

# Performance Evaluation of Different Types of CMOS Operational Transconductance Amplifier

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**Abstract:** The OTA is a basic building blocks found in many analog circuits such as data converter's (ADC & DAC) and Gm-C filters. Performance of Gm-C filters is related to the OTA's performance. The OTA is a Transconductance device in which the input voltage controls the output current, it means that OTA is a voltage controlled current source whereas the op-amps are voltage controlled voltage source. An OTA is basically an op-amp without output buffer, so it can only drive loads. The paper represents the different types of CMOS OTA with its fundamentals. The different topology of CMOS OTA is also described and at last comparison between different configurations is given.

**Keywords:** OTA, Single stage OTA, Two stage OTA, Telescopic cascode OTA, Gain boosting OTA, Folded cascode OTA

## 1. Introduction

Today's competitive, manufactures and developers are searching ways to build high performance devices that are smaller in size, operate at low power and lighter in weight. Low static power consumption, full rail dynamic range, characteristics as well as it is ease of scaling creates the perfect combination for the high performance integrated circuit(IC).

The Operational Transconductance Amplifier (OTA) is the block with the highest power consumption in analog integrated circuits in many applications. Low power consumption is becoming more important in handset devices, so it is a challenge to design a low power OTA. There is a trade-off between speed, power, and gain for an OTA design because usually these parameters are contradicting parameters. There are three kinds of OTAs: two stage OTAs, folded-cascode OTAs, and telescopic OTAs. The telescopic amplifier consumes the least power compared with the other two amplifiers, so it is widely used in low power consumption applications. It has also high speed compare to other two topologies. In this paper we present a number of A/D converter architectures. We discuss different types of OTA that includes Single stage OTA, Two stage OTA, Telescopic cascode OTA, Gain boosting OTA, Folded cascode OTA [1][8].

## 2. OTA Concept

An operational transconductance amplifier (OTA) is a voltage input, current output amplifier. The input voltage  $V_{in}$  and the output current  $I_o$  are related to each other by a constant of proportionality and the constant of proportionality is the transconductance "g<sub>m</sub>" of the amplifier.

$$I_o = g_m V_{in} \quad (1)$$

Where  $g_m$  = Transconductance of OTA.

$V_{in}$  = Differential input voltage

Figure 1 shows how to represent OTA symbolically.

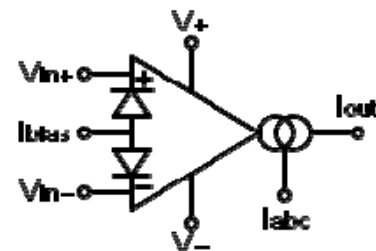


Figure 1: OTA symbol

The transconductance  $g_m$  of the OTA can be varied by varying the value of the external controlling current  $I_C$ .

$$g_m = K I_C \quad (2)$$

Where K = suitable constant of proportionality

Substituting equation (2) into equation (1), we get,

$$I_o = K V_{in} I_C \quad (3)$$

Equation (3) tells us that output current is proportional to the product of  $V_{in}$  and  $I_C$ .

Actually OTA consist of a differential transistor pair with a current mirror circuit acting as a load. Since OTA operates on the principal of processing current rather than voltage, it is an inherently fast device. As  $g_m$  can be controlled by changing the control current  $I_C$ , the OTA are suitable to electronically programmable functions.

### 3. Different OTA Topology

There are five types of OTA topologies. Each topology has its own advantage and disadvantage [1][6][8].

#### 3.1 Single stage OTA

Single stage OTA is as shown in fig 2. This single stage OTA is less complex compare to other types of OTA topology. Because of its less complex property its speed is higher compare to other topology.

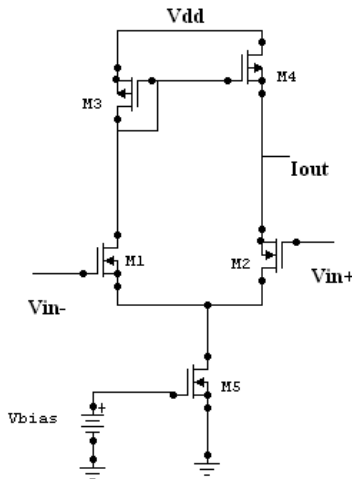


Figure 2: Single stage OTA

The drawback of this type of OTA is lower gain due to the fact that output impedance of this type configuration is relatively low. However this low impedance also leads to high unity gain bandwidth and high speed [3].

