BENHA UNIVERSITY
FACULTY OF ENGINEERING AT SHOUBRA

ECE-291
Electronic Engineering

Lecture #3 (2 weeks)
Transistors

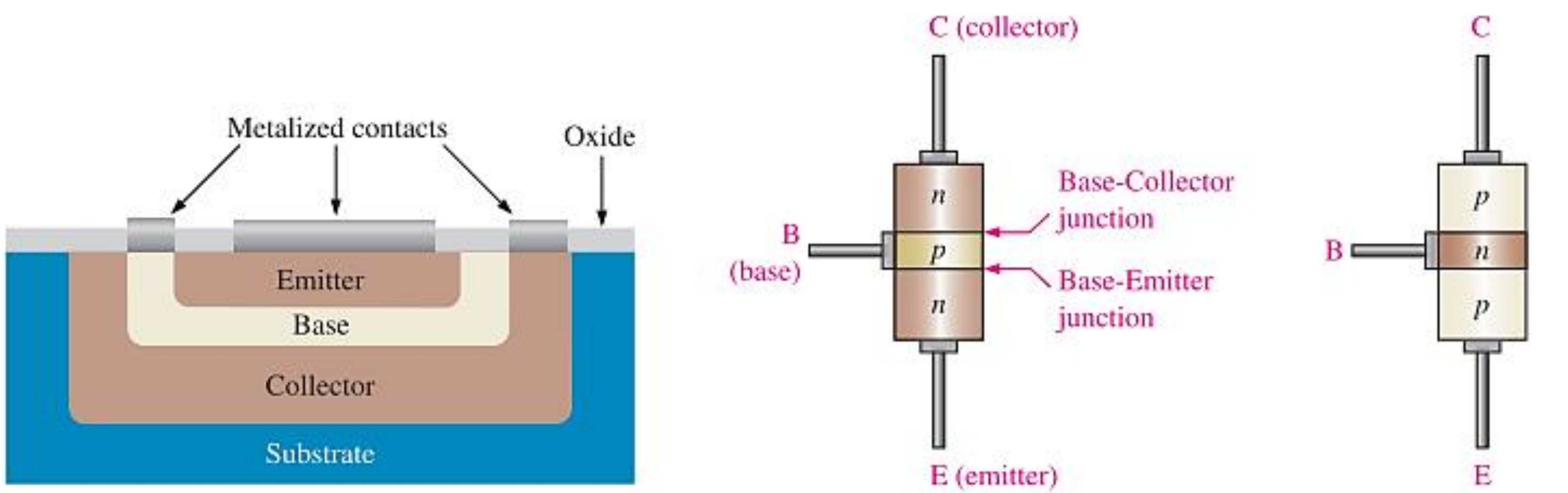
Instructor:
Dr. Ahmad El-Banna

SPRING 2015

Agenda

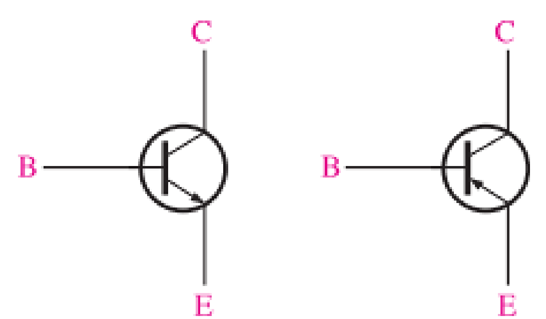
- BJT Structure
- Basic Operation
- Transistor as an Amplifier
- Transistor as a Switch
- DC & AC Analysis

BIPOLAR JUNCTION TRANSISTOR (BJT) STRUCTURE



(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

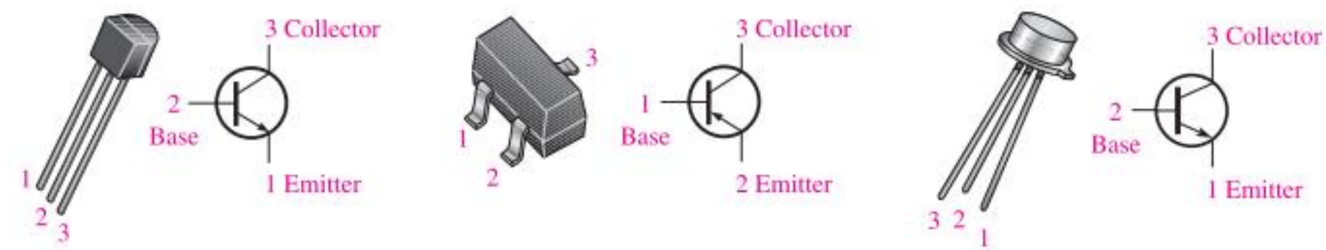
BJT symbol



(a) *npn* (b) *pnp*

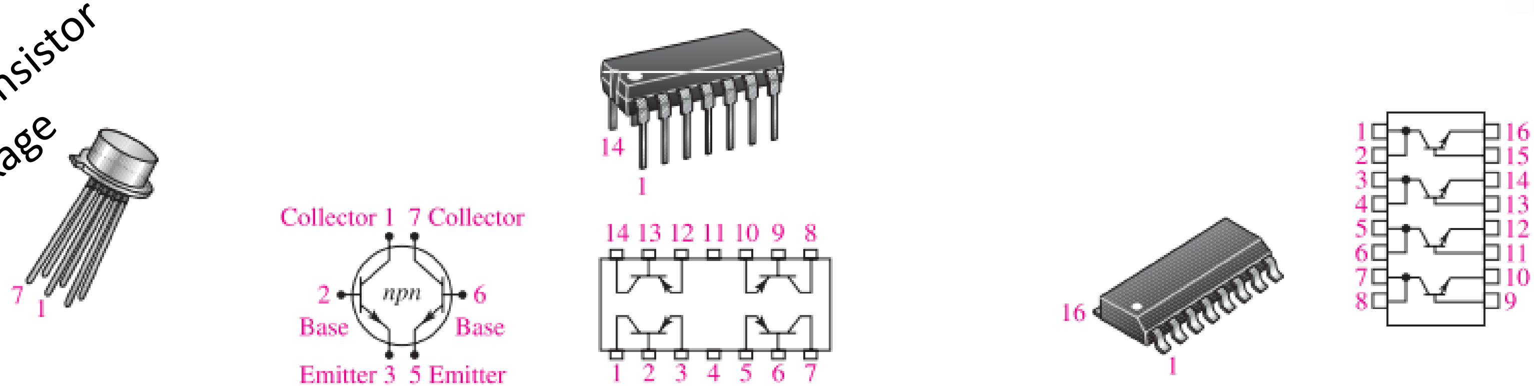
Transistor Packages

General Purpose



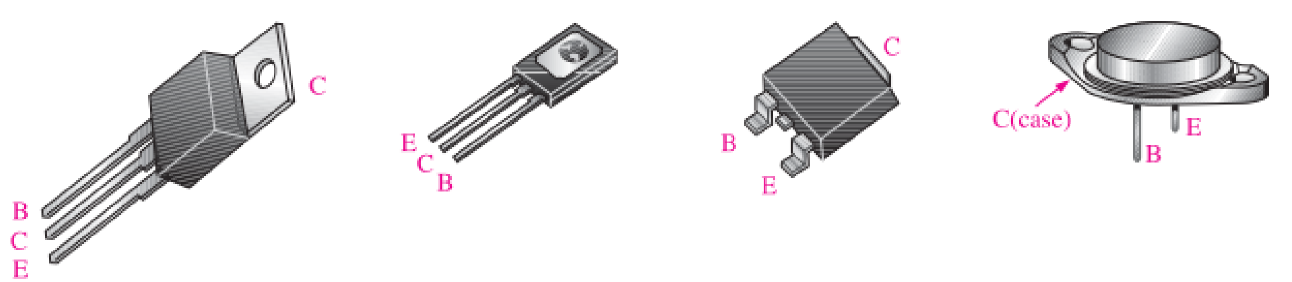
(a) TO-92 (b) SOT-23 (c) TO-18. Emitter is closest to tab.

Multiple Transistor Package



(a) Dual metal can. Emitters are closest to tab. (b) Quad dual in-line (DIP) and quad flat-pack. Dot indicates pin 1. (c) Quad small outline (SO) package for surface-mount technology

