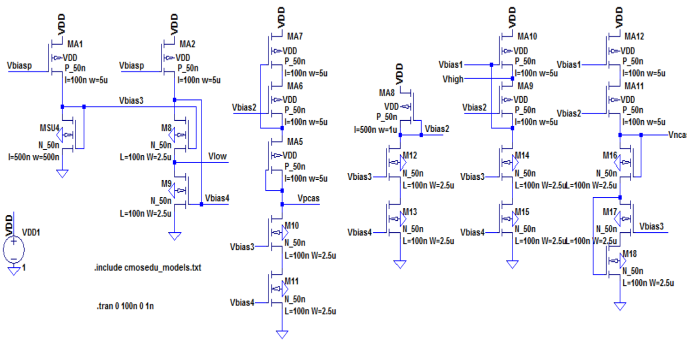

Figure 4: Biasing circuit.

Figure 3 shows the biasing circuit for telescopic differential amplifier. It consists of three branches that will generate the bias voltage to amplifier circuit. Figure 4 show a biasing circuit for Folded cascade OTA. This biasing circuit uses a Beta-multiplier and M7 is the critical capacitance for stability. By using PMOS devices in Beta-multiplier to bias the current mirror because PMOS will increase the capacitance on Vbiasp and to further stabilize the circuit. This design is to increase the output resistance of the circuit.

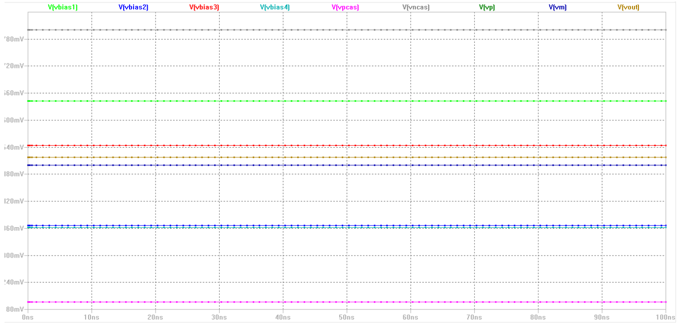

Figure 5: Bias voltage of biasing circuit.

In figure 5 shows that the biasing voltage of biasing circuit. The minimum voltage across the current source is above $2V_{ds,sat}$.

B. Telescopic Differential op-amp

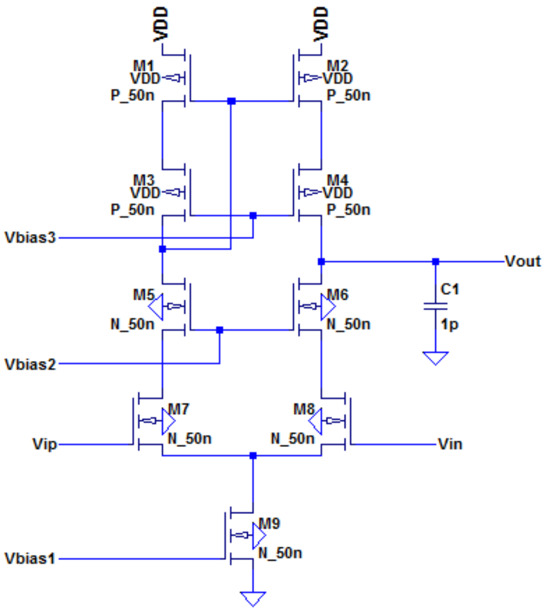

Figure 6: Telescopic differential amplifier topology.

Figure 6 shows the structure of a telescopic differential op-amp. This structure has been called a ‘telescopic cascode’ op-amp because the cascades are connected between the power supplies in series with the transistor in the differential pair, resulting in which the transistors in each branch are connected along the straight line. This telescopic amplifier consists of a differential amplifier and cascade load. The stacking of this cascade load is to achieve a high gain and provides high output impedance in order to make the current source closer to ideal. This telescopic amplifier consists of 5 NMOS and 4 PMOS. In the telescopic op-amp, all transistors are based in saturation region. Transistors M3-M4, M5-M6 and the tail current source M9 must have at least Vdsat to offer good common-mode rejection, frequency response and gain [2].

