ECE 65: Components & Circuits Lab

Practice 4

Amplifier practice problems

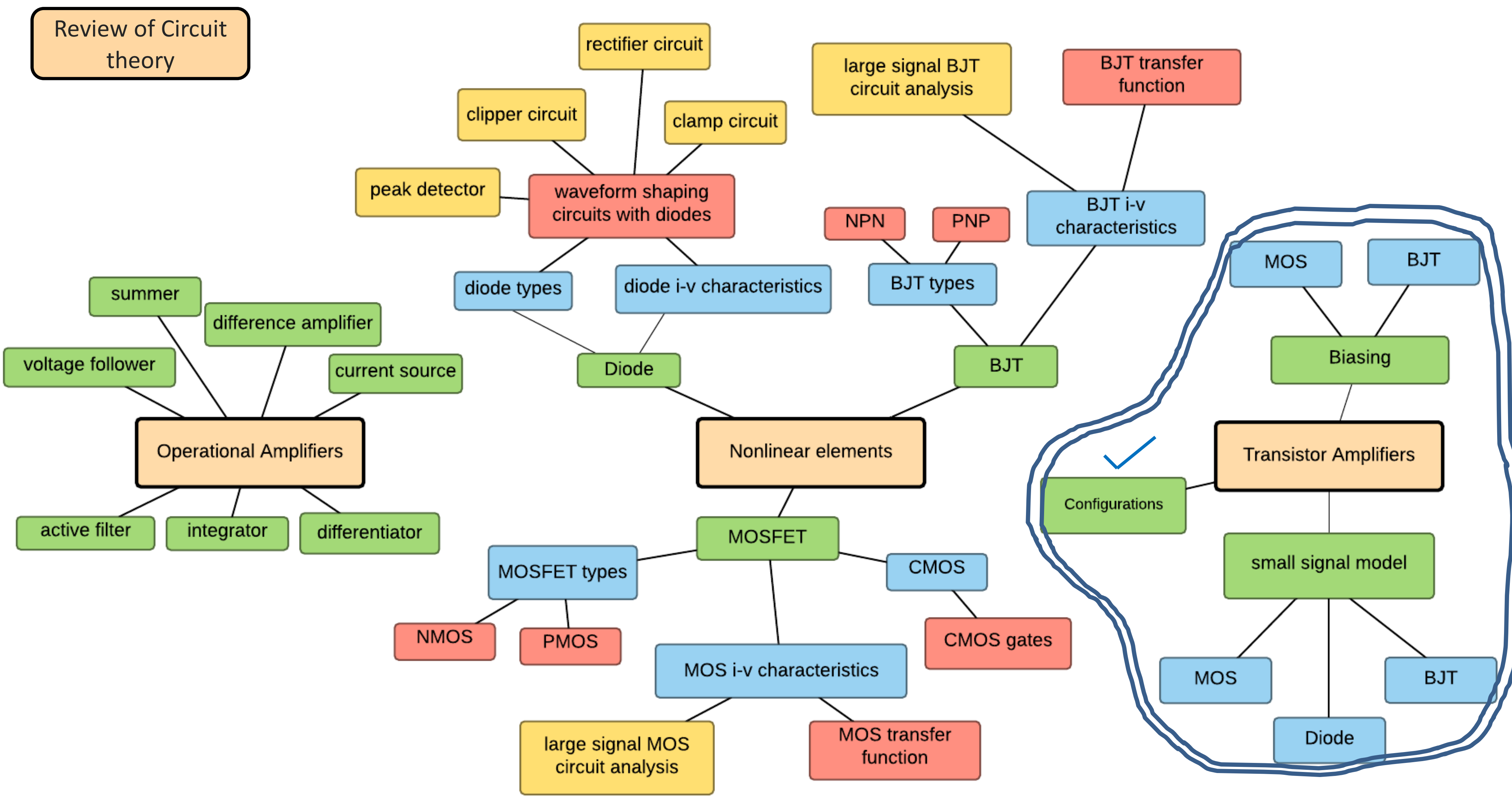
Reference notes: sections 6.1, 6.2

Sedra & Smith (7th Ed): section 7.3

Saharnaz Baghdadchi

Course map

7. Transistor Amplifier Configurations



Practice problem 1.

Design the following amplifier circuit, to achieve a voltage gain of $v_0/v_{sig} = -40\ V/V$.

a) You have a 15 V power supply available.

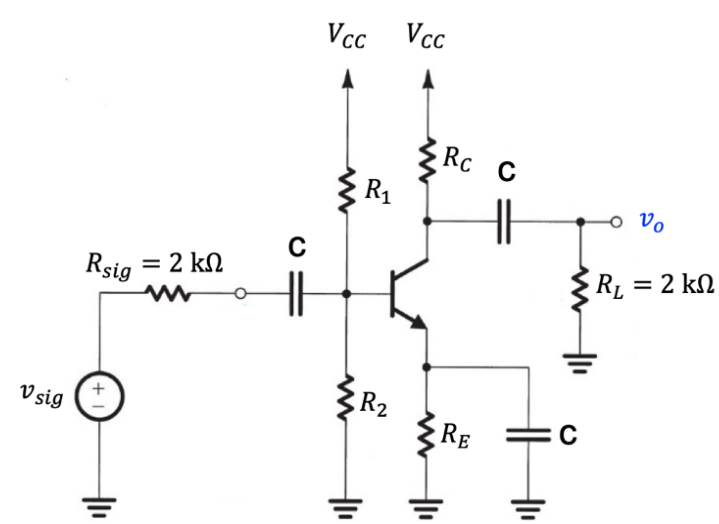
b) An emitter current of 2 mA is desired.

c) The current through R_2 is to be one-tenth of I_E.

d) The DC voltage at the base should be equal to one-third of the power supply.

The available transistor has $\beta = 100$ and $V_{D0} = 0.7\ V$. Ignore the early effect in bias and signal circuits. Assume Capacitors are short in the signal circuit. Use $V_T = 25\ mV$.

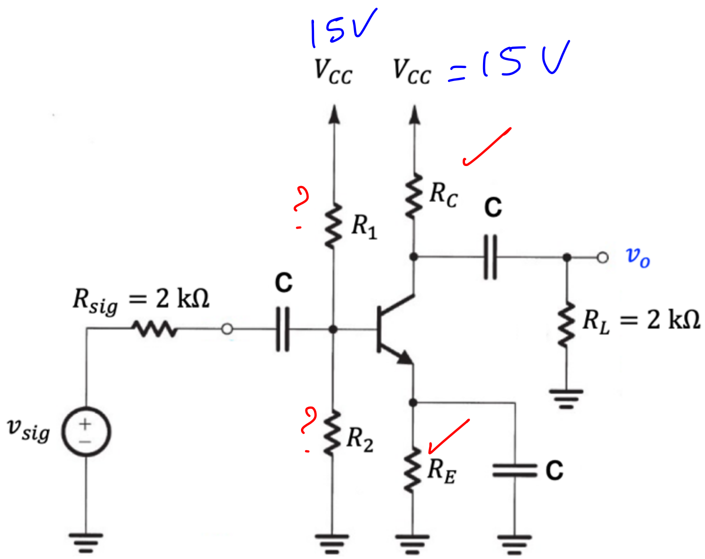
Draw the signal circuit and calculate the signal parameters.



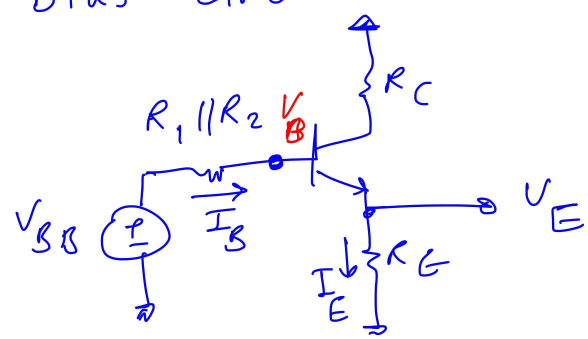
Practice problem 1.

$v_o / v_{sig} = -40\,V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
d) The DC voltage at the base should be equal to one-third of the power supply.



Bias circuit:



$$V_{BB} = 15\,V \times \frac{R_2}{R_1 + R_2}$$

$$V_B = \frac{1}{3} \times V_{CC} = 5\,V$$

$$V_B = V_{BE} + V_E$$

$$V_B = V_{BE} + R_E I_E \longrightarrow 5\,V = 0.7 + R_E \times 2\,mA \longrightarrow \boxed{R_E = 2.15\ k\Omega}$$

Practice problem 1.