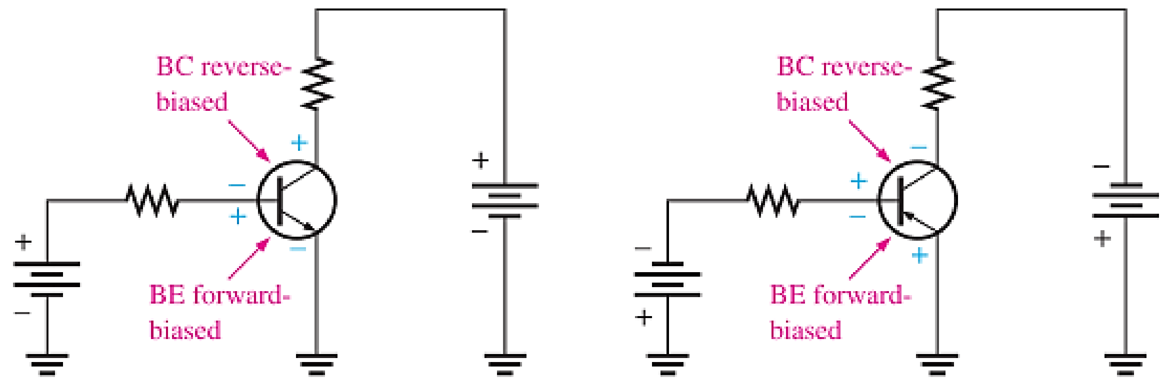
Power Transistors



(a) TO-220 (b) TO-225 (c) D-Pack (d) TO-3

Basic Operation

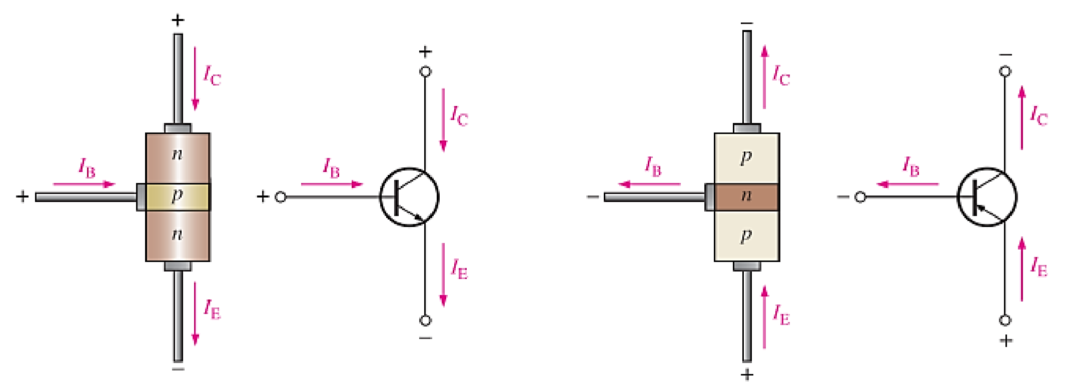
- **Biasing & Operation**



(a) *npn* (b) *pnp*

- **Transistor Currents**

$$I_E = I_C + I_B$$

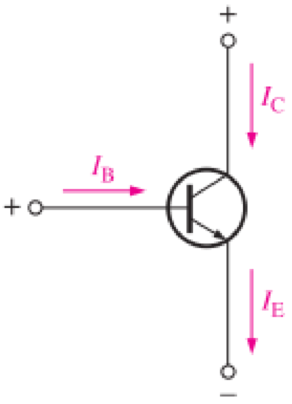


(a) *npn* (b) *pnp*

BJT Configurations

Configuration	Input	Output
Common Emitter	Base	Collector
Common Base	Emitter	Collector
Common Collector	Base	Emitter

- Base terminal can't be output
- Collector terminal can't be input



BJT Parameters

$$\beta_{DC} = \frac{I_C}{I_B}$$

- The dc current gain of a transistor is the ratio of the dc collector current (I_C) to the dc base current (I_B) and is designated dc **beta** (β_{DC}).

$$h_{FE} = \beta_{DC}$$

- Typical values of β_{DC} range from less than 20 to 200 or higher.
- β_{DC} is usually designated as an equivalent hybrid (h) parameter, h_{FE}, on transistor datasheets.

$$\alpha_{DC} = \frac{I_C}{I_E}$$

- The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc alpha (α_{DC}).