The main potential advantage of telescopic cascode op-amp is that they can be designed so that the signal variations are entirely handled by the fastest-polarity transistors in a given process [9, 10].The single stage architecture naturally suggests low power consumption. The telescopic configuration has half as many current legs and fewer devices. A telescopic cascode op-amp consumes less power than other topologies. The telescopic-cascode topology, although has extremely high gain on the order of $(g_m r_o)^2$ can provide enough gain and minimize power due to current flowing through only one branch [2].

C. Folded-Cascode OTA

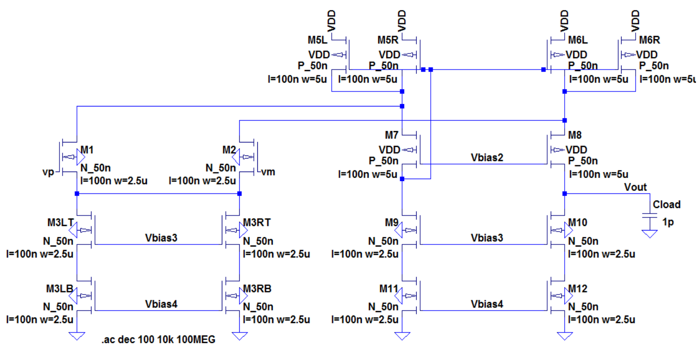

Figure 7: Folded-cascode OTA topology.

Figure 7shows the structure of a Folded-cascode OTA. For folded-cascode differential op-amp, the structure of Folded-cascodeOTA is selected. The folded cascode op-amp has a push pull output stage which can sink or source current from the load. Thus extra current will flow in or out of the current mirrors.In general, the folded cascode connection dissipates more power. The gain of a folded cascode op amp is normally lower than that of a corresponding telescopic differential op amp due to lower impedance of the devices in parallel. A folded cascode op amp has a pole at the folding connection which is lower compared to that node pole of the telescopic differential op-amp. When $V_p > V_m$, M1 turn on and M2 shut off. Then M1 pulls down the drain on M5 causes M7 to shut off. The gate of M5 is pulled down causes the current of M6 increases. At the same time, the current in M8 is increasing and the output voltage increases, because the current in M2 is decreasing.

III. Results and Discussion

A. Gain

Gain of the op-amp topologies is determined by AC analysis. Simulation command for AC analysis is shown as below:

.ac dec 100 10k 100MEG

The equation of gain for folded-cascode OTA is determined by:

$$Av = V_{out}/V_p - V_m = g_{mn}*(R_{ocasn}||R_{ocasp}) \quad (1)$$

The eguation of gain for telescopic differential op-amp showedas below:

$$Av = g_{m1}(g_{m2}r_{o1}r_{o2}||g_{m3}r_{o3}r_{o4}) \quad (2)$$

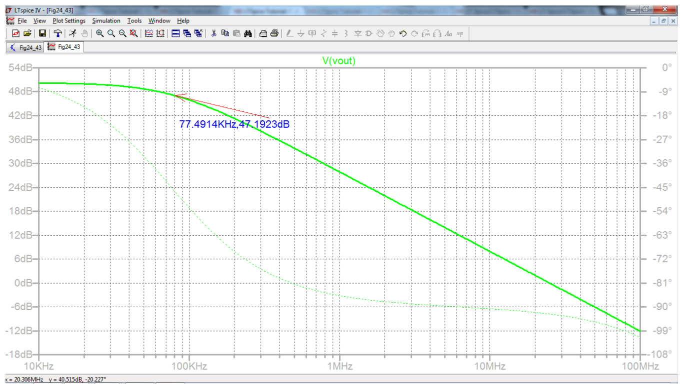

Figure 8: The output gain of folded-cascode OTA.

