A High Accurate and High Output Impedance Current Mirror

KUO-HSING CHENG, CHI-CHE CHEN and PO-YU LI
Department of Electrical Engineering
Tamkang University
Taiwan, R.O.C.

Abstract: Current mirror is one of the most important building blocks of analog integrated circuits. For high performance analog circuit applications, accuracy and output impedance are the most important parameters to determine the performance of the current mirror. A new current mirror based upon regulated-gate cascode (RGC) circuit is proposed to provide very high accuracy and high output impedance. A novel feedback gain stage is used to increase the output impedance and the current matching accuracy significantly. The proposed circuit also has output swing similar as traditional two-stage cascode current mirror.

Key-words: Regular-Gate Cascode (RGC), Improved Active-Feedback Cascode Current Mirror (IAFCCM), current-mode, accuracy, current mirror.

1 Introduction
Because the current-mode approach has better performance, it is gaining interest to use to analog circuit design [1]. In lots of analog circuit design, the current mirror is widely used in the biasing or the loading elements. Thus the current mirror is one of the most important building blocks of analog integrated circuits.

Both the accuracy and the output impedance determined the performance of a current mirror and both must be sufficiently high. Much works focus on these two features. The cascode current mirror and the regular-gate cascode (RGC) current mirror [2] were used to increase output impedance. Improved active-feedback cascode current mirror (IAFCCM) [3] was proposed to improve the accuracy. And the three-stage feedback current mirror [4] was proposed to improve both the accuracy and the output impedance. They still have some problems of output voltage swing, accuracy or output impedance.

In the paper, a new high accurate current mirror is proposed. It based upon the RGC circuit to improve the output impedance and also to improve the current accuracy of the current mirror. A novel feedback gain stage is used to increase the output impedance and matching accuracy significantly. Moreover, the proposed new current mirror also has output swing similar as the traditional two-stage cascode current mirror and without the stability problem. Therefore, the performance of the proposed current mirror is better than that of the RGC and IAFCCM.

2 Analysis of previous circuits and the proposed circuit
2.1 Previous current mirror circuits

The accuracy and output impedance of a classical cascode current mirror are much higher than that of a simple current mirror. But it is possible to gain in higher accuracy and output impedance by using novel circuit schemes.

The IAFCCM and the three-stage feedback current mirror are shown in Fig.1 and Fig.2, respectively. They are both proposed to increase the output impedance and the accuracy. In the high precision applications, the cascode current mirror and the IAFCCM may not suitable because the output impedance of them is not high enough. The output node voltage can influence the output current in the cascode current mirror and the IAFCCM.

Although, the three-stage feedback current
mirror improves lots of the output impedance and accuracy, it has the problems of the stability and power dissipation. Because of the three-gain stage feedback circuit, it needs compensation to make the whole circuit stable. The additional compensation capacitor increases the circuit area. Moreover, it also needs an additional biasing circuit and increases the cost of power dissipation.

2.2 The proposed current mirror

As shown in Fig.3, an appropriate solution is proposed. It improved the output impedance without any additional compensation and biasing circuit. So it reduces the circuit area and saves the power. Furthermore, it also improves the matching accuracy.

The MOS transistors MN1 – MN4 are used as a two-stage cascode current mirror. The biasing MOS transistors MN5, MN6, and MP1 – MP4 are used to improve the matching accuracy of the cascode current mirror. The novel cascode negative feedback gain stage, which is formed by the MOS transistors MN7 and MN8, increases the output impedance of the cascode current mirror.

