ECE 65: Components & Circuits Lab

Lecture 20

Transistor Amplifier Biasing

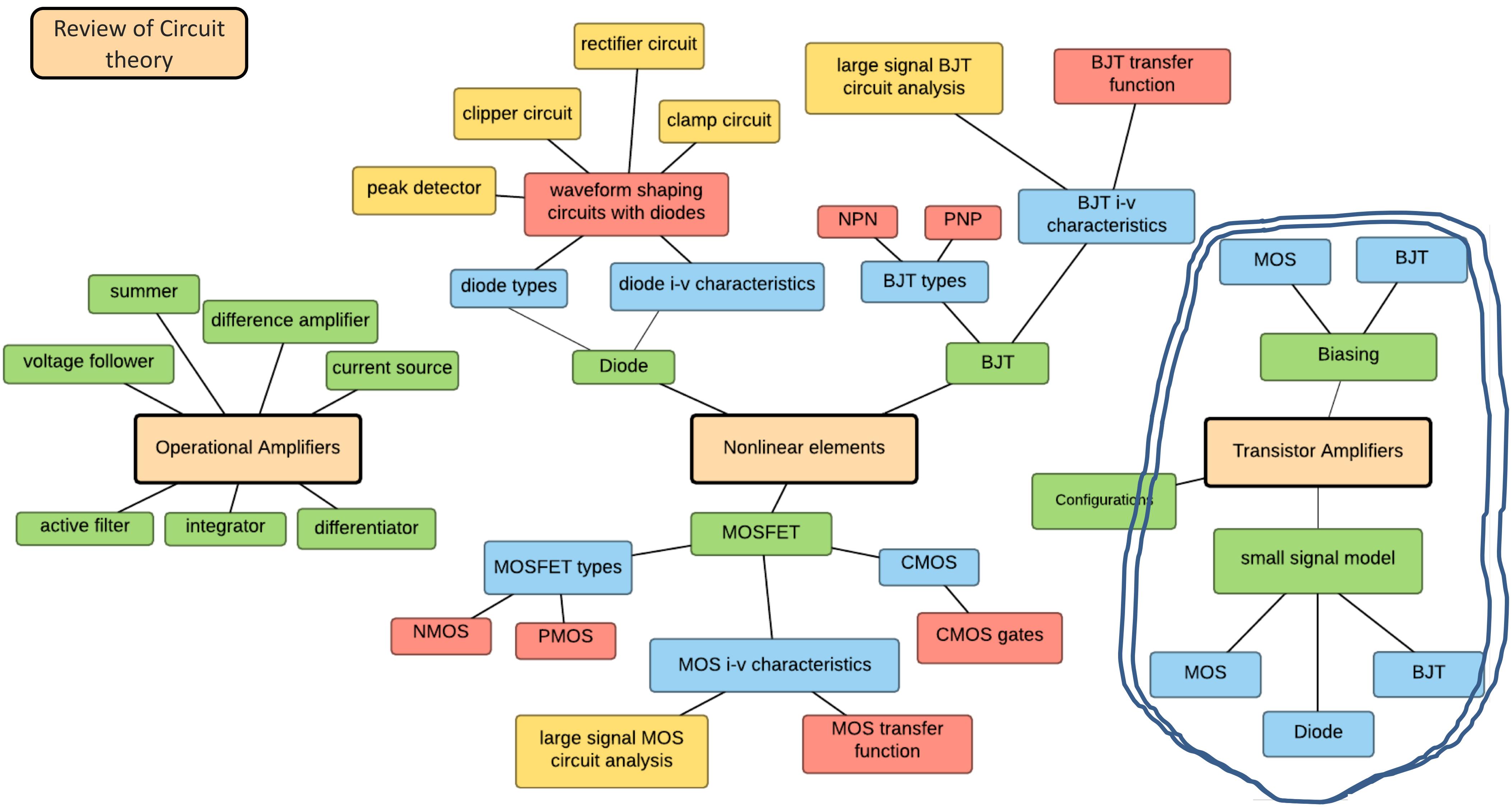
Reference notes: sections 5.3

Sedra & Smith (7th Ed): sections 7.4

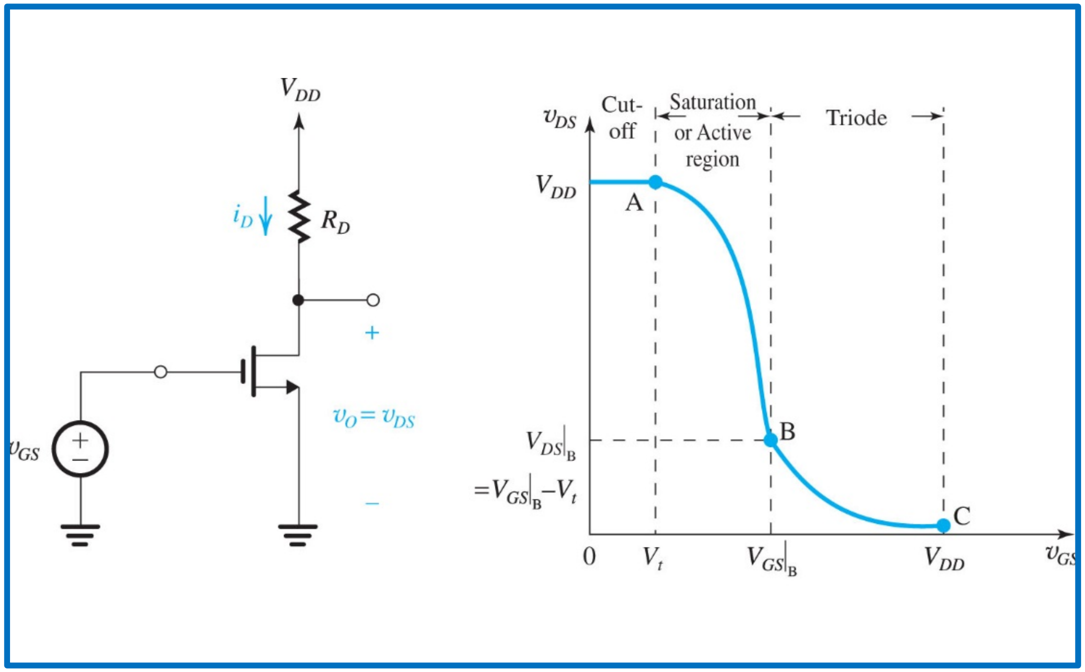
Saharnaz Baghdadchi

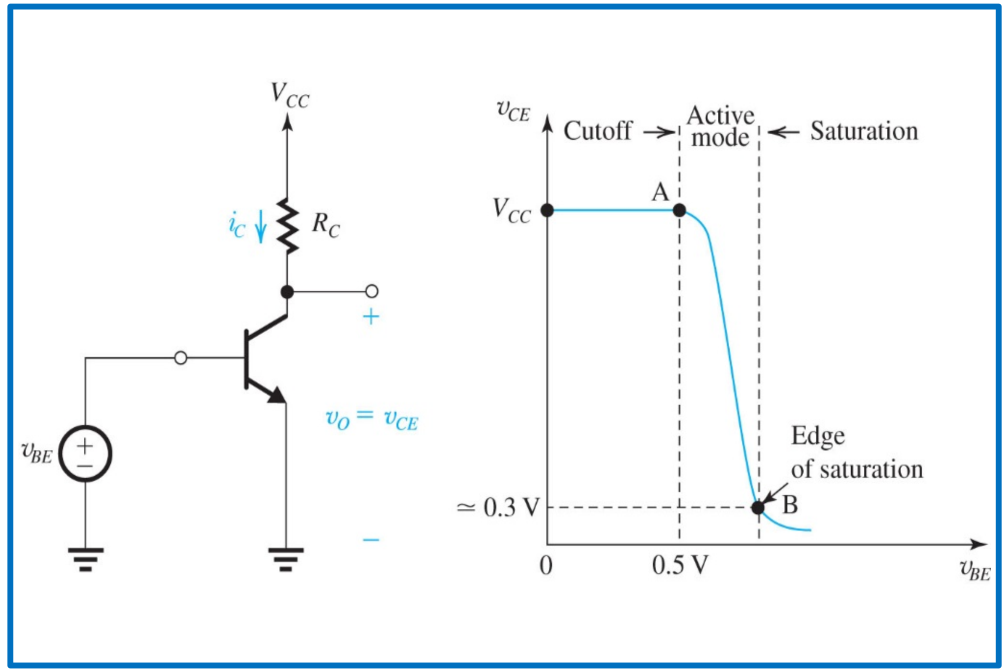
Course map

6. Transistor Amplifiers – Bias and small signal



How to establish a Bias point

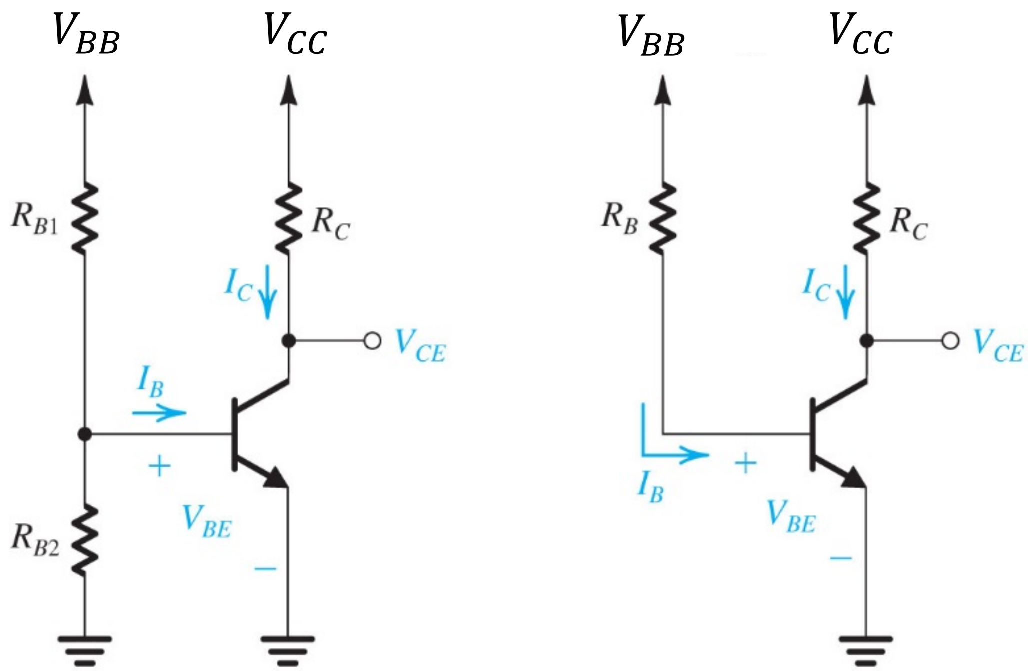




- Stable and robust bias point should be predictable and insensitive to variations in temperature and to the manufacturing variability in the transistor parameter values such as V_t , μ_n ,C_{ox} , (W/L) and β.

