ECE 65: Components & Circuits Lab

Lecture 20

Transistor Amplifier Biasing

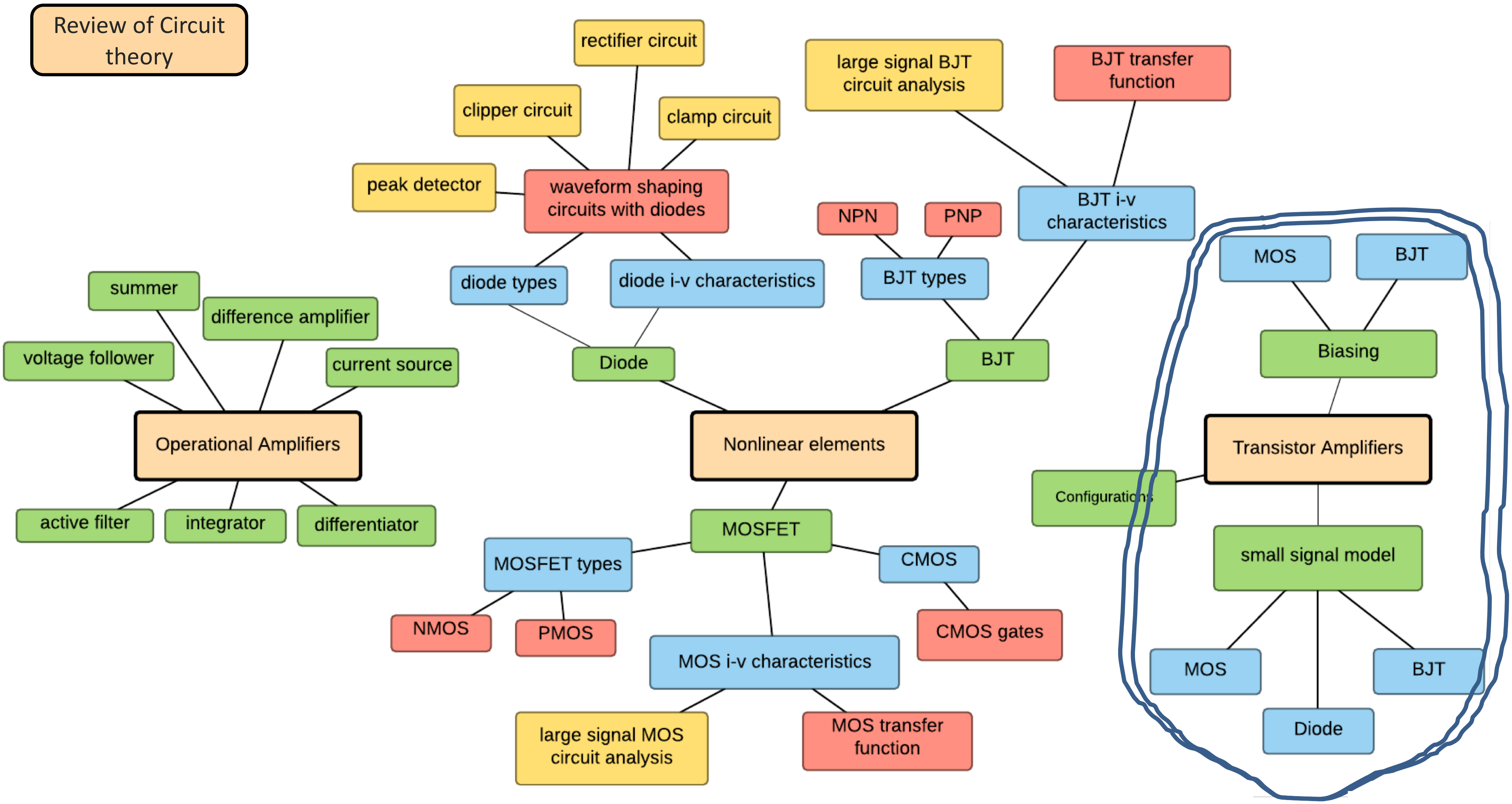
Reference notes: sections 5.3

Sedra & Smith (7th Ed): sections 7.4

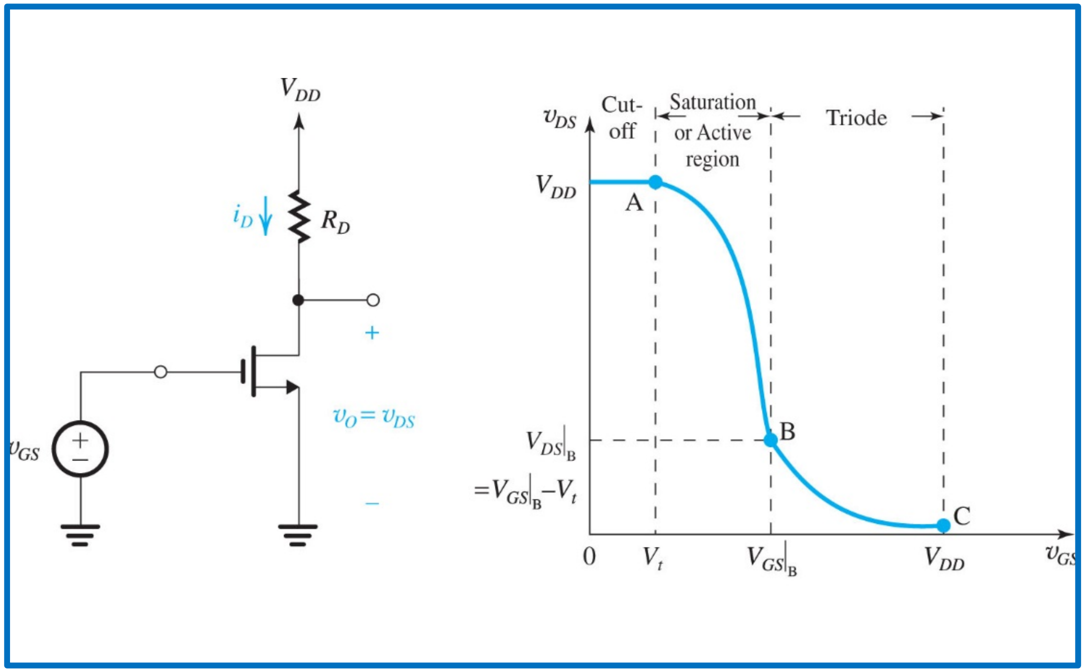
Saharnaz Baghdadchi

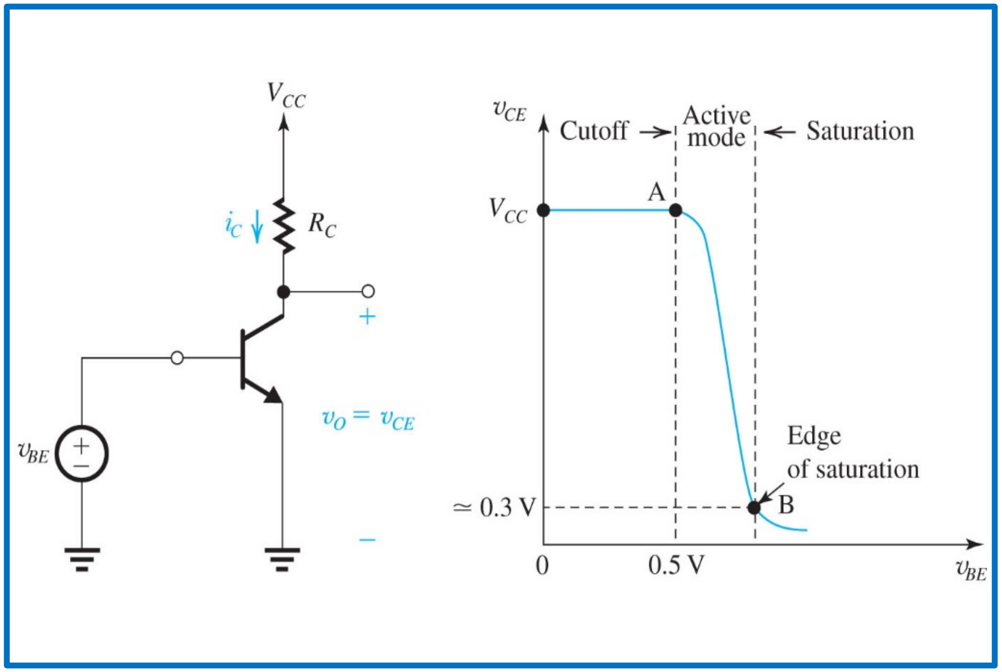
Course map

6. Transistor Amplifiers – Bias and small signal



How to establish a Bias point

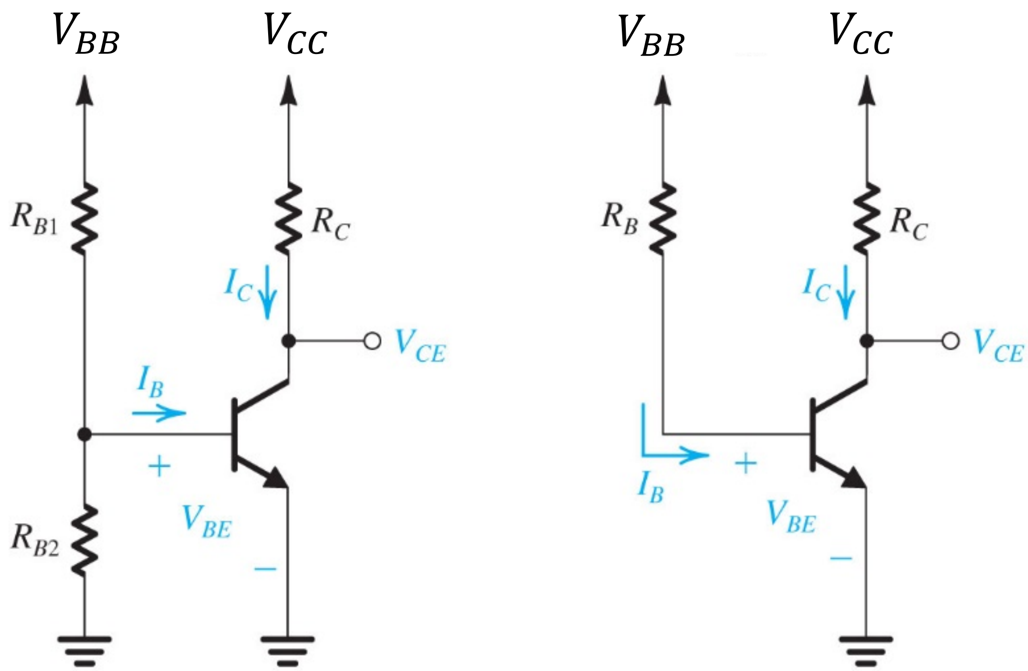




- Stable and robust bias point should be predictable and insensitive to variations in temperature and to the manufacturing variability in the transistor parameter values such as V_t , μ_n ,C_{ox} , (W/L) and β.

