Continue with review of concepts from 2.2-80:

Ch.1: Review sections 1.1 - 1.6; do problem 1.39 (a), 1.46, 1.56

Ch.2 (Op-amps): Review sections 2.1 - 2.3; do problem 2.15

Op-amp symbol: [Image]

Voltage Amplifier model:

Ideal Op-amp Characteristics:

1. Infinite input impedance
2. Zero output impedance
3. Zero common-mode gain
4. Infinite open-loop gain $A \rightarrow$ leads to "virtual ground"
5. Infinite bandwidth

Ch.3 (MOSFETs): Review sections 4.1 - 4.7

MOSFET Review

Structure:

(n-type)

- Often body is connected to the source and the symbol only has 3 terminals (as in FET transistors)
- Symmetry (in ICS, not in discrete devices)

Operation:

- When gate voltage is at same potential as body, source and drain are connected by back to back diode, no current.

- When positive voltage is applied to the gate, depletion layer forms, then an N+ inversion layer connecting the N+ source and drain regions so current can flow for positive $V_{GS}$.

- Voltage at which channel forms is called threshold voltage ($V_T$).
Now as we apply a small $V_{DS}$, current will flow - this is called the "triode" region.

- At some end of channel, the full $V_{DS}$ appears across gate-body interface.

- Since channel acts like a resistor, at drain end the channel voltage is higher, only $V_{GS} - V_{DS}$ appears across interface.

In triode region:

$$I_D = \frac{M \cdot I}{L} \left[ (V_{GS} - V_t) - \frac{1}{2} V_{DS}^2 \right] \quad \text{(large signal)}$$

- If $V_{GS} - V_{DS}$ drops below $V_t$, we no longer have an inversion layer, channel is "pinned off".
  - Further increases in $V_{DS}$ do not increase the current further, it has "saturated" for this $V_{GS}$ voltage.
  - Called the saturation region for this reason.

In saturation region:

$$I_D = \frac{M \cdot I}{L} \left( V_{GS} - V_t \right)^2 \quad \text{(large signal)}$$

Plot $I_D$ vs. $V_{GS}$:

- Channel length modulation: as $V_{GS}$ increases, depletion layer around $S + D$ widens, reducing the effective length of the channel, leading to higher current (see eqn.)
  - Results in a finite slope of $I_D - V_{GS}$ curves, finite $r_D$ in saturation.
  - Can be included in $I_D$ equation with extra factor $(1 + 2V_{GS})$

PMOS device:
- Same analysis holds, but switch p of n-type regions
  - Now body is connected to VDD (positive supply voltage), $V_{GS}$ must be negative to attract holes and form a p-type channel
- Same equations hold as for n-type.
Small Signal Operation and Analysis

- Assume we have the following circuit, where \( R_B \) is chosen to keep the device in saturation for the values of \( I_D \) encountered.

\[
\begin{align*}
\text{V}_{DD} & \quad \text{+} \\
\text{I}_D & \quad \text{\downarrow} \text{\scriptsize \text{R}_B} \\
\text{V}_B & \quad \text{-} \\
\end{align*}
\]

- body connection not shown (assume connected to source)

\[ \text{Assume device operates in saturation and ignoring channel length modulation: } \]
\[ \text{id} = \frac{2}{2} \text{L} \frac{(V_{GS} - V_t)^2}{(V_{GS} - V_t) + \text{offset voltage}} \]

- We can plot this:

\[
\begin{array}{c}
\text{id} \\
V_t \\
V_{GS} \\
V_B \\
\end{array}
\]

- to simplify our analysis, if the signal component is small, we can linearize this expression around the bias point.
- the slope of this linear curve is defined as the transconductance (\( G_m \))

\[ G_m \equiv \frac{\text{d}i_d}{\text{d}V_{GS}} \bigg|_{V_{GS}=V_{GS}} \]

- Taking the derivative leads to:

\[ G_m = \frac{M_0}{2} \text{L} (V_{GS} - V_t) \]

- we can express this in another potentially useful form by substituting \( M_0 \) for \( (V_{GS} - V_t) \):

\[ G_m = \sqrt{2} \frac{M_0}{2} \text{L} \frac{I_D}{I_D} \]

\( G_m \) is important, as it determines the gain we can get from the amplifier above.

- as \( V_{GS} \) changes, it changes the current flowing through the device, changing the output voltage.
- larger values of \( G_m \) mean that the same input voltage induces a larger change in current, and hence a larger output voltage (more gain).

From curve above, as \( I_D \) increases (continued, \( G_m \) increases).