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

BJT Fixed Bias

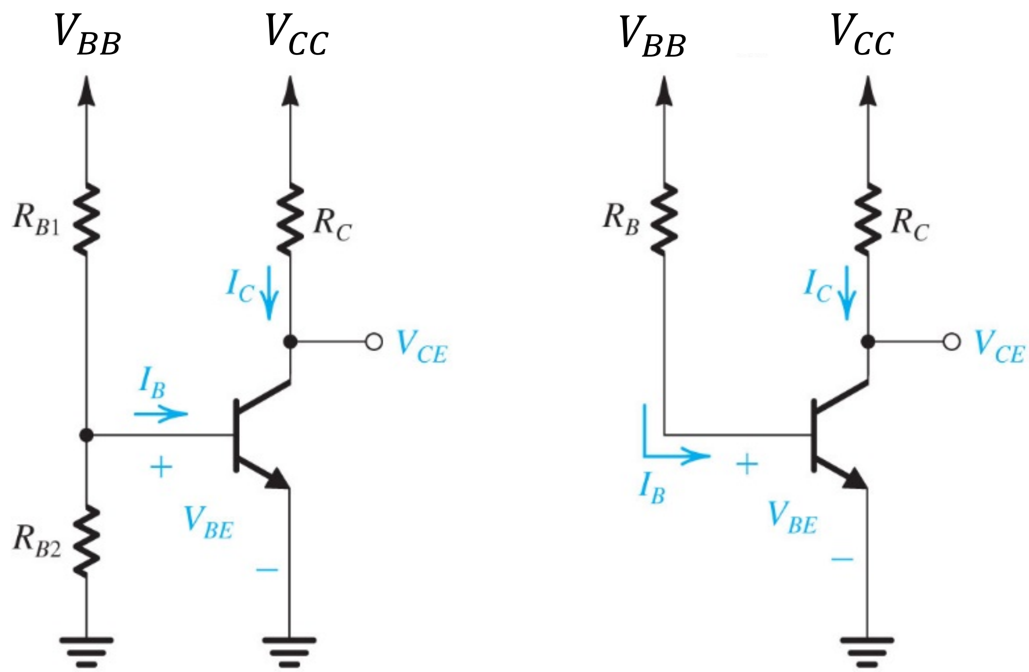


BE KVL: $V_{BB} = I_B R_B + V_{BE}$

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

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

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



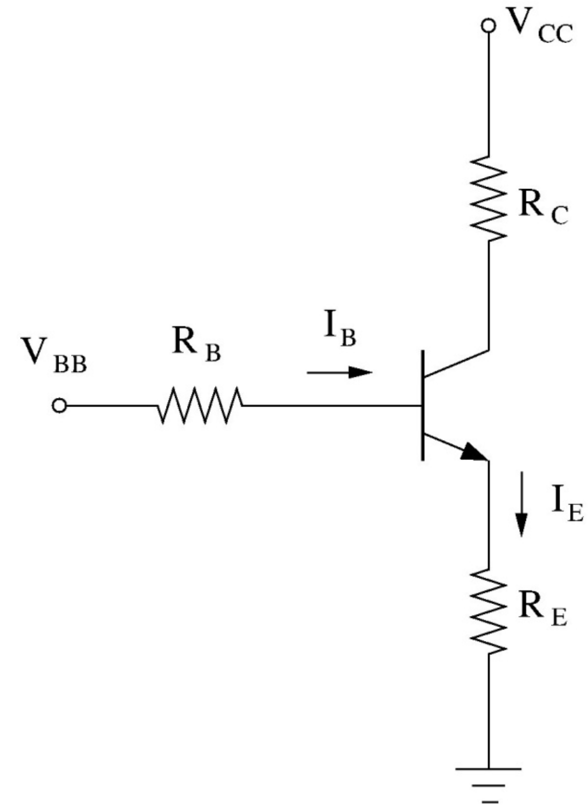
Changes in BJT β or V_{BE} values, changes the bias point drastically.

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

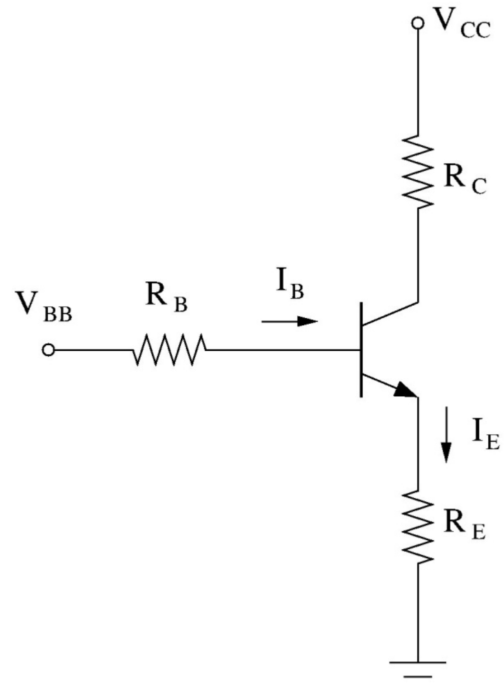
$$V_{BB} - V_{BE} \approx I_E R_E$$

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

I_C is independent of β

Emitter resistor provides negative feedback!