#### 3.2 Two stage OTA

The drawback of having limited gain of the single stage OTA is overcome by two stages OTA. In this type of configuration two stages are used. One of them provides high gain followed by second stage which provides high voltage swing. This modification increases the gain up to some certain extent compared to single stage OTA. But this addition of extra stage also increases complexity. And the increased complexity will reduce the speed in comparison to a single stage amplifier. [2][3]

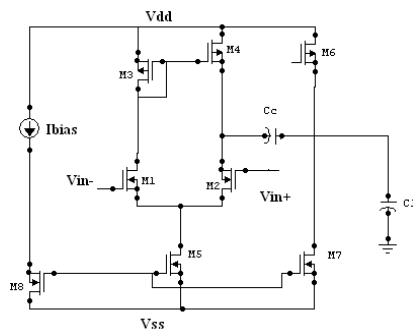


Figure 3: Two stage OTA

Advantages:

1. It has high output voltage swing.

2. It has higher gain compare to single stage OTA.

Disadvantages:

1. It has a compromised frequency response.
2. This topology has high power consumption because of two stages in its design.
3. It has a poor negative Power Supply Rejection at higher frequencies.

#### 3.3 Telescopic cascode OTA

The Telescopic Cascode OTA configuration is as shown in fig 4. Single Stage OTA have low gain due to fact that it has low output impedance, One way of increasing the impedance is to add some transistors at the output including using an active load. Transistors are stacked on top of each other. The transistors are called "cascode", and will increase the output impedance and thereby increase the gain. [1][8]

Advantage:

- 1) It provides higher speed.
- 2) It has lower power consumption.

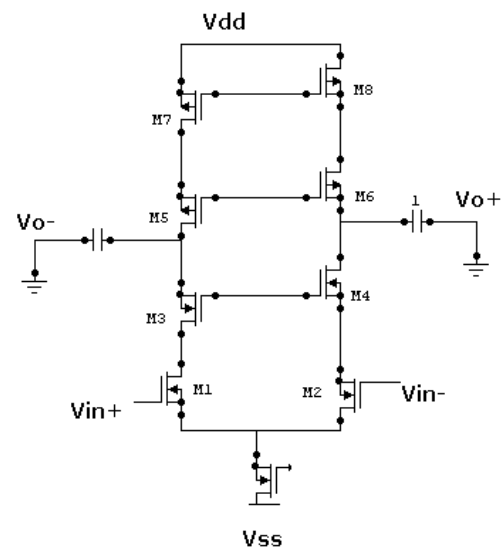


Figure 4: Telescopic OTA

Disadvantage:

- 1) Limited output swing.
- 2) Shorting the input and output is difficult.

#### 3.4 Regulated Cascode (Gain Boosting) OTA

In this type of configuration gain is further increased without decreasing output voltage swing. i.e. gain is further increased without adding more cascode devices. The Regulated Cascode OTA is shown in fig 5.

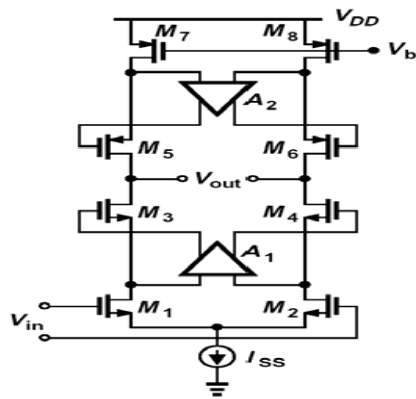


Figure 5: Gain boosting OTA

The drawback of this configuration is that these extra amplifiers might reduce the speed of the overall amplifier. Hence, they should be designed to have a large bandwidth so as not to affect the bandwidth of the entire configuration.

### 3.5 Folded Cascode OTA

In order to remove the drawback of telescopic OTA i.e. limited output swing and difficulty in shorting the input and output a Folded Cascode OTA is used. The fig of Folded Cascode OTA is shown in fig 6. [4]

Advantage:

- 1) This design has corresponding superior frequency response than two-stage operational Amplifiers.
- 2) It has better high frequency Power Supply Rejection Ratio (PSRR). The power consumption of this design is approximately the same as that of the two-stage design

Disadvantages:

- 1) Folded cascode has two extra current legs, and thus for a given settling requirement, they will double the power dissipation.
- 2) The folded cascode stage also has more devices, which contribute significant input Referred thermal noise to the signal.

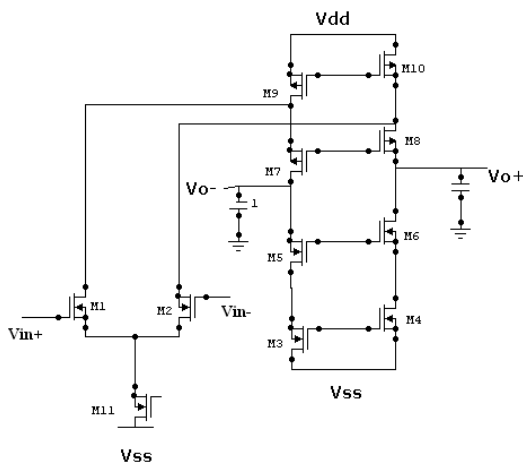


Figure 6: Folded cascode OTA

## 4. Comparison of Different Topology

The table presents a comparison of basic op-amp parameters for different configurations described above [8].

Topology	Gain	Output-swing	Speed	Power
Two stage	High	Highest	Low	Medium
Telescopic cascode	Medium	Medium	Highest	Low
Gain boosted	High	Medium	Medium	Highest
Folded cascode	Medium	Medium	High	Medium

## 5. Types of OTA

Depending on the input and output configurations, OTAs can be categorized into three types:

- 1) Single input/output OTA,
- 2) Differential-input single-output OTA,
- 3) Differential input/output (fully differential) OTA.

In these three types of OTAs, the transconductance  $g_m$  can be tuned via their DC current bias  $I_{tune}$ .

### 5.1 Single input/output OTA

This is the first type of operational transconductance amplifier based on its input/output configuration. It has single input and single output; hence the name is given single input/output OTA. The symbol and its equivalent circuit is shown in fig 7.

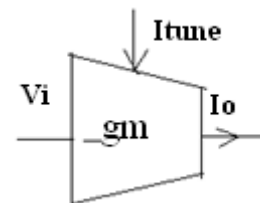


Figure 7: Single input/output OTA

The single input/output transconductor shown in Fig.7 is the simplest to implement, e.g. a single-NMOS common-source transconductor. The simplicity of this type of OTA makes it interesting for high frequency implementation. [5][6]

The output current for this type of OTA is given by,

$$I_o = -g_m V_i \quad (5.1)$$

Some common CMOS topologies are presents below to implement the single input/output OTAs. The one in Fig. 7.1(a) is a single-NMOS common-source transconductor. Although it is the simplest, it has relatively low output impedance due to its Miller effect (input-output coupling) and low linearity, deviating from an ideal OTA.

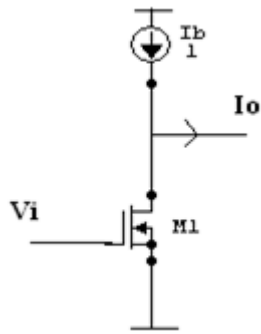


Figure 7.1(a) Single-input/output OTA with common source transconductor

To alleviate this problem, a cascode topology in Fig. 7.1 (b) is suggested, where a common-gate transistor M2 is introduced to provide isolation between the input and output. This method increases not only the output impedance and linearity, but also the bandwidth and the available transconductance, at the expense of a higher voltage supply.

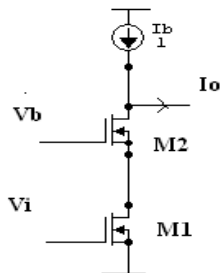


Figure 7.1(b) Single-input/output OTA with cascode transconductor

The third topology in Fig. 7.1(c) differs from the cascode topology in its common-gate transistor, where a PMOS transistor is applied instead of a NMOS one, resulting in a folded cascode topology. It provides the same isolation, but with a reduced voltage supply.

