Transconductance improvement technique for bulk-driven OTA in nanometre CMOS process

Xiao Zhao, Huajun Fang, Tong Ling and Jun Xu

A transconductance improvement technique for a bulk-driven operational transconductance amplifier (OTA) working in the weak inversion region is presented. Using the quasi-floating gate method, the proposed technique achieves larger transconductance improvement than conventional approaches with the CMOS technologies scaling. Moreover, its enhanced performance is at no expense of the power budget. Simulated on UMC 180 nm technology, the results demonstrate that the proposed bulk-driven OTA achieves more than two times gain-bandwidth improvement than that of the traditional counterpart with the same power.

Introduction: With the CMOS technology scaling, ultra-low-voltage and ultra-low-power analogue circuits are in increasing demand for portable electronic equipment [1]. The operational transconductance amplifier (OTA) is the mostly used and has the largest power consumption. For low-voltage and low-power applications, the bulk-driven OTA working in the weak inversion region is a good choice [2]. Nevertheless, the reduction in the $g_{m1}/g_{m0}$ ratio with the CMOS technologies scaling is the main obstacle, which leads to gain-bandwidth (GBW) degradation. In recent years, some techniques have been used to improve the effective transconductance of the bulk-driven OTA [3–6]. Especially in [3], the positive-feedback source degeneration technique is adopted in bulk-driven input differential pairs to improve the transconductance of the OTA. Moreover, with the $g_{m1}/g_{m0}$ ratio decreasing, the effective transconductance of the OTA instead increases. The energy efficiency $g_{m1}/I$ is improved with the CMOS technology scaling, and thus this technique is suitable for the nanometre CMOS process.

In this Letter, a more effective transconductance improvement technique for the bulk-driven OTA is presented. The proposed technique, utilising the quasi-floating gate method [7], not only obtains a larger transconductance enhancement factor with technology scaling than that in [3], but also does not consume additional power.

Proposed transconductance improvement technique: The bulk-driven OTA with a positive-feedback source degeneration differential pair (PBD) is shown in Fig. 1. Transistors $M_1$ and $M_2$ are configured as positive-feedback source degeneration, which enhance the transconductance of input pairs $M_3$ and $M_4$. Thus, the effective transconductance ($G_m$) of the OTA can be expressed as

$$G_m \simeq \left( 1 + \frac{1}{\eta} \right) g_{m13} \tag{1}$$

where $\eta$ is the ratio of $g_{m1}/g_{m0}$ and $g_{m13}$ is the bulk transconductance of transistor $M_3$. Note that when compared with the traditional bulk-driven OTA, the $G_m$ of the PBD is improved by a factor of $1 + 2/\eta$, and also it greatly increases with decreasing $\eta$ owing to the CMOS technology scaling.

A bulk-driven OTA with the proposed quasi-floating differential input pair (QFBD) is shown in Fig. 2. The enhanced input stage consists of four matched transistors: $M_5$, $M_6$, $M_7$, and $M_8$ with equal size ratio. Transistors $M_5$ and $M_6$ are also configured as positive-feedback source degeneration, while transistors $M_7$ and $M_8$ are configured as quasi-floating gate transistors. Their gate is connected to the bulk through capacitors $C_5$ and $C_6$ and to ground through a large-valued resistor $R_{hg}$. The transistors $M_5$ and $M_6$ form a highpass filter. The cutoff frequency is around $1/(2\pi R_{hg} C_1)$. By using the reverse bias diode-connected PMOS transistors $M_5$ and $M_6$, $R_{hg}$, and $C_5$, $C_6$ form a highpass filter. The cutoff frequency is about $1/(2\pi R_{hg} C_1)$, and the amplitude of the bulk input signal transferred to the gate is $k = C_1/(C_1 + C_5)$, where $C_5$ is the capacitance at the gate node. Owing to the large-value resistance used, the cutoff frequency can be lower than 1 Hz. Also, in practice, $C_5$ can be neglected in comparison with $C_1$, thus $k$ is approximately equal to 1. From the small-signal analysis of Fig. 2, the $G_m$ of the proposed QFBD OTA results in the following expression:

$$G_m = \left( 1 + \frac{1}{\eta} + \frac{k}{\eta} \right) g_{m13} \simeq \left( 1 + \frac{1}{\eta} \right)^2 g_{m13} \tag{2}$$

Note that the $G_m$ of the proposed QFBD OTA is improved by a factor of $(1 + 1/\eta)^2$, which is proportional to the square of $1/\eta$, whereas that of the PBD OTA has a linear relationship with $1/\eta$. Therefore, with the decreasing of $\eta$, the $G_m$ of the QFBD OTA is enhanced greater than that of the PBD counterpart, leading to higher energy efficiency. At the same time, the improved performance does not increase additional power dissipation or the supply voltage requirements.

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The relationship between the $G_m$ enhancement factor against $\eta$ of the two OTAs is shown in Fig. 3. Note that the increasing trend of the proposed QFBD OTA is much faster than that of the PBD as $\eta$ decreases. It indicates that the proposed technique effectively enhances $G_m$ for the bulk-driven transistor in weak inversion as the CMOS technology scaling. The proposed QFBD OTA obtains a better energy efficiency $G_m/I$, and is thus suitable for low-voltage and low-power applications.

Simulation results: The two OTAs shown in Figs. 1 and 2 with simulated on UMC 180 nm process. The supply voltage is 0.5 V, and the threshold voltages of NMOS and PMOS are 0.4 and 0.47 V, respectively. The AC response of the two OTAs is shown in Fig. 4, and the load capacitance $C_L$ is 15 pF. Note that the GBW of the proposed QFBD OTA is 10.37 kHz, which is improved by 120% over that of the PBD OTA with the same power. Fig. 5 shows the small-signal transient response of the two OTAs. A square wave of 50 mV is generated by a function generator at 2.5 kHz. Note that the settling time of the proposed QFBD OTA has a significant boost due to the enhancement of the GBW. The simulation results of key parameters of the two OTAs are listed in Table 1.

Conclusion: Using the quasi-floating gate method, a more effective transconductance improvement technique for the bulk-driven OTA working in the weak inversion region is presented in this Letter. The proposed technique achieves larger transconductance improvement performance with the technologies scaling. Simulated on UMC 180 nm technology, the proposed OTA obtains more than two times GBW than that of the conventional counterpart with the same power.

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References

Fig. 4 AC response of PBD and QFBD OTAs

Fig. 5 Transient response of PBD and QFBD OTAs

Table 1: Performance summary of two OTAs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PBD</th>
<th>QFBD</th>
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<tr>
<td>Voltage supply (V)</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>$C_L$ (pF)</td>
<td>15</td>
<td>15</td>
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<tr>
<td>GBW (kHz)</td>
<td>4.35</td>
<td>10.37</td>
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<td>Open-loop gain (dB)</td>
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<td>68.7</td>
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<td>Power of OTAs (nW)</td>
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<tr>
<td>Phase margin (°)</td>
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<tr>
<td>1% Settling time (μs)</td>
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<td>69</td>
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<tr>
<td>FoM (V−1)</td>
<td>163</td>
<td>389</td>
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