HW6

Due Thursday 6/2 at 3:00PM on Gradescope

You are not required to submit the solutions to Part 1, but you still should solve these questions since <u>op amps will be on the final</u>.

Part 1 (Practice Problems):

Q1. Problem 11.3

A certain NMOS transistor has $V_{t0} = 1V$, $KP = 50\mu A/V^2$, $L = 5\mu m$, and $W = 50\mu m$. For each set of voltages, state the region of operation and compute the drain current.

a. $v_{GS} = 4V$ and $v_{DS} = 10V$
b. $v_{GS} = 4V$ and $v_{DS} = 2V$
c. $v_{GS} = 0V$ and $v_{DS} = 10V$

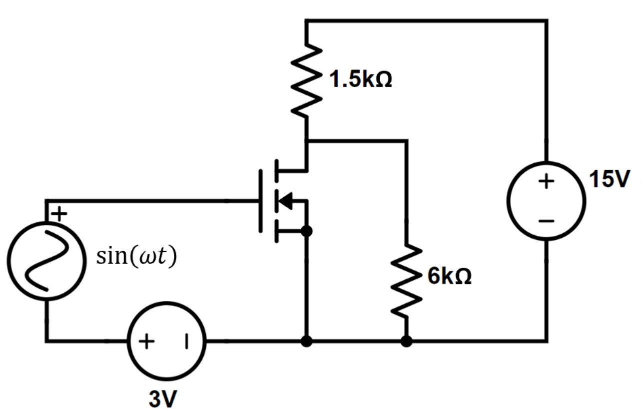
Solution:

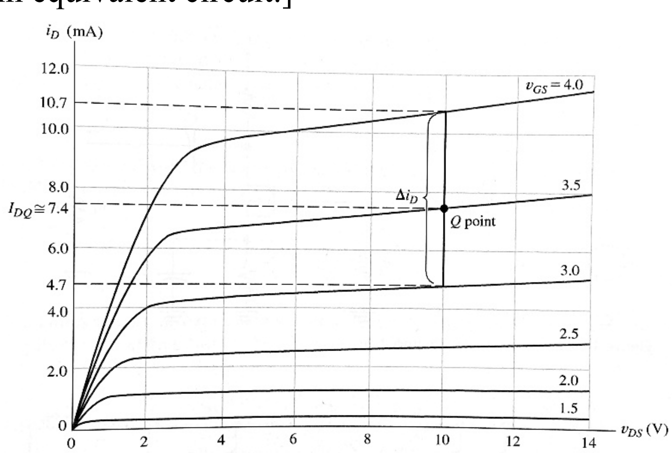
$$KP = \frac{1}{2}KP\left(\frac{W}{L}\right) = 0.25mA/V^2$$

a. Saturation because we have $v_{GS} \geq V_{to}$ and $v_{DS} \geq v_{GS} - V_{to}$.
$i_D = K(v_{GS} - V_{to})^2 = 2.25mA$
b. Triode because we have $v_{DS} < v_{GS} - V_{to}$ and $v_{GS} \geq V_{to}$.
$i_D = K[2(v_{GS} - V_{to})v_{DS} - v_{DS}^2] = 2mA$
c. Cutoff because we have $v_{GS} \leq V_{to}$.
$i_D = 0$

Q2. Problem 11.22

Use a load-line analysis of the circuit shown in the figure below to determine the values of V_{DSQ}, V_{DSmin}, and V_{DSmax}. The characteristics of the FET are shown in the plot on the right. Note that the labelled I_{DQ} is for a different textbook example, not for this problem. [Hint: First, replace the 15V source and the resistances by their Thevenin equivalent circuit.]