Transistor DC Model

I_B: dc base current

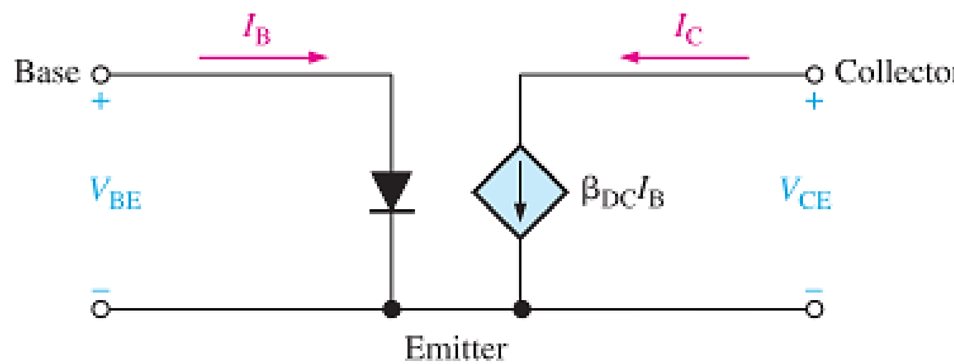
I_E: dc emitter current

I_C: dc collector current

V_{BE}: dc voltage at base with respect to emitter

V_{CB}: dc voltage at collector with respect to base

V_{CE}: dc voltage at collector with respect to emitter



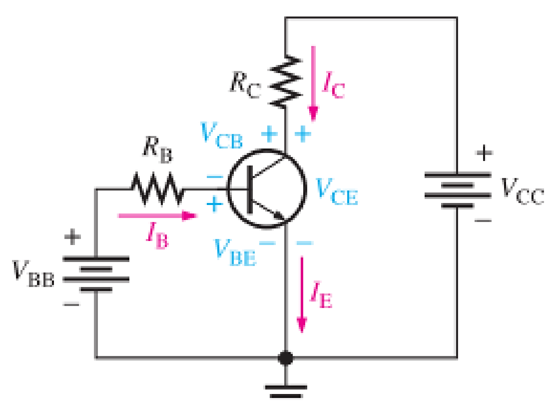
$$V_{BE} \cong 0.7\ V$$

$$V_{R_B} = V_{BB} - V_{BE}$$

$$V_{R_B} = I_B R_B$$

$$I_B R_B = V_{BB} - V_{BE}$$

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



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

$$V_{R_C} = I_C R_C$$

$$I_c = \beta I_B$$

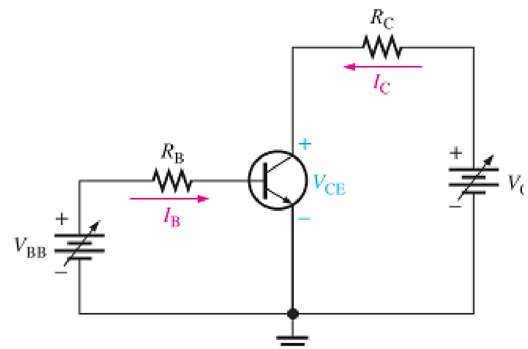
$$V_{CE} = V_{CC} - I_C R_C$$

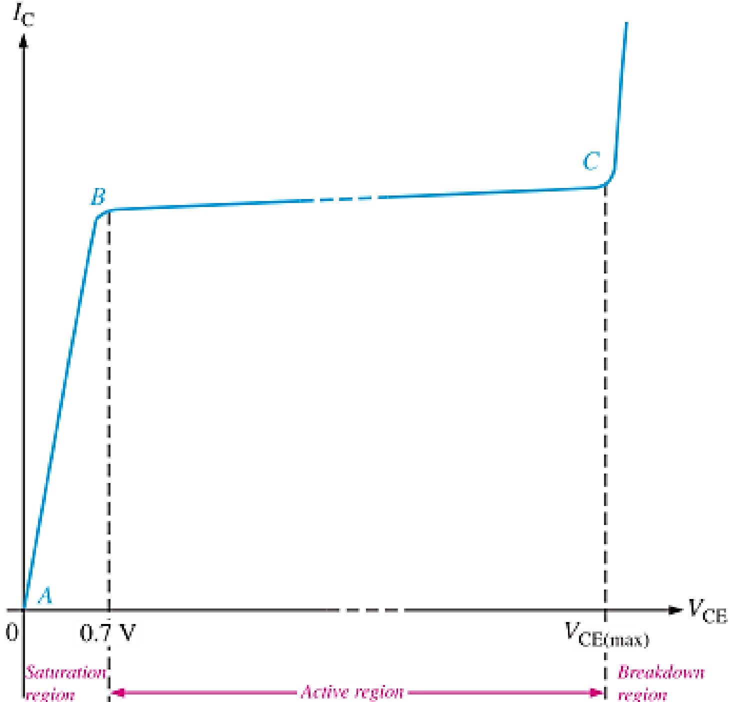
$$V_{CB} = V_{CE} - V_{BE}$$

Collector characteristic curves

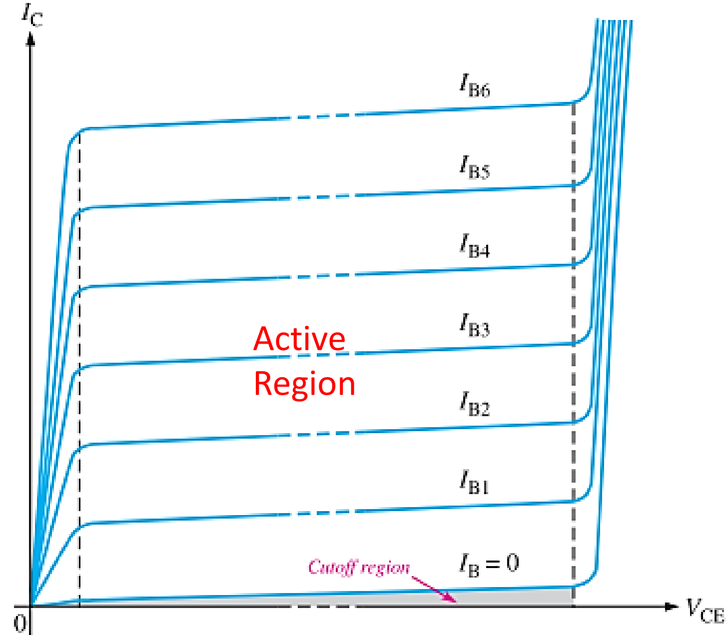
Operation Regions

- Active
- Cut-off
- Saturation



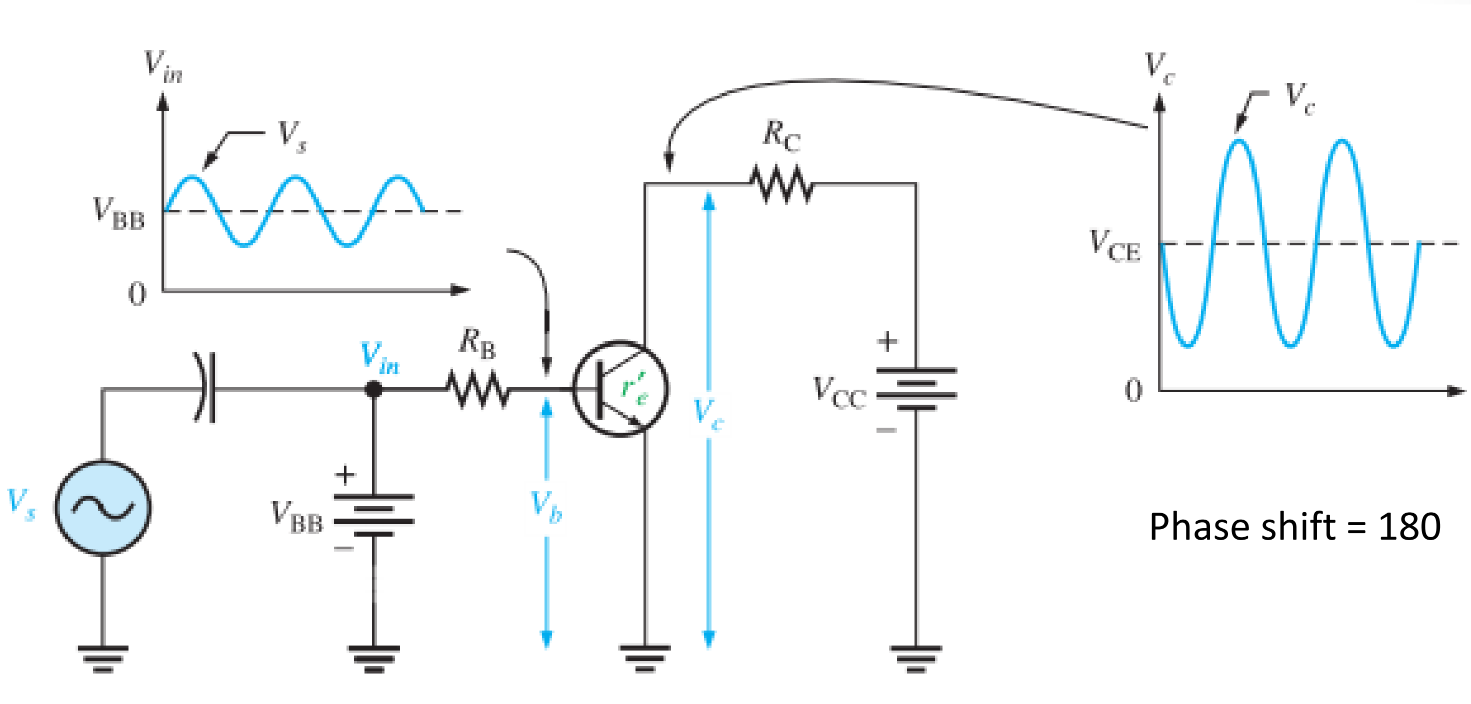


(b) I_C versus V_{CE} curve for one value of I_B



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

BJT as an Amplifier



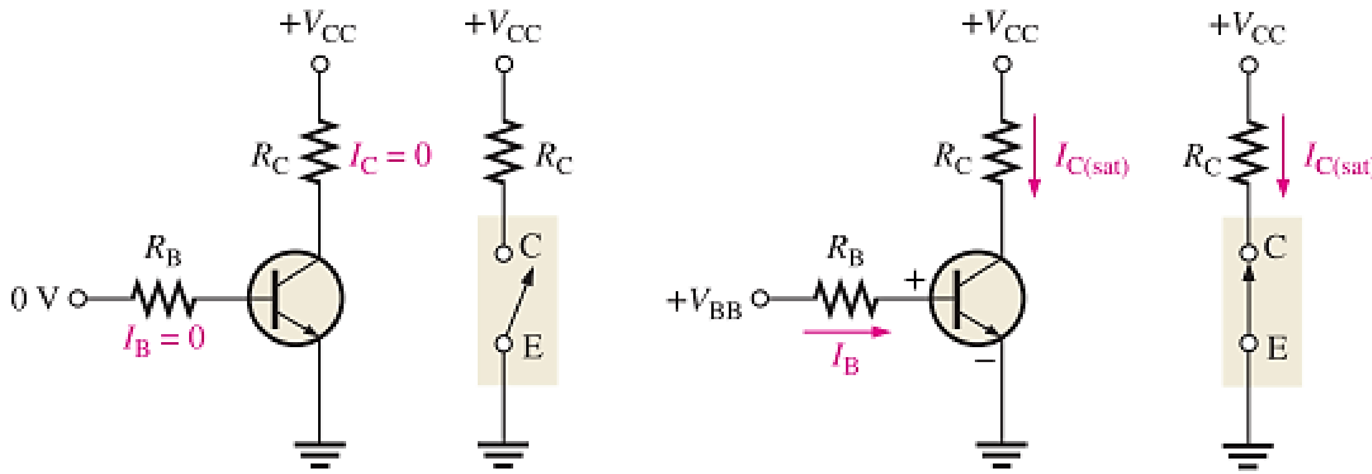
Phase shift = 180

Voltage gain magnitude: $A_v \cong \frac{R_C}{r'_e}$

r_e = 26 mv/ I_E

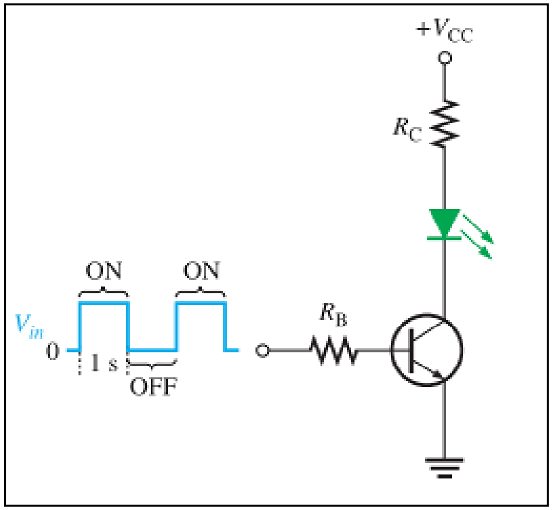
$I_E = I_C + I_B$

BJT as a Switch



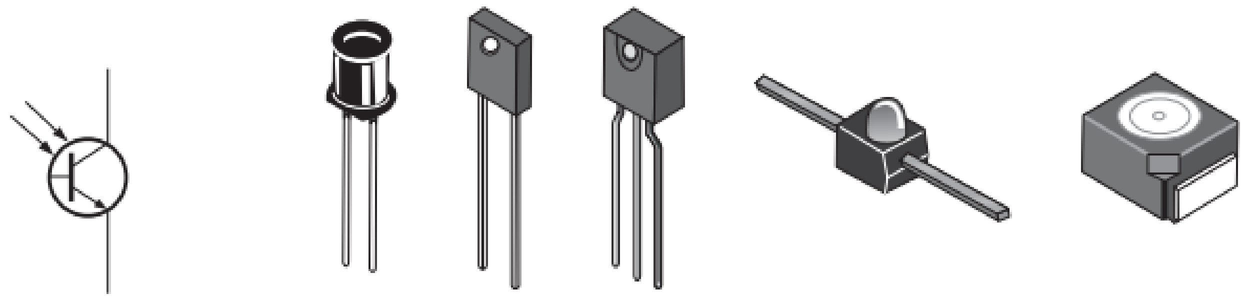
(a) Cutoff — open switch

(b) Saturation — closed switch

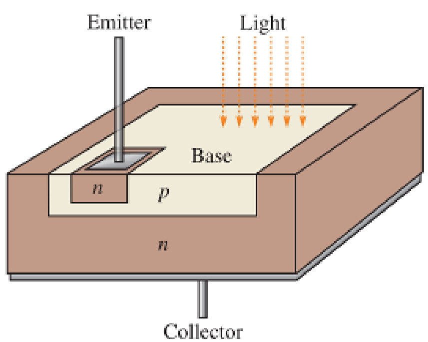


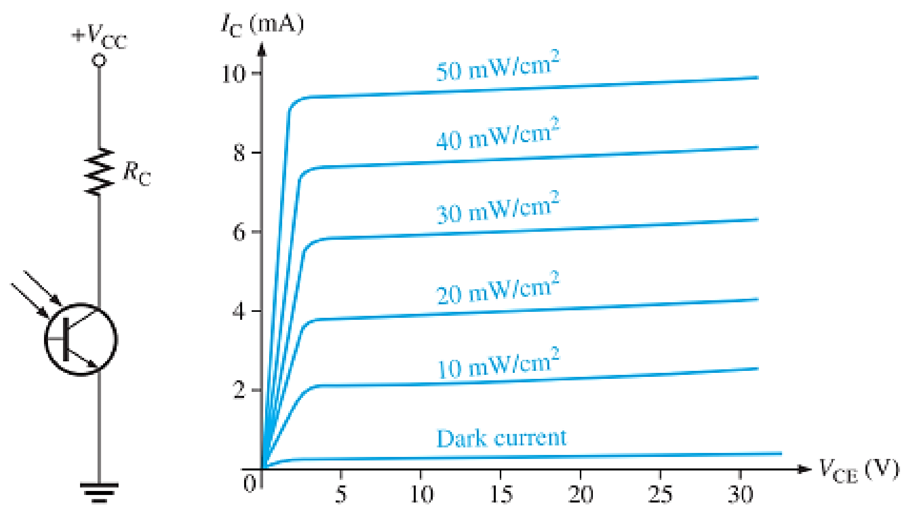
The Phototransistor

$$I_C = \beta_{DC} I_\lambda$$



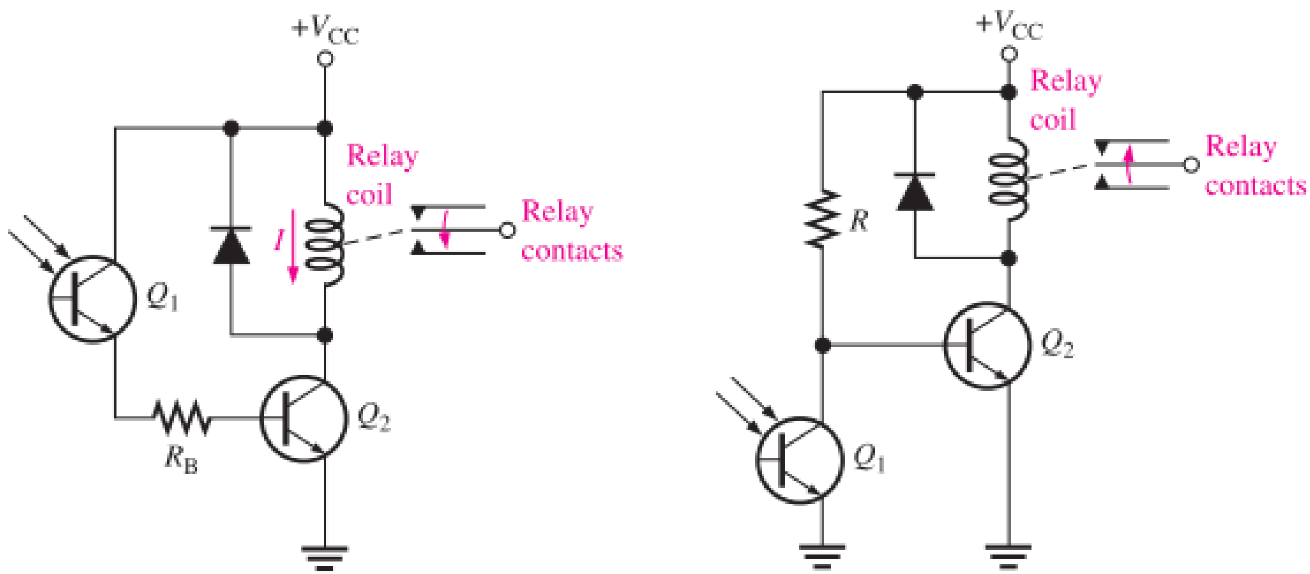
(a) Schematic symbol (b) Typical packages





Phototransistor Application

Relay circuits driven by a phototransistor

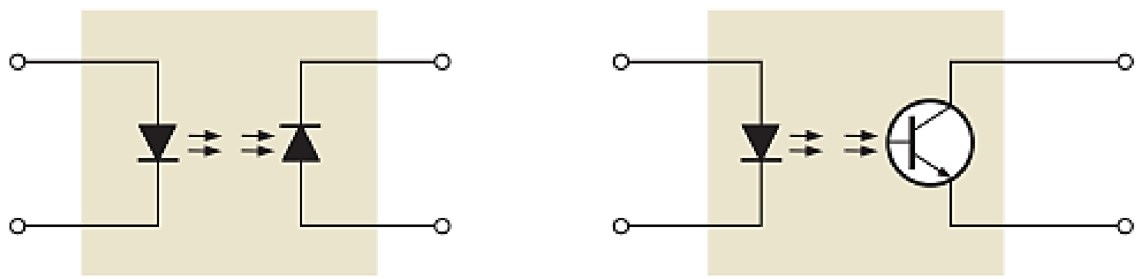


(a) Light activated (b) Light deactivated

- A **relay** is an electrically operated switch.
- **relays** use an electromagnet to mechanically operate a switch

Optocouplers

- **Basic optocouplers**



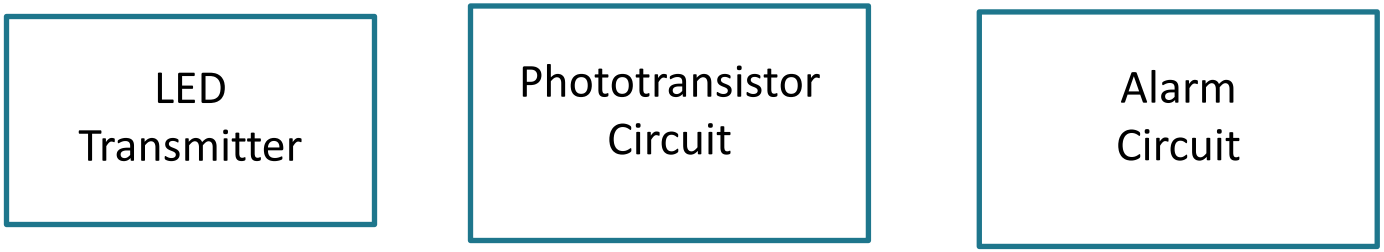
(a) LED-to-photodiode (b) LED-to-phototransistor