![Fig.3 The proposed new current mirror](image)

Figure 4 shows the feedback circuit of the proposed current mirror. The output impedance of the node Vo can be estimated by following equations,

\[
V_i = i_{out} \frac{1}{g_d} \tag{1}
\]

\[
i_{out} = g_m v_{gs} + g_d v_{ds} \tag{2}
\]

the Eq.(2) can be rewritten as,

\[
i_{out} = g_m \left[ \frac{g_m}{g_d} \frac{1}{g_d} \left( v_i + g_d \left( v_o - v_i \right) \right) \right] \tag{3}
\]

\[
R_{out} = \frac{g_m g_m g_m}{g_d g_d g_d} \frac{1}{g_d} \tag{4}
\]

Figure 4 shows the feedback circuit of the proposed current mirror. The output impedance of the node Vo can be estimated by following equations,

\[
V_i = i_{out} \frac{1}{g_d} \tag{1}
\]

\[
i_{out} = g_m v_{gs} + g_d v_{ds} \tag{2}
\]

the Eq.(2) can be rewritten as,

\[
i_{out} = g_m \left[ \frac{g_m}{g_d} \frac{1}{g_d} \left( v_i + g_d \left( v_o - v_i \right) \right) \right] \tag{3}
\]

\[
R_{out} = \frac{g_m g_m g_m}{g_d g_d g_d} \frac{1}{g_d} \tag{4}
\]

where \( g_m \) and \( g_d \) represent the transconductance and the channel conductance of the MOS MNi, respectively.

![Fig.4 The feedback circuit](image)

3 Simulation Result

The HSPICE simulation results are based upon 0.35um 1P4M CMOS process with 3.3V supply voltage. Figure 5 shows the I-V curve simulation results of the proposed new current mirror and the three-stage feedback current mirror. The middle line is the I-V plot of the input reference current, \( I_{in} \). The top line is the I-V plot of the three-stage feedback
current mirror, and it shows that the output impedance is higher than the proposed circuit. As mentioned earlier, it needs compensation to make it stable, which does not require in the proposed circuit. The lowest line is the I-V plot of the proposed circuit. Although the output impedance is a little lower than that of the three-stage feedback current mirror, it is high enough for lots of high precision applications.

In Fig.5, it also shows the comparison result of the accuracy. The current matching accuracy of the proposed current mirror is better than that of the three-stage feedback current mirror.

![Fig.5 The I-V curve of the simulation result](image)

**Table 1 Performance comparison**

<table>
<thead>
<tr>
<th>Issues</th>
<th>IAFCCM</th>
<th>Three-stage feedback current mirror</th>
<th>Proposed current mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirroring error at I_{in}=5uA</td>
<td>0.036%</td>
<td>0.0162%</td>
<td>0.00002%</td>
</tr>
<tr>
<td>Mirroring error at I_{in}=10uA</td>
<td>0.03%</td>
<td>0.0121%</td>
<td>0.00002%</td>
</tr>
<tr>
<td>Mirroring error at I_{in}=50uA</td>
<td>0.024%</td>
<td>0.0043%</td>
<td>0.00008%</td>
</tr>
<tr>
<td>Mirroring error at I_{in}=100uA</td>
<td>0.019%</td>
<td>0.0008%</td>
<td>0.00027%</td>
</tr>
<tr>
<td>Mirroring error at I_{in}=150uA</td>
<td>0.017%</td>
<td>0.0021%</td>
<td>0.0025%</td>
</tr>
</tbody>
</table>

Table 1 compares the performance of IAFCCM, the three-stage feedback current mirror, and the proposed current mirror under various input currents. The input reference current changes from 5uA to 150uA. The proposed current mirror has highest accuracy when the input reference current is lower than 150uA. Due to the cascode structure of the proposed current mirror, some MOS transistors will leave saturation region when the input reference current is over 150uA. Therefore the matching accuracy would worse than the three-stage feedback current mirror. From Table 1, it also can be found that the output impedance of the proposed current mirror is between that of IAFCCM and the three-stage feedback current mirror.

Figure 6 is the step response of the proposed current mirror. The step curve is the input reference current which changes from 50uA to 100uA. The other curve is the output current response. From fig.6, it can be found that the proposed current mirror is stable when the input current changes.

![Fig.6 Step response of the proposed circuit](image)

### 4 Conclusion

An appropriate current mirror circuit is proposed which has higher accuracy and lower output impedance compared with the three-stage feedback current mirror. The main advantage between the proposed circuit and the three-stage feedback current mirror is that the proposed circuit is stable without any compensation. Therefore, the proposed structure is a much suitable current mirror for use in high linearity, high output impedance current output stages.

**Reference:**