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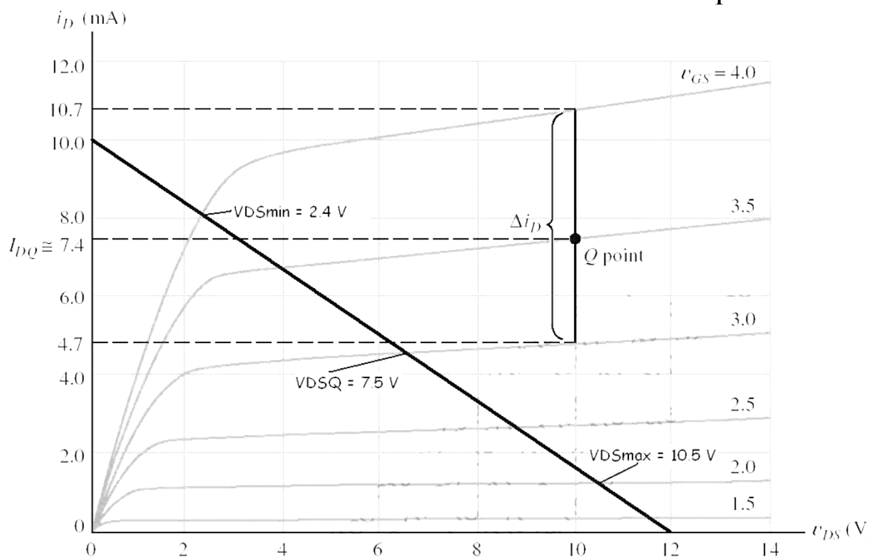
Solution:
The Thevenin equivalent for the drain circuit contains a 12V source in series with a 1.2kΩ resistance. Then, we can construct the load line and determine the required voltages as shown:

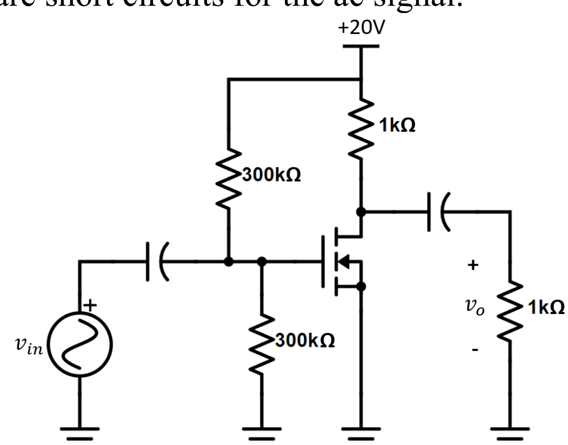


Q3. Problem 11.50

Consider the common-source amplifier shown in the figure below. The NMOS transistor has $KP = 50\mu A/V^2$, $L = 5\mu m$, $W = 500\mu m$, $V_{to} = 1V$, and $r_d = \infty$.

a. Determine the values of I_{DQ}, V_{DSQ}, and g_m.

b. Compute the voltage gain, input resistance, and the output resistance, assuming that the coupling capacitors are short circuits for the ac signal.



Solution:

a. $V_G = V_{DD}\left(\frac{R_2}{R_1+R_2}\right) = 20\left(\frac{0.3}{1.7+0.3}\right) = 3V$

