Design and Analysis of High Gain CMOS Telescopic OTA in 180nm Technology

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ABSTRACT
The Operational Trans-conductance Amplifier (OTA) is the block with the highest power consumption in analog integrated circuits and many applications. Low power consumption is becoming more important in miniature device, so it is challenging to design a low power OTA. At a large supply voltages, there is a trade-off between speed, gain and power for an OTA design since these parameters are contradicting each other. The telescopic trans-conductance amplifier consume less power compared with the other Trans-conductance amplifiers, so it is widely used in low power consumption and it also has the high speed characteristic. In This Paper Telescopic OTA is designed for 180nm BSIM4 Technology using LT–Spice Orcad simulator, This designed Telescopic OTA achieved gain 136db, Phase Margin 81 degree, UGBW 80MHz which are the basic performance parameter of an OTA.

Keywords: OTA, Telescopic OTA, Gain, Phase Margin, UGB, CMRR

1. INTRODUCTION
The OTA is a basic building block usually used in designing many analog circuits such as data converters and Gm-C filters. Performance of Gm-C filters is related and used on to the OTA’s performance. The OTA is a Transconductance device where the input voltage controls the output current; it means that OTA is a voltage controlled current source device whereas the op-amp is voltage controlled voltage source electronic device. An OTA is basically an op-amp without output buffer, so it can only drive loads.

An operational trans-conductance 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 Trans-conductance “$g_m$” of the amplifier.

$$I_o = g_m V$$

(1)

Where $g_m$= Transconductance of OTA
$V_{in}$= Differential input voltage

Figure 1 shows how to represent OTA symbolically.

![OTA symbol](image)

Figure 1: OTA symbol [4]

The trans-conductance $g_m$ of the OTA can be obtained by varying the value of the external controlling current $I_c$.

$$g_m = KV_c$$

(2)

Where $K$= suitable constant of proportionality

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

$$I_o = KV_{in}I_c$$

(3)

Equation (3) depicts that output current is proportional to the product of $V_{in}$ and $I_c$. In general OTA consists of a differential transistor pair with a current mirror circuit acting as a load. As OTA operates on the principal of processing current rather than voltage, it is an inherently robust device. As $g_m$ can be controlled by changing the control $I_c$, the OTAs are suitable for electronically programmable function.

2. Different Configuration of OTA
There are different configurations of OTA topologies.
1. Single–Stage OTA
2. Two Stage OTA
3. Telescopic Cascode OTA
4. Regulated Cascode OTA (Gain boosting)
5. Folded Cascode OTA

2.1 Comparison of Different types of OTA

Table 1 Comparison between various parameters

<table>
<thead>
<tr>
<th>Topology</th>
<th>Gain</th>
<th>Power Consumption</th>
<th>Speed</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Stage</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Two Stage</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Telescopic OTA</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Folded Cascode</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Gain-Boosted</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>

3. CIRCUIT IMPLEMENTATION

3.1 Design of Telescopic OTA

A telescopic OTA as shown in Fig.7, typically has a higher frequency capability and consumes less power than other topologies. Its high-frequency response stems from the fact that its second pole corresponding to the source nodes of the n-channel cascode devices is determined by the trans-conductance of n-channel devices as opposed to p-channel devices, as in the case of a folded cascode. Also, the parasitic capacitance at this node arises from only two transistors instead of three, as in the latter. The single stage architecture naturally suggests low power consumption. The disadvantage of a telescopic op-amp is severely limited output swing. It is smaller than that of the folded cascode because the tail transistor directly cuts into the output swing from both sides of the output.

