ECE 342
Electronic Circuits

Lecture 15
BJT – DC Operation

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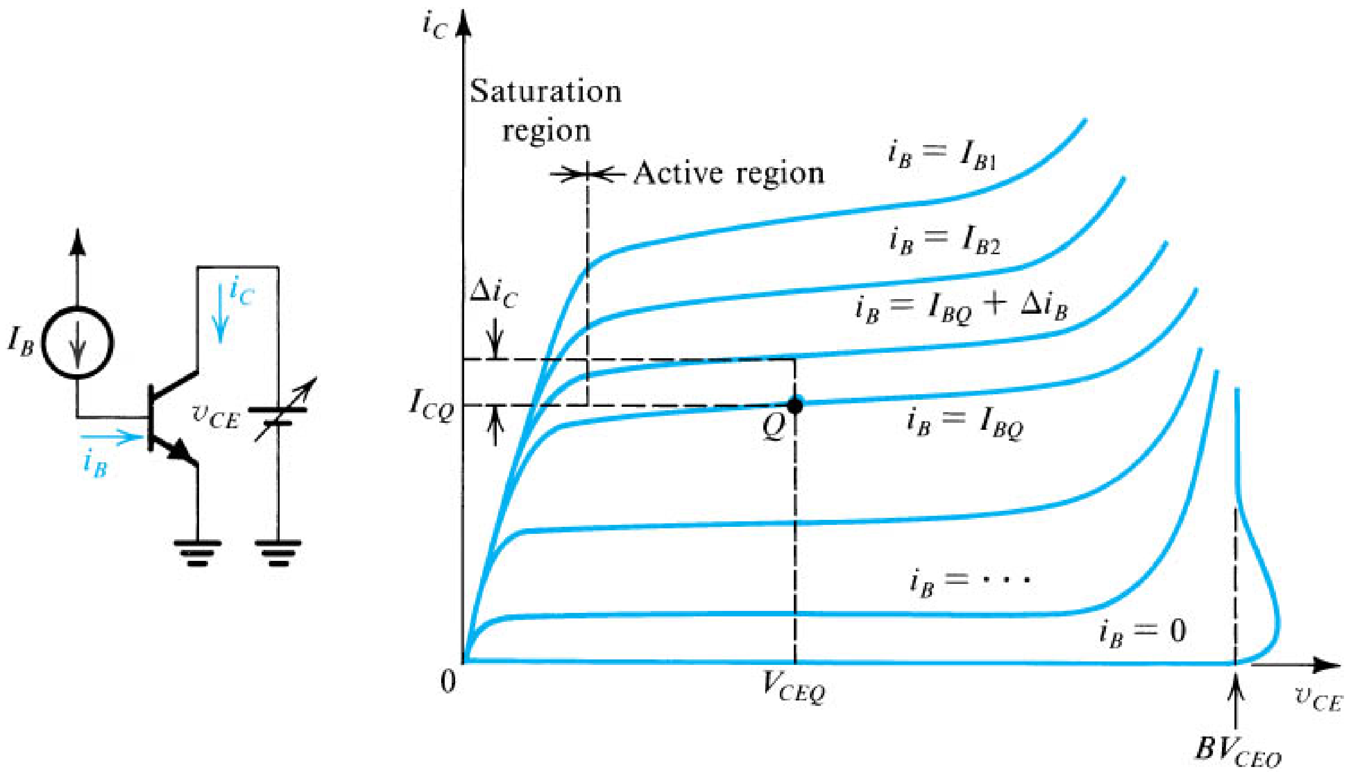
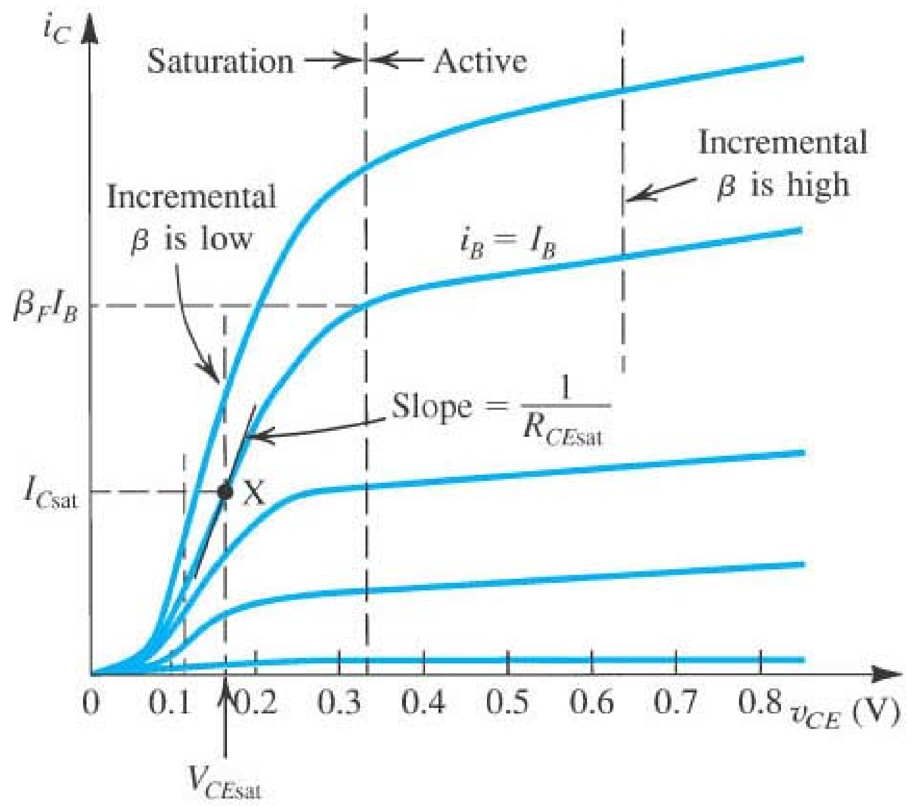
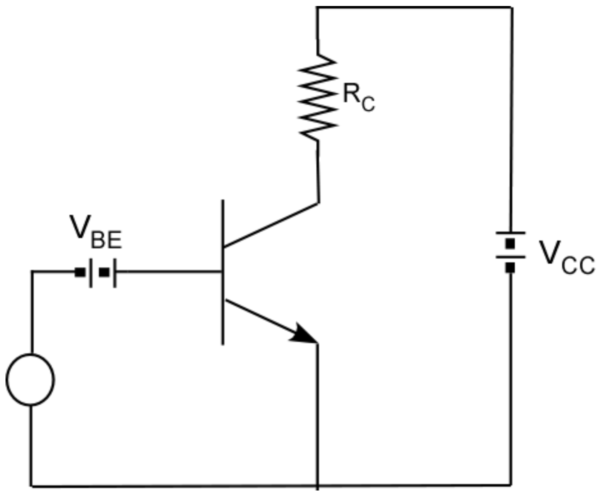
BJT – Common-Emitter Characteristics