$v_o / v_{sig} = -40 \, V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
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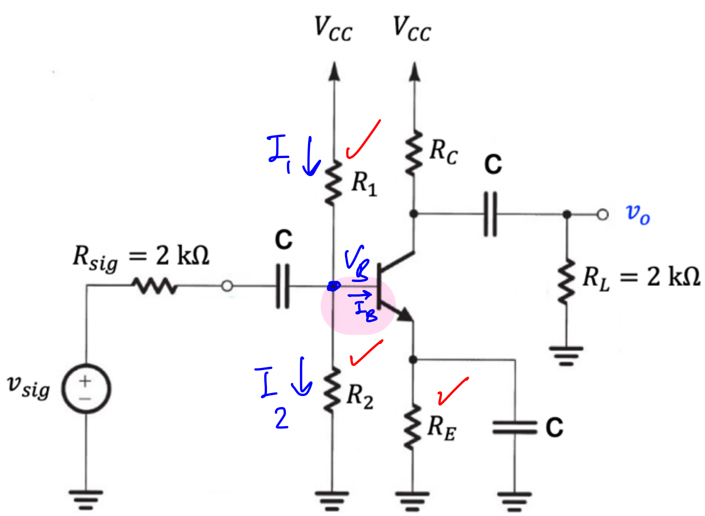

$I_2 = \frac{1}{10} \times I_E = 0.2\,mA$

$V_B = 5\,V$

$V_B = R_2 I_2 \longrightarrow R_2 = \frac{5\,V}{0.2\,mA} = 25\,k\Omega$

$I_E = I_C + I_B$, $I_C = \beta I_B = 100\, I_B \longrightarrow I_E = (1+\beta) I_B \rightarrow I_B = \frac{I_E}{101}$

$I_B = \frac{2}{101}\,mA = 0.0198\,mA$

KCL at Base : $I_1 = I_B + I_2 = 0.2198\,mA \longrightarrow R_1 = \frac{V_{CC} - V_B}{I_1} = 45.49\,k\Omega$

Practice problem 1.

$v_o/v_{sig} = -40\ V/V$

a) You have a 15 V power supply available.
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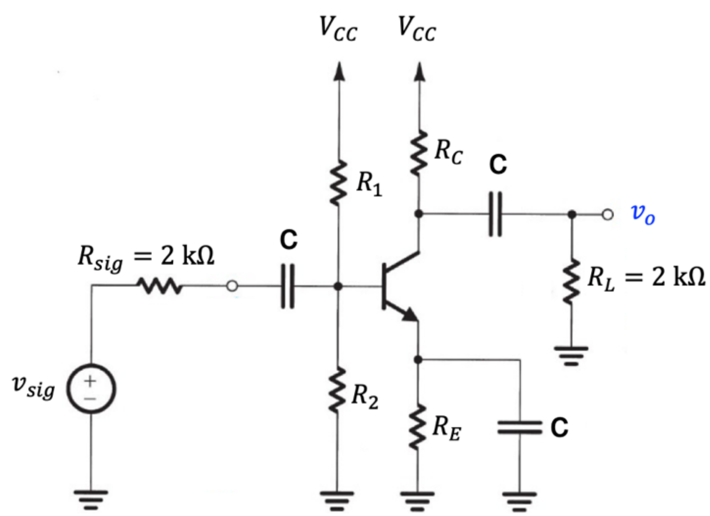
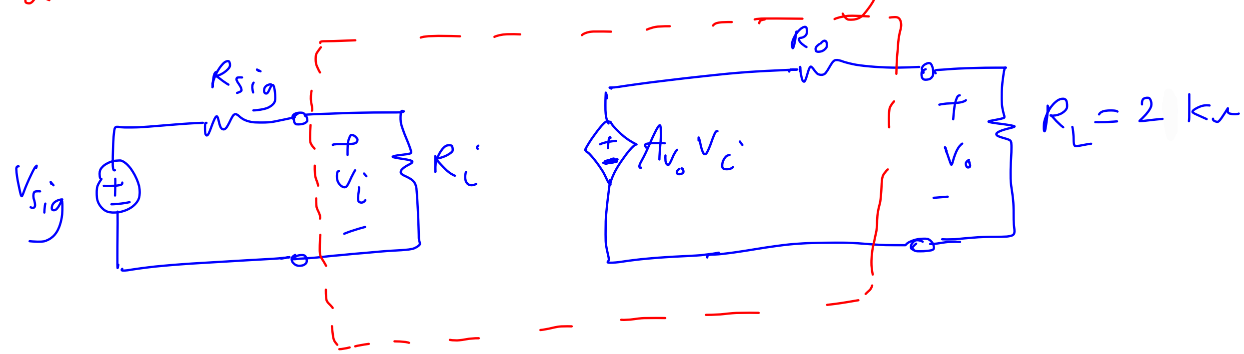


a different method of finding R_C :



$R_B = R_1 || R_2 = 16.13\ k\Omega$

$r_\pi = \frac{V_T}{I_B} = \frac{25\ mV}{I_E/101} = 1.26\ k\Omega$

$g_m = \frac{\beta}{r_\pi} = 79.36\ mA/V$

$R_i = R_B || r_\pi \simeq 1.17\ k\Omega$

$R_o = R_C || r_o = R_C || \infty = R_C$

$A_{v_o} = -g_m R_C = -79.36\ R_C$

Practice problem 1.

$v_o/v_{sig} = -40\,V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
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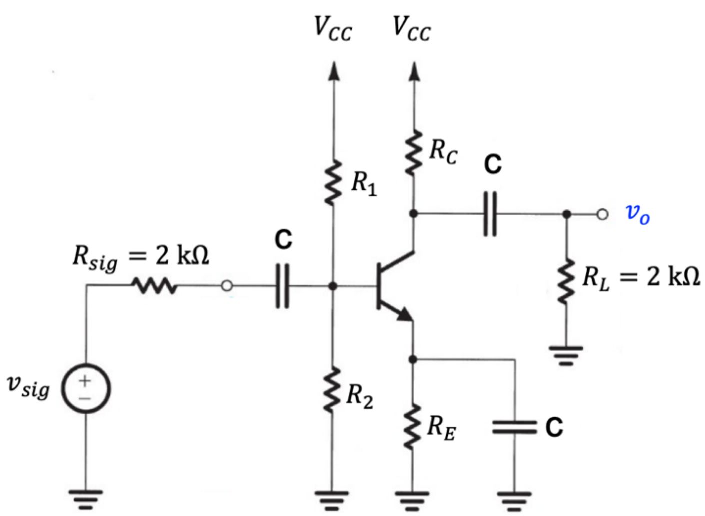
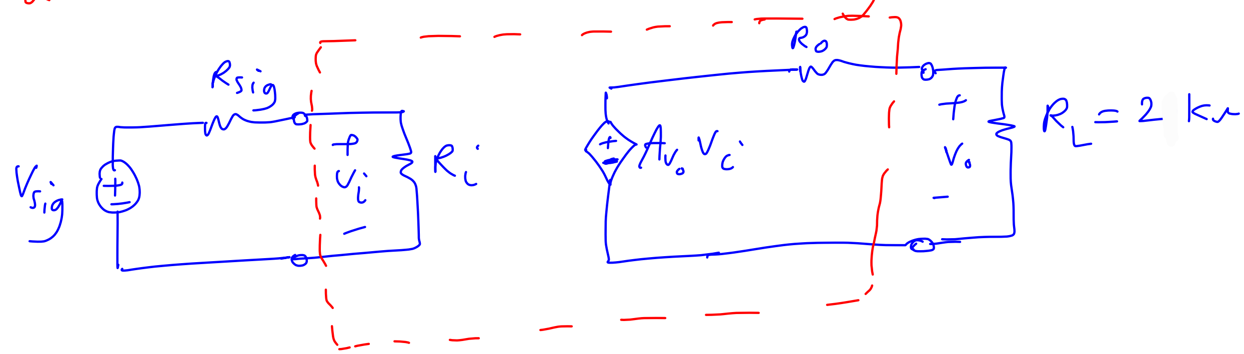


a different method of finding R_C:



$$\frac{v_o}{v_{sig}} = \frac{R_L}{R_o + R_L} \cdot A_{v_o} \cdot \frac{R_i}{R_i + R_{sig}}$$

$R_o = R_C \| r_o = R_C \| \infty = R_C$

$A_{v_o} = -g_m R_C = -74.36\, R_C$

$$-40\,V/V = \frac{2\,k\Omega}{R_C + 2\,k\Omega} \cdot (-74.36\, R_C) \cdot \frac{1.17\,k\Omega}{3.17\,k\Omega}$$

$R_C = 4.3\,k\Omega$

Practice problem 1.