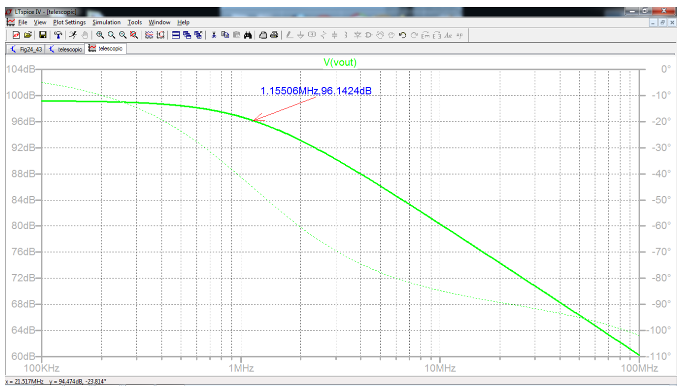

Figure 9: The output gain of telescopic differential op-amp.

Figure 8 shows the telescopic differential op-amp and the value is 96.1424 dB (as indicated with the red arrow). Figure 9 shows the output gain of folded-cascode (OTA) and the gain value is 47.1424 dB (as indicated with the red arrow). The gain of a folded cascode (OTA) is normally lower than a telescopic differential op-amp due to lower impedance of the devices in parallel. A folded cascode (OTA) has a pole at the folding connection which is lower compared to that node pole of the telescopic differential op-amp. This is due to the larger parasitic capacitance of extra and possible wider devices in folded structure.

TABLE 2: COMPARISON OF GAIN BETWEEN TWO TYPES OF TOPOLOGIES

Op-amp	Gain (dB)
Telescopic differential op-amp	99
Folded-cascodeOTA	52

The result of Table 2 shows that the telescopic differential op-amp has higher gain than folded-cascode OTA.

TABLE 3: DIFFERENT TRANSISTOR SIZING

	LENGTH	WIDTH(PMOS)	WIDTH (NMOS)
SIZING A	100 nm	5µm	2.5µm
SIZING B	90 nm	12µm	6µm
SIZING C	50 nm	5µm	2.5µm

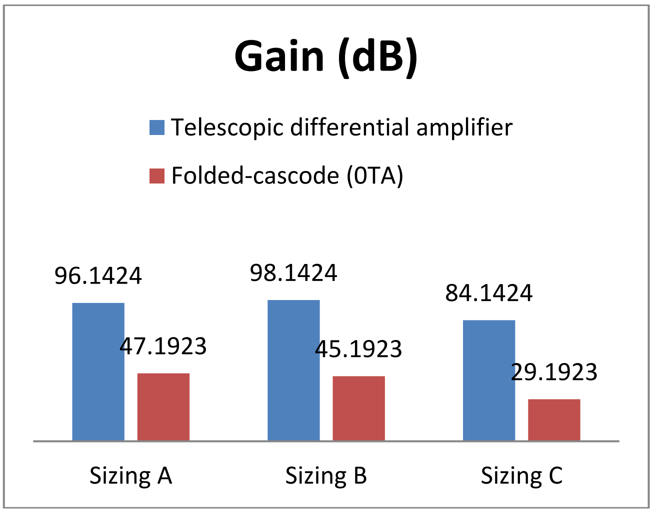

Figure 10: Gain of different transistor sizing.

Figure 10 shows that the gain of different sizing transistor. The sizing of transistors is stated in Table 4.7. For telescopic structure, the highest gain measured as 98.1424 dB (sizing B) and the lowest 84.1424 dB (sizing C). For the Folded structure, sizing A measured highest gain of 47.1923 dB and lowest gain in sizing C, 29.1923 dB.

B. Power Dissipation

The power dissipation is determined by the total current supplied by the constant current source and multiplies the result with VDD. Power dissipation can be in form of heat and voltage drop. The power dissipation in operational amplifiers depends mainly upon the number of current branches in the amplifier. The other factor that determines the power dissipation is the amount of current needed to charge the load capacitance. Figure below show the total current from each topologies, by multiply each one to supply voltage 1.0V, power dissipation are obtained. It can conclude through Equation (4) as below:

$$P = I_{Dtotal} V_{DD} \qquad (4)$$

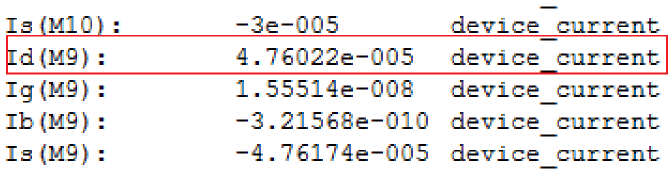

Figure 11: Total current of telescopic differential op-amp.

