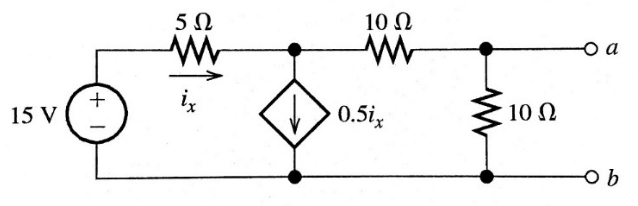
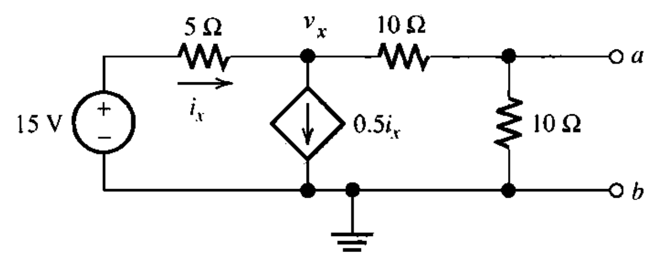
ECE100 Practice Final

Q1: Find Thevenin and Norton equivalent circuits for the circuit shown below.



Solution:

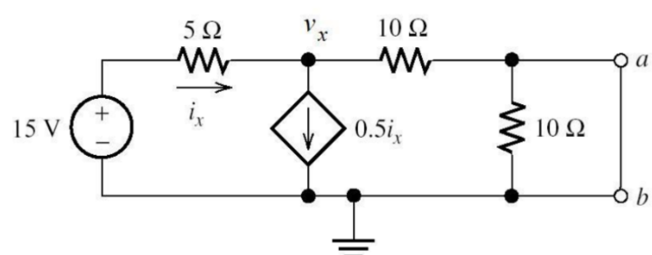
Open-circuit conditions:



$$i_x = \frac{15 - v_x}{5} \qquad \frac{v_x}{10+10} - i_x + 0.5i_x = 0$$

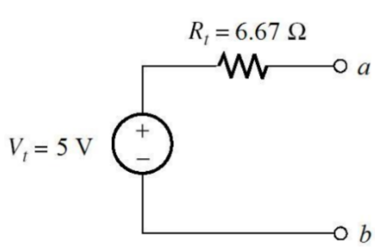
Solving, we find $v_x = 10V$ and then we have $V_t = v_{oc} = v_x \frac{10}{10+10} = 5V$.

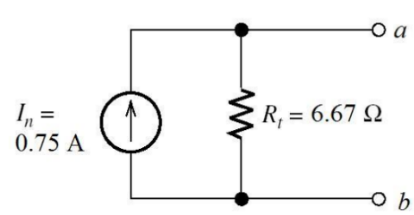
Short-circuit conditions:



$$i_x = \frac{15 - v_x}{5} \qquad \frac{v_x}{10} - i_x + 0.5i_x = 0$$

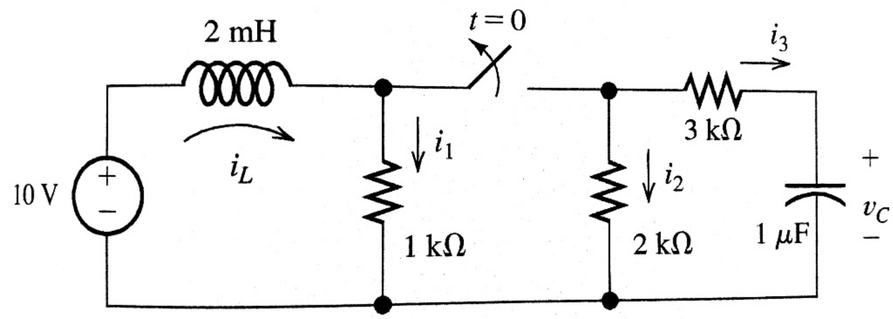
Solving, we find $v_x = 7.5V$ and then we have $i_{sc} = \frac{v_x}{10} = 0.75A$. Then we have $R_t = \frac{v_{oc}}{i_{sc}} = 6.67\Omega$. Thus the equivalents are:





Q2: Consider the circuit shown below. The circuit has been operating for a long time with the switch closed prior to $t = 0$.

a. Determine the values of i_L, i_1, i_2, i_3, and v_C just before the switch opens.
b. Determine the values of i_L, i_1, i_2, i_3, and v_C immediately after the switch opens.
c. Find $i_L(t)$ for $t > 0$.
d. Find $v_C(t)$ for $t > 0$.