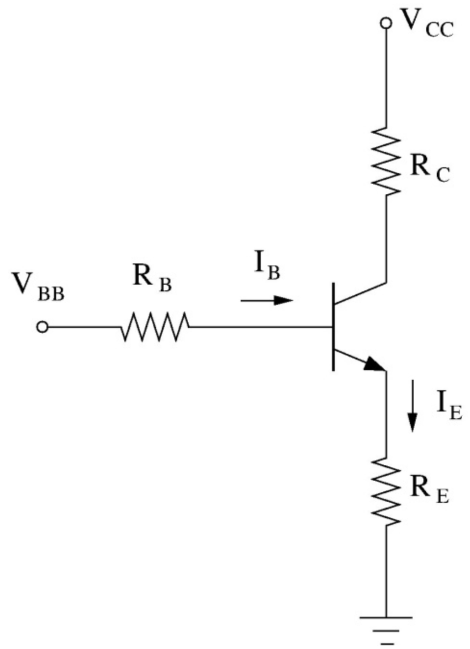
$$\begin{cases} V_{BB} - V_{BE} \approx I_E R_E \\ I_C \propto e^{V_{BE}/V_T} \end{cases}$$



Negative Feedback:

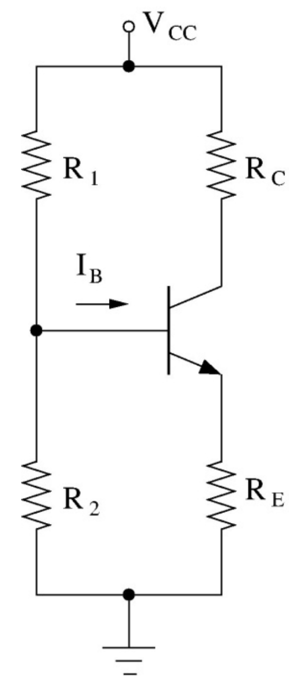
- If $I_C \approx I_E \uparrow$ (because $\beta\uparrow$) , $\xrightarrow{\text{BE -KVL}} V_{BE}\downarrow \xrightarrow{\text{BE junction}} I_C \approx I_E \downarrow$
- If $I_C \approx I_E \downarrow$ (because $\beta\downarrow$) , $\xrightarrow{\text{BE -KVL}} V_{BE}\uparrow \xrightarrow{\text{BE junction}}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

Emitter-degeneration bias circuits



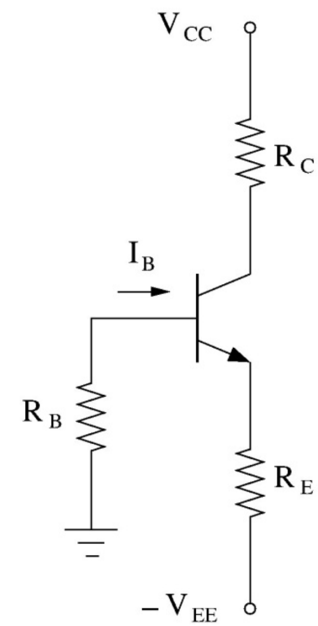
Basic Arrangement

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



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

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



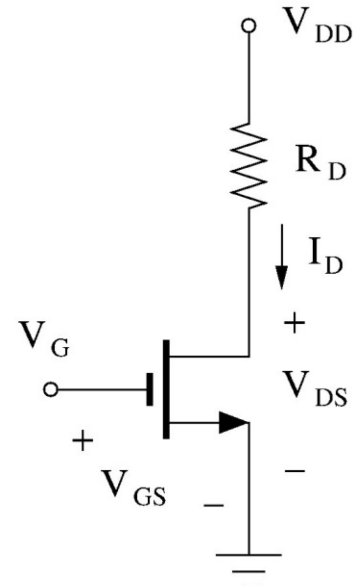
Bias with <u>two</u> power supplies

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

MOS Fixed Bias

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

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

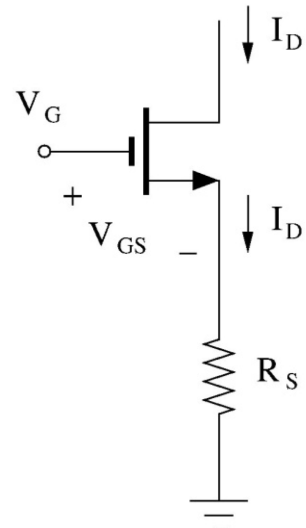


This method is NOT desirable as $\mu_n C_{ox}\ (W/L)$ and V_t vary widely among devises of the same manufacturer’s part number.

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!)