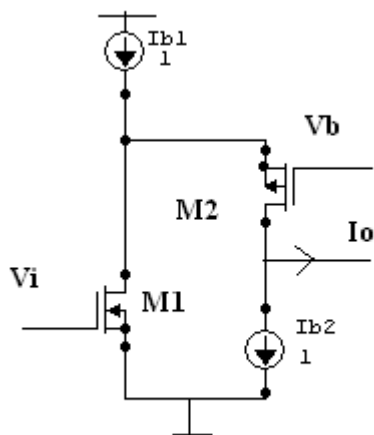


Figure 7.1 (c) Single-input/output OTA with folded-cascode transconductor

Fig.7.1 (d) is a regulated-cascode transconductor, which is an enhanced cascode transconductor. It replaces the gate DC bias of M2 in Fig. 7.1 (b) with a negative feedback from its source. This feedback further improves the linearity and the output impedance by a factor of  $(A+1)$  compared to the cascode transconductor, where  $-A$  is the feedback gain.

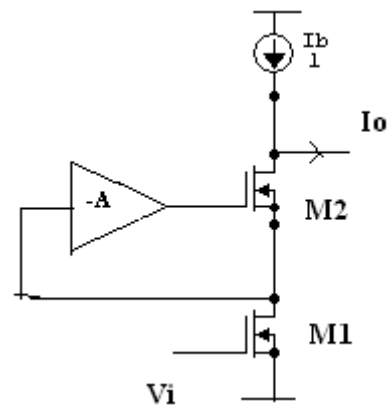


Figure 7.1(d) Single-input/output OTA with regulated-cascode transconductor

Fig.7.1 (e) utilizes a PMOS current mirror to convert a negative transconductor to a positive one, for which the output polarities of the block diagram and the circuit model in Fig. 7 have to be inverted in order to represent it.

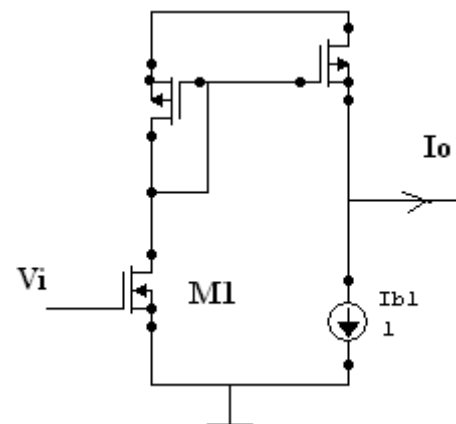


Figure 7.1(e) Single-input/output OTA with regulated-cascode transconductor

5.2 Differential-input single-output OTA :

This is the second type of operational transconductance amplifier based on its input/output configuration. It has differential input and single output; hence the name is given differential input single output OTA. The symbol and its equivalent circuit is shown in fig 8. [7][8]

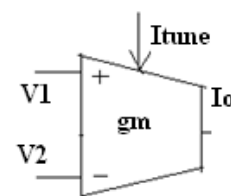


Figure 8: Differential input single output OTA

For differential input single output OTA, output current is given by,

$$I_0 = g_m(v_{i+} - v_{i-}) \quad (5.2)$$

Fig. 8.1 shows two typical CMOS implementations of the Differential input single output OTA. They both contain a source-coupled differential-pair input stage, which can provide high input impedance, high gain, and high common-mode rejection simultaneously without much sacrifice.