Solution:

(a) Prior to the switch opening, the circuit is operating in DC steady state, so the inductor acts as a short circuit, and the capacitor acts as an open circuit.

$i_1(0^-) = \frac{10}{1000} = 10mA$ $\qquad$ $i_2(0^-) = \frac{10}{2000} = 5mA$

$i_3(0^-) = 0$ $\qquad$ $i_L(0^-) = i_1(0^-) + i_2(0^-) + i_3(0^-) = 15mA$

$v_C(0^-) = 10V$

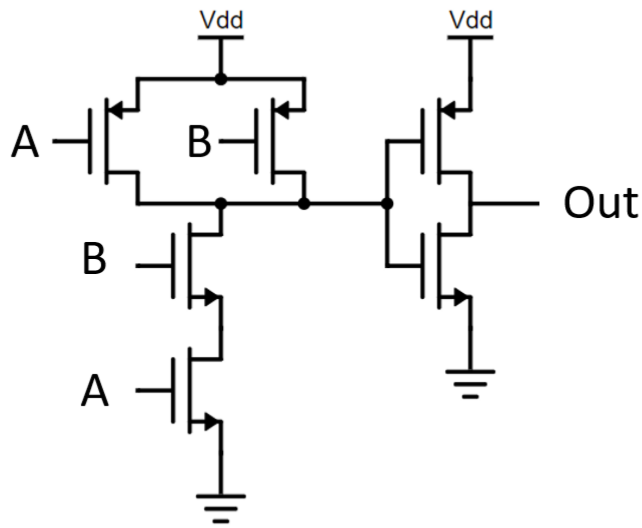
(b) Because infinite voltage or infinite current are not possible in this circuit, the current in the inductor and the voltage across the capacitor cannot change instantaneously. Thus, we have $i_L(0^+) = i_L(0^-) = 15mA$ and $v_C(0^+) = v_C(0^-) = 10V$.
Also, we have $i_1(0^+) = i_L(0^+) = 15mA$, $i_2(0^+) = \frac{v_C(0^+)}{5000} = 2mA$, and $i_3(0^+) = -i_2(0^+) = -2mA$.

(c) The current is of the form $i_L(t) = A + B\exp\left(-\frac{t}{\tau}\right)$. Because the inductor acts as a short circuit in steady state, we have $i_L(\infty) = A = \frac{10}{1000} = 10mA$.
At $t = 0^+$, we have $i_L(0^+) = A + B = 15mA$, so we find $B = 5mA$.
The time constant si $\tau = \frac{L}{R} = 2 \times \frac{10^{-3}}{1000} = 2 \times 10^{-6}s$.
Thus, we have $i_L(t) = 10 + 5\exp(-5 \times 10^5 t)\, mA$.

(d) This is a case of an initially charged capacitance discharging through a resistance. The time constant is $\tau = RC = 5000 \times 10^{-6} = 5 \times 10^{-3}s$. Thus we have $v_C(t) = V_i \exp\left(-\frac{t}{\tau}\right) = 10\exp(-200t)\,V$.