$v_o/v_{sig} = -40\ V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
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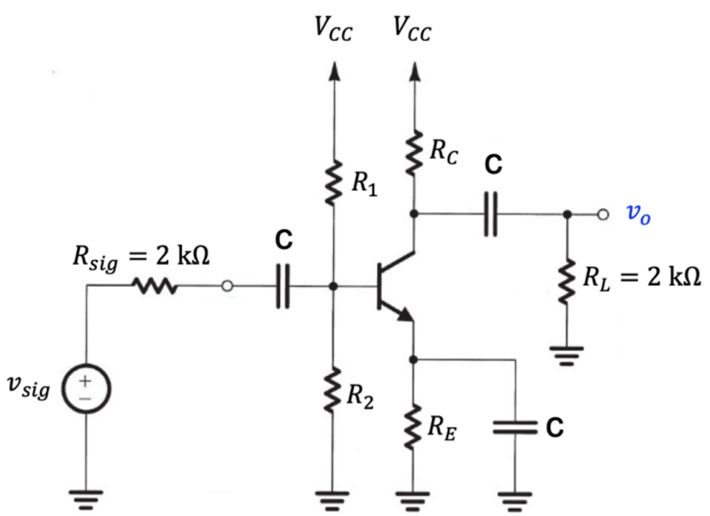
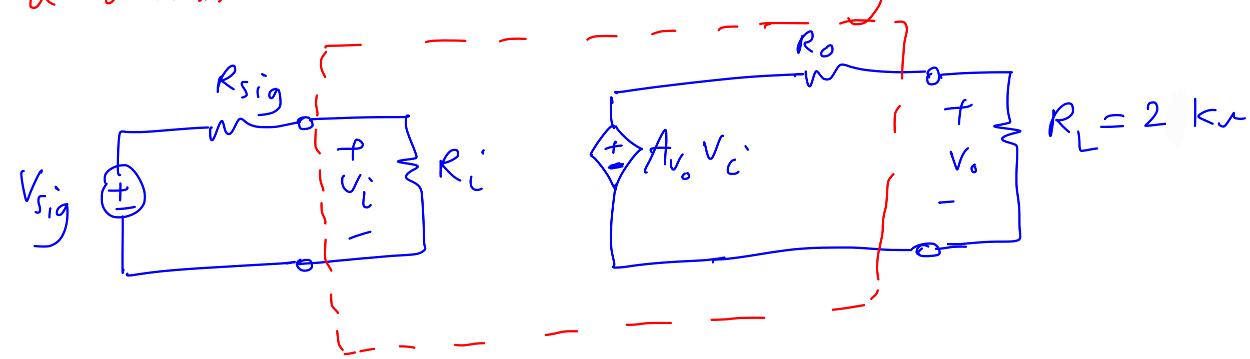


a different method of finding R_C:



$R_o = R_C \| r_o = R_C \| \infty = R_C$

$A_{v_o} = -g_m R_C = -74.36\ R_C$

$$\frac{V_o}{V_{sig}} = \frac{R_L}{R_o + R_L} \cdot A_{v_o} \cdot \frac{R_i}{R_i + R_{sig}}$$

$$-40\ V/V = \frac{2\ k\Omega}{R_C + 2\ k\Omega} \cdot (-74.36\ R_C) \cdot \frac{1.17\ k\Omega}{3.17\ k\Omega}$$

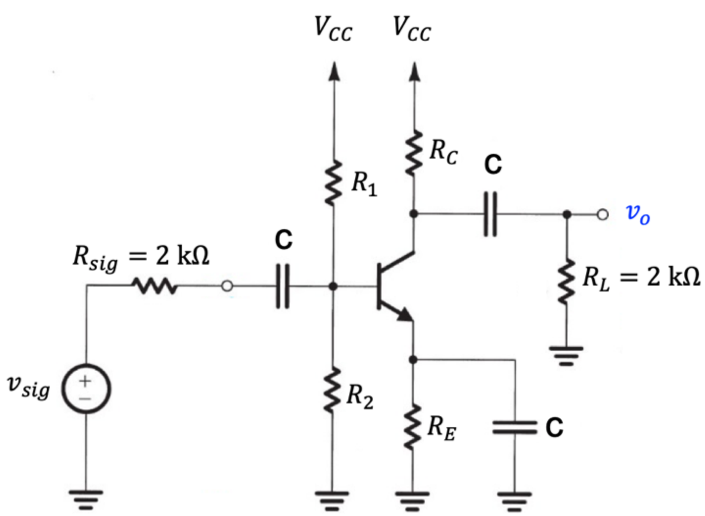
$R_C = 4.3\ k\Omega$

Practice problem 1.

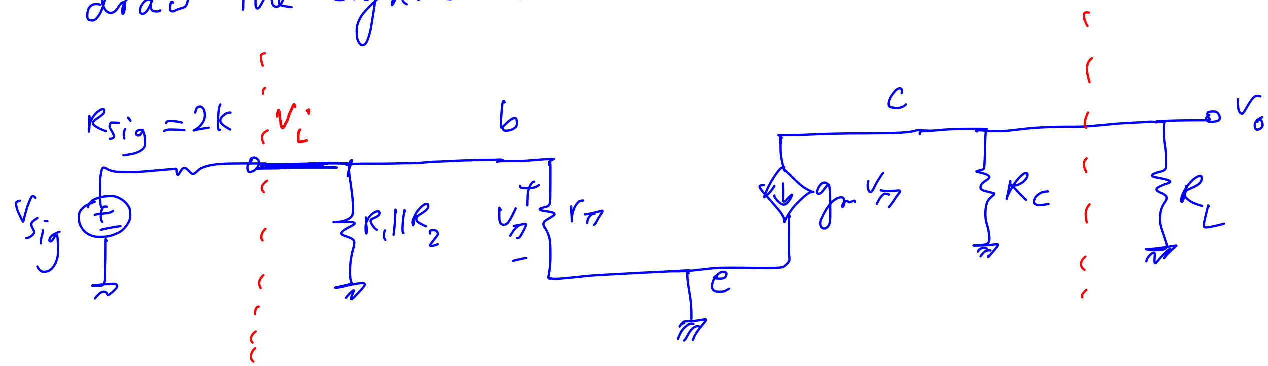
$r_o = \infty$

$v_o / v_{sig} = -40\,V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
d) The DC voltage at the base should be equal to one-third of the power supply.



draw the signal circuit to find R_c.



Common-emitter, in the signal circuit:

$R_B = R_1 || R_2$, $R_E = 0$, $R_C = ?$

$$\frac{V_o}{V_{sig}} = -40\ V/V$$

$$V_o = -g_m V_\pi \left(R_C || R_L \right)$$

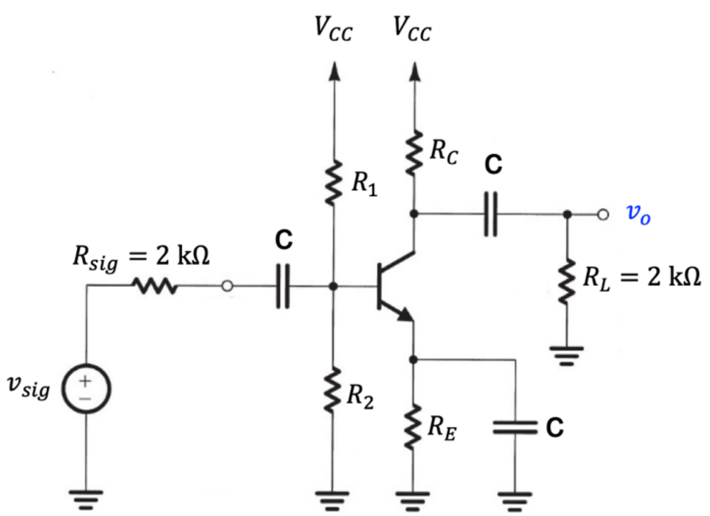
$$V_\pi = \frac{(r_\pi || R_1 || R_2)}{(r_\pi || R_1 || R_2) + R_{sig}} V_{sig}$$

Practice problem 1.

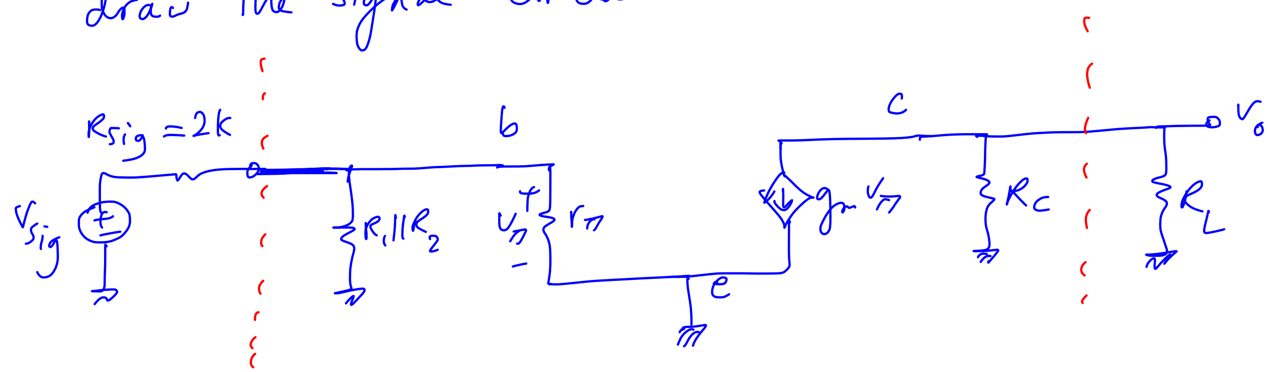
$r_o = \infty$

$v_o / v_{sig} = -40\,V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
d) The DC voltage at the base should be equal to one-third of the power supply.



draw the signal circuit to find R_C.



