Intermission: Review signal convention, small signal vs. large signal.

- Did not use book much in 2280.
- In 2280, biased was done with active circuits, not in I.C. design.

Read book section before you attempt each homework set.

Signal convention:

\[ V_{\text{IN}} = V_{\text{IN}} + V_{\text{in}} \]

- For small signal component, use linearized small signal model.
- For large signal (bias) component, use exact, non-linear, large signal equation.

Circuit Analysis Procedure:

- (When to use small signal, when to use large signal)
- \[ V_{\text{IN}} = 0.6 \text{ V, } W = 10, \ V_{\text{AN}} = 20 \text{ V.} \]
- \[ V_{\text{IN}} = V_{\text{IN}} + V_{\text{in}} = 1.6 + 0.1 \cdot \sin(\omega t) \]
- \[ V_{\text{OUT}} = V_{\text{OUT}} + V_{\text{OUT}} \]

1. Use large signal equations to establish bias currents and voltages.
   - Need to know region of operation: Assume saturation.
   - Initially neglect channel length modulation (\( V_{\text{th}} \)).

\[ I_D = \frac{M_{\text{C}} \cdot W}{2} \left( \frac{V_{\text{GS}} - V_{\text{th}}}{W} \right) \]

\[ = \frac{200 \cdot 10^{-6}}{2} \left( \frac{1.6 - 0.6}{10} \right)^2 \]

\[ = 1 \text{ mA} \]  \( \text{(We only bias component)} \)

- Now, \( V_{\text{DS}} = V_{\text{DD}} - I_D \cdot R = 5 - 1 \text{ mA} \cdot 3 \text{ k}\Omega = 2 \text{ V} \)

- We are in saturation, since \( V_{\text{DS}} > \frac{V_{\text{GS}} - V_{\text{th}}}{V_{\text{DD}}} = 1 \text{ V} \)

- Go back and check how much was erred by not including channel length modulation:

\[ I_D = \frac{M_{\text{C}} \cdot W}{2} \left( \frac{V_{\text{GS}} - V_{\text{th}}}{W} \right)^2 \left( 1 + \frac{V_{\text{DS}}}{V_{\text{th}}} \right) = 1 \text{ mA} \cdot \left( 1 + \frac{2}{20} \right) = 1.1 \text{ mA}. \]
To get a more accurate value, we iterate several times:

\[ V_{DS} = V_{DD} - I_D R_C = 5 - 1.09 \times 3 \text{ k}\Omega = 1.7 \text{ V} \]

Now, let's say \( I_D = 1.09 \text{ mA} \) and call it good.

\[ V_{DS} = 5V - 1.09 \times 3 = 1.73 \text{ V}. \]

This is \( V_{out} \), the large signal component of \( V_{out} \).

We also know \( I_D \), the large signal component of the bias current.

2. We bias current to determine small signal model parameters:

\[ g_m = \sqrt{2 \cdot k \cdot I_D} = \sqrt{2 \cdot 200 \times 10^{-6} \cdot 10^{-3}} = 2 \text{ mS} \]

\[ R_C = \frac{V_A}{I_D} = \frac{20}{10^{-3}} = 20 \text{ k}\Omega. \]

3. Analyze response to signal component by switching in S.S. model.

Get rid of biasing sources, only consider signal (charging)

\[ V_{out} = -g_m \cdot R \cdot V_{in} \]

\[ R_{roll} = \left( \frac{1}{3} + \frac{1}{20} \right) \text{ k}\Omega = \frac{60}{23} \approx 2.6 \text{ k}\Omega \]

\[ V_{out} = -2e-3 \times 2.6e3 \times 0.1 = -0.52 \text{ V} = -0.52 \cdot \sin(\omega t) \]

\[ I_{bias} = 0.2 \text{ mA} \Rightarrow 0.2e-3 \cdot \sin(\omega t) \text{ A} \]

\[ \text{Complete output voltage: } V_{out} = V_{out} + V_{out} \]

\[ = 1.73 - 0.52 \sin(\omega t) \text{ V} \]

\[ \text{Phase change from input signal.} \]
What do the signals actually look like?

- If we hooked up a DC coupled scope to the inputs and outputs, we would see the following:

\[ V_{out} = V_{os} - V_D \] (min. \( V_{os} \) to remain in saturation)

- As a check, device remains in saturation for this signal amplitude. If it entered triode region we would see significant distortion in the output wave.

This is the general procedure to use for any circuit that you analyze:

1. Establish bias conditions (ignoring signal components)
2. Calculate small signal parameters using bias conditions
3. Use small signal model to calculate signal components (ignoring bias voltages and currents)
4. Check that assumptions used for small signal model hold true across signal range

It is very important to understand these concepts. If you learn anything at all from this course, this should be it.

Next: Active loads with differential pair

But first, review frequency behavior of amplifiers, relevant to the next lab.

- So far we have not included capacitances in our S.S. model. These become important at higher frequencies.

More complete S.S. model:

- Can include other capacitances as well, but these are the dominant ones.

These capacitances will cause the gain of MOSTFET amplifiers to fall off at higher frequencies.