(a) Dual-in-line (b) Surface-mount (c) Ball-grid

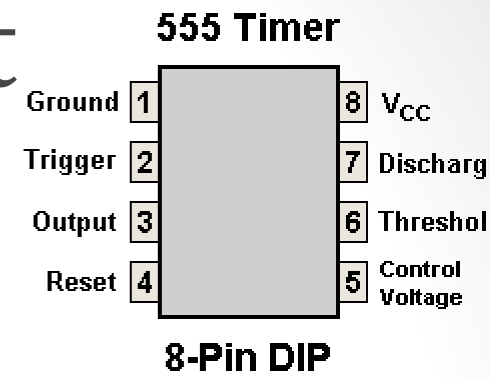
Examples of optocoupler packages

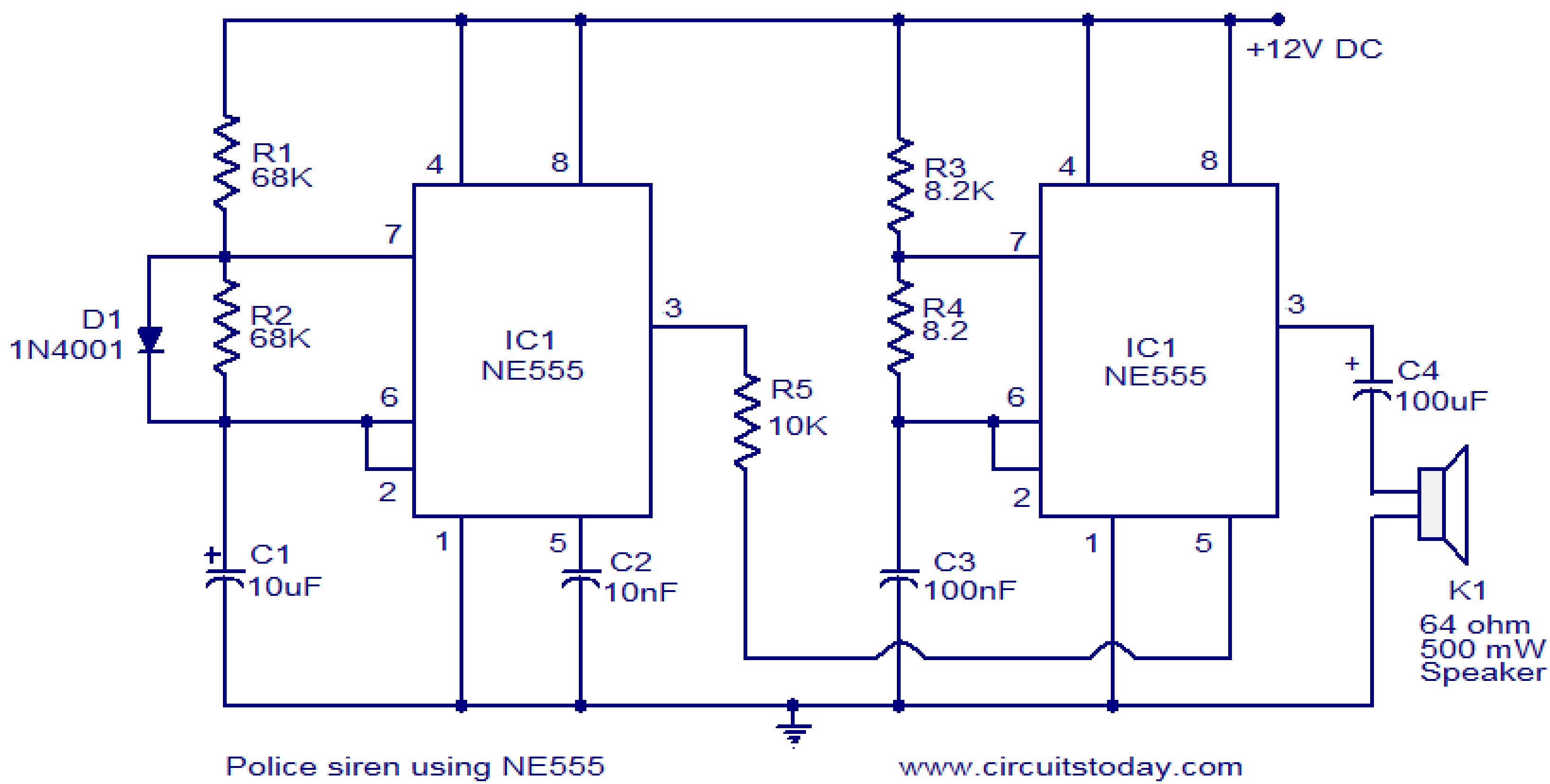
Project

Motion Detection Alarm

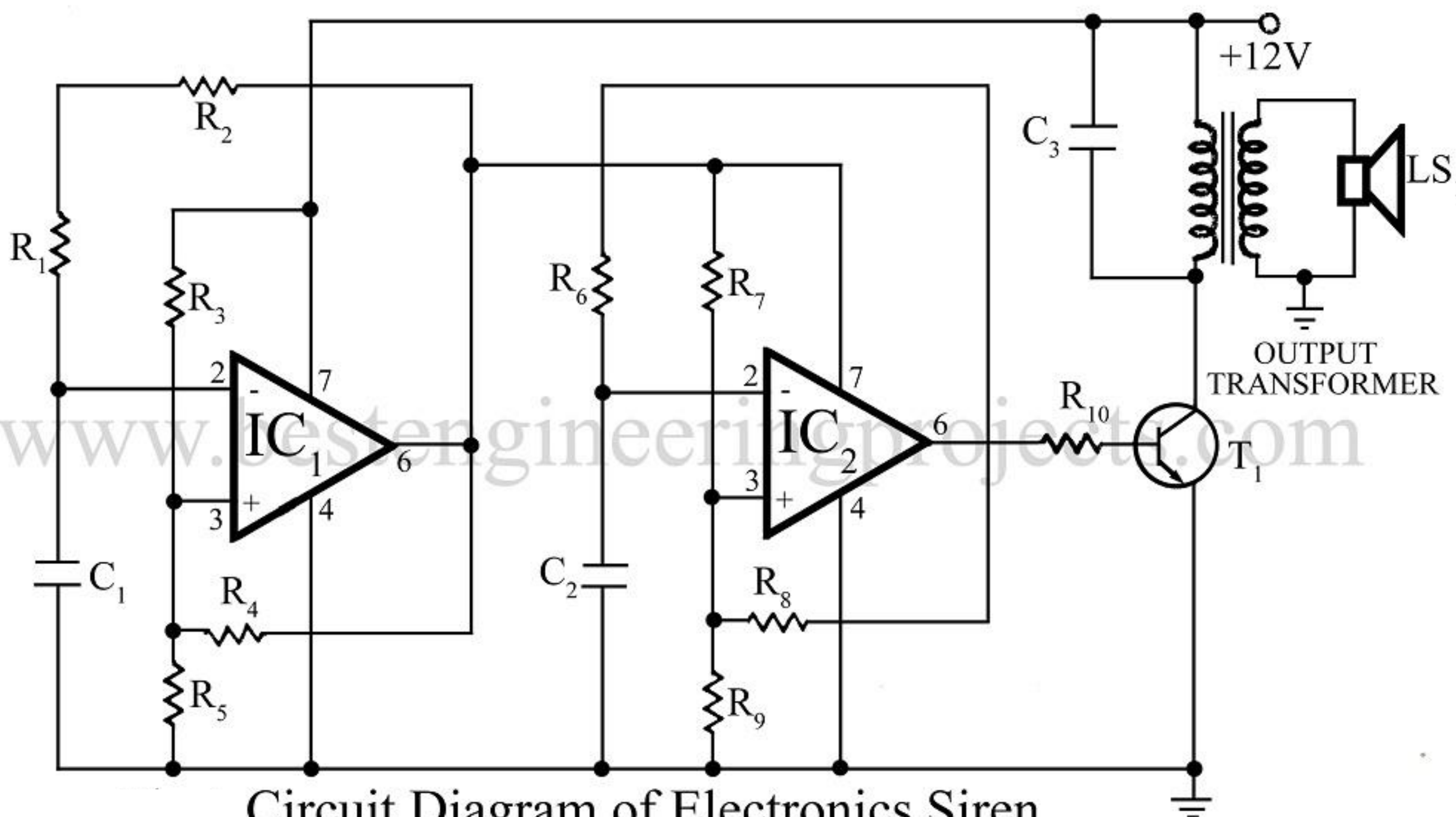


555 Timer Siren Circuit





Siren Using Op-Amp

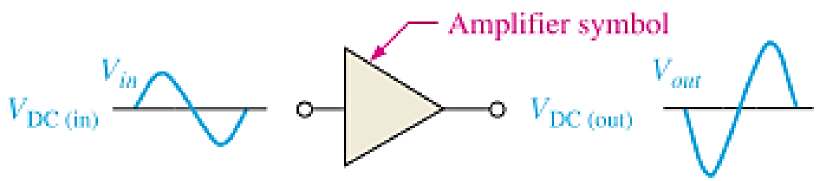


Circuit Diagram of Electronics Siren

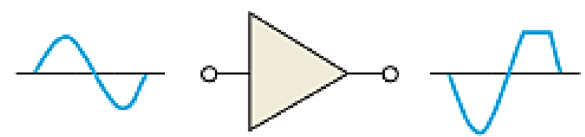
http://bestengineeringprojects.com/electronics-projects/electronic-siren/

Transistor Bias Circuit

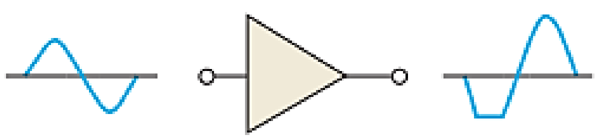
- What's Biasing?
  - Bias establishes the dc operating point (Q-point) for proper linear operation of an amplifier.
- Why?
  - If an amplifier is not biased with correct dc voltages on the input and output, it can go into saturation or cutoff when an input signal is applied.



(a) Linear operation: larger output has same shape as input except that it is inverted

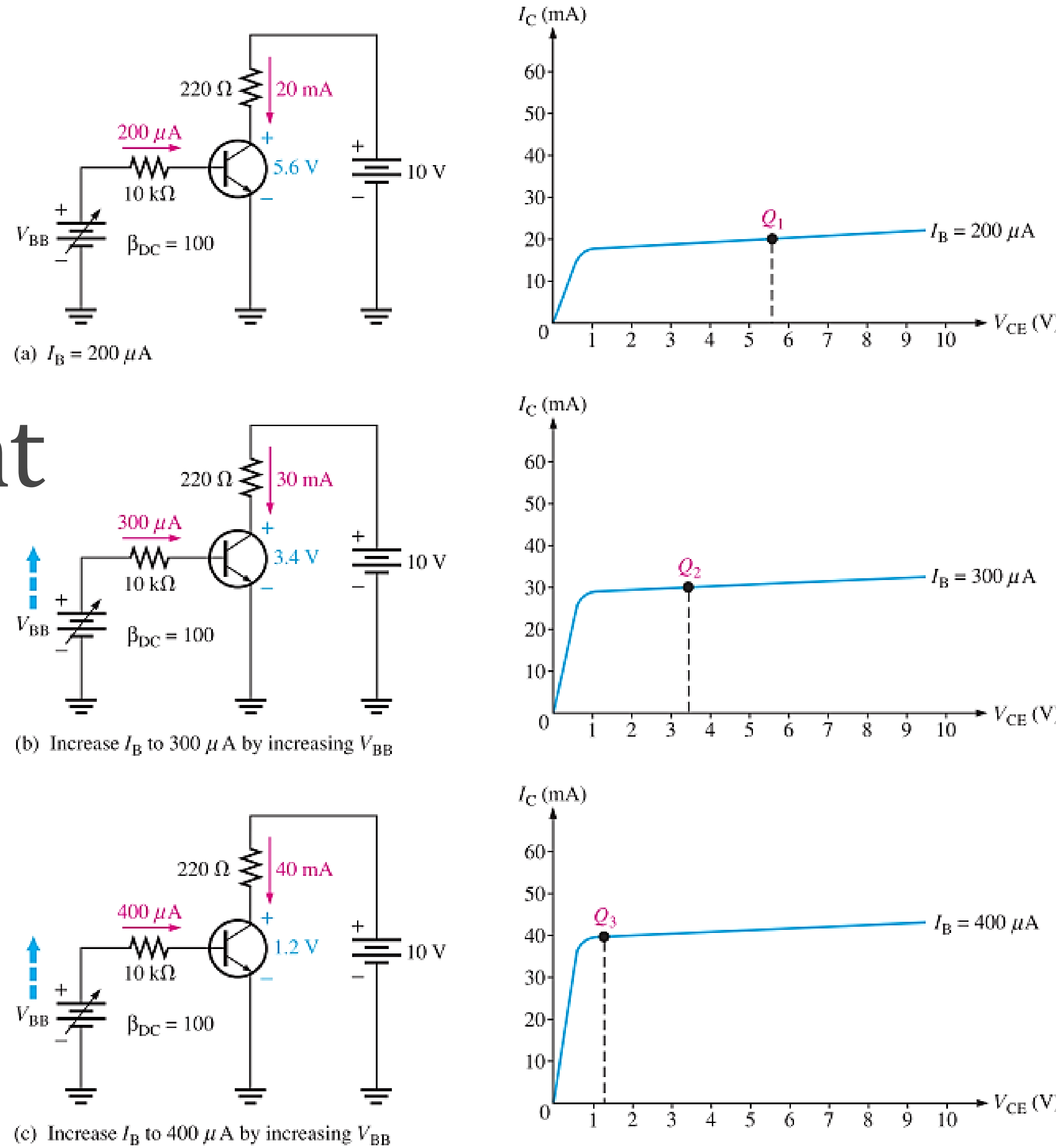


(b) Nonlinear operation: output voltage limited (clipped) by cutoff

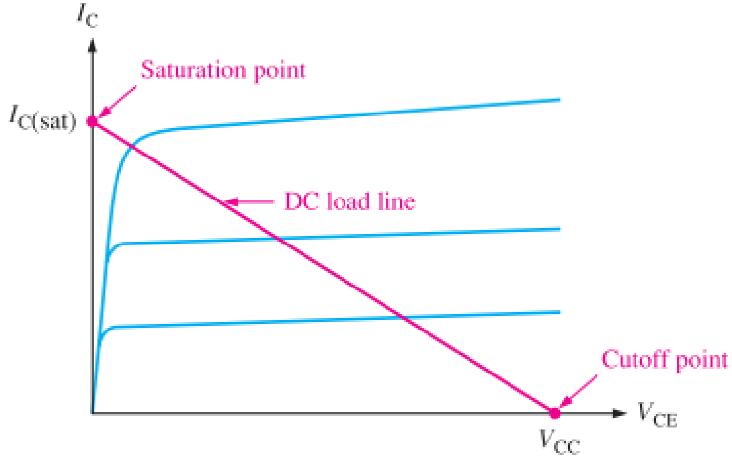


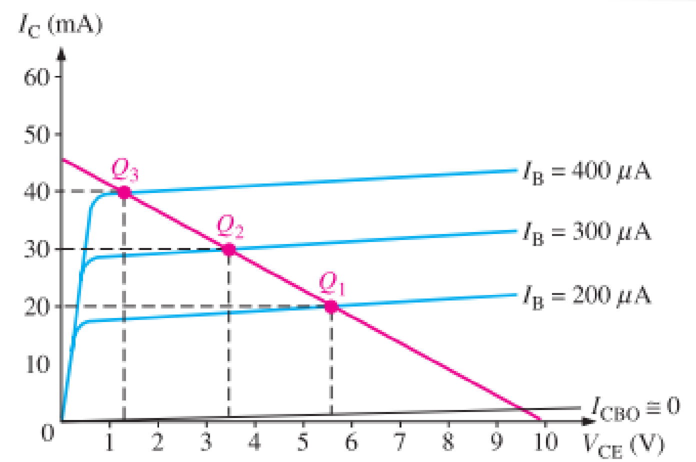
(c) Nonlinear operation: output voltage limited (clipped) by saturation