Common-emitter, in the signal circuit:

$R_B = R_1 \| R_2$, $R_E = 0$, $R_C = ?$

$$\frac{V_o}{V_{sig}} = -40\ V/V$$

$$V_o = -g_m V_\pi (R_C \| R_L)$$

$$V_\pi = \frac{(r_\pi \| R_1 \| R_2)}{(r_\pi \| R_1 \| R_2) + R_{sig}} V_{sig}$$

Practice problem 1.

$r_o = \infty$ $\quad$ $R_1 \| R_2 = R_B$

$v_o / v_{sig} = -40\ V/V$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
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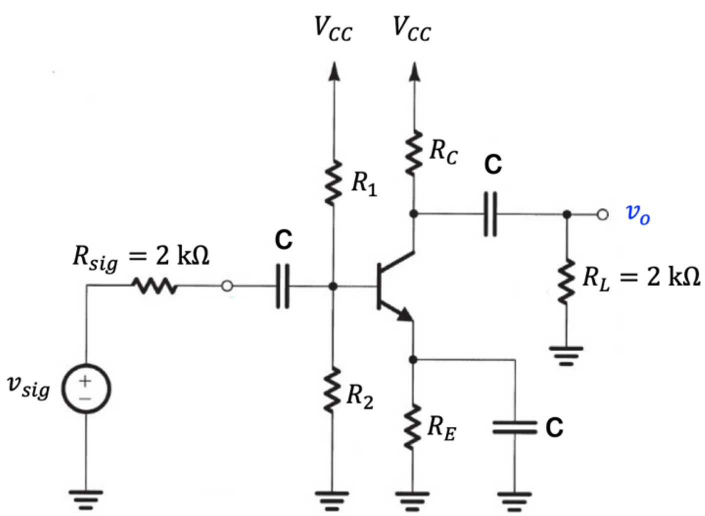
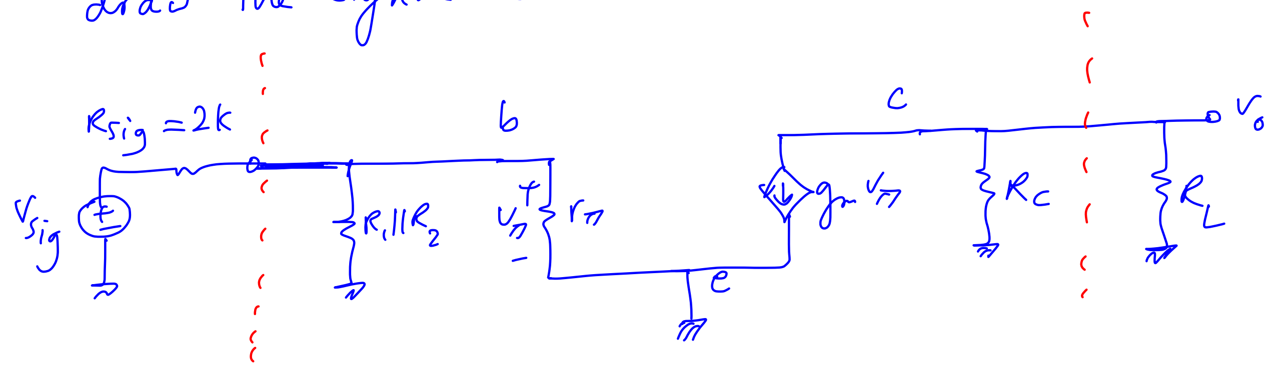


draw the signal circuit to find R_C.



$$v_o = -g_m v_\pi \left(R_C \| R_L\right)$$

$$v_\pi = \frac{(r_\pi \| \overbrace{R_1 \| R_2}^{R_B})}{(r_\pi \| \underbrace{R_1 \| R_2}_{R_B}) + R_{sig}}\, v_{sig}$$

$$\Rightarrow \frac{v_o}{v_{sig}} = \frac{(r_\pi \| R_B)}{(r_\pi \| R_B) + R_{sig}} \cdot (-g_m)\left(\frac{R_C R_L}{R_C + R_L}\right)$$

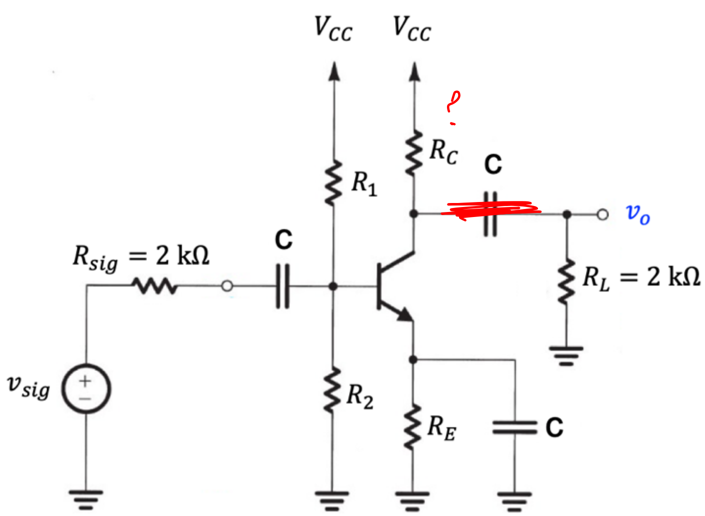
$$\Rightarrow R_C = 4.3\ \text{k}\Omega$$

Practice problem 1.

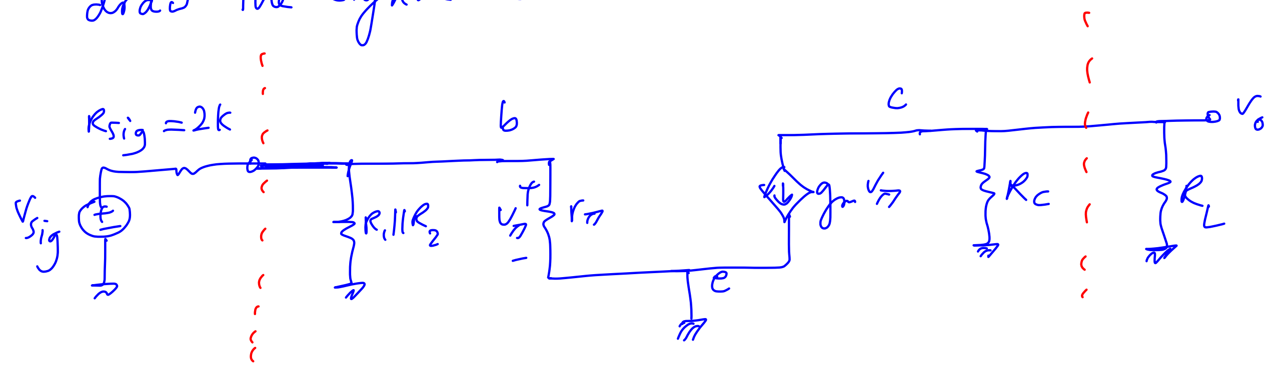
$r_o = \infty$ $R_1 \| R_2 = R_B$

$v_o / v_{sig} = -40\,\text{V/V}$

a) You have a 15 V power supply available.
b) An emitter current of 2 mA is desired.
c) The current through R_2 is to be one-tenth of I_E.
d) The DC voltage at the base should be equal to one-third of the power supply.



draw the signal circuit to find R_C.



$$\begin{cases} v_o = -g_m v_\pi \left(R_C \| R_L \right) \\ v_\pi = \dfrac{(r_\pi \| R_1 \| R_2)}{(r_\pi \| R_1 \| R_2) + R_{sig}} v_{sig} \end{cases} \Rightarrow$$

We can rewrite the same equation:

$$\frac{v_o}{v_{sig}} = \frac{\overbrace{(r_\pi \| R_B)}^{R_i}}{\underbrace{(r_\pi \| R_B)}_{R_i} + R_{sig}} \cdot (-g_m) \left(\frac{R_C R_L}{R_C + R_L} \right)$$

$$\frac{v_o}{v_{sig}} = \frac{R_i}{R_i + R_{sig}} \left(-g_m R_C \right) \frac{R_L}{R_o + R_L}$$

Practice problem 2.