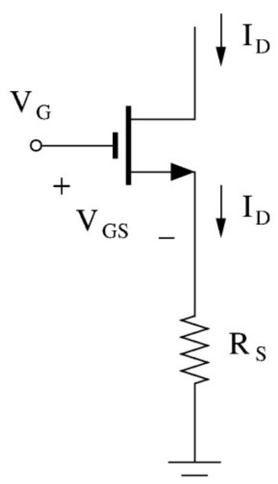
$$
\begin{cases}
V_{GS} = V_G - I_D R_S \\
I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2
\end{cases}
$$



Negative Feedback:

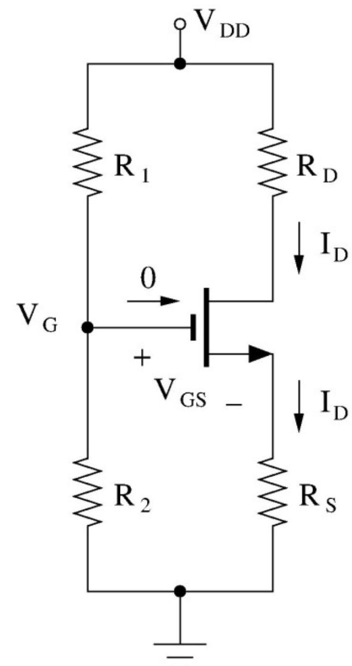
- If $I_D \uparrow$ (because $\mu_n C_{ox}(W/L)\uparrow$ or $V_t \downarrow$) $\xrightarrow{\text{GS KVL}}$ $V_{GS}\downarrow$ $\xrightarrow{I_D \text{ Eq.}}$ $I_D \downarrow$
- If $I_D \downarrow$ (because $\mu_n C_{ox}(W/L)\downarrow$ or $V_t \uparrow$) $\xrightarrow{\text{GS KVL}}$ $V_{GS}\uparrow$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

Source-degeneration bias circuits



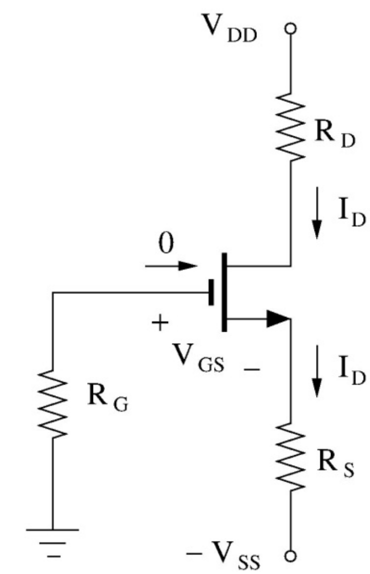
Basic Arrangement

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



Bias with one power supply (voltage divider)

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



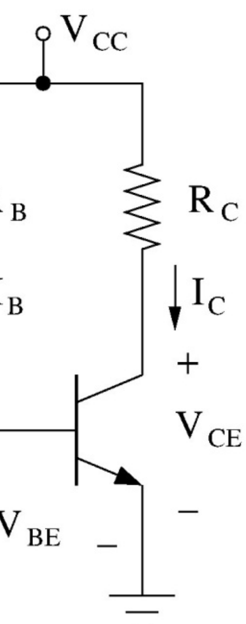
Bias with two power supplies

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

Biasing circuit examples

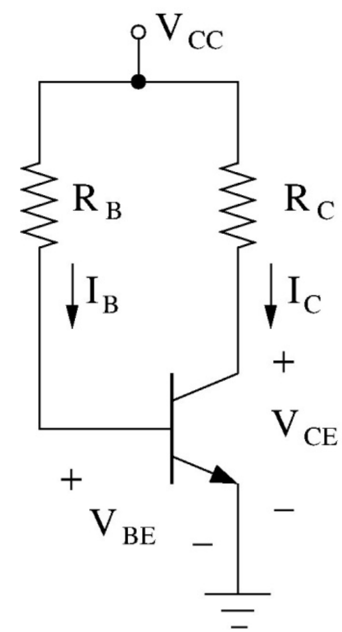
Lecture 20 reading quiz.

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 $\beta = 100$ and $V_A = \infty$).



Discussion question 1.

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

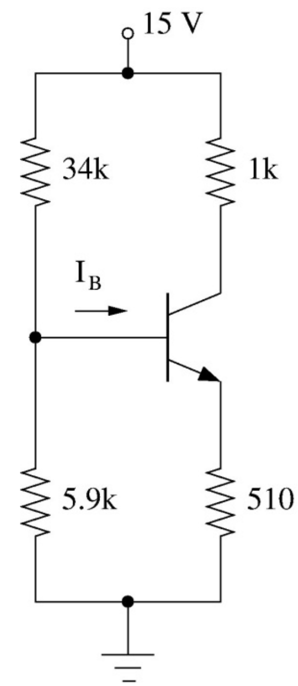


Discussion question 2.