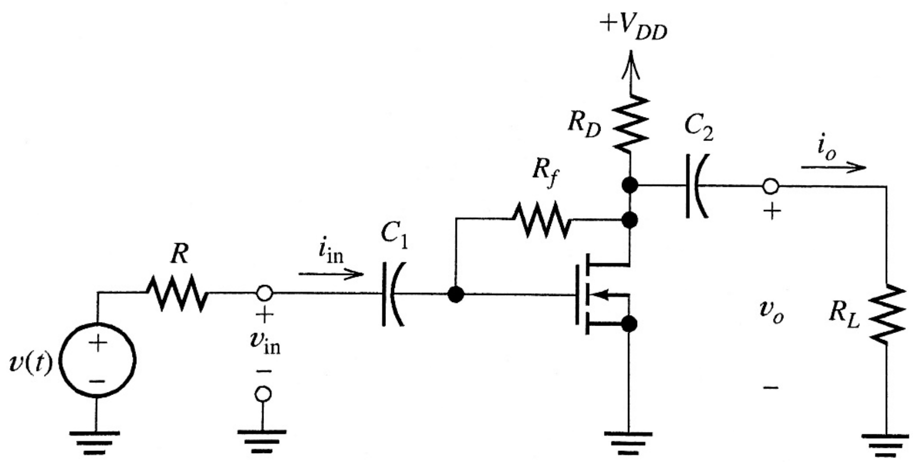
Q3: Draw a CMOS logic circuit for a 2-input AND gate using NMOS and PMOS transistors.

Solution: A NAND gate followed by an inverter.



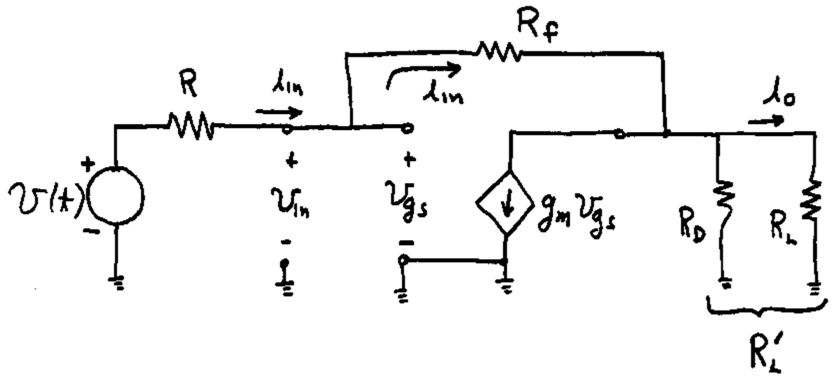
Q4: Consider the amplifier shown below.

a. Draw the small signal equivalent circuit assuming that the capacitors are short circuits for the signal.
b. Assume that $r_d = \infty$ and derive an expression for the voltage gain.
c. Find I_{DQ} if $R = 100k\Omega$, $R_f = 100k\Omega$, $R_D = 3k\Omega$, $R_L = 10k\Omega$, $V_{DD} = 20V$, $V_{t0} = 5V$, and $K = 1mA/V^2$. Determine the value of g_m at the Q point.
d. Evaluate the expression from part b using the values in part c.
e. Is this amplifier inverting or noninverting?



Solutions:

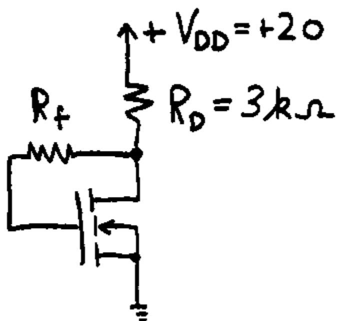
a.



b. $v_o = R_L'(i_{in} - g_m v_{in})$ $\qquad$ $i_{in} = \frac{(v_{in} - v_o)}{R_f}$

$A_v = \frac{v_o}{v_{in}} = \frac{R_L' - g_m R_L' R_f}{R_L' + R_f}$

c. The DC circuit is:



$V_{GSQ} = V_{DSQ}$ $\qquad$ $I_{DQ} = K\left(V_{DSQ} - V_{t0}\right)^2$ $\qquad$ $I_{DQ} = \frac{V_{DD} - V_{DSQ}}{R_D}$

Using the above equations, we obtain

$3V_{DSQ}^2 - 29V_{DSQ} + 55 = 0$

$V_{DSQ} = 7.08V$ and $I_{DQ} = 4.32\ mA$

At the bias point:

$g_m = \frac{di_D}{dV_{GS}} = 2K\left(V_{GSQ} - V_{t0}\right) = 4.16 \times 10^{-3} S$

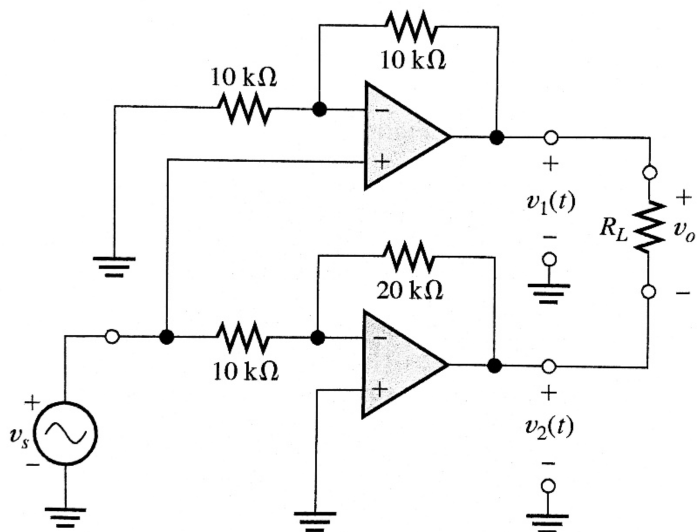
d. $R_L' = R_D || R_L = 2.31k\Omega$

$A_v = -9.37$

e. This is an inverting amplifier that has a very low input impedance compared to many other MOSFET amplifiers.

Q5: Consider the bridge amplifier shown below.

a. Assuming ideal op amps, derive an expression for the voltage gain v_o/v_s
b. If $v_s(t) = 3\sin(\omega t)$, sketch $v_1(t)$, $v_2(t)$, and $v_o(t)$ to scale versus time.
c. If the op amps are supplied from $\pm 15V$ and clip at output voltages of $\pm 14V$, what is the peak value of $v_o(t)$ just at the threshold of clipping? (Note: This circuit can be useful if a peak output voltage greater than the magnitude of the supply voltages is required.)

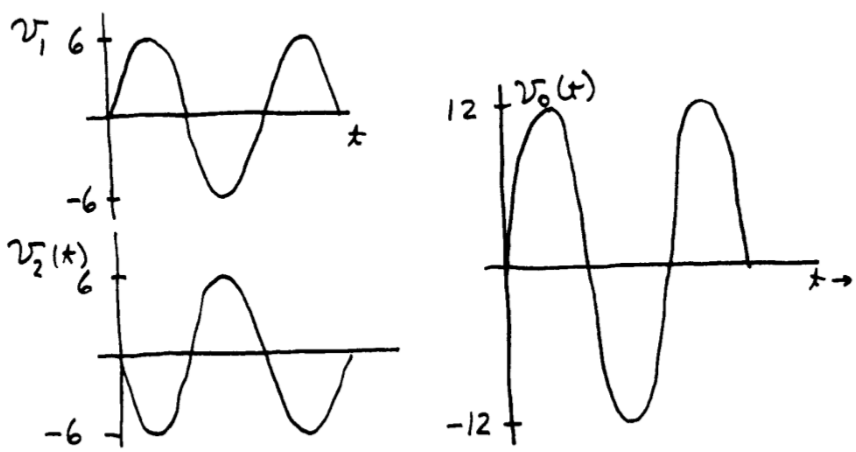


Solution:

a. One op amp is configured as an inverting amplifier with a gain of -2 and the other op amp is configured as a noninverting amplifier with a gain of +2. Thus we can write:

$$v_2(t) = -2v_s(t)$$
$$v_1(t) = 2v_s(t)$$
$$v_o(t) = v_1(t) - v_2(t) = 4v_s(t)$$
$$A_v = \frac{v_o}{v_s} = 4$$

b.



c. The peak value of $v_o(t)$ at the threshold of clipping is 28V.