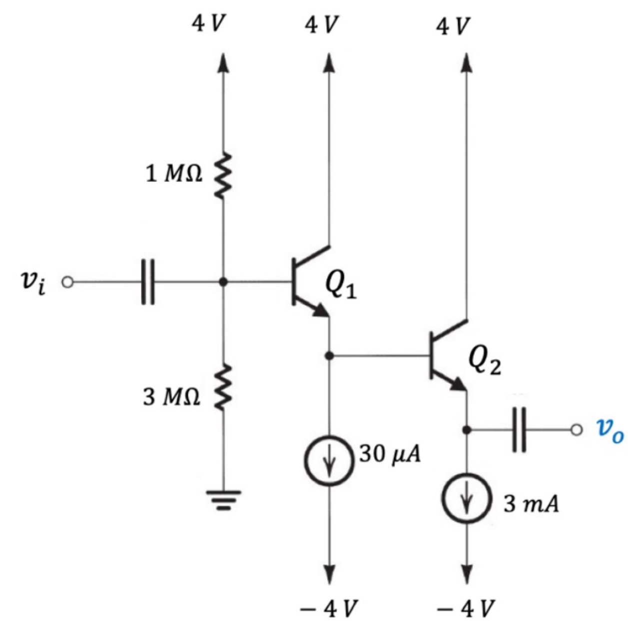
In the below amplifier circuit,

a) Find the DC emitter currents and the DC Base node voltages of Q1 and Q2.

b) Find the small signal parameters.

c) If a load resistance $R_L = 10\ k\Omega$ is connected to the output terminal, and a signal source with $R_{sig} = 0$ is connected to the input terminal, final $A = \frac{v_o}{v_{sig}}$.

$\beta_1 = 60, \beta_2 = 100, V_T = 25\ mV, V_{D0} = 0.7\ V$.
Neglect the early effect in the bias and signal circuits. The capacitors are short for the signal circuit.



The input resistance of the second stage will act as the load resistor for the first stage.

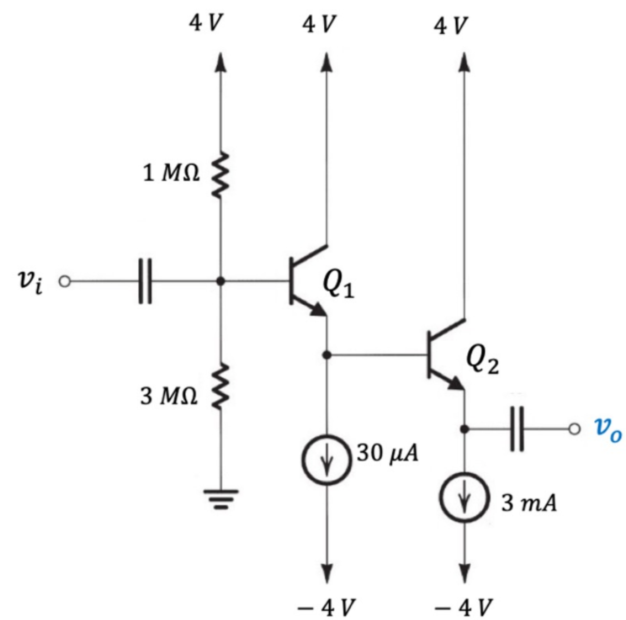
For a common-collector amplifier use $A_{vo} = \frac{(1/g_m)\|r_\pi\|R_E\|r_o}{(1/g_m)\|r_\pi}$

Practice problem 2.

a) $I_{E_2} = 3\,mA$

KCL at Emitter of Q_1 : $I_{E_1} = I_{B_2} + 30\,\mu A$

This is an amplifier circuit so the BJTs will be in active mode.

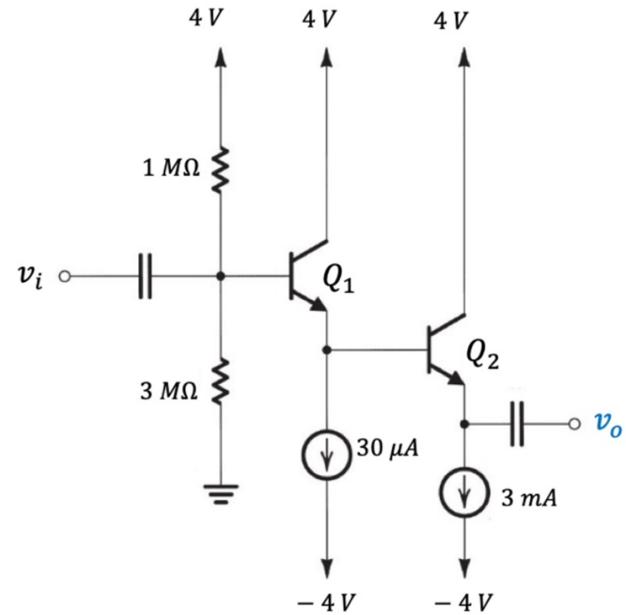


$$I_{B_2} = \frac{I_{E_2}}{1+\beta_2} = \frac{3\,mA}{101} = 29.7\,\mu A$$

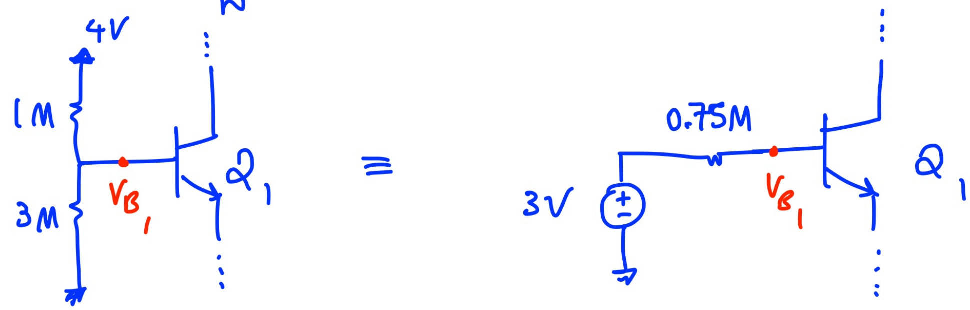
$$I_{E_1} = 29.7\,\mu A + 30\,\mu A = 59.7\,\mu A$$

$I_{E_1} = 59.7\,\mu A$

Practice problem 2.



The Thevenin equivalent



$$V_{B_1} = 3V - 0.75M\Omega \times I_{B_1}$$

$$I_{B_1} = \frac{I_{E_1}}{1+\beta_1} = \frac{59.7\mu A}{61} \simeq 0.98\,\mu A$$

$$V_{B_1} = 3V - 0.75 \times 0.98 = 2.265 \; V$$

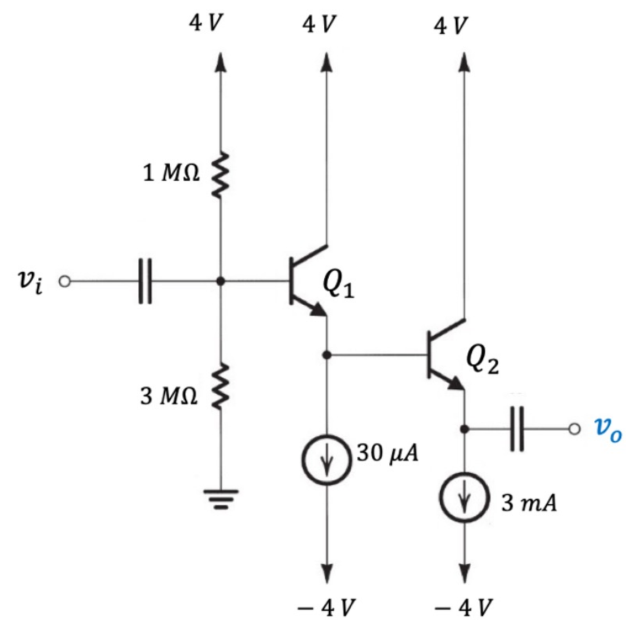
$$V_{B_2} = V_{E_1} = V_{B_1} - V_{BE_1} = 1.565 \; V$$

$$\boxed{V_{B_1} = 2.265 \; V}$$

$$\boxed{V_{B_2} = 1.565 \; V}$$

Practice problem 2.

b)



$$g_{m_2} = \frac{I_{C_2}}{V_T} = \frac{3mA \times \frac{100}{101}}{25mV} \simeq 118.8 \ mA/V$$