Q-point Adjustment

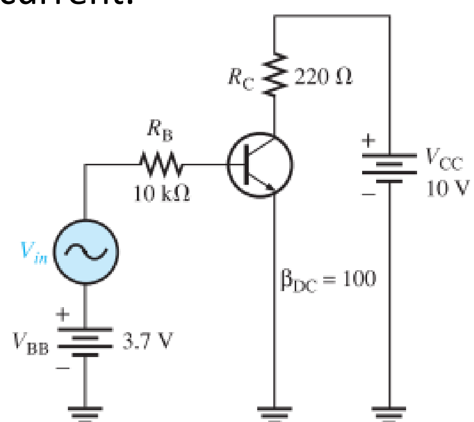


DC Load Line





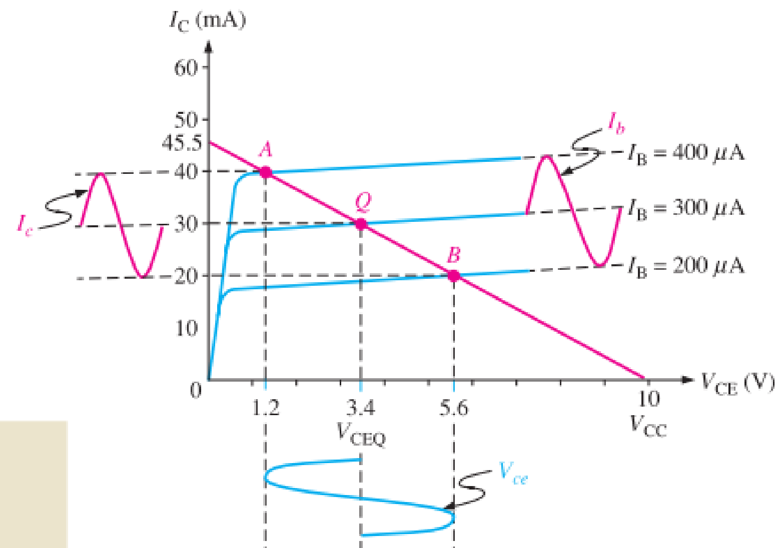
- Variations in collector current and collector-to-emitter voltage as a result of a variation in base current.



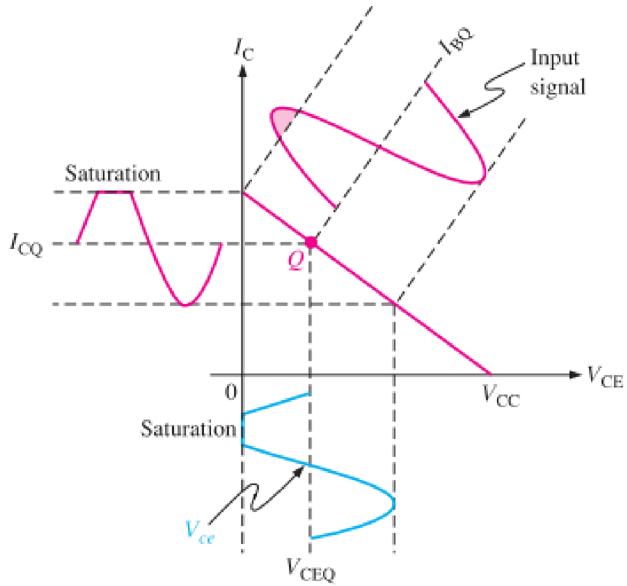
$$I_{BQ} = \frac{V_{BB} - 0.7\text{ V}}{R_B} = \frac{3.7\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = 300\ \mu\text{A}$$

$$I_{CQ} = \beta_{DC} I_{BQ} = (100)(300\ \mu\text{A}) = 30\text{ mA}$$

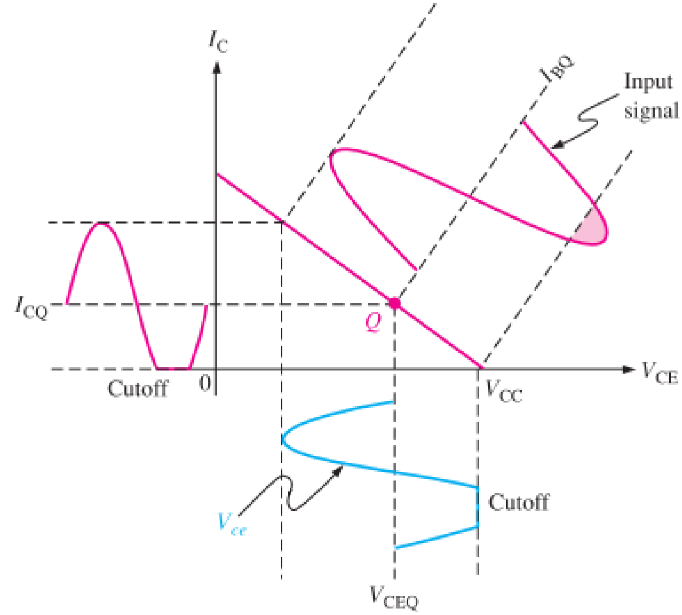
$$V_{CEQ} = V_{CC} - I_{CQ}R_C = 10\text{ V} - (30\text{ mA})(220\ \Omega) = 3.4\text{ V}$$



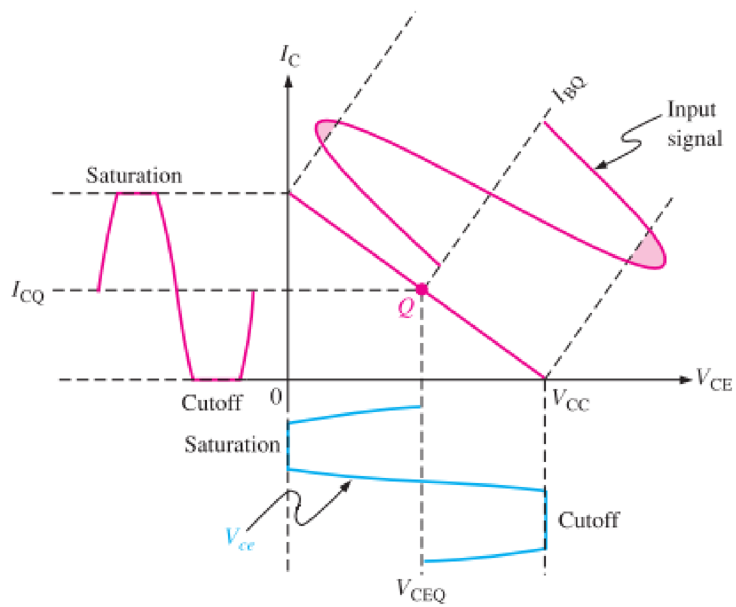
Waveform Distortion



(a) Transistor is driven into saturation because the Q-point is too close to saturation for the given input signal.

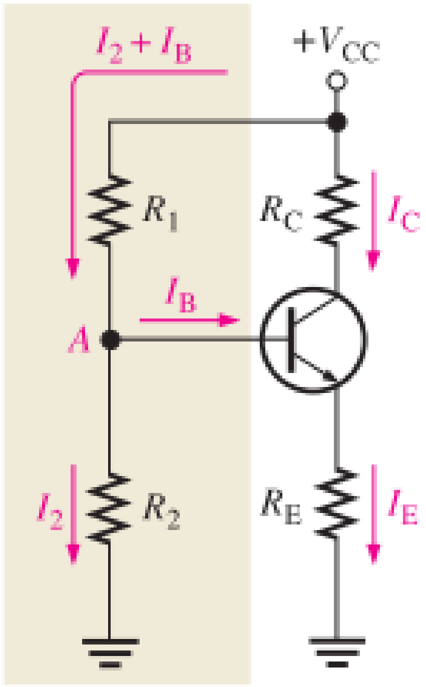


(b) Transistor is driven into cutoff because the Q-point is too close to cutoff for the given input signal.



(c) Transistor is driven into both saturation and cutoff because the input signal is too large.

VOLTAGE-DIVIDER BIAS



$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$$

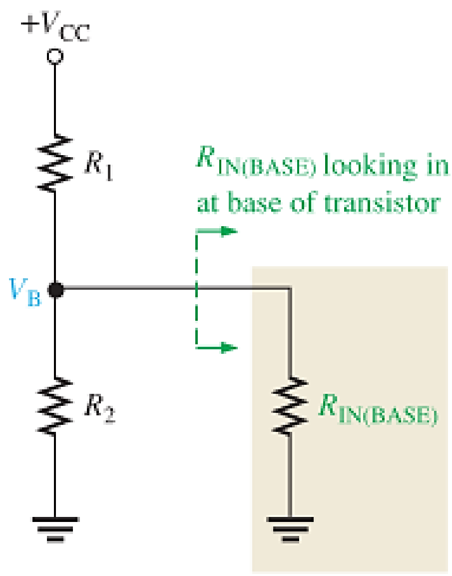
$$V_E = V_B - V_{BE}$$

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

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

$$V_{CE} = V_C - V_E$$

Loading Effects of Voltage-Divider Bias



Stiff:

$R_{IN(BASE)} \cong 10R_2$

$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$

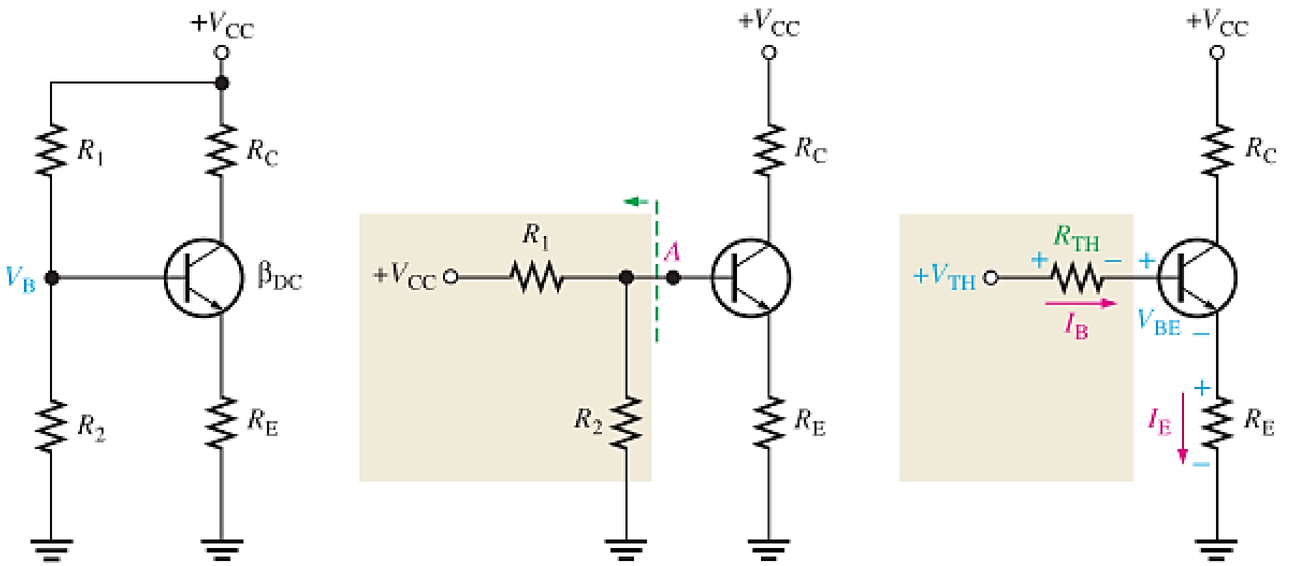
Not stiff:

$R_{IN(BASE)} < 10R_2$

$V_B = \left(\frac{R_2 \parallel R_{IN(BASE)}}{R_1 + R_2 \parallel R_{IN(BASE)}}\right)V_{CC}$

$$R_{IN(BASE)} = \frac{\beta_{DC}V_B}{I_E}$$

Thevenin's Theorem Applied to Voltage-Divider Bias



$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

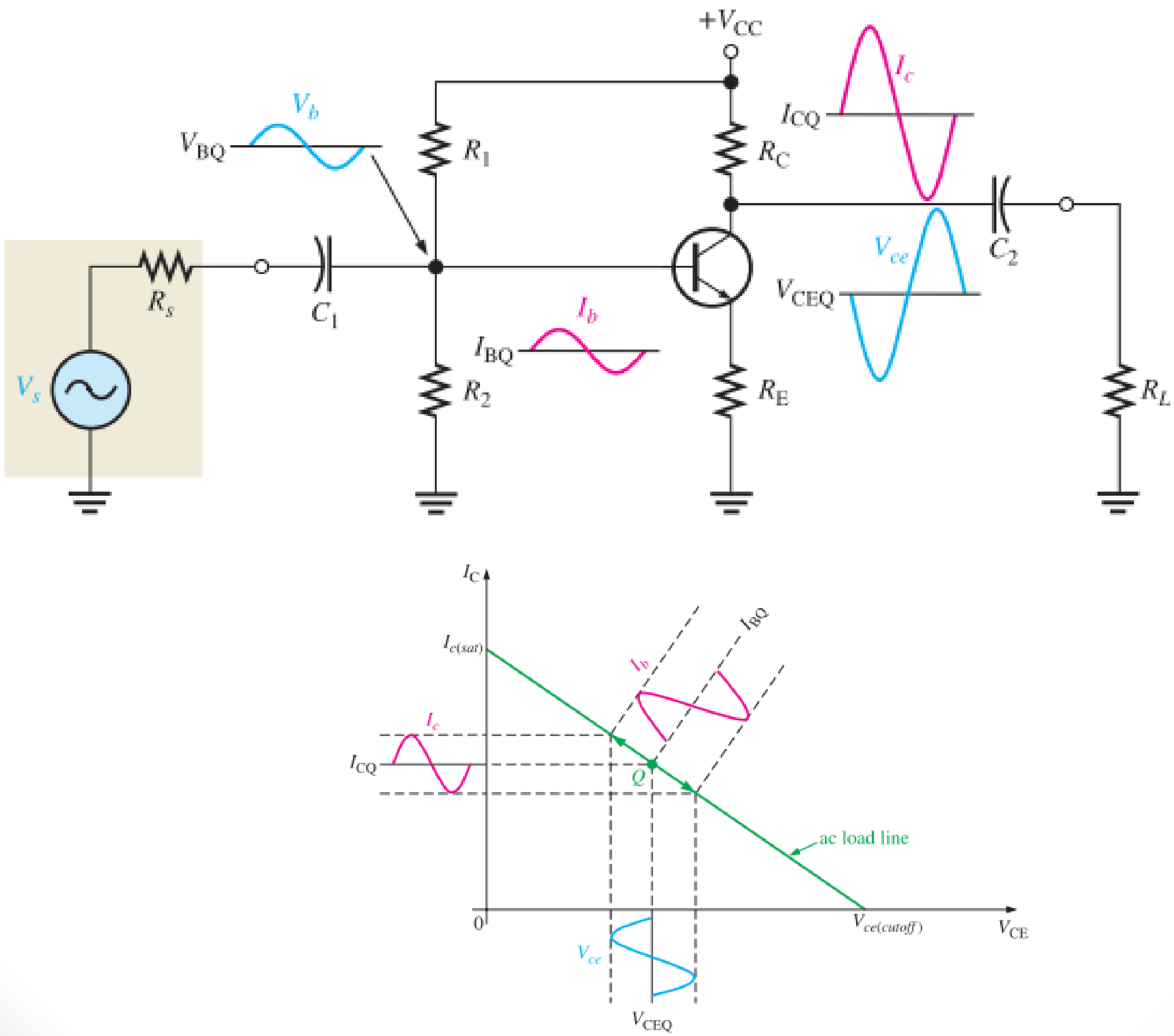
$$V_{TH} - V_{R_{TH}} - V_{BE} - V_{R_E} = 0$$

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

$$V_{TH} = I_E(R_E + R_{TH}/\beta_{DC}) + V_{BE}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}}$$

Linear Amplifier



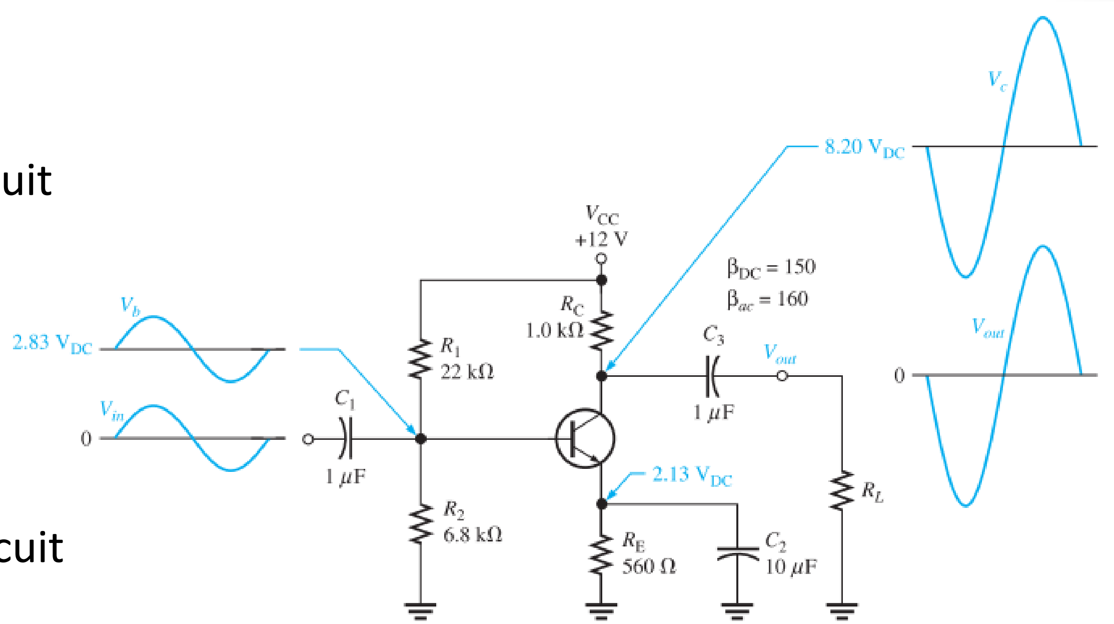
C.E. AC Analysis

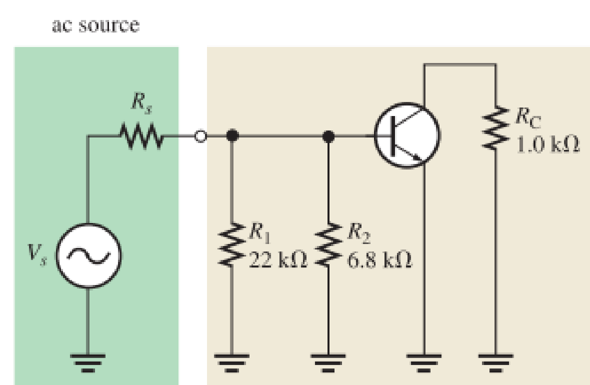
- **DC Analysis:**

Capacitors → Open Circuit
(See before)

