Frequency Compensation of Two Stage Op-Amp using Triode Mode Compensation Stage

Yogesh Yadav
Electronics and Instrumentation Engineering Department
Galgotias College of engineering and technology, Greater noida, INDIA

Vijaya Bhadouria
Electronics and Communication Engineering Department
Motilal Nehru National Institute of Technology, Allahabad, INDIA

Abstract
A frequency compensation technique for the improvement of unity gain bandwidth (UGB) and power supply rejection ratio (PSRR) of two stage operational amplifiers is presented in this paper. Performance of proposed op-amp is compared with classical miller compensated op-amp and op-amp proposed by G. Blakiewicz [13]. The technique exploits the triode mode operation of a MOSFET in the compensation stage which leads to the improvement in the UGB and Power Supply Rejection Ratio (PSRR). Small signal analysis for these parameters is carried out and theoretical improvements are verified through simulations in cadence VIRTUOSO environment using UMC 0.18 μm CMOS process technology.

Keywords
Miller compensation, triode mode MOSFET, unity gain bandwidth, Power supply rejection ratio, phase margin, Op-amp.

1. INTRODUCTION
Most integrated circuit realizations nowadays include both digital and analog functions, on the same chip. Most often, the analog blocks on the chip sense and get affected by the spikes on the ground and supply lines generated by the digital blocks. Coupling effects tend to deteriorate the dynamic range of high performance analog functions, so these effects need to be controlled and minimized [1]. The most important specification with this respect is the PSRR. The operational amplifiers (op-amps) are considered as important building blocks in mixed signal systems. The popular two stage operational amplifier shows a poor PSRR to supply voltage. At higher frequencies, the output drive transistor becomes ‘diode connected’ [2], with its drain ac shorted to its gate by the compensating capacitor which couples the supply signal to the output. It is seen mostly that the PSRR is degraded at higher frequencies due to the compensation circuitry [3-5]. A cascade technique was developed to overcome this drawback [6], [7] and was successful too but at the cost of reduction in common mode input range. Various techniques have been reported earlier from a voltage current buffer scheme to multipath compensation schemes [2], [8-12] which emphasize on a single effective low frequency dominant pole which provides a proper phase margin at the cost of ~3 dB bandwidth of open loop gain. In this paper the compensation technique reported in [13] is modified using a triode mode operating MOSFET in the compensation circuitry and a resistor in series with the compensation capacitor. The resulting topology offers higher UGB, PSRR and a suitable phase margin.

2. PROPOSED TECHNIQUE
The proposed technique takes an idea from [13] with a modification in the region of operation of the MOSFETs. The MOSFET of the compensation stage is operated in the triode region and a resistance is added in series with the compensation capacitor. The resulting circuit diagram, its small signal models for GB and PSRR are shown in Figure 1 (a), (b) and (c) respectively.

![Figure 1](image-url)
\[ R_1 = \frac{1}{R_c C_c (R_c / R_1)} , \]
\[ P_2 = \frac{1}{R_c C_c}, \quad P_3 = \frac{1}{R_c C_c}, \]
\[ \text{PSSR}_{\text{dominant}} = \frac{1}{R_c (C_c + C_1 + C_t)} + R_c C_c \]

(2)

The UGB comes out to be

\[ \text{UGB} = \sqrt{\frac{g_m g_m}{R_c (R_c / R_1) C_c C_1}} \]

(3)

Comparing the dominant pole \( P \) and UGB frequency to those derived in [13] we see that the DC voltage gain of the compensation stage \( (A_c) \) is replaced by \( (R_c / R_1) \), the latter being less than 1. \( (A_c \) was set around 10) which in turn increases the dominant pole frequency and the GB. \( R_c \) here is the triode resistance of the MOSFET \( M_8 \) and \( R_1 \) is the output resistance of the first stage. The ratio \( (R_c / R_1) \) being less than one and in the denominator increases the magnitude of the whole fraction. The above PSRR dominant pole position when compared to the equation from [13] through simulations we find out that the modified circuit has a high dominant pole frequency which increases the bandwidth for high PSRR.

### 3. SIMULATION RESULTS

The circuits are simulated in cadence VIRTUSO environment using UMC 0.18 µm CMOS process with dual power supply of +/- 1.8 volts. Three operational amplifiers were designed: 1) classical miller compensated, 2) as given in [13] and 3) using proposed technique. Simulations for UGB and PSRR are carried out for a range of capacitive loads from 1 pf to 30 pf which gives the \( C_c \) as 24 pf to 6.6 pf.

Figure 2 (a) Gain and phase vs frequency for classical miller compensated op-amp

Figure 2 (b) PSRR+ vs frequency for classical miller compensated op-amp for different values of \( C_c \)

Figure 3 (a) Gain and phase vs frequency for op-amp reported in [13]

Figure 3 (b) PSRR+ vs frequency for op-amp reported in [13] for different values of \( C_c \)

Figure 4 (a) Gain and phase vs frequency for proposed op-amp
Plots for gain and phase vs frequency-applying load of 10 pf in 1) classical miller compensated, 2) as given in [13] and 3) using proposed technique are given in Figure 2 (a), Figure 3 (a) and Figure 4 (a) respectively. Similarly, plots for PSRR vs frequency for $C_c$ varying between 24 pf to 6.0 pf are obtained as given in Figure 2 (b) (classical miller compensated), Figure 3(b) (reported in [13]) and Figure 4(b) (proposed). Significant improvement in the unity gain frequency and the PSRR for wide bandwidth was noted for the proposed technique which varies as an inverse function to the $C_c$. The improvement is noted at the cost of degraded phase margin at higher capacitive loads which renders the system marginally stable for those loads. Result summary is presented in Table 1.

**Table 1. Results Summary**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>DC voltage gain in dB</td>
<td>60 dB</td>
<td>60 dB</td>
<td>60 dB</td>
</tr>
<tr>
<td>Power consum.</td>
<td>1240 $\mu$W</td>
<td>512 $\mu$W</td>
<td>512 $\mu$W</td>
</tr>
<tr>
<td>Area occupied</td>
<td>3700 $\mu$m$^2$</td>
<td>1875 $\mu$m$^2$</td>
<td>1915 $\mu$m$^2$</td>
</tr>
<tr>
<td>Comp. Cap</td>
<td>4 pf</td>
<td>0.25 pf</td>
<td>0.25 pf</td>
</tr>
<tr>
<td>$-3$ dB reduction in PSRR</td>
<td>7.594 $\mu$Hz</td>
<td>44.77 $\mu$Hz</td>
<td>124.2 $\mu$Hz</td>
</tr>
<tr>
<td>$C_c$ = 5 pf</td>
<td>GB 1.59 Mhz</td>
<td>24.2 Mhz</td>
<td>48.1 Mhz</td>
</tr>
<tr>
<td></td>
<td>Phase 86.0 deg</td>
<td>67.6 deg</td>
<td>47.6 deg</td>
</tr>
<tr>
<td>$C_c$ = 10 pf</td>
<td>GB 1.64 Mhz</td>
<td>14.0 Mhz</td>
<td>30.0 Mhz</td>
</tr>
<tr>
<td></td>
<td>Phase 83 deg</td>
<td>60.3 deg</td>
<td>49.2 deg</td>
</tr>
<tr>
<td>$C_c$ = 20 pf</td>
<td>GB 1.57 Mhz</td>
<td>8.28 Mhz</td>
<td>18.7 Mhz</td>
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<tr>
<td></td>
<td>Phase 77 deg</td>
<td>47.7 deg</td>
<td>44.7 deg</td>
</tr>
<tr>
<td>$C_c$ = 30 pf</td>
<td>GB 1.57 Mhz</td>
<td>6.53 Mhz</td>
<td>13.9 Mhz</td>
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<tr>
<td></td>
<td>Phase 70 deg</td>
<td>44 deg</td>
<td>40 deg</td>
</tr>
</tbody>
</table>

4. CONCLUSION

The technique described above is applicable to most of the op-amp configurations and its effectiveness with the classical circuit has been verified theoretically as well as experimentally. A significant improvement in bandwidth for high PSRR and UGB is found with an optimization in the chip area.

ACKNOWLEDGEMENT

This work has been performed using the resources of VLSI Laboratory developed under Special Manpower Development Programme for VLSI Design and related software (SMDP-II) project funded by Department of Information Technology, Ministry of Communication and Information Technology Government of India.

REFERENCES