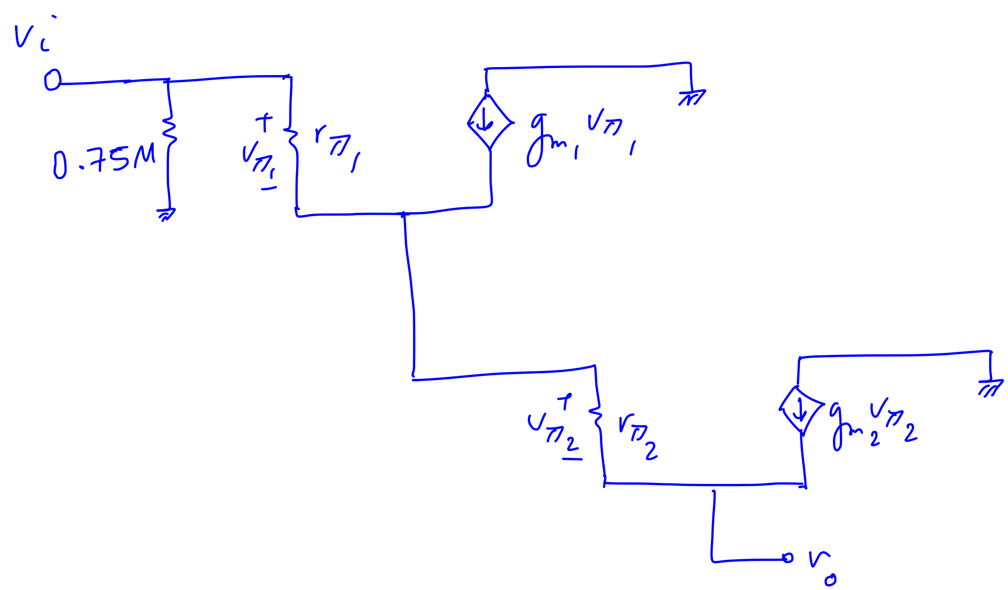
$$r_{\pi_2} = \frac{\beta_2}{g_{m_2}} \simeq 842 \ \Omega$$

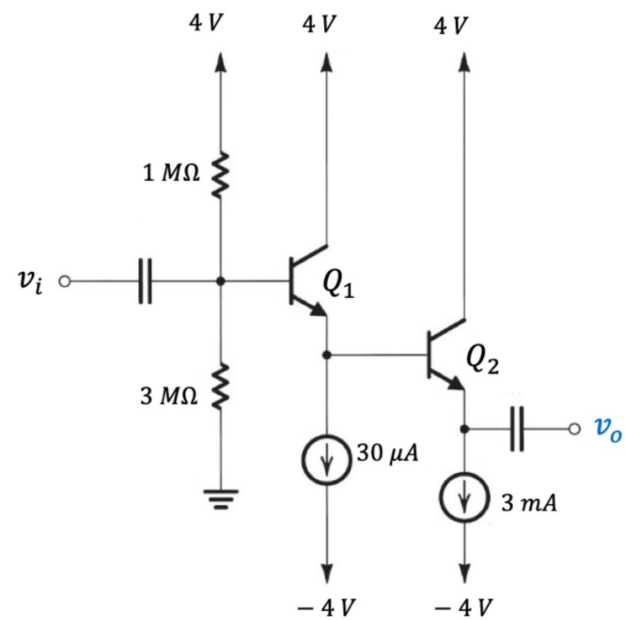
$$g_{m_1} = \frac{I_{C_1}}{V_T} = \frac{59.7 \mu A \times \frac{60}{61}}{25mV} = 2.35 \ mA/V$$

$$r_{\pi_1} = \frac{\beta_1}{g_{m_1}} = 25.53 \ k\Omega$$

Practice problem 2.

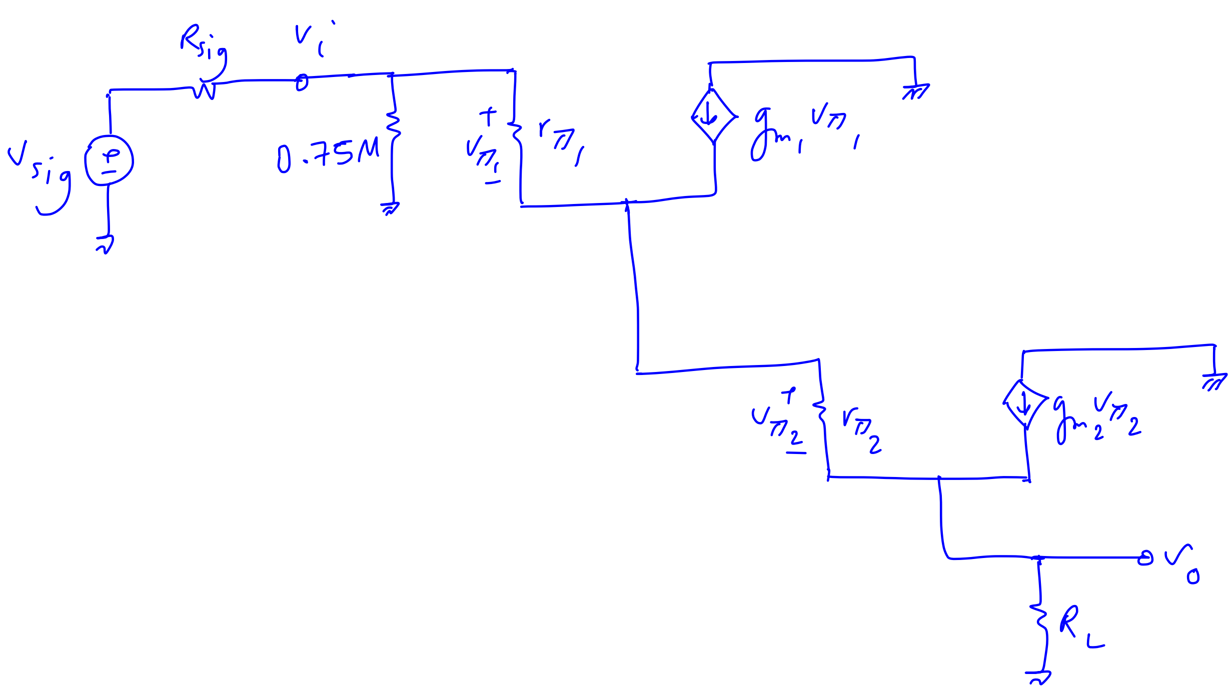
Small signal circuit:

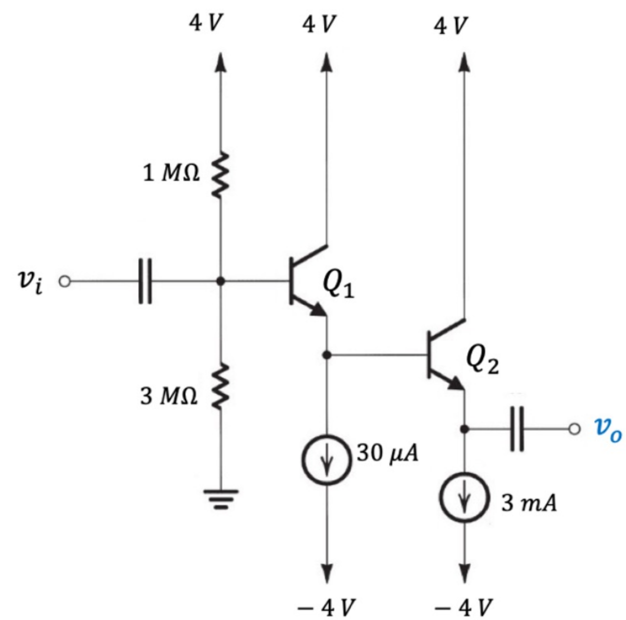




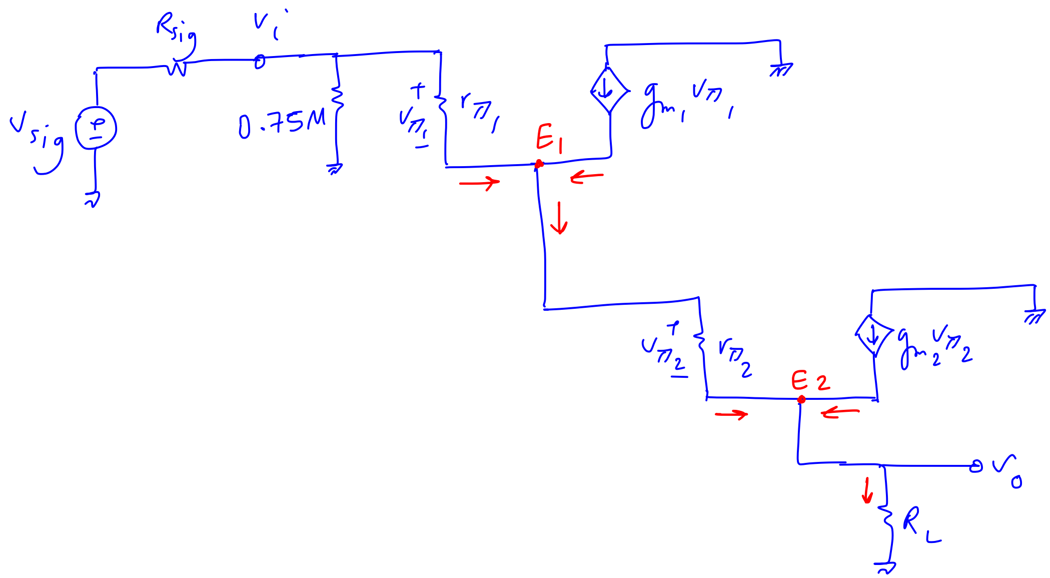
Practice problem 2.