BJT – Voltage-Current Characteristics



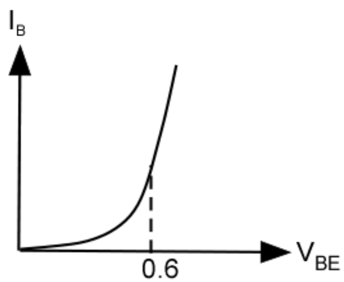
Common Emitter Configuration

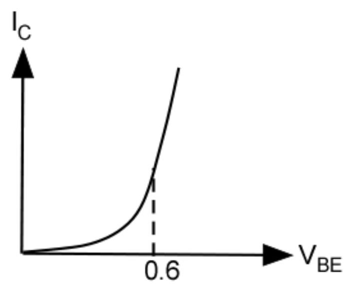


$$I_E = I_B + I_C$$

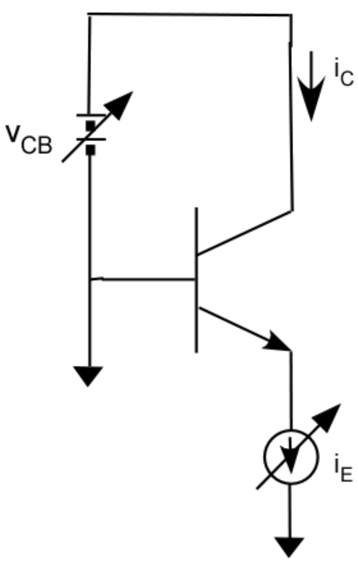
$$I_C = \alpha I_E$$

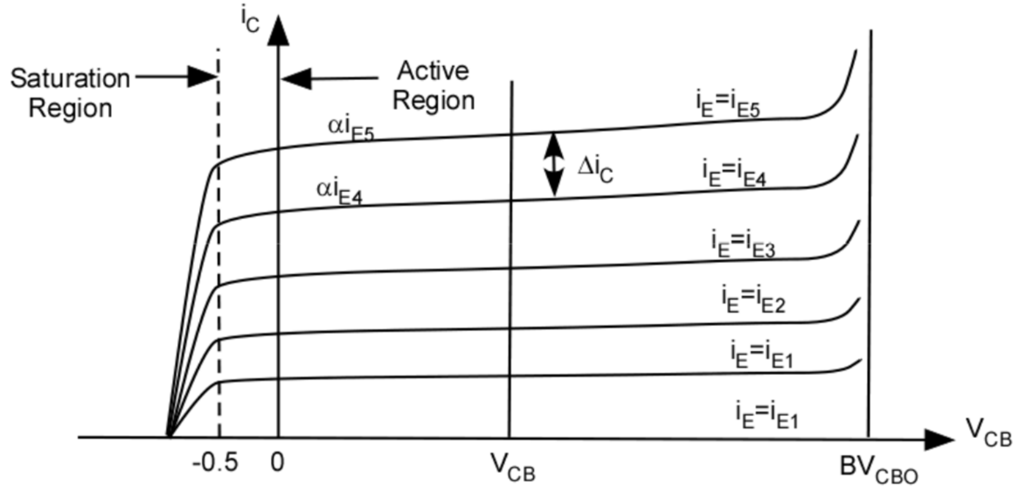
$$I_C = \frac{\alpha}{1-\alpha} I_B = \beta I_B$$



