ECE 65: Components & Circuits Lab

Lecture 22

Common collector amplifier parameters

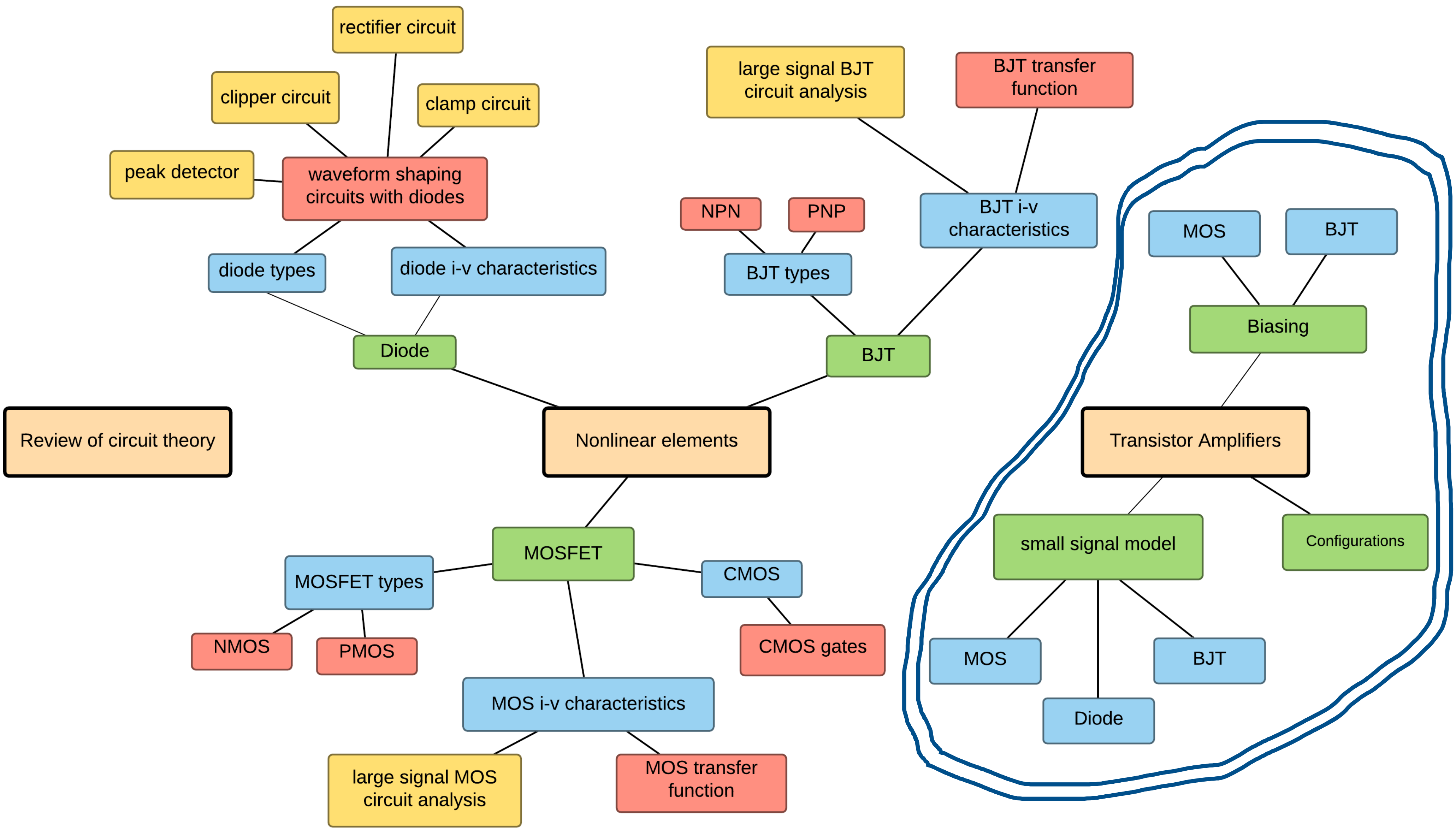
Reference notes: sections 6.1, 6.2

Sedra & Smith (7^{th} Ed): sections 7.3

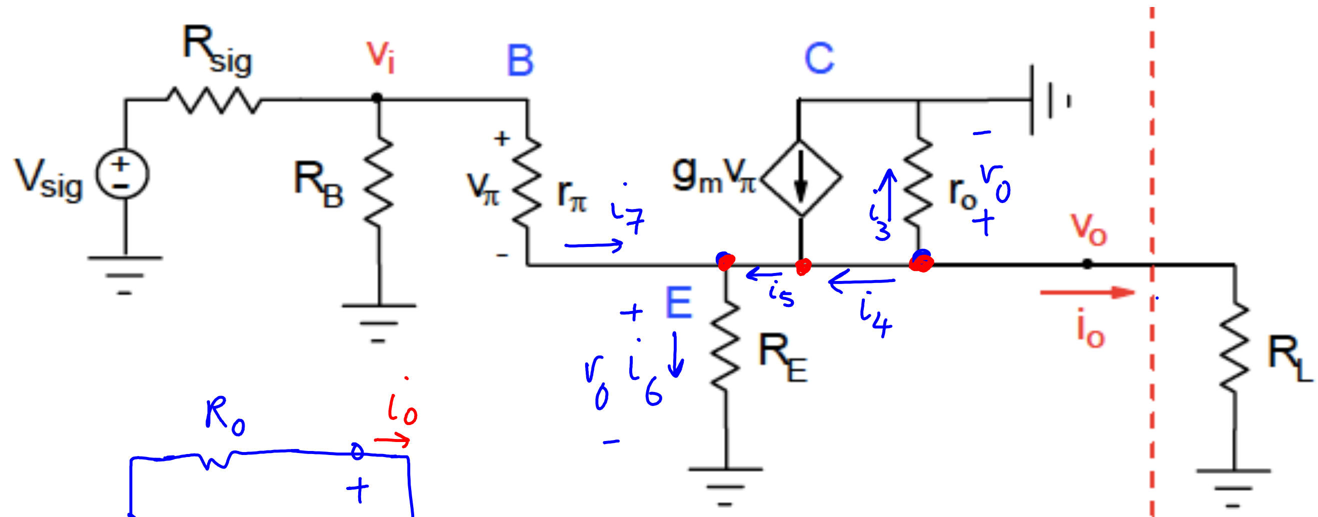
Saharnaz Baghdadchi

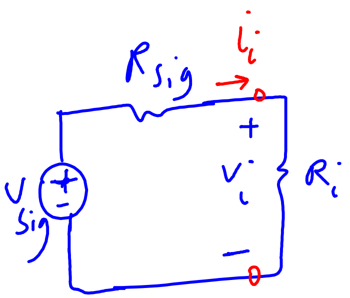
Course map

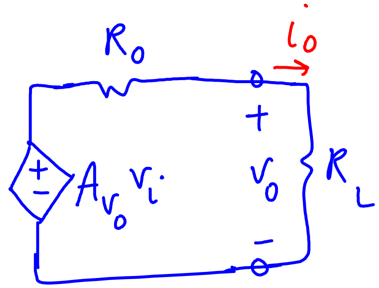
6. Transistor Amplifier Configurations



Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier







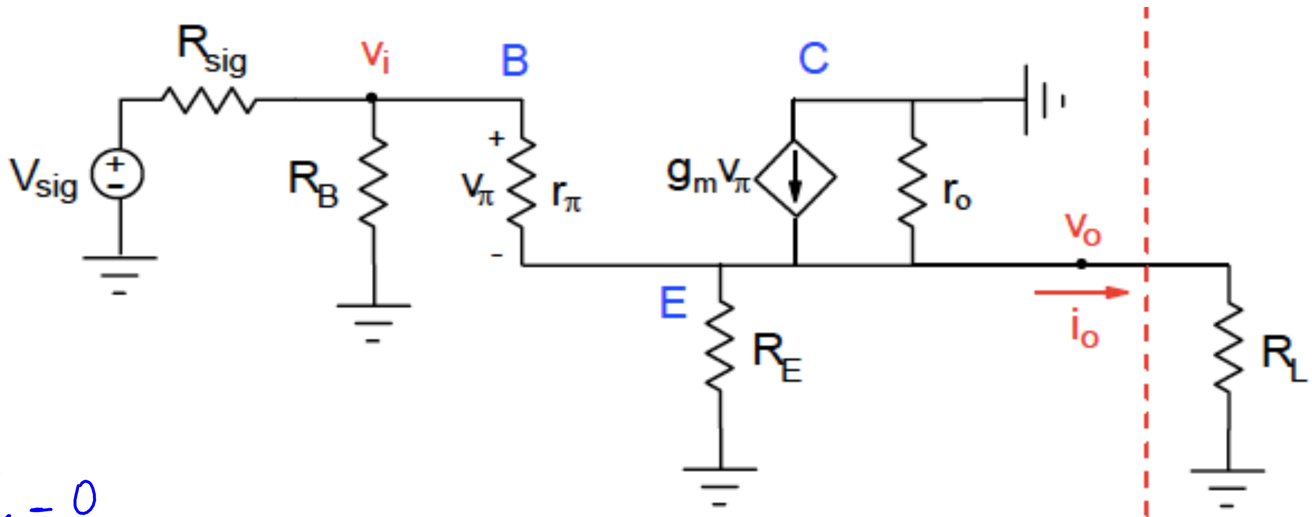
$$A_{v_o} v_i = v_o + R_o i_o$$

$$i_3 = \frac{v_o}{r_o}, \quad i_4 + i_o + i_3 = 0 \longrightarrow i_4 = -\left(i_o + \frac{v_o}{r_o}\right)$$

$$g_m v_\pi + i_4 - i_5 = 0 \longrightarrow i_5 = i_4 + g_m v_\pi = -\left(i_o + \frac{v_o}{r_o}\right) + g_m v_\pi$$