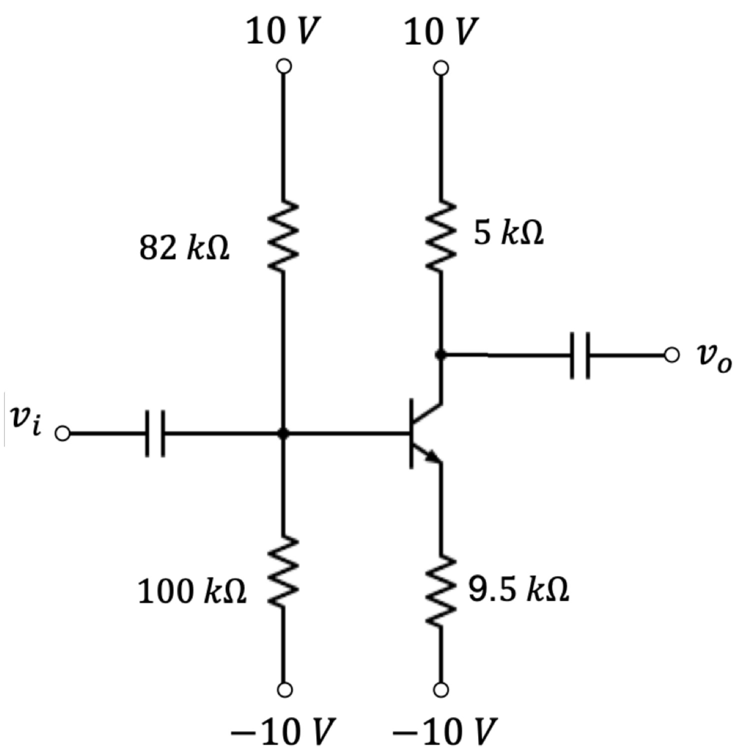
100

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

Compare your results for both beta values.

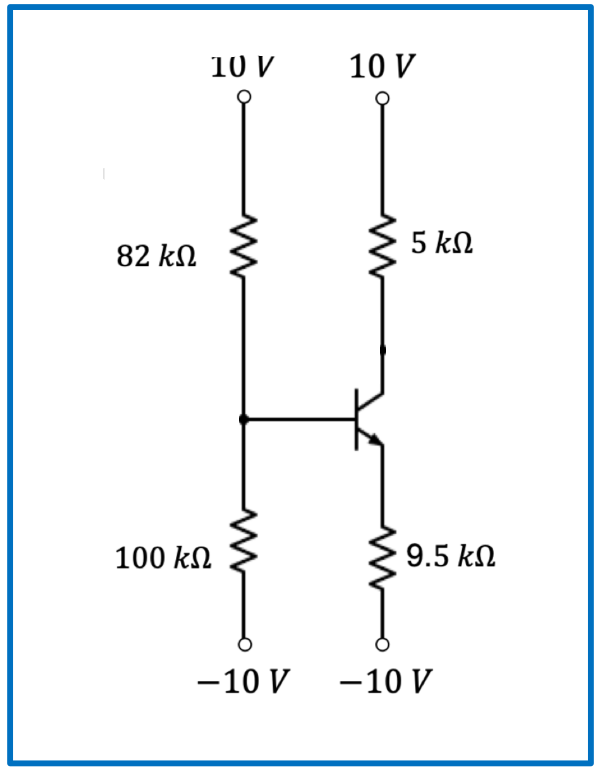


Example of finding the Bias point/Thevenin equivalent circuit

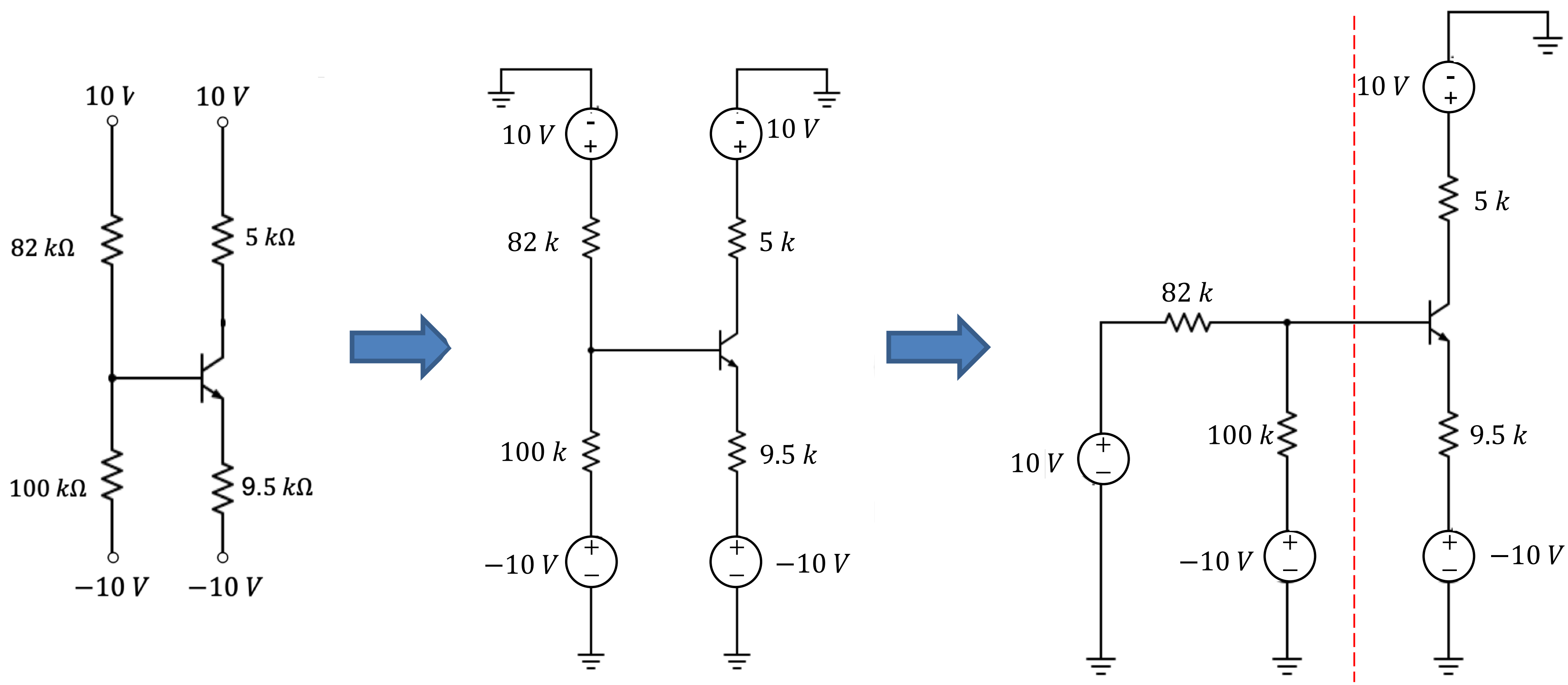


$\beta = 100 \quad V_T = 25\,mV \quad V_A = \infty$

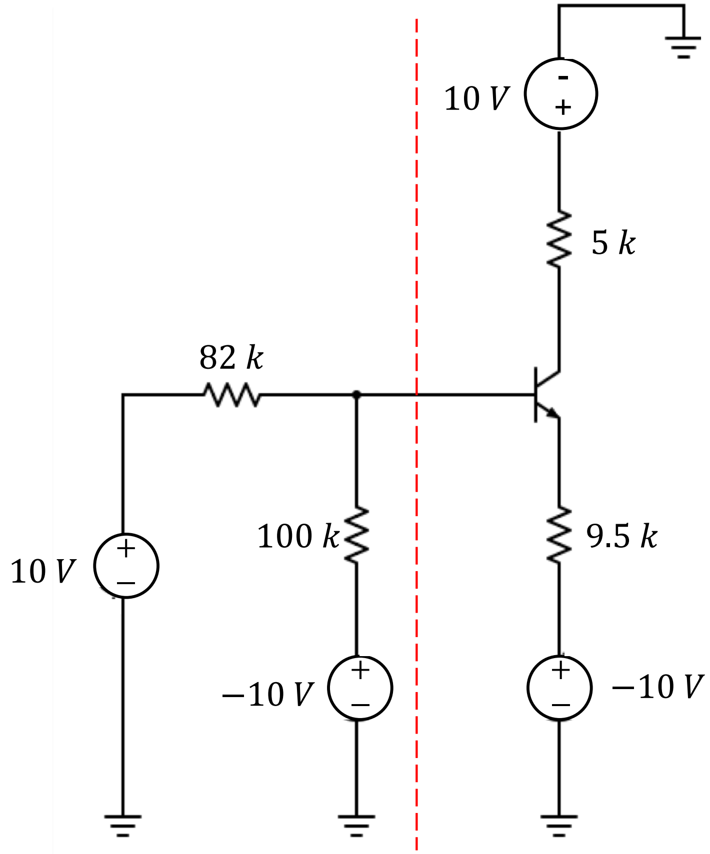
Bias circuit:

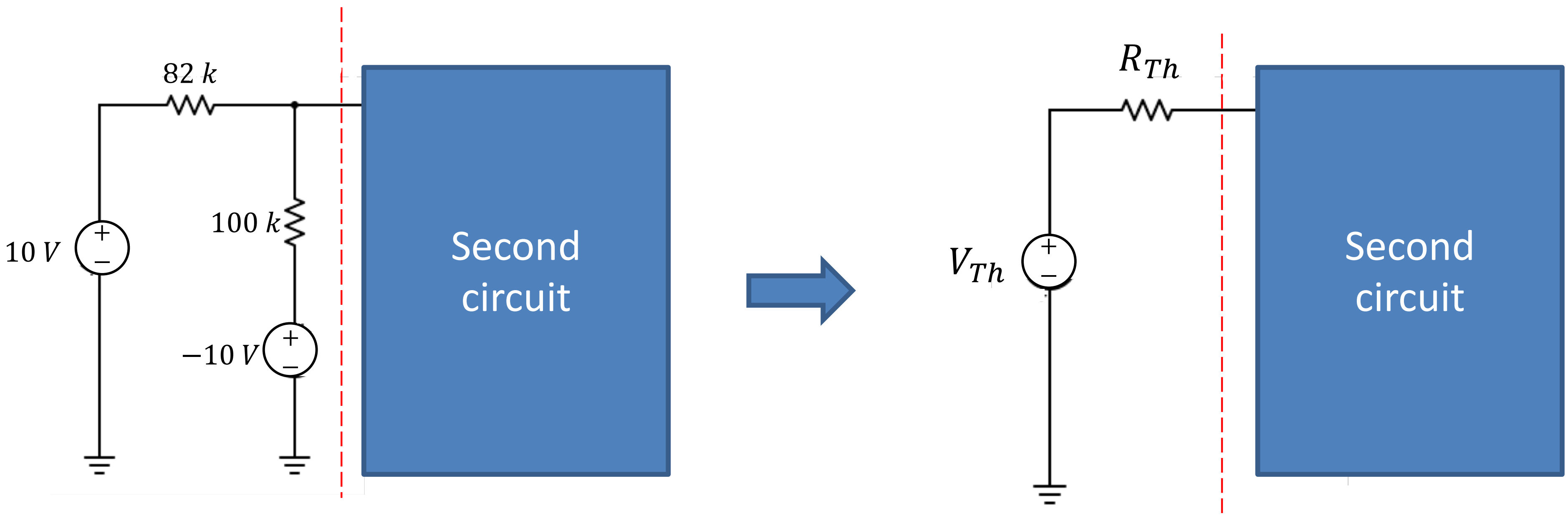


Example cont.

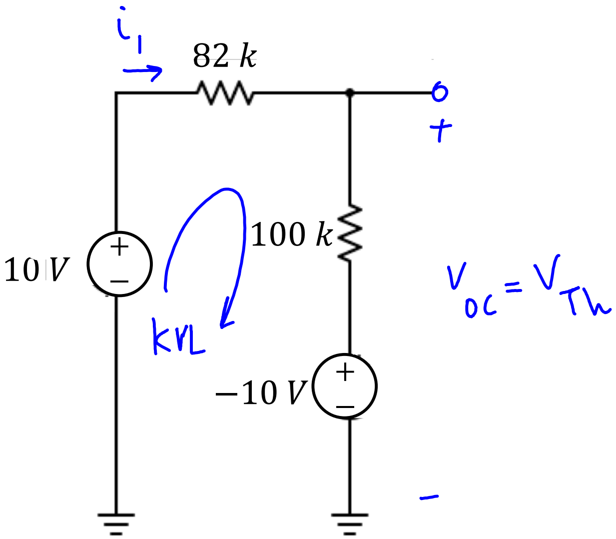


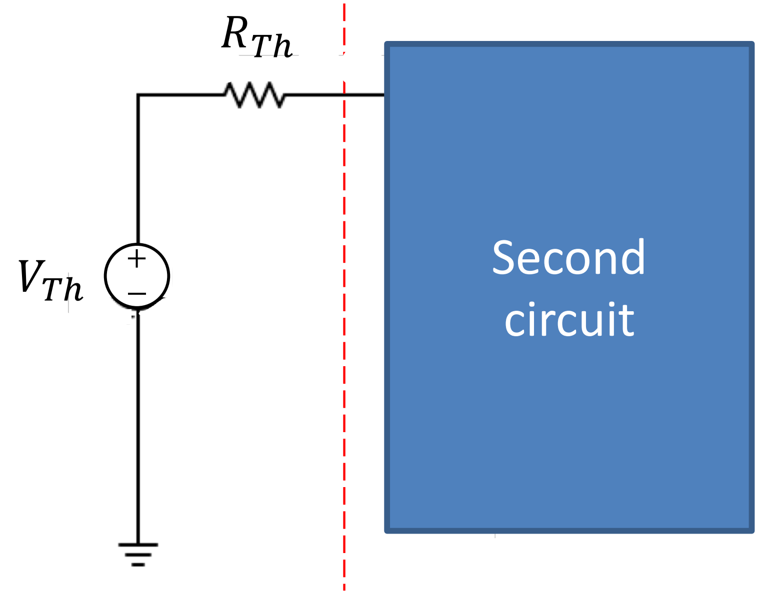
Example cont.





Example cont.

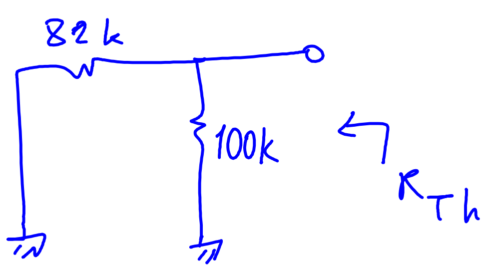




KVL : $-10\,V + 82\,k \times i_1 + 100\,k \times i_1 - 10 = 0$

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

R_{Th} : zero the independant voltage sources.

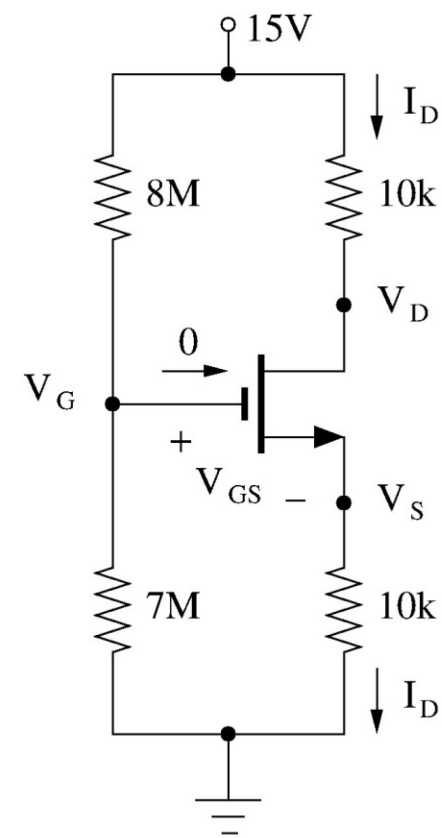


$R_{Th} = 100\,k \parallel 82\,k \simeq 45.05\,k\Omega$

Clicker question 1.

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

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



A. $V_G = V_{GS} + I_D R_S = 7\ V$

B. $5V_{OV}^2 + V_{OV}^2 - 6 = 0$

C. $V_S = 5\ V$

D. $I_D = 0.5\ mA$

E. All of the above.

Required equations:

$$I_D = 0.5\ k_n V_{OV}^2$$

$$V_{OV} = V_{GS} - V_t$$

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. $|V_t| = 1\,V$, $k_p = 0.5\,mA/V^2$