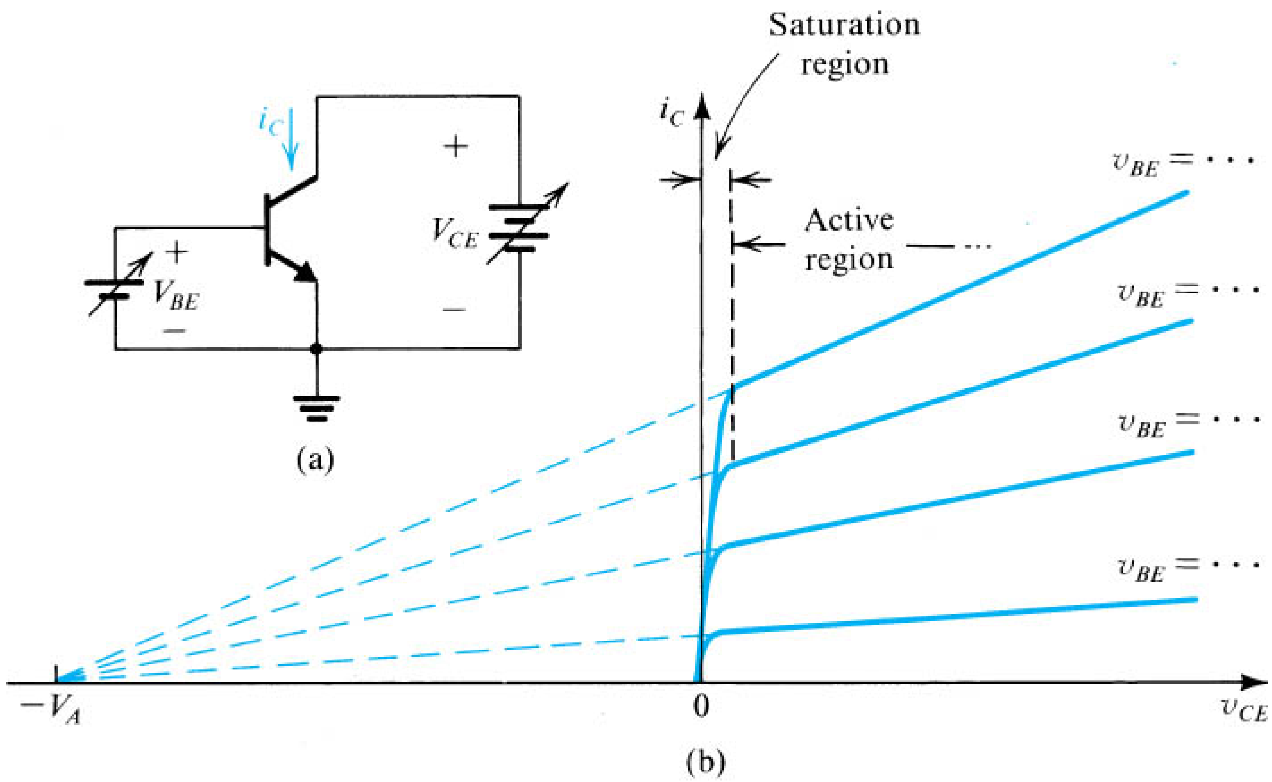


Common Emitter I-V Characteristics





Early Voltage



- **Early Voltage V_A**
  - Dependence of collector current on collector voltage
  - Increasing V_{CE} increases the width of the depletion region

Output Resistance

r_o is output resistance seen from collector terminal

$$i_C = I_S e^{v_{BE}/V_T}\left(1+\frac{v_{CE}}{V_A}\right)$$

$$r_o = \left[\left.\frac{\partial i_C}{\partial V_{CE}}\right|_{V_{BE}=constant}\right]^{-1}$$

$$r_o = \frac{V_A + V_{CE}}{I_C}$$

Alternatively, neglecting the Early effect on the collector current, we define

$$I_C^{'} = I_S e^{V_{BE}/V_T}$$

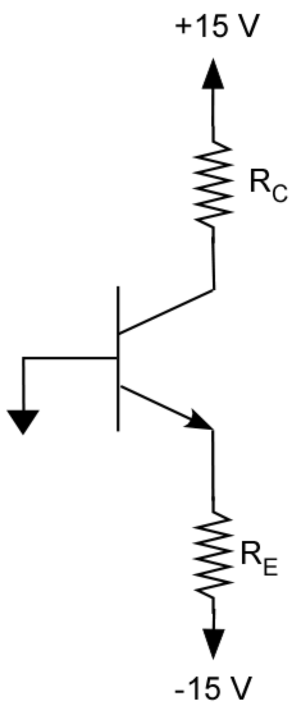
The output resistance then becomes

$$r_o = \frac{V_A}{I_C^{'}}$$

Problem

A transistor has $\beta = 100$, $v_{BE} = 0.7$V with $I_C = 1$ mA. Design a circuit such that a current of 2 mA flows through the collector and a voltage of 5V appears at the collector.

CBJ reversed biased ➔ FAR



Voltage drop across R_C = 15-5 =10V

I_C = 2mA ➔ R_C = 10V/2mA = 5kΩ

Since v_{BE}=0.7V at I_C = 1 mA

$$v_{BE} = 0.7 + V_T \ln\left(\frac{2}{1}\right) = 0.717\ V \text{ at 2 mA}$$

Since base is at 0V, emitter voltage is at *–0.717 volts* =V_E

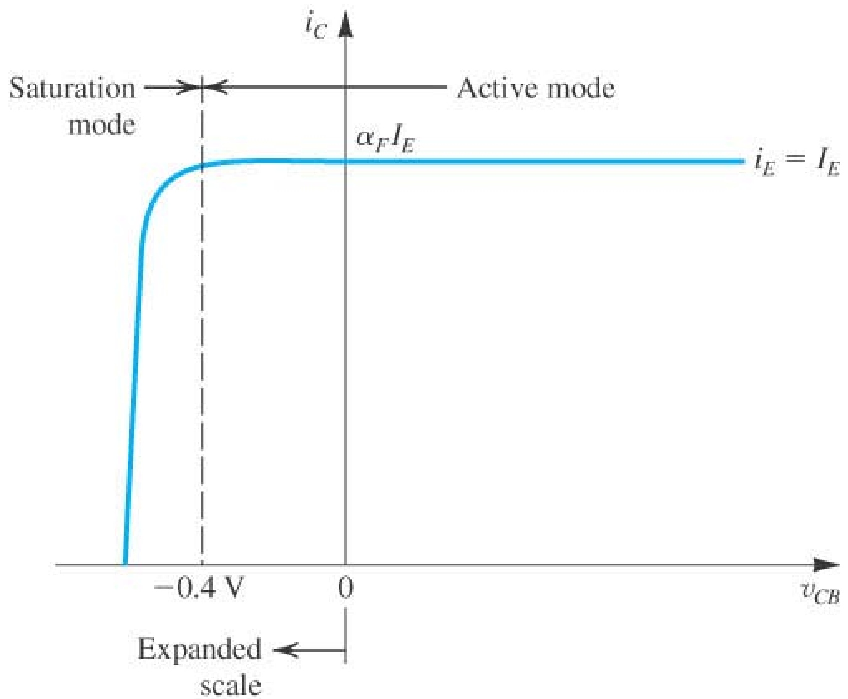
For β = 100, α = 100/101=0.99 ➔ $I_E = I_C/\alpha$ = 2/0.99 = 2.02 mA

Now, $$R_E = \frac{V_E - (-15)}{I_E} = \frac{-0.717 + 15}{2.02} = 7.07\ k\Omega$$

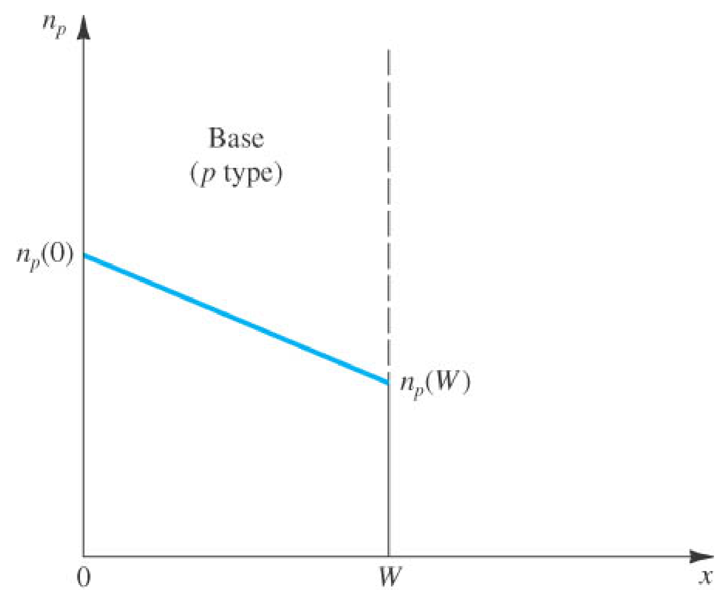
This order of accuracy is not necessary

Operation in the Saturation Mode

IV Characteristics



Minority Carrier Profile



- Forward active region can be maintained for negative v_{CB} down to about -0.4V
- Beyond that point, the transistor enters the saturation mode and i_C decreases with decreasing v_{CB}

Operation in the Saturation Mode

If v_{BC} increases, i_C will decrease, as described by

$$i_C = I_S\left(e^{v_{BE}/V_T} - 1\right) - \left(\frac{I_S}{\alpha_R}\right)\left(e^{v_{BC}/V_T} - 1\right)$$

The base current i_B will decrease, as described by

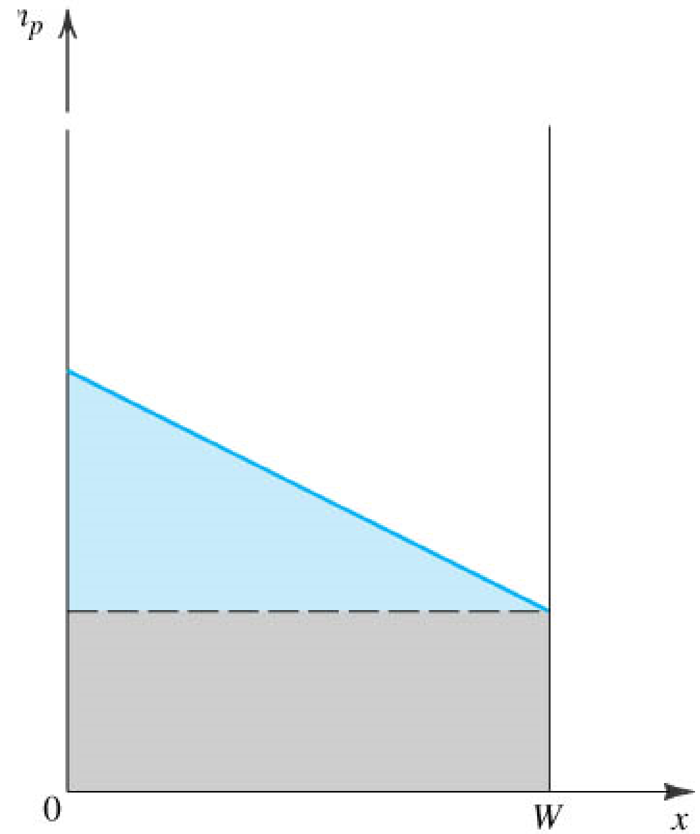
$$i_B = \left(\frac{I_S}{\beta_F}\right)\left(e^{v_{BE}/V_T} - 1\right) + \left(\frac{I_S}{\beta_R}\right)\left(e^{v_{BC}/V_T} - 1\right)$$

The current gain will decrease to a value lower than β_F described as:

$$\beta_{forced} = \left.\frac{i_C}{i_B}\right|_{saturation} \leq \beta_F$$

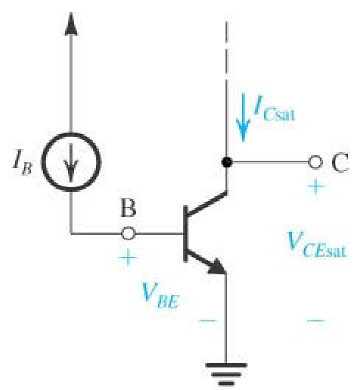
We will also have: $V_{CEsat} = V_{BE} - V_{BC}$

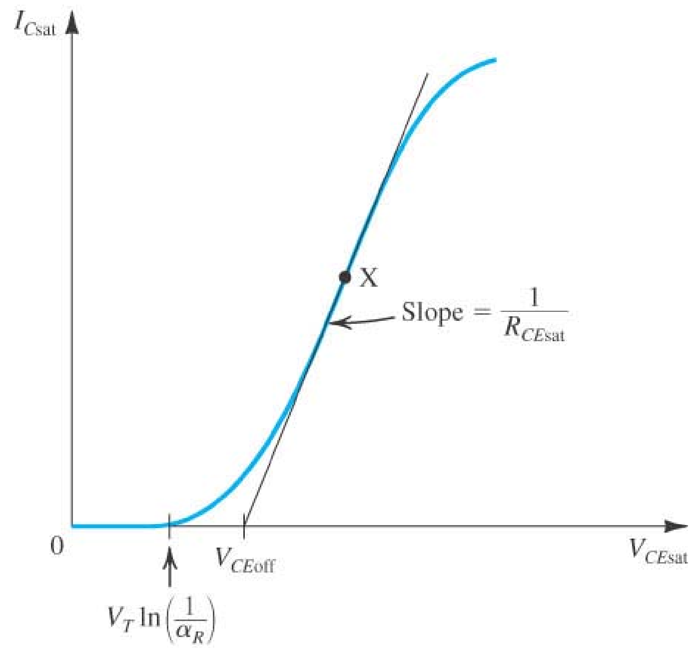
Operation in the Saturation Mode

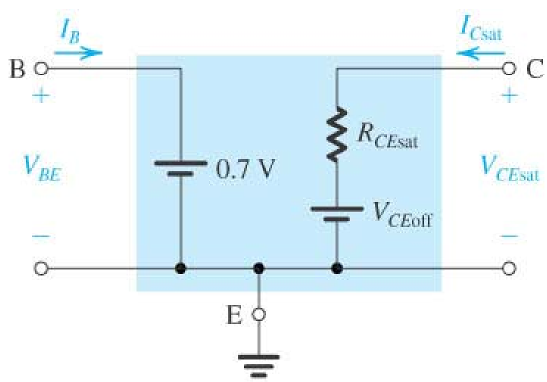


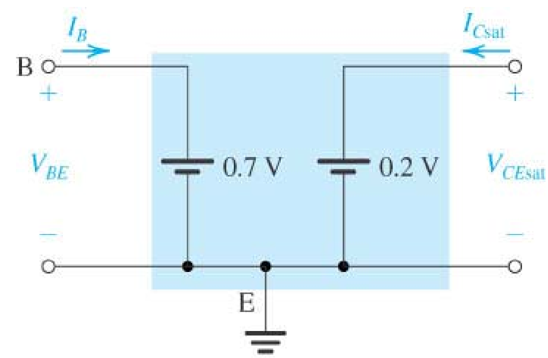
- **Blue: Gradient that gives rise to diffusion current**
- **Gray: Minority carriers driving transistor deeper into saturation**

NPN in Saturation Mode

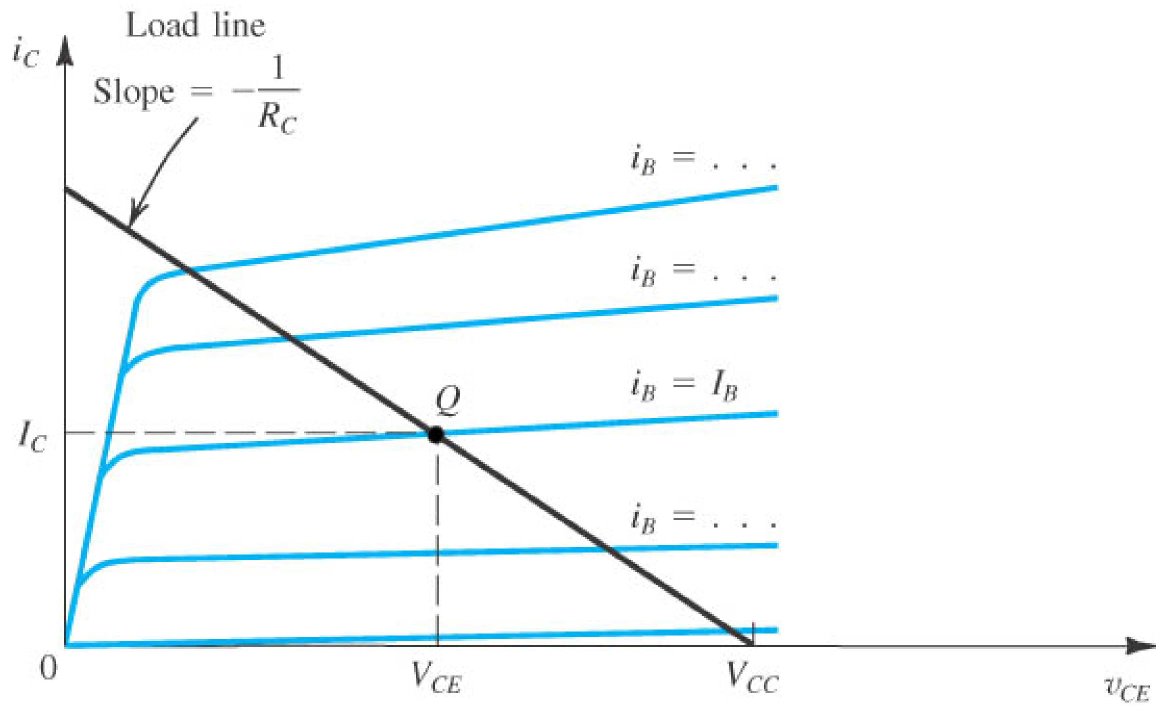






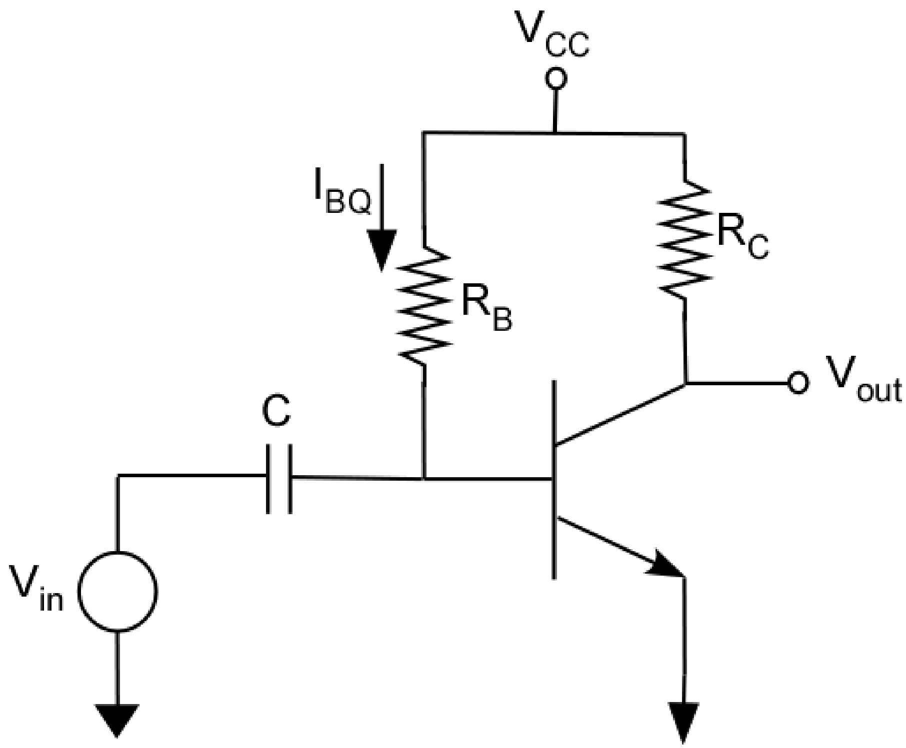


Biasing Bipolar Transistors



BJT Bias

1. Base Current Bias



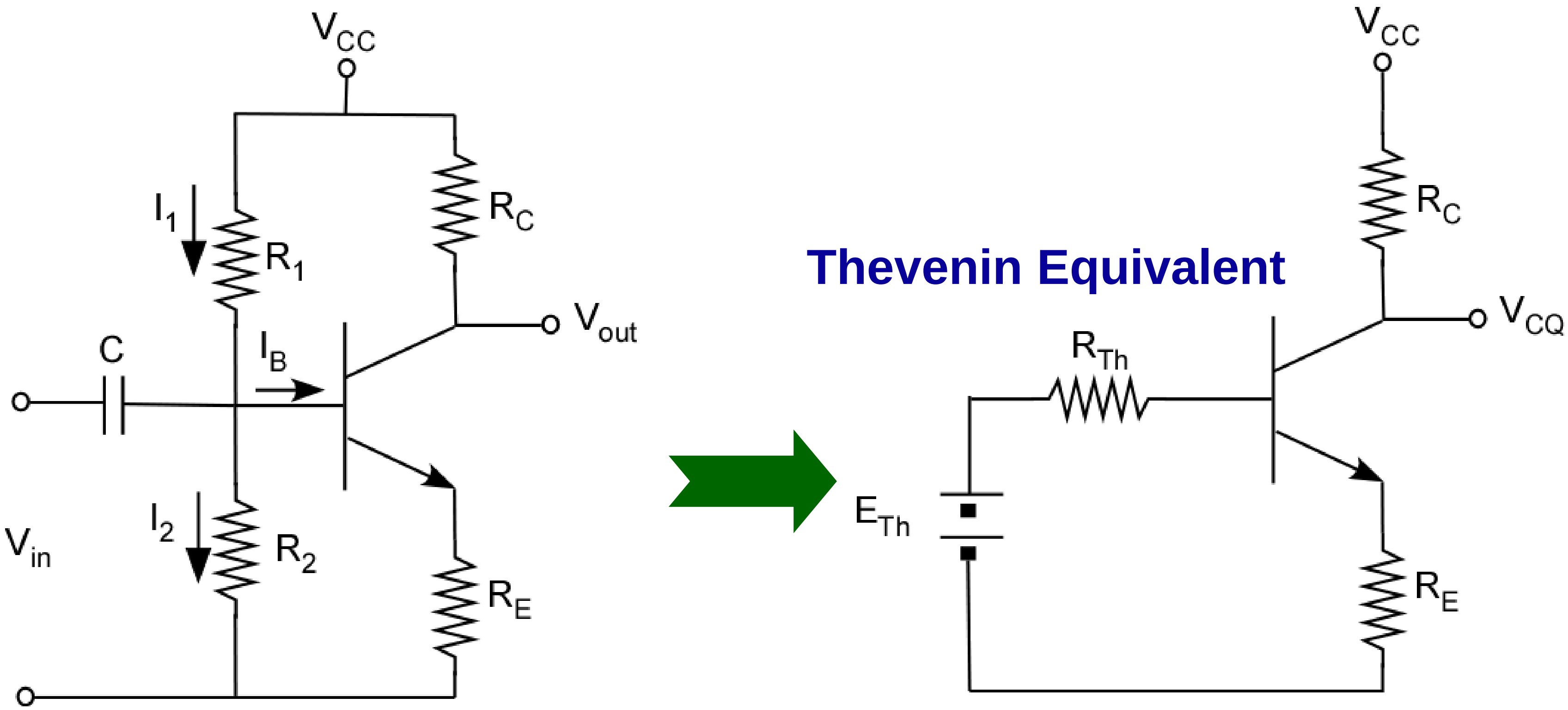
$$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B}$$