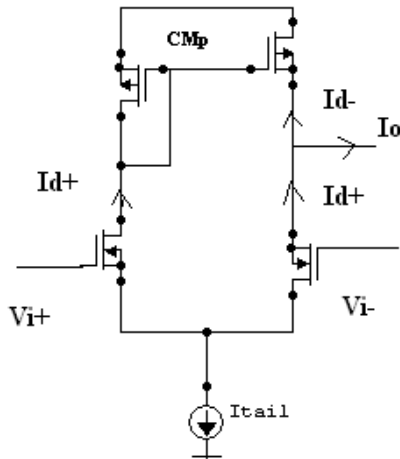


Figure 8.1 (a) Differential-input single-output simple CMOS OTA

In Fig. 8.1 (a), the current mirror CMp transfers the left output current of the input differential pair,  $i_{d+}$  to the right to combine with its right output current  $i_{d-}$  from which the transconductor output current is doubled.  $v_{i+}$  and  $v_{i-}$  are the differential input voltages.

The balanced implementation in Fig 8.1 (b) is different from the one in Fig. 8.1(a) in that two PMOS current mirrors are added after the input differential pair in order to improve the balance between its two differential input paths.

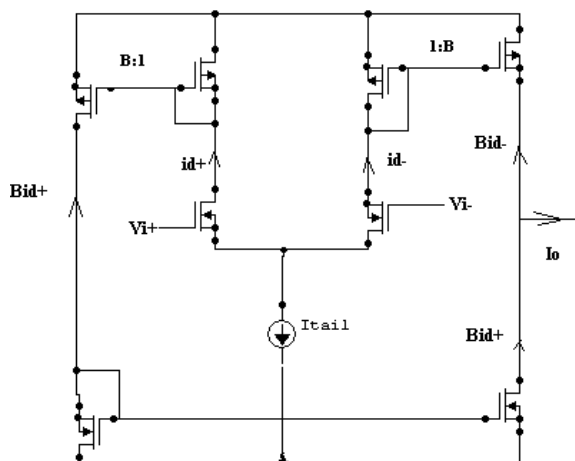


Figure 8.1 (b) Differential-input single-output balanced OTA

### 5.3 Differential input/output (fully differential) OTA

This is the third type of operational transconductance amplifier based on its input/output configuration. It has differential input and differential output, hence the name is given differential input differential output OTA. The symbol and its equivalent circuit is shown in fig 9.

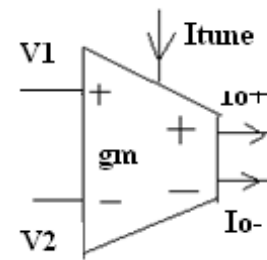


Figure 9: Differential input differential output OTA

For differential input differential output OTA, output current is given by,

$$I_0 = I_{0+} - I_{0-} = g_m(v_{i+} - v_{i-}) \quad (5.3)$$

The CMOS OTAs in Fig. 9.1 illustrate two OTA implementations for the differential input/output OTA type.

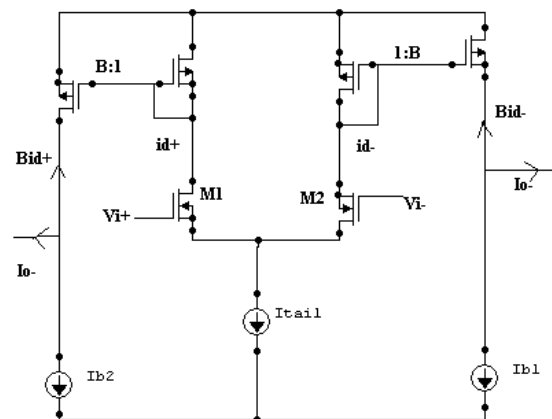


Figure 9.1 (a) Differential input/output CMOS OTA

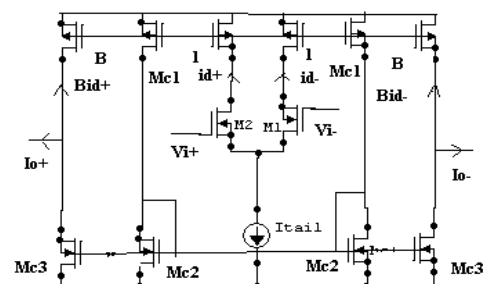


Figure 9.1 (b) Differential-input/output CMOS OTA

## 6. Conclusion

In this paper basic concept of Operational transconductance Amplifier is described. Different topology of OTA is also described along with its advantage and disadvantage. Comparison of this topology is also described. At last the different types of OTA are presented.

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