$$i_5 + i_7 - i_6 = 0, \quad i_6 = \frac{v_o}{R_E}, \quad i_7 = \frac{v_i - v_o}{r_\pi}, \quad v_\pi = v_i - v_o$$

Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier



$$i_5 + i_7 - i_6 = 0$$

$$-\left(i_o + \frac{v_o}{r_o}\right) + g_m (v_i - v_o) + \frac{v_i - v_o}{r_\pi} - v_o/R_E = 0$$

$$\left(g_m + \frac{1}{r_\pi}\right) v_i = \left(g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}\right) v_o + i_o$$

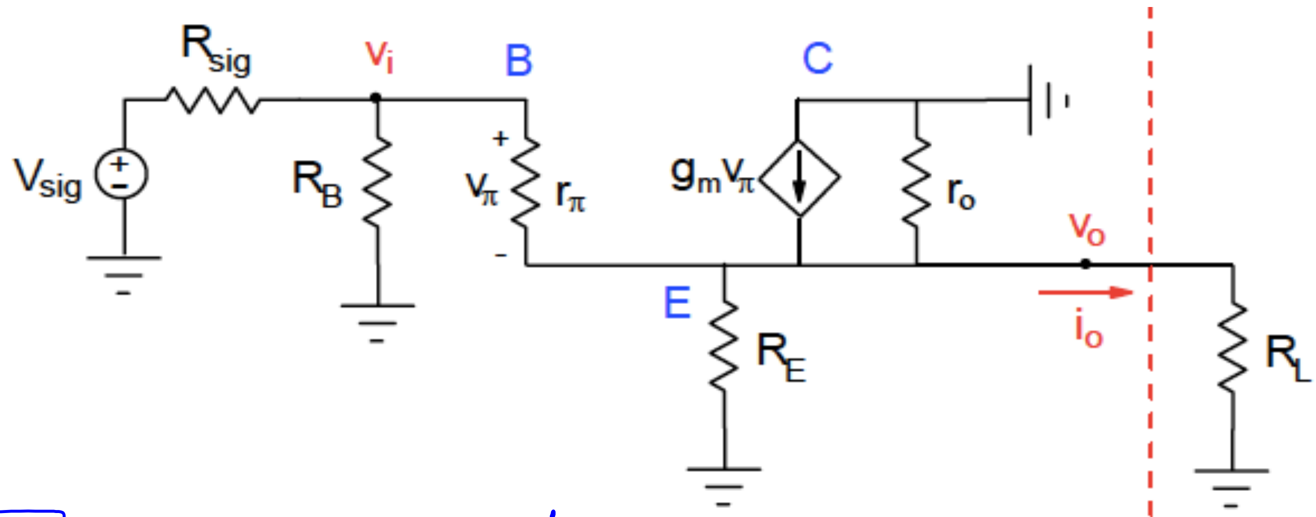
$$\Rightarrow \underbrace{\left(\frac{1}{g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}}\right)\left(g_m + \frac{1}{r_\pi}\right)}_{A_{vo}} v_i = v_o + \underbrace{\left(\frac{1}{g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}}\right)}_{R_o} i_o$$