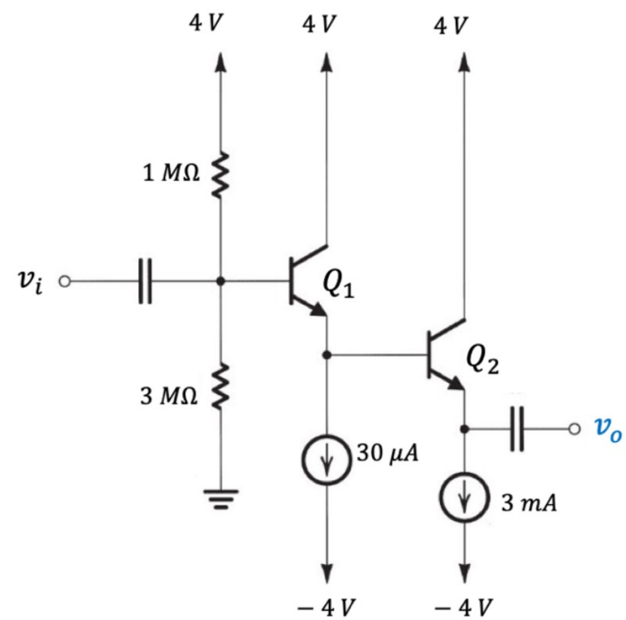
Small signal circuit After adding the load and the signal source:





Practice problem 2.





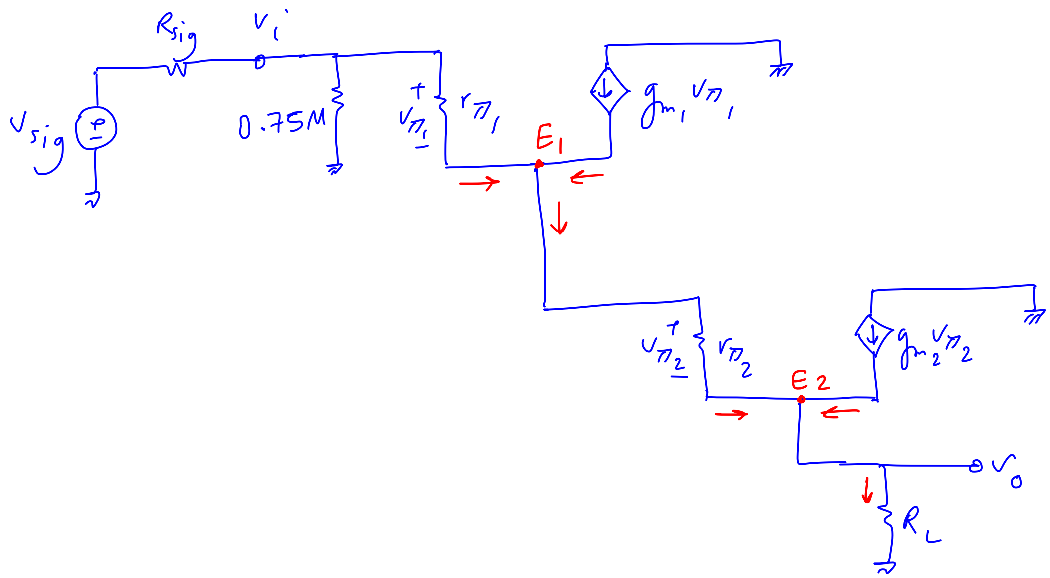
KCL at E_2 :

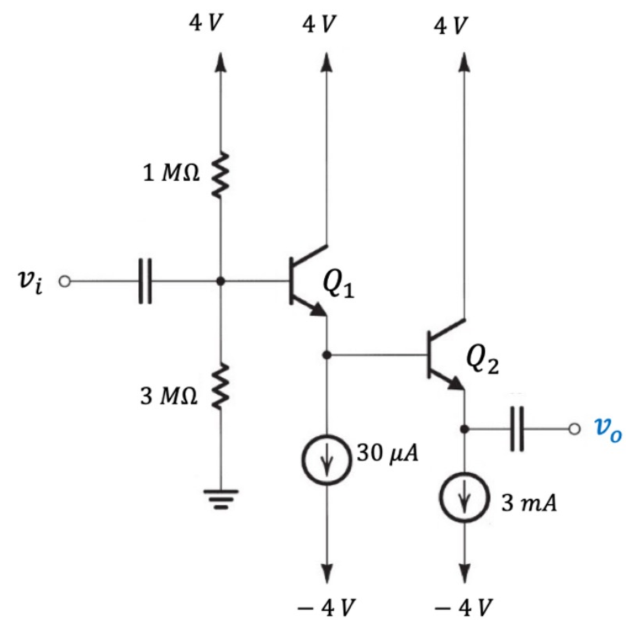
$$g_{m_2} V_{\pi_2} + \frac{V_{\pi_2}}{r_{\pi_2}} = \frac{V_o}{R_L} \longrightarrow V_{\pi_2} = \frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right) V_o$$

KCL at E_1 :

$$g_{m_1} V_{\pi_1} + \frac{V_{\pi_1}}{r_{\pi_1}} = \frac{V_{\pi_2}}{r_{\pi_2}} \longrightarrow V_{\pi_1} = \frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right) V_{\pi_2}$$

Practice problem 2.



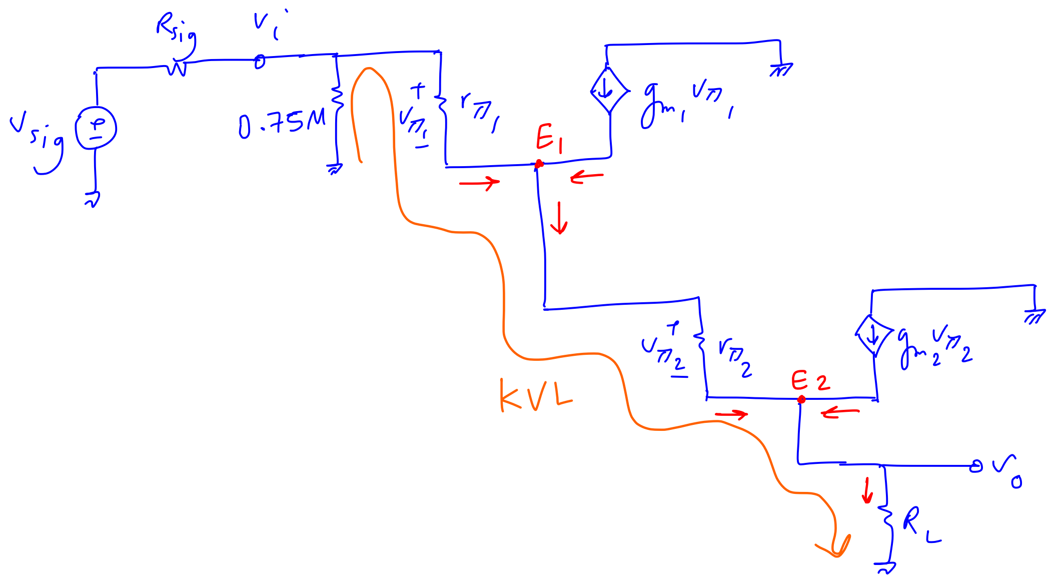


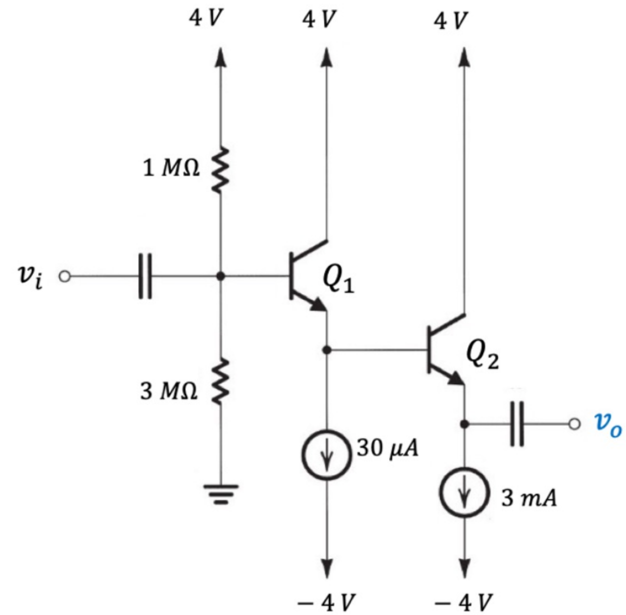
$$v_{\pi_2} = \frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right) v_o$$

$$v_{\pi_1} = \frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right) v_{\pi_2}$$

$$v_{\pi_1} = \frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right)\right) v_o$$

Practice problem 2.



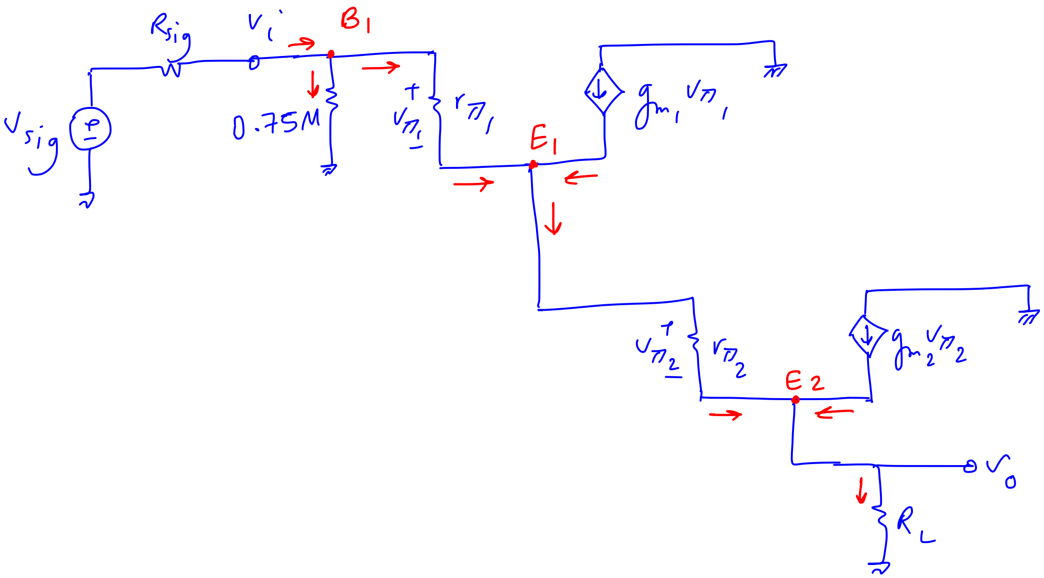


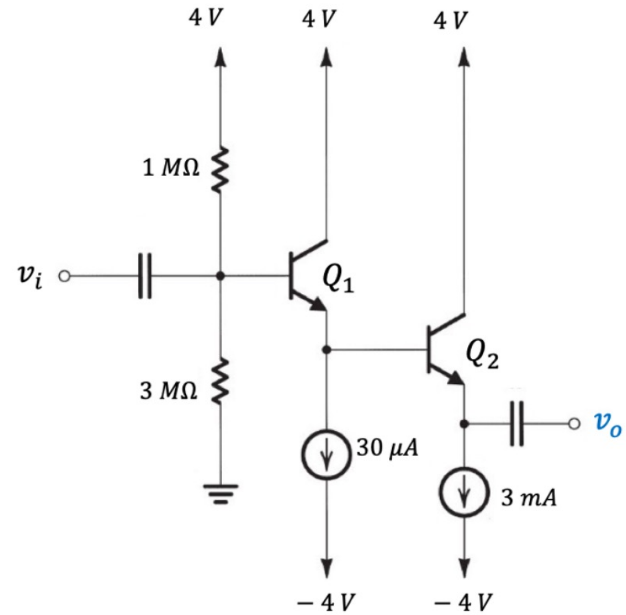
B_1E_2 KVL :

$$v_i = v_{\pi_1} + v_{\pi_2} + v_o = v_o\left(\boxed{\frac{v_{\pi_1}}{v_o}} + \boxed{\frac{v_{\pi_2}}{v_o}} + \boxed{1}\right)$$

$$v_i = v_o\left(\boxed{\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right)\right)} + \boxed{\frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_\pi}}\right)} + \boxed{1}\right)$$

Practice problem 2.





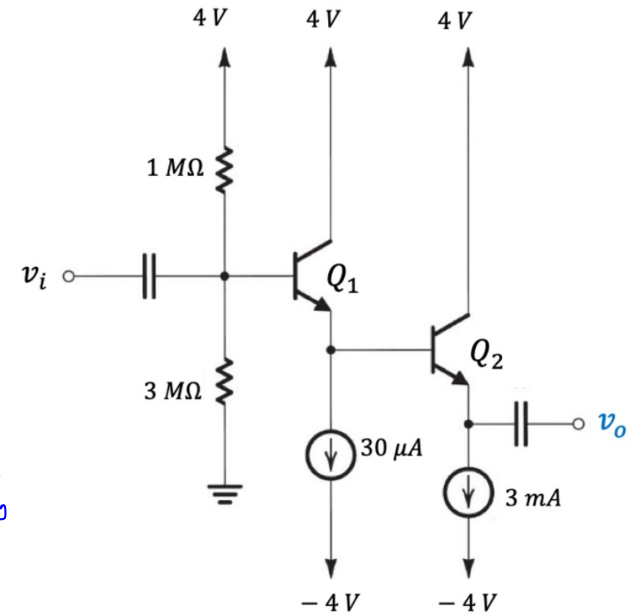
KCL at B_1

$$\frac{v_{sig} - v_i}{R_{sig}} = \frac{v_i}{0.75\,M\Omega} + \frac{v_{\pi_1}}{r_{\pi_1}}$$

$$v_{sig} = \left(1 + \frac{R_{sig}}{0.75\,M\Omega}\right) v_i + \frac{R_{sig}}{r_{\pi_1}} v_{\pi_1}$$

Practice problem 2.

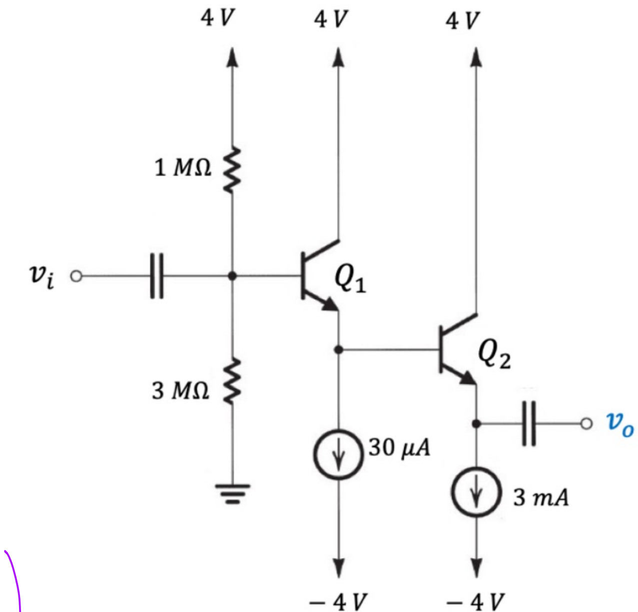
$$v_{sig} = \left(1 + \frac{R_{sig}}{0.75\,M\Omega}\right)\boxed{v_i} + \boxed{\frac{R_{sig}}{r_{\pi_1}} \quad v_{\pi_1}}$$



$$\boxed{\frac{R_{sig}}{r_{\pi_1}} \quad v_{\pi_1}} = \frac{R_{sig}}{r_{\pi_1}}\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right)\right)\right) v_o$$

$$\boxed{v_i} = v_o\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1} + \frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi_2}}}\right)\right) + \frac{1}{R_L}\left(\frac{1}{g_{m_2} + \frac{1}{r_{\pi}}}\right) + 1\right)$$

Practice problem 2.



$$V_{sig} = \left(1 + \frac{R_{sig}}{0.75\ M\Omega}\right)\boxed{V_i} + \boxed{\frac{R_{sig}}{r_{\pi_1}} V_{\pi_1}}$$

$$\boxed{\frac{R_{sig}}{r_{\pi_1}} V_{\pi_1}} = \frac{R_{sig}}{r_{\pi_1}}\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1}+\frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi_2}}}\right)\right)\right)V_o$$

$$\boxed{V_i} = V_o\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1}+\frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi_2}}}\right)\right) + \frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi}}}\right) + 1\right)$$

$$\frac{V_{sig}}{V_o} = \left(1 + \frac{R_{sig}}{0.75\ M\Omega}\right)\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1}+\frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi_2}}}\right)\right) + \frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi}}}\right) + 1\right) +$$

$$\frac{R_{sig}}{r_{\pi_1}}\left(\frac{1}{r_{\pi_2}}\left(\frac{1}{g_{m_1}+\frac{1}{r_{\pi_1}}}\right)\left(\frac{1}{R_L}\left(\frac{1}{g_{m_2}+\frac{1}{r_{\pi_2}}}\right)\right)\right)$$

$$\boxed{\frac{v_o}{v_{sig}} \simeq 0.997\ V/V}$$