3.2 Design Steps of Telescopic OTA

According to the design steps we get the values of NMOS and PMOS

**STEP I**
In 1st step we have to find W/L of two NMOS transistors, $M_9$ and $M_{10}$
\[ I_d = \mu_n C_{ox} / 2 \ (W/L) \ [V_{gs} - V_{th}]^2 \]
\[ 24 \times 10^{-6} = 0.045 \times 0.0045 \ (W/L) \ [1.0-0.7]^2 \]
\[ (W/L) \ _7 = 2.7 \]
\[ (W/L) \ _8 = (W/L) \ _10 = 2.7 \]

**STEP II**

As per the 2nd step we have to find the W/L ratio of NMOS transistors M7 and M8

\[ I_d = \mu \ C_{ox} / 2 \ (W/L) \ [V_{gs} - V_{th}]^2 \]
\[ 15.7 \times 10^{-6} = 2.025 \times 10^{-6} \ (W/L) \ [0.56 - 0.42]^2 \]
\[ (W/L) \ _7 = 3.9 \]
\[ (W/L) \ _8 = 3.9 \]

**For transistor M_7 and M_8**

\[ I_d = \mu \ C_{ox} / 2 \ (W/L) \ [V_{gs} - V_{th}]^2 \]
\[ 15.7 \times 10^{-6} = 2.025 \times 10^{-6} / 2 \ (W/L) \ [0.56-0.42]^2 \]
\[ (W/L) \ _7 = 7.9 \]
\[ (W/L) \ _8 = 7.9 \]

**STEP III**

After finding all NMOS transistors, we found The W/L ratio of M_1, M_2, M_3 and M_4. Which all are PMOS type

\[ I_d = \mu \ C_{ox} / 2 \ (W/L) \ [V_{gs} - V_{th}]^2 \]
\[ 15.7 \times 10^{-6} = 0.0011 \times 0.0045 / 2 \ (W/L) \ [-0.42 + 0.56]^2 \]
\[ (W/L) \ _1 = (W/L) \ _2 = (W/L) \ _3 = (W/L) \ _4 = 32.3 \]

The respective aspect ratio values of all MOSFETs are shown in Table 1.

<table>
<thead>
<tr>
<th>MOS</th>
<th>Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>M9,M10</td>
<td>2.7</td>
</tr>
<tr>
<td>M7,M8</td>
<td>3.9</td>
</tr>
<tr>
<td>M5,M6</td>
<td>7.9</td>
</tr>
<tr>
<td>M1,M2,M3,M4</td>
<td>32.36</td>
</tr>
</tbody>
</table>

### 4. SIMULATION RESULT

The CMOS Telescopic Operational Trans-conductance amplifier is simulated on LT-Spice software for a 180nm Technology for obtaining different parameter such as UGB (unity gain bandwidth), Gain, Phase margin, etc. These parameters shown below.

**Simulated results waveforms**

**4.1 Gain & Unit Gain Bandwidth**

The gain obtained for this telescopic operational Trans-conductance Amplifier is about 136dB. The unity Gain bandwidth is 80 MHz. As per good UGB this system is quite accurate.

![Figure 3: Gain of Telescopic OTA](image)

**4.2 Phase Margin**

The Phase Margin of OTA is 81 degree. Any of OTA requires the PM of minimum 60 degree to make system stable. Less than 40 degree it causes problems by ringing effects at output.
4.3 CMRR
Common mode Rejection Ratio (CMRR) is defined as the ratio of differential gain to common mode gain. CMRR of this OTA is 176 dB.

Table 3 Summarized result of Telescopic OTA

<table>
<thead>
<tr>
<th>Specification</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>180nm</td>
</tr>
<tr>
<td>UGB</td>
<td>80MHz</td>
</tr>
<tr>
<td>Supply Voltage(+VDD,VSS)</td>
<td>1.8V</td>
</tr>
<tr>
<td>Gain</td>
<td>136dB</td>
</tr>
<tr>
<td>CMRR</td>
<td>176dB</td>
</tr>
<tr>
<td>Phase Margin</td>
<td>81dB</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS
In this paper, the basic concept of different OTA is described along with its advantage and dis-advantage. The telescopic OTA is designed for a 180nm technology with the help of LT-Spice Orcad simulator. The unity gain bandwidth achieved for the design is 80MHz, the gain is 136dB and Phase margin is of 81dB. Also the CMRR is of 176dB.

6. FUTURE SCOPE
There is scope to improve gain further for enhanced output. For this purpose telescopic topology can be used as gain boosting technique. Also there is improvement require in post layout work.

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