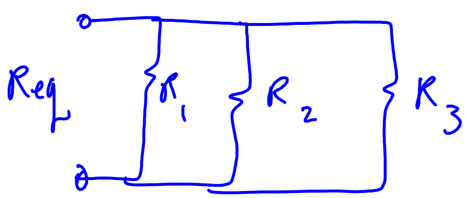
$$\boxed{A_{vo} v_i = v_o + R_o i_o}$$

$$g_m = \frac{1}{1/g_m}$$

g_m has the units of A/V

Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier



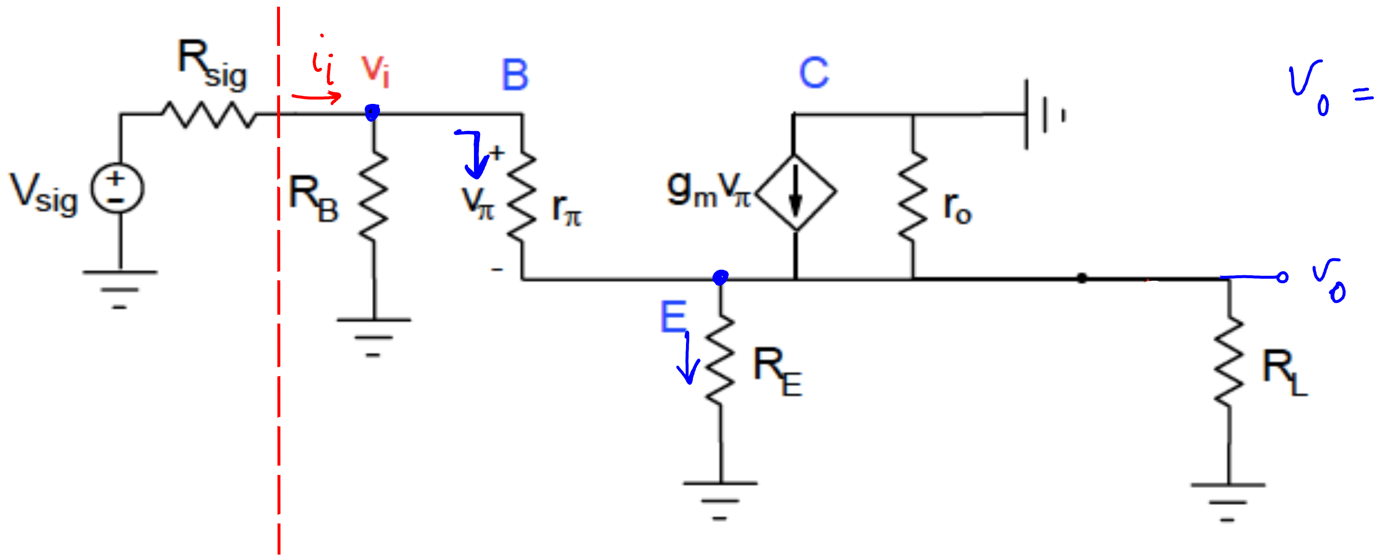


$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_o = \left(\frac{1}{g_m}\right) \| r_\pi \| R_E \| r_o$$

$$A_{v_o} = \frac{\left(\frac{1}{g_m}\right) \| r_\pi \| R_E \| r_o}{\left(\frac{1}{g_m}\right) \| r_\pi}$$

Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier



$v_o = v_i - v_\pi$

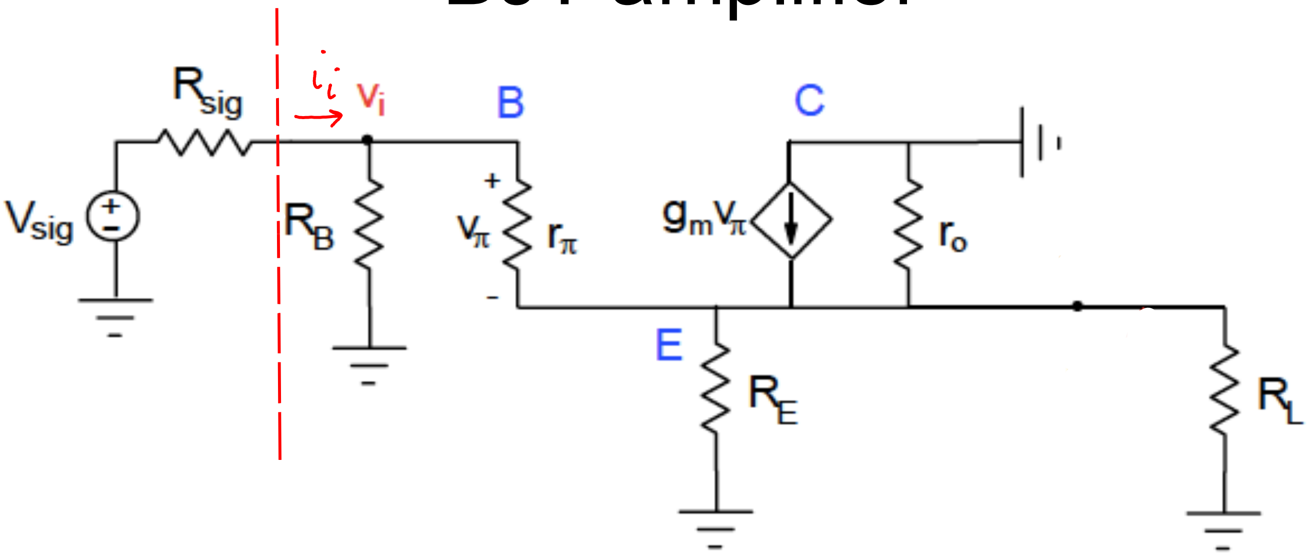
$R_i = \frac{v_i}{i_i}$

$i_i = \frac{v_i}{R_B} + \frac{v_\pi}{r_\pi}$

$\frac{v_\pi}{r_\pi} + g_m v_\pi = \left(\frac{v_i - v_\pi}{R_E}\right) + \left(\frac{v_i - v_\pi}{r_o}\right) + \frac{v_i - v_\pi}{R_L}$