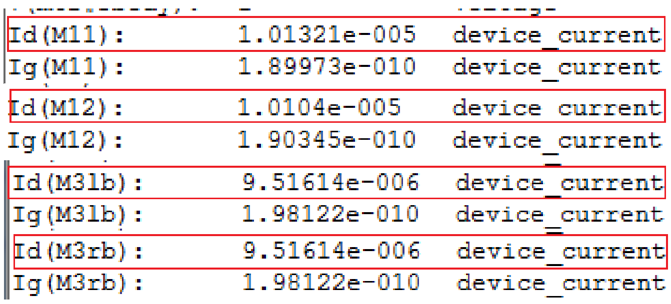

Figure 12: Total current of folded-cascode OTA.

Figure 11 shows the total current of telescopic differential op-amp. The current flow through drain M9 is 32.07 mV. This telescopic structure has half as many current legs and fewer devices. Thus leads to lower power dissipation compared with folded structure. Figure 12 shows the total current of folded-cascode OTA. The sum of current legs flow through M11, M12, M3rb, and M3lb are 60.8 mV. The folded cascode op-amp has a push pull output stage which can sink or source current from the load. Thus extra current will flow in or out of the current mirrors. This folded structure has more current legs and more devices in single path. Thus leads to larger static current and dissipated more power than telescopic structure.

TABLE 4: COMPARISON OF POWER DISSIPATION BETWEEN TWO TYPES OF TOPOLOGIES

Op-amp	Power dissipation,(mV)
Telescopic differential op-amp	32.07
Folded-cascode OTA	60.8

For Table 4, telescopic structure consumes less power dissipation than folded structure.

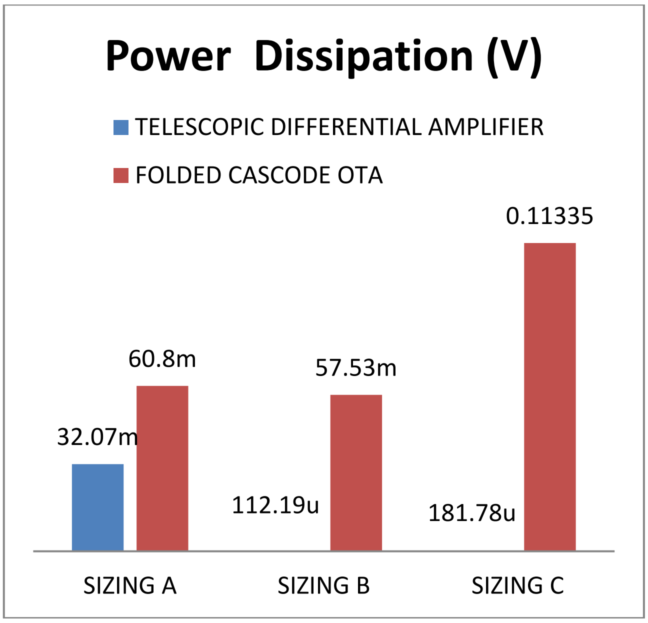

Figure 13: Power dissipation of different transistor sizing.

Figure above shows the power dissipation between both models by using different sizing of transistors. The sizing of transistors is stated in Table 3. In sizing A, telescopic structure produced highest power dissipation of 32.07 mW and lowest in sizing C (181.78 mW). For folded structure, the highest power dissipated in sizing C (113.35 mW) and lowest in sizing B (57.53 mW).

IV. Conclusion

This paper has compared the differential op-amp topologies between telescopic differential op-amp and folded-cascode OTA. Comparison has been done between these two models in term of gain and power dissipation. The telescopic differential op-amp has gain of 96.1424 dB and dissipated power of 32.07 mV. The Folded-Cascode OTA has 47.1424 dB of gain and 60.8 mV of power dissipation. From the simulation results, the Telescopic structure is better in gain and power dissipation than folded-cascode structure.

V. Recommendation

For future recommendation, this paper should compared four difference topologies which are telescopic, folded-cascode, cascode, two-stage and gain-boosted amplifier. This paper also can be implemented using latest Silterra 0.13um Technology.

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