$$I_{BQ} = \frac{V_{CC} - 0.6}{R_B}$$

$$I_{BQ} \simeq \frac{V_{CC}}{R_B}$$

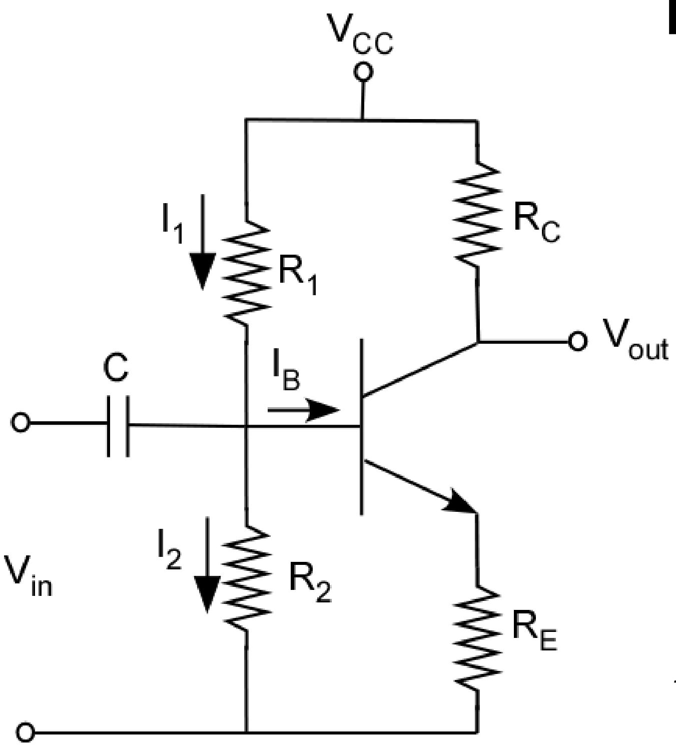
BJT Bias

2. Emitter Bias



Provides good stability with respect to changes in β with temperature

BJT Emitter Bias



$$E_{th} = R_{th} I_B + V_{BE} + R_E I_E$$

$$I_E = I_B + I_C = (\beta + 1) I_B$$

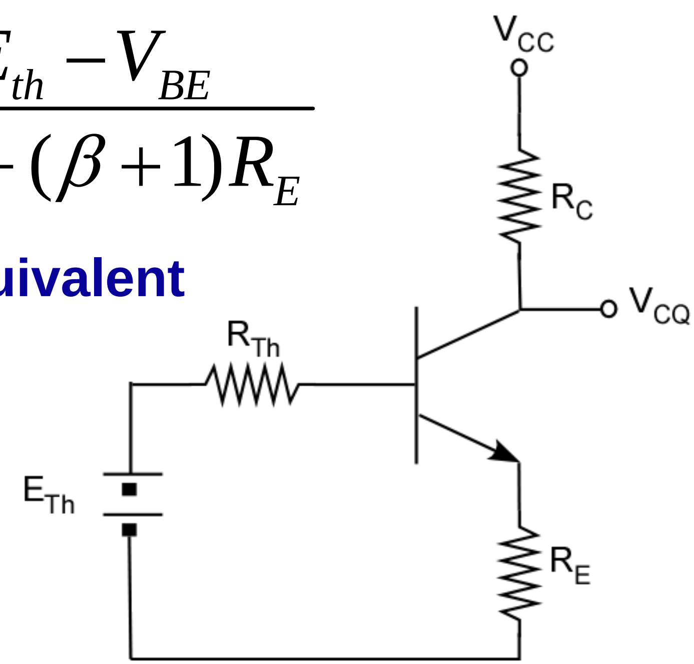
$$E_{th} - V_{BE} = R_{th} I_B + R_E (\beta + 1) I_B$$

$$I_B = I_{BQ} = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$$

$$E_{th} = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$R_{th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Thevenin Equivalent

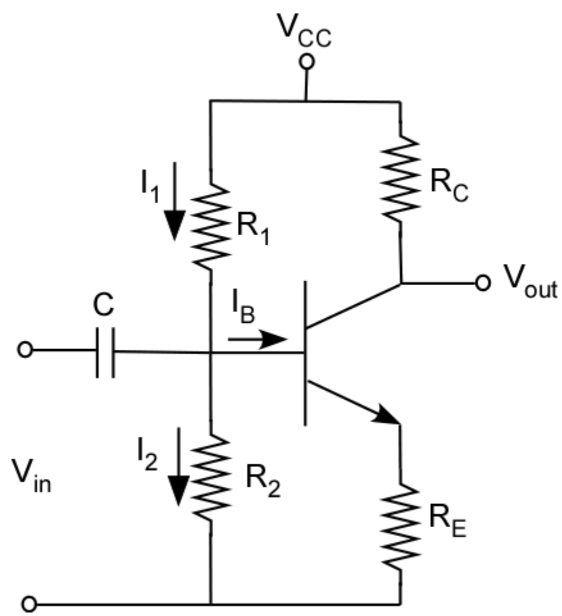


Bipolar Biasing Approach

- **Methods**
  - First method is to find R_1 & R_2 from E_{th} and R_{th} and I_{BQ}
  - Second method is to select R_2 to be 10 times to 20 times R_E to provide good stability & then select R_1 to give proper I_{BQ}

Remark: To keep collector voltage at the middle of the forward active region, use:

$$V_{CQ} = \frac{V_{C\min} + V_{C\max}}{2} = \frac{V_{CC}}{2}\left(1 + \frac{R_E}{R_E + R_C}\right)$$



Stability Considerations

Objective: Minimize effect of variations in β. Circuit must be stable with respect to changes in β.

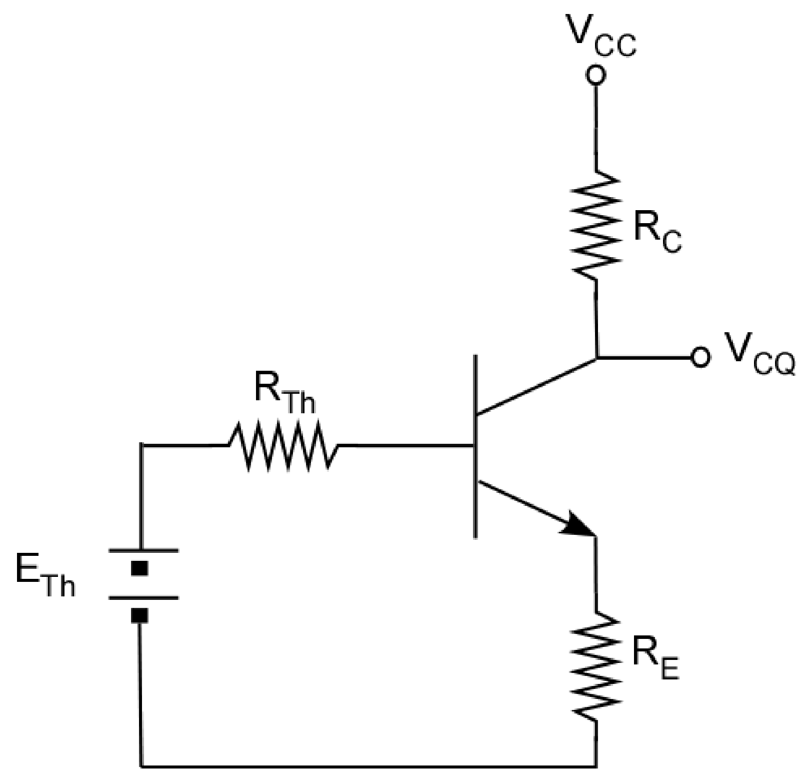
– Need to examine quiescent point in variations for interchanged BJT's

$$V_{CQ} = V_{CC} - I_{CQ} R_C = V_{CC} - \beta I_{BQ} R_C$$

$$R_{th} I_{BQ} + (\beta + 1) I_{BQ} R_E = E_{th} - V_{BE}$$

$$I_{BQ} = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$$

$$V_{CQ} = V_{CC} - \frac{\beta (E_{th} - V_{BE}) R_C}{R_{th} + (\beta + 1) R_E}$$



Stability Considerations

(A) If $R_{th} >> (\beta+1)R_E$

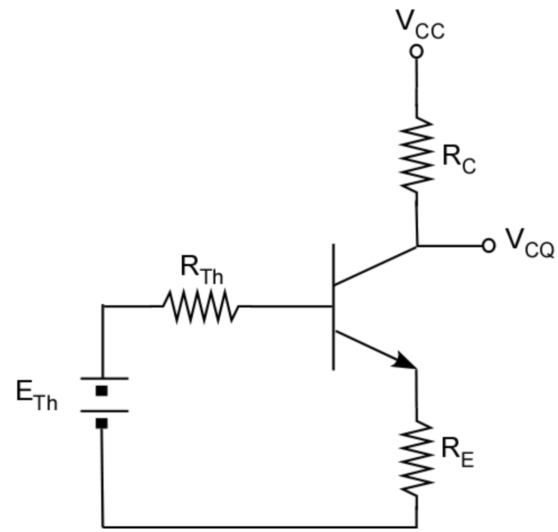
$$V_{CQ} \simeq V_{CC} - \frac{\beta R_C}{R_{th}}\left(E_{th} - V_{BE}\right)$$

Changes in β lead to significant changes in V_{CQ}

(B) If $(\beta+1)R_E >> R_{th}$

$$V_{CQ} \simeq V_{CC} - \frac{\beta R_C}{(\beta+1)R_E}\left(E_{th} - V_{BE}\right)$$

$$V_{CQ} \simeq V_{CC} - \frac{\alpha R_C}{R_E}\left(E_{th} - V_{BE}\right)$$



$$\beta = 60 \Rightarrow \alpha = \frac{60}{61} = 0.983$$

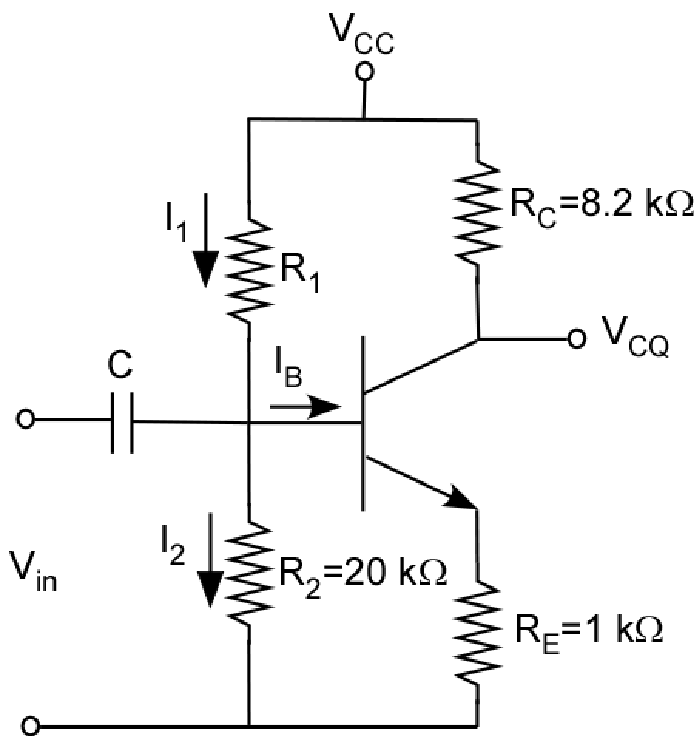
$$\beta = 100 \Rightarrow \alpha = \frac{100}{101} = 0.99$$

α varies only 1% to 2% for large β variations ➔ (B) is good choice.

Bias Example

The circuit shown below has R_C = 8.2 kΩ, R_E = 1 kΩ, R_2=20 kΩ, V_{CC} = 12 V, β = 100, V_{BE} = 0.7V

- Select R_1 to place V_{CQ} at midpoint of the (forward) active region.
- Find maximum symmetrical peak-to-peak output voltage that can be obtained before saturation or cutoff occurs.



Bias Example - Solution

Minimum:
$$V_{CQ\min} = V_{CC}\frac{R_E}{R_E + R_C} = \frac{12}{1+8.2} = \frac{12}{9.2} = 1.3043\ V$$

Maximum:
$$V_{CQ\max} = V_{CC}$$

Midpoint:
$$V_{CQ} = \frac{V_{CQ\min} + V_{CQ\max}}{2} = \frac{13.3043}{2} = 6.65\ V$$

$$I_{CQ} = \frac{12 - 6.65}{R_C} = 0.652\ mA$$

$$I_{BQ} = \frac{0.652}{100} = 0.00652\ \text{mA} = 6.52\ \mu A$$

Bias Example (con't)

$$V_{BQ} = R_E I_E + 0.7 = 0.652 + 0.7 = 1.35 \text{ V}$$

$$I_2 = \frac{1.35 \text{ V}}{20 \text{ k}\Omega} = 0.0676 \text{ mA} = 67.6 \ \mu A$$

$$I_1 = I_2 + I_B = 67.6 \ \mu A + 6.82 \ \mu A = 74.1 \ \mu A$$

$$R_1 = \frac{V_{CC} - 1.35}{I_1} = \frac{12 - 1.35}{74.1 \ \mu A} = 143.6 \ k\Omega$$

$$V_{\max} = 12 - 6.65 = 5.35 V$$

$$R_1 = 143.6 \ k\Omega$$
$$V_{\max} = 5.35 V$$