ECE 65: Components & Circuits Lab

Lecture 22

Common collector amplifier parameters

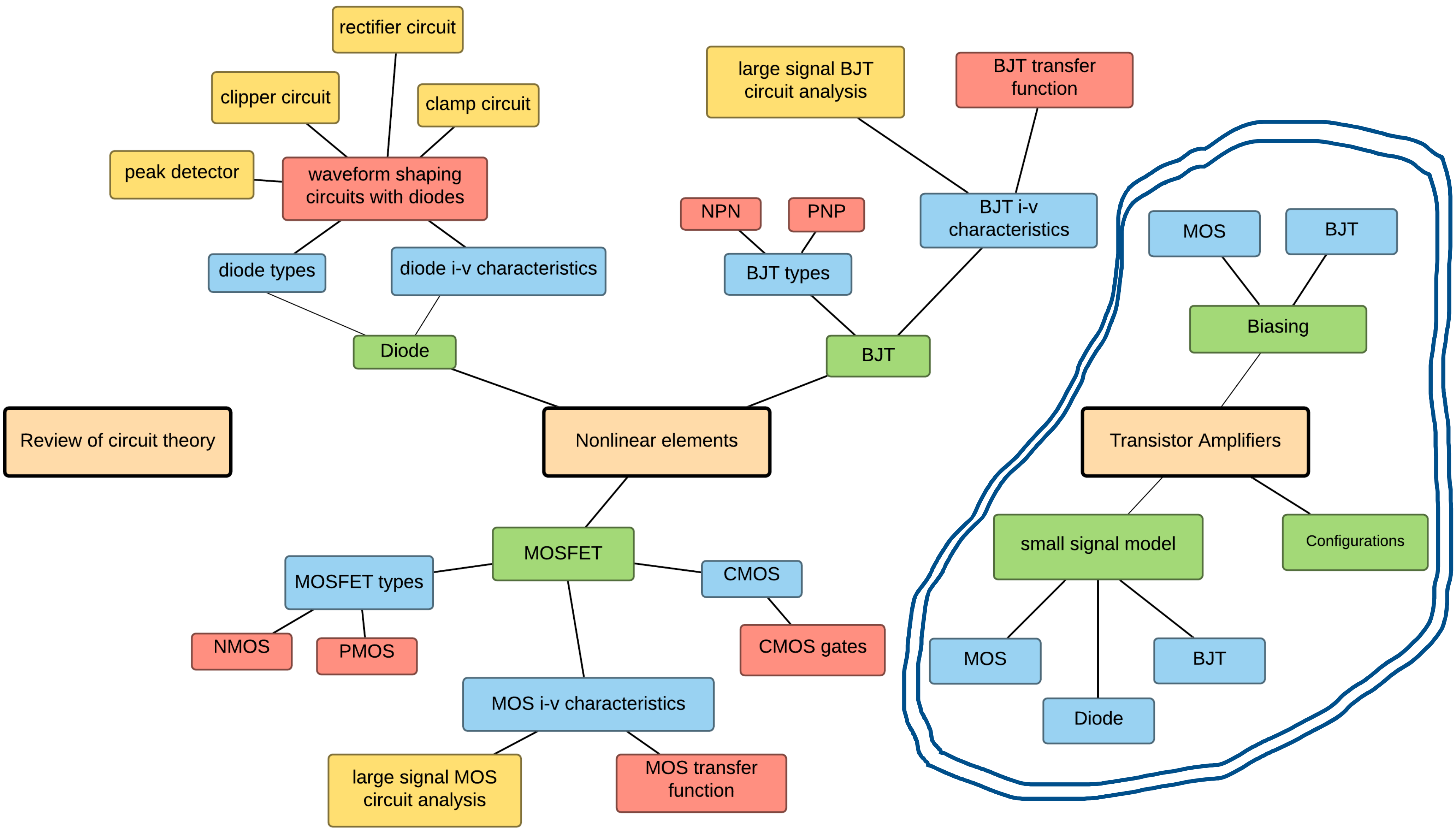
Reference notes: sections 6.1, 6.2

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

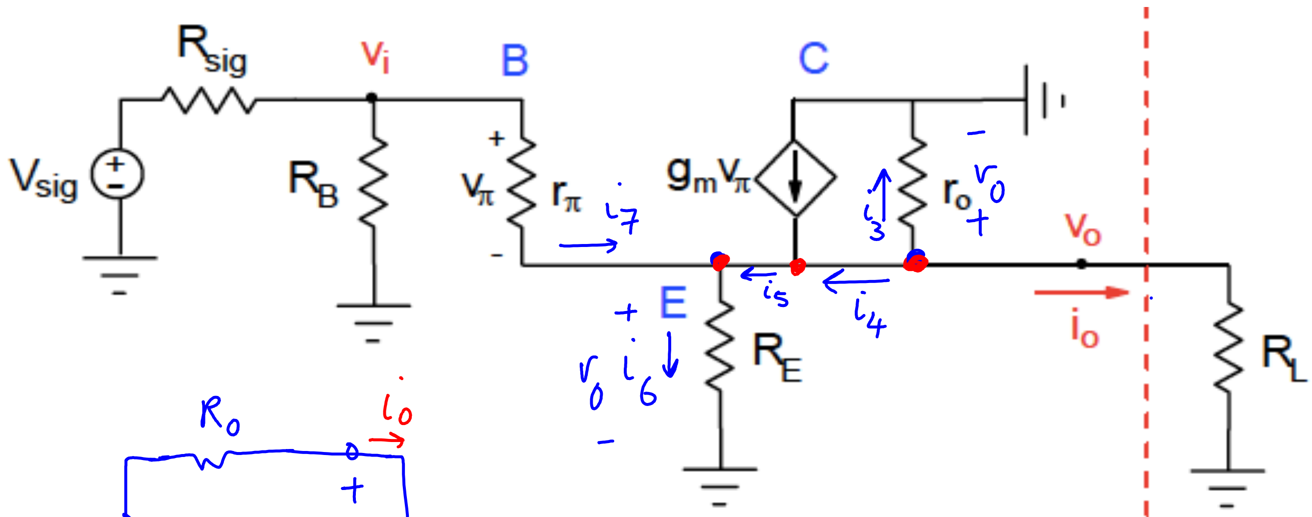
Saharnaz Baghdadchi

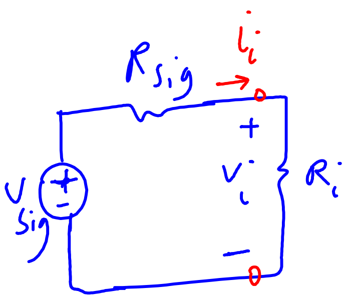
Course map

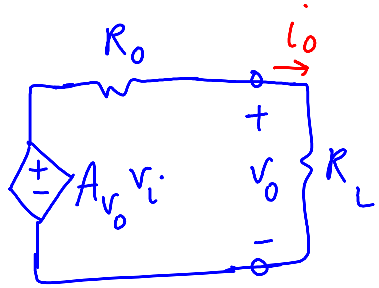
6. Transistor Amplifier Configurations



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







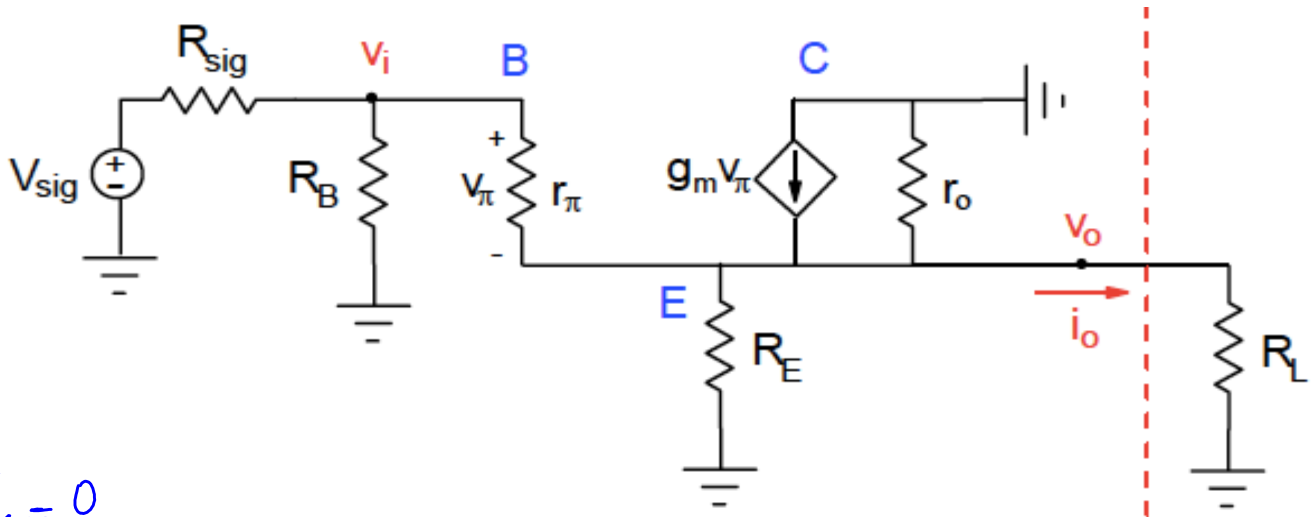
$$A_{v_o} v_i = v_o + R_o i_o$$

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

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

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

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



$$i_5 + i_7 - i_6 = 0$$

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

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

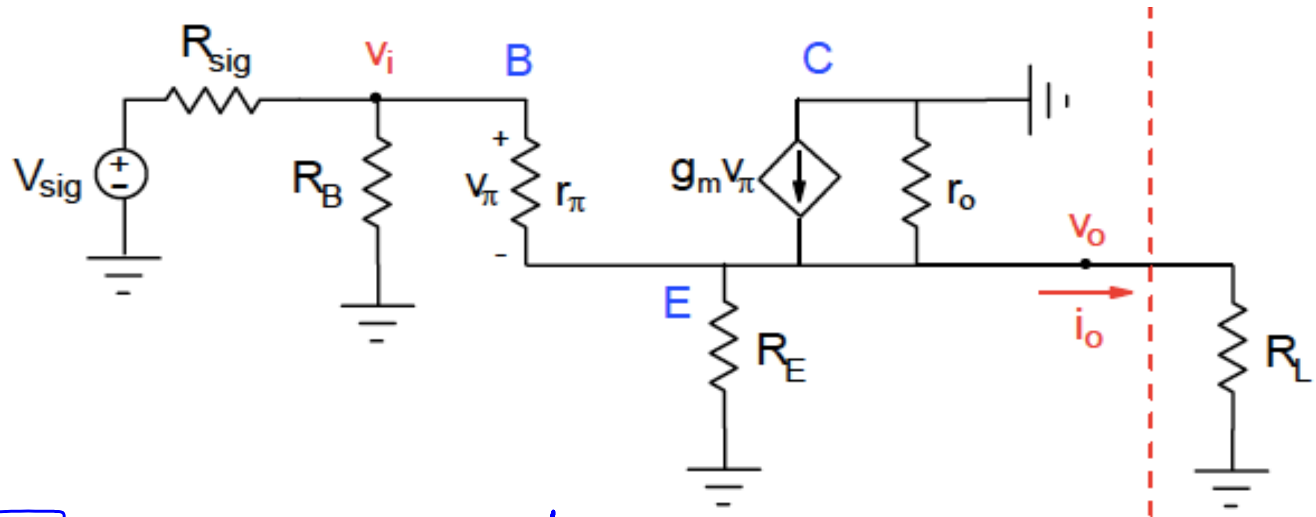
$$\Rightarrow \overbrace{\boxed{\left(\frac{1}{g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}}\right)\left(g_m + \frac{1}{r_\pi}\right)}}^{A_{vo}} v_i = v_o + \overbrace{\boxed{\left(\frac{1}{g_m + \frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}}\right)}}^{R_o} i_o$$

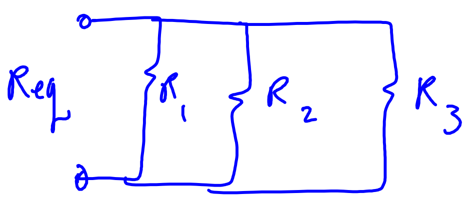
$$\boxed{A_{vo}\, v_i = v_o + R_o\, i_o}$$

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

g_m has the units of A/V

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



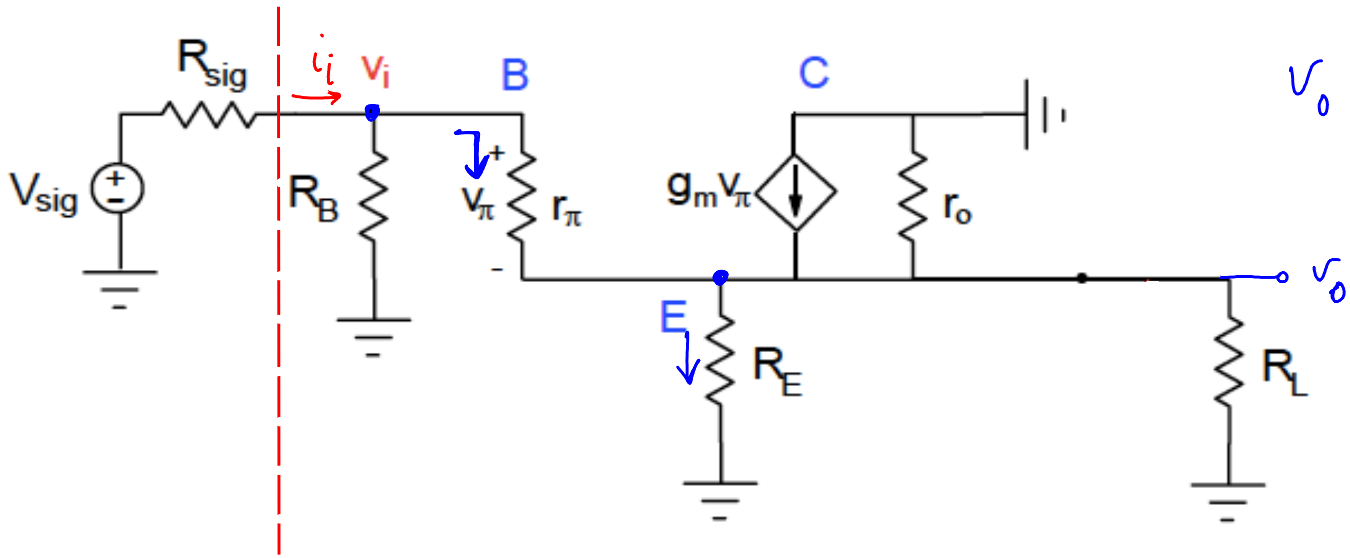


$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

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

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

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



$$v_o = v_i - v_\pi$$

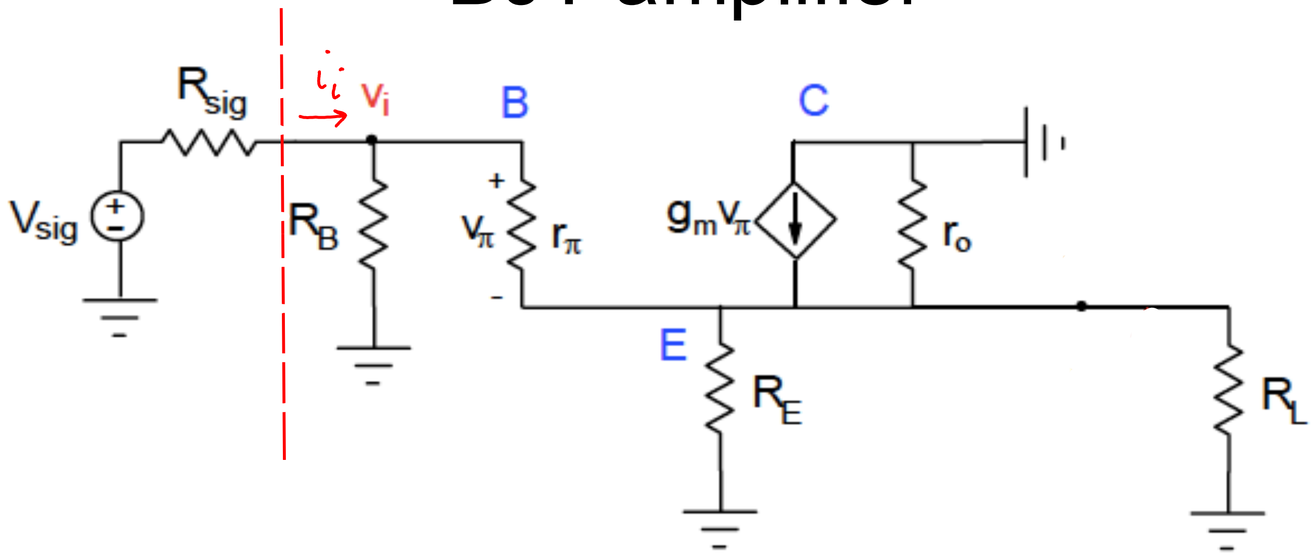
$$R_i = \frac{v_i}{i_i}$$

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

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

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

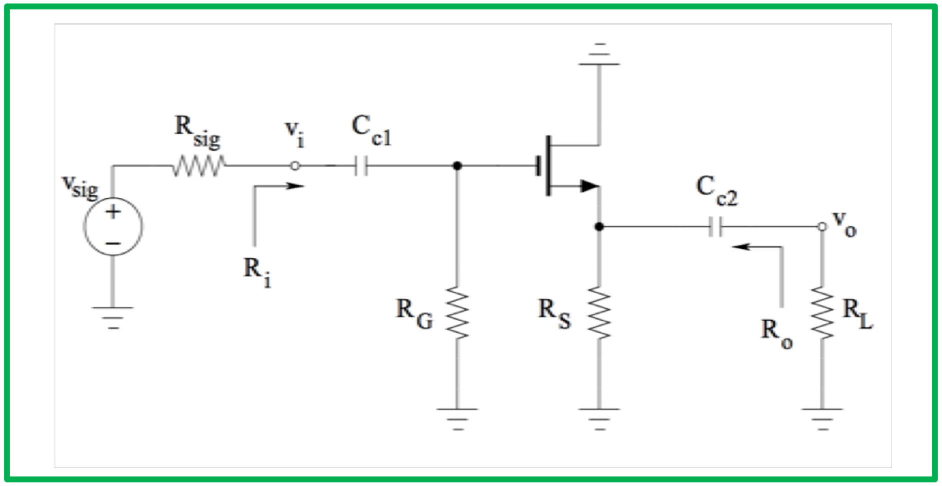
Derivation of A_{vo}, R_o, R_i for the common collector BJT amplifier

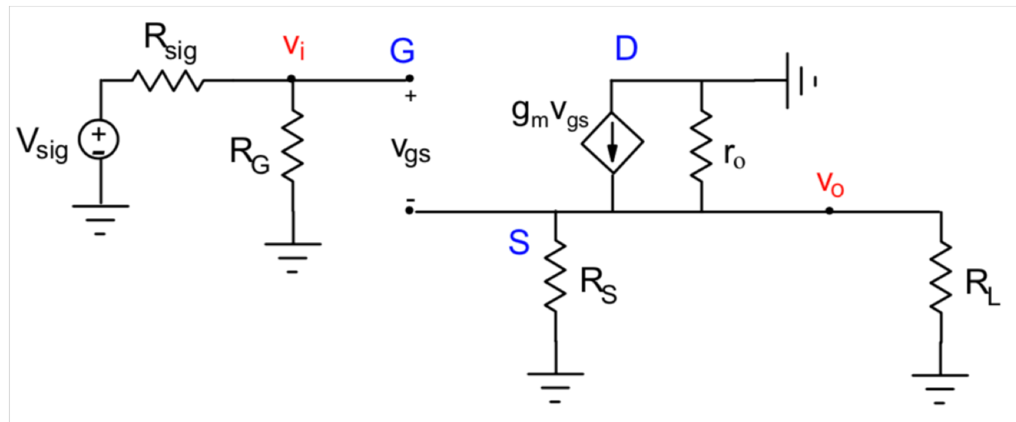


$$i_i = \frac{v_i}{R_B} + \frac{v_i}{r_\pi + (\beta+1)(R_E \| r_o \| R_L)}$$

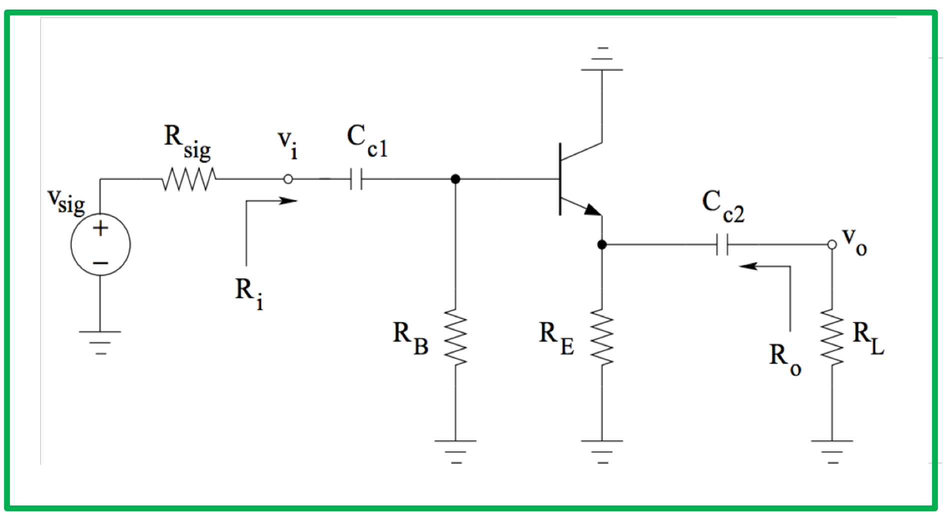
$$R_i = \frac{v_i}{i_i} \longrightarrow R_i = R_B \| \left[r_\pi + (\beta+1)(R_E \| r_o \| R_L) \right]$$

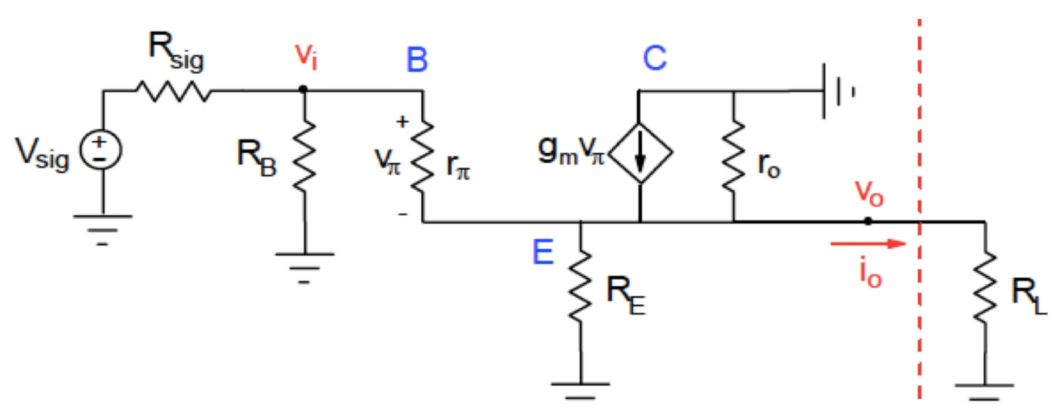
Common-Darin MOS amplifier parameters





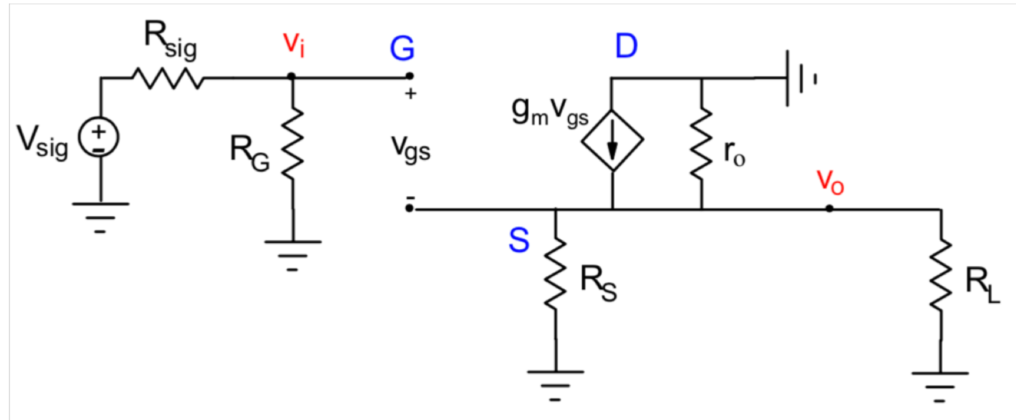
Compare it with the signal circuit for a common collector BJT amplifier:





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 $r_\pi \rightarrow \infty$.

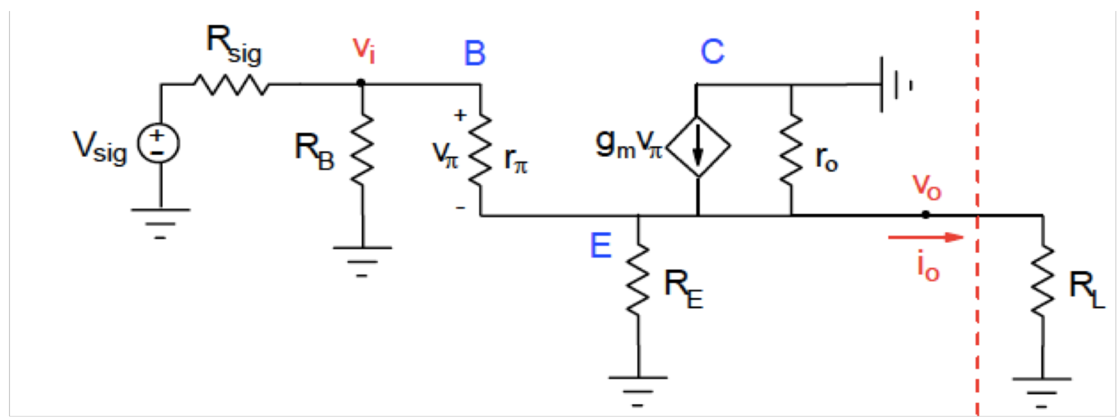


$$A_{vo} = \frac{g_m (R_S \,||\, r_o)}{1 + g_m (R_S \,||\, r_o)}$$

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

$$R_i = R_G$$

common collector BJT amplifier:



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

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

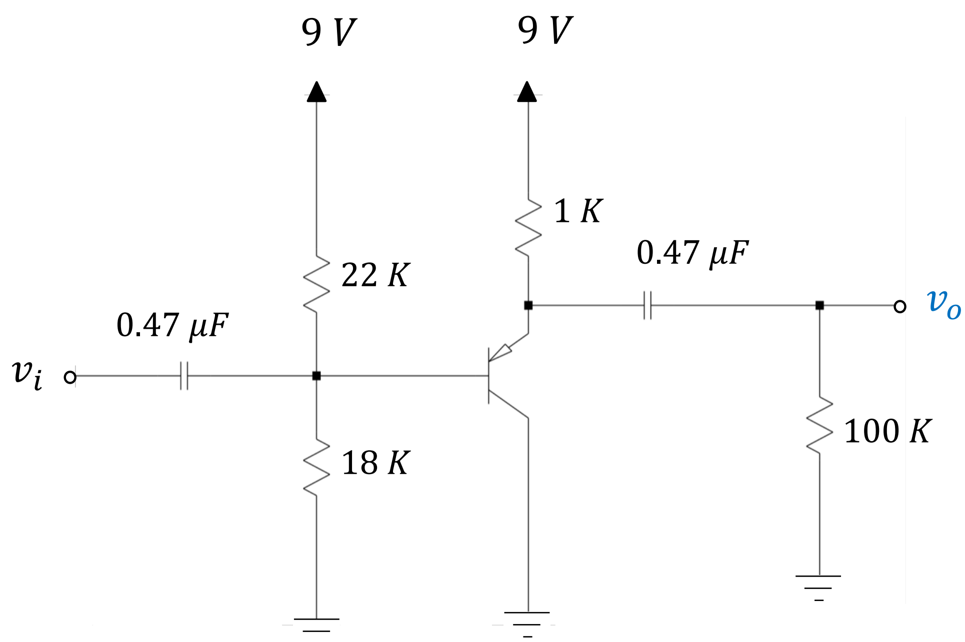
$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

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

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.

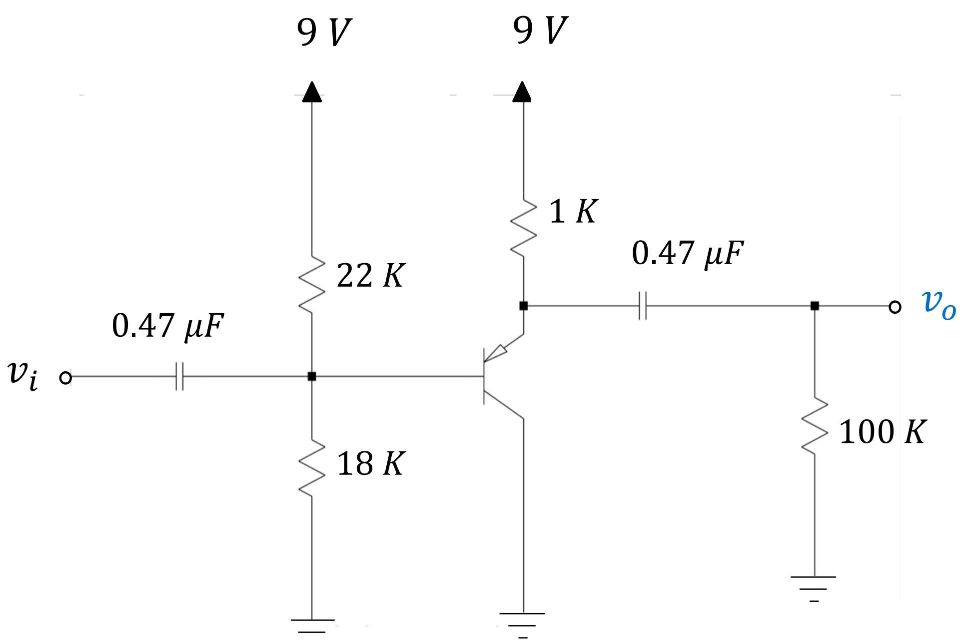


$$I_E = I_C + I_B = I_C + \frac{I_C}{\beta} = \frac{\beta+1}{\beta} I_C$$

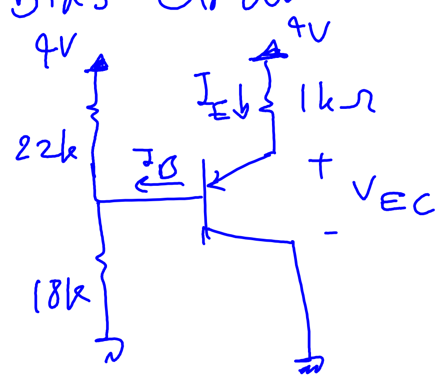
Lecture 22 reading quiz

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.



Bias Circuit:



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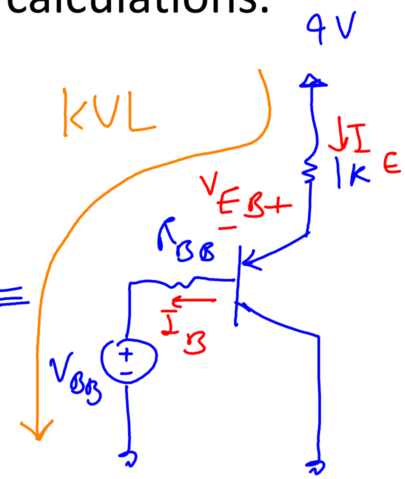


$R_{BB} = 22\,k\Omega \parallel 18\,k\Omega = 9.9\,k\Omega$

$V_{BB} = \frac{18\,k\Omega}{18\,k\Omega + 22\,k\Omega} \times 9V = 4.05\ V$

KVL: $9V = 1\,k\Omega \times I_E + 0.7V + R_{BB} \times \frac{I_E}{101} + 4.05$

$I_E = 3.87\ mA$

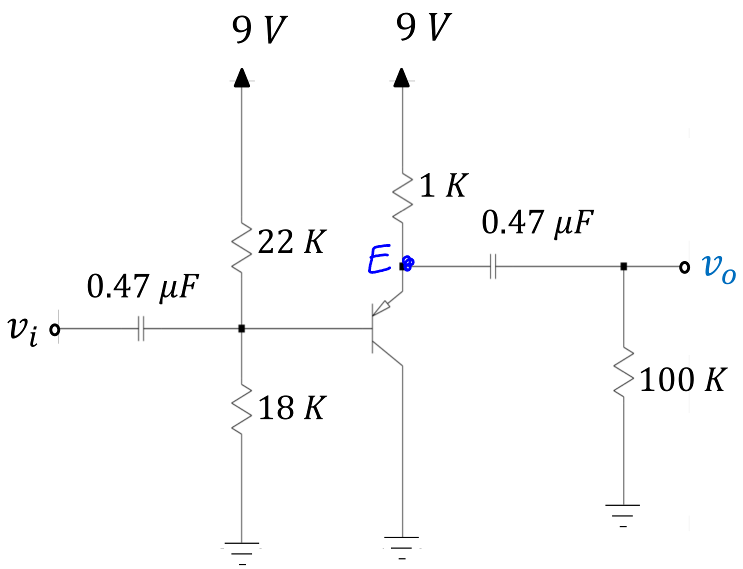
$I_B = 38.3\ \mu A$

$I_C \approx I_E = 3.87\ mA$

$V_{EC} = 9V - 1k \times I_E$

$V_{EC} = 5.13\ V$

Lecture 22 reading quiz



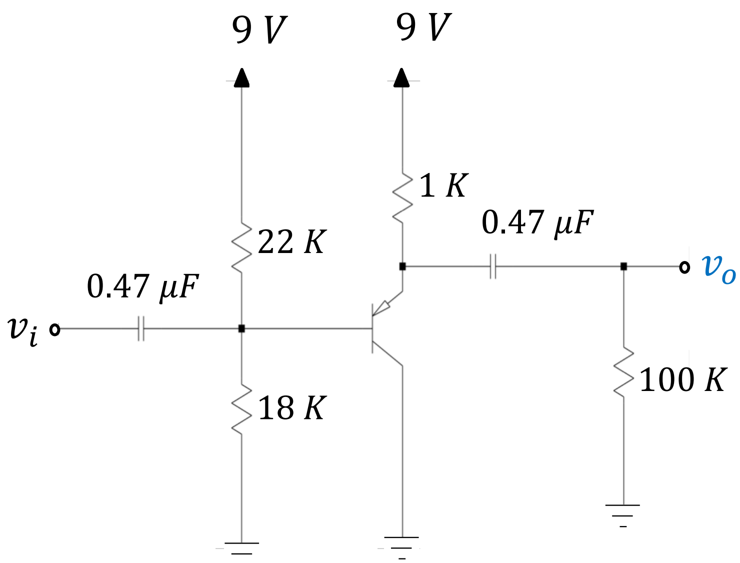
small signal parameters:

$$g_m = \frac{I_C}{V_T} = \frac{3.87\,mA}{25\,mV} \simeq 155\ mA/V$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{155\,mA/V} \simeq 645\ \Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{150\,V}{3.87\,mA} \simeq 39k$$

Lecture 22 reading quiz



Amplifier parameters:

$$A_{v_o} = \frac{g_m (R_E \parallel r_o)}{1 + g_m (R_E \parallel r_o)} = \frac{155\,mA/V\,(39k \parallel 1k)}{1 + 155\,mA/V\,(39k \parallel 1k)}$$

$$\boxed{A_{v_o} \simeq 0.99\ V/V}$$

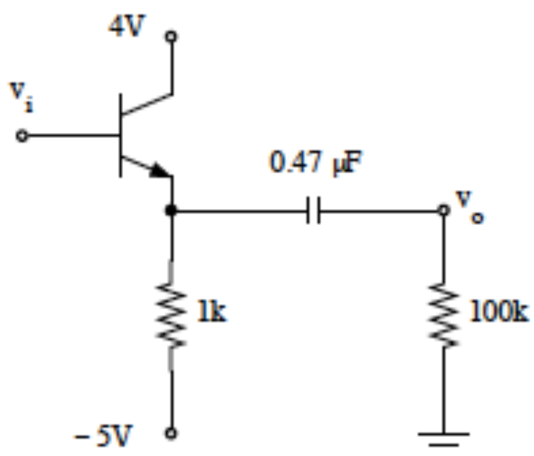
$$R_i = R_B \parallel \left[r_\pi + 101 \times (r_o \parallel R_E \parallel R_L) \right] \simeq 9\,k\Omega$$

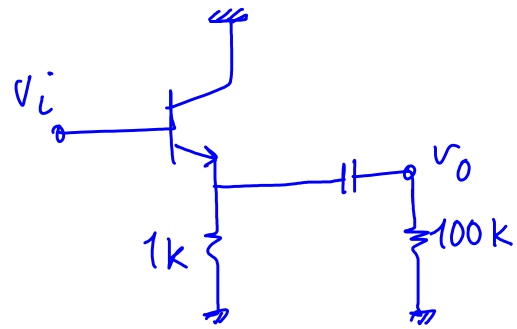
$$R_o = \left(\frac{1}{g_m}\right) \parallel r_\pi \parallel R_E \parallel r_o \simeq 6.3\,\Omega$$

Discussion question 1

β, V_A, λ, V_T, will be given to you.

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.



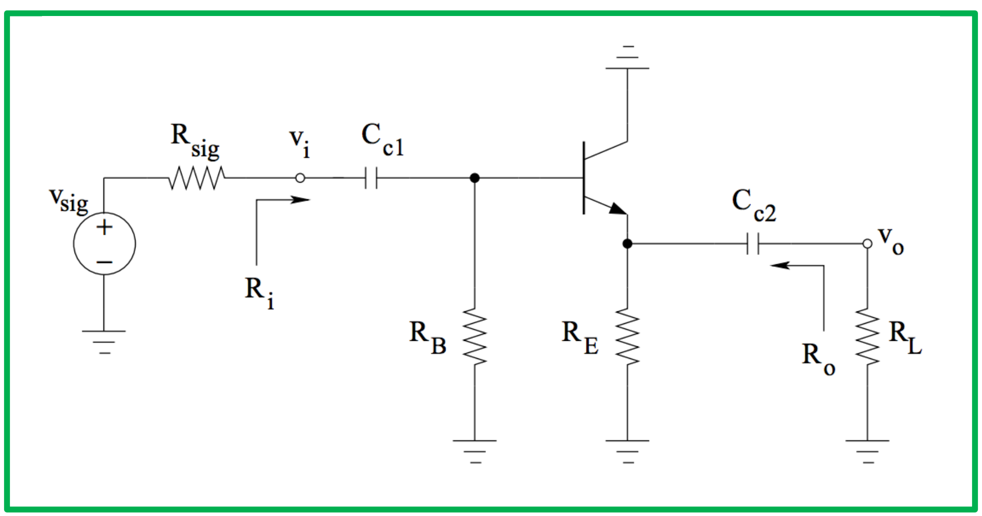


The equations for A_{v_o} and R_o will be the same.

If we set $R_B = \infty$, we can can use the already derived equations to find R_i.

$$\boxed{R_i = r_\pi + (1+\beta)(r_o || R_E || R_L)}$$

The prototype common-collector circuit:



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

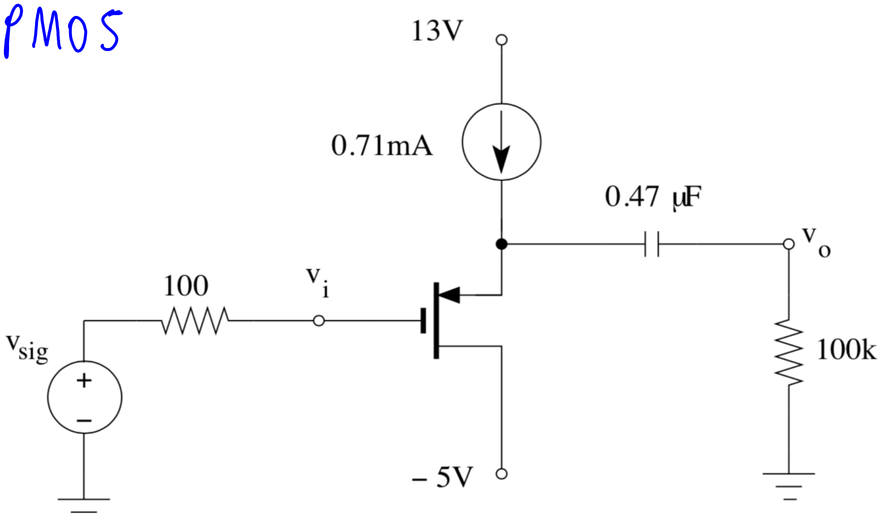
$$R_o = (1/g_m) \,||\, r_\pi \,||\, R_E \,||\, r_o$$

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

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.

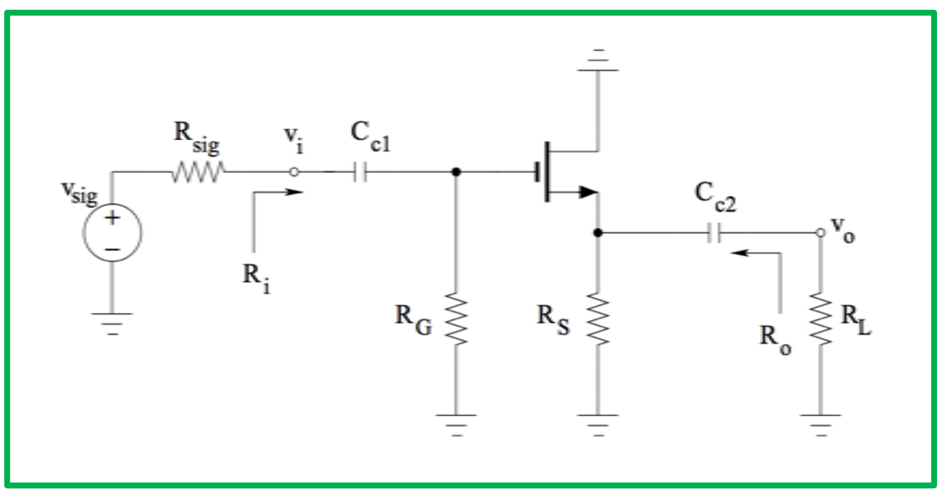
PMOS



Comparing the given circuit with the prototype circuit, we can use the already derived equations by setting $R_G = \infty$ and $R_S = \infty$

$A_{v_o} = \dfrac{g_m r_o}{1 + g_m r_o}$, $R_o = (\frac{1}{g_m}) \,||\, r_o$, $R_i = \infty$

The prototype common-drain circuit:



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

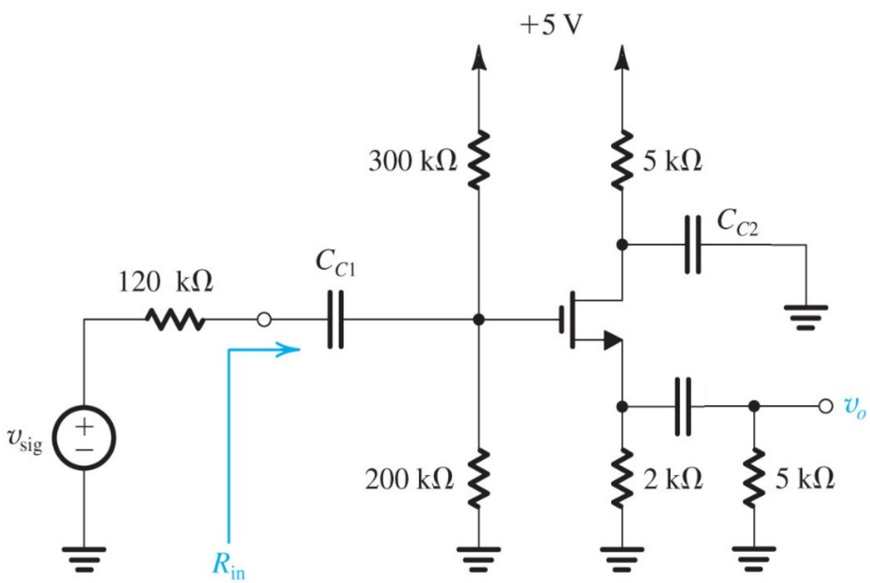
$$R_o = (1/g_m) \,||\, R_S \,||\, r_o$$

$$R_i = R_G$$

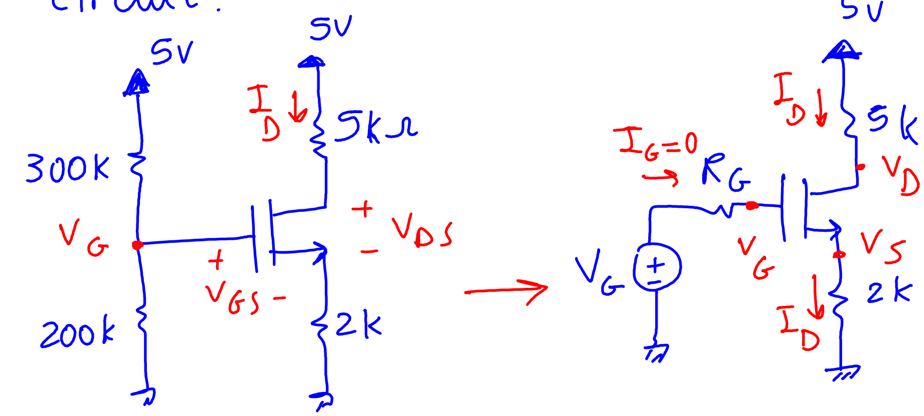
Discussion question 3.

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_o}.



Bias circuit:



$$V_G = \frac{200\,k\Omega}{200\,k + 300\,k} \times 5\,V = 2\,V$$

$I_D = 0.5 \rightarrow V_S = 2k \times I_D = 1\,V \rightarrow \boxed{V_S = 1V}$

$V_D = 5\,V - 5\,k \times I_D = 2.5\,V \rightarrow \boxed{V_D = 2.5V} \rightarrow \boxed{V_{DS} = 1.5\,V > V_{OV}}$

$k_n = \frac{2 I_D}{V_{OV}^2} \Rightarrow \boxed{k_n = 11.1\ mA/V^2}$

Transistor is in saturation

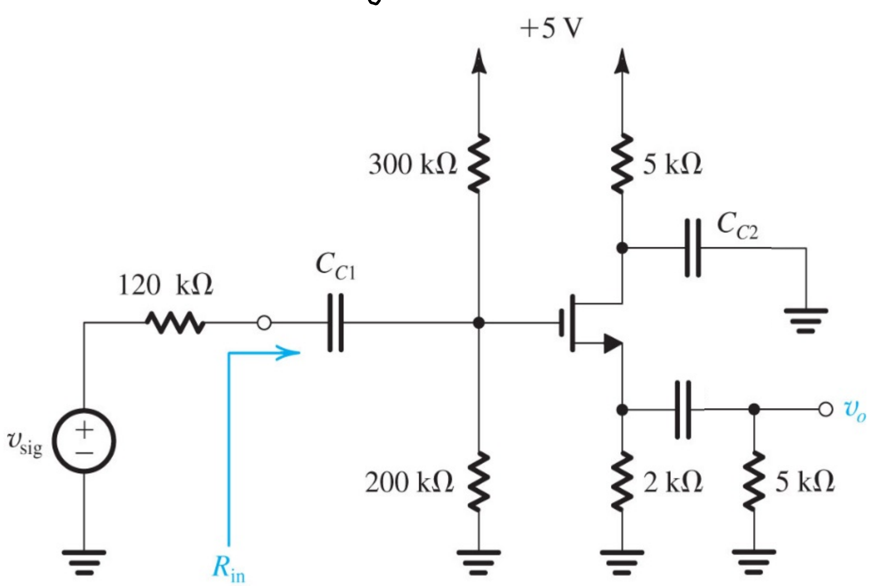
Discussion question 3.

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?

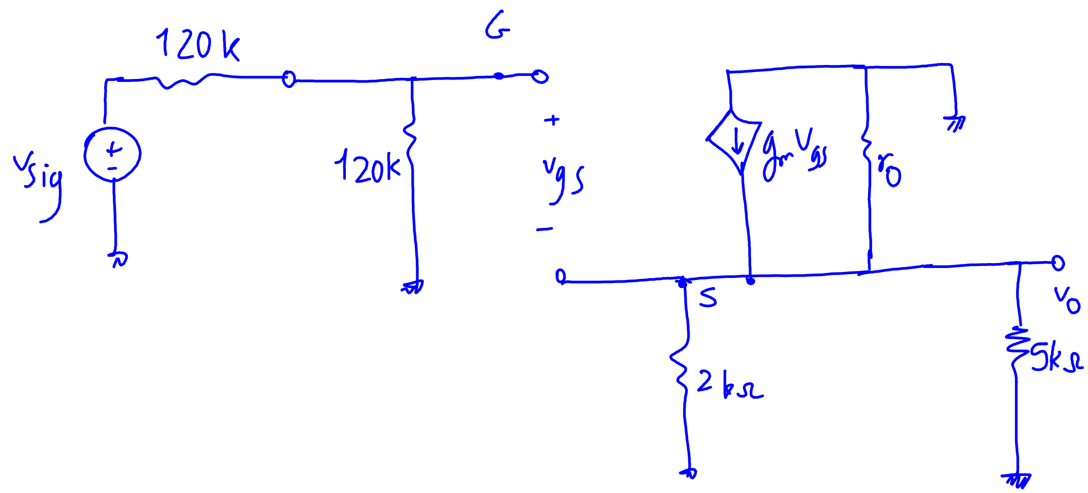
$$g_m = \frac{2I_D}{V_{OV}} = 3.3\ mA/V$$

Find R_i and A_{v_o}.

$$r_o = \frac{1}{\lambda . I_D} = \frac{V_A}{I_D} = 100k\Omega$$



Signal circuit:



$$A_{v_o} = \frac{g_m (R_s \parallel r_o)}{1 + g_m (R_s \parallel r_o)} = \frac{3.3\ mA/V (2k \parallel 100k)}{1 + 3.3\ mA/V (2k \parallel 100k)}$$

$A_{v_o} \simeq 0.87\ V/V$, $R_i = R_G = 200\,k\Omega \parallel 300\,k\Omega = 120\ k\Omega$