Basic Gain Stages

• Here, we review the three most commonly used configurations for a mosfet as an amplifier.
• Let us tabulate (and memorize) generalized equations for each so that we can solve future amplifiers "by inspection" rather than re-solving the ssm each time.
• We do this 1st at low frequencies, where the caps have negligible effect → then we consider simple approaches for adding in the caps.

Generalized configuration:

<table>
<thead>
<tr>
<th>Inputs</th>
<th>G</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vdd</td>
<td>Rd</td>
<td>C0-amp</td>
</tr>
<tr>
<td>equiv. drain load</td>
<td></td>
<td>source follower</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>non-inverting</td>
</tr>
<tr>
<td>equiv. source load</td>
<td></td>
<td>unity gain (near)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th>D</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-amp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>inverting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>high vlt. gain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG-amp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>non-inverting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;cascade&quot; stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unity current gain</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Common Source Amplifier: CS-amp

- used as inverting, high gain amp
- generally, high input + output impedance.

\[ \begin{align*}
\text{SSM:} \\
\text{gm} \cdot V_{gs} & = V_i + \frac{R_s}{R_o} \cdot V_o \\
\Rightarrow \quad u_o & = - \frac{R_s}{R_o} \cdot V_o - \left( \frac{V_o}{R_o} + \text{gm} \cdot V_i + \text{gm} \cdot \frac{R_s}{R_o} \cdot V_o + \text{gmb} \cdot \frac{R_s}{R_o} \cdot V_o \right) \cdot R_{ds} \\
\Rightarrow \quad \frac{V_o}{V_i} & = \frac{- \text{gm} \cdot R_{ds} \cdot R_o}{R_o + R_s + R_{ds} + \text{gm} \cdot R_{ds} \cdot R_s}, \quad \text{gm}' = \text{gm} + \text{gmb} \\
& \quad \text{gmb} = \pi \cdot \text{gm} \\
\approx & \quad - \text{gm} \left( R_{ds} || R_o \right); \text{otherwise, use full eqn.}
\end{align*} \]

Desire very large \( R_0 \gg R_{ds} \) + small \( R_s \ll R_{ds} \) for high gain.
Common Drain Amp: CD-Amp
- Used as a non-inverting, near unity gain buffer.
- Also called, "source-follower"
- Used for buffering: high input & low output imped.
- Also used as level shift (shifts DC voltage by \( V_{GS} \))

\[ V_{GS} = V_i - V_o \]

\[ V_o = \frac{-R_o}{R_s} V_o - \left( \frac{V_o}{R_s} - g_m V_i + g_m V_o + g_m b V_o \right) R_{DS} \]

\[ \frac{V_o}{V_i} = \frac{g_m R_{DS} R_s}{R_s + R_o + R_{DS} + g_m R_{DS} R_s} \]

* \( \approx \frac{g_m}{R_s} \), for: large \( R_s \) (order of \( R_{DS} \))
* \( \frac{g_m}{R_s} \), for: small \( R_o \ll R_{DS} \)

\( \)
Common-Gate Amp: CG-amp
- non-inverting voltage gain
- generally used as a near unity current gain amp \(\rightarrow\) cascade connection.
- Has low input impedance & high (cascade) output imped.
- we will look at generalized current gain:

\[ V_{gs} = V_{ds} = (i_{in} - i_o) R_s \]

\[ \Rightarrow i_o = \frac{(i_{in} - i_o) R_s + (g_m' R_s i_{in} - g_m' R_s i_o - i_o) R_{ds}}{R_0} \]

\[ \Rightarrow \]

\[ \frac{i_o}{i_{in}} = \frac{R_s + g_m' R_{ds} R_s}{R_0 + R_s + R_{ds} + g_m' R_{ds} R_s} \]
C6-amp:
\[ \frac{i_o}{i_{in}} = \frac{g_m' R_{ds} R_S}{R_o + g_m' R_{ds} R_S} \]  

Best to visualize as a current source with output impedance \( g_m' R_{ds} R_S \).

Model C6-amp as:

\[ \begin{align*}
&\text{same as } \frac{i_o}{i_{in}} \text{ equation, with} \\
&R_o \text{ and } g_m' R_{ds} R_S \text{ divider.}
\end{align*} \]

Examples:

- CS-C6: cascade:

\[ A_v = \frac{V_o}{V_{in}} = -g_m R_{out} \]

\[ R_{out} = g_{m2} R_{ds2} R_{ds1} || R_0 \]
CS-CD:

\[ V_o + V_i = \frac{V_x}{\frac{V_i}{m}} = \frac{V_o}{\frac{V_i}{m}} = \frac{V_x}{m} \]

\[ \Rightarrow \frac{V_o}{V_i} = -\frac{g_{m1} R_{ds1}}{g_{m2}} \approx -\frac{g_{m1} R_{ds1}}{g_{m2}} \]

if \( V_2 = 0 \) (ignore body effect)

or tie well of \( M2 \) to source of \( M2 \) \( \Rightarrow V_{S2} = 0 \)

If \( I_{b1} + I_{b2} \) are non-ideal \( \Rightarrow \) add in your resistances into CS + CD equations.