Design of a two stage amplifier using ACM model

ECEN 607(ESS)

Courtesy of
Judy Amanour-Boadu
Contents

• ACM model
• Amplifier specifications
• Extraction of parameters
• Design of amplifier
• Simulation results
Why ACM model?

- Powerful tool for the simulation of MOS transistors
- Simple, precise equations to extract physical parameters
- Parameters describe effects particular to newer small channel technologies
- Valid for the efficient design of analog circuits
- Better match between simulations and actual circuit performance
**Amplifier Specifications**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_v$ (DC gain)</td>
<td>&gt; 50 dB</td>
</tr>
<tr>
<td>GBW</td>
<td>&gt; 20 MHz</td>
</tr>
<tr>
<td>PM (Phase Margin)</td>
<td>&gt; 50°</td>
</tr>
<tr>
<td>SR (Slew Rate)</td>
<td>&gt; 1.7 V/us</td>
</tr>
<tr>
<td>$C_L$</td>
<td>50pF</td>
</tr>
<tr>
<td>$C_{in}$</td>
<td>&lt;0.8 pF</td>
</tr>
<tr>
<td>In band noise (DC-10MHz)</td>
<td>&lt;10μV</td>
</tr>
<tr>
<td>Supply</td>
<td>1V</td>
</tr>
</tbody>
</table>

![Amplifier Circuit Diagram]
Amplifier Specifications

- **Boundary conditions**

  - \[
    \frac{g_m_1}{C_0} = GBW > 20 \text{ MHz} \quad \text{........(1)}
    \]
  - \[
    \frac{I_{tail}}{CC} = Slew \text{ Rate} > \frac{1.7V}{\mu s} \quad \text{........(2)}
    \]
  - \[
    V_{eq_{in}} = \frac{16KT}{3g_{m_1}}\left[1 + \frac{g_{m_8}}{g_{m_1}}\right] \quad \text{........(3)}
    \]
  - \[
    PM = 180 - tan^{-1}\left[\frac{GBW}{w_{p1}}\right] - tan^{-1}\left[\frac{GBW}{w_{p2}}\right] - tan^{-1}\left[\frac{GBW}{w_{z\mp}}\right] \quad \text{....(4)}
    \]
  - Cancel zero by using \[
    R_z = \frac{1}{g_{m_8}}
    \]
  - Assume phase contribution of \(w_{p1}\) is about \(\frac{\pi}{2}\) and \(f_{p2} > 80 MHz\) (from (4) and amplifier specifications for phase margin > 60°)
  - \[
    \frac{g_{m_8}}{C_L} = f_{p2} \Rightarrow g_{m_8} > 1mS
    \]
  - From (1) \(g_{m_1} > 240\mu S\)
  - From (3), \(I_{tail} > 8.5\mu A\)
Parameter extraction for design (65nm)

- Using [1], the following parameters can be extracted

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NMOS (65nm)</th>
<th>PMOS (65nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is/nA</td>
<td>333.8</td>
<td>46.8</td>
</tr>
<tr>
<td>Vth0/V</td>
<td>0.4238</td>
<td>-0.349</td>
</tr>
<tr>
<td>Gamma/V^{1/2}</td>
<td>0.207</td>
<td>0.293</td>
</tr>
<tr>
<td>Sigma/m^2</td>
<td>21.12f</td>
<td>5.679p</td>
</tr>
<tr>
<td>PCLM</td>
<td>0.0409</td>
<td>0.159</td>
</tr>
<tr>
<td>μ_o /cm^2/Vs</td>
<td>267.3</td>
<td>70.4</td>
</tr>
<tr>
<td>θ/V^{-1}</td>
<td>0.32</td>
<td>0.1995</td>
</tr>
</tbody>
</table>

Amplifier dimensions calculations

- Choose $i_f = 0.5$, assume $g_{m1,8} = 1.5 mS$
- Check intrinsic cutoff frequency of transistor at $i_f = 0.5$
  
  $$f_T = \frac{\mu \phi_t}{2\pi L^2} \left(2\sqrt{1+i_f} - 1\right) = 51.5\text{GHz} \gg 20\text{MHz}$$ — *(5)*

- $I_d = g_m \times n \times \phi_t \frac{1+\sqrt{1+i_f}}{2} \approx 50 \mu A$ — *(6)*

- $\frac{W}{L} = \frac{g_m}{\mu C_{ox} \phi_t (-1+\sqrt{1+i_f})}$ — *(7)*

- $\frac{W}{L_N} (65nm) = 336 \frac{W}{L_P} (65nm) = 1276$

- $\frac{V_{DSAT}}{\phi_t} \approx (\sqrt{1+i_f} - 1) + 4 \Rightarrow V_{DSAT} \approx 0.1V$
Amplifier design (if = 8)

- Choose $i_f = 8$, choose $g_{m1,8} = 1.5 \text{mS}$
- Check intrinsic cutoff frequency of transistor at $i_f = 8$ using (5)

\[ f_T = 130 \text{GHz} \gg 20 \text{MHz} \]

- $I_d \approx 93 \mu A$

\[ \frac{W}{L} \mid_{N} (65 \text{nm}) = 4; \quad \frac{W}{L} \mid_{P} (65 \text{nm}) = 16 \]

- $V_{DSAT} \approx 0.208 \text{V}$
Amplifier design recap

- First extract transistor parameters using ACM model and test benches
- First check if selected inversion level is adequate for your design, this is done by calculating the $f_t$ of transistor, $f_t \gg 3 \times \text{GBW}$ (5)
- Use extracted parameters to calculate required transconductances, saturation voltage, dimensions based on specifications given as a first trial point
- Bias your circuit properly and perform your simulations
- Calculated values of M1, M2, M8 kept the same producing relative same gm at selected currents when ACM model is used (1)-(6).
- Reevaluate operational points to obtain required specifications
Example of results
## Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$I_t=0.5$</th>
<th>$I_t=8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain (dB)</td>
<td>65</td>
<td>61</td>
</tr>
<tr>
<td>Phase margin (deg)</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Power dissipation (μW)</td>
<td>409</td>
<td>558</td>
</tr>
<tr>
<td>Settling time (nsec)</td>
<td>180</td>
<td>130</td>
</tr>
<tr>
<td>PSRR (dB)</td>
<td>66.3</td>
<td>62.4</td>
</tr>
<tr>
<td>Slew rate (V/μsec)</td>
<td>8.4</td>
<td>17.3</td>
</tr>
<tr>
<td>Area estimation (μ²m²)</td>
<td>2400</td>
<td>100</td>
</tr>
</tbody>
</table>

- Smaller inversion level, larger area, slower response, lower power consumption
- Moderated inversion level, smaller area, larger power consumption, faster response
Conclusions

- ACM model effective in calculation of design parameters
- Very good first approximation
- Not region of operation specific