Complementary Metal Oxide Semiconductor (CMOS) Current Mirror and Types of Current Mirror and Its Application

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Abstract— Although large electronic systems can be constructed almost entirely with digital techniques, many systems still have analog components and current mirror is the core structure for almost all analog and mixed mode circuits. It determines the performance of analog structures, which largely depends on their characteristics. In this paper represents a current mirror and types of current mirror and application over CMOS logic.

Keywords: CMOS Current Mirror, Minimum output voltage, MOSFET, Output impedance

I. INTRODUCTION

A two terminal circuit whose output current is independent of the output terminal voltage and depends only on the input current is called current mirror. Generally, it is used to generate a replica of given reference current. If necessary, it can also amplify or attenuate the reference current. A current mirror can be thought as a current controlled current source. Ideally, the output impedance of a current source/sink should be infinite and capable of generating or drawing a constant current over a wide range of voltages. However, finite value of output resistance and a limited output voltage required to keep device in saturation will ultimately limit the performance of the current mirror. Current mirror is used for biasing, loading, current amplification etc. Current mirrors are employed in many applications such as operational amplifiers, analog to digital and digital to analog converters.

Fig. 1 shows the symbols of current mirror circuits in which arrow is used to designate the direction of the current flow on the input side. The ratio 1: K represents the current gain of the mirror circuit. [4]

Fig. 1: current mirror symbols (a) nmos (b) pmos

Current mirrors mimic the performance of an ideal current source. Therefore their designs must fulfill the following requirements. [3]
- Input impedance should be zero
- Output impedance should be infinite
- Output current should be constant over wide swing of voltage
- Accurate copy of input current.

The paper is organized as follows: Various current mirror topologies are described in section, Application of current mirror and conclusion.

II. TOPOLOGIES OF CURRENT MIRROR

A. Basic Current Mirror

Fig. 2 shows the basic current mirror. A current flows through M1 corresponding to VGS1. Since VGS1 = VGS2, ideally the same current, or a multiple of the current in M1, flows through M2. If the MOSFETs are of the same size, the same drain current flows in each MOSFET, provided M2 stays in the saturation region [1]. The current through M1 can be given by,

\[ I_{D1} = \frac{1}{2} (V_{GS1} - V_{T1})^2 \]

The output current, assuming M2 in saturation is given by

\[ I_{D2} = \frac{1}{2} (V_{GS2} - V_{T2})^2 \]

Fig. 2: Basic current mirror

Since VGS1=VGS2, the ratio of the drain currents is the desired output current can be obtained by adjusting W/L ratios of two devices. [1]

Here it is required that M2 remains in saturation. Therefore the minimum output voltage across the current mirror is given by \( V_{out} = V_{DS(SAT)} = V_{GS1} - V_{THN} \). The output resistance of current mirror is equal to output resistance of M2.

\[ \frac{I_{D1}}{I_{D2}} = \frac{1}{2} \left( \frac{W}{L1} \right)^2 \]

The desired output current can be obtained by adjusting W/L ratios of two devices. [1]

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\[ R_{o} = \frac{1}{I_{D1}} \]

B. Cascode Current Mirror

Double cascode configuration is used to increase the output resistance of a current source or sink. Fig. 3 shows schematic diagram for this configuration. If we define \( \Delta V \) as excess gate-source voltage, the gate voltage of M4 is \( 2(\Delta V + V_{THN}) \) and source voltage is \( \Delta V + V_{THN} \). The minimum voltage across the current sink is limited by the requirement that M4 remains in the saturation region. \( V_{DS4} \geq V_{GS4} - V_{THN} \) or \( V_{DS4} \geq 2(\Delta V + V_{THN}) [1] \). This minimum voltage across the cascode current mirror is significantly larger than the minimum voltage across the basic current mirror.
Fig. 3: Cascode current mirror

Fig. 4 shows the small signal model for double cascode current mirror. The output resistance of the double cascode current source is given by
\[ R_0 = r_{o4} + R_{o4} \approx g_{m4} r_0^2 \]

Fig. 4: small signal model of cascode current mirror

C. Wilson current mirror

Two widely used current mirrors with feedback are Wilson current mirror and Regulated cascode current mirror. Both will give stable output current for wide voltage swings and enhanced output impedance.

Fig. 5: Wilson current mirror

Wilson current mirror is consisting of four transistor M1 to M4, where M1 is separated biased with \(V_{bias}\). \(V_{bias}\) is fixed voltage so whenever \(V_{bias}\) is fixed \(I_{D1}\) is also constant and that current is going through M2 also. We will see the operation latter first we will see the important point of wison current mirror.

“Wilson current mirror having negative feedback because of negative feedback drain current is stabilize.”

Fig. 6: small signal model of Wilson current mirror

If \(r_0\) is neglected at that time \(R_{out}\) is equal to \(g_{m2} r_0^2 / 2\)

D. Regulated Cascode Current Mirror

This configuration uses negative feedback concept to stabilizes the output current \(I_o\). This configuration is shown in fig. 7.

Fig. 7: Regulated cascode current mirror

MOSFETs M2 and M3 provides negative feedback while, M1 and M4 form current mirror.[1] Here, the voltages \(V_{Bias1}\) and \(V_{Bias2}\) are applied in such a way that only constant current can pass through M1 and M3 respectively. If output current increases due to some reason, voltage at node-A rises since only constant current can pass through M3. So it increases current through M2, but because of \(V_{Bias1}\), current cannot increase for M1. This results in decrease in voltage at node-B. Thus, excess current from M4 is absorbed by M2 and it balances the output current \(I_o\).

Fig. 8: Small signal model of regulated cascode current mirror

The minimum output voltage for regulated cascade is given by \(V_{DS3(sat)}\). The small-signal model is shown in fig. 7. The output impedance can be given by,
\[ R_0 = \frac{g_{m4} g_{m2} r_0 \| r_{o2}}{r_{o4}} \approx g_{m2} r_0^2 / 2 \]

Where \(g_m\) is trans-conductance for particular MOSFET and \(r_o\) is output impedance.

III. APPLICATION OF CURRENT MIRROR

- Used as biasing element.
- Current mirror are used as active load for amplifier stages.
- In analog to digital converters.
Current mirror are more economical then passive resister in term of die area required to provide bias

Table: 1 different type of current mirror

<table>
<thead>
<tr>
<th>Type</th>
<th>Current gain</th>
<th>R_{out}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>(\frac{1 + V_{ds2}}{1 + V_{ds1}})</td>
<td>(r_{ds})</td>
</tr>
<tr>
<td>Wilson</td>
<td>(\frac{1 + V_{ds2}}{1 + V_{ds1}})</td>
<td>(G_m r_{ds})</td>
</tr>
<tr>
<td>Improved Wilson</td>
<td>1</td>
<td>(G_m r_{ds})</td>
</tr>
<tr>
<td>Cascode</td>
<td>1</td>
<td>(G_m r_{ds})</td>
</tr>
<tr>
<td>Triple cascode</td>
<td>1</td>
<td>(G_m r_{ds})</td>
</tr>
<tr>
<td>Regulated cascode</td>
<td>(\frac{1 + V_{ds2}}{1 + V_{ds1}})</td>
<td>(G_m^2 r_{ds})</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

Main intention of this paper is to present the simple idea of designing a new CMOS Voltage Divider based Current Mirror, than its comparison with the Basic and types of Current Mirrors. This new Mirror is well suited for low current biasing applications. Like the Wilson and regulated current Mirror Circuits, this new Current Mirror can be used as a Low Current Biasing circuit. Also, when compared with Basic Current Mirror, improved one impedance of Basic Current Mirror.

REFERENCES