$V_{GSQ} = V_G = 3V$

$K = \frac{1}{2}KP\left(\frac{W}{L}\right) = 2.5mA/V^2$

$I_{DQ} = K\left(V_{GSQ} - V_{to}\right)^2 = 10mA$

$V_{DSQ} = V_{DD} - R_D I_{DSQ} = 10V$

$g_m = 2\sqrt{KI_{DQ}} = 0.01S$

b. $R'_L = \frac{1}{\frac{1}{R_D}+\frac{1}{R_L}} = 500\Omega$

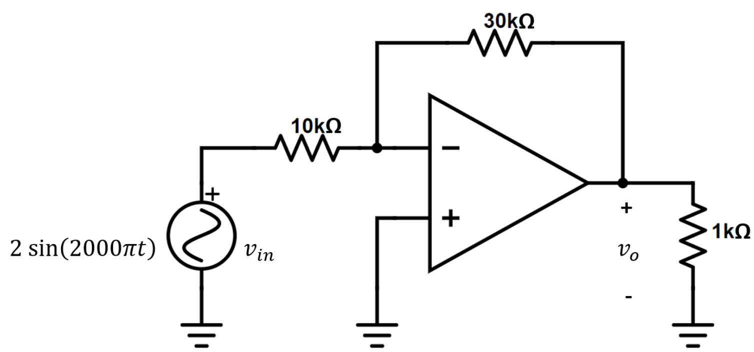
$A_V = -g_m R'_L = -5$

$R_{in} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}} = 255k\Omega$

$R_o = R_D = 1k\Omega$

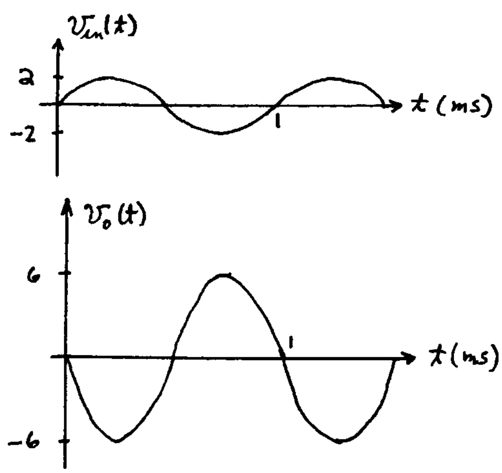
Q4. Problem 13.9

Consider the circuit shown in the figure below. Sketch $v_{in}(t)$ and $v_o(t)$ to scale versus time. The op amp is ideal.



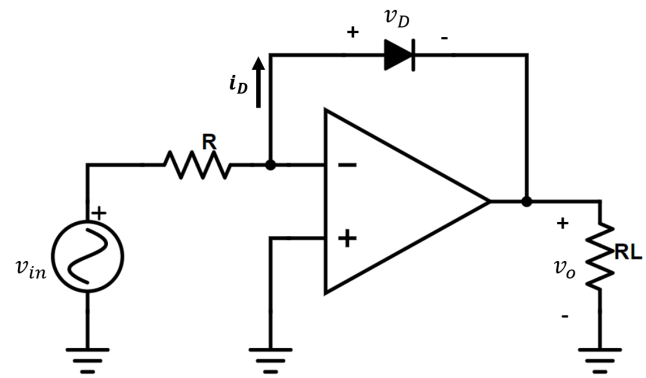
Solution:

This is an inverting amplifier having a voltage gain given by $A_V = -\frac{R_2}{R_1} = -3$. Thus, we have $v_o(t) = -3 \times [2\cos(2000\pi t)]$. Sketches of $v_{in}(t)$ and $v_o(t)$ are:



Q5. Problem 13.12

Consider the inverting amplifier shown in the figure below, in which one of the resistors has been replaced with a diode. Assume an ideal op amp, v_{in} positive, and a diode current given by $i_D = I_s\exp(v_D/nV_T)$. Derive an expression for v_o in terms of v_{in}, R, I_s, n, and V_T.



Solution:
Using the summing-point constraint, we have

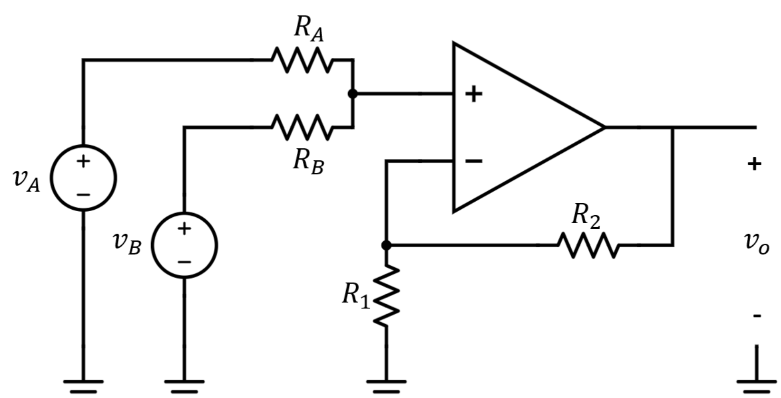
$$i_D = \frac{v_{in}}{R} = I_S \exp\left(\frac{v_D}{nV_T}\right)$$
$$v_o = -v_D$$