- **AC Analysis:**

Capacitors → short Circuit
DC supply → ground





AC r-parameter Model

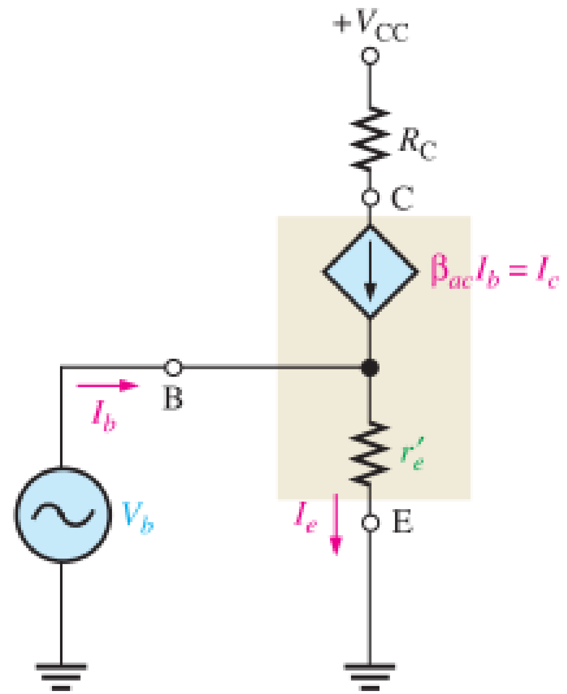
Input resistance $R_{in(base)} = \beta_{ac} r'_e$

Output resistance $R_{out} \cong R_C$

Voltage gain $A_v = \frac{R_C}{r'_e}$

Current gain $A_i = \frac{I_c}{I_s}$

Power gain $A_p = A'_v A_i$

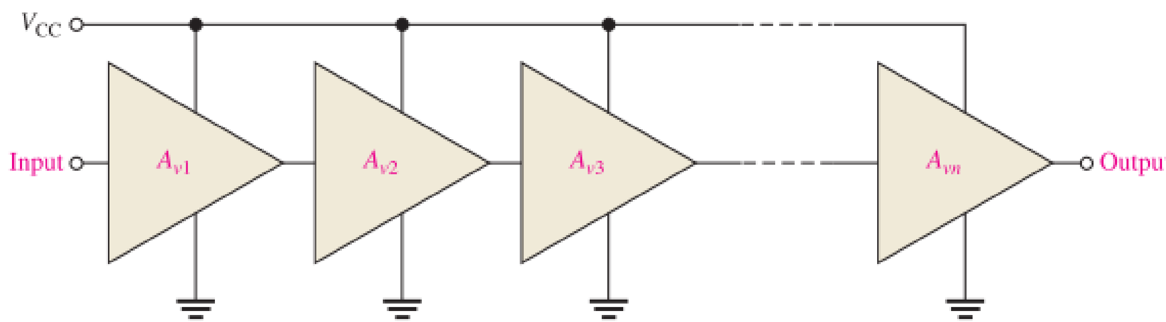


Multistage Amplifier

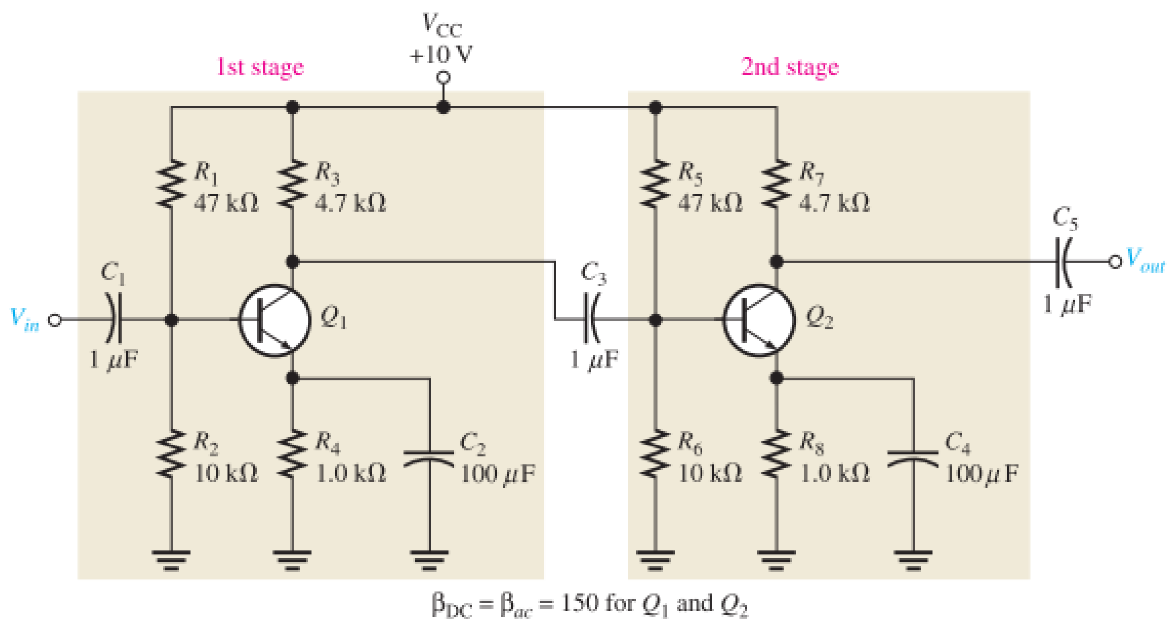
$$A'_v = A_{v1}A_{v2}A_{v3}\ldots A_{vn}$$

$$A_{v(\mathrm{dB})} = 20\log A_v$$

$$A'_{v(\mathrm{dB})} = A_{v1(\mathrm{dB})} + A_{v2(\mathrm{dB})} + \cdots + A_{vn(\mathrm{dB})}$$

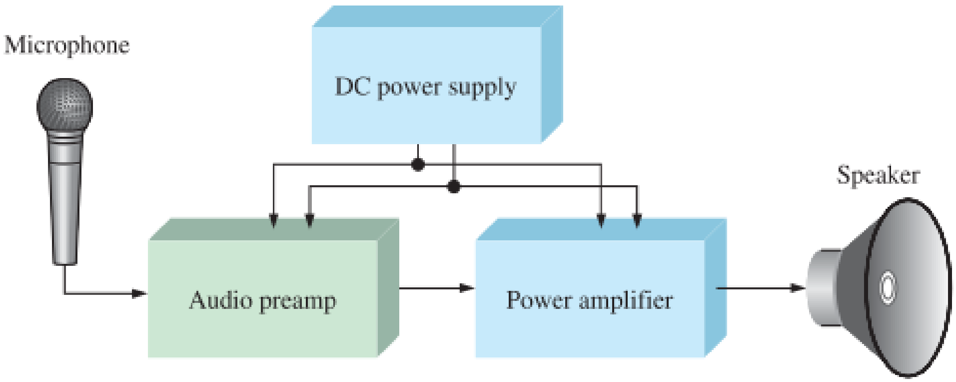


- A two-stage common-emitter amplifier.

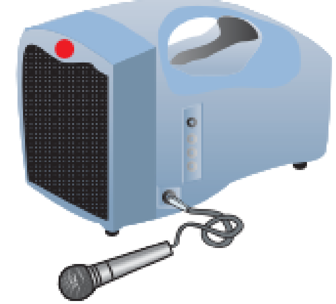


Project II

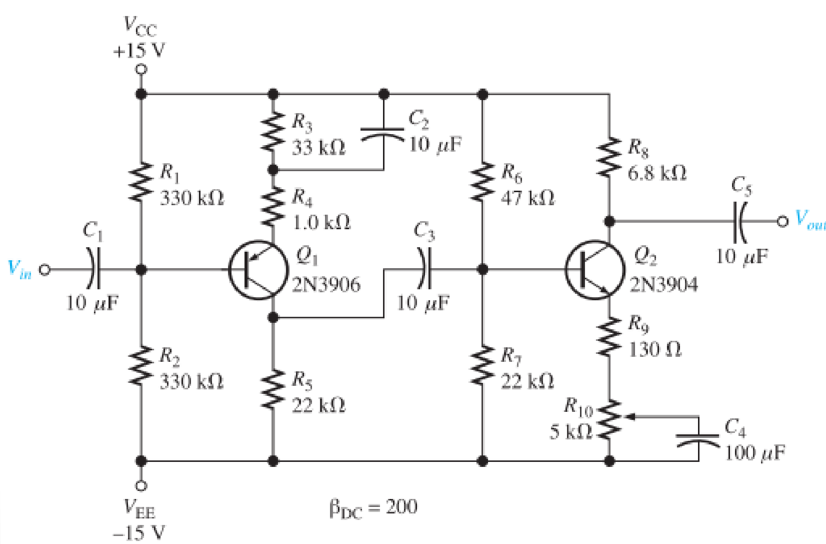
Audio Preamplifier for PA System



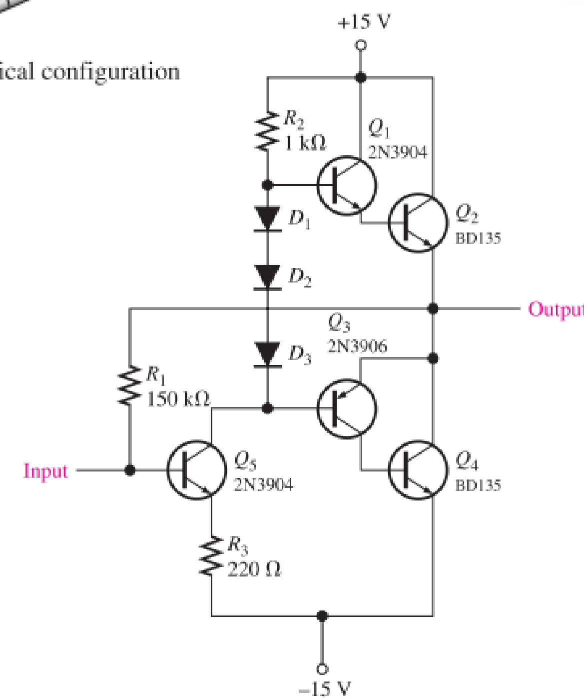
(a) PA system block diagram



(b) Physical configuration



Pre AMP, chapter 4



Class AB Power AMP, chapter 7

- For more details, refer to:
  - Chapters 4-6, T. Floyd, **Electronic Devices and Circuit Theory**, 11th edition, Prentice Hall.
- The lecture is available online at:
  - *http://bu.edu.eg/staff/ahmad.elbanna-courses/12136*
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg