# ECE 65: Components & Circuits Lab

Lecture 12

**BJT Transfer function**

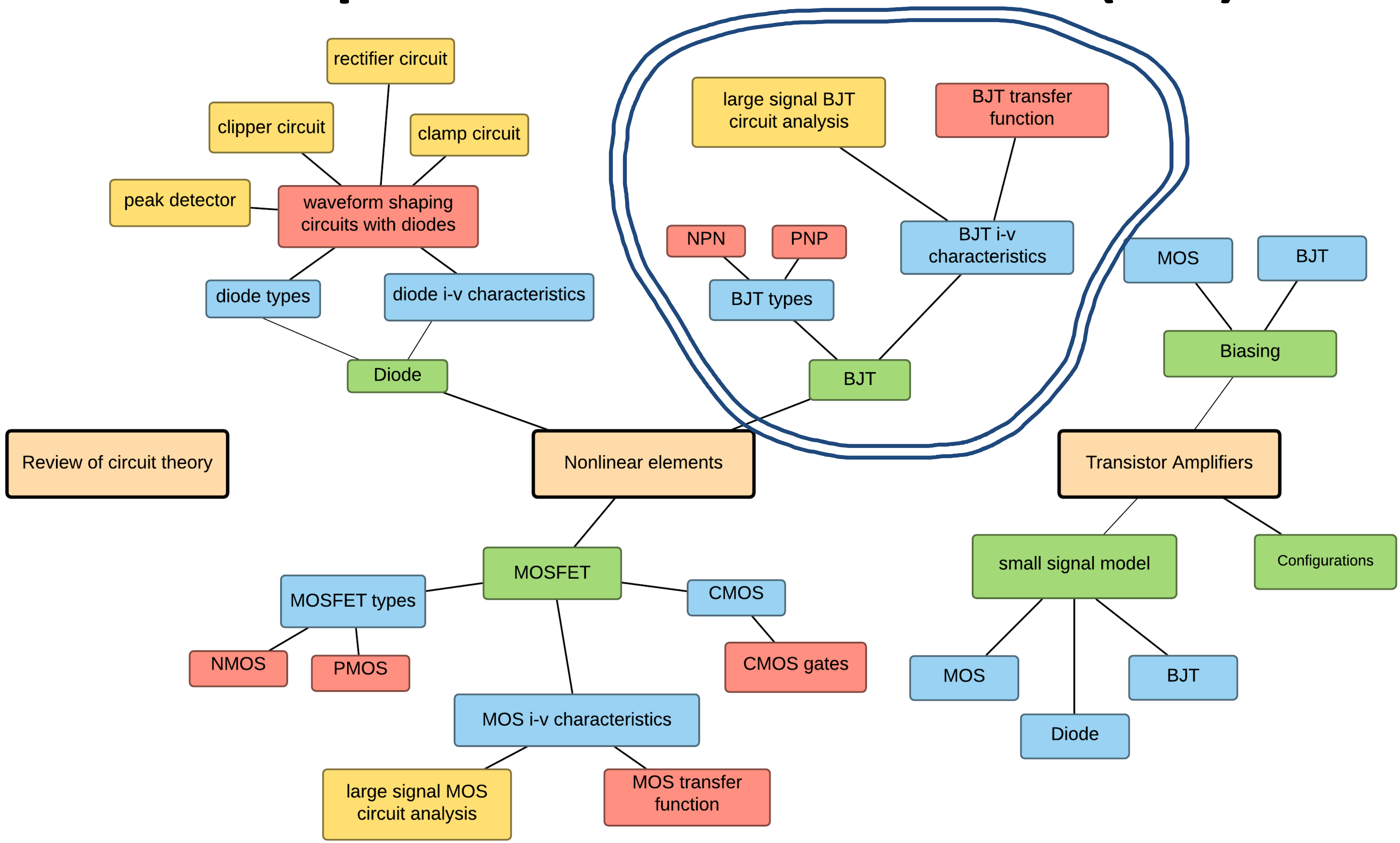
Reference notes: sections 3.2

Sedra & Smith ($7^{th}$ Ed): sections 6.1,6.4

Saharnaz Baghdadchi

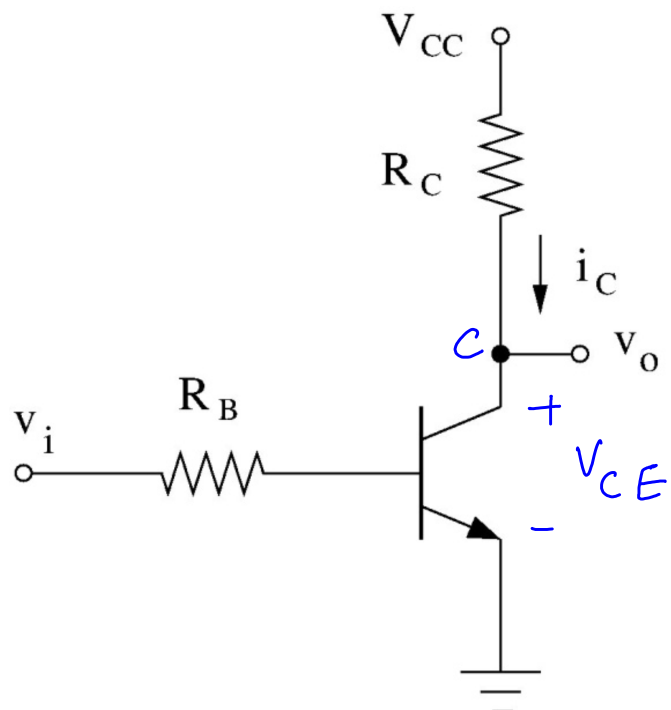
# Course map

# 3. Bipolar Junction Transistor (BJT)



**Discussion question:** BJT Transfer Function

how would the output $v_o = v_{CE}$ change in terms of $v_i$?



# BJT Transfer Function

BE KVL: $\underline{v_i = R_B i_B + v_{BE}}$

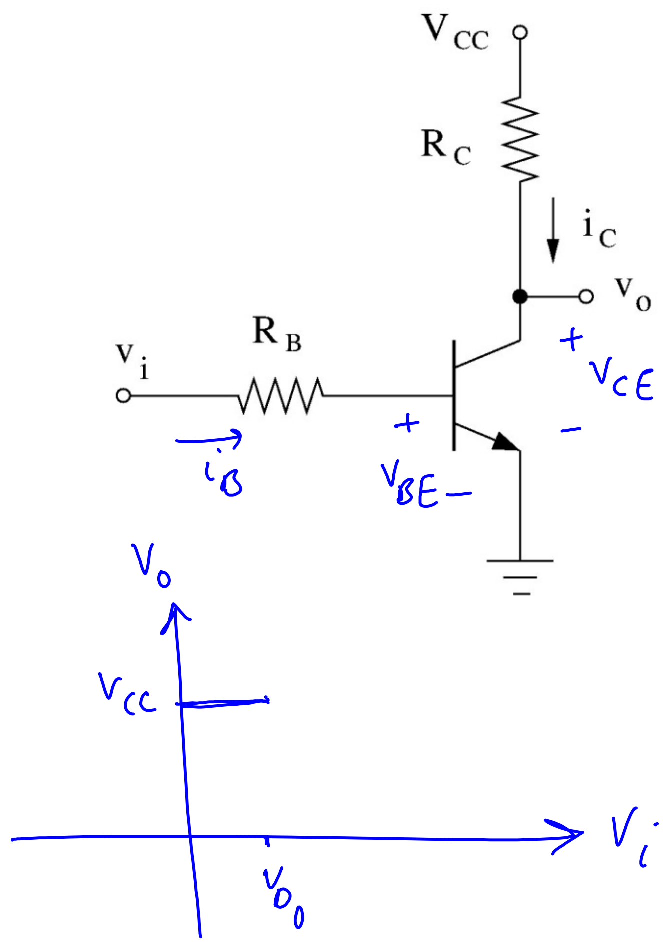
CE KVL: $\underline{V_{CC} = R_C i_C + v_{CE}}$

Case 1: BJT is in cut-off

$i_B = 0$, $V_{BE} < V_{D0}$, $i_C = 0$, $i_E = 0$

$V_i = V_{BE} < V_{D_0} \longrightarrow V_i < V_{D_0}$

$V_{CC} = R_C \times 0 + V_o \longrightarrow V_o = V_{CC}$

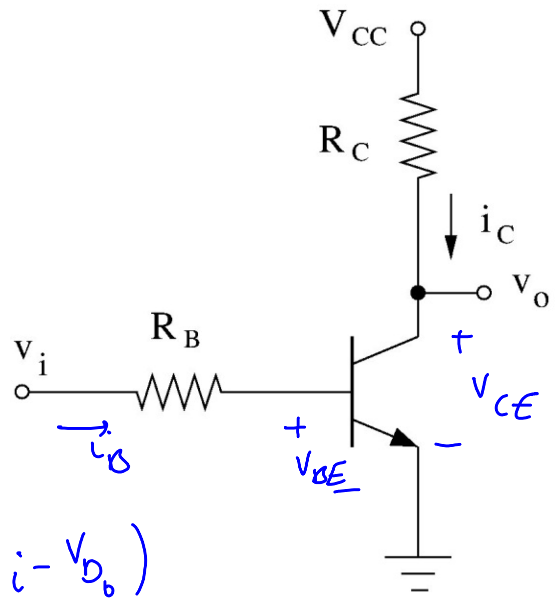



For $V_i < V_{D_0}$, BJT is in cut-off, $V_o = V_{CC}$

# BJT Transfer Function

Case 2: BJT is ON, $V_{BE} = V_{D_0}$

$$i_B = \frac{V_i - V_{BE}}{R_B} = \frac{V_i - V_{D_0}}{R_B},$$




$$\boxed{V_{CE} = V_{CC} - R_C i_C}$$

$$i_C = \beta i_B, \quad V_{CE} \geq V_{D_0}$$

$$\downarrow$$

$$i_C = \frac{\beta}{R_B}(V_i - V_{D_0}), \quad V_{CE} = V_{CC} - \frac{\beta R_C}{R_B}(V_i - V_{D_0})$$

$$V_{CE} \geq V_{D_0} \longrightarrow V_i \leq V_{D_0} + \frac{V_{CC} - V_{D_0}}{\beta R_C / R_B}$$

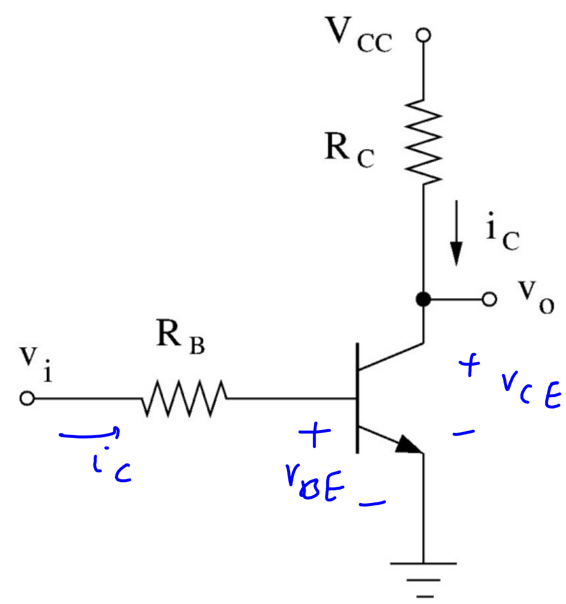
$$V_o = \left(V_{CC} + \frac{\beta R_C}{R_B} V_{D_0}\right) - \frac{\beta R_C}{R_B} V_i$$

For $V_i \leq V_{D_0} + \dfrac{V_{CC} - V_{D_0}}{\beta R_C / R_B}$ the BJT is in active mode.

# BJT Transfer Function

Case 3: BJT is in saturation.

$v_{BE} = V_{D_0}$ , $\boxed{i_C < \beta i_B}$ , $v_{CE} = V_{sat}$




$$i_B = \frac{v_i - v_{BE}}{R_B} ,$$

$$v_{CE} = V_{CC} - R_C i_C \quad , \quad i_C = \frac{V_{CC} - V_{sat}}{R_C}$$

$$i_C < \beta i_B \longrightarrow \frac{V_{CC} - V_{sat}}{R_C} < \frac{\beta}{R_B}(v_i - V_{D_0})$$

$$v_i > V_{D_0} + \frac{V_{CC} - V_{sat}}{\beta R_C / R_B}$$

For $v_i > V_{D_0} + \dfrac{V_{CC} - V_{sat}}{\beta R_C/R_B}$ , BJT is in saturation

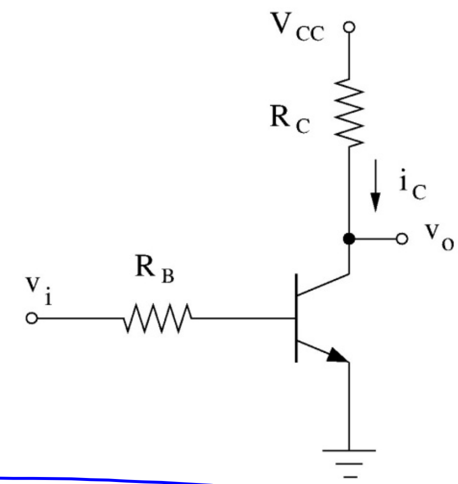
$v_o = V_{sat}$

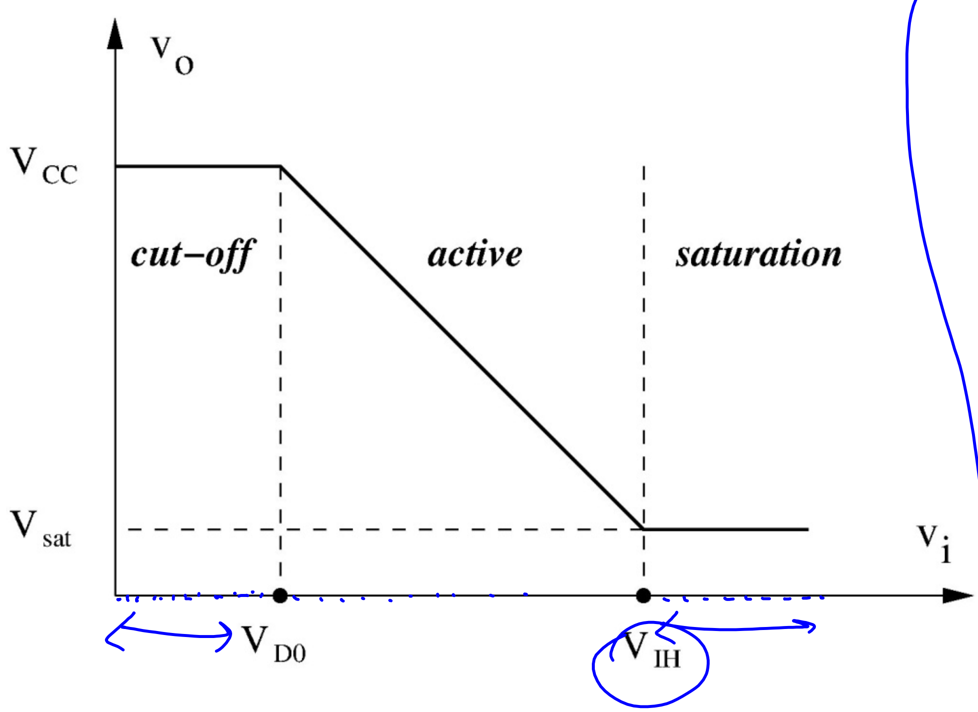
# BJT Transfer Function

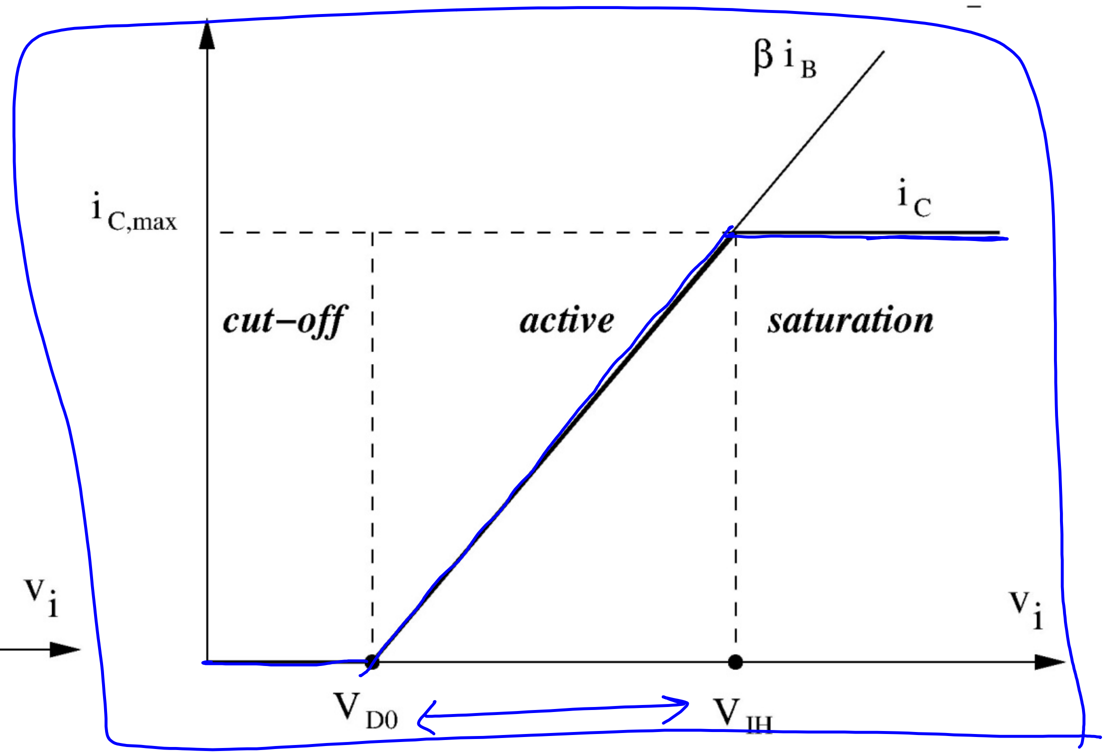
$$v_i < V_{D0} \quad \rightarrow \text{BJT in Cutoff}$$

$$V_{D0} \le v_i \le V_{D0} + \frac{V_{CC} - V_{D0}}{\beta R_C / R_B} \quad \rightarrow \text{BJT in active}$$

$$V_{D0} + \frac{V_{CC} - V_{sat}}{\beta R_C / R_B} < v_i \quad \rightarrow \text{BJT in deep saturation}$$



# BJT transfer function on the load line

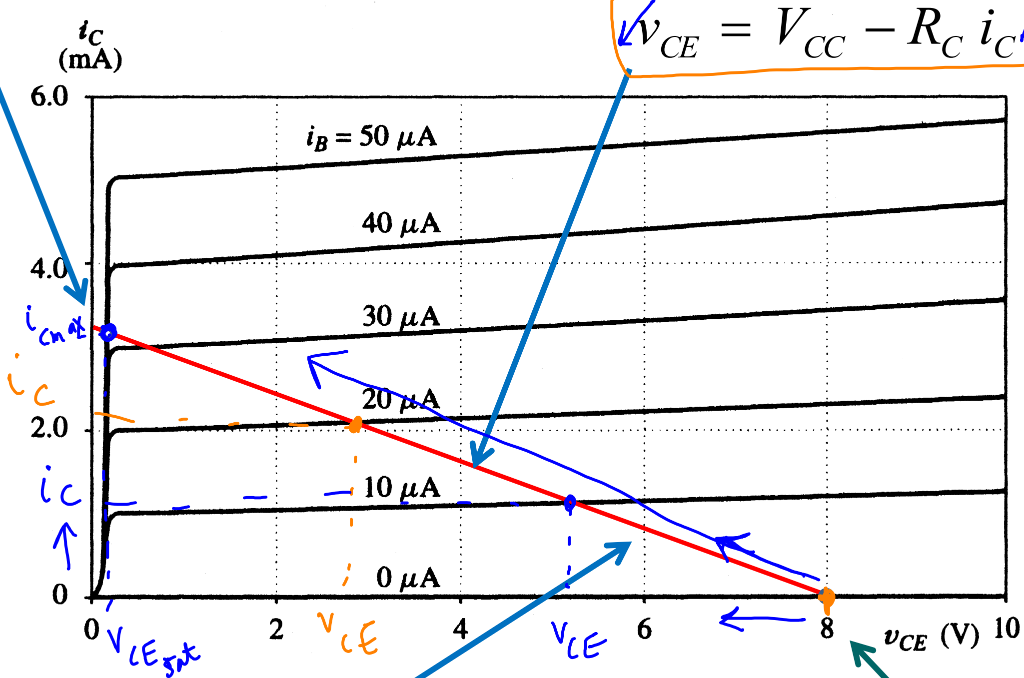
8V

$\text{Saturation}: V_{IH} < v_i$

$i_B$ increases but $i_C$ unchanged

Load Line (CE - KVL)

$$v_{CE} = V_{CC} - R_C\, i_C$$

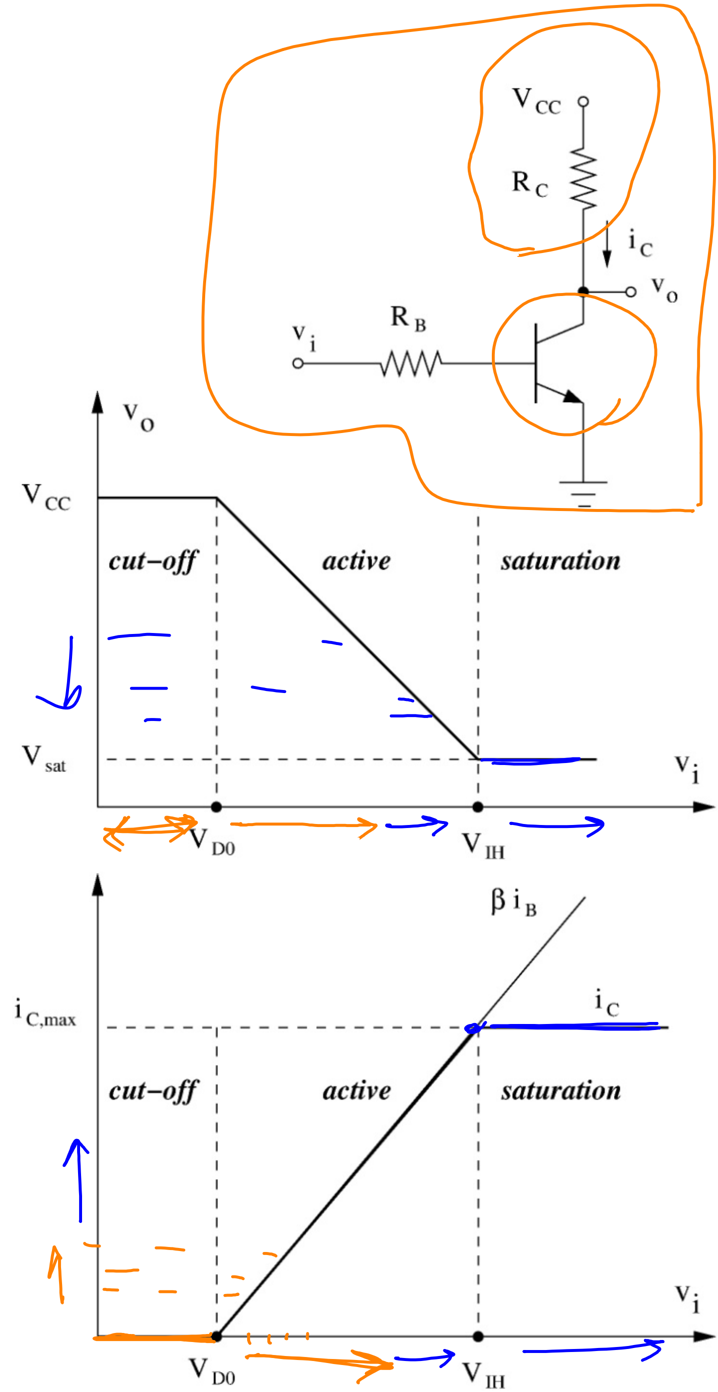



$\text{Active}: V_{D0} \le v_i \le V_{IH}$

$i_B$ & $i_C$ increase together

$\text{Cut-off}:$

$v_i < V_{D0}$



# BJT $\beta$ varies substantially

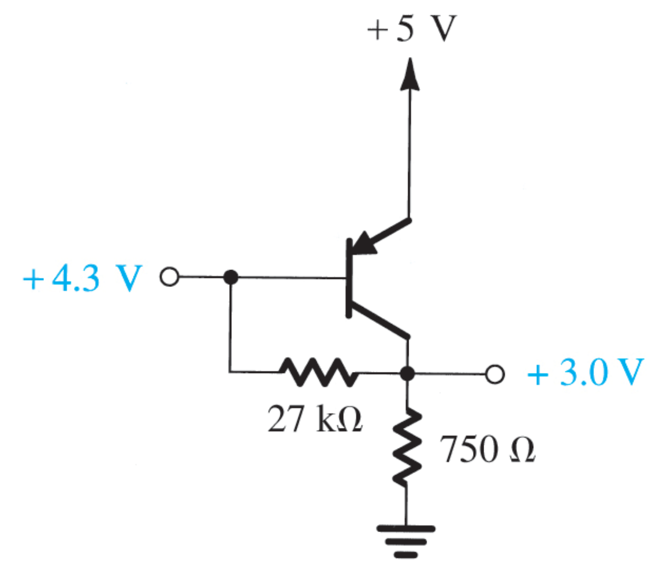
Transistor $\beta$ depends on many factors:

- Strongly depends on temperature (9% increase per $^{o}$C)
- Depends on $i_C$ (not constant as assumed in the model)
- $\beta$ of similarly manufactured BJT can vary (manufacturer spec sheet typically gives a range as well as an average value for $\beta$)
- $\beta_{min}$ is an important parameter. For example, to ensure operation in deep saturation for all similar model BJTs, we need to set $i_C / i_B < \beta_{min}$

# Lecture 12 reading quiz

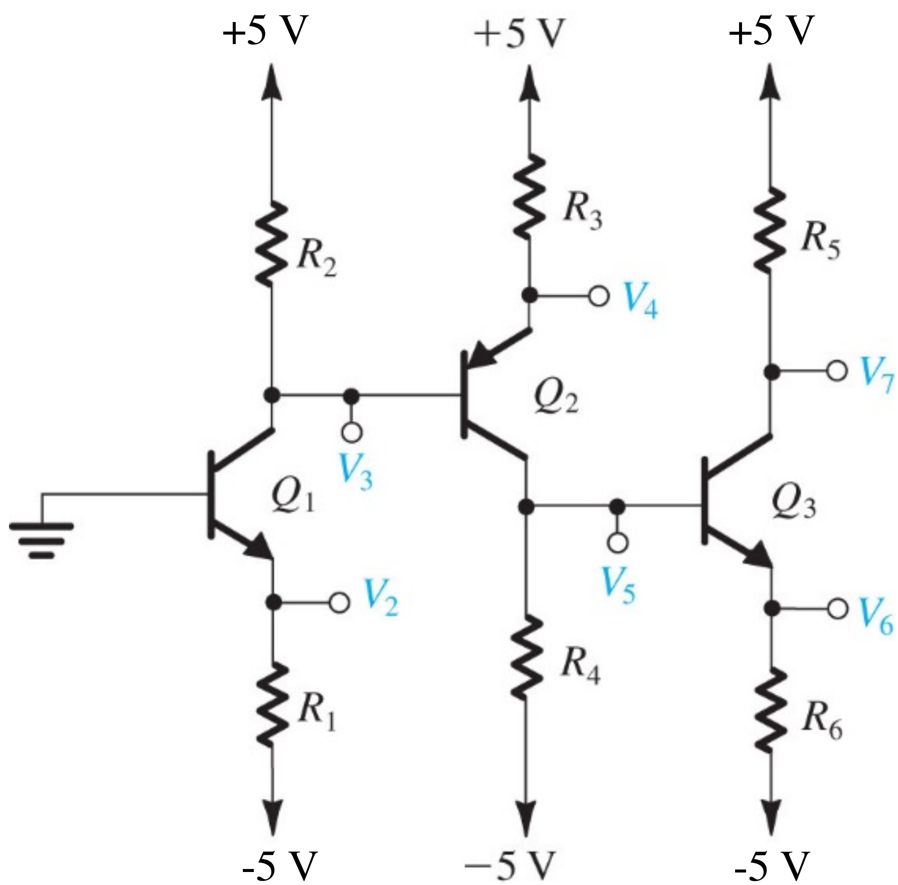
A few measurements on the below circuit produces the labeled voltages.

Find the value of $\beta$ ( Assume $V_{D0} = 0.7V$ ).



# Discussion question 1.

Using $\beta = \infty$, design the following circuit so that the transistors operate in the active region and the collector currents in $Q_1$, $Q_2$, and $Q_3$ are 2 mA, 2 mA, and 4 mA, respectively, and $V_3 = 0$, $V_5 = -4\ V$, and $V_7 = 2\ V$.

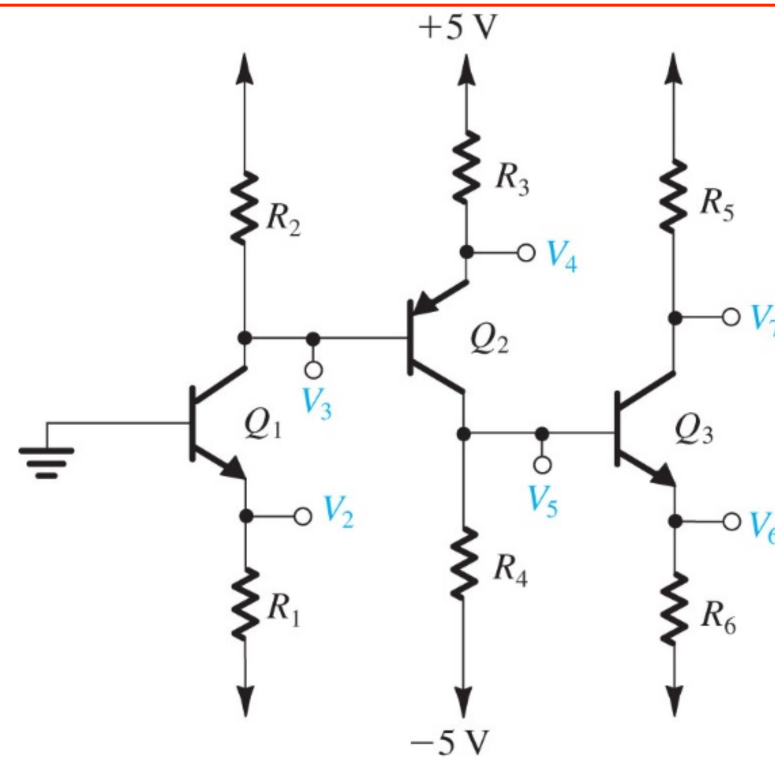


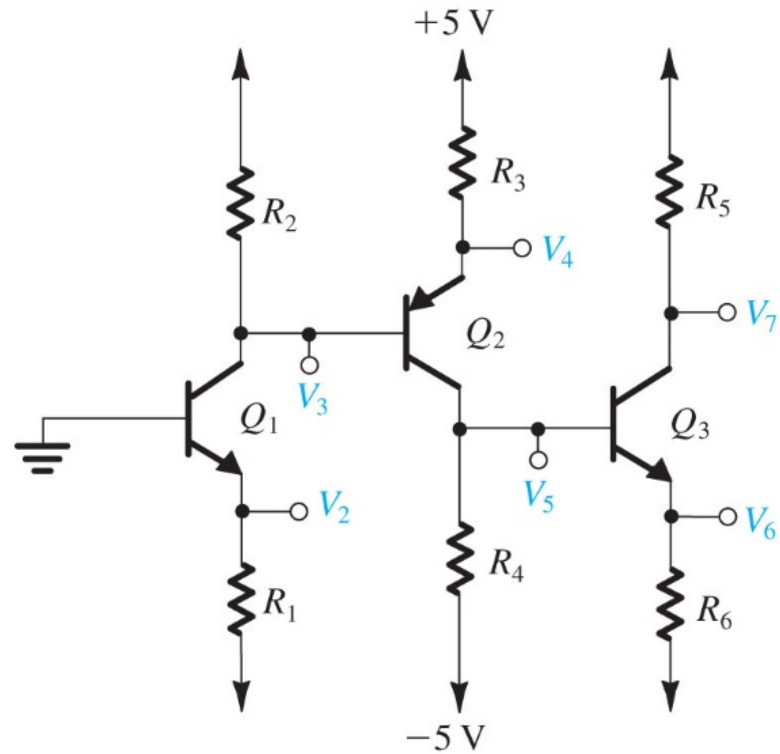
Hints:

- Assume beta is a very large number such as 10^6. If a BJT is in the active mode with I_C= 2mA and beta=10^6, what is I_B? What is I_B approximately equal to?

- Start with R5 and use Ohm’s Law to find the resistor values.

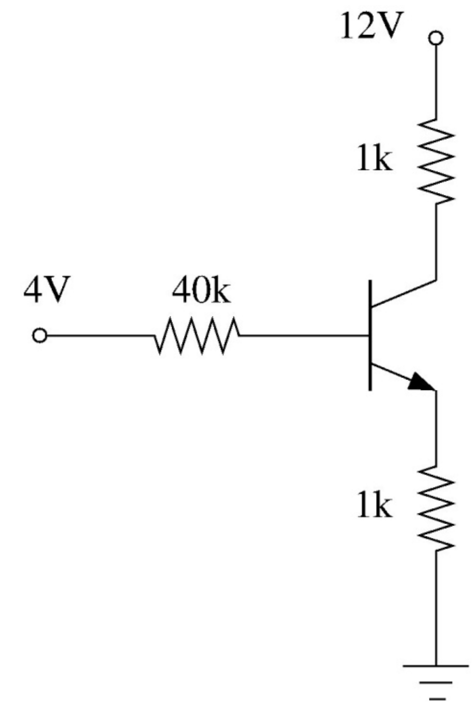
- Remember that all BJTs are ON and in the active mode. Because of this you can use V_{BE}=0.7 V for NPN and V_{EB}=0.7 V for PNP transistors. You can also use the approximate values of I_B in your equations to find I_E from I_C when needed.



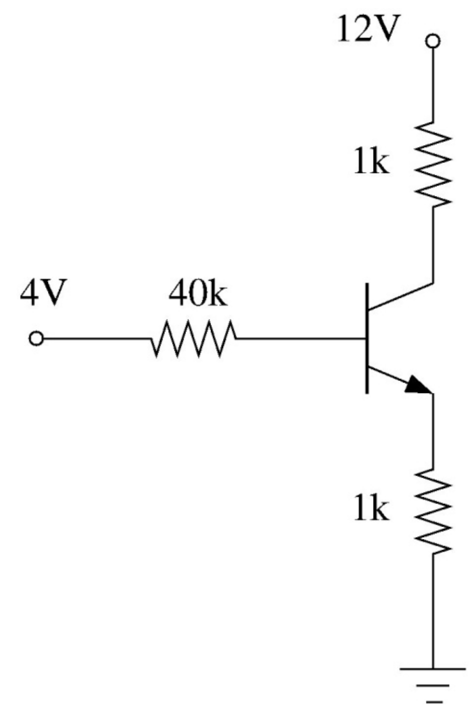

+5 V
$R_2$
$R_3$
$V_4$
$R_5$
$V_7$
$Q_2$
$V_3$
$Q_1$
$Q_3$
$V_2$
$V_5$
$V_6$
$R_4$
$R_1$
$R_6$
−5 V

# Discussion question 2.

Find the transistor parameters in this BJT circuit. ($\beta = 100$, $V_{D0} = 0.7V$, $V_{sat} = 0.2\ V$).



Hints:



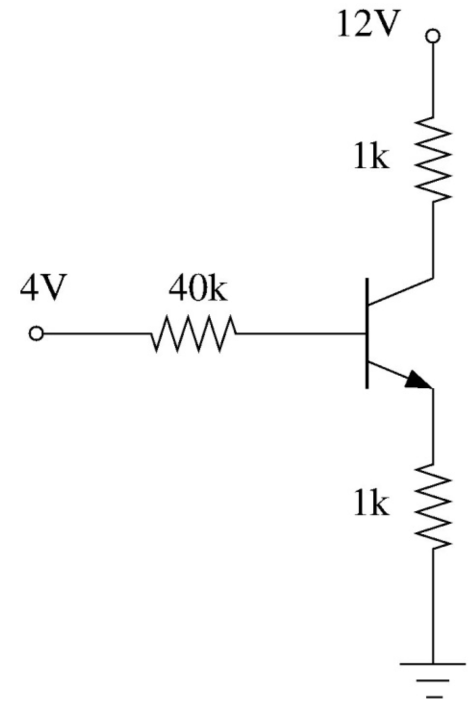

- Write a KVL for the BE loop and check if the BJT is in cut-off. If the BJT is ON, you can use V_{BE}=0.7V.

- Assume Active mode of operation.

- Write a KVL for the BE loop and another KVL for the CE loop. Also, write relationship between I_C and I_B in the active mode and the KCL equation that relates I_E to I_B and I_C.

- Solve the above equations to find all the BJT parameters and verify your assumption.

- You can also start by assuming saturation mode, find the BJT currents and node voltages and check your assumptions.


12V
1k
4V
40k
1k