Solving, we have

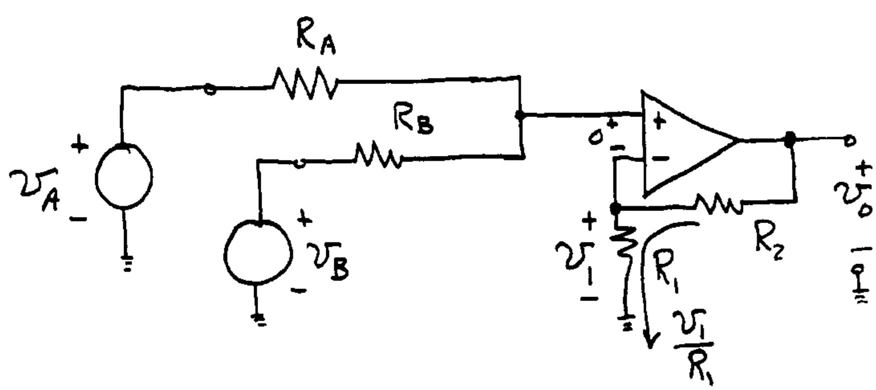
$$v_o = -nV_T \ln\left(\frac{v_{in}}{RI_S}\right)$$

Q6. Problem 13.21

Analyze the ideal-op-amp circuit shown in the figure below to find an expression for v_o in terms of v_A, v_B, and the resistance values.



Solution:



Writing a current equation at the noninverting input, we have

$$\frac{v_1 - v_A}{R_A} + \frac{v_1 - v_B}{R_B} = 0$$

Using the voltage-division principle we can write

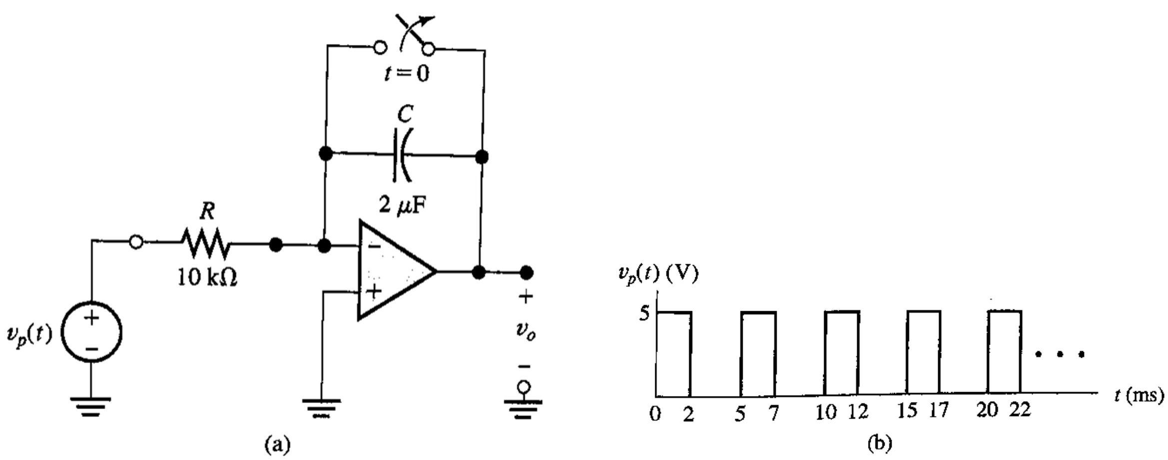
$$v_1 = \frac{R_1}{R_1 + R_2} v_o$$

Using the second equation to substitute for v_1 in the first equation and rearranging, we get:

$$v_o = \frac{R_1 + R_2}{R_1}\left(\frac{v_A R_B + v_B R_A}{R_A + R_B}\right)$$

Q7. Problem 13.74

Sketch the output voltage of the idea-op-amp circuit shown in the figure below to scale versus time. The circuit is shown in (a) and the input voltage $v_p(t)$ is shown in (b).



Solution:

This is an integrator circuit and the output is given by:

$$v_o(t) = -\frac{1}{RC}\int_0^t v_{in} dt = -50\int_0^t v_{in} dt$$

A sketch of $v_o(t)$ versus t is: