

# Chapter 4: DC Biasing–BJTs

# Biasing

***Biasing*** refers to the DC voltages applied to a transistor in order to turn it on so that it can amplify the AC signal.

- To provide energy for amplification
- To provide a proper response to an input AC signal by determining the operating point

## *Nonlinear Devices*

- DC and AC response are different, so DC analysis can be totally separated from the ac response
- The choice of parameters for DC levels will affect the AC response, and vice versa

## 4.2 Operating Point

The DC input establishes an operating or *quiescent point* called the *Q-point*.

### Biasing and Three States of Operation

- **Active or Linear Region Operation**

Base-Emitter junction is forward biased

Base-Collector junction is reverse biased

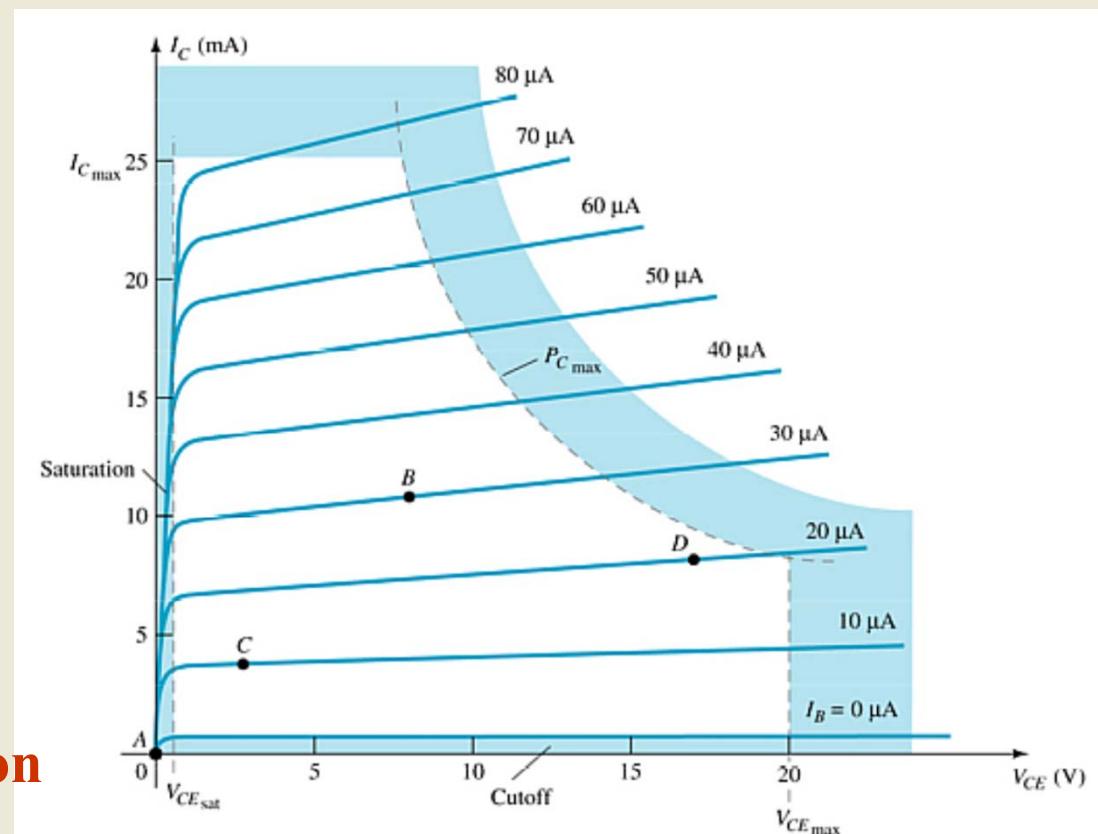
- **Cutoff Region Operation**

Base-Emitter junction is reverse biased

- **Saturation Region Operation**

Base-Emitter junction is forward biased

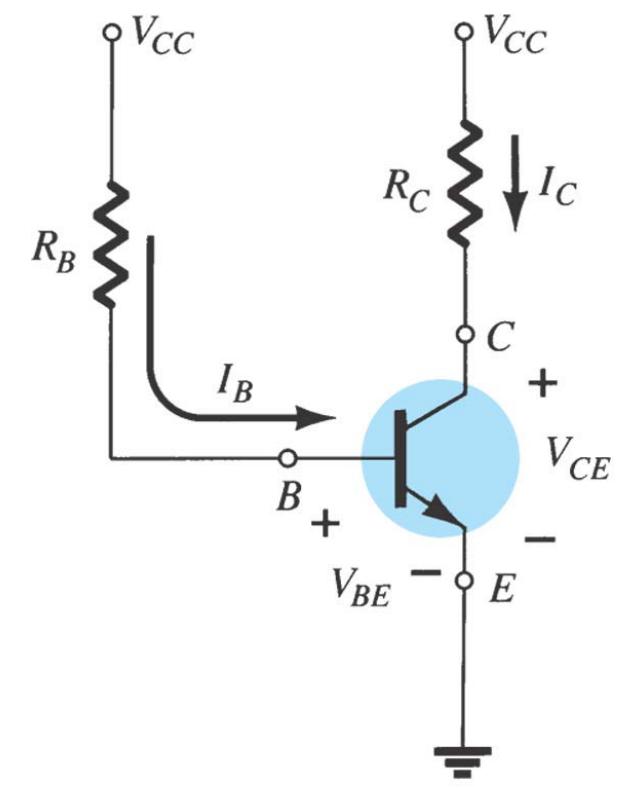
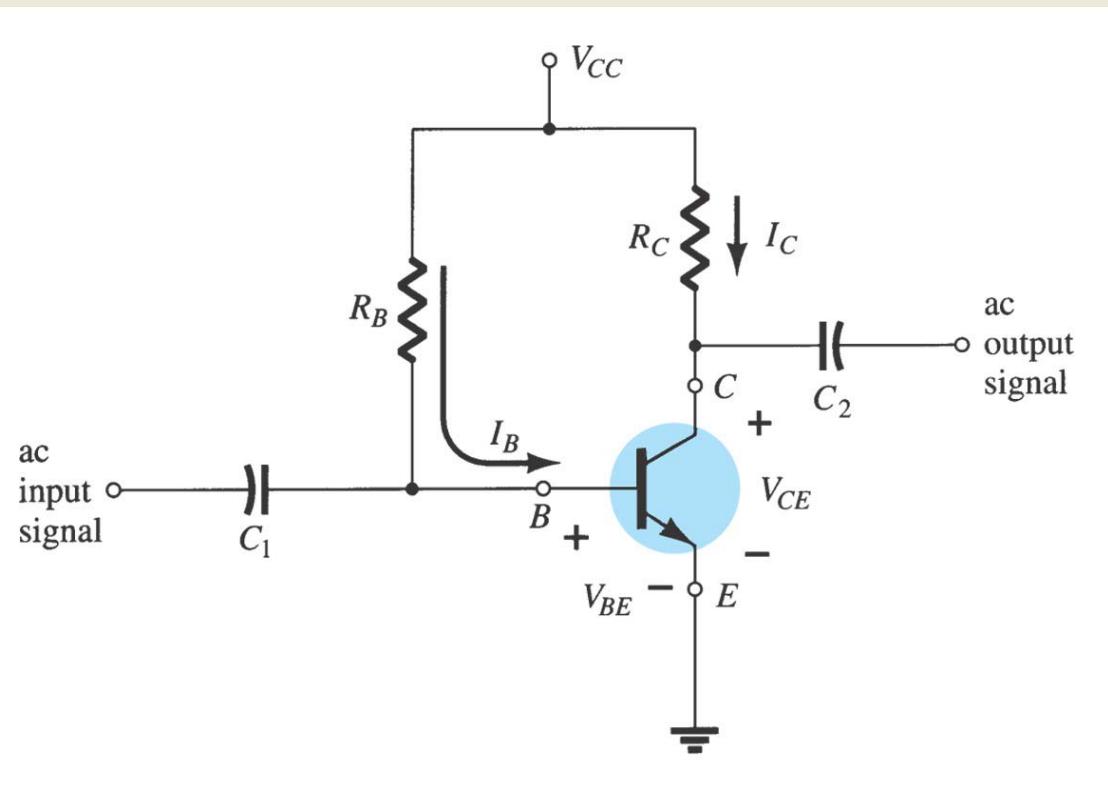
Base-Collector junction is forward biased



### DC Biasing Circuits

- Fixed-bias circuit
- Emitter-stabilized bias circuit
- Voltage divider bias circuit
- DC bias with voltage feedback

## 4.3 Fixed Bias Circuit

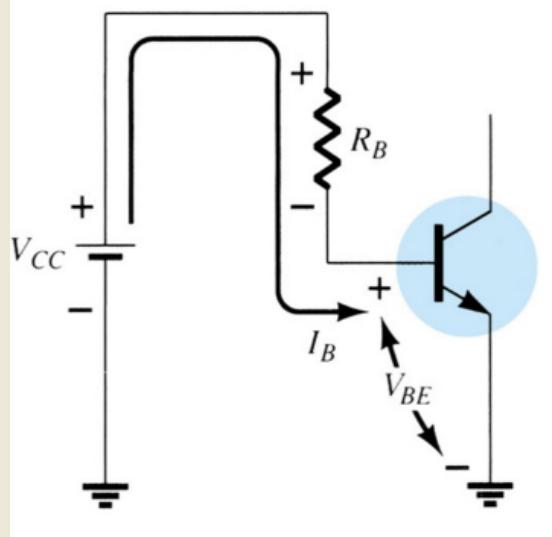


Sketching the DC equivalent is the first step for DC analysis:

1. Replacing the capacitor with an open-circuit equivalent.
2. Replacing the inductor with a short-circuit equivalent.
3. DC supply can be separated for analysis purpose only

# Mathematical Analysis

Base-emitter loop



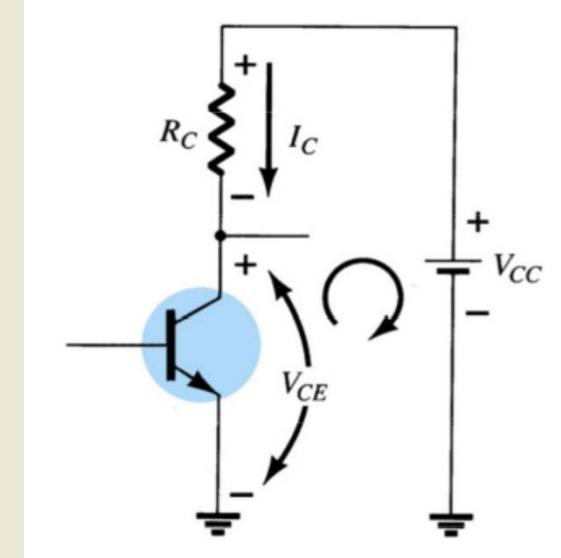
From Kirchhoff's voltage law:

$$+V_{CC} - I_B R_B - V_{BE} = 0$$

Solving for the base current:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Collector-emitter loop



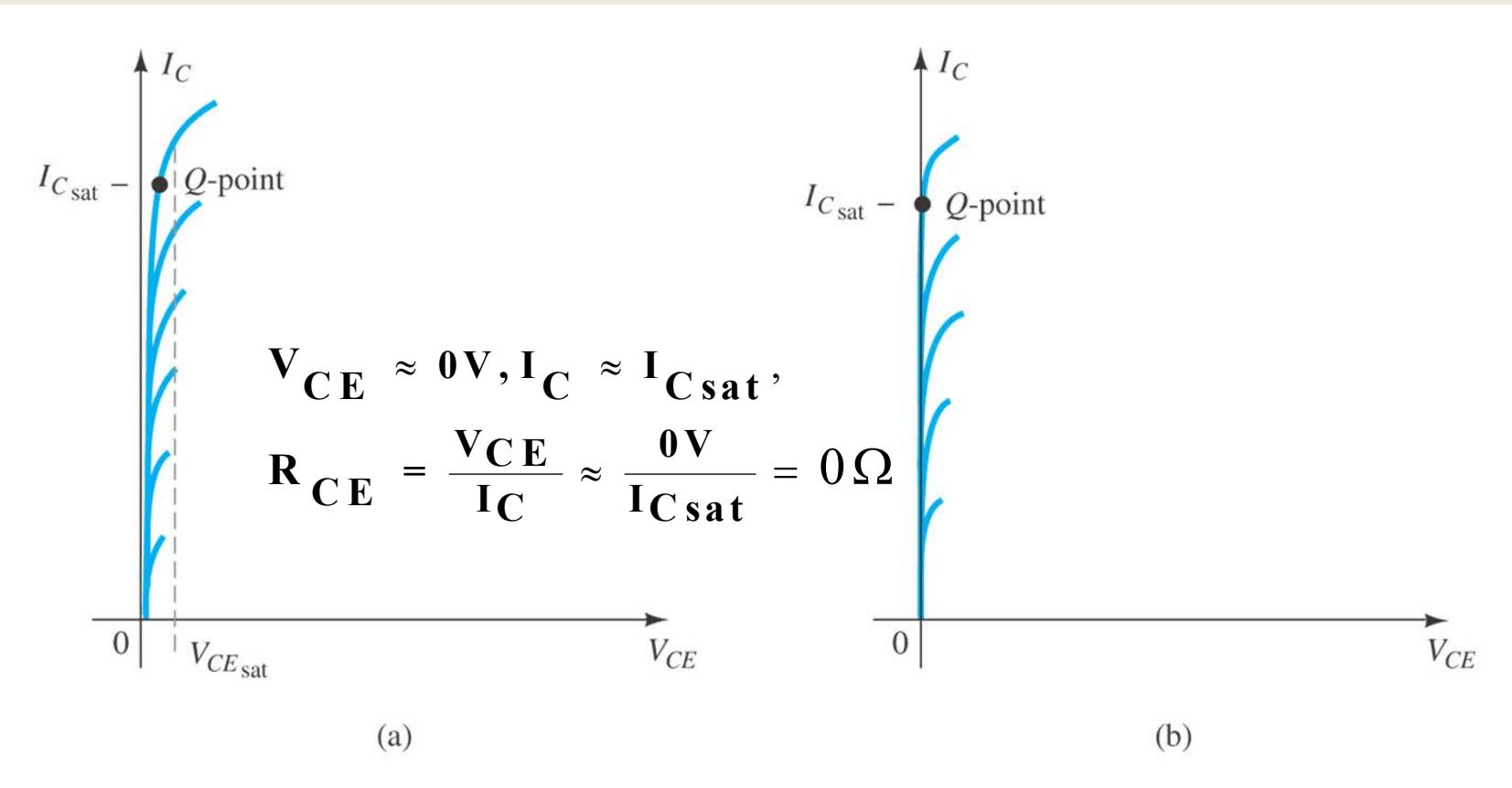
The collector current is given by:

$$I_C = \beta I_B$$

From Kirchhoff's voltage law:

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

# Transistor Saturation



## Transistor Saturation Level

When the transistor is operating in the saturation region, it is conducting at **maximum current flow through the transistor**.

$$I_{C_{sat}} = \frac{V_{CC}}{R_C} \quad V_{CE} \cong 0V$$

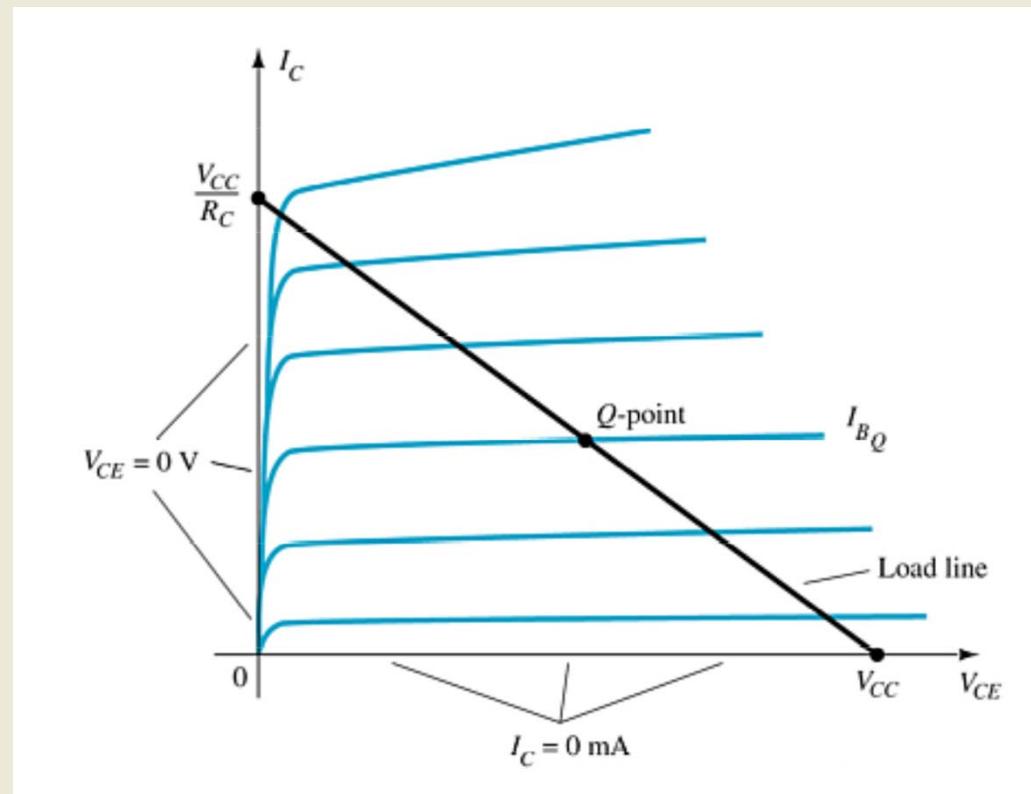
# Load Line Analysis

Load equation by KVL:

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

The end points of the load line are:

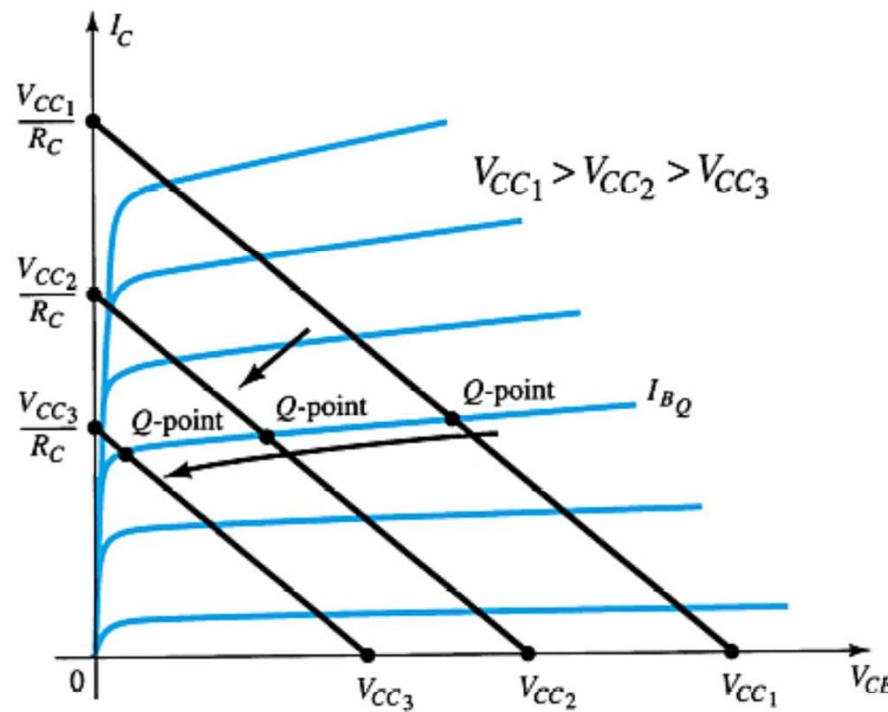
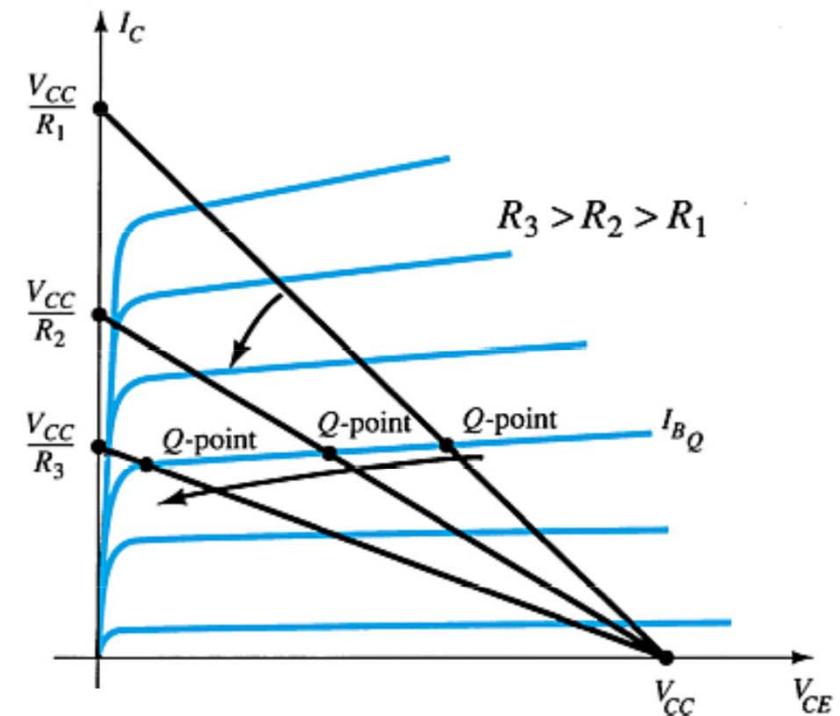
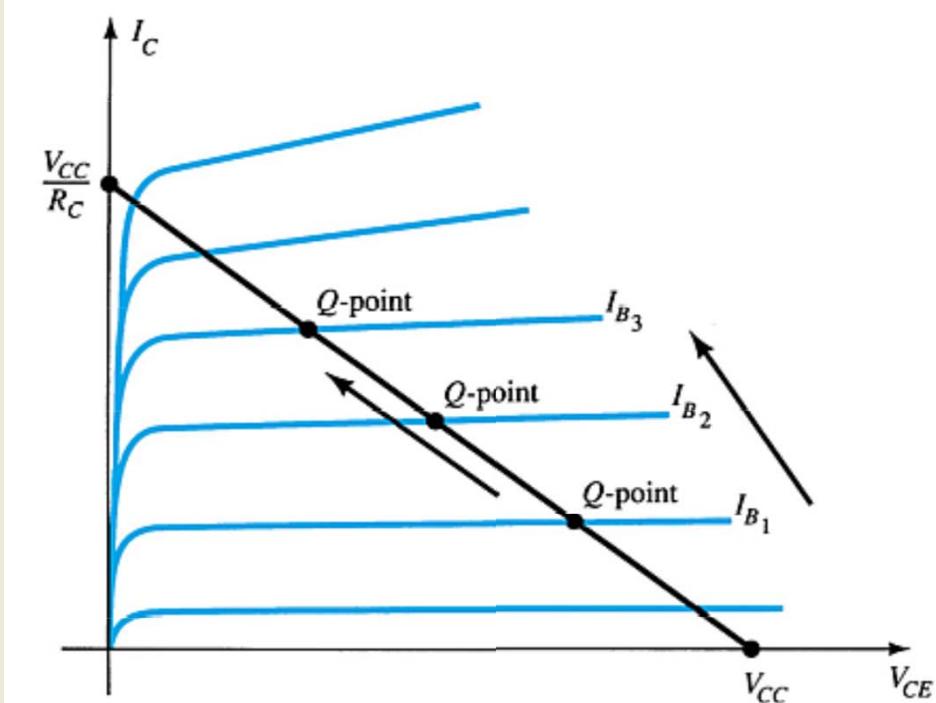
- $I_{C\text{sat}}$ 
  - ♦  $I_C = V_{CC} / R_C$
  - ♦  $V_{CE} = 0 \text{ V}$
- $V_{CE\text{cutoff}}$ 
  - ♦  $V_{CE} = V_{CC}$
  - ♦  $I_C = 0 \text{ mA}$



