ECE 65: Components & Circuits Lab

Lecture 23

Common-emitter / Common-source amplifier parameters

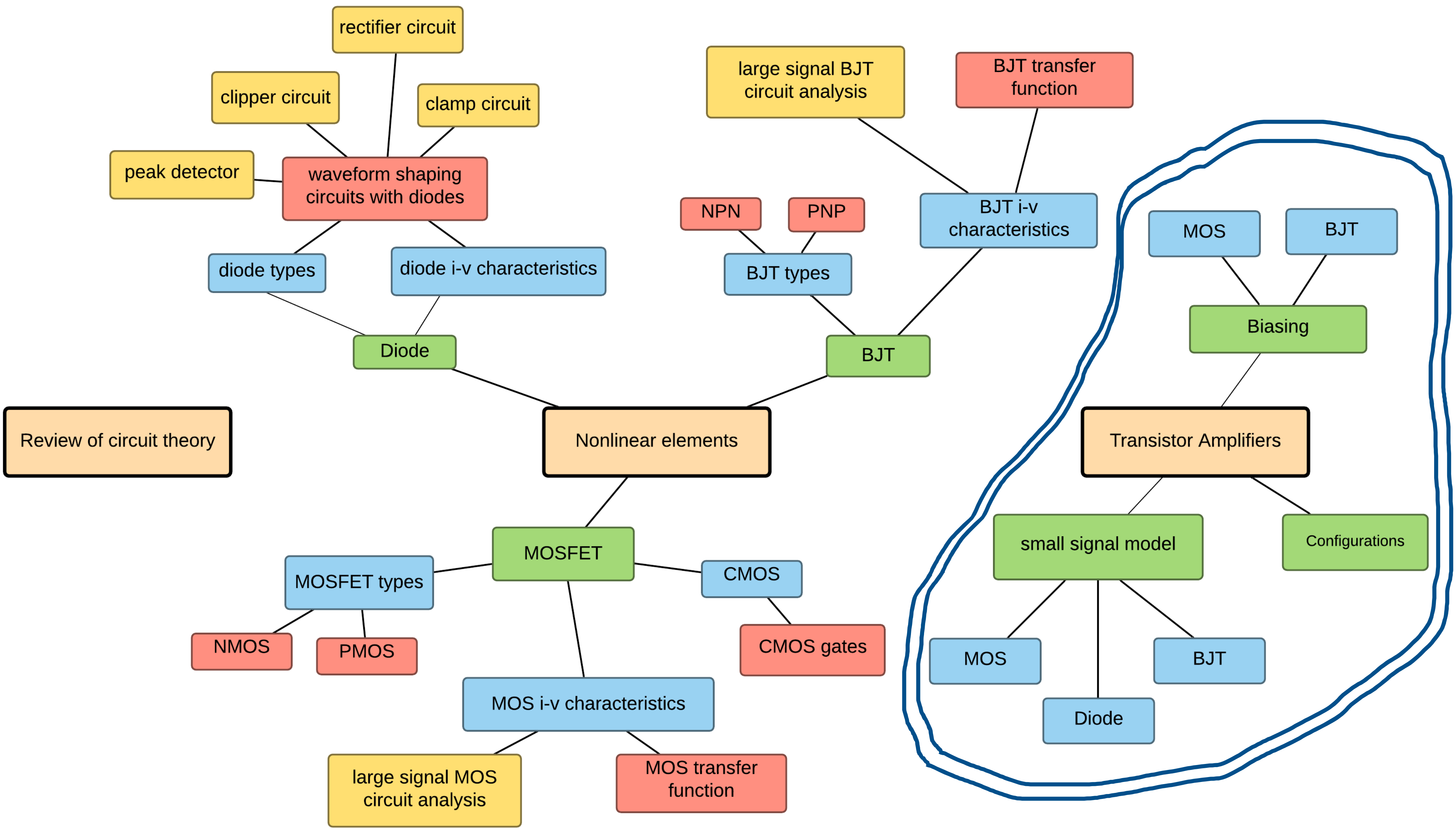
Reference notes: sections 6.1, 6.2

Sedra & Smith (7th Ed): sections 7.3

Saharnaz Baghdadchi

Course map

6. Transistor Amplifier Configurations



What are the amplifier parameters?

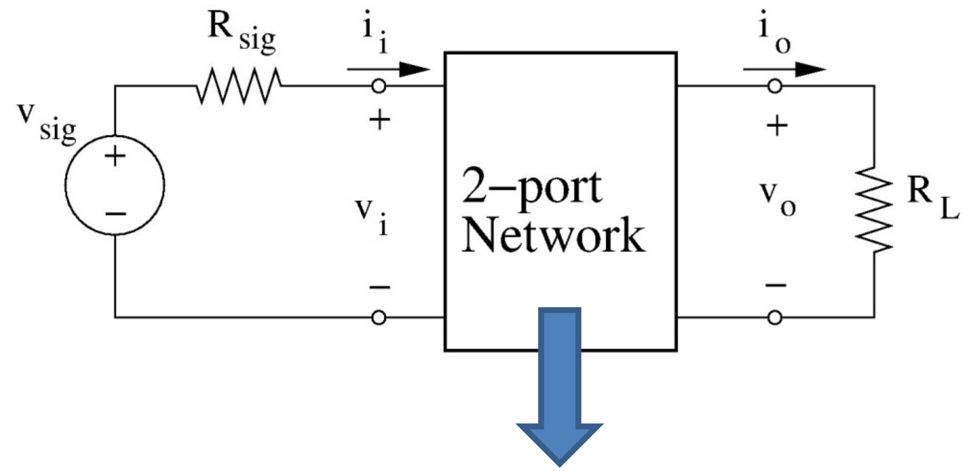
Voltage Gain of the Circuit: $A = \frac{v_o}{v_{sig}}$

Voltage Gain of the Amplifier: $A_v = \frac{v_o}{v_i}$

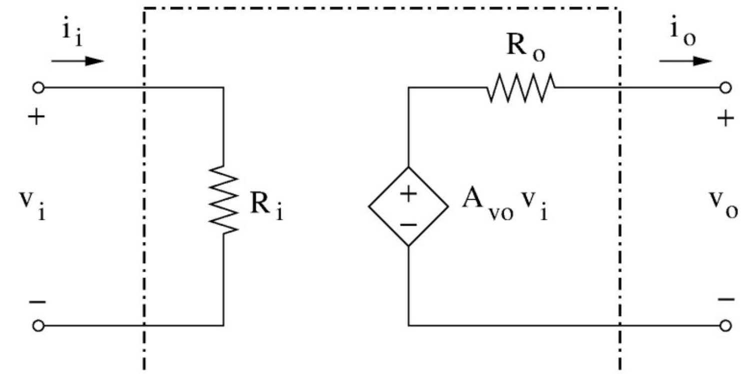
Open-loop Gain: $A_{vo} = \left.\frac{v_o}{v_i}\right|_{R_L \to \infty}$

Input Resistance: $R_i = \frac{v_i}{i}$

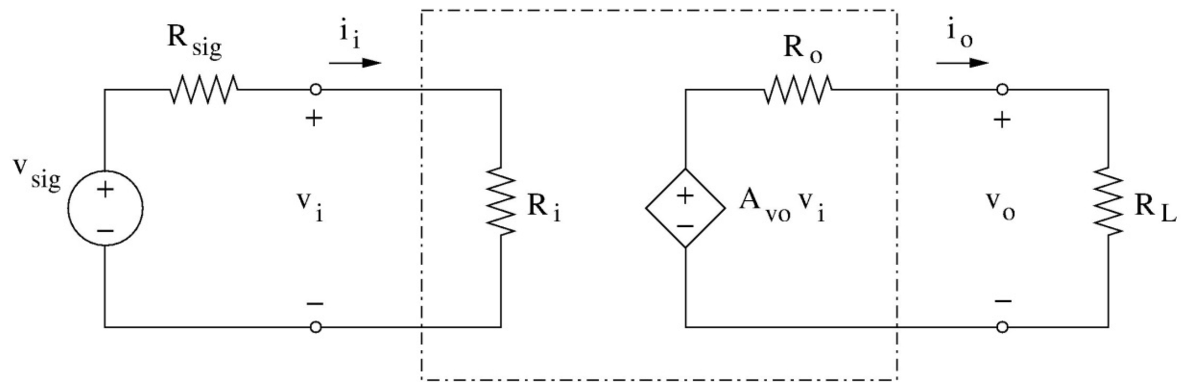
Output Resistance of Amplifier: $R_o = -\left.\frac{v_o}{i_o}\right|_{v_i=0}$



Voltage Amplifier Model



Observations on the amplifier parameters



$$A = \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} \times \frac{v_o}{v_i} = \frac{R_i}{R_i + R_{sig}} A_v$$

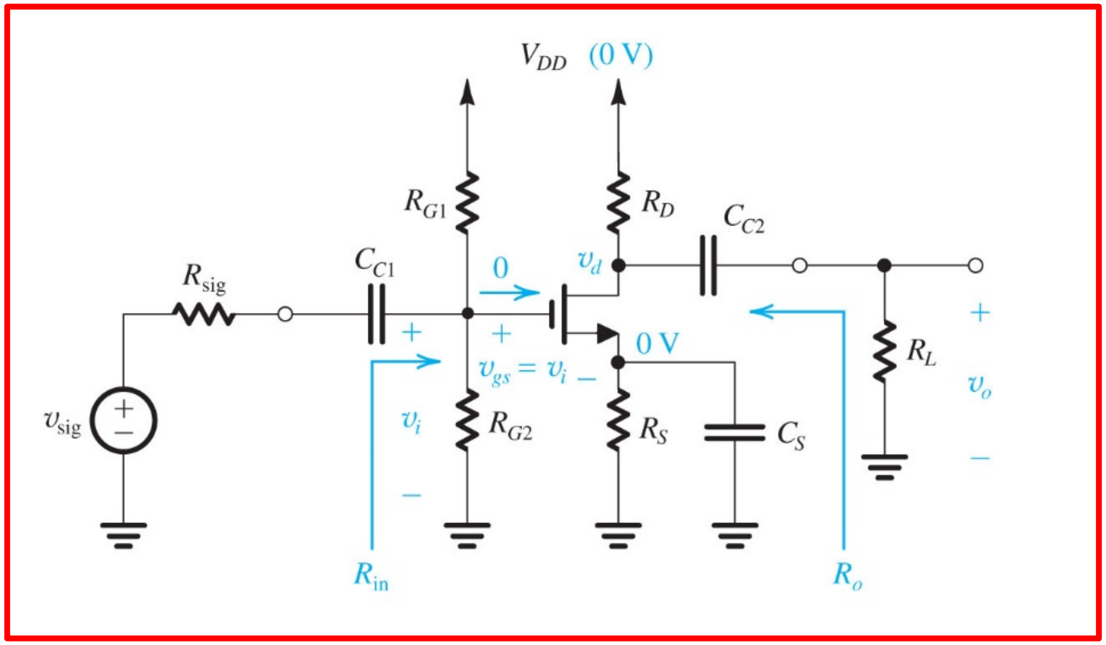
When $R_{sig} = 0$, $A = A_v$

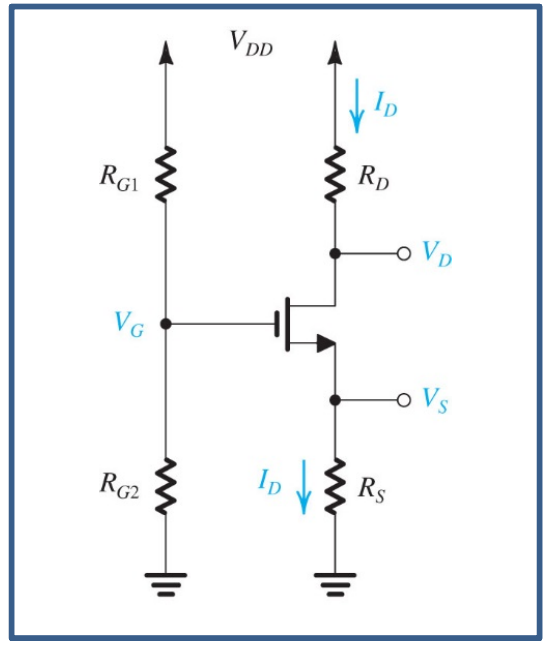
$$A_v = \frac{v_o}{v_i} = \frac{R_L}{R_L + R_o} A_{vo}$$

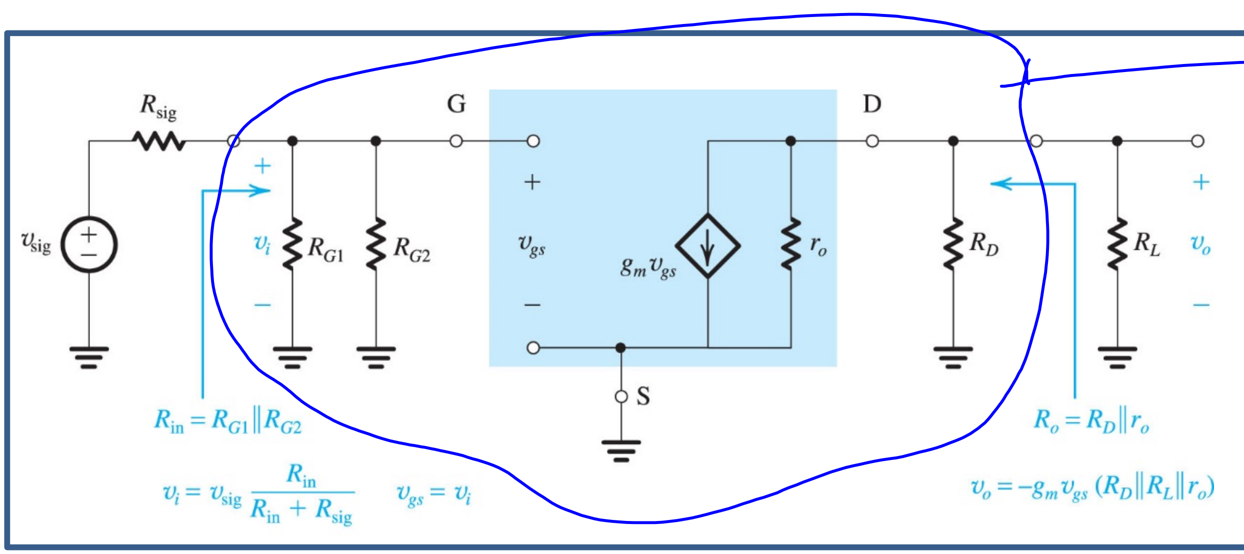
When $R_L = \infty$, $A_v = A_{vo}$

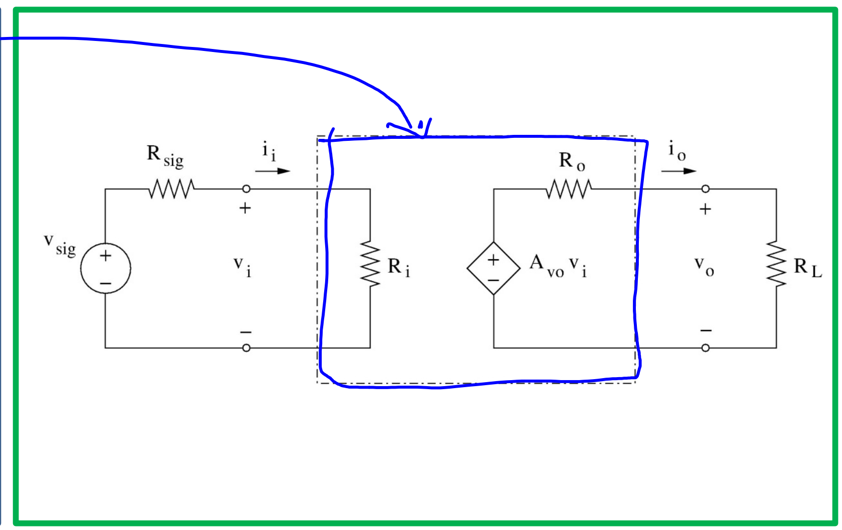
A_{vo} is the maximum possible gain of the amplifier

From an amplifier circuit to the building block representation



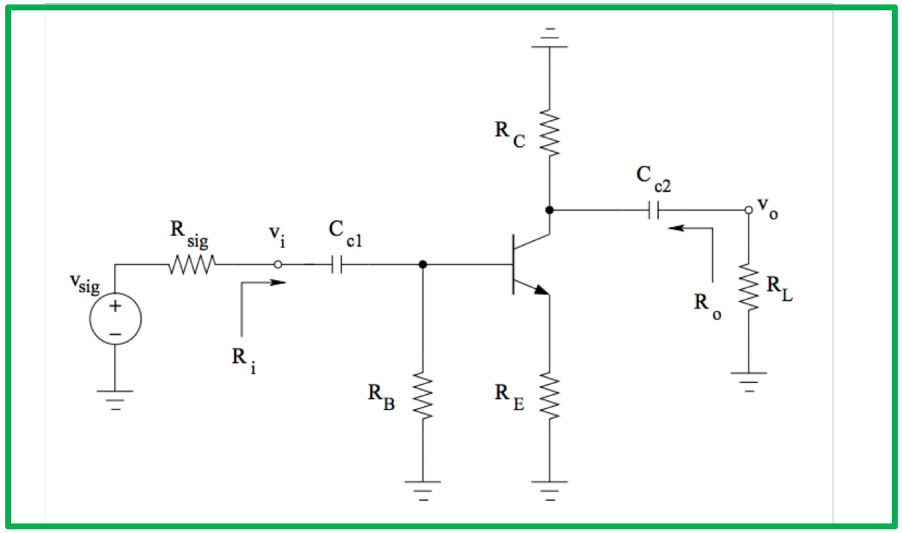






Equations of A_{vo}, R_o, R_i for the common-emitter with an emitter resistance BJT amplifier

Please follow the derivations of the below parameters from the reference notes.

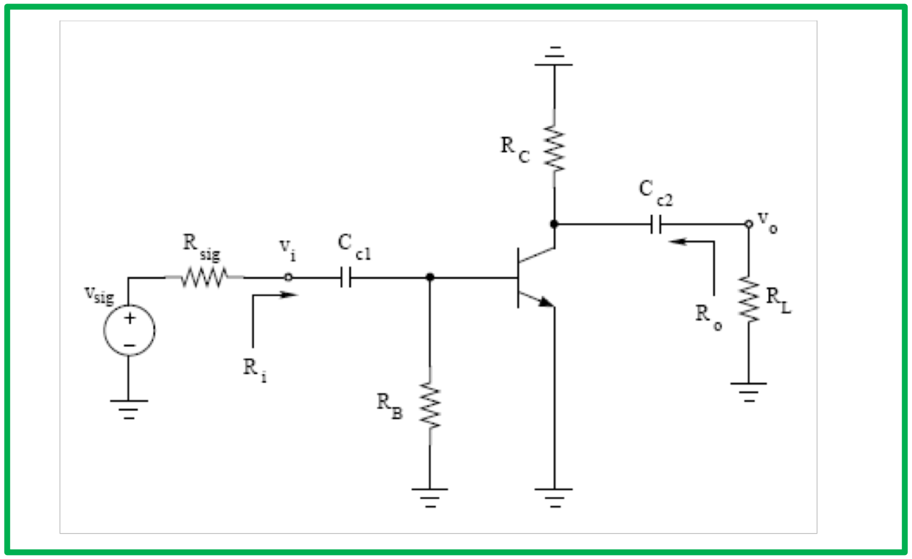


$$A_{vo} = \frac{-R_C}{R_E + (1 + R_C / r_o)\dfrac{R_E + r_\pi}{\beta}}$$

$$R_o = \left[\frac{\left(\dfrac{1}{g_m}\right) || r_o}{R_C \,||\, r_o} + \frac{r_\pi || R_E}{R_C}\right]^{-1} [(r_\pi \,||\, R_E) + (1/g_m) \,||\, r_o]$$

$$R_i = R_B \,||\, \left[R_E + r_\pi + \frac{\beta R_E}{1 + (R_E + R_C || R_L)/ r_o}\right]$$

Common-emitter BJT amplifier parameters



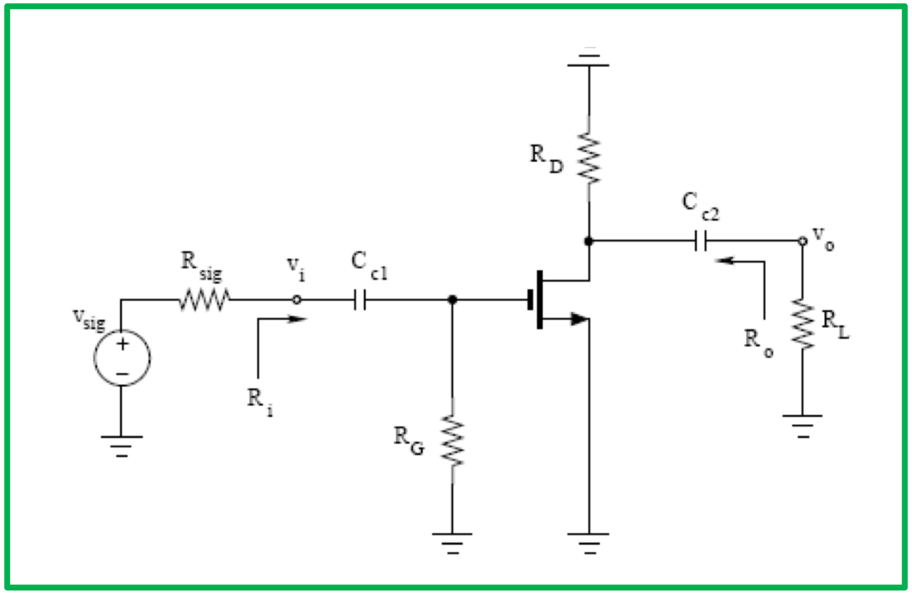
The amplifier parameters derived for the common emitter amplifier with an emitter resistor can be used for this amplifier by setting $R_E = 0$.

$$A_{vo} = -g_m(R_C || \, r_o)$$

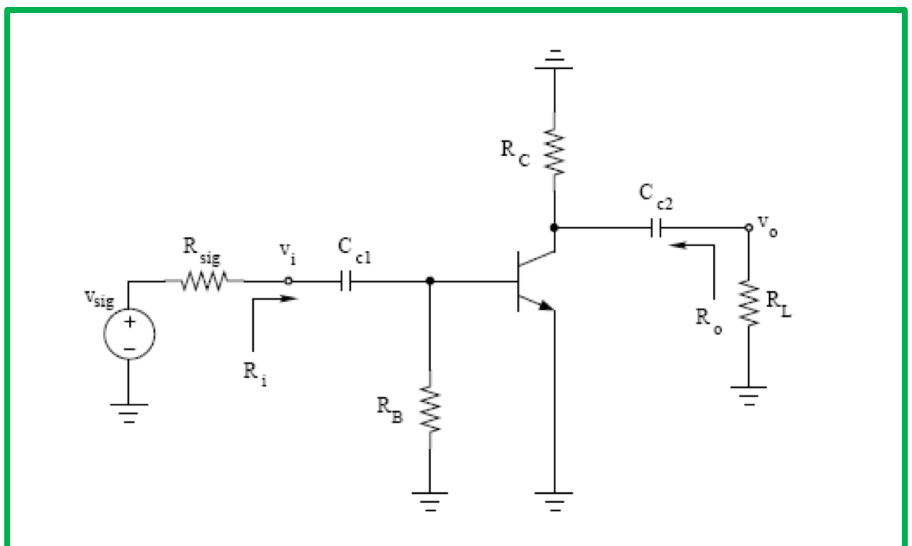
$$R_o = R_C || \, r_o$$

$$R_i = R_B \, || \, r_\pi$$

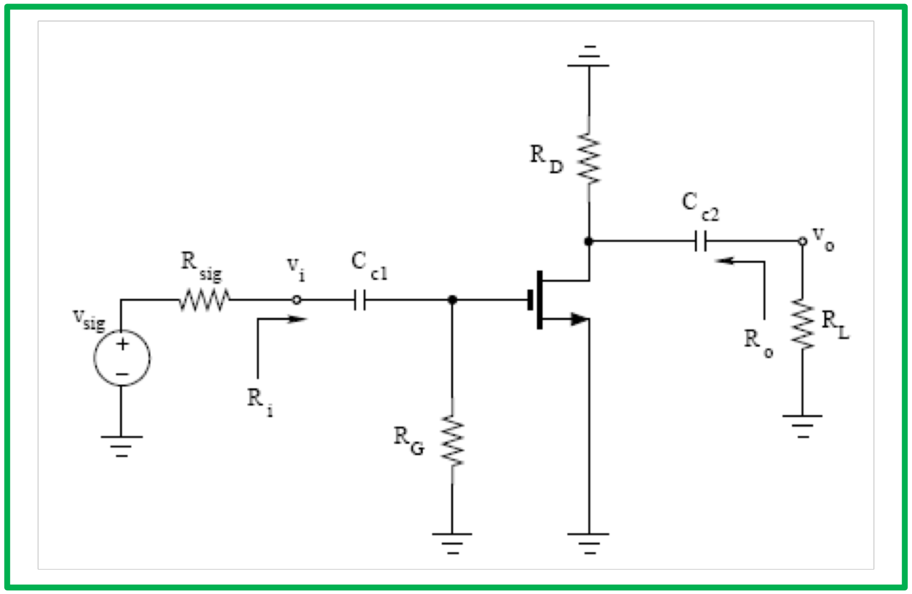
Common-Source MOS amplifier parameters



Compare it with the signal circuit for the common-emitter BJT amplifier:



Common-source MOS amplifier parameters



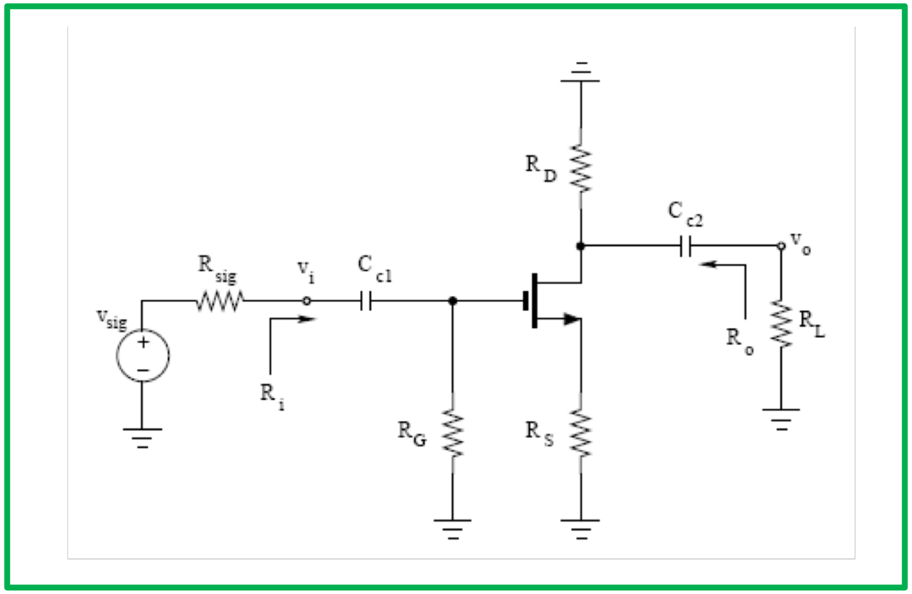
The common emitter BJT amplifier parameters can be used for this amplifier when R_B is replaced with R_G, and R_C is replaced with R_D, and $r_\pi \to \infty$.

$$A_{vo} = -g_m(R_D || r_o)$$

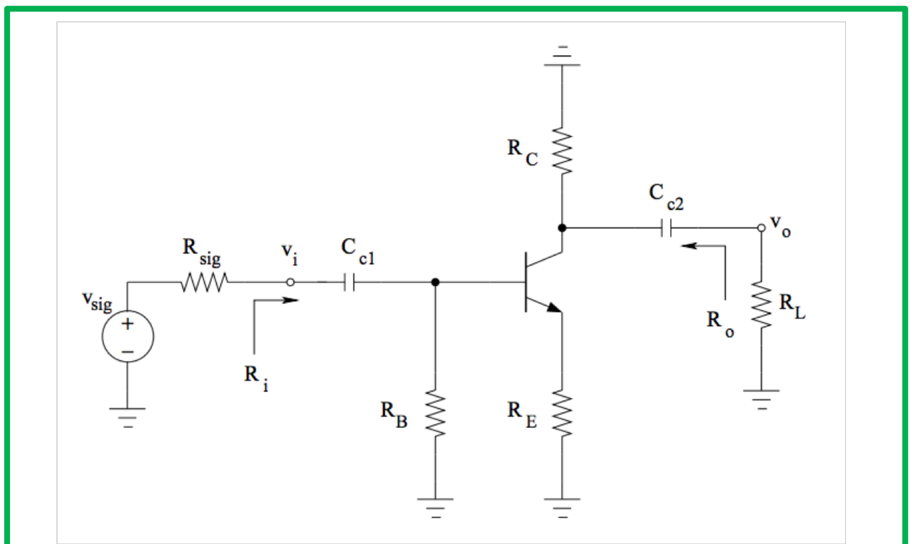
$$R_o = R_D || r_o$$

$$R_i = R_G$$

Common-source MOS with a source resistance amplifier parameters

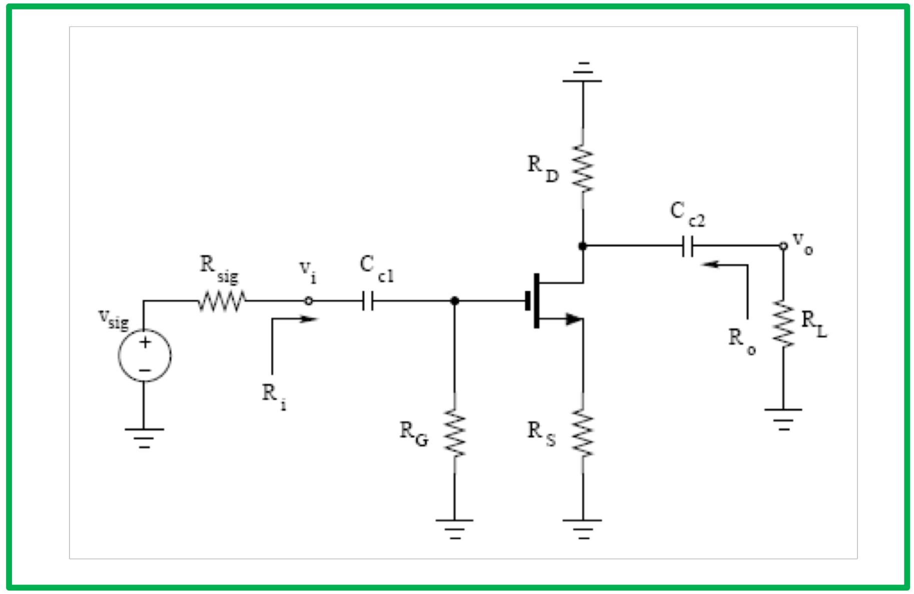


Compare it with the signal circuit for the common-emitter with an emitter resistor BJT amplifier:



Common-source MOS with a source resistance amplifier parameters

The common-emitter with an emitter resistor BJT amplifier parameters can be used for this amplifier when R_B is replaced with R_G, R_C is replaced with R_D, R_E is replaced with R_S, β / r_π is replaced with g_m and $r_\pi \rightarrow \infty$.



$$A_{vo} = \frac{-g_m R_D}{1 + g_m R_S + R_D \; / \; r_o}$$

$$R_o = R_D \,||\, [\, r_o (1 + g_m \, R_S)]$$

$$R_i = R_G$$

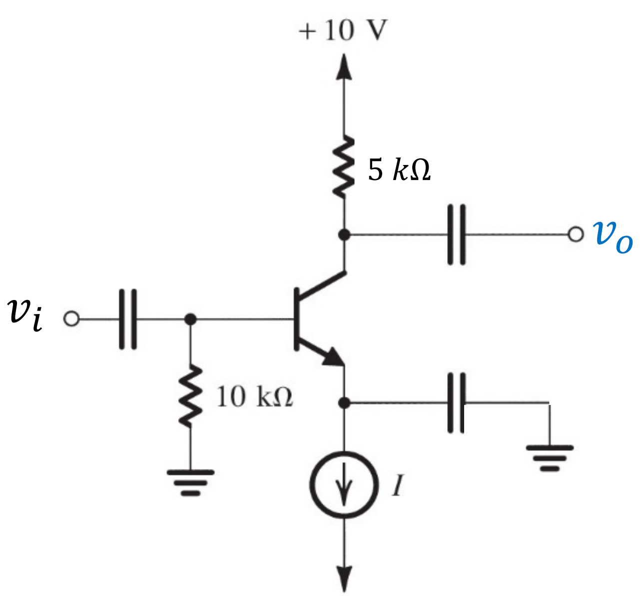
Some notes on *common-emitter* (CE) and *common-source* (CS) amplifiers:

- They have a high voltage gain.
- Ignoring R_G, CS has an infinite input resistance.
- Ignoring R_B, CE has a modest input resistance.
- Both CE and CS have a rather high output resistances.
- Adding R_S to the source of a CS or R_E to the emitter of a CE amplifier can have the benefits of raising the input resistance of CE amplifier, increasing linearity and increasing the amplifier bandwidth.

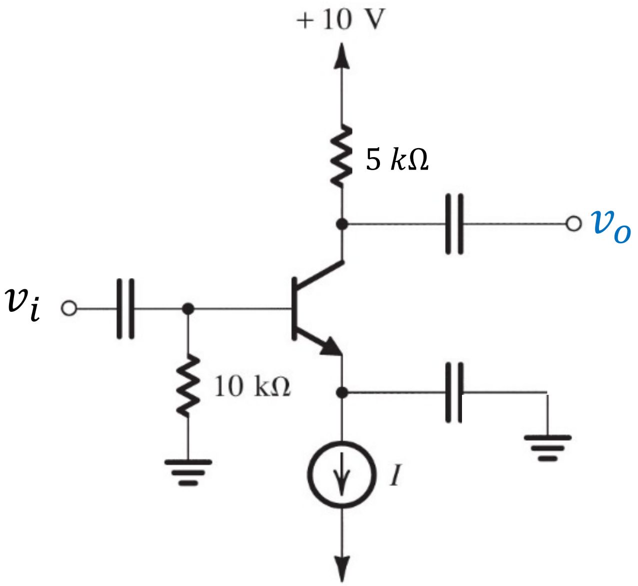
Lecture 23 reading quiz.

The below BJT common-emitter amplifier with β = 100 is fed with a signal source having a resistance of 5 kΩ. A load resistor of 5 kΩ is connected to the output. In this amplifier, $R_i = 2$ kΩ, and $R_o = 5$ kΩ. $V_T = 25\ mV$.

If the peak value of v_π (denoted by $\hat{v}_\pi$) is to be limited to 5mV, what are the corresponding peak values of v_{sig} (denoted by $\hat{v}_{sig}$), and v_o (denoted by $\hat{v}_o$)?



Lecture 23 reading quiz.



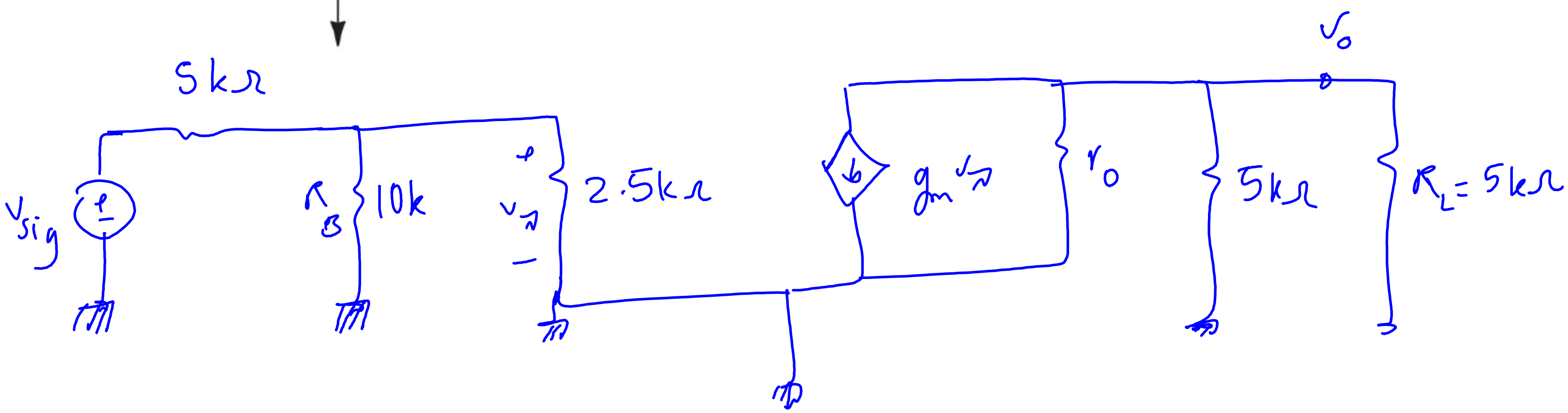
$$R_i = R_B \| r_\pi = 2\,k\Omega$$

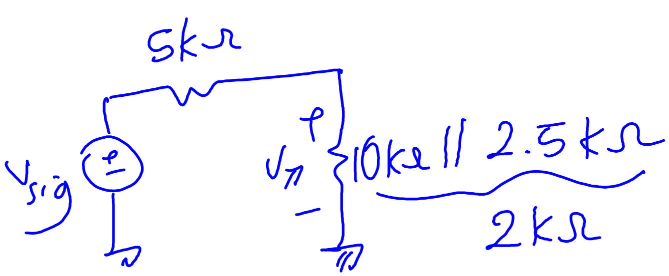
$$10\,k\Omega \| r_\pi = 2\,k\Omega \longrightarrow r_\pi = 2.5\,k\Omega$$

$$r_\pi = \frac{\beta}{g_m} \longrightarrow g_m = 40\ mA/V$$

$$R_o = R_C \| r_o = 5\,k\Omega\ ,\quad R_C = 5\,k\Omega$$

$$r_o = \infty$$

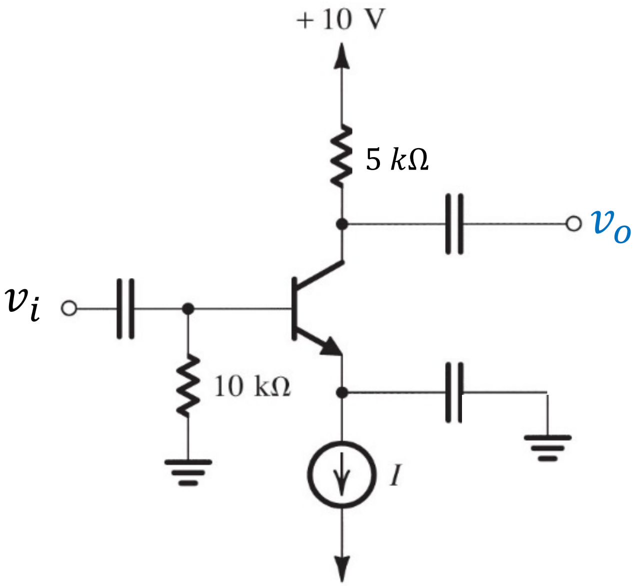


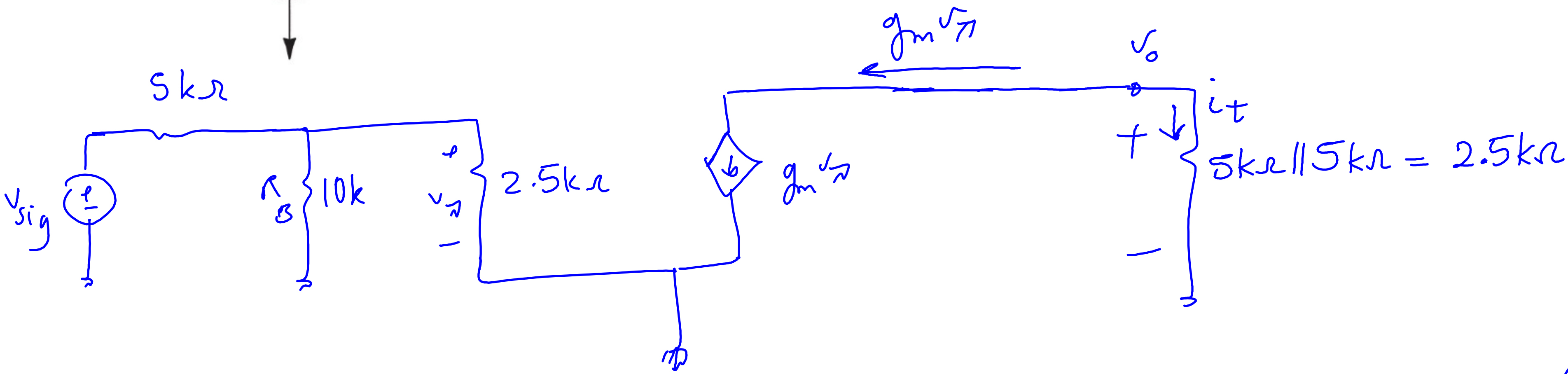


$$V_\pi = \frac{2\,k\Omega}{2\,k\Omega + 5\,k\Omega} \times V_{sig} \Rightarrow V_\pi = \frac{2}{7} V_{sig}$$

$$\hat{V}_{sig} = \frac{7}{2} \times 5\,mV = 17.5\ mV$$

Lecture 23 reading quiz.



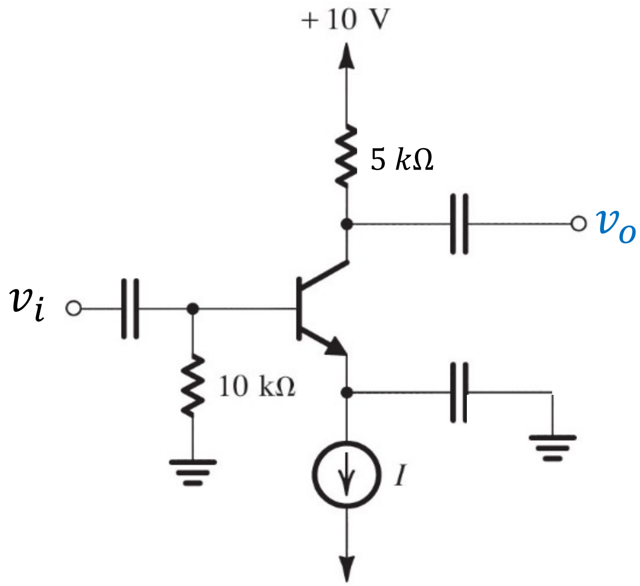


$$v_o = 2.5\,k\Omega \times i_t$$

$$i_t = -g_m v_\pi \longrightarrow v_o = -g_m v_\pi \times 2.5\,k\Omega = -40\,mA/V \times 2.5\,k\Omega \times v_\pi = -100\,v_\pi$$

$$v_o = -100\,v_\pi \longrightarrow \hat{v}_o = |100 \times 0.005\,V| = 0.5\,V$$

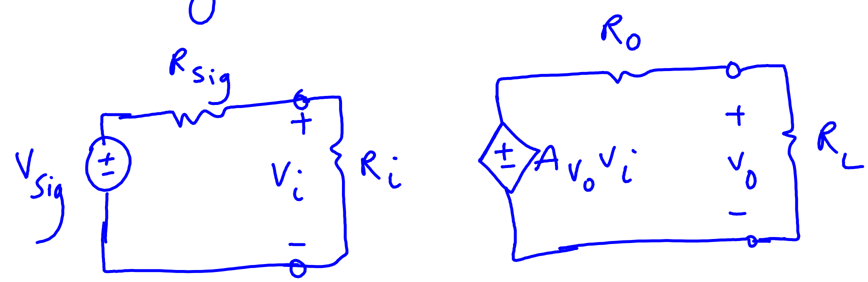
Lecture 23 reading quiz.



Another way of finding the peak value of vo:

$$\hat{V}_o = |A|\,\hat{V}_{sig}$$

Voltage amplifier model:



$$A = \frac{V_o}{V_{sig}} = \frac{V_o}{V_i} \times \frac{V_i}{V_{sig}} = \left(\frac{R_L}{R_L + R_o} \times A_{v_o}\right)\left(\frac{R_i}{R_i + R_{sig}}\right)$$

$$A_{v_o} = -g_m R_c = -\left(40\ mA/_V\right) \times 5k = -200\ V/_V$$

$$A = \left(\frac{5k}{5k+5k} \times \left(-200\ V/_V\right)\right)\left(\frac{2k}{2k+5k}\right) = -28.57\ V/_V \longrightarrow \boxed{A = -28.57\ V/_V}$$

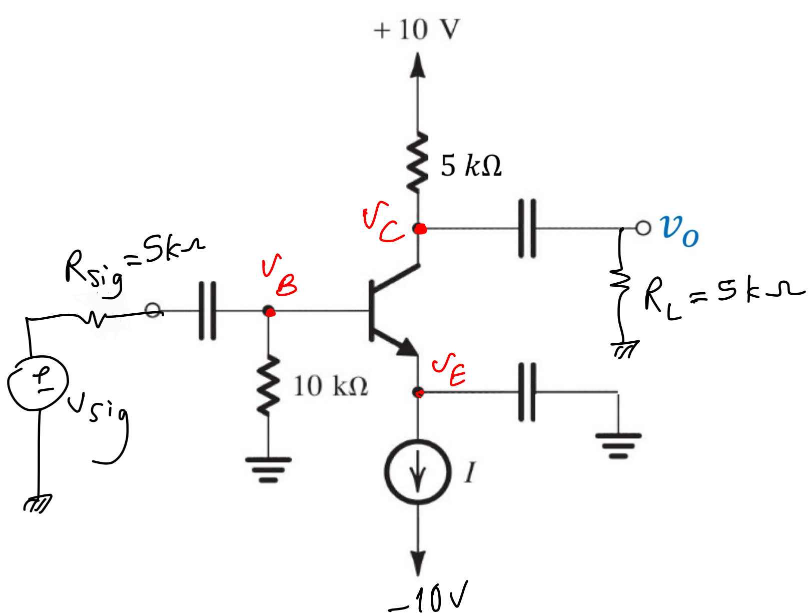
$$\hat{V}_o = |A|\,\hat{V}_{sig} = 28.57 \times 17.5\,mV = 0.5\,V \longrightarrow \boxed{\hat{V}_o = 0.5\,V}$$

If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$v_{sig} = 7 \sin(\omega t)$ (mV),

find and sketch all the instantaneous node voltages.

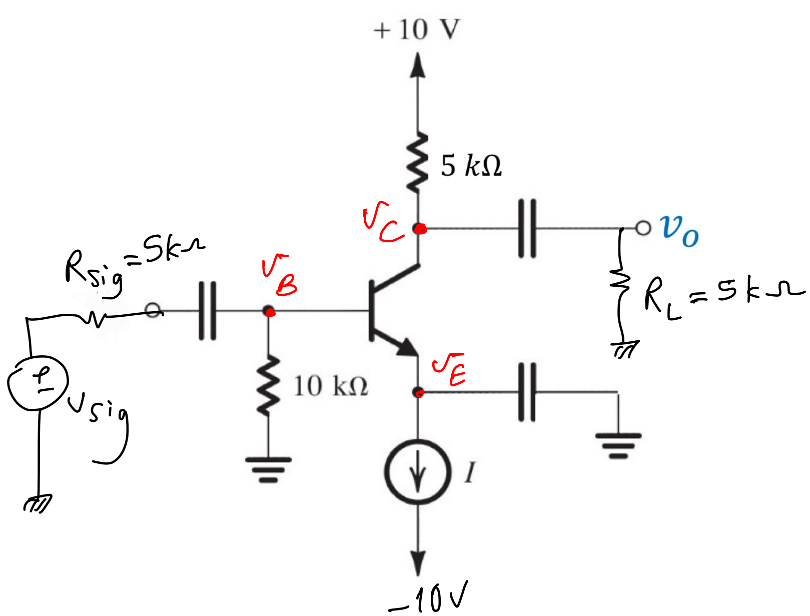
Assume $V_{D_0} = 0.7$ V



If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages



$$v_B = V_B + v_b$$

$$v_C = V_C + v_c$$

$$v_E = V_E + v_e$$

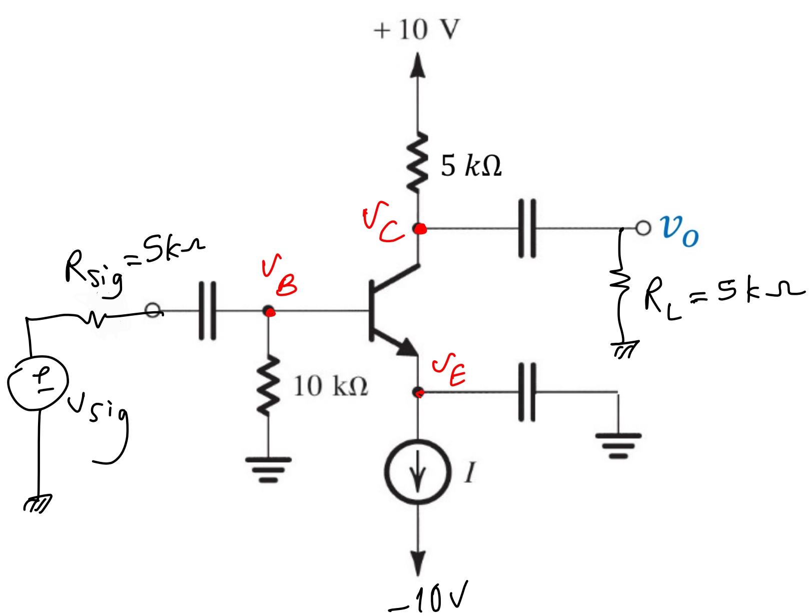
From the signal circuit

From Bias circuit

If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages

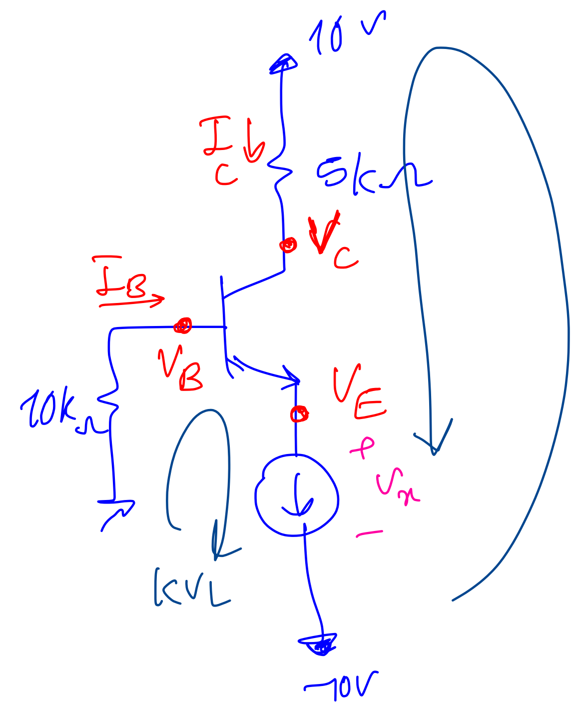


$$V_{BE} = 0.7V$$

$$V_B = -I_B \times 10k\Omega$$

$$I_C = 100 I_B$$

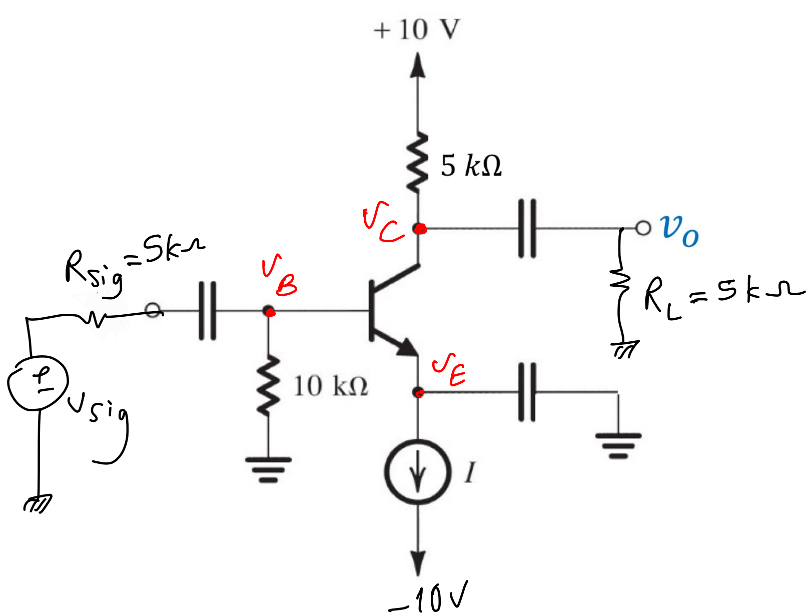
$$I_C = \frac{10V - V_C}{5k\Omega}$$



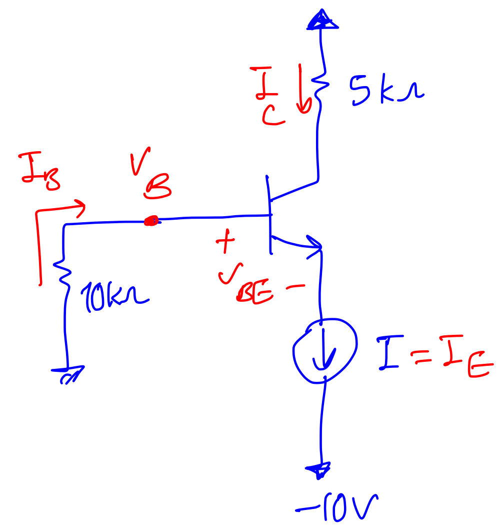
If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages



Bias circuit:



$$g_m = \frac{I_C}{V_T}$$

$$\Rightarrow I_C = g_m V_T$$

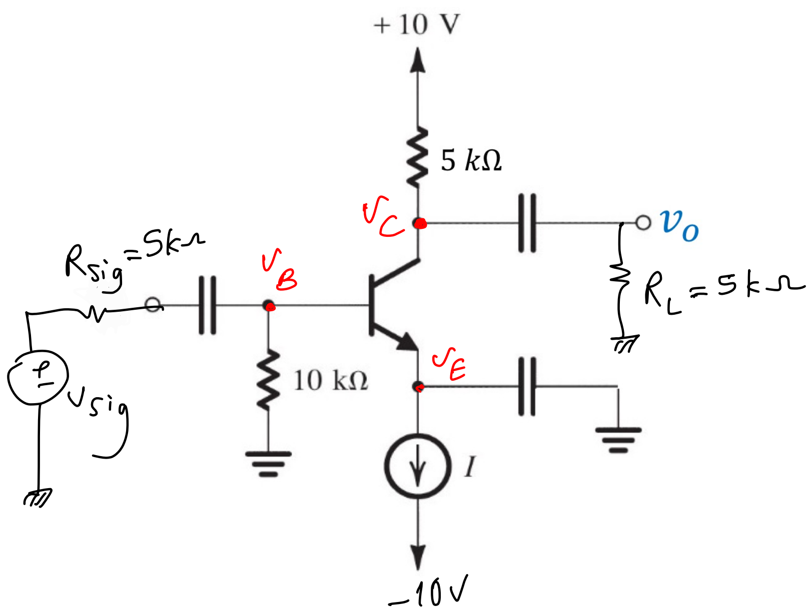
$$= 40 \text{ mA/V} \times 25 \text{ mV} = 1 \text{ mA}$$

$$I_B = \frac{I_C}{\beta} = \frac{1 \text{ mA}}{100} = 10 \ \mu A$$

If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages



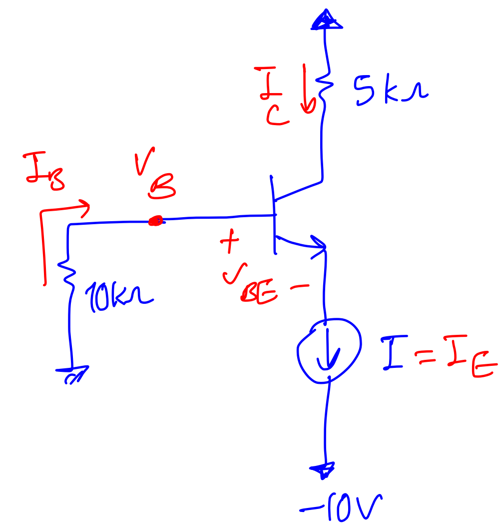
Bias circuit:

$I_C = 1$ mA

$I_B = 10$ μA

$V_B = -10k\Omega \times 10$ μA

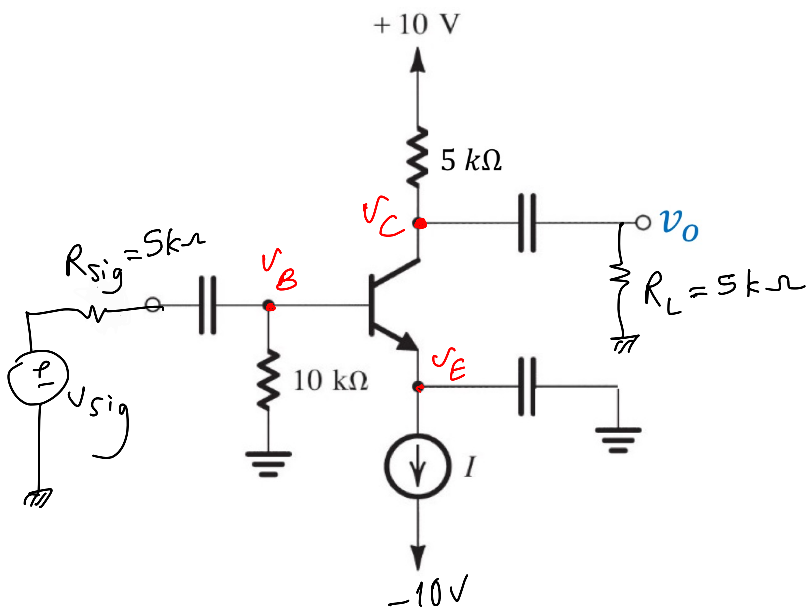
$= -100$ mV



If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$v_{sig} = 7 \sin(\omega t)$ (mV)

find and sketch all the instantaneous node voltages



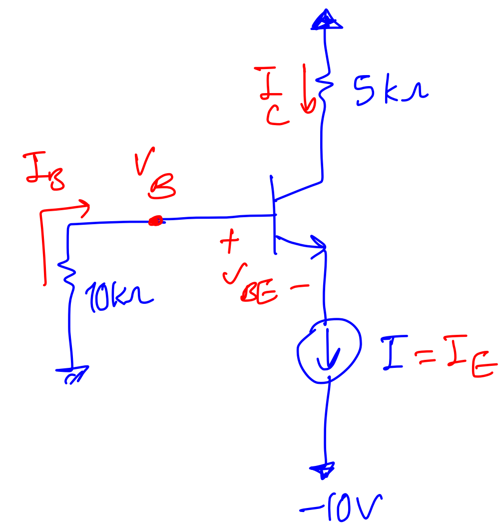
Bias circuit:

$I_C = 1$ mA

$I_B = 10\ \mu A$

$V_B = -10k\Omega \times 10\ \mu A$

$= -100$ mV



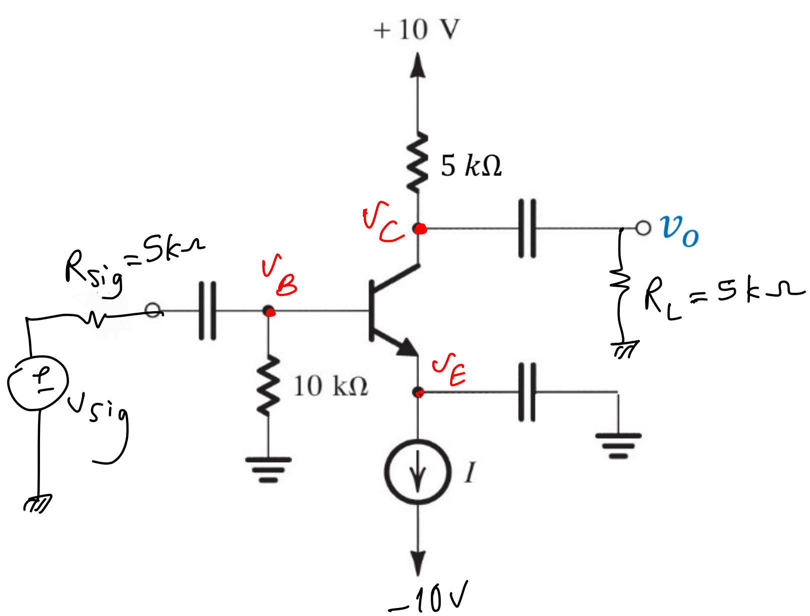
$V_{BE} = 0.7$ V $= V_B - V_E \longrightarrow V_E = V_B - 0.7$V

$\Rightarrow V_E = -800$ mV

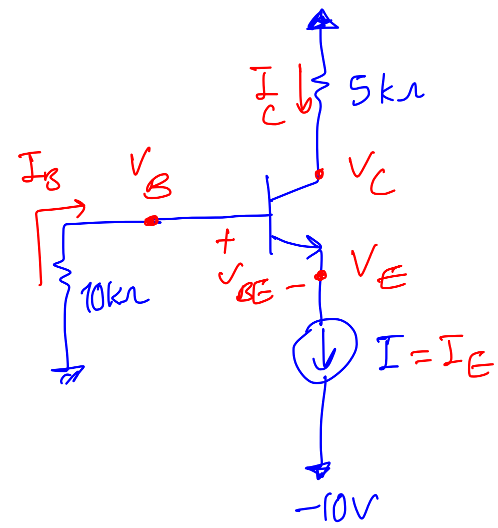
If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages



Bias circuit:



$I_C = 1$ mA

$I_B = 10\ \mu A$

$V_B = -100$ mV

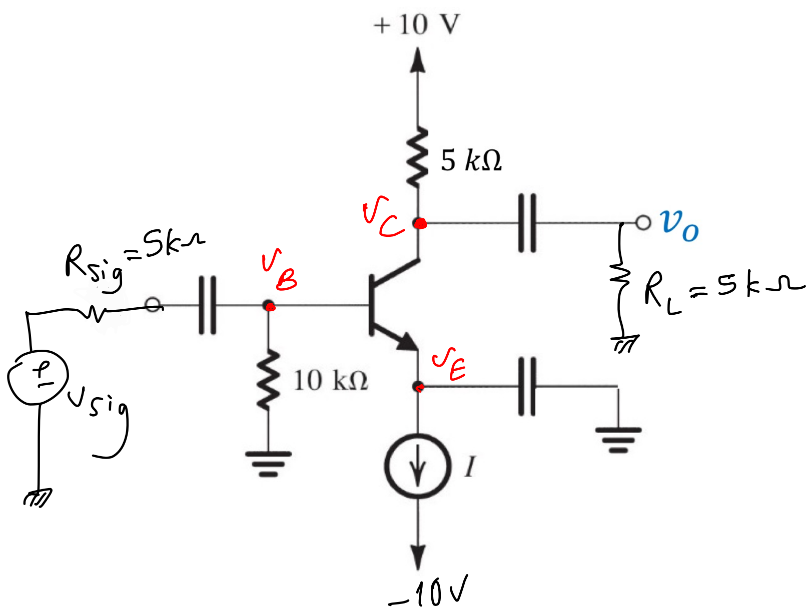
$V_E = -800$ mV

$V_C = 10\text{ V} - 5k\Omega \times I_C = 5\text{ V}$

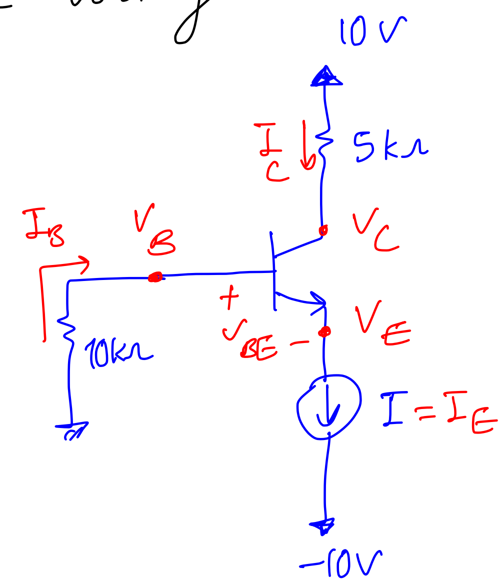
If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$v_{sig} = 7 \sin(\omega t)$ (mV) , use $V_{D_0} = 0.7$ V

find and sketch all the instantaneous node voltages



Bias circuit:



$I_C = 1$ mA

$I_B = 10$ μA

$V_B = -100$ mV

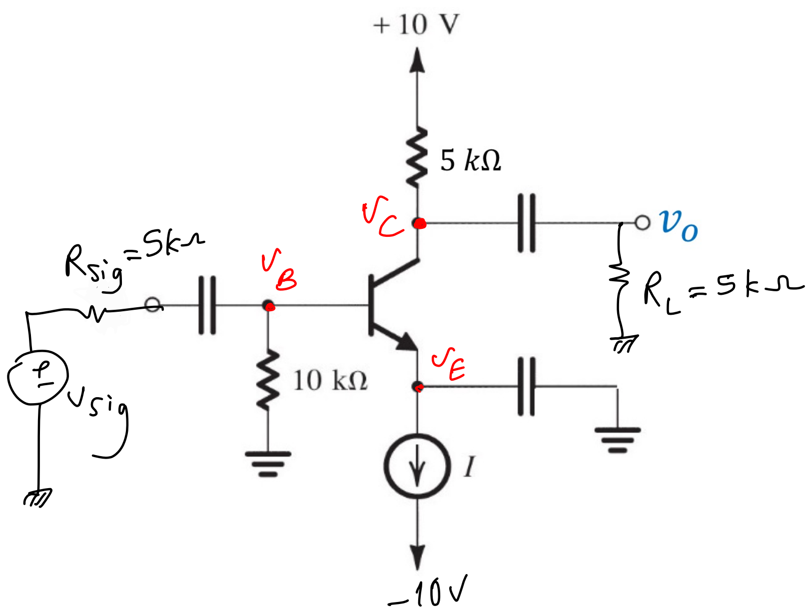
$V_E = -800$ mV

$V_C = 5$ V

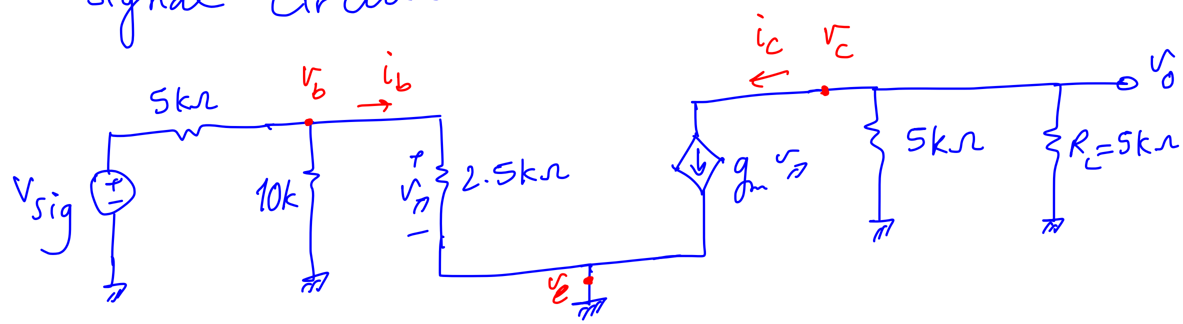
If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \text{ (mV)}$$

find and sketch all the instantaneous node voltages



Signal circuit:



$$v_b = v_\pi = \frac{(10k \parallel 2.5k)}{(10k \parallel 2.5k) + 5k} \times v_{sig} = \frac{2}{7} v_{sig}$$

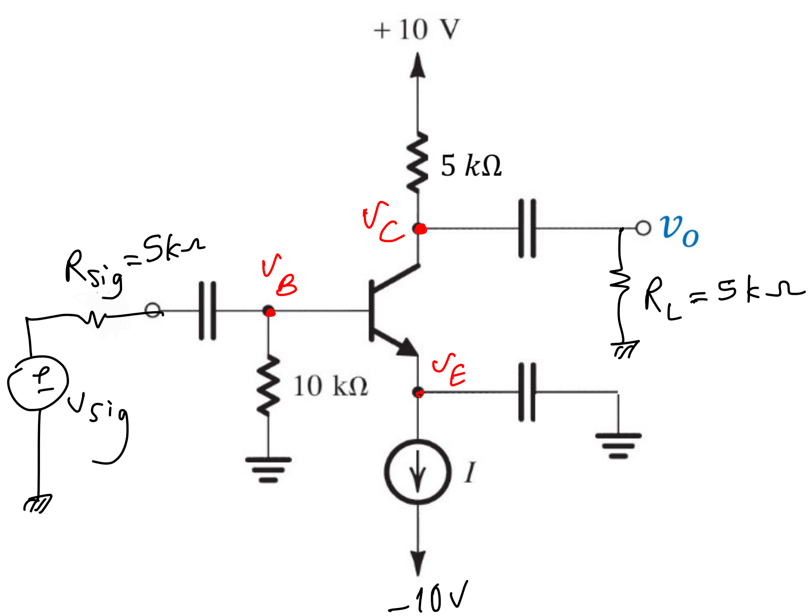
$$\Rightarrow v_b = \frac{2}{7} \times 7 \sin(\omega t) \text{ (mV)} = 2 \sin \omega t \text{ (mV)}$$

$v_e = 0$, the emitter in the signal circuit is grounded

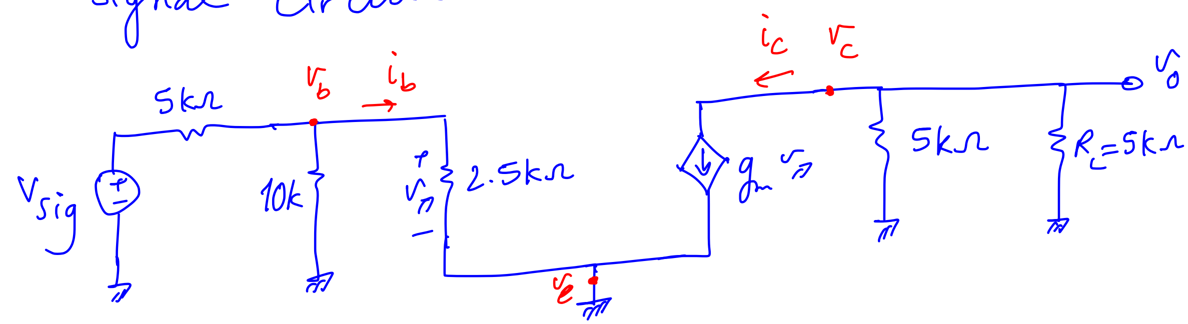
If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7 \sin(\omega t) \ (mV)$$

find and sketch all the instantaneous node voltages



Signal circuit:



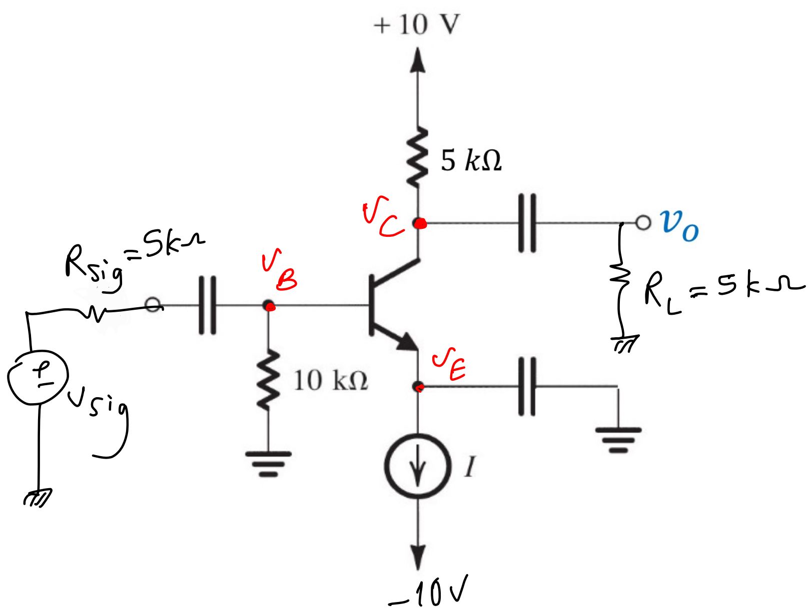
$$v_c = v_o = -100\, v_\pi$$ (as previously calculated.)

$$\Rightarrow v_c = -200 \sin(\omega t) \ (mV)$$

If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$$v_{sig} = 7\sin(\omega t)\ (\text{mV})$$

find and sketch all the instantaneous node voltages



The instantaneous node voltages:

$$v_B = V_B + v_b = \left[-100 + 2\sin(\omega t)\right]\ (\text{mV})$$

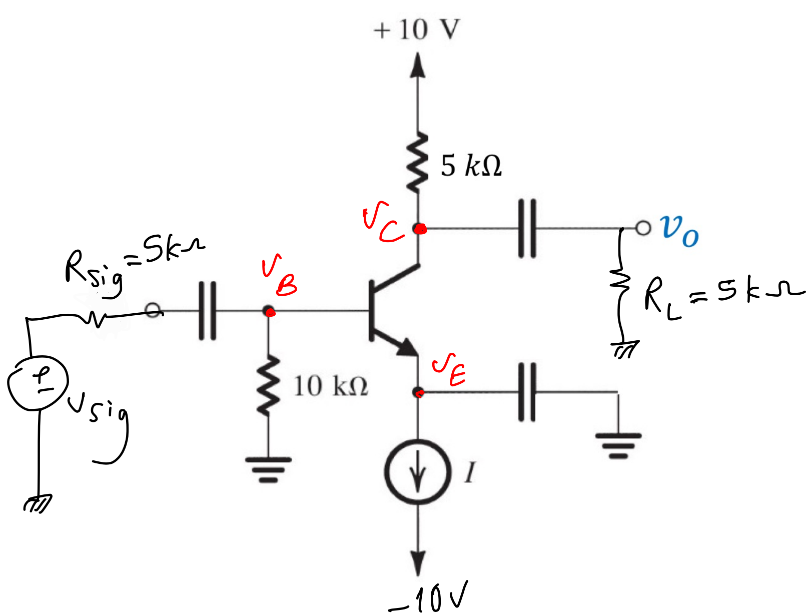
$$v_C = V_C + v_c = \left[5000 - 200\sin(\omega t)\right]\ (\text{mV})$$

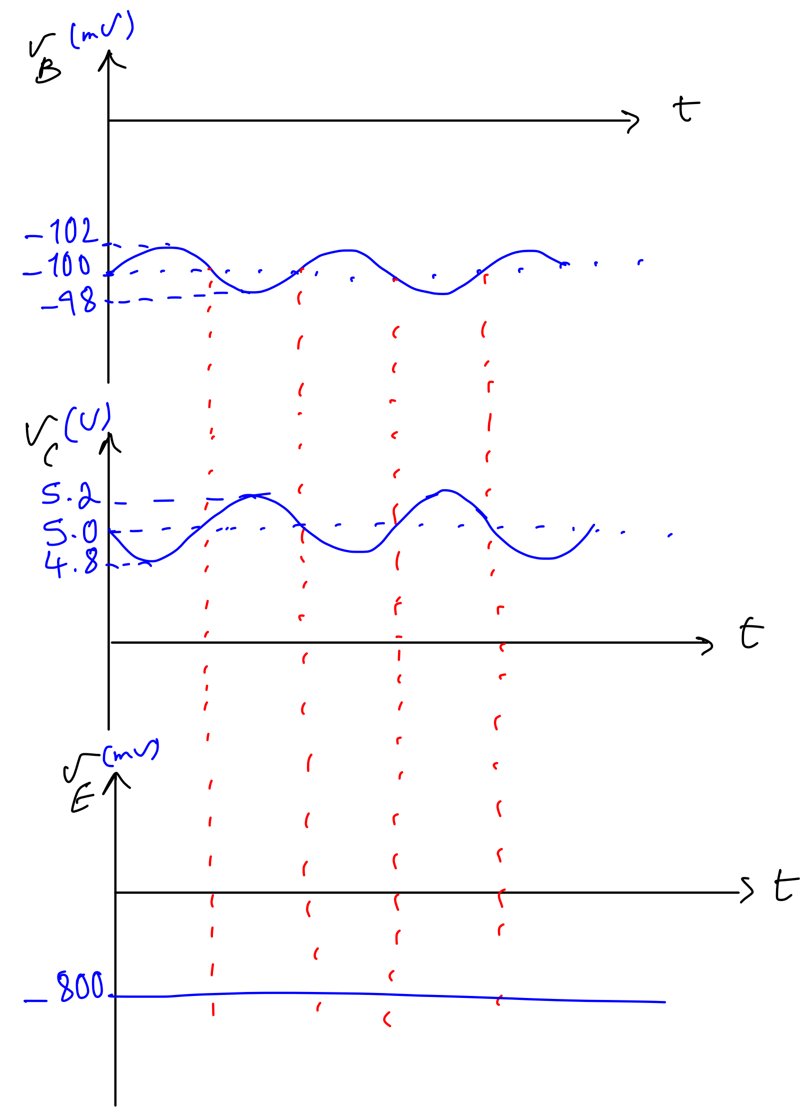
$$v_E = V_E + v_e = -800\ \text{mV}$$

If v_{sig} is a sine wave with peak amplitude of 7 (mV),

$v_{sig} = 7 \sin(\omega t)$ (mV)

find and sketch all the instantaneous node voltages





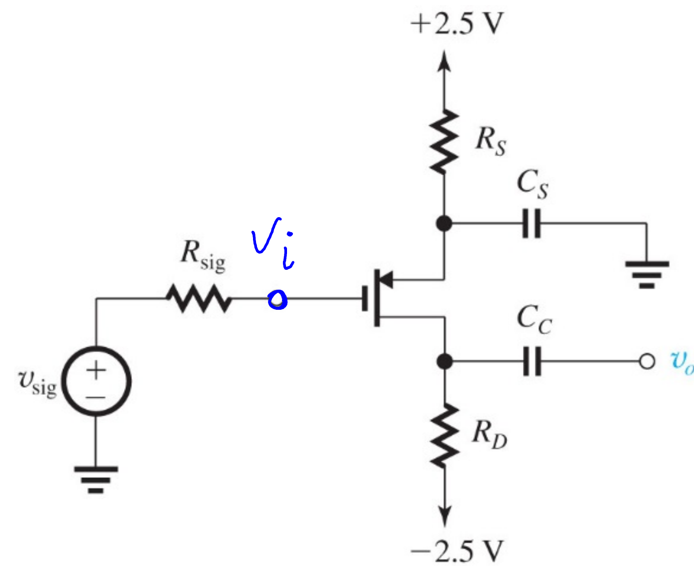
Clicker question 1.

Amplifier design problem

The PMOS in the below common-source amplifier circuit has $V_{tp} = -0.7\ V$ and $\lambda = 0$.

1. Select a value for R_S to bias the transistor at $I_D = 0.3\ mA$ and $V_{OV} = 0.3\ V$.

2. Select a value for R_D that results in $A_V = -10\ V/V$.



Clicker question 1.

The PMOS in the below common-source amplifier circuit has $V_{tp} = -0.7\ V$ and $\lambda = 0$.

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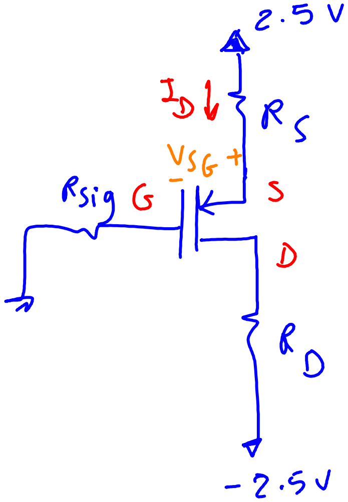
Bias circuit:



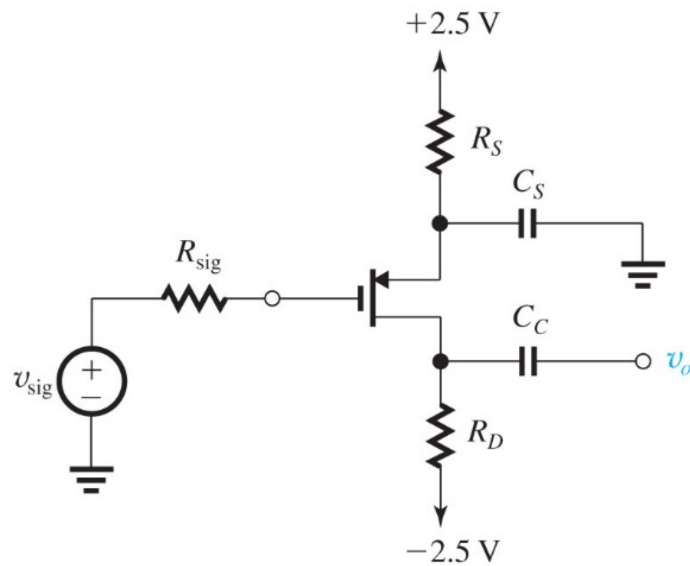
Since $I_G = 0 \longrightarrow V_G = 0$

$$V_{OV} = V_{SG} - |V_{tp}|$$

$$V_{SG} = 0.3\ V + 0.7\ V = 1\ V$$

$$V_{SG} = V_S - V_G = V_S = 1\ V$$

$$\boxed{V_S = 1\ V} \longrightarrow R_S = \frac{2.5\ V - 1\ V}{0.3\ mA} = 5\ k\Omega$$



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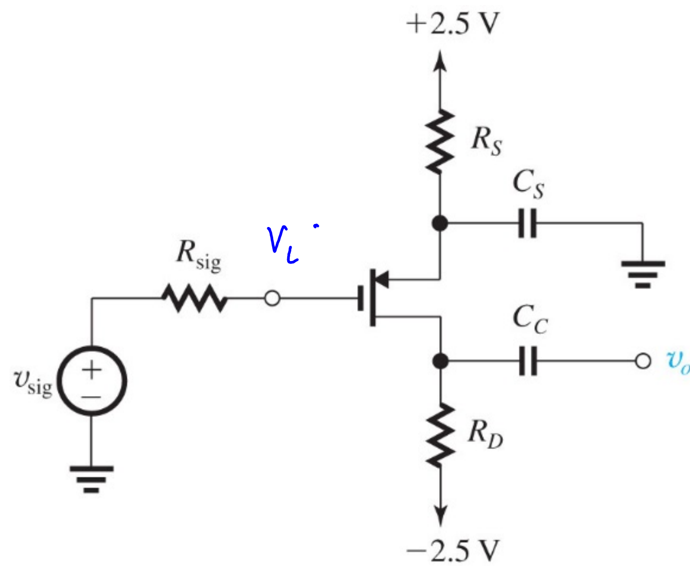

$A_{v_o} = -g_m R_D = -10\ V/V$

$g_m = \frac{2 I_D}{V_{OV}} = \frac{2 \times 0.3 mA}{0.3 V} = 2\ mA/V$

$2\ (mA/V)\ R_D = 10 \longrightarrow \boxed{R_D = 5 k\Omega}$