$g_m = \frac{\beta}{r_\pi} \longrightarrow (\beta+1)\frac{v_\pi}{r_\pi} = \frac{v_i - v_\pi}{R_E \| r_o \| R_L}$

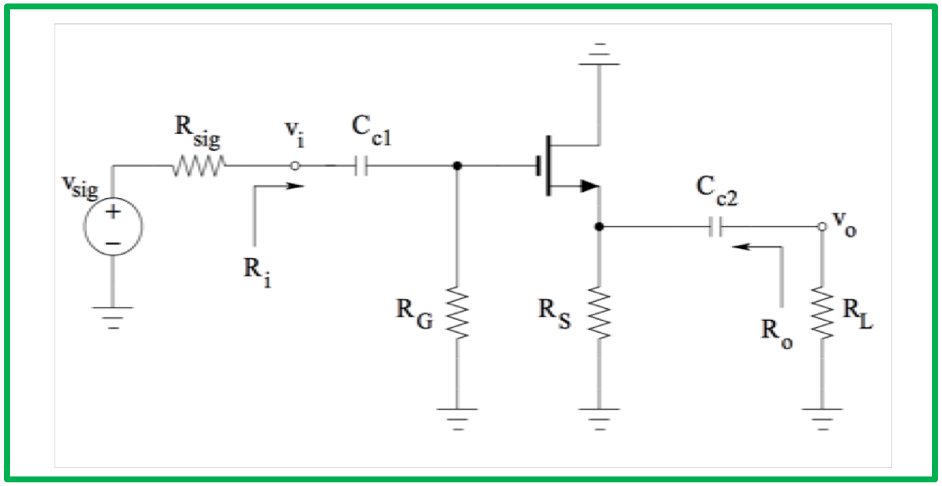
Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier

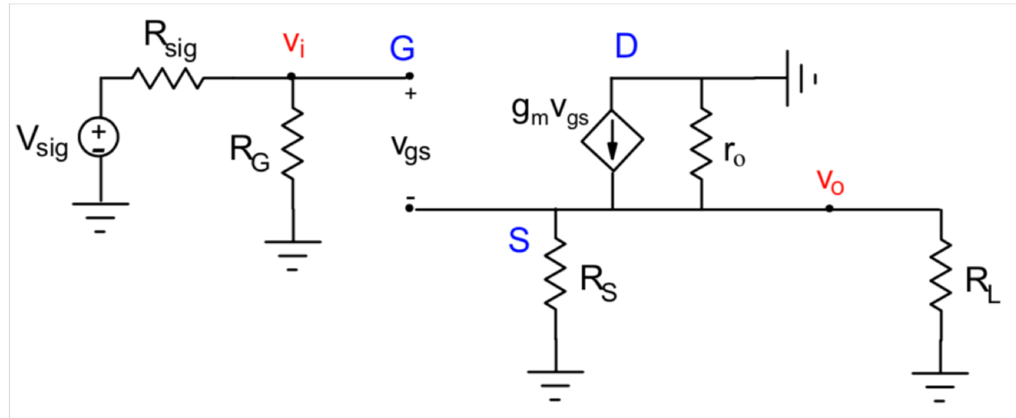


$$i_i = \frac{v_i}{R_B} + \frac{v_i}{r_\pi + (\beta+1)(R_E \| r_o \| R_L)}$$

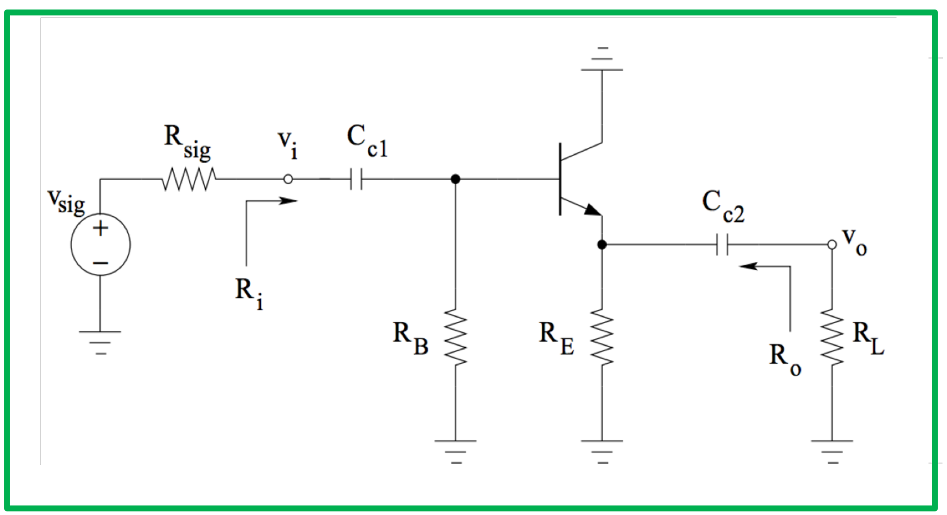
$$R_i = \frac{v_i}{i_i} \longrightarrow R_i = R_B \| \left[r_\pi + (\beta+1)(R_E \| r_o \| R_L) \right]$$

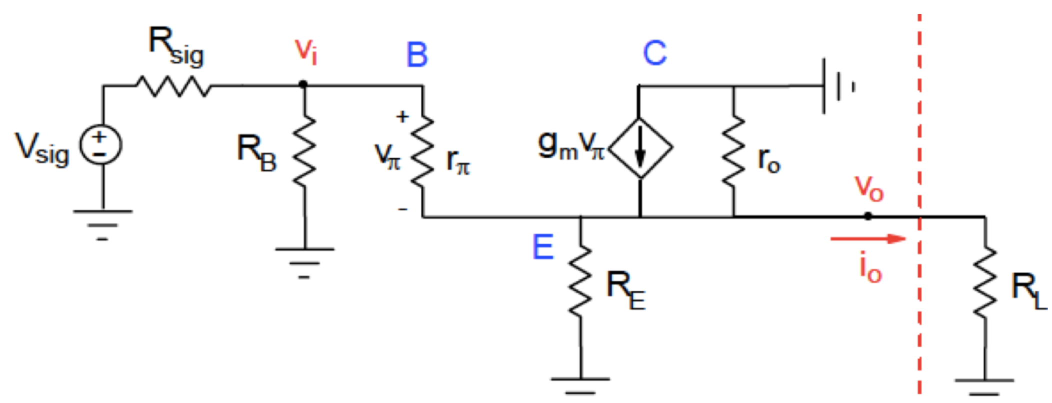
Common-Darin MOS amplifier parameters





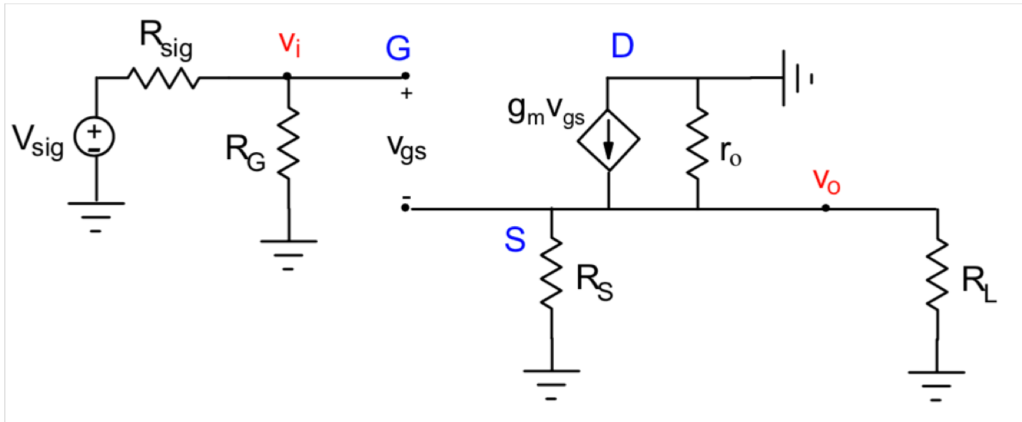
Compare it with the signal circuit for a common collector BJT amplifier:



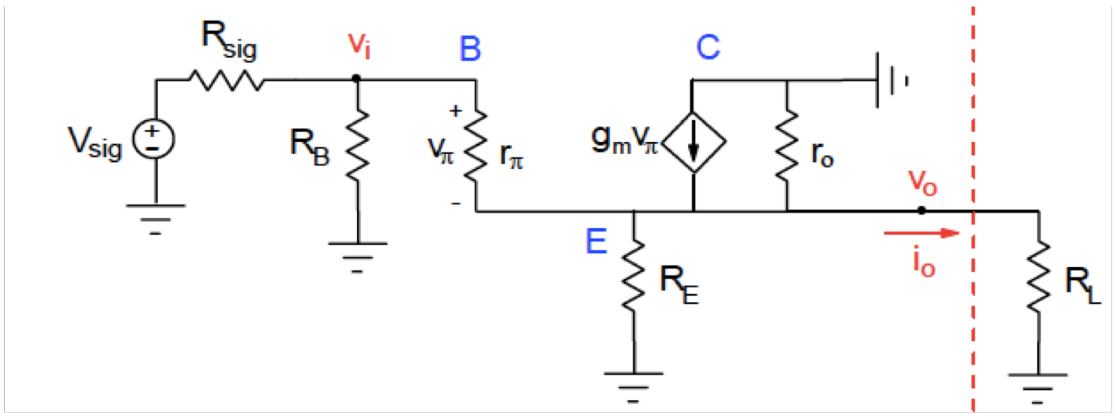


Common-Darin MOS amplifier parameters

In the derived equations for the common-collector BJT amplifier, replace R_B with R_G, R_E with R_S, and $r_\pi \to \infty$.



common collector BJT amplifier:



$$A_{vo} = \frac{g_m(R_S \,||\, r_o)}{1 + g_m(R_S \,||\, r_o)}$$

$$R_o = (1/g_m) \,||\, R_S \,||\, r_o$$

$$R_i = R_G$$

Some notes on *source follower* and *emitter follower* amplifiers:

- They have a voltage gain of lower than but close to unity.
- They have a low output resistance and a high input resistance.
- They are usually used as a voltage buffer.

source follower

$$A_{vo} = \frac{g_m(R_S \,||\, r_o)}{1 + g_m(R_S \,||\, r_o)}$$

$$R_o = (1/g_m) \,||\, R_S \,||\, r_o$$

$$R_i = R_G$$

emitter follower

$$A_{vo} = \frac{g_m(R_E \,||\, r_o)}{1 + g_m(R_E \,||\, r_o)}$$

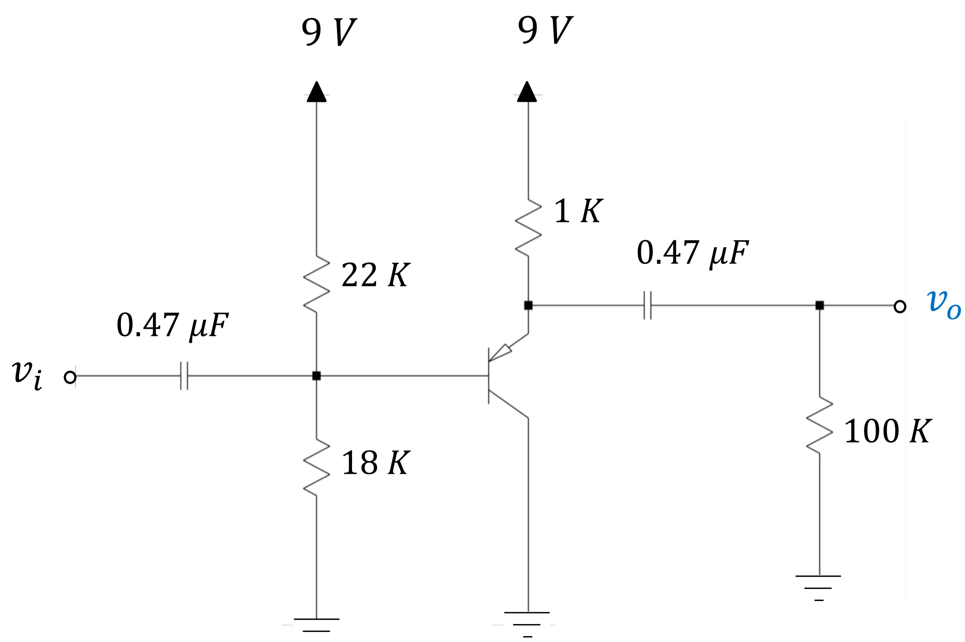
$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

$$R_i = R_B \,||\, [\, r_\pi + (\beta + 1)(\, r_o \,||\, R_E \,||\, R_L)]$$

Lecture 22 reading quiz

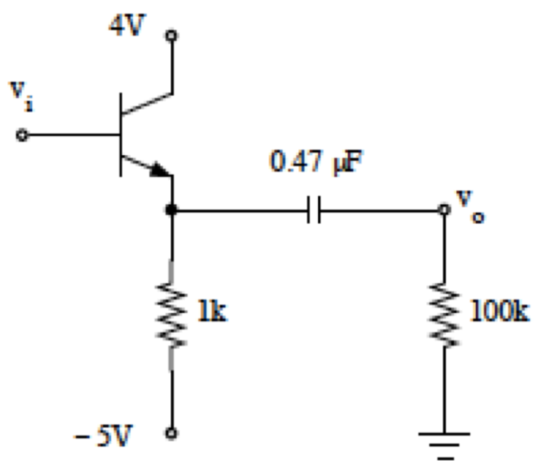
In the following circuit, find the amplifier parameters, R_o, R_i, A_{vo}.

Let $\beta = 100,\ V_T = 25\ mV,\ V_A = 150\ V$. Ignore the early effect in bias calculations.

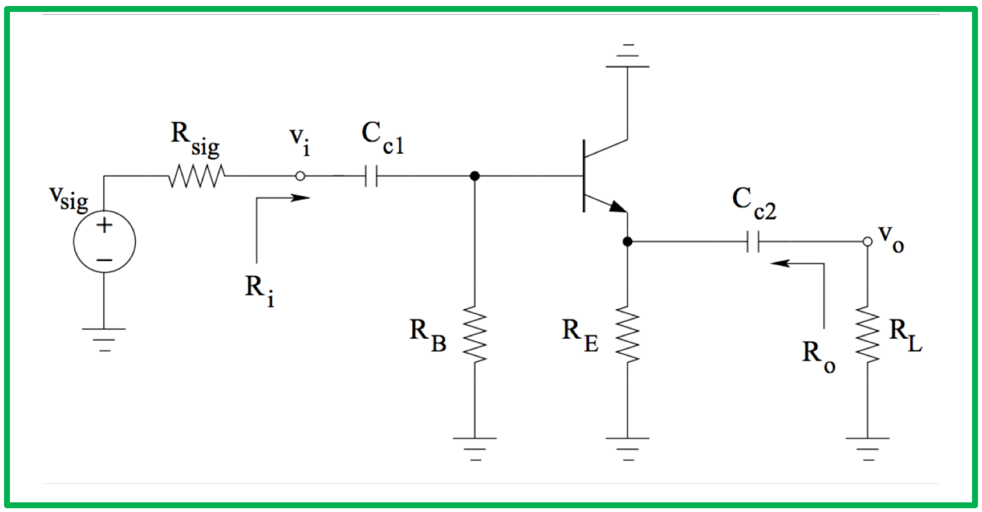


Discussion question 1

Write the A_{vo}, R_o, R_i equations for the following circuit by comparing it to the prototype circuit and using the derived equations.



The prototype common-collector circuit:



$$A_{vo} = \frac{g_m(R_E \,||\, r_o)}{1 + g_m(R_E \,||\, r_o)}$$

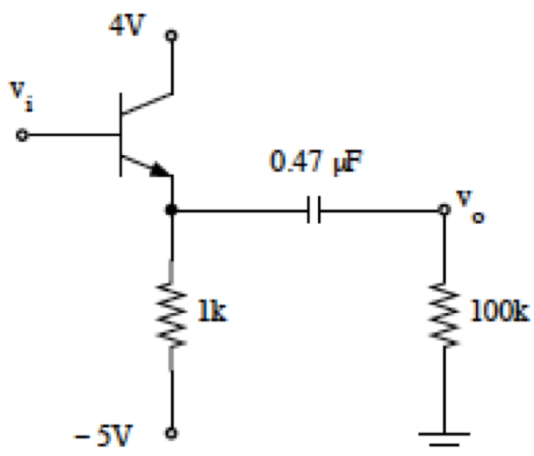
$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

$$R_i = R_B \,||\, [\, r_\pi + (\beta + 1)(\, r_o \,||\, R_E \,||\, R_L)]$$

Hints:

Discussion question 1

Write the A_{vo}, R_o, R_i equations for the following circuit by comparing it to the prototype circuit and using the derived equations.

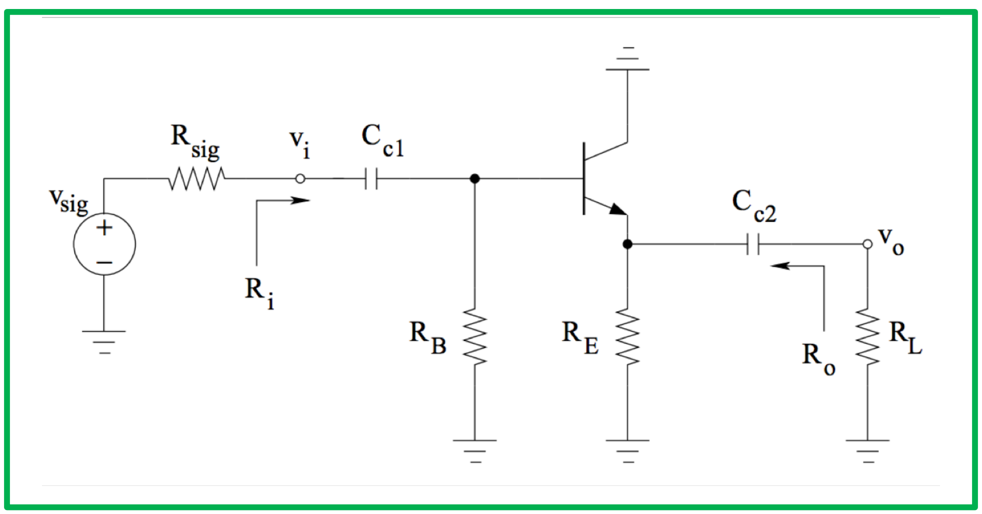


- Start with the equation of the input resistance. Look at the given circuit in the problem and find what RE,RL,RB are. Do all of them exist in the given circuit. If not how should you modify the equation of the input resistance to take that into account?

- Note that r_{pi}, r_o, and g_m are small signal parameters and will be calculated after solving the bias circuit, so in the modified equations, they will not be removed or changed.

- Do we need to change the equations of A_{vo} and R_o?

The prototype common-collector circuit:



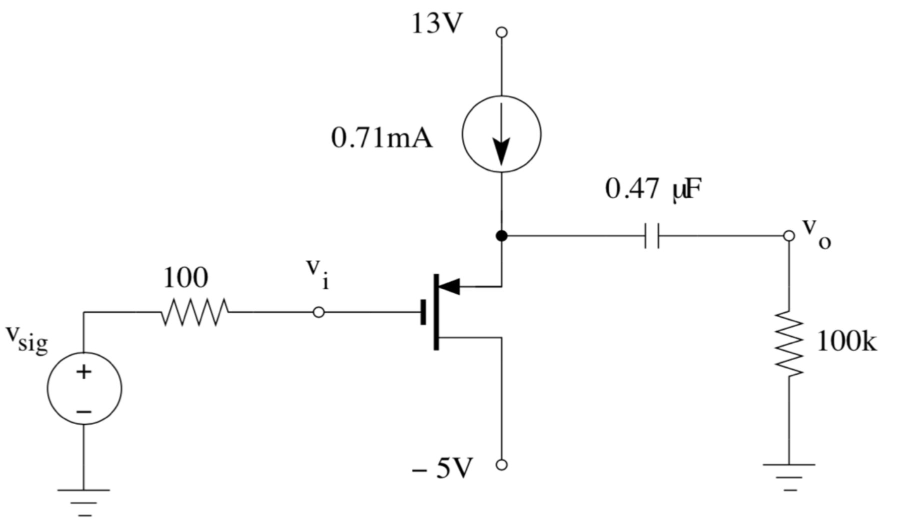
$$A_{vo} = \frac{g_m(R_E \,||\, r_o)}{1 + g_m(R_E \,||\, r_o)}$$

$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

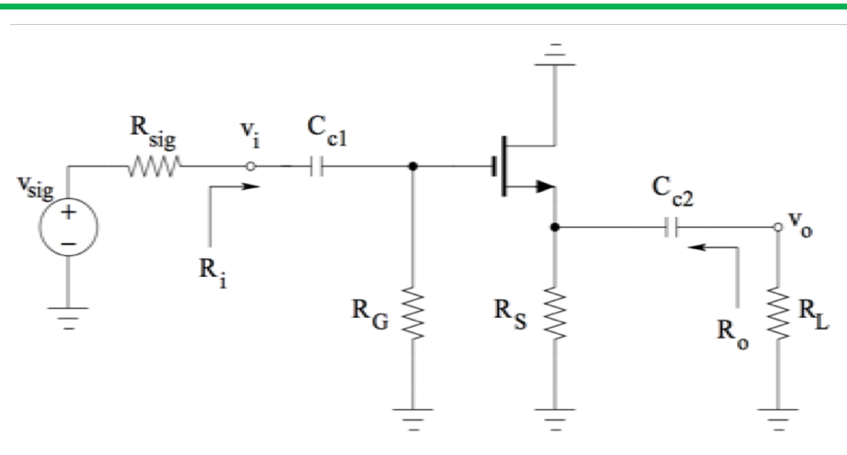
$$R_i = R_B \,||\, [\, r_\pi + (\beta + 1)(\, r_o \,||\, R_E \,||\, R_L)]$$

Discussion question 2.

Write the A_{vo}, R_o, R_i equations for the following circuit by comparing it to the prototype circuit and using the derived equations.



The prototype common-drain circuit:



$$A_{vo} = \frac{g_m(R_S \,||\, r_o)}{1 + g_m(R_S \,||\, r_o)}$$

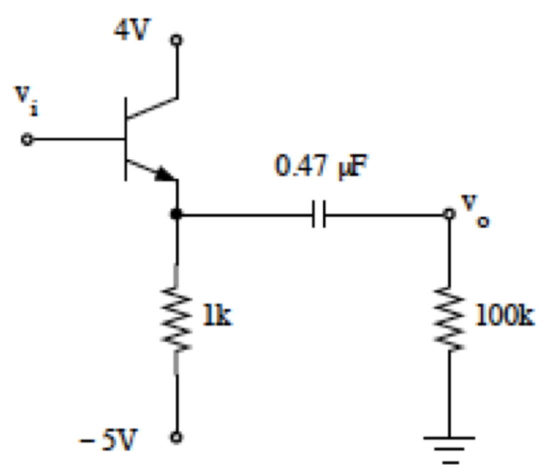
$$R_o = (1/g_m) \,||\, R_S \,||\, r_o$$

$$R_i = R_G$$

Hints:

Discussion question 1

Write the A_{vo}, R_o, R_i equations for the following circuit by comparing it to the prototype circuit and using the derived equations.

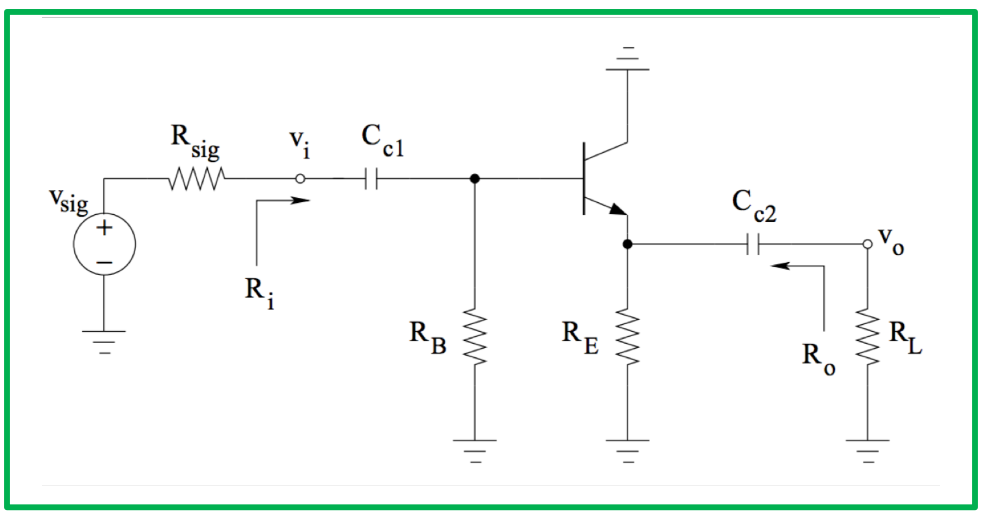


- Start with the equation of the input resistance. Look at the given circuit in the problem and find what RE,RL,RB are. Do all of them exist in the given circuit. If not how should you modify the equation of the input resistance to take that into account?

- Note that r_{pi}, r_o, and g_m are small signal parameters and will be calculated after solving the bias circuit, so in the modified equations, they will not be removed or changed.

- Do we need to change the equations of A_{vo} and R_o?

The prototype common-collector circuit:



$$A_{vo} = \frac{g_m(R_E \,||\, r_o)}{1 + g_m(R_E \,||\, r_o)}$$

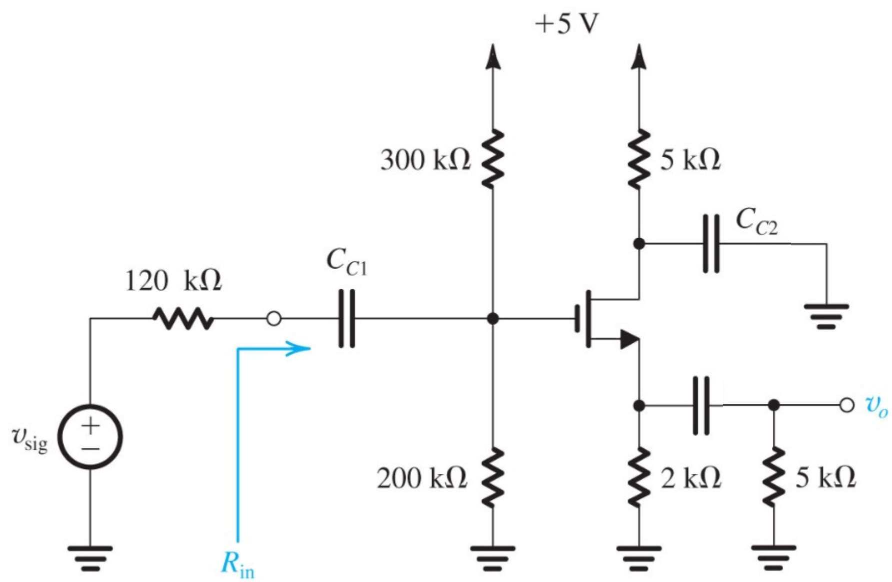
$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

$$R_i = R_B \,||\, [\, r_\pi + (\beta + 1)(\, r_o \,||\, R_E \,||\, R_L)]$$

Discussion question 3.

The NMOS in the below amplifier has $V_{tn} = 0.7\ V$ and $V_A = 50$ V. Neglecting the early effect, verify that the transistor is in saturation with $I_D = 0.5$ mA and $V_{OV} = 0.3$ V . What must the MOSFET's k_n be? What is the DC voltage at the drain?

Find R_i and A_v.



Hints:

Discussion question 3.

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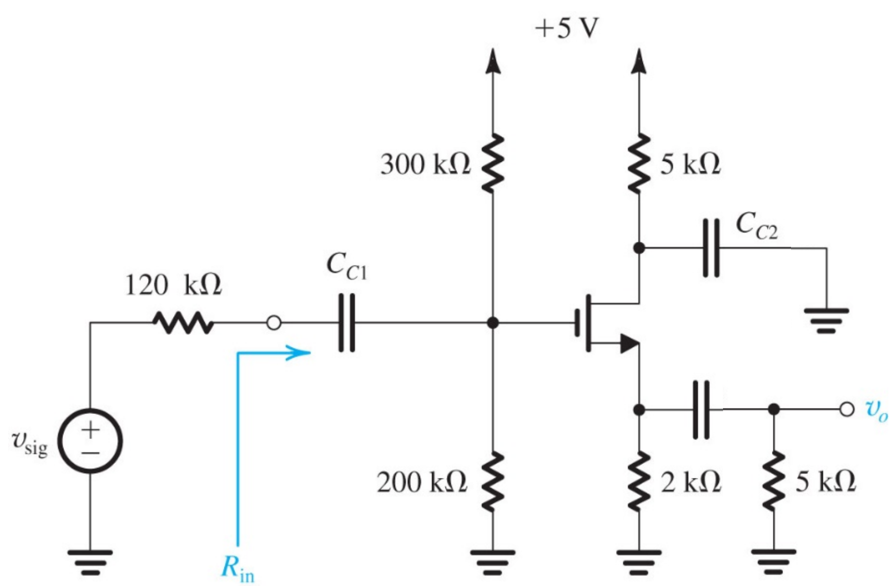
Find R_i and A_v.



- What is the condition of MOSFET operating in the saturation region?

- Draw and solve the bias circuit and verify that NMOS is in saturation.

- Use the characteristic drain current equation to find k_n.

- Identify the MOSFET amplifier type, and using the related set of equations, find R_i and A_v.