- Bias point details impact the small signal response (e.g., gain of the amplifier).

BJT Fixed Bias

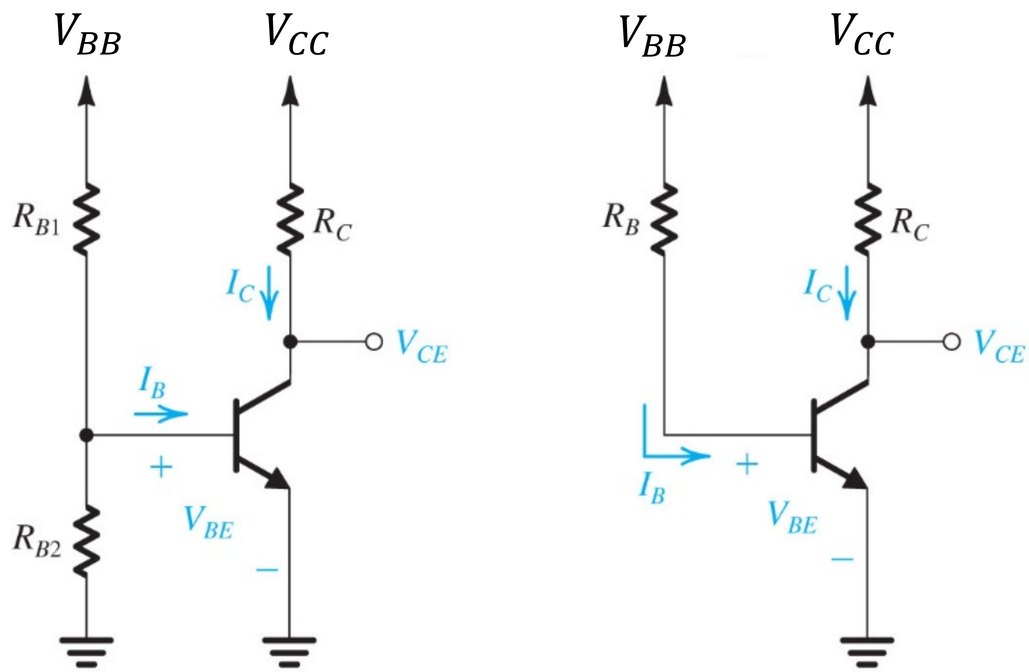


BE KVL: $V_{BB} = I_B R_B + V_{BE}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \quad , \quad I_C = \beta I_B = \beta \frac{V_{BB} - V_{BE}}{R_B}$$

CE KVL: $V_{CC} = I_C R_C + V_{CE}$

Why biasing with base voltage (fixed bias) does not work?



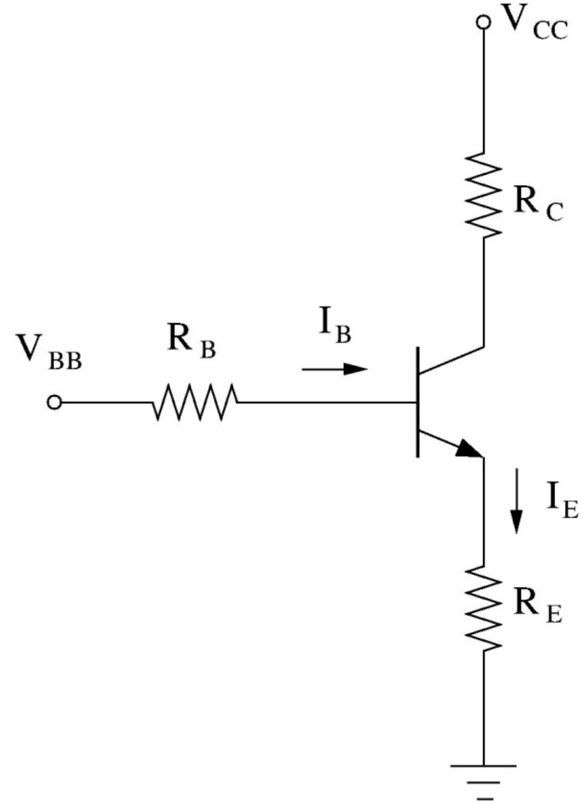
Changes in BJT β or V_{BE} values, changes the bias point drastically.

- BJT can end up in saturation or in cut-off easily.

To operate a BJT in the active region, $I_C > 0$, $V_{CE} > V_{D0}$

Biasing with Emitter Degeneration

Requires a resistor in the emitter circuit!



BE KVL: $V_{BB} = I_B R_B + V_{BE} + I_E R_E$

$$V_{BB} - V_{BE} = I_E\left(\frac{R_B}{\beta + 1} + R_E \right)$$

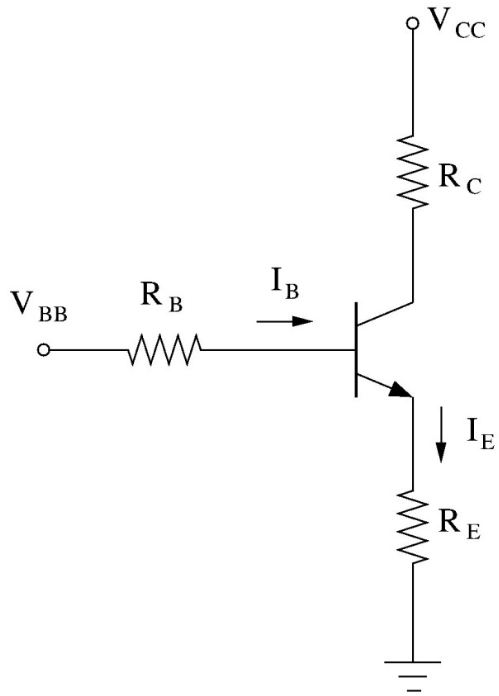
If $R_B \ll (\beta + 1) R_E$

$$V_{BB} - V_{BE} \approx I_E R_E$$

$$I_E \approx I_C \approx \frac{V_{BB} - V_{BE}}{R_E}$$ ⇦ I_C is independent of β

Emitter resistor provides negative feedback!

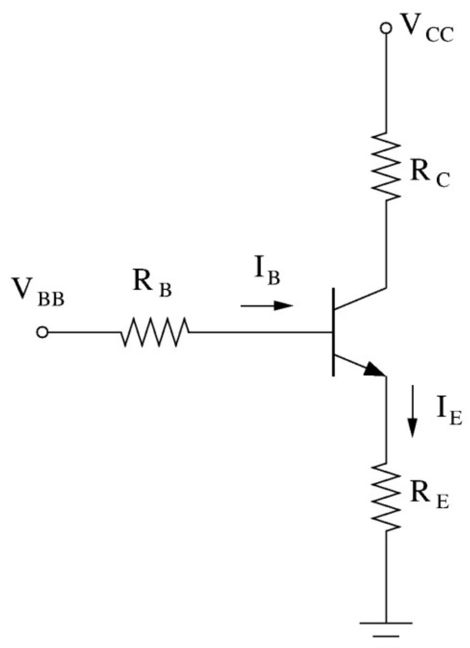
$$\begin{cases} V_{BB} - V_{BE} \approx I_E R_E \\ I_C \propto e^{V_{BE}/V_T} \end{cases}$$



Negative Feedback:

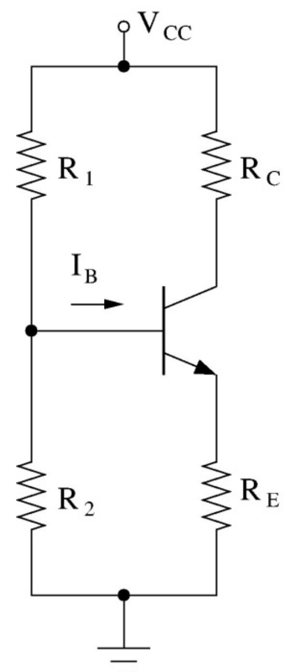
- If $I_C \approx I_E \uparrow$ (because $\beta\uparrow$) , $\xrightarrow{\text{BE -KVL}} V_{BE}\downarrow \xrightarrow{\text{BE junction}} I_C \approx I_E \downarrow$
- If $I_C \approx I_E \downarrow$ (because $\beta\downarrow$) , $\xrightarrow{\text{BE -KVL}} V_{BE}\uparrow \xrightarrow{\text{BE junction}} I_C \approx I_E \uparrow$

Emitter-degeneration bias circuits



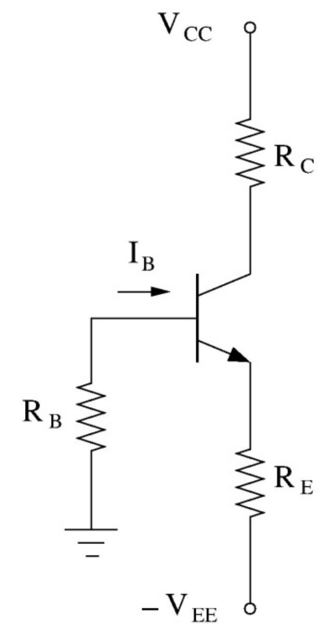
Basic Arrangement

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E$$



Bias with <u>one</u> power supply (voltage divider)

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E$$



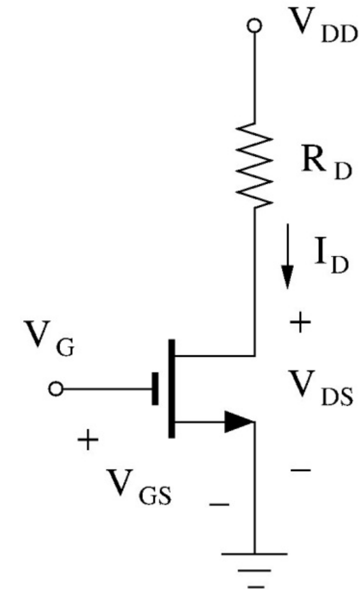
Bias with <u>two</u> power supplies

$$V_{EE} = I_B R_B + V_{BE} + I_E R_E$$

MOS Fixed Bias

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$V_{DS} = V_{DD} - I_D R_D$$

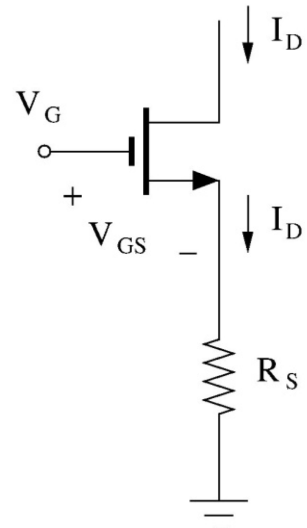


This method is NOT desirable as $\mu_n C_{ox}\ (W/L)$ and V_t vary widely among devises of the same manufacturer’s part number.

Bias point (i.e., I_D and V_{DS}) can change drastically due to temperature and/or manufacturing variability.

MOS bias with Source Degeneration
(Resistor R_S provides negative feedback!)

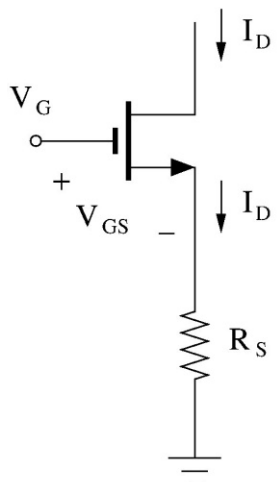
$$\begin{cases} V_{GS} = V_G - I_D R_S \\ I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2 \end{cases}$$



Negative Feedback:

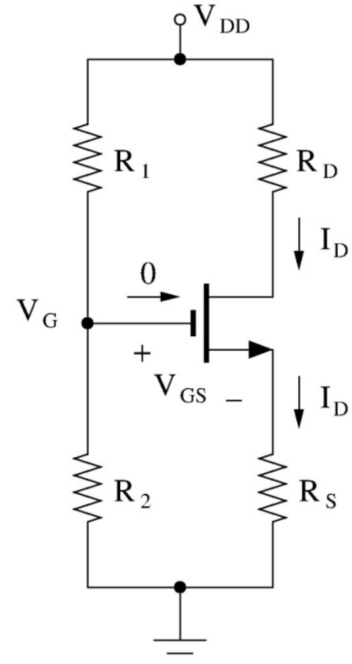
- If $I_D \uparrow$ (because $\mu_n C_{ox}(W/L)\uparrow$ or $V_t \downarrow$) $\xrightarrow{\text{GS KVL}} V_{GS}\downarrow \xrightarrow{I_D \text{ Eq.}} I_D \downarrow$
- If $I_D \downarrow$ (because $\mu_n C_{ox}(W/L)\downarrow$ or $V_t \uparrow$) $\xrightarrow{\text{GS KVL}} V_{GS}\uparrow \xrightarrow{I_D \text{ Eq.}} I_D \uparrow$

Source-degeneration bias circuits



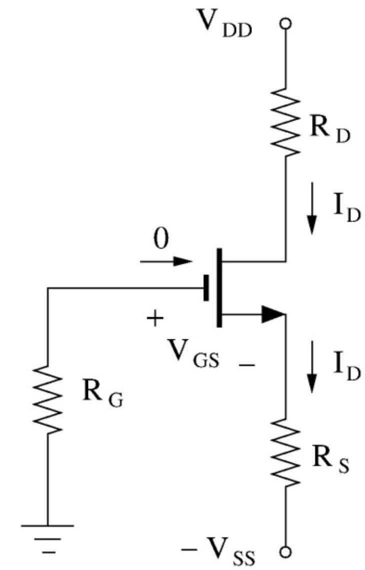
Basic Arrangement

$$V_G = V_{GS} + I_D R_S$$



Bias with <u>one</u> power supply (voltage divider)

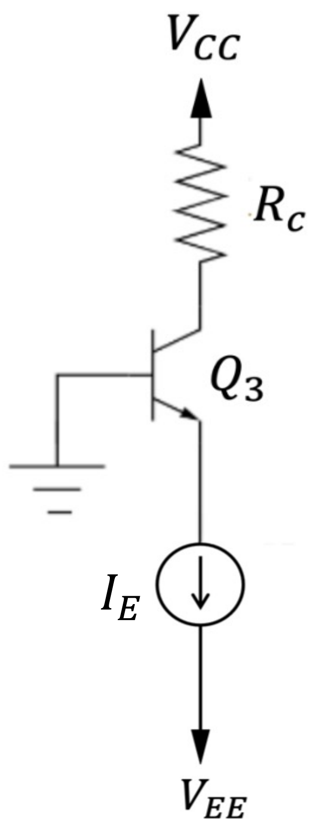
$$V_G = V_{GS} + I_D R_S$$

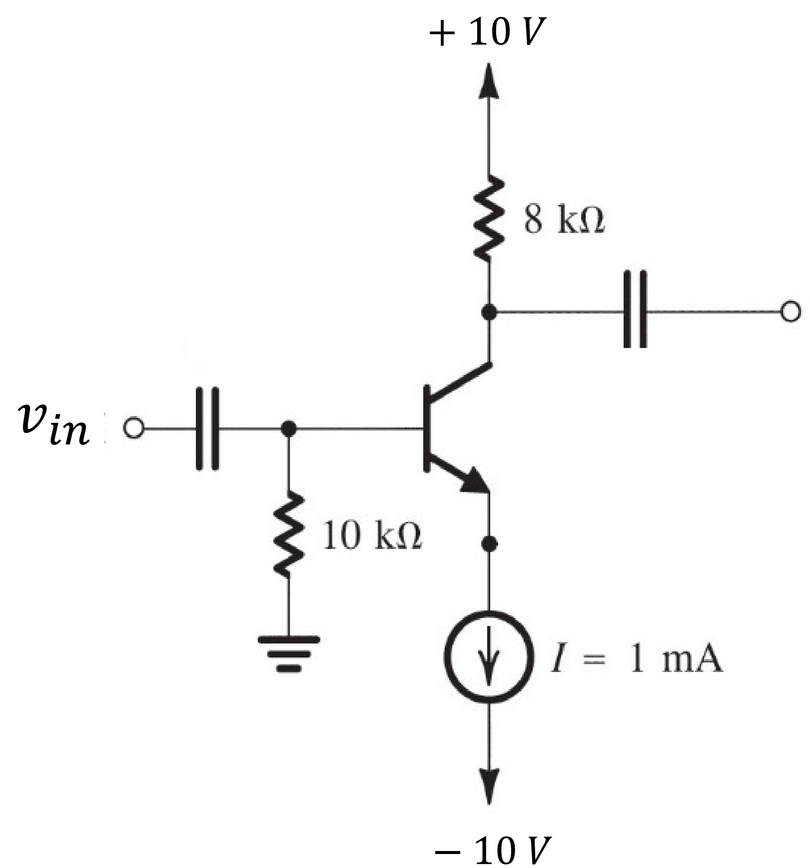


Bias with <u>two</u> power supplies

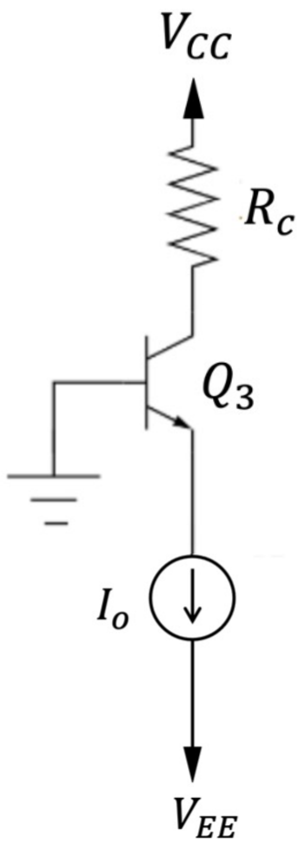
$$V_{SS} = V_{GS} + I_D R_S$$

Biasing with a current source





Biasing with a current source



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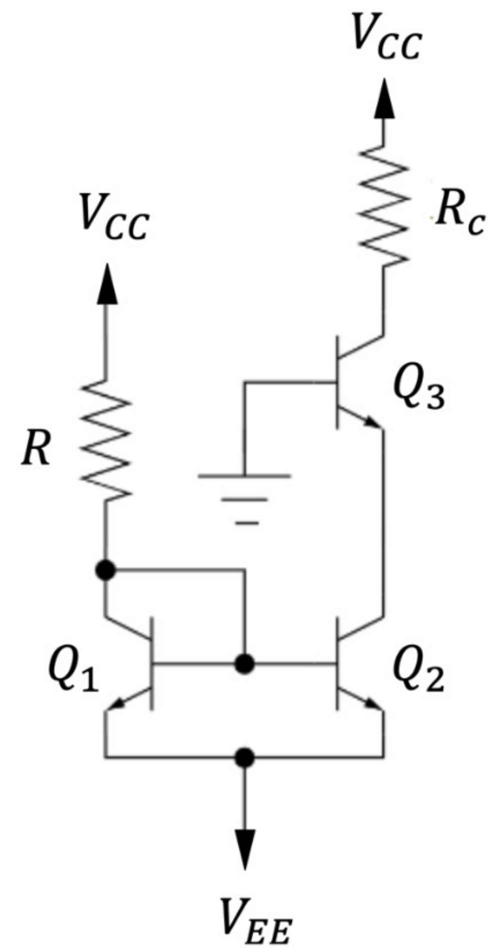
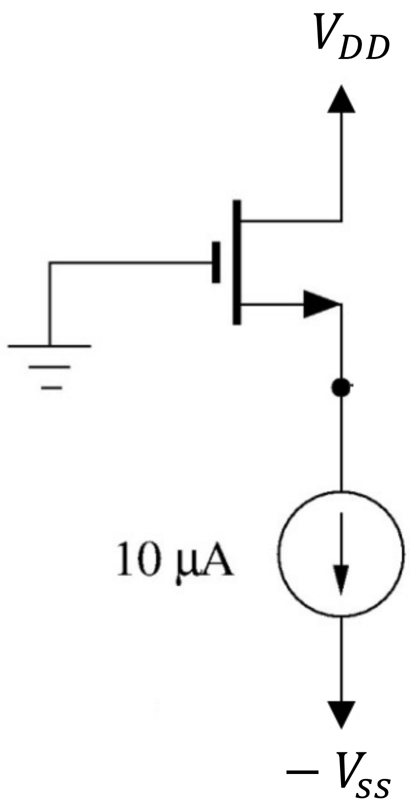
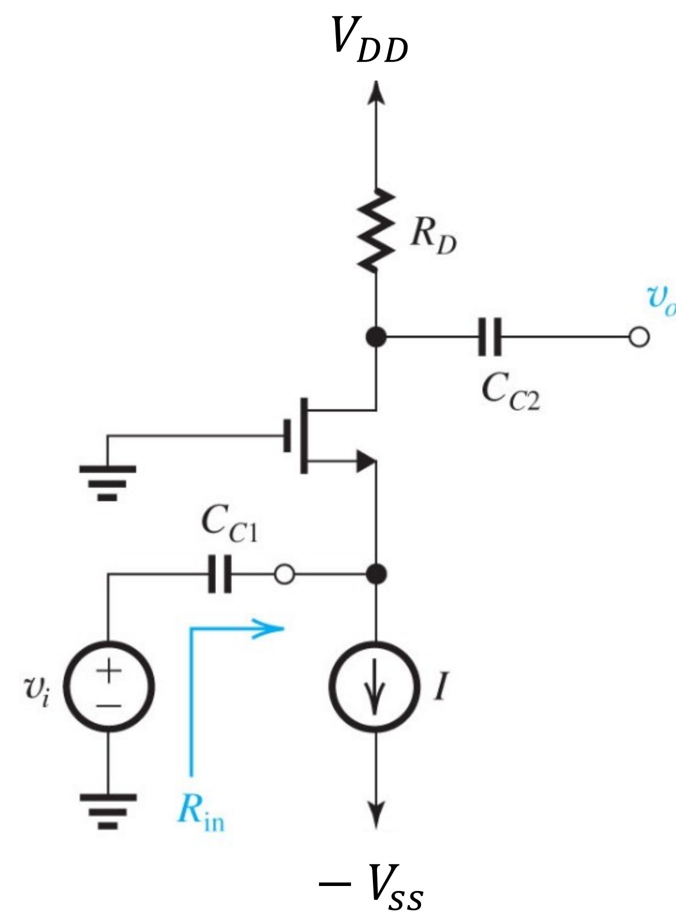


Biasing with a current source





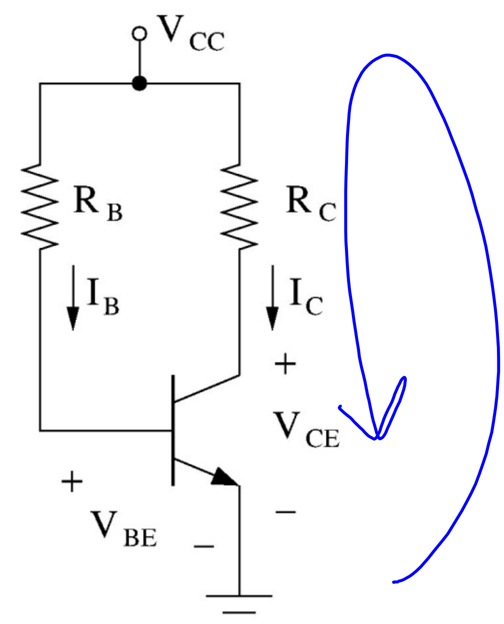
Biasing circuit examples

Lecture 21 reading quiz.

Find R_C and R_B such that BJT would be in active with V_{CE} = 5V and I_C = 25 mA. (V_{CC} = 15 V, Si BJT with β = 100 and $V_A = \infty$). $V_{D_0} = 0.7\,V$

$I_C > 0 \longrightarrow$ BJT is ON

$V_{CE} > V_{D_0} \longrightarrow$ BJT is in active mode



CE KVL:

$V_{CC} = R_C I_C + V_{CE}$

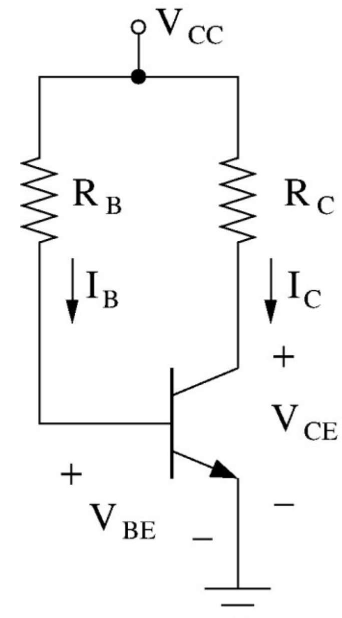
$15 = R_C \times 25mA + 5V \longrightarrow R_C = 400\,\Omega$

$I_C = \beta I_B \longrightarrow \boxed{I_B = \frac{25mA}{100} = 0.25\,mA}$

BE - KVL $\longrightarrow V_{CC} = R_B I_B + V_{BE} \longrightarrow R_B = 57.2\,k\Omega$

Discussion question 1.

Consider the circuit designed in the reading quiz (R_C =400 , R_B = 57.2 k, V_{CC} = 15 V). Find the operating point of BJT if $\beta = 200$. ($V_A = \infty$).



BE - KVL :

$15 = I_B R_B + V_{BE} \longrightarrow 15 = I_B \times 57.2k + 0.7$

$\longrightarrow I_B = 0.25 mA$

$I_C = \beta I_B = 200 \times 0.25 mA = 50 mA$

CE KVL : $15 = R_C I_C + V_{CE} \longrightarrow 15 = 0.4 k\Omega \times 50 mA + V_{CE}$

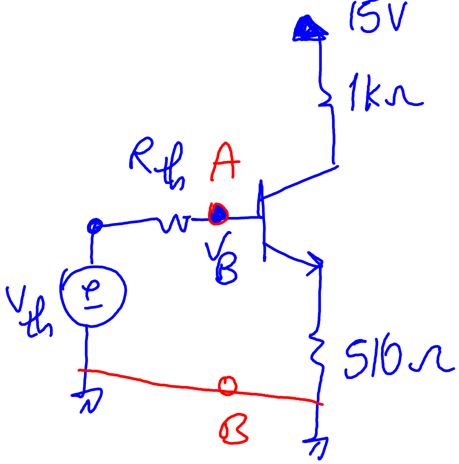
$V_{CE} = -5V < V_{D_0} \longrightarrow$ BJT is in saturation !

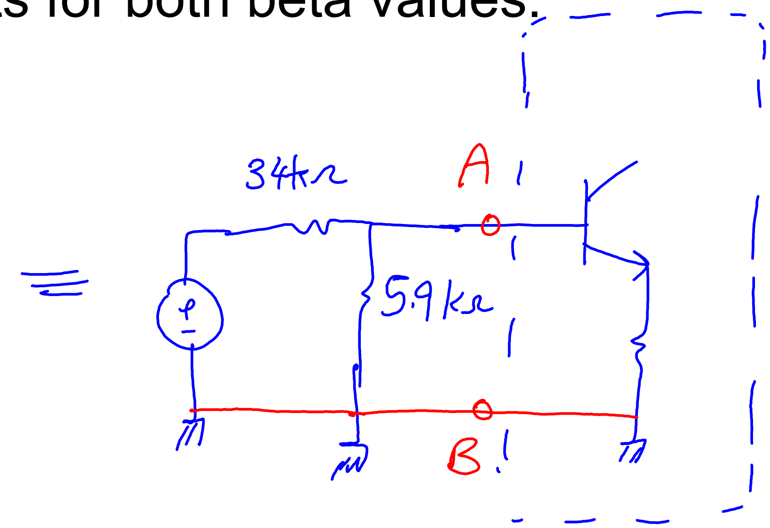
$V_{CE} = 0.2 V$, $I_C = \frac{15V - 0.2V}{400\Omega} = 37 mA$, $I_B = 0.25 mA$

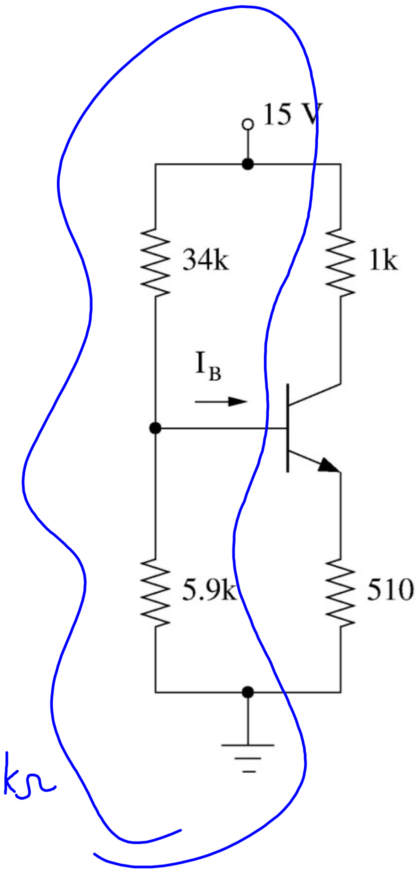
Discussion question 2.

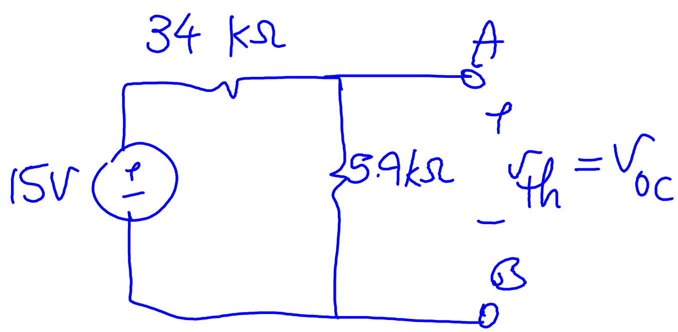
Find the bias point of the BJT (Si BJT with $\beta = \overset{100}{200}$ and $V_A = \infty$).

Compare your results for both beta values.









, $R_{th} = 34k\Omega \,||\, 5.9k\Omega = 5.03k\Omega$

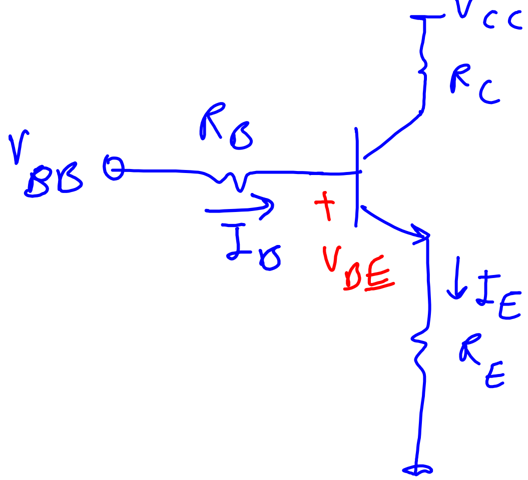
$$V_{th} = \frac{5.9\,k\Omega}{5.9k + 34k} \times 15V = 2.22V$$

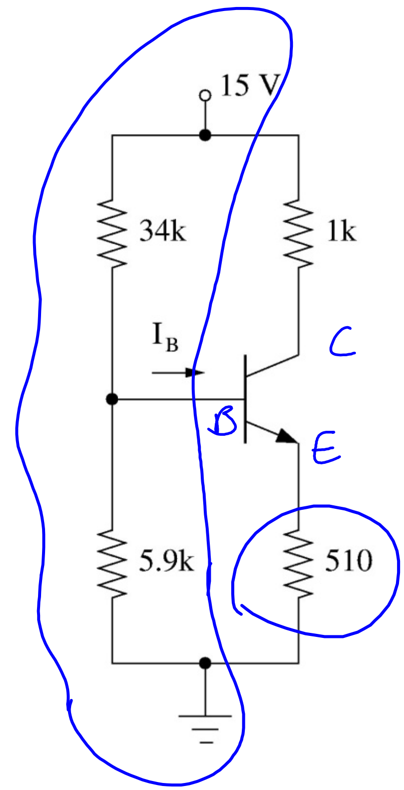
Discussion question 2.

$I_C = \beta I_B$ in active region

Always valid: $\boxed{I_E = I_C + I_B} \rightarrow I_E = I_B + \beta I_B = (1+\beta) I_B$

Find the bias point of the BJT (Si BJT with $\beta = 200$ and $V_A = \infty$). $V_{D_0} = 0.7$





$R_B = 34k\Omega \parallel 5.9\,k\Omega = 5.03\,k$

$$V_{BB} = \frac{5.9k}{34k + 5.9k} \times 15 = 2.22\,V$$

BE KVL: $V_{BB} = R_B I_B + V_{BE} + I_E R_E$

$$2.22 = 5.03k \times \frac{I_E}{1+\beta} + 0.7 + I_E \times 0.510$$

$I_E = 2.84\,mA$, $I_C = \beta I_B = \dfrac{\beta}{\beta+1} \times I_E = 2.82\,mA$, $I_B = 14.1\,\mu A$

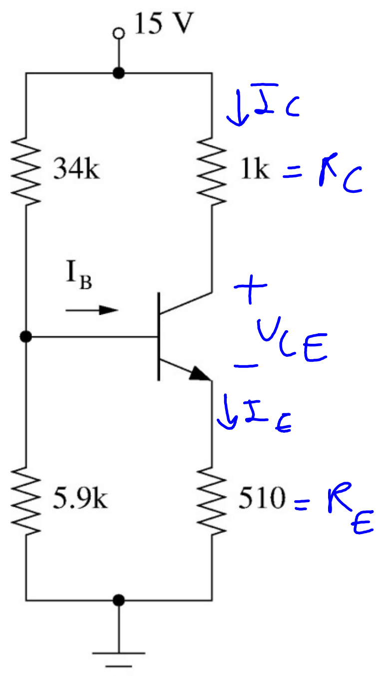
Discussion question 2.

Find the bias point of the BJT (Si BJT with $\beta = 200$ and $V_A = \infty$).

CE KVL :

$15 = I_C R_C + V_{CE} + R_E I_E$

$\rightarrow V_{CE} = 10.7V > 0.7\,V \longrightarrow$ BJT is in active mode



Discussion question 2.

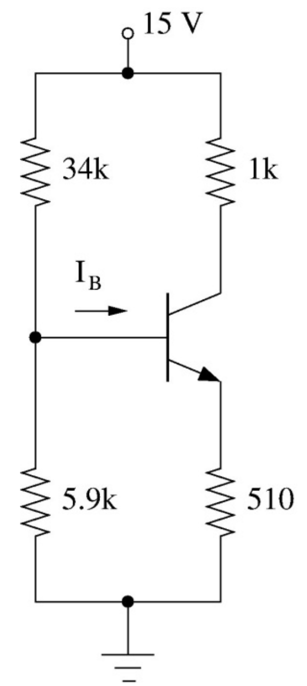
Find the bias point of the BJT (Si BJT with $\beta = 200$ and $V_A = \infty$).

If β changes to 100,

$$2.22 = 5.03\ k \times \frac{I_E}{101} + 0.7 + 0.510\ k \times I_E$$

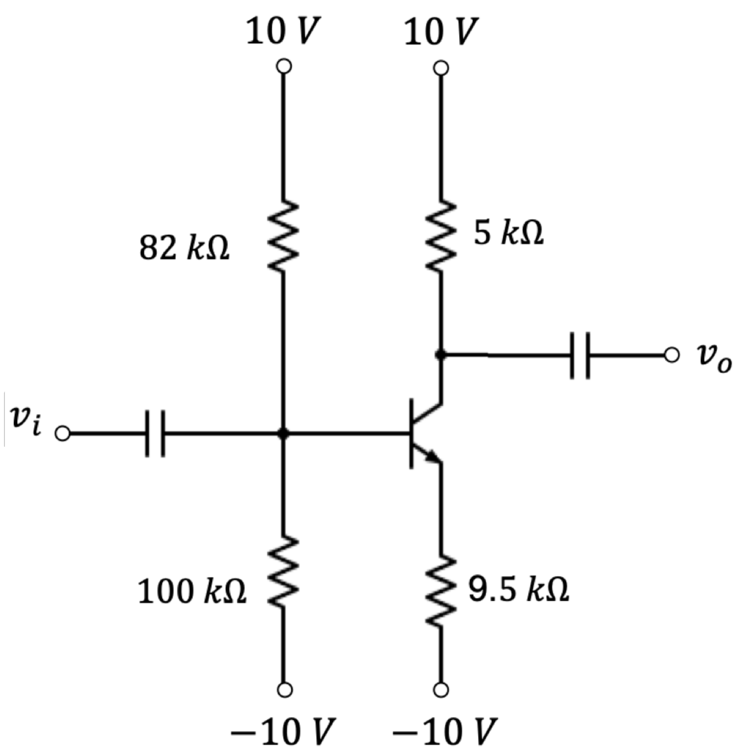
$$I_E = 2.71\ mA$$

$$V_{CE} = 15 - (1.510\ k) \times 2.71\ mA = 10.91\ V > V_{D0}$$



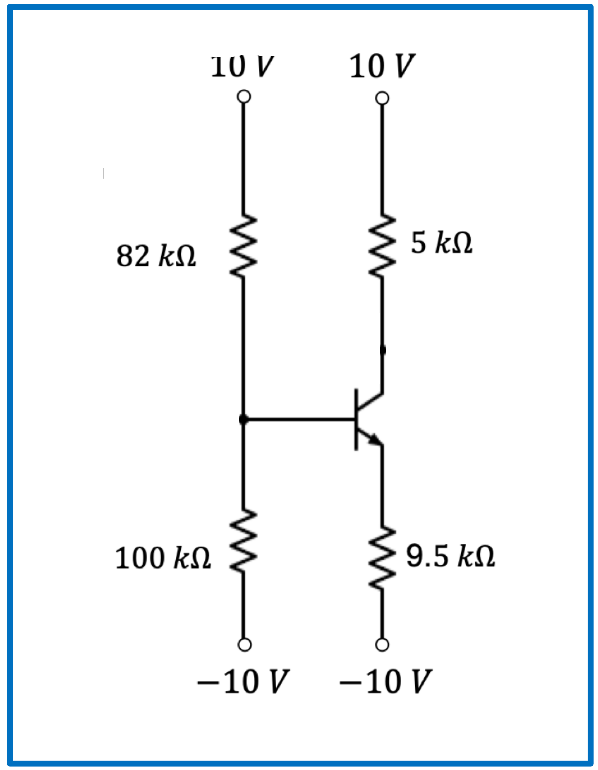
BJT is still in active mode and I_E changed by about -4%.

Example of finding the Bias point/Thevenin equivalent circuit

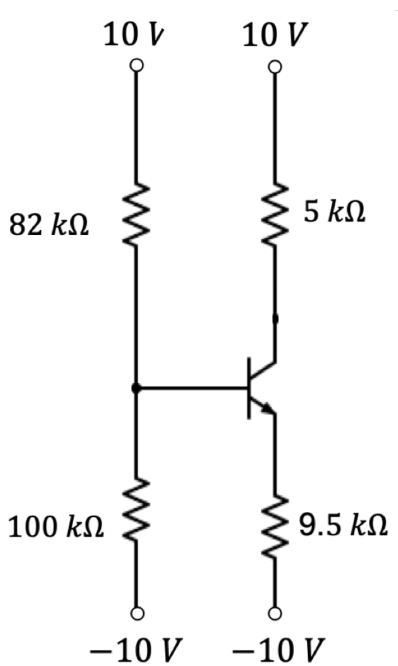


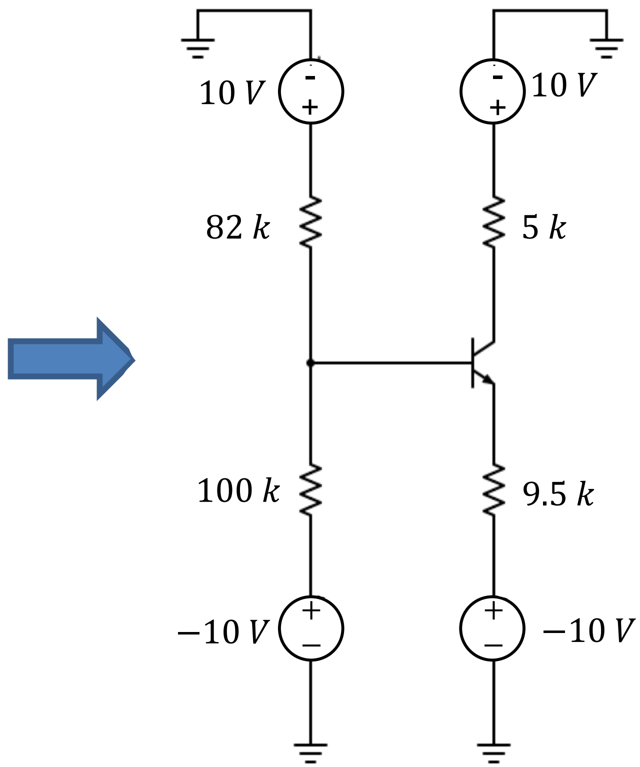
$\beta = 100 \quad V_T = 25\ mV \quad V_A = \infty$

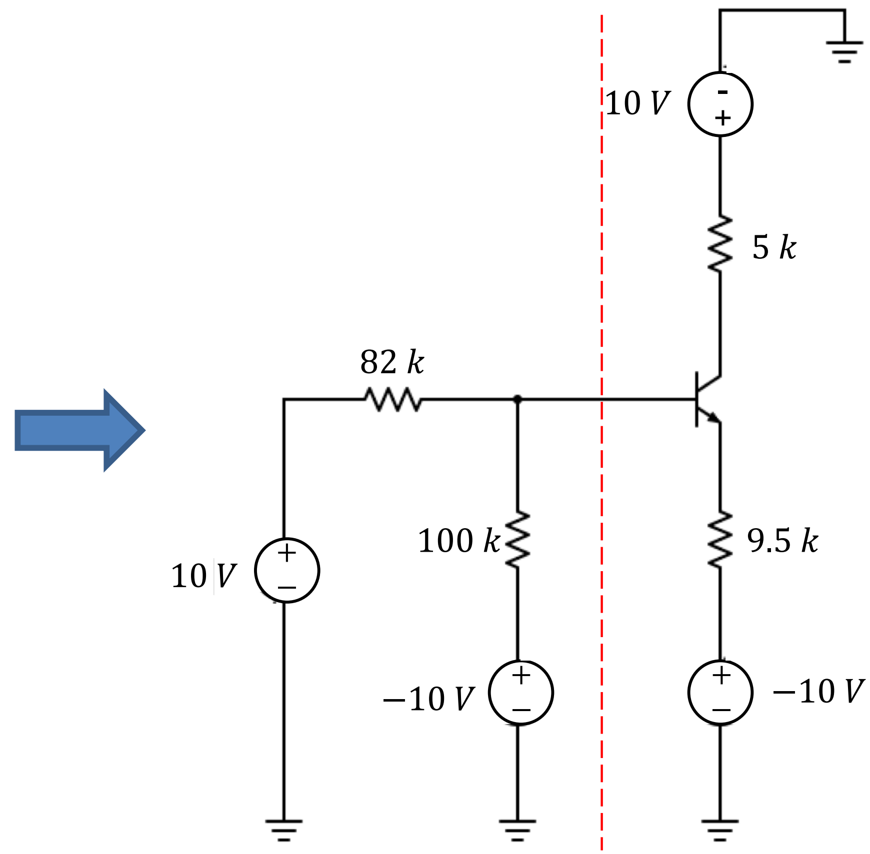
Bias circuit:



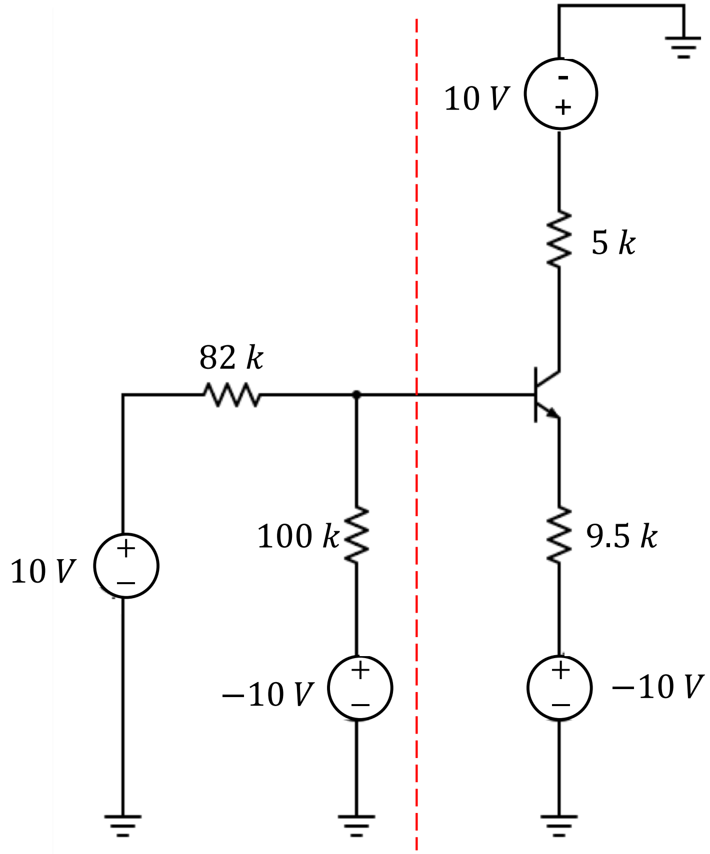
Example cont.

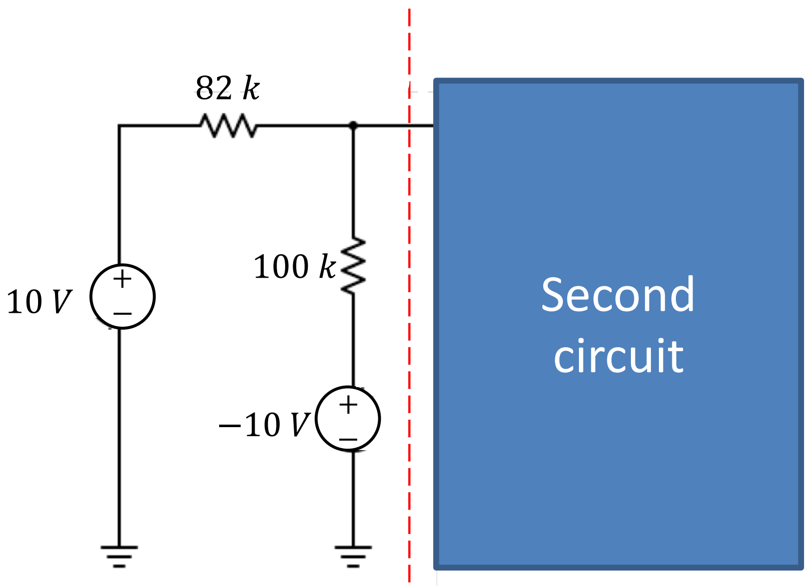


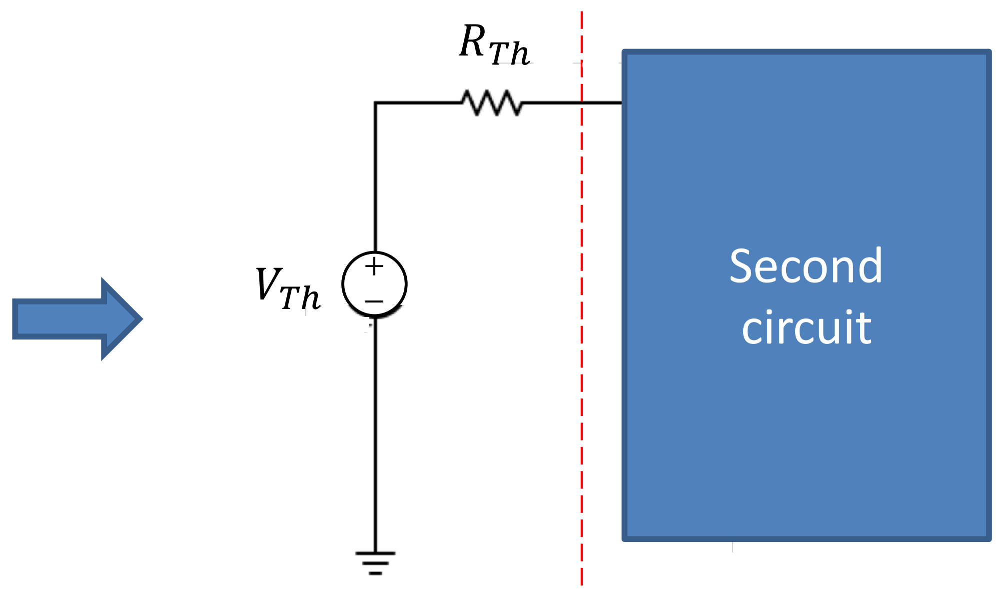




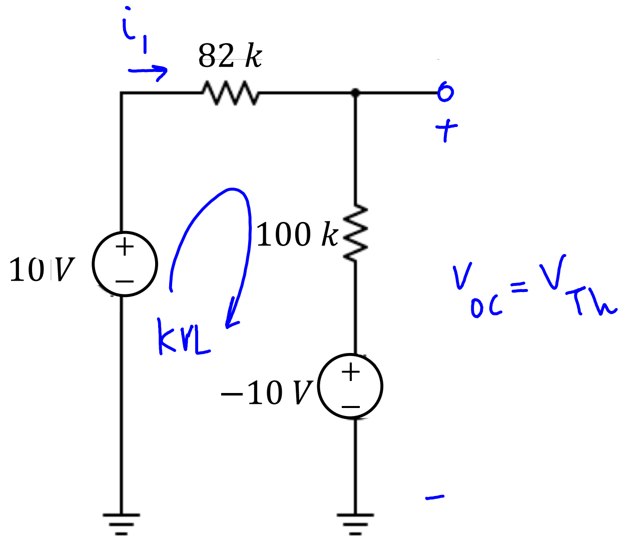
Example cont.

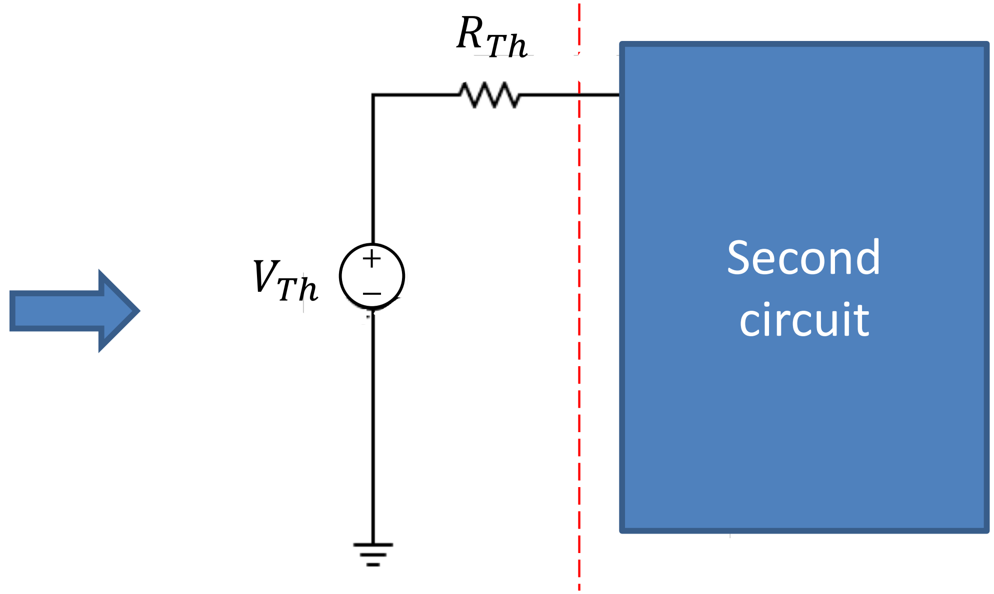






Example cont.

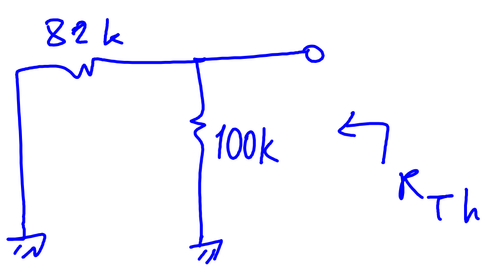




KVL : $-10\,V + 82\,k \times i_1 + 100\,k \times i_1 - 10 = 0$

$\rightarrow i_1 = \dfrac{20\,V}{182\,k} \rightarrow V_{Th} = 100\,k \times i_1 - 10\,V \rightarrow V_{Th} = 0.989\,V$

R_{Th} : zero the independant voltage sources.

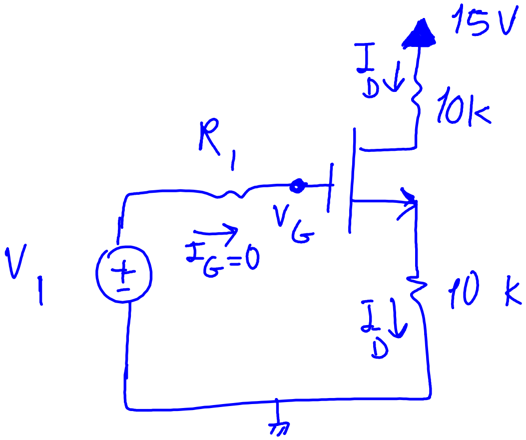


$R_{Th} = 100\,k \parallel 82\,k \simeq 45.05\,k\Omega$

Clicker question 1.

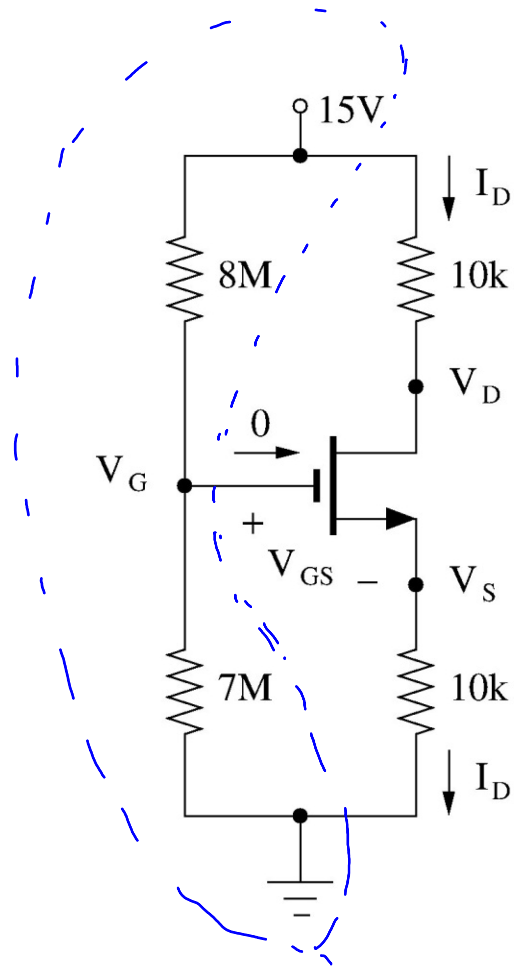
Which one of the options is correct for the following bias circuit?

$V_t = 1$ V and $k_n = 1.0\ \text{mA/V}^2$, $\lambda = 0.$



$$V_1 = \frac{7\,M\Omega}{7\,M\Omega + 8\,M\Omega} \times 15\,V$$

$$V_1 = 7\,V$$



$$R_1 = 7\,M\Omega \parallel 8\,M\Omega$$

Since $I_G = 0 \longrightarrow R_1 I_G = 0 \longrightarrow V_G = V_1 = 7\,V$

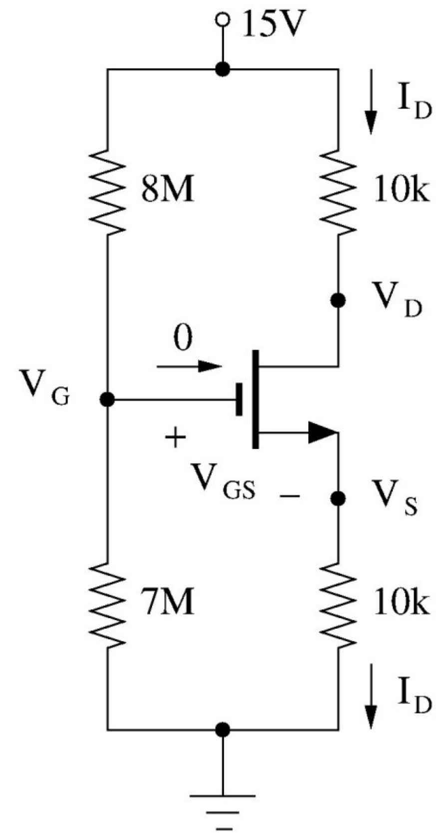
$$\begin{cases} V_{GS} = V_G - 10k \times I_D = \underbrace{7\,V - 10\,k\Omega \times I_D} \\ I_D = \frac{1}{2} k_n (\underbrace{V_{GS}} - V_t)^2 \end{cases}$$

This is an amplifier circuit, so MOS will be in saturation.

Clicker question 1.

Which one of the options is correct for the following bias circuit?

$V_t = 1$ V and $k_n = 1.0$ mA/V^2 , $\lambda = 0$.



$$V_{GS} = 7\,V - 10\,k\Omega \times I_D$$

$$\underbrace{V_{GS} - V_t}_{V_{OV}} = 7\,V - 10\,k\Omega \times I_D - 1$$

$$\begin{cases} V_{OV} = 6\,V - 10\,k\Omega \times I_D \\ I_D = \frac{1}{2} k_n V_{OV}^2 \end{cases} \Downarrow$$

$$\Rightarrow V_{OV} = 6\,V - \frac{10k}{2} \times 1\left(mA/V^2\right) V_{OV}^2$$

$$\boxed{5 V_{OV}^2 + V_{OV} - 6 = 0} \rightarrow V_{OV} = \begin{cases} 1\,V > 0 \\ -6/5\,V \quad \times \end{cases} \rightarrow \boxed{V_{OV} = 1\,V}$$

Clicker question 1.

Which one of the options is correct for the following bias circuit?

$V_t = 1$ V and $k_n = 1.0$ mA/V^2 , $\lambda = 0.$

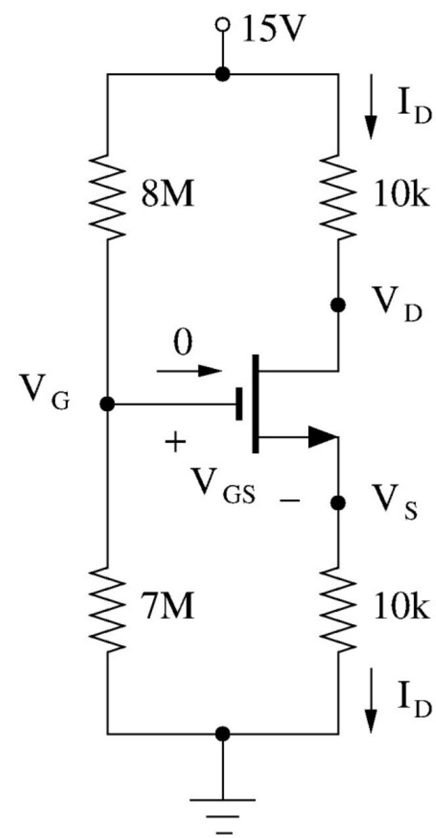
$V_{OV} = 1\,V \longrightarrow V_{GS} - V_t = 1 \longrightarrow V_{GS} = V_t + 1 = 2V$

$V_{GS} = V_G - V_S = 2\,V \longrightarrow 7\,V - V_S = 2\,V$

$\longrightarrow \boxed{V_S = 5V}$

$I_D = \frac{1}{2} \times 1 \left(mA/V^2\right) \times 1^2 (V^2) = 0.5\,mA$

$\boxed{I_D = 0.5\ mA}$



Discussion question 3.

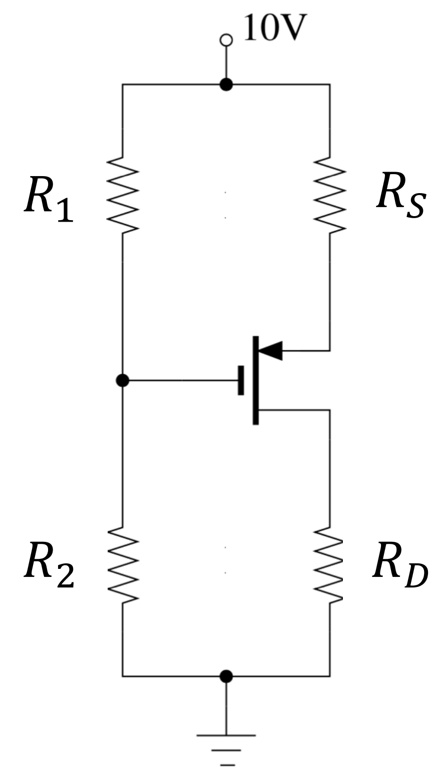
Design the below circuit so that the transistor operates in saturation with V_{SD} biased 1-V from the edge of the saturation, with $I_D = 1\,mA$ and $V_D = 3\,V$. Use a $10\,\mu A$ current in the voltage divider. $|V_t| = 1\,V$, $k_p = 0.5\,mA/V^2$

In the saturation region : $V_{SD} \geq V_{ov}$

V_{SD} biased 1 volt from the edge of saturation &

MOS operates in saturation means :

$V_{SD} = V_{ov} + 1$

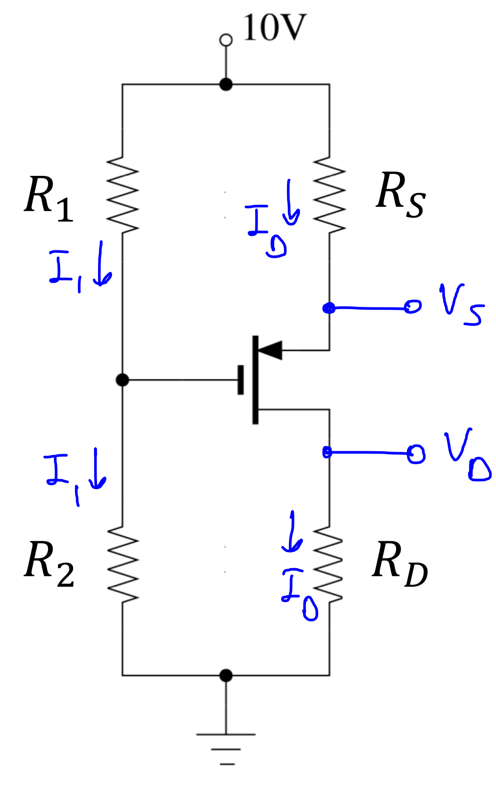


$I_D = \frac{1}{2} k_n V_{ov}^2 \longrightarrow 1\,mA = \frac{1}{2} \times 0.5 \frac{mA}{V^2} \times V_{ov}^2$

$\longrightarrow V_{ov} = 2\,V \longrightarrow V_{SG} = V_{ov} + |V_t| = 3\,V$

Discussion question 3.

Design the below circuit so that the transistor operates in saturation with V_{SD} biased 1-V from the edge of the saturation, with $I_D = 1\,mA$ and $V_D = 3\,V$. Use a $10\,\mu A$ current in the voltage divider. $|V_t| = 1\,V$, $k_p = 0.5\,mA/V^2$



$$V_{SD} = V_{ov} + 1 = 2 + 1 = 3V$$

$$V_D = R_D I_D \longrightarrow 3V = R_D \times 1mA \longrightarrow \boxed{R_D = 3k\Omega}$$

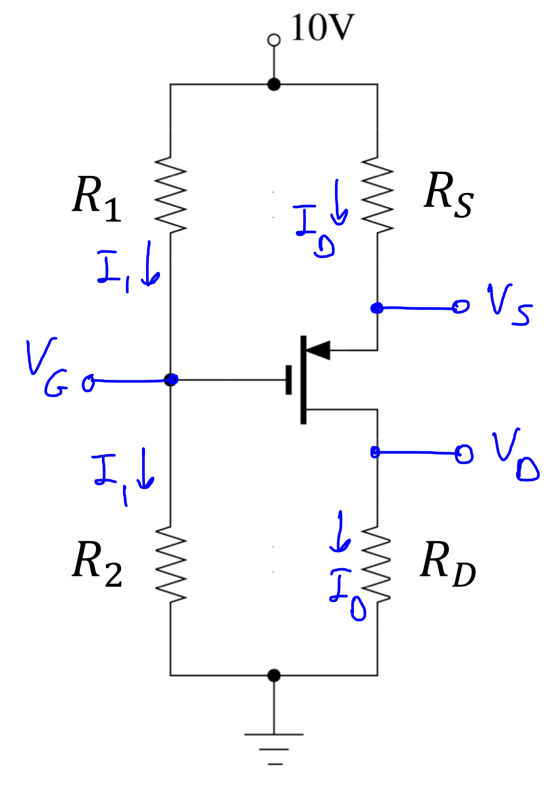
$$V_{SD} = V_S - V_D = V_S - 3V = 3V \longrightarrow V_S = 6V$$

$$V_S = 10V - R_S I_D \longrightarrow 6V = 10V - R_S \times 1mA$$

$$\longrightarrow \boxed{R_S = 4k\Omega}$$

Discussion question 3.

Design the below circuit so that the transistor operates in saturation with V_{SD} biased 1-V from the edge of the saturation, with $I_D = 1\,mA$ and $V_D = 3\,V$. Use a $10\,\mu A$ current in the voltage divider. $|V_t| = 1\,V$, $k_p = 0.5\,mA/V^2$



$$V_{SG} = V_S - V_G = 3\,V \longrightarrow V_G = V_S - 3V = 6 - 3 = 3V$$

$$V_G = 10\,V - R_1 I_1 \longrightarrow 3V = 10\,V - R_1 \times 10\,\mu A$$

$$R_1 = \frac{7\,V}{10\,\mu A} = 0.7\ M\Omega$$

$$V_G = R_2 I_2 \longrightarrow R_2 = \frac{3\,V}{10\,\mu A} = 0.3\ M\Omega$$