The Q-point is the particular operating point:

- where the value of  $R_B$  sets the value of  $I_B$
- where  $I_B$  and the load line intersect
- that sets the values of  $V_{CE}$  and  $I_C$

# Circuit Values Affect the Q-Point

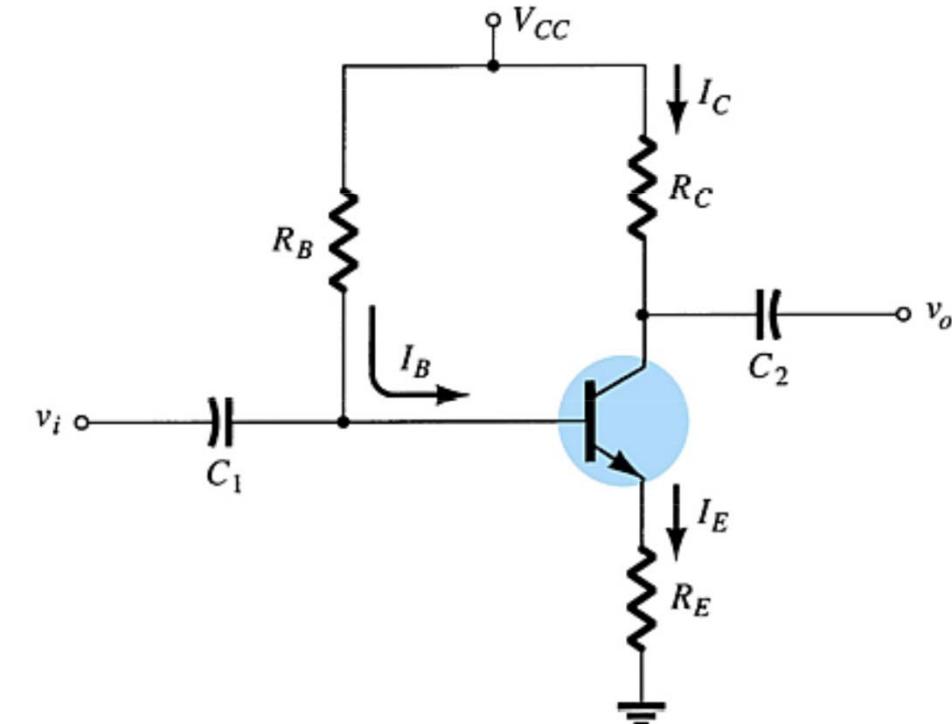


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## 4.4 Emitter-Stabilized Bias Circuit

### Improved Biased Stability

**Adding a resistor ( $R_E$ ) to the emitter improves the stability of a transistor.**



*Stability* refers to a bias circuit in which the currents and voltages will remain fairly constant for a wide range of temperatures and transistor Beta ( $\beta$ ) values.

# Mathematical Analysis

## Base-Emitter Loop

From Kirchhoff's voltage law :

$$+V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

Since  $I_E = (\beta + 1)I_B$ :

$$V_{CC} - V_{BE} - I_B R_B - (\beta + 1)I_B R_E = 0$$

Solving for  $I_B$ :

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$$

## Collector-Emitter Loop

The collector current is given by:

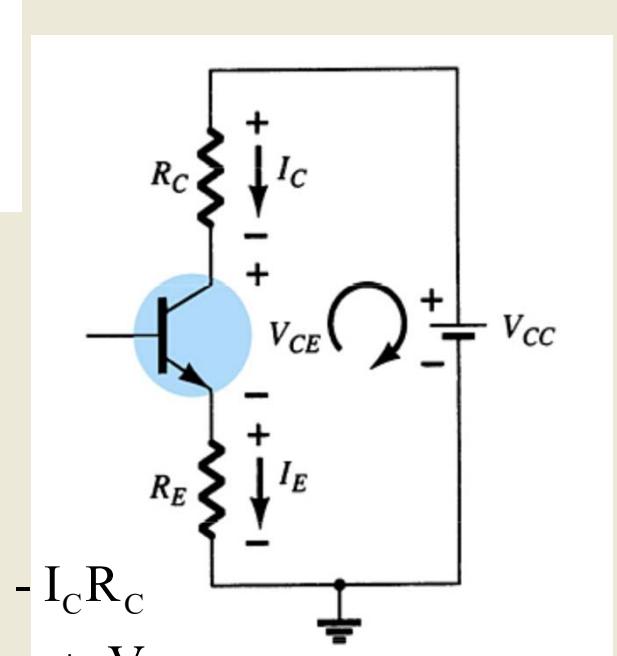
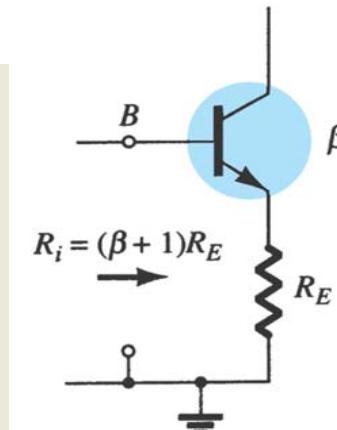
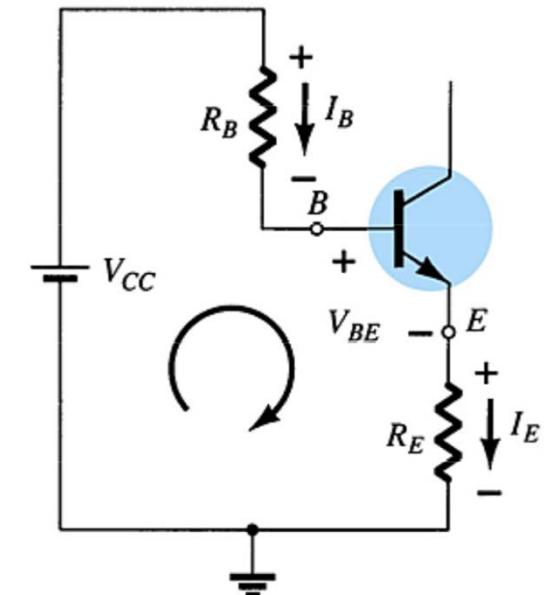
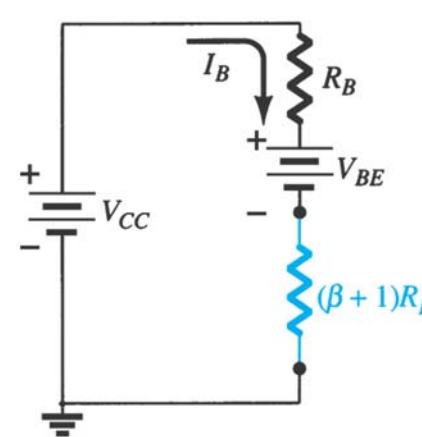
$$I_C = \beta I_B$$

From Kirchhoff's voltage law :

$$+ I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0$$

Since  $I_E \approx I_C$ :

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$



## The role of $R_E$ ?

Also:

$$V_E = I_E R_E$$

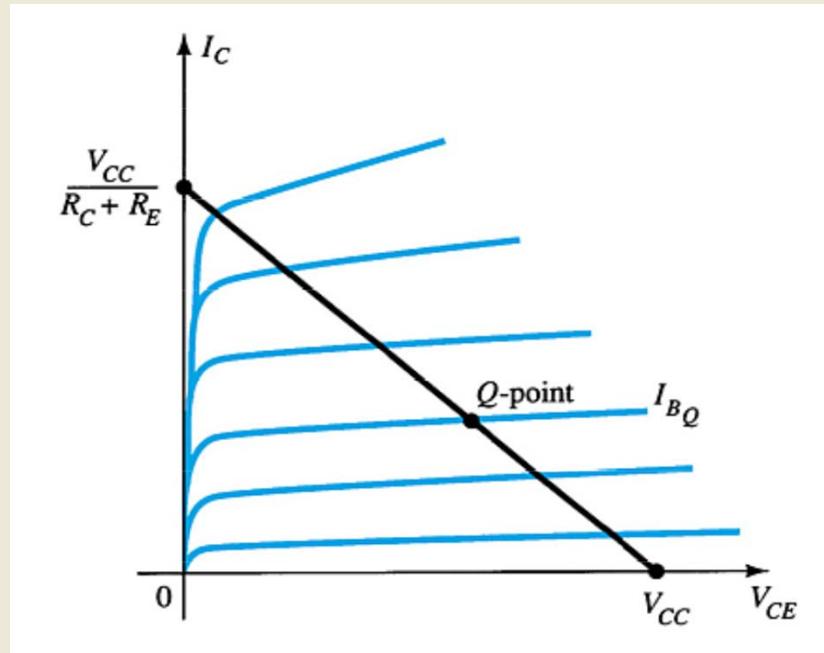
$$V_C = V_{CE} + V_E = V_{CC} - I_C R_C$$

$$V_B = V_{CC} - I_B R_B = V_{BE} + V_E$$

# Load line Analysis

Load equation by KVL:

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$



The endpoints can be determined from the load line.

$V_{CE\text{cutoff}}$ :

$$V_{CE} = V_{CC}$$

$$I_C = 0 \text{ mA}$$

$I_{C\text{sat}}$ :

$$V_{CE} = 0 \text{ V}$$

$$I_C = \frac{V_{CC}}{R_C + R_E}$$

## 4.5 Voltage Divider Bias

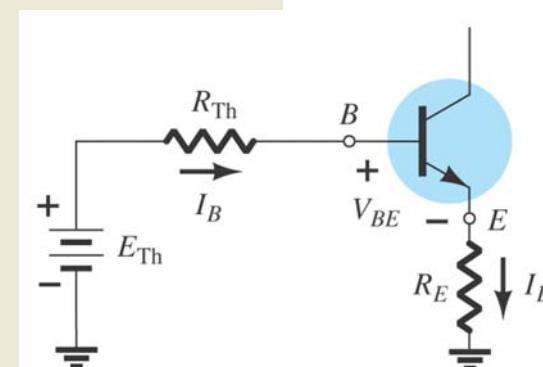
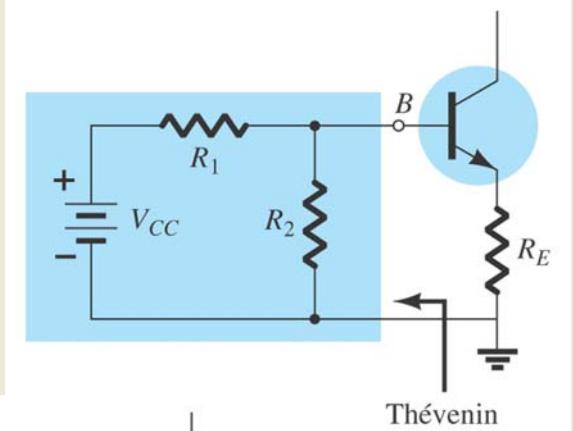
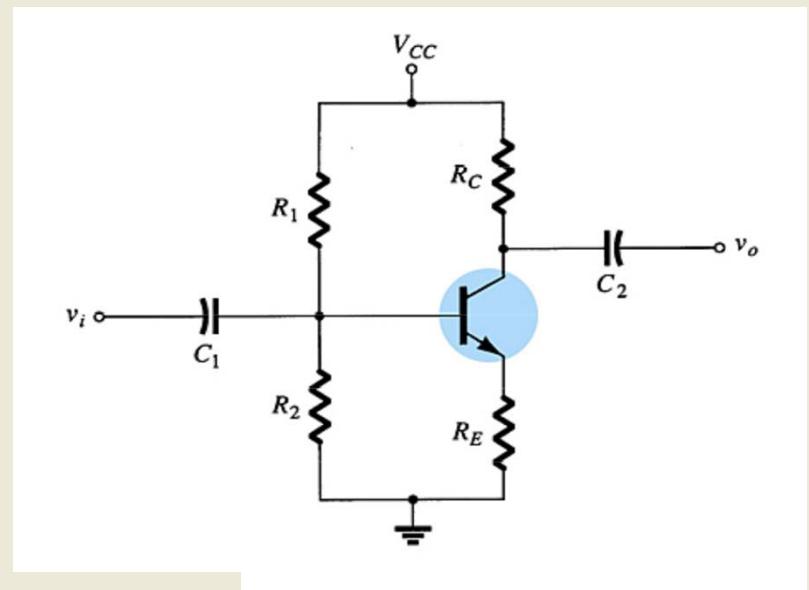
This is a very stable bias circuit.

The currents and voltages are almost independent of variations in  $\beta$ .

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

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

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$



$$R_{Th} = R_1 \parallel R_2$$

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

# Approximate Analysis

Where  $I_B \ll I_1$  and  $I_2$  and  $I_1 \cong I_2$ :

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$$

Where  $\beta R_E > 10R_2$ :

$$I_E = \frac{V_E}{R_E}$$

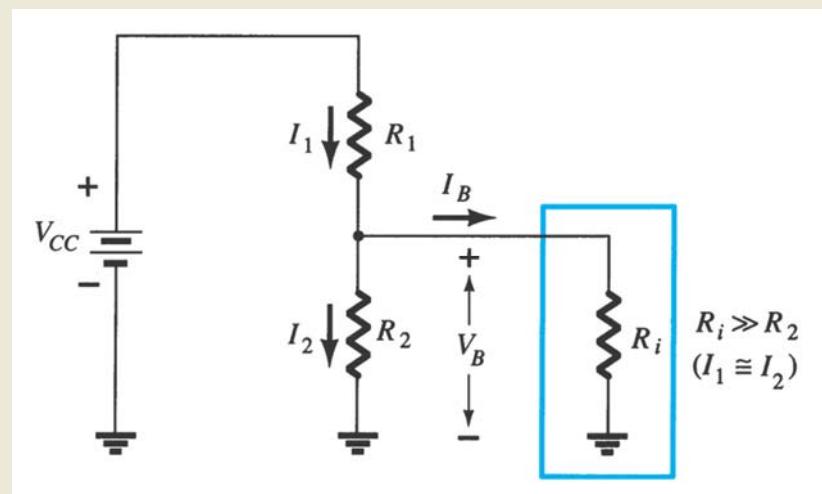
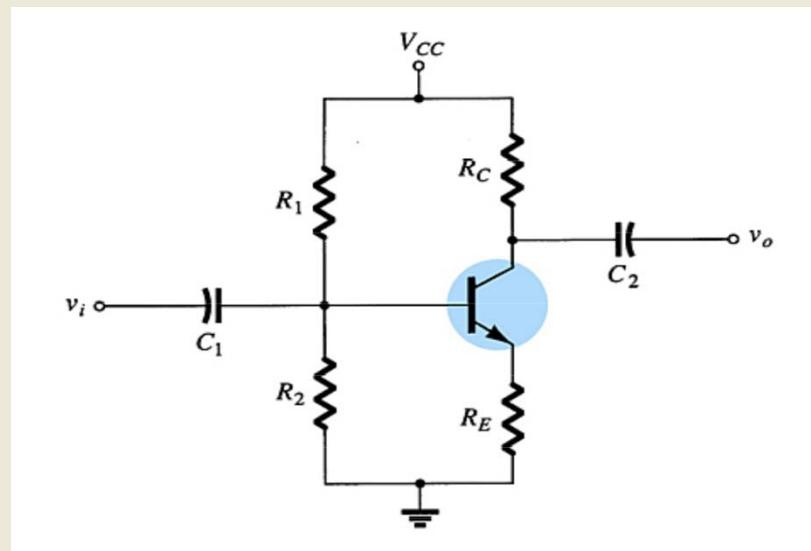
$$V_E = V_B - V_{BE}$$

From Kirchhoff's voltage law:

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$I_E \cong I_C$$

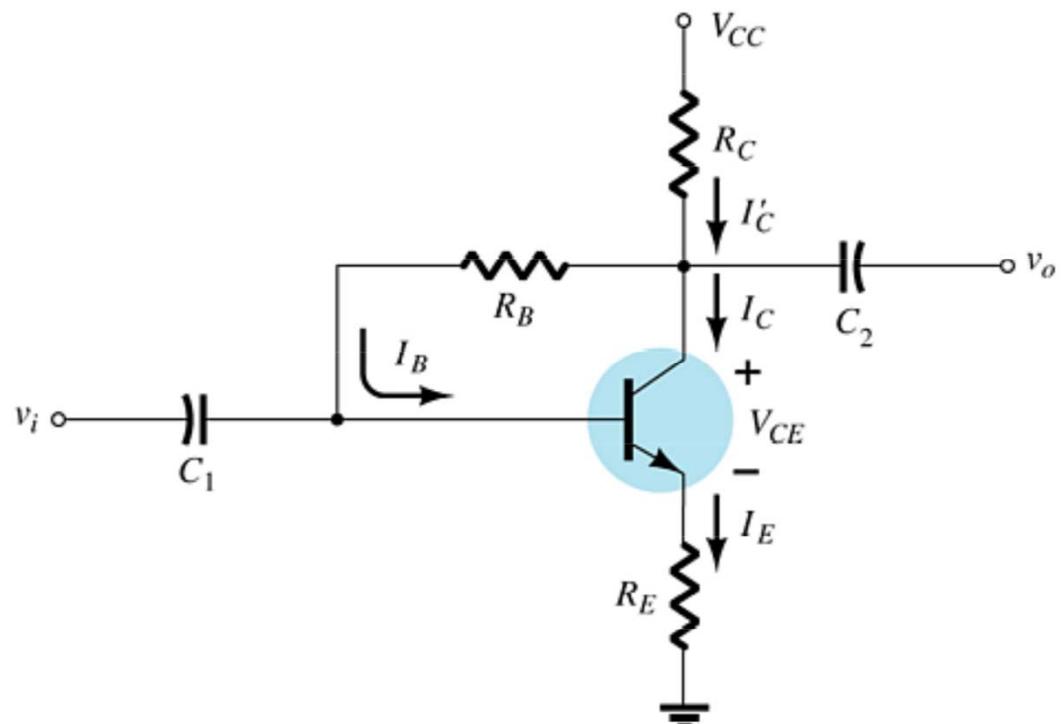
$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$



## 4.6 DC Bias with Voltage Feedback

Another way to improve the stability of a bias circuit is to add a feedback path from collector to base.

In this bias circuit the Q-point is only slightly dependent on the transistor beta,  $\beta$ .



# Base-Emitter Loop

## Base-Emitter Loop

From Kirchhoff's voltage law:

$$V_{CC} - I'_C R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

Where  $I_B \ll I_C$ :

$$I'_C = I_C + I_B = I_C$$

Knowing  $I_C = \beta I_B$  and  $I_E \approx I_C$ , the loop equation becomes:

$$V_{CC} - \beta I_B R_C - I_B R_B - V_{BE} - \beta I_B R_E = 0$$

Solving for  $I_B$ :

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}$$

## Collector-Emitter Loop

Applying Kirchoff's voltage law:

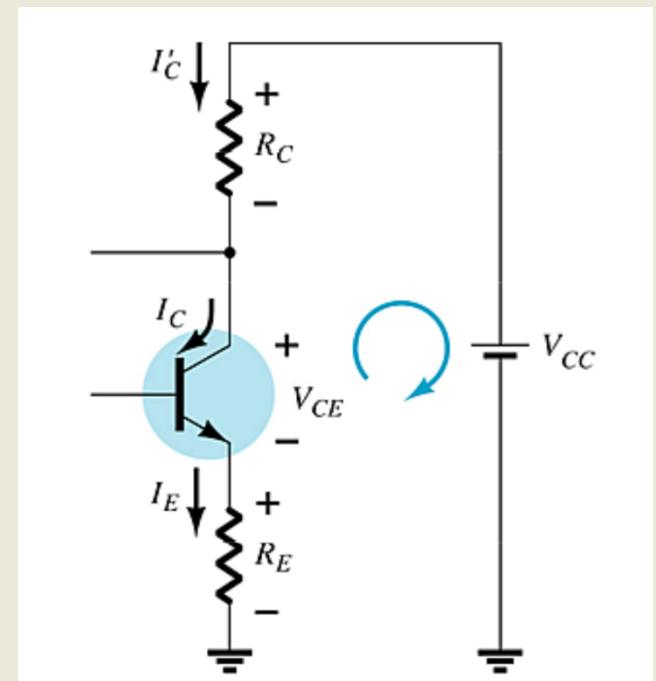
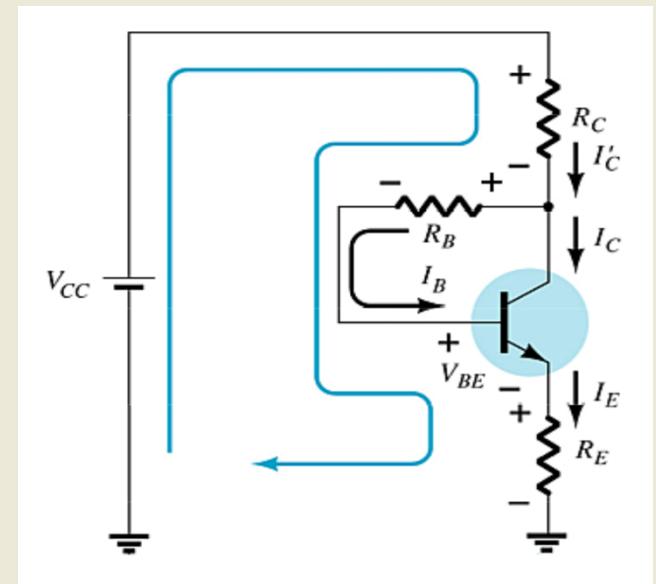
$$I_E R_E + V_{CE} + I'_C R_C - V_{CC} = 0$$

Since  $I'_C \approx I_C$  and  $I_C = \beta I_B$ :

$$I_C(R_C + R_E) + V_{CE} - V_{CC} = 0$$

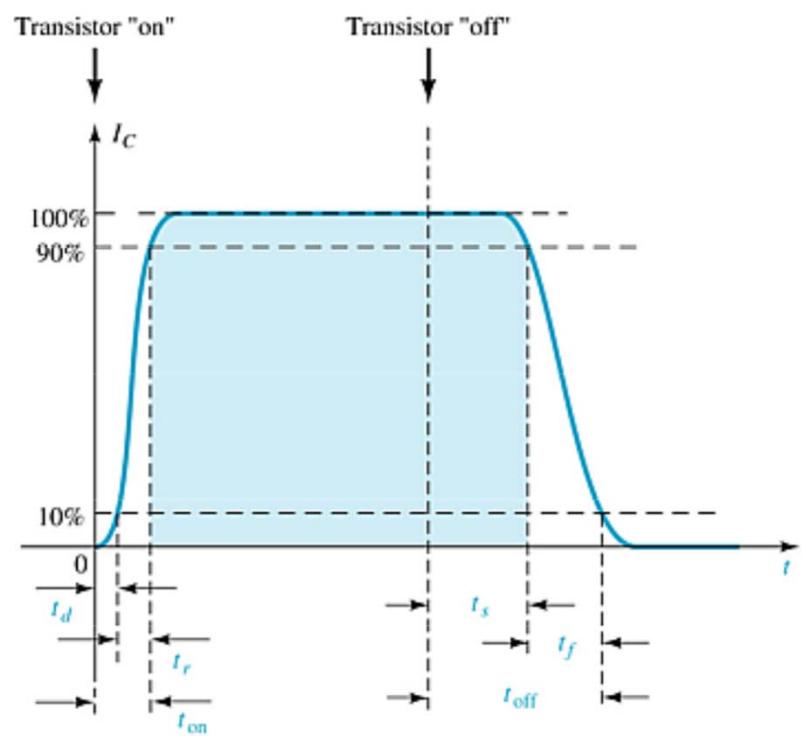
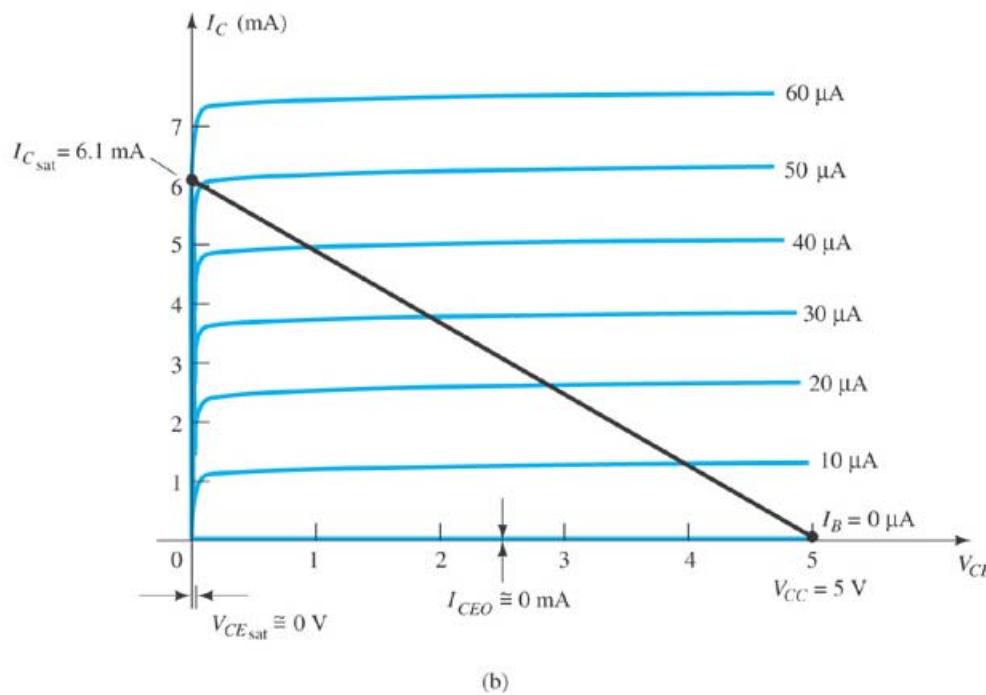
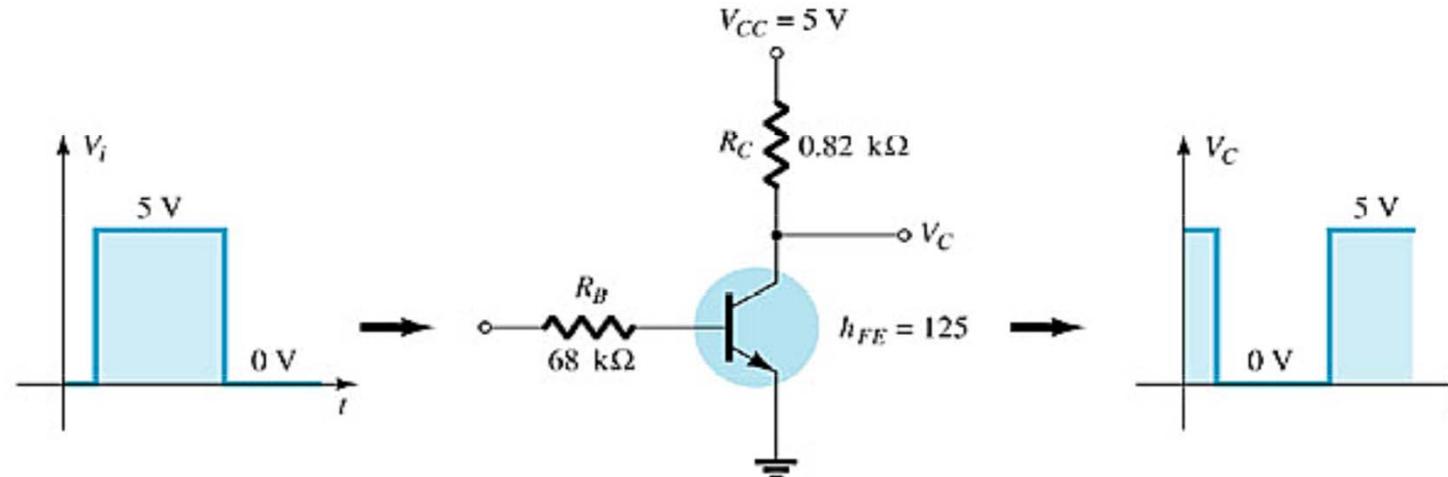
Solving for  $V_{CE}$ :

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$



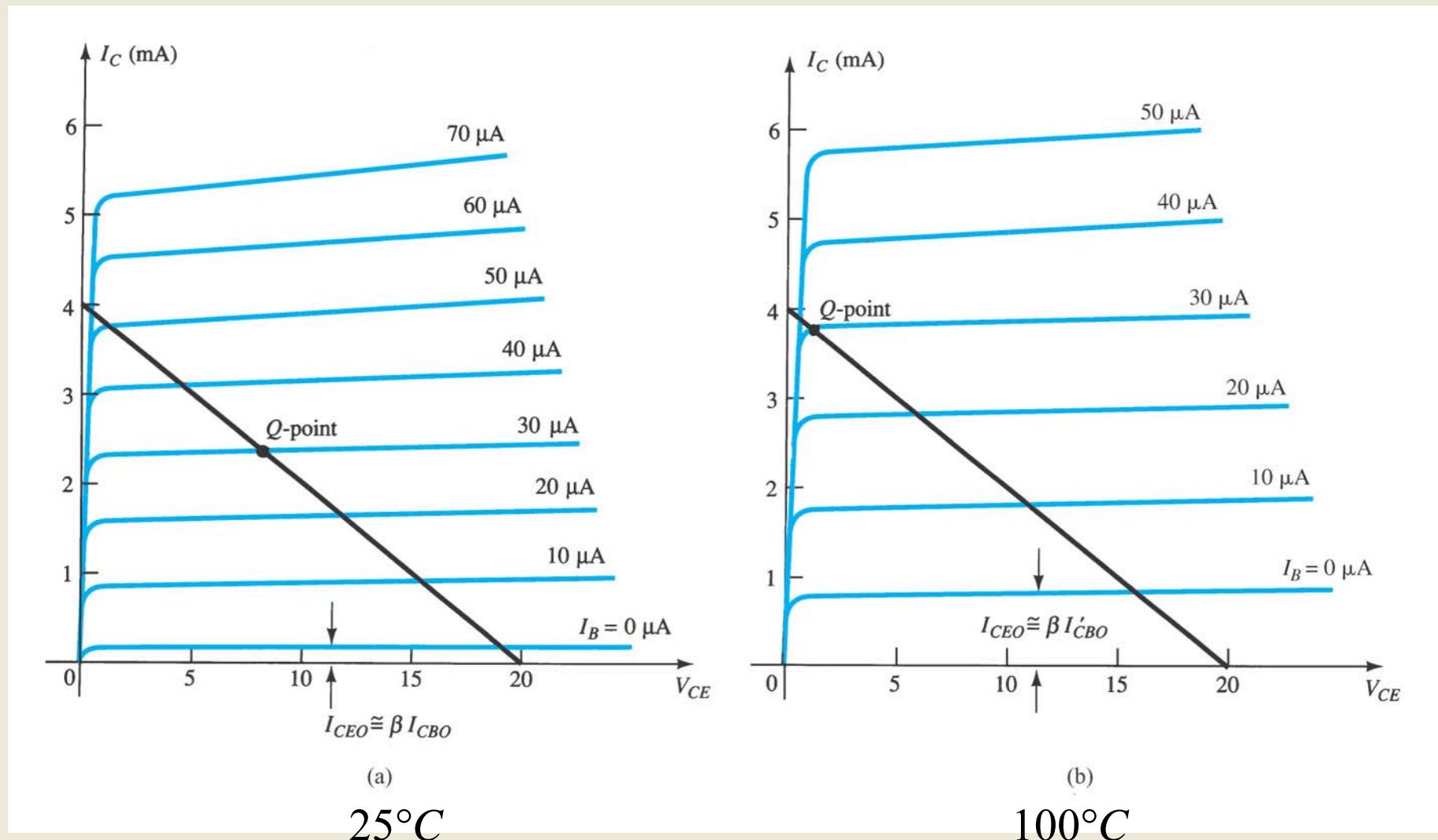
## 4.8 Transistor Switching Networks

Transistors with only the DC source applied can be used as electronic switches.



## 4.10 Bias Stabilization

- $I_C$  is sensitive to  $\beta$ , temperature,  $V_{BE}$ , and  $I_{CO}$



## Summary of Chapter 4

- DC analysis: DC equivalent circuit
  - ◆ Mathematical analysis ( $V_{BE}=.7V$ )
  - ◆ Load-line analysis
- Typical DC biasing circuits
  - ◆ Fixed-bias circuit
  - ◆ Emitter-stabilized bias circuit
  - ◆ Voltage divider bias circuit
  - ◆ DC bias with voltage feedback
- Factors affecting bias stability

**Note:** The analysis for *pnp* transistor biasing circuits is the same as that for *npn* transistor circuits. The only difference is that the currents are flowing in the opposite direction.