Transistors

Course Content

Transistors:

Transistor configurations: CB, CE and CC; Transistor parameters: alpha, beta and gamma, working of transistor as a switch, Amplifier.

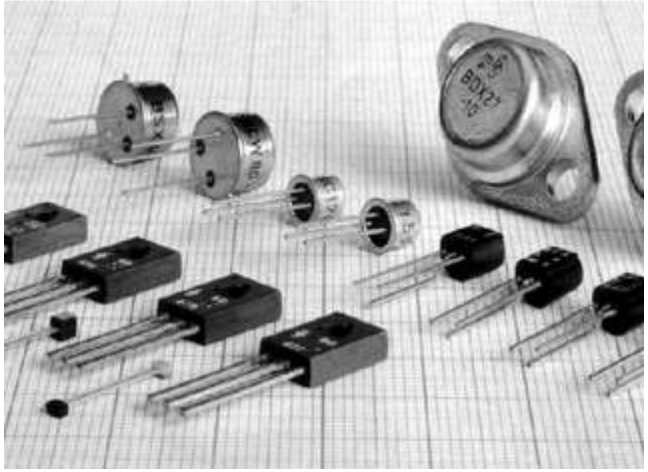
Bipolar Transistor Configurations

- At the end of this lecture, student will be able to :
  - Define transistor
  - Explain the working of transistor
  - Explain the transistor configurations
  - Draw the input output characteristics of BJT

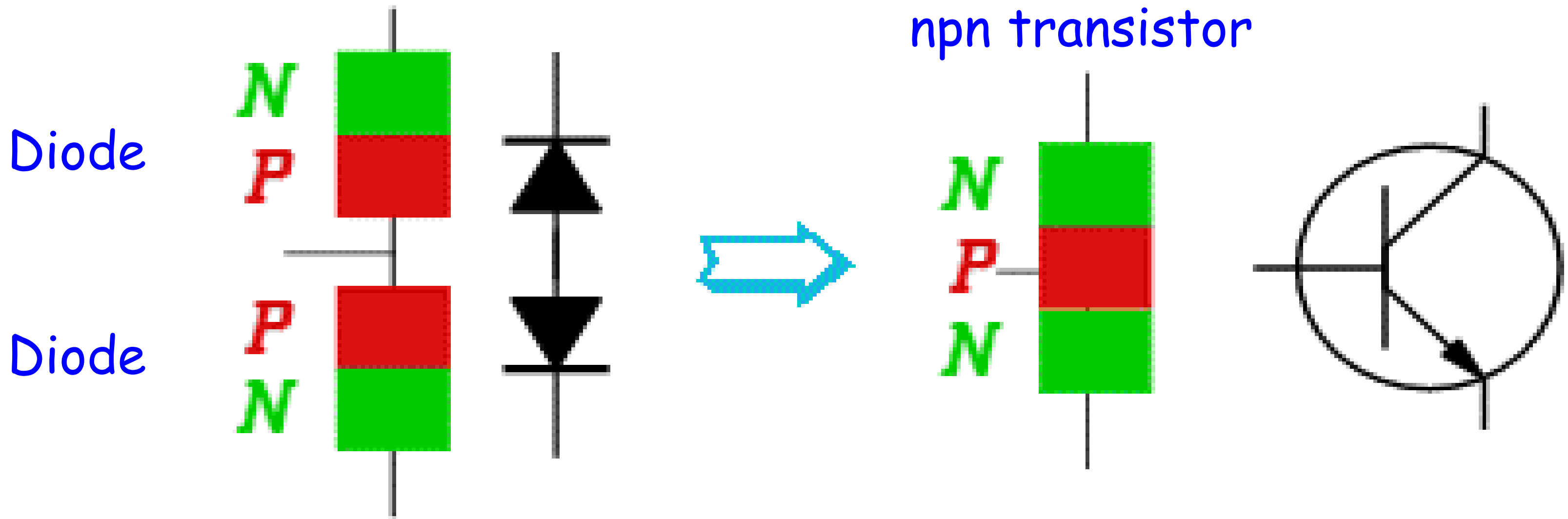
Topics

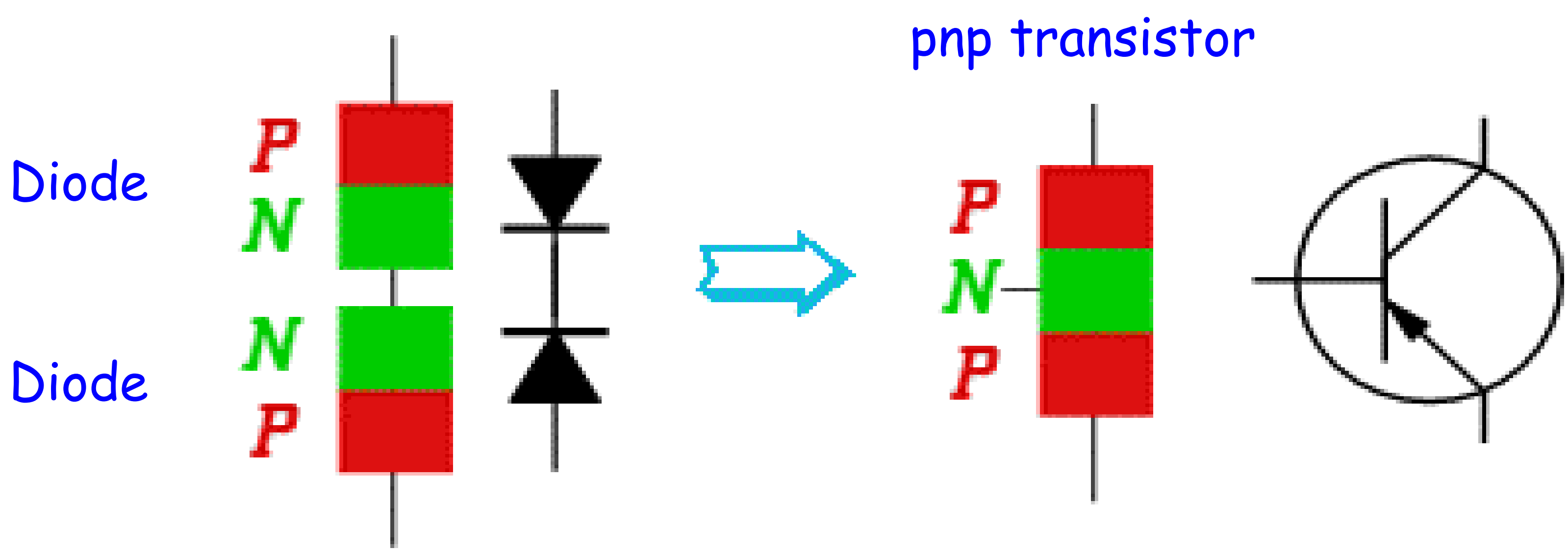
- Introduction
- An Overview of Bipolar Transistors
- Bipolar Transistor Operation
- Bipolar Transistor configurations
- Bipolar Transistor Characteristics

Introduction to BJT

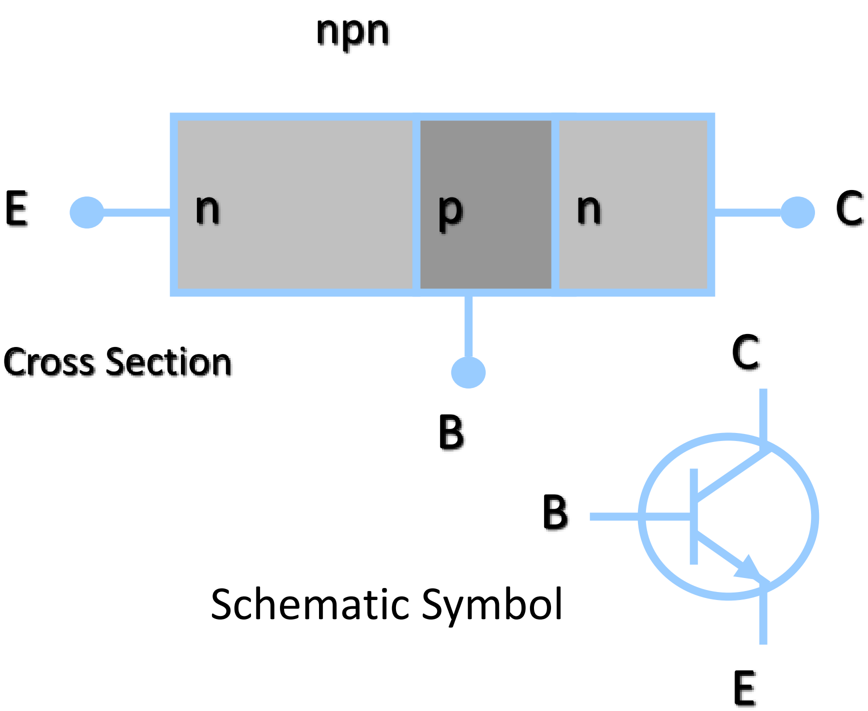


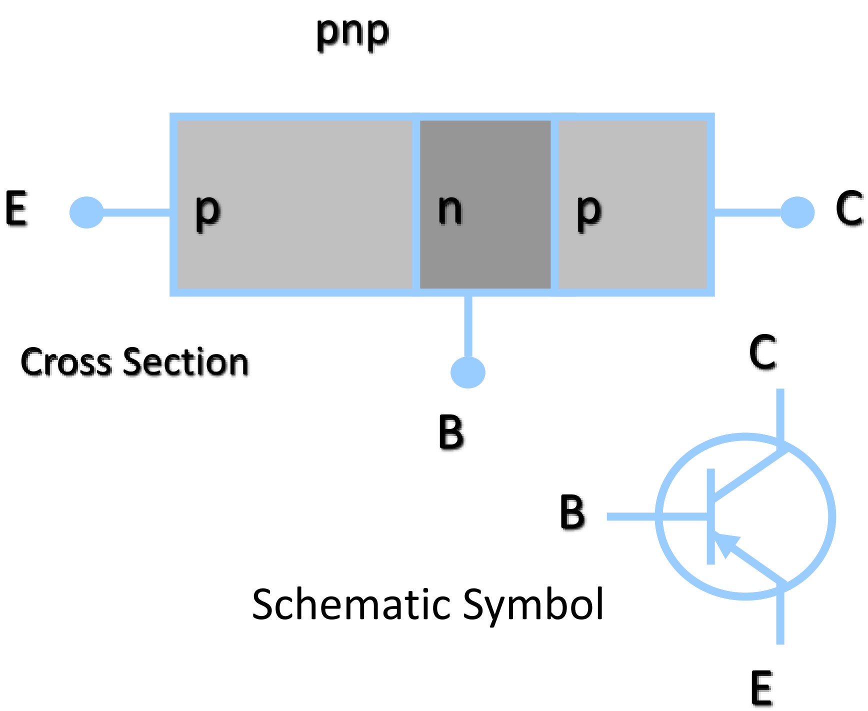
Basic models of BJT





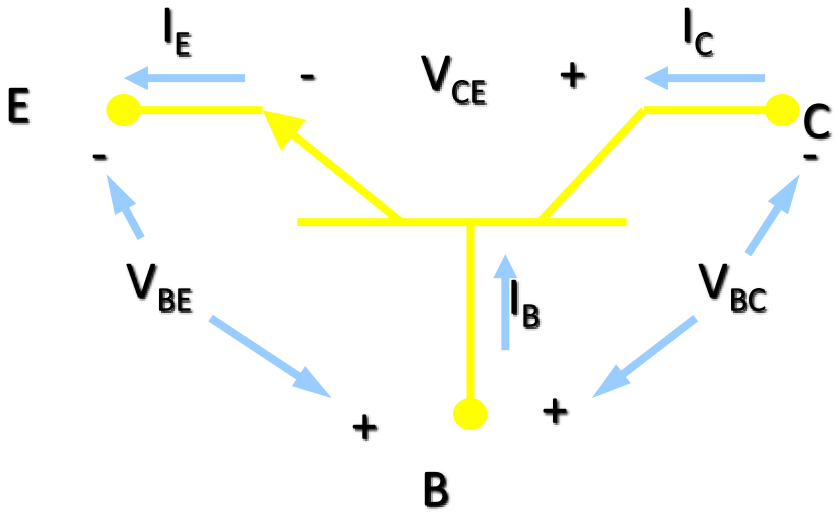
Transistor Structure





- Collector doping is usually ~ 10^9
- Base doping is slightly higher ~ $10^{10} – 10^{11}$
- Emitter doping is much higher ~ 10^{17}

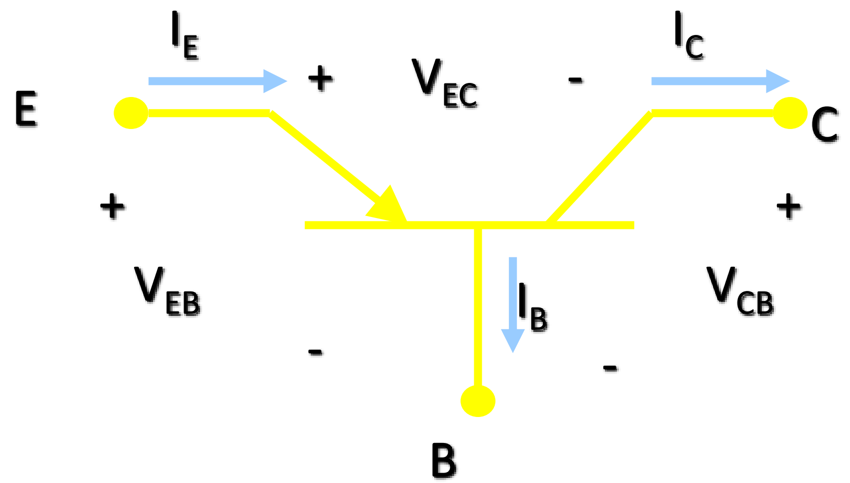
BJT Current and Voltage - Equations



n p n

$I_E = I_B + I_C$

$V_{CE} = -V_{BC} + V_{BE}$

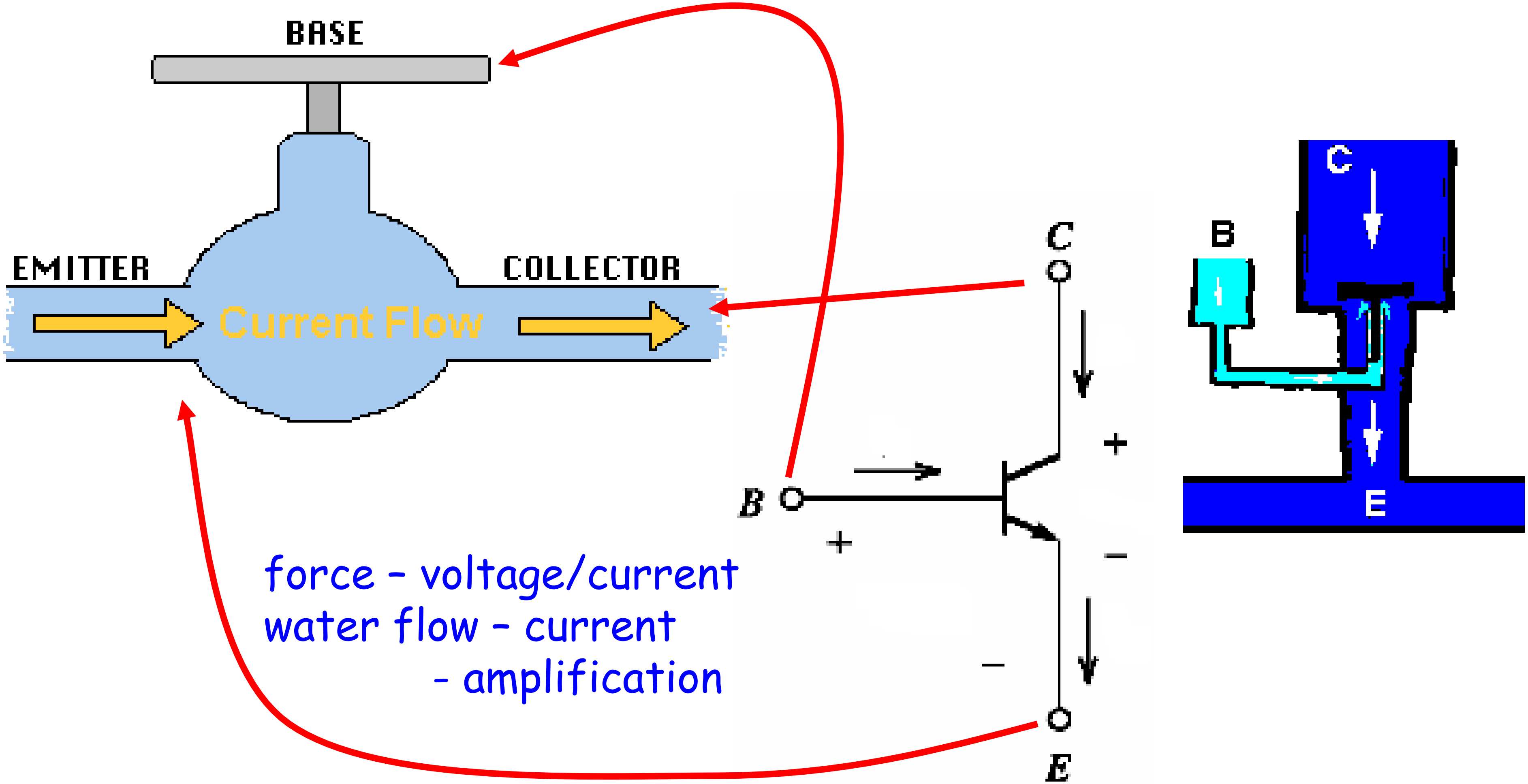


p n p

$I_E = I_B + I_C$

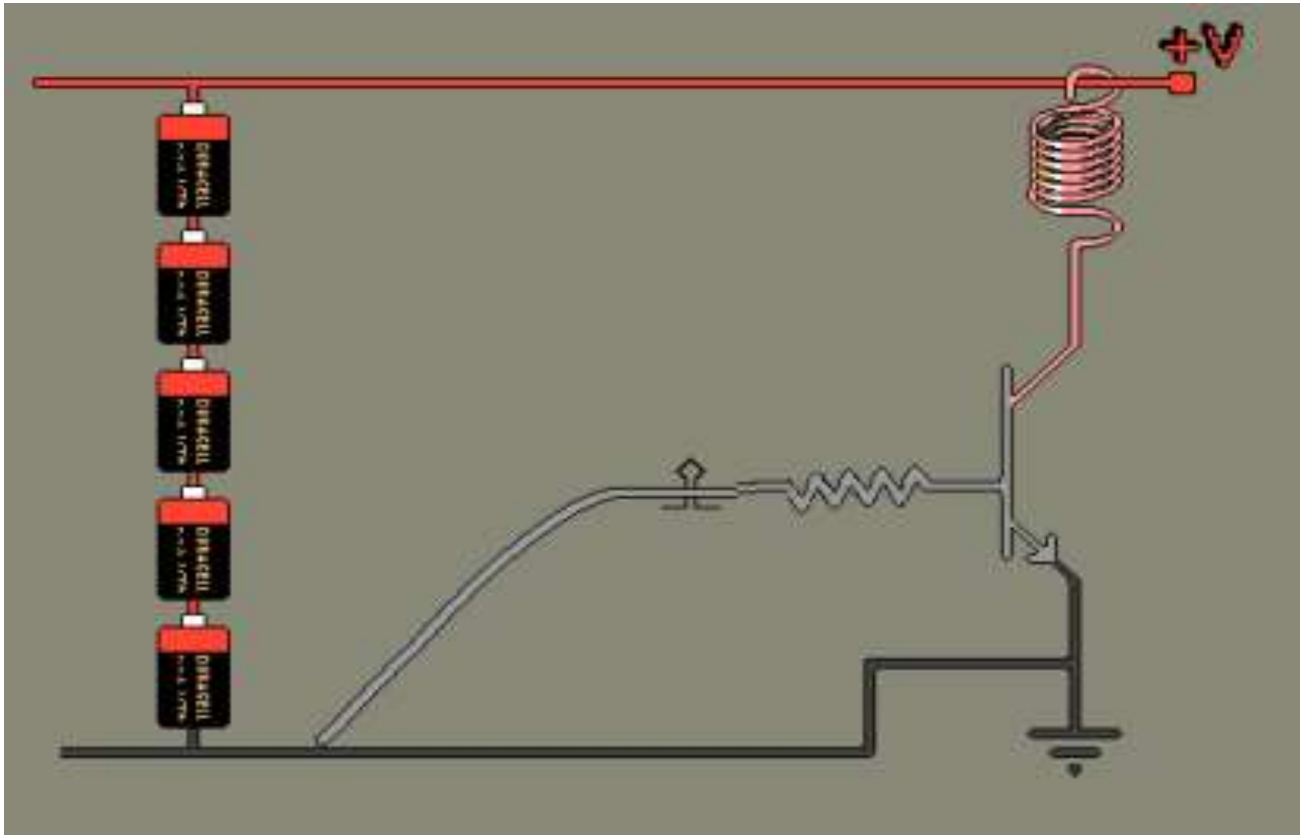
$V_{EC} = V_{EB} - V_{CB}$

Understanding of BJT



force – voltage/current
water flow – current
- amplification

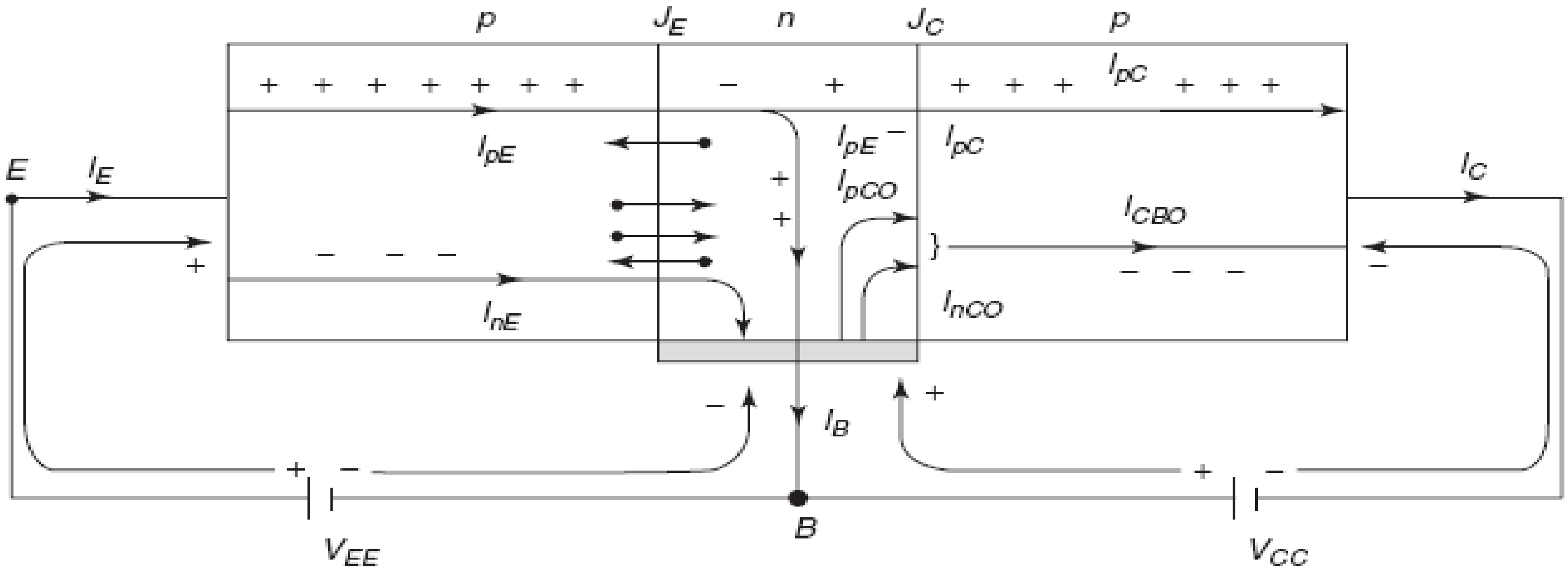
BJT Operation



Voltage to current convertor in the base circuit

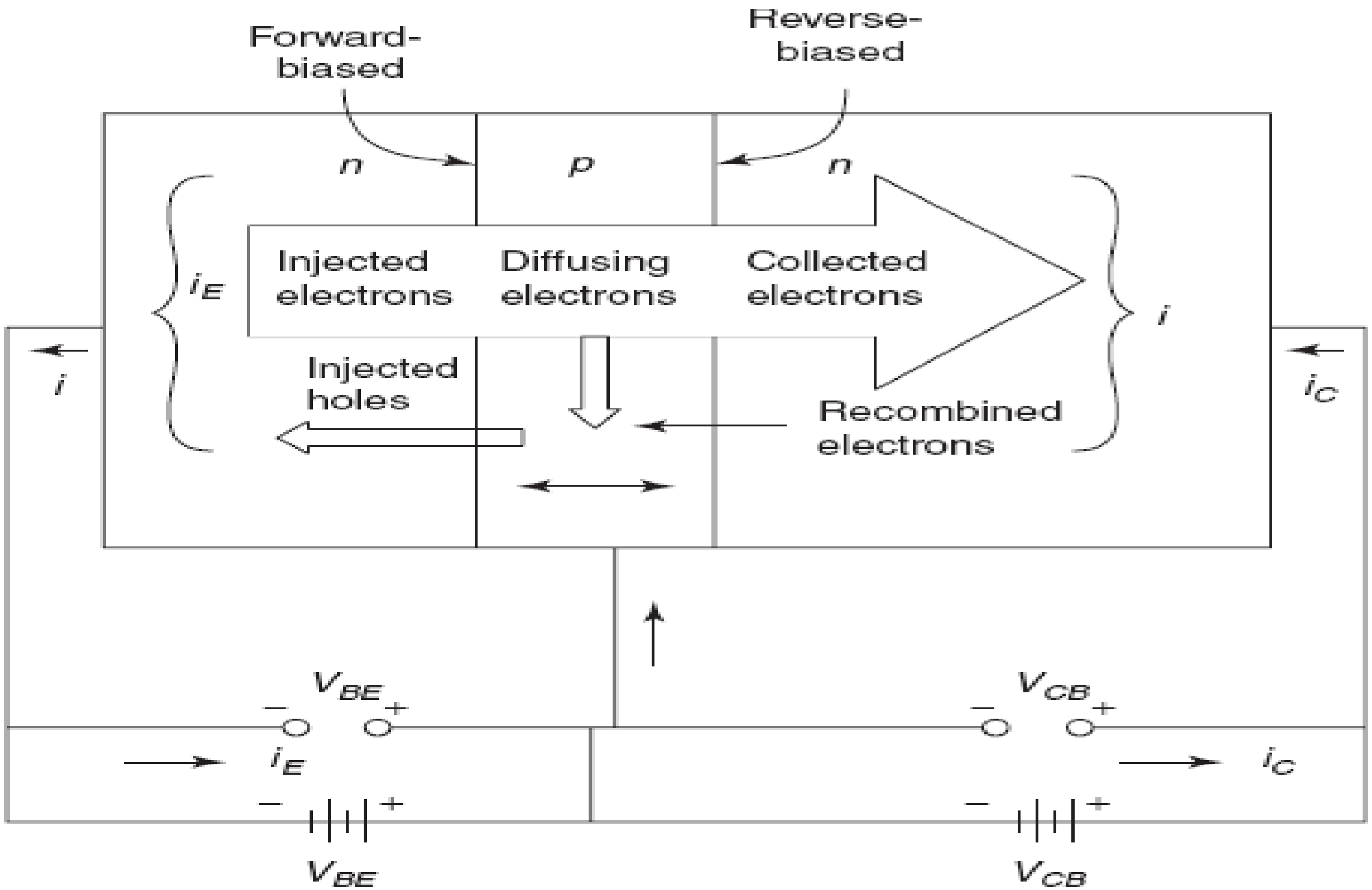
Transistor Current Components

- **Current Components in *p–n–p Transistor***

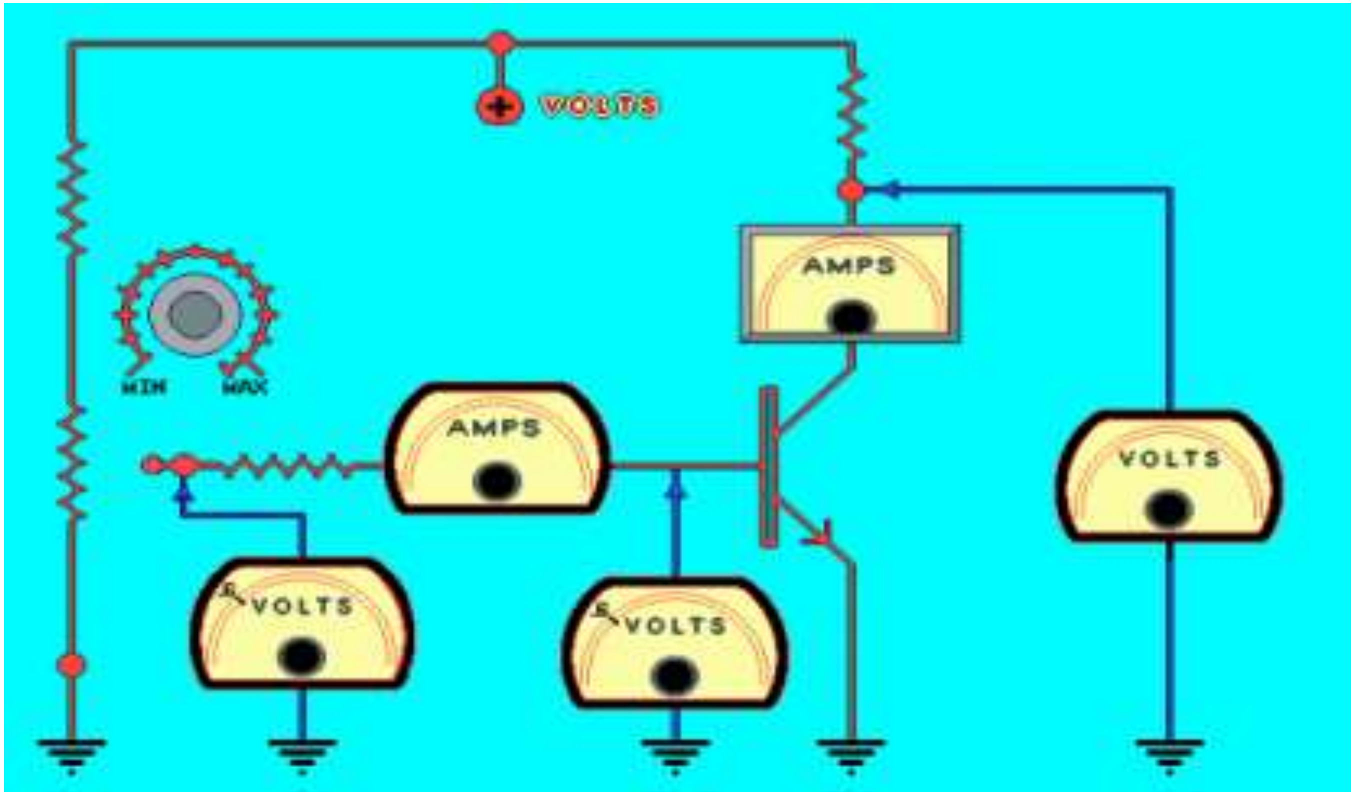


Transistor Current Components continued..

❖ **Current Components in an *n–p–n Transistor***



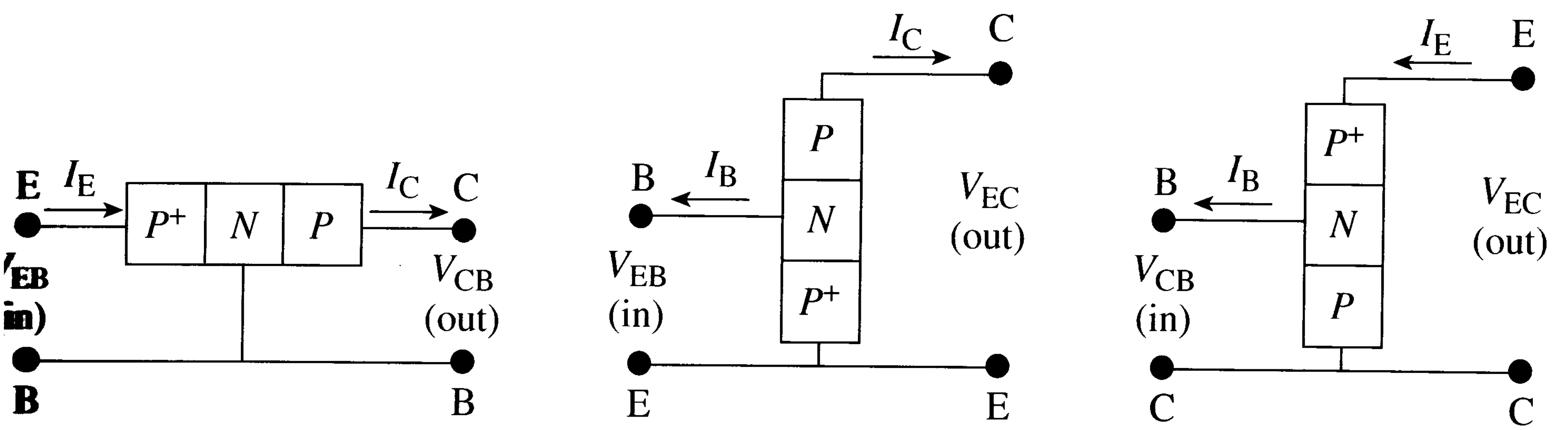
How Transistor Works



Bipolar Transistor Operation

- Consider npn transistors
  - pnp devices are similar but with different polarities of voltage and currents
  - when using npn transistors
    - collector is normally more positive than the emitter
    - V_{CE} might be a few volts
    - device resembles two back-to-back diodes – but has very different characteristics
    - with the base open-circuit negligible current flows from the collector to the emitter

BJT configurations



(a) Common base

(b) Common emitter

(c) Common collector

BJT configurations Continued..

Biasing the transistor refers to applying voltages to the transistor to achieve certain operating conditions.

1. Common-Base Configuration (CB) : input = V_{EB} & I_E
   output = V_{CB} & I_C

2. Common-Emitter Configuration (CE): input = V_{BE} & I_B
   output= V_{CE} & I_C

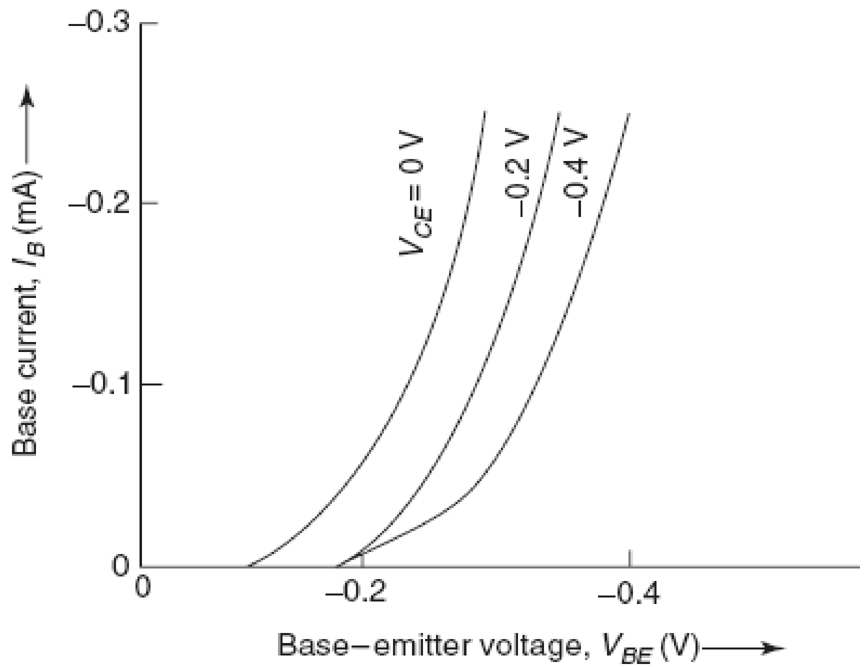
3. Common-Collector Configuration (CC) :input = V_{BC} & I_B
   (Also known as Emitter follower) output = V_{EC} & I_E

BJT Biasing Modes

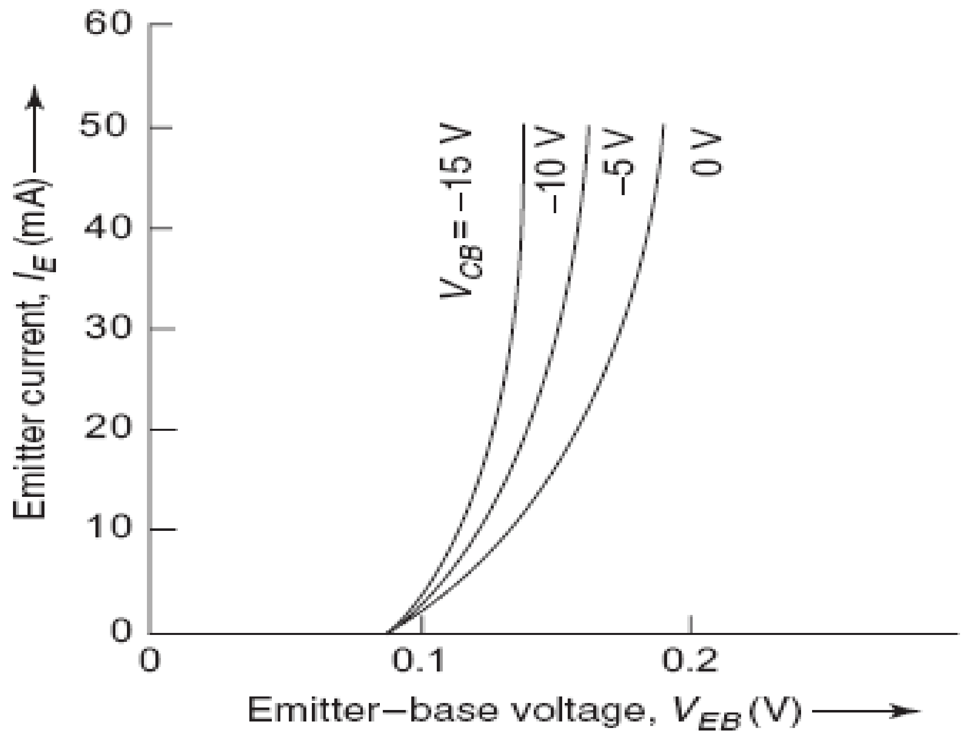
Bias Mode	**E-B Junction**	**C-B Junction**
Saturation	Forward	Forward
Active	**Forward**	**Reverse**
Inverted	Reverse	Forward
Cutoff	Reverse	Reverse

Transistor Characteristics

Input Characteristics

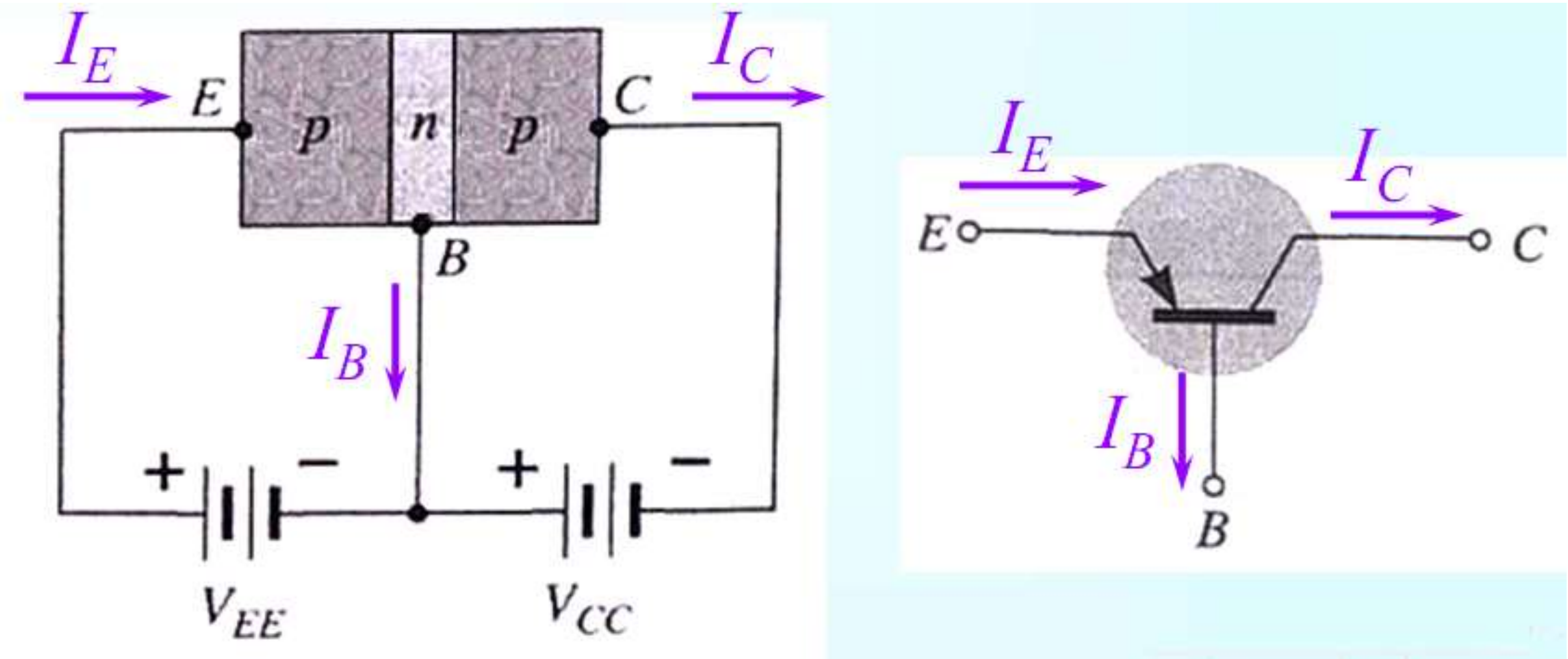


Input characteristics in the CE mode

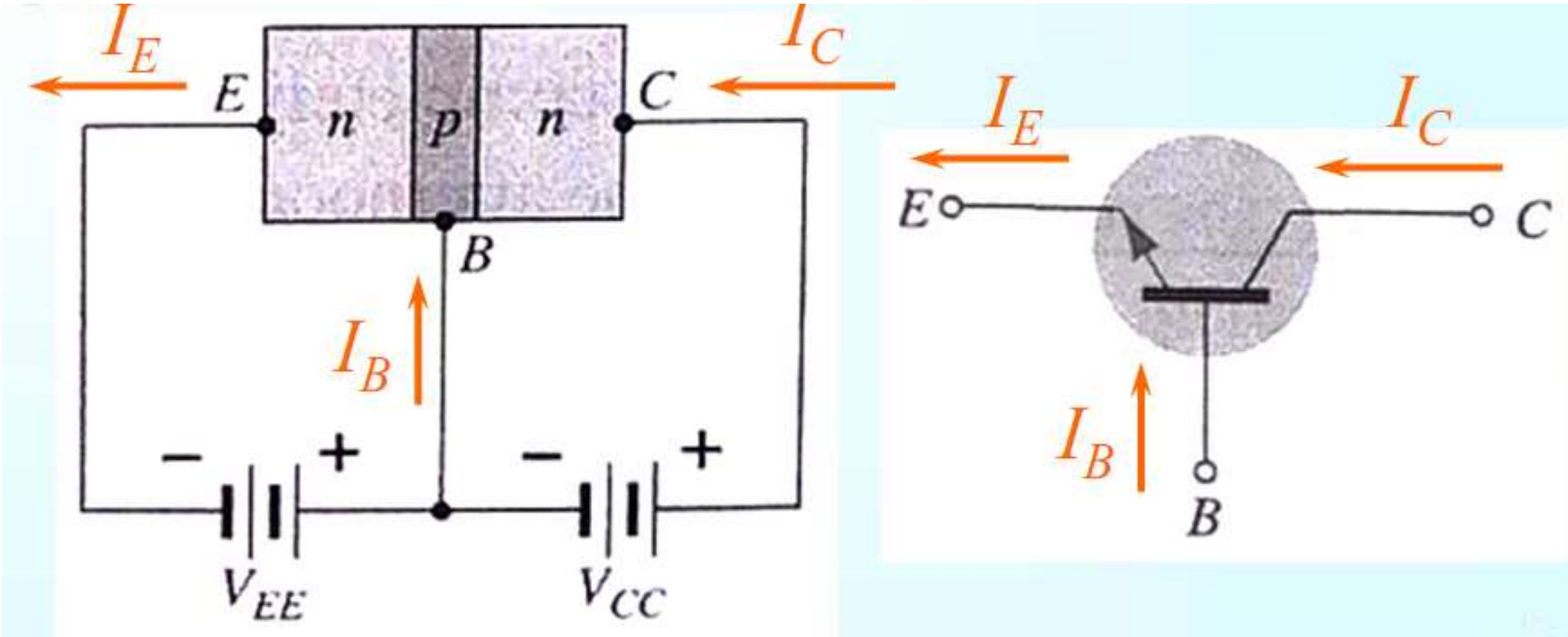


Input characteristics in the CB mode

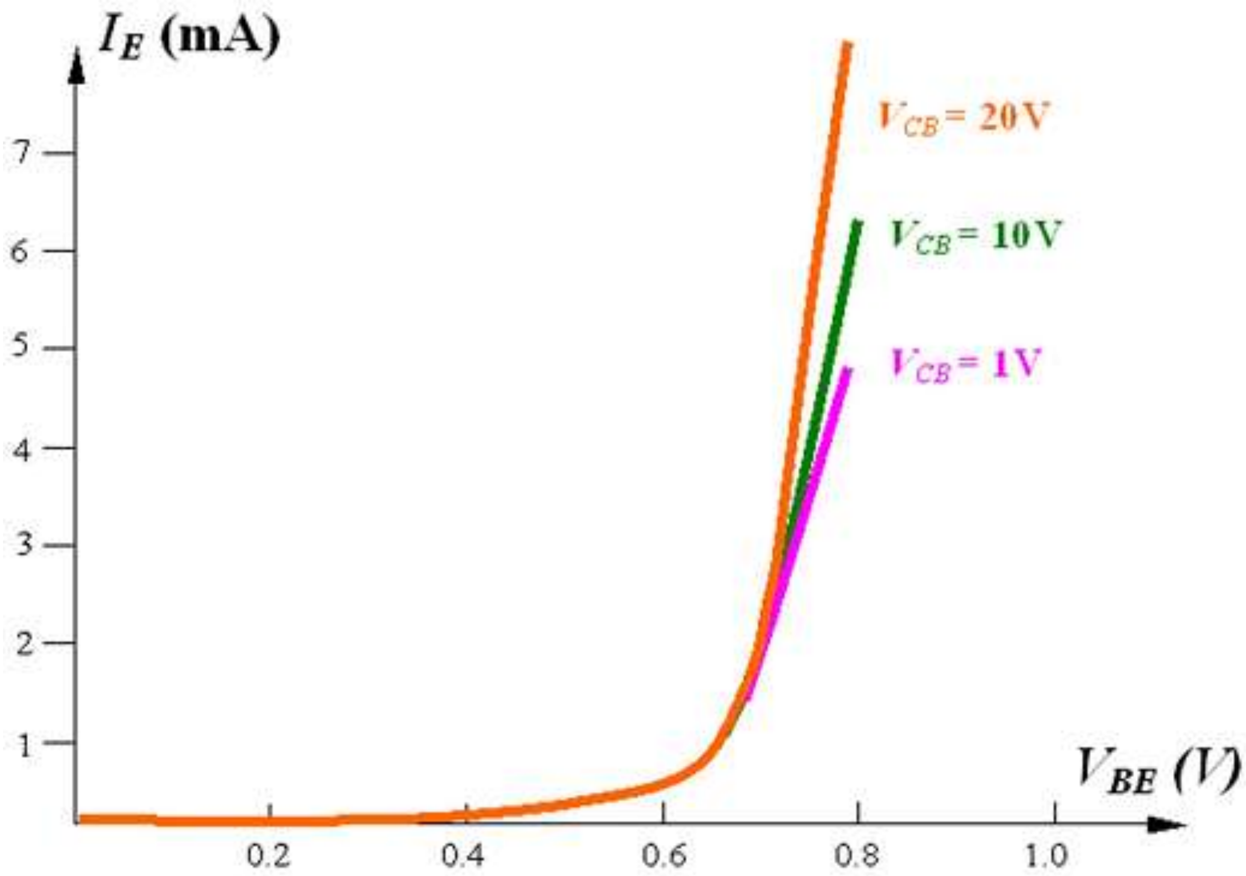
Common-Base Configuration of pnp Transistor



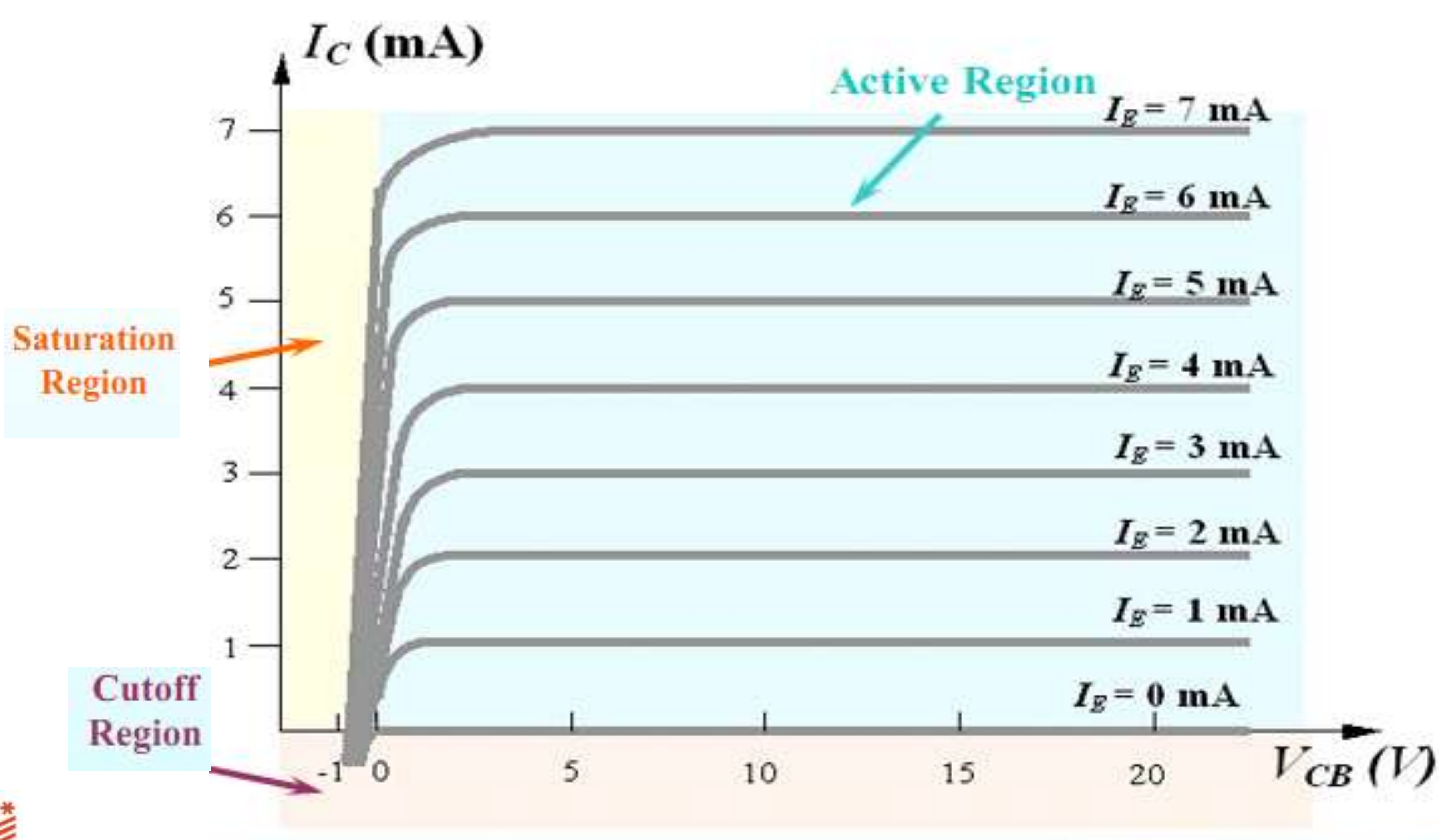
Common-Base Configuration of npn transistor



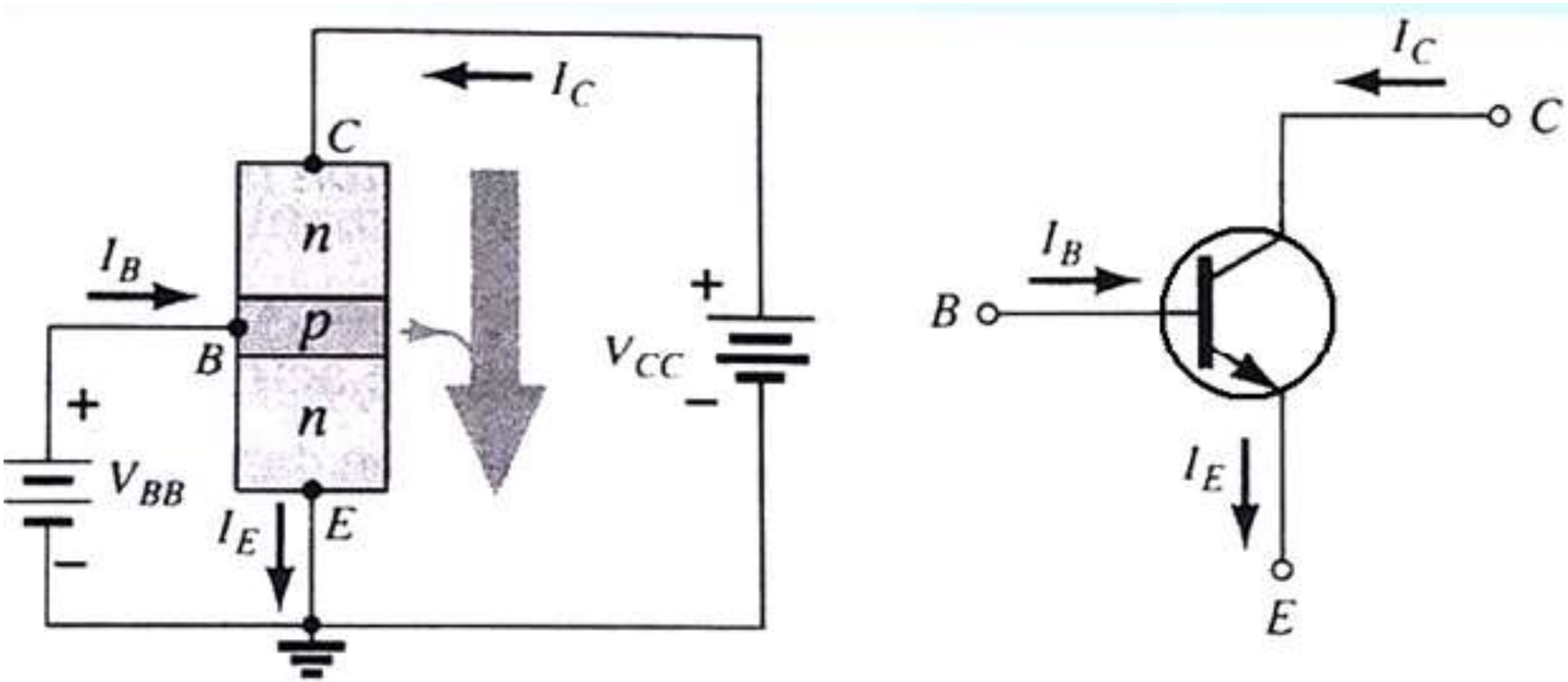
Common Base Input Characteristics



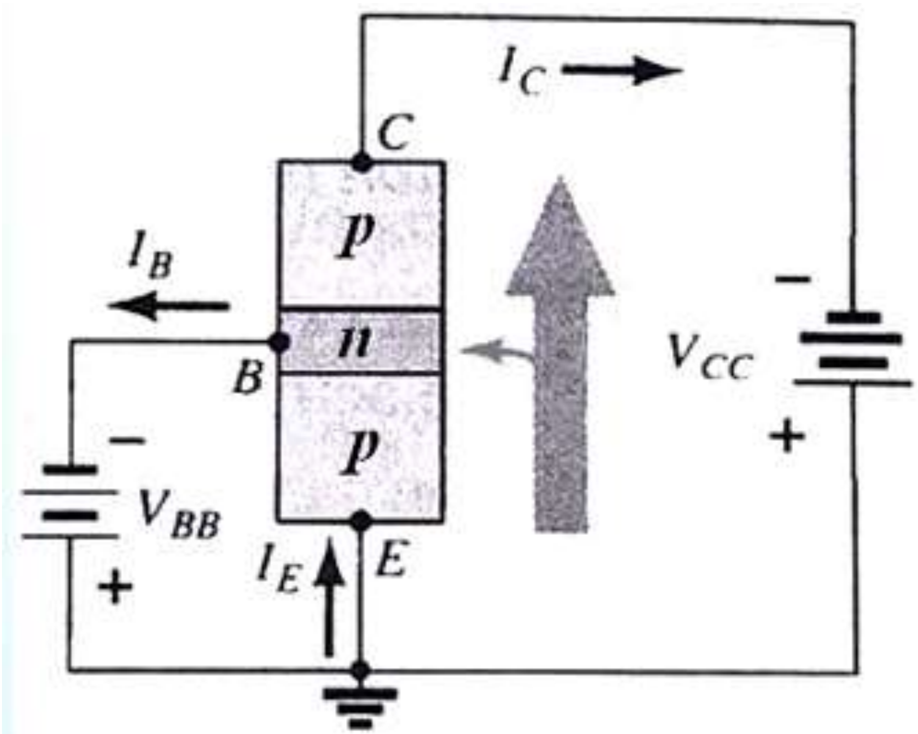
Common Base Output Characteristics

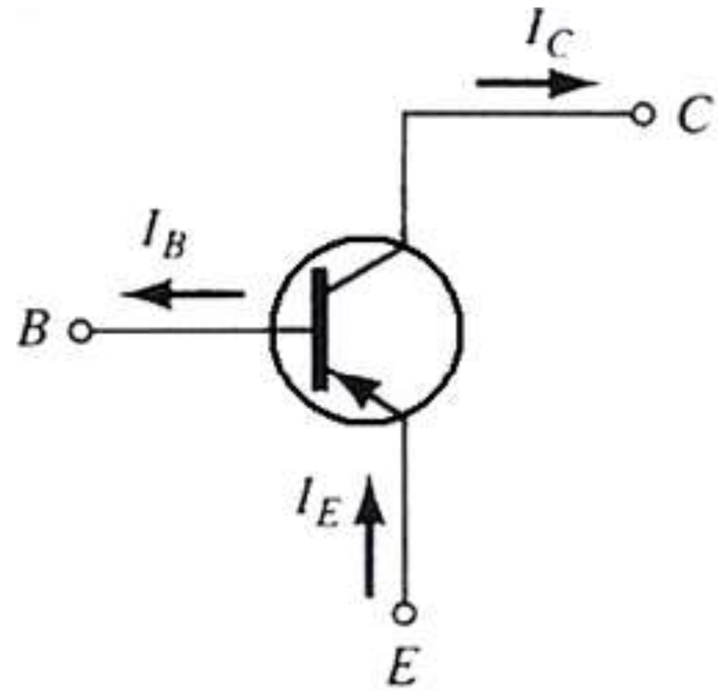


Common-Emitter Configuration of npn Transistor

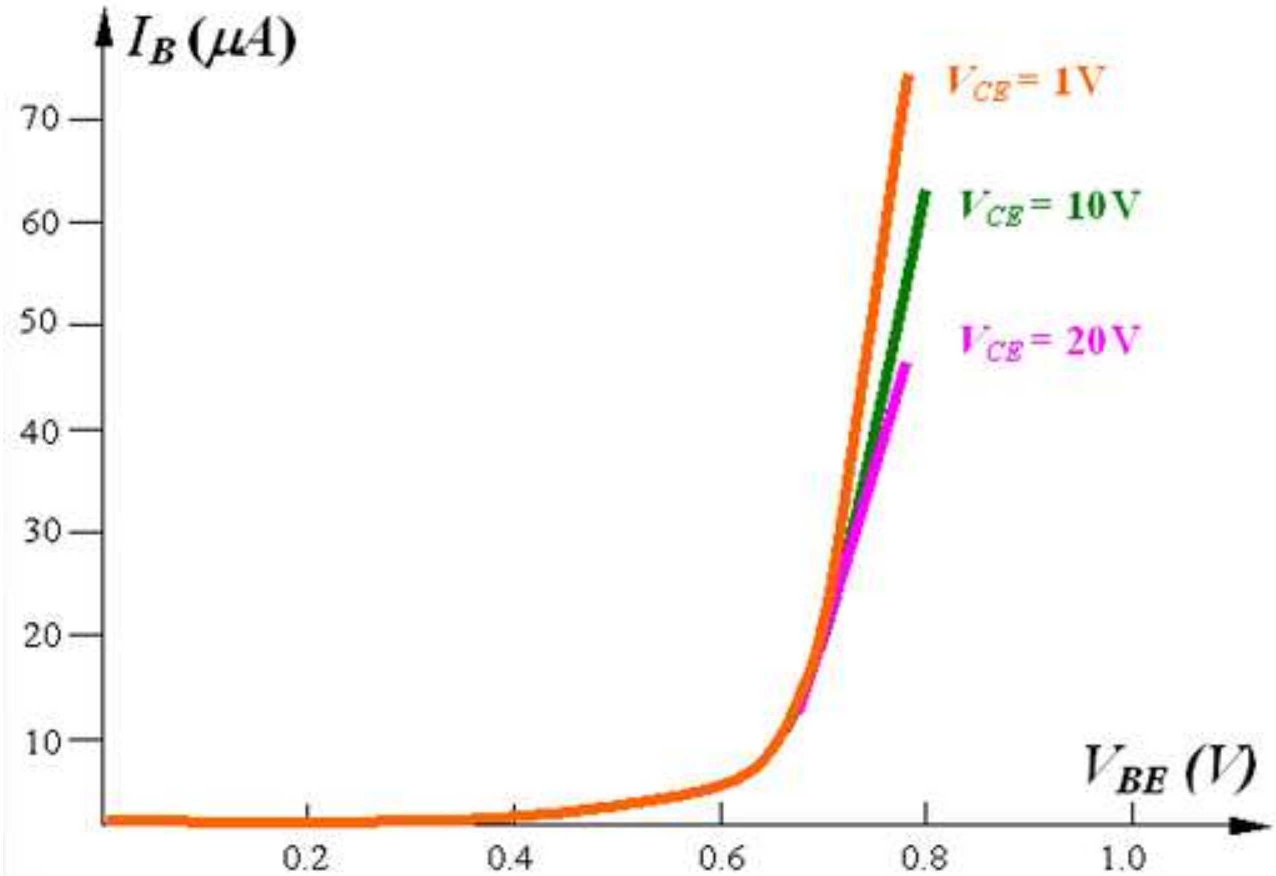


Common-Emitter Configuration of pnp Transistor

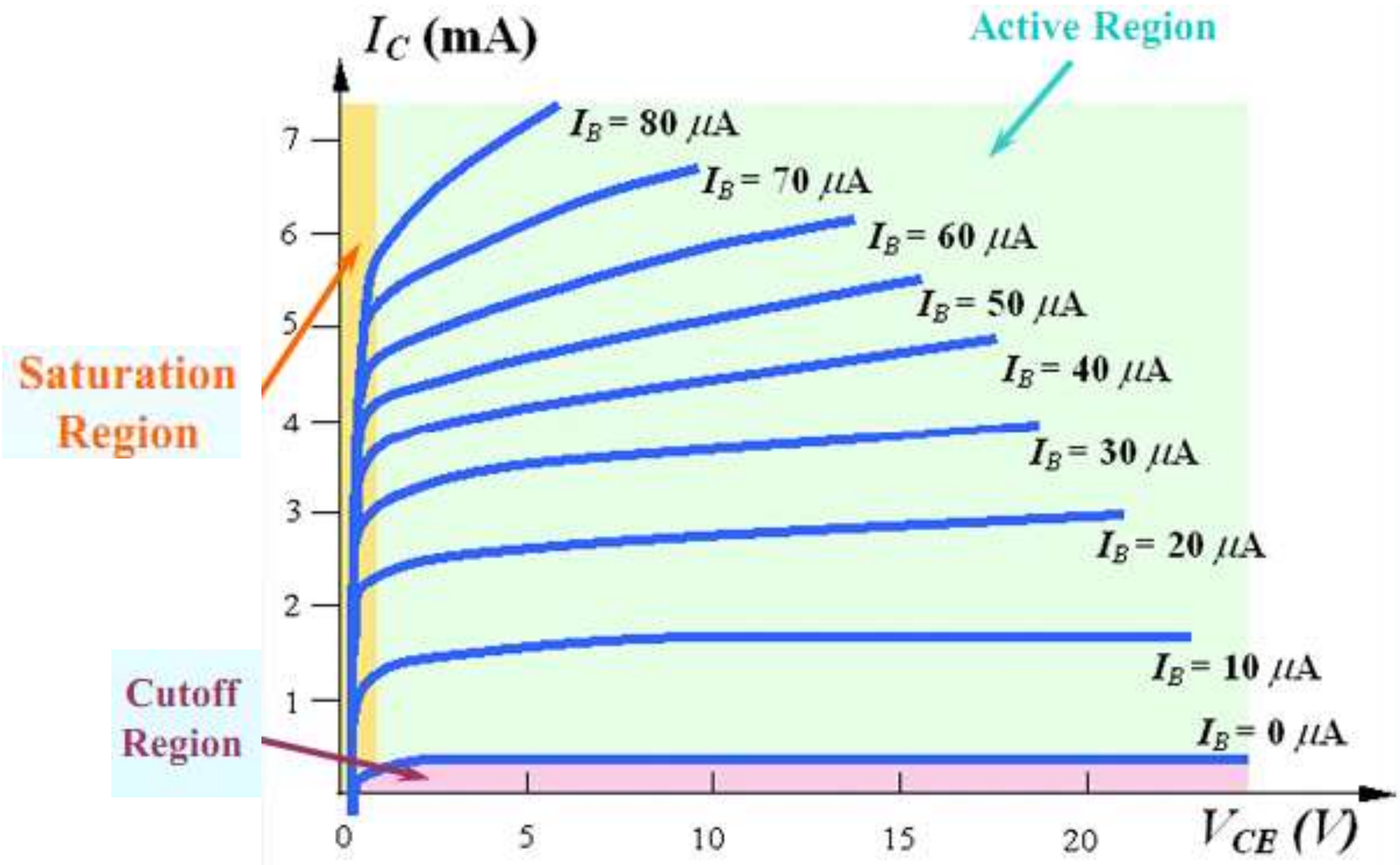




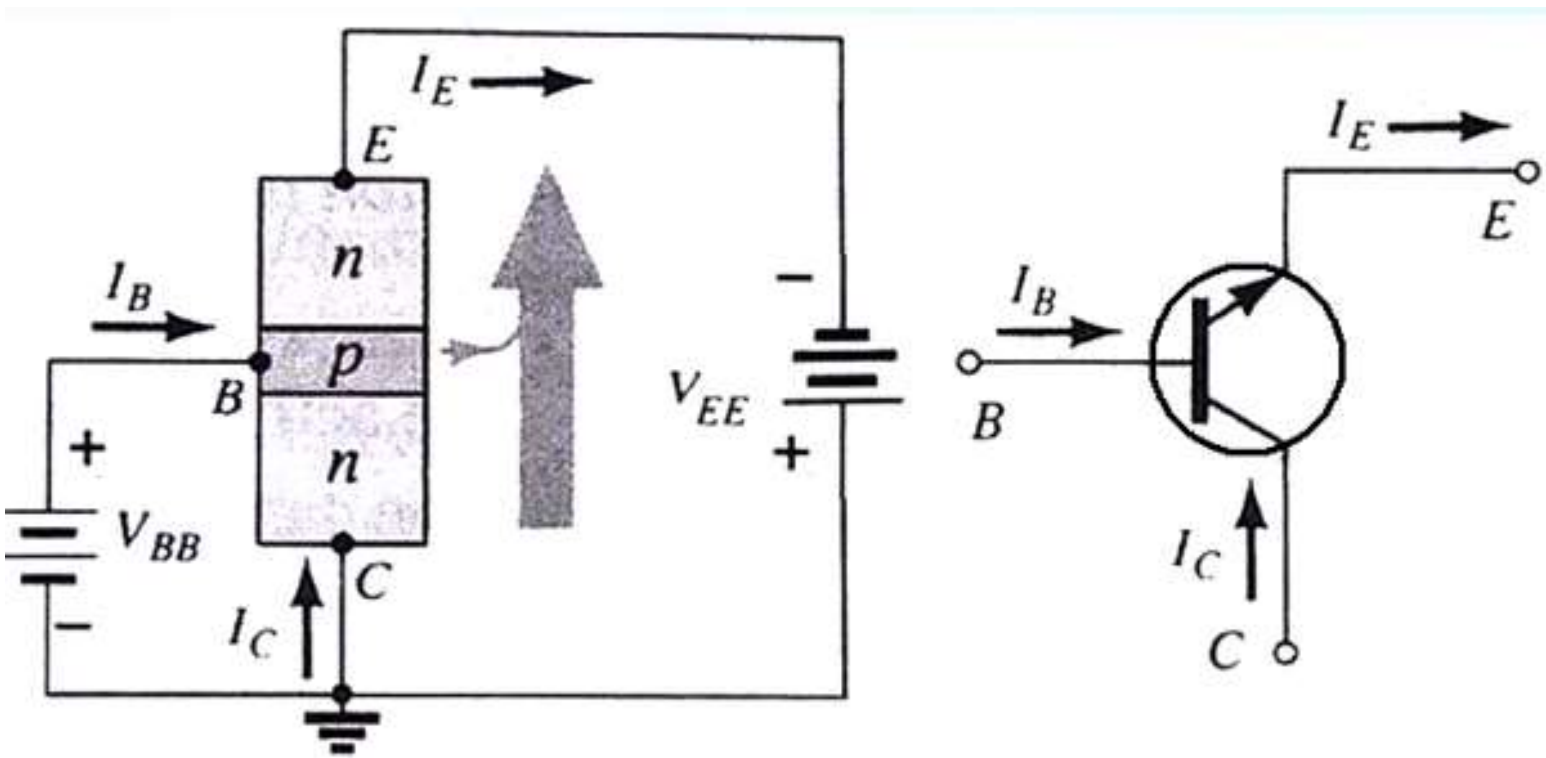
Common Emitter Input Characteristics



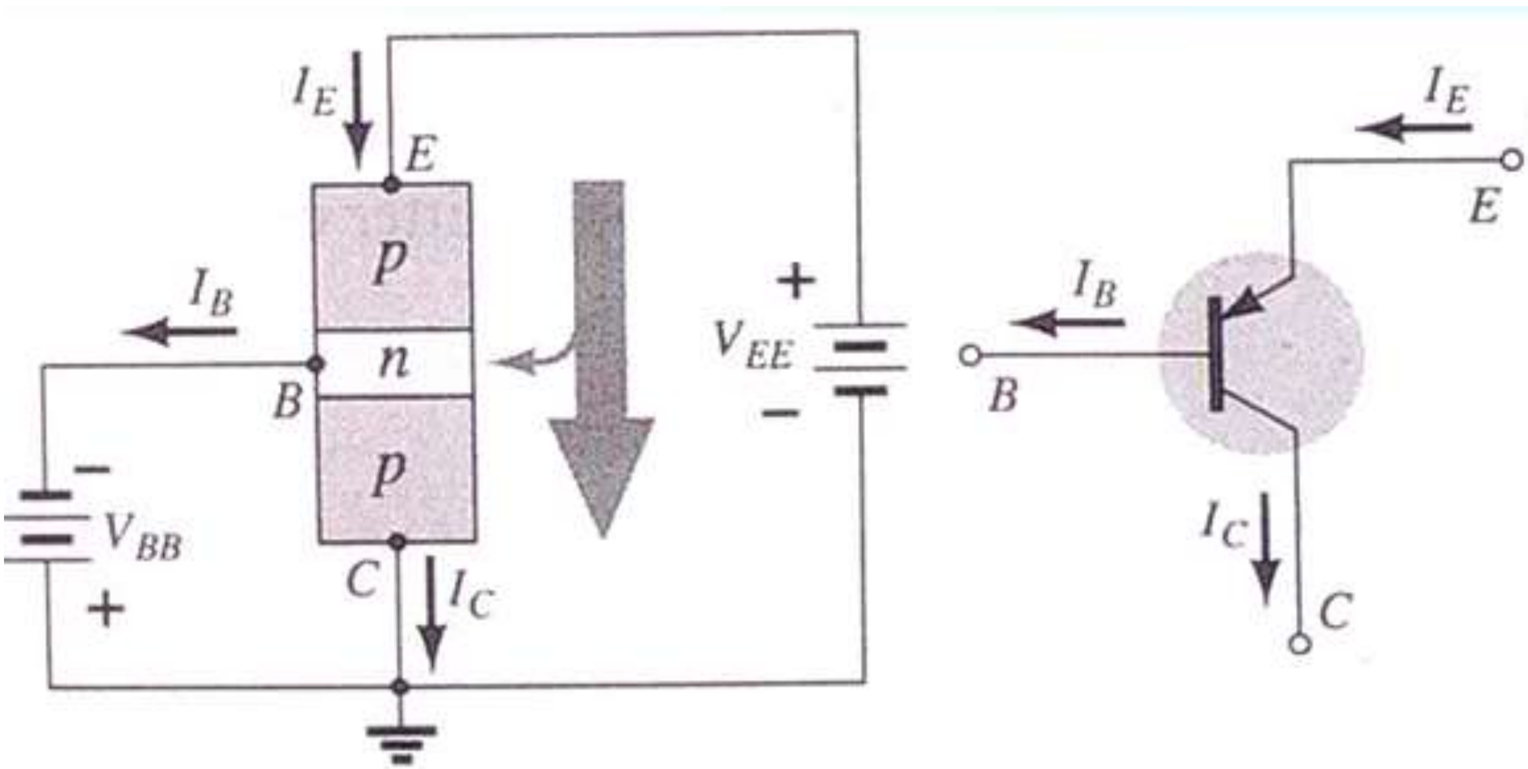
Common Emitter Output Characteristics



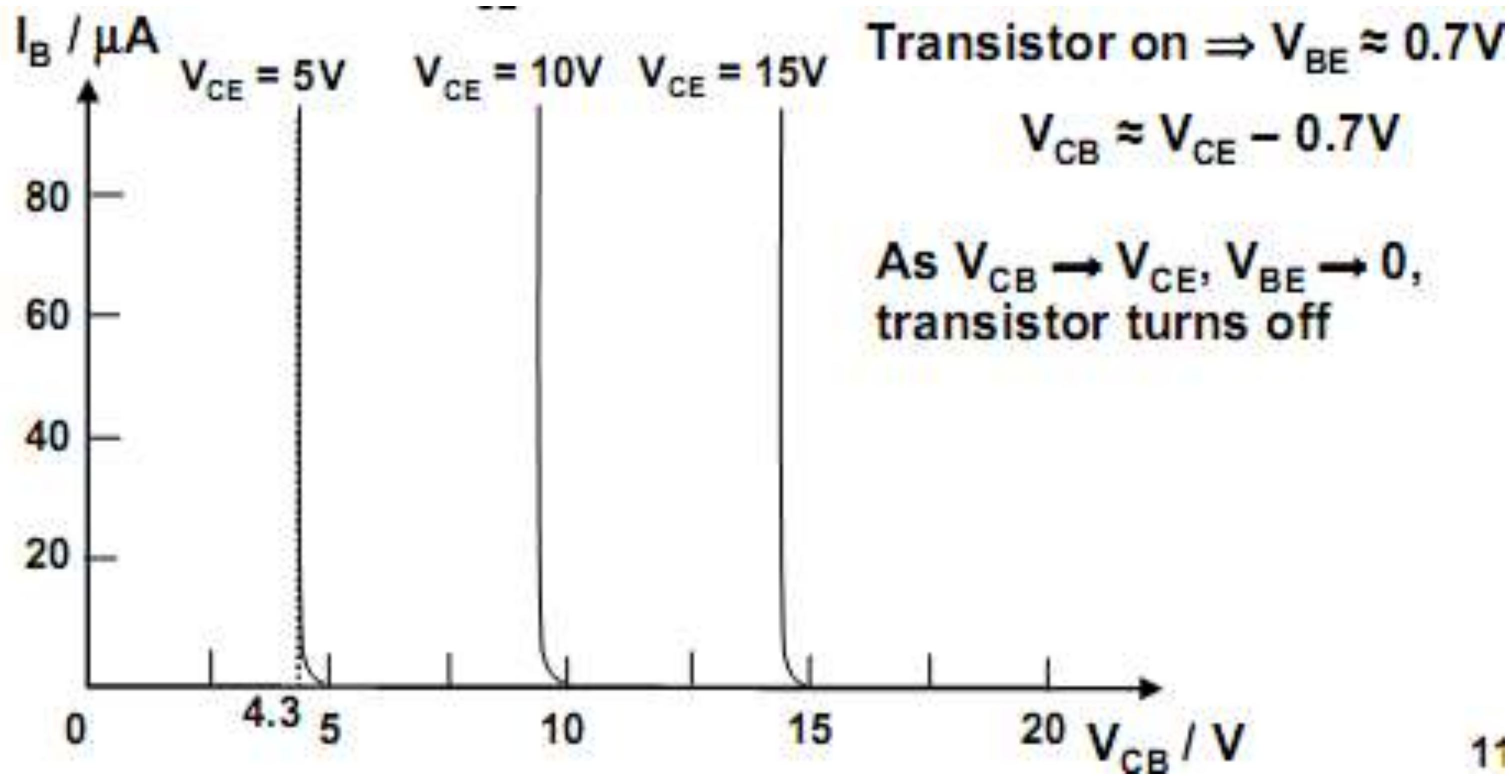
Common-Collector Configuration of npn Transistor



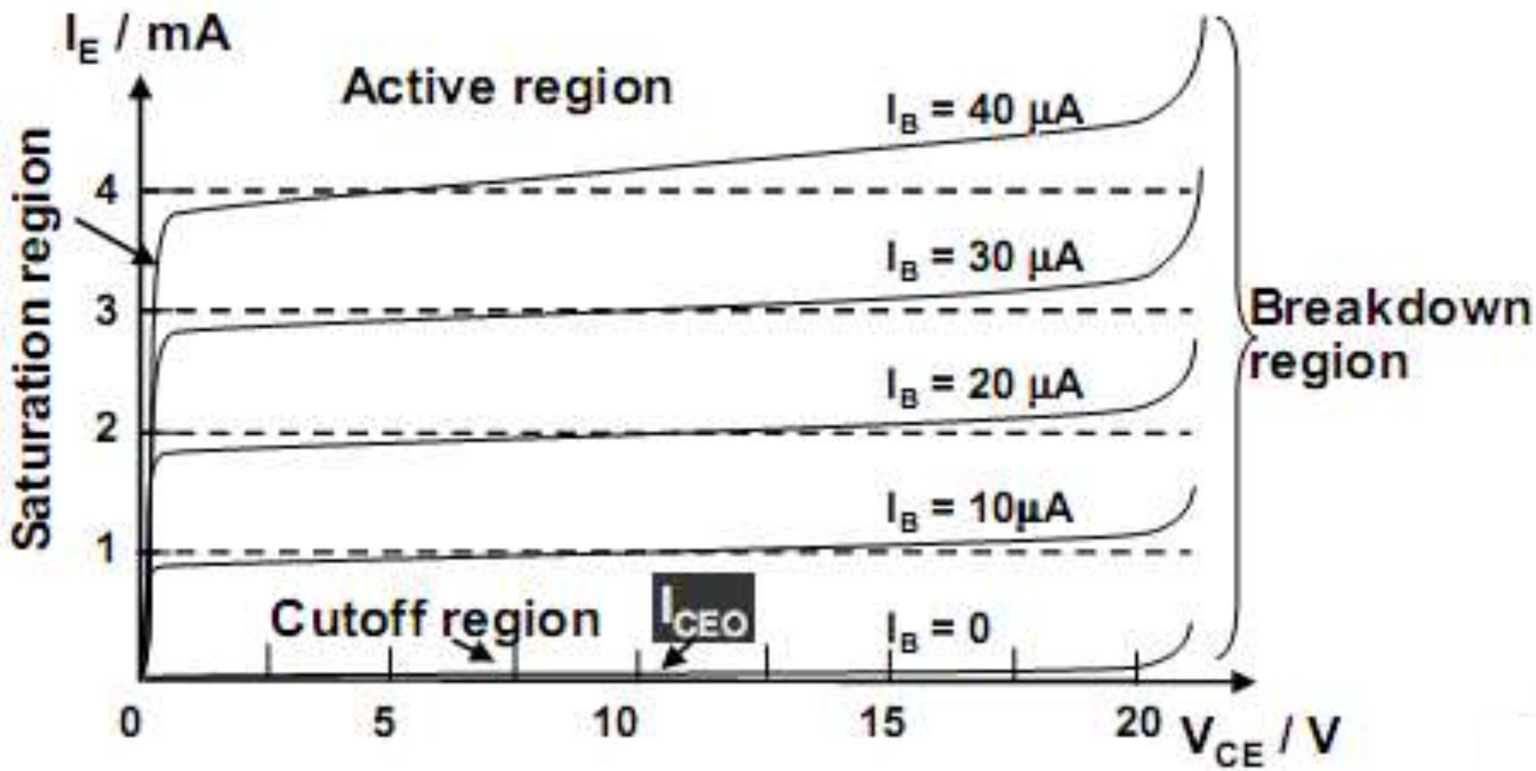
Common-Collector Configuration of pnp Transistor



Common Collector Input Characteristics



Common Collector Output Characteristics



Summary

- BJT consist of either a P-N-P or an N-P-N semiconductor structure.
- BJT has three leads called Emitter, Base, and Collector
- BJT has three configurations: common base, common emitter and common collector
- Transistor operates in 3 regions: Active, saturation and cut off

Transistor Parameters

- At the end of this lecture, student will be able to :
  - Draw the equivalent circuit of a transistor
  - Explain about the transistor Parameters
  - Derive the relation between alpha, beta and gamma

Topics

- Equivalent circuit of transistor
- Transistor Parameters
- Relation between alpha, beta and gamma

Transfer Characteristics Continued..

Transfer characteristics

- It can be described by either the current gain or by the transconductance
- DC current gain h_{FE} or β is given by

$$\beta\ (h_{FE}) = I_C / I_B$$

- AC current gain h_{FE} is given by

$$h_{FE} = i_c / i_b$$

- Transconductance g_m is given approximately by

$$g_m \approx 40 I_C \approx 40\ I_E \text{ Siemens}$$

Current Amplification Factors

β = Common-emitter current gain

α = Common-base current gain

γ = Common collector current gain

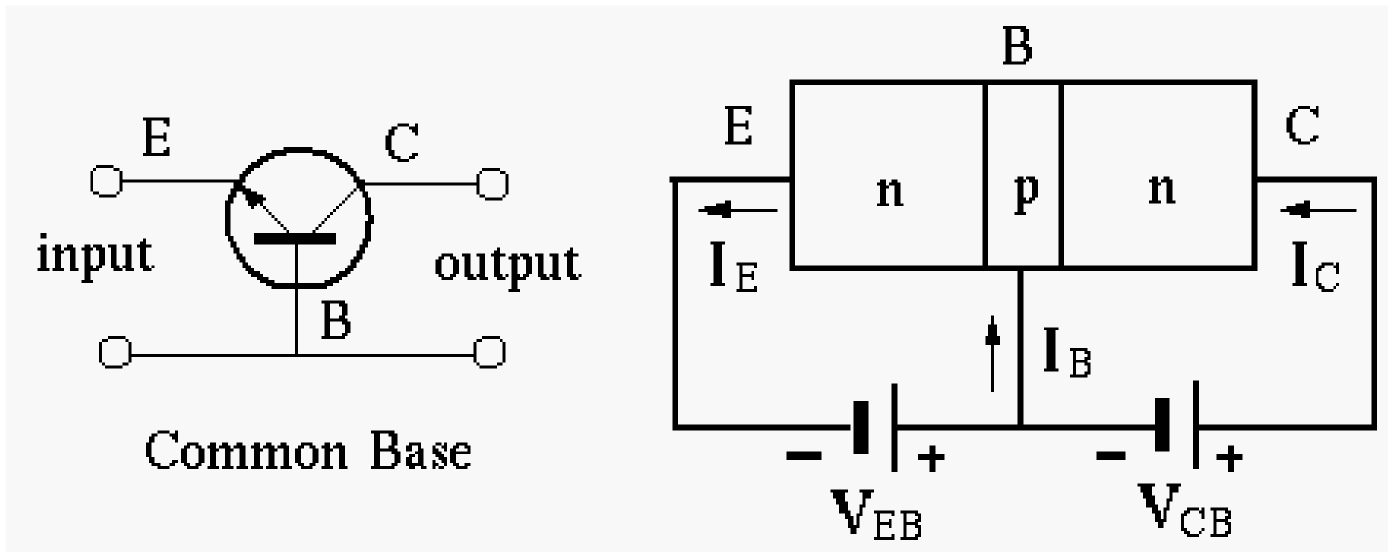
$$I_E = I_C + I_B$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad \beta = \frac{\Delta I_C}{\Delta I_B} \qquad \gamma = \frac{\Delta I_E}{\Delta I_B}$$

$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha} \qquad \gamma = \beta + 1$$

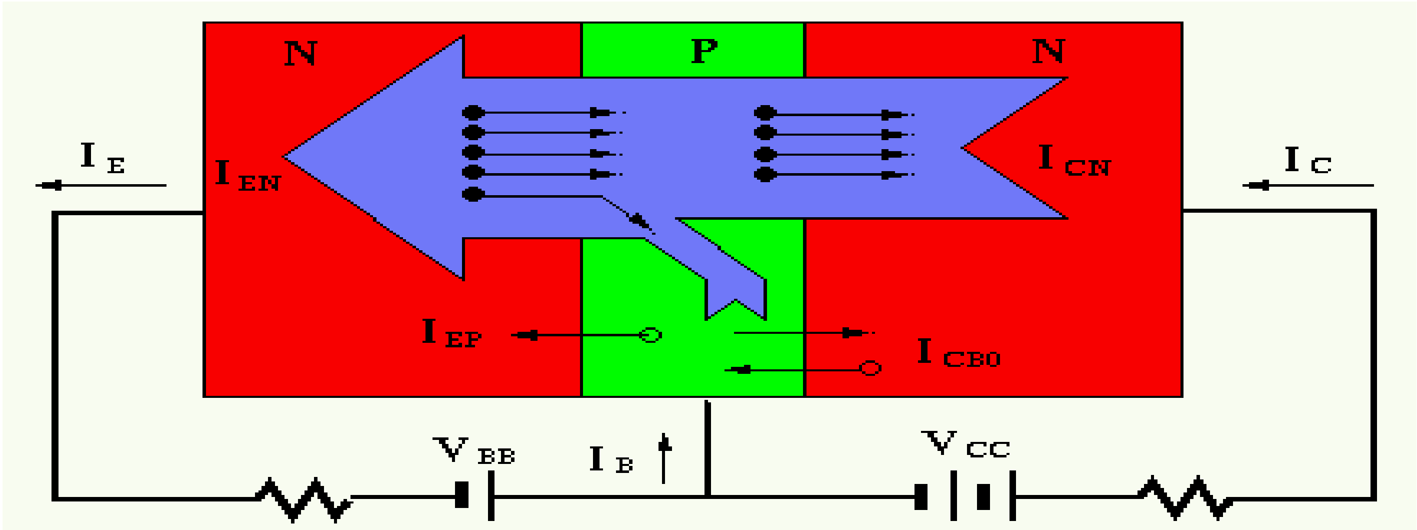
Common Base Transistor Circuit

Schematic symbols



Common Base Transistor Working

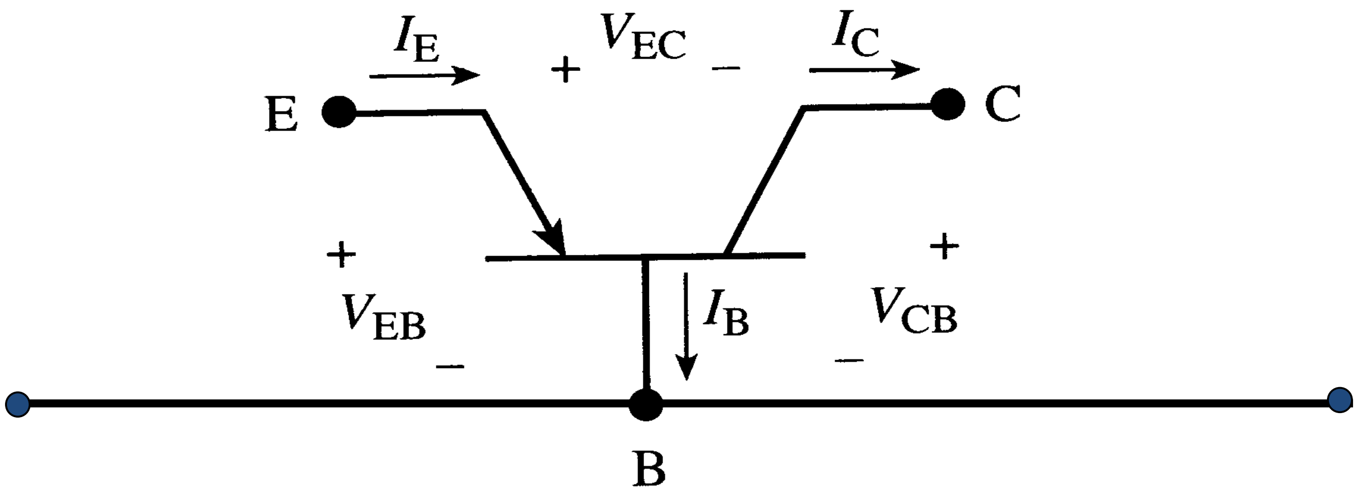
Dramatic symbol



Common Base DC current gain - PNP

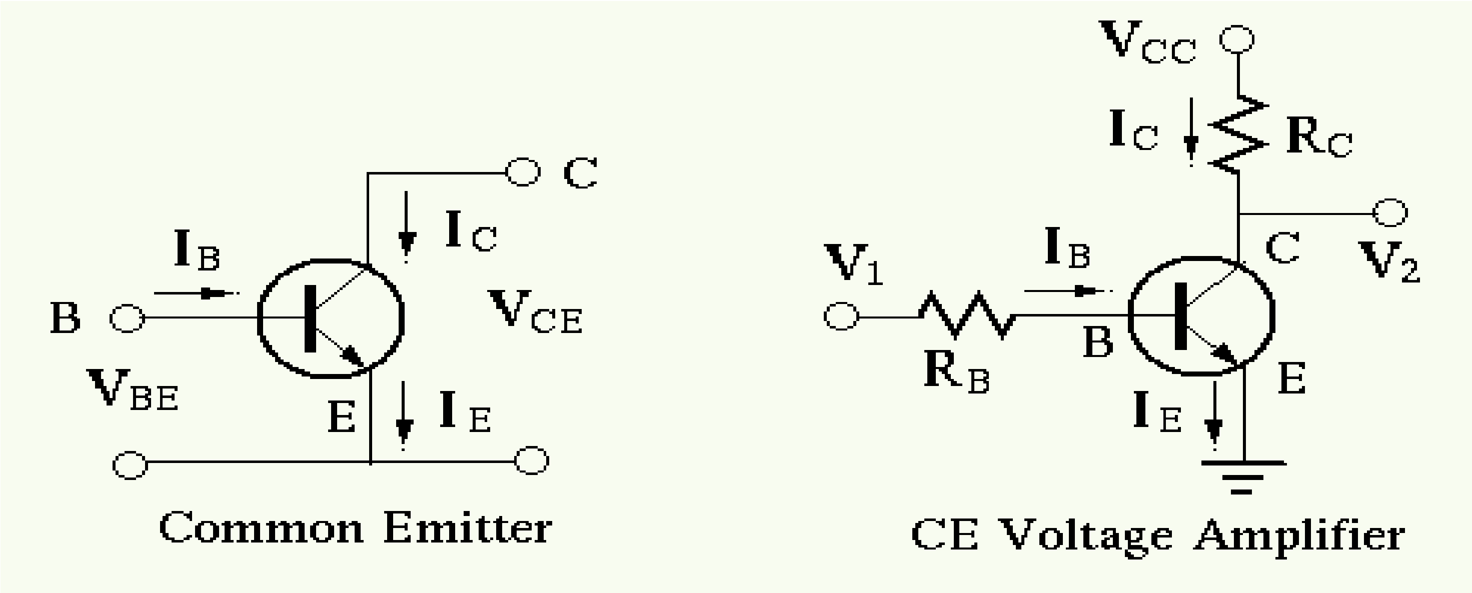
Common Base – Active Bias mode:

$$I_C = \alpha_{DC} I_E + I_{CBO}$$



Common Emitter Amplifier Circuit

Schematic symbols



Common Emitter Amplifier Equations

$$I_{C(max)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = I_{C(sat)}$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{dc}}$$

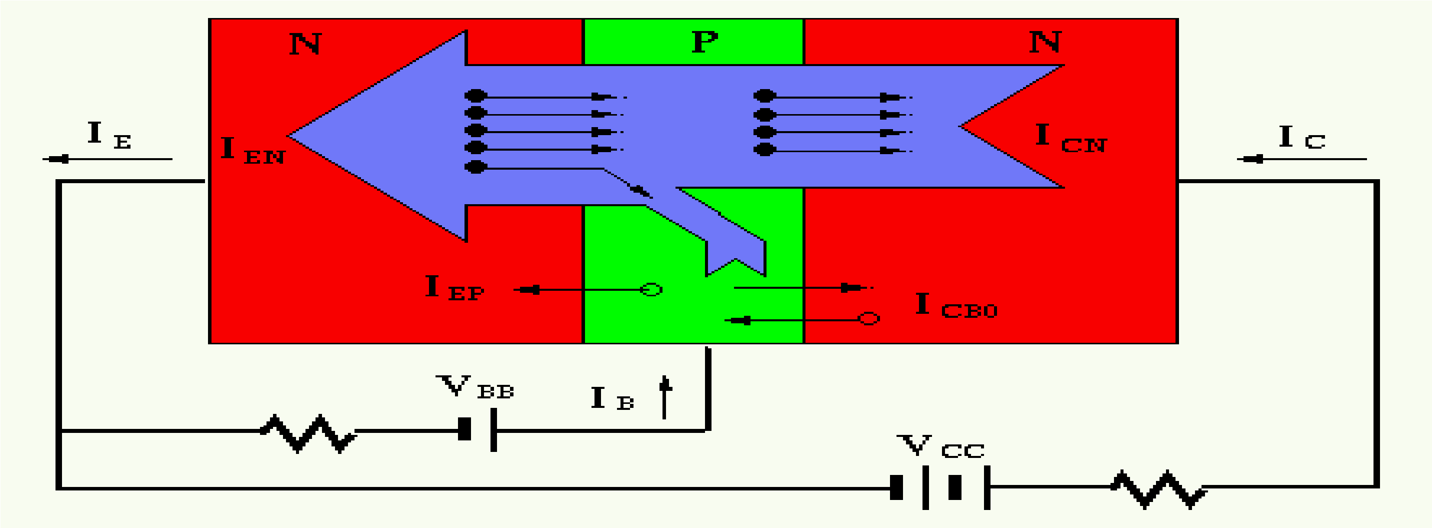
$$\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}}$$

$$= \frac{\dfrac{I_C - I_{CO}}{I_E}}{1 - \dfrac{I_C - I_{CO}}{I_E}} = \frac{I_C - I_{CO}}{I_E - I_C + I_{CO}}$$

$$= \frac{I_C - I_{CO}}{I_B + I_{CO}}$$

Common Emitter Amplifier Working

Dramatic symbol



Common Emitter DC current gain - PNP

Common Emitter Active Bias mode:

$$I_E = \beta_{DC} I_B + I_{CEO}$$

$$I_C = \alpha_{DC} I_E + I_{CBO}$$

$$= \alpha_{DC}(I_C + I_B) + I_{CBO}$$

$$\beta_{DC} = \alpha_{DC} / (1 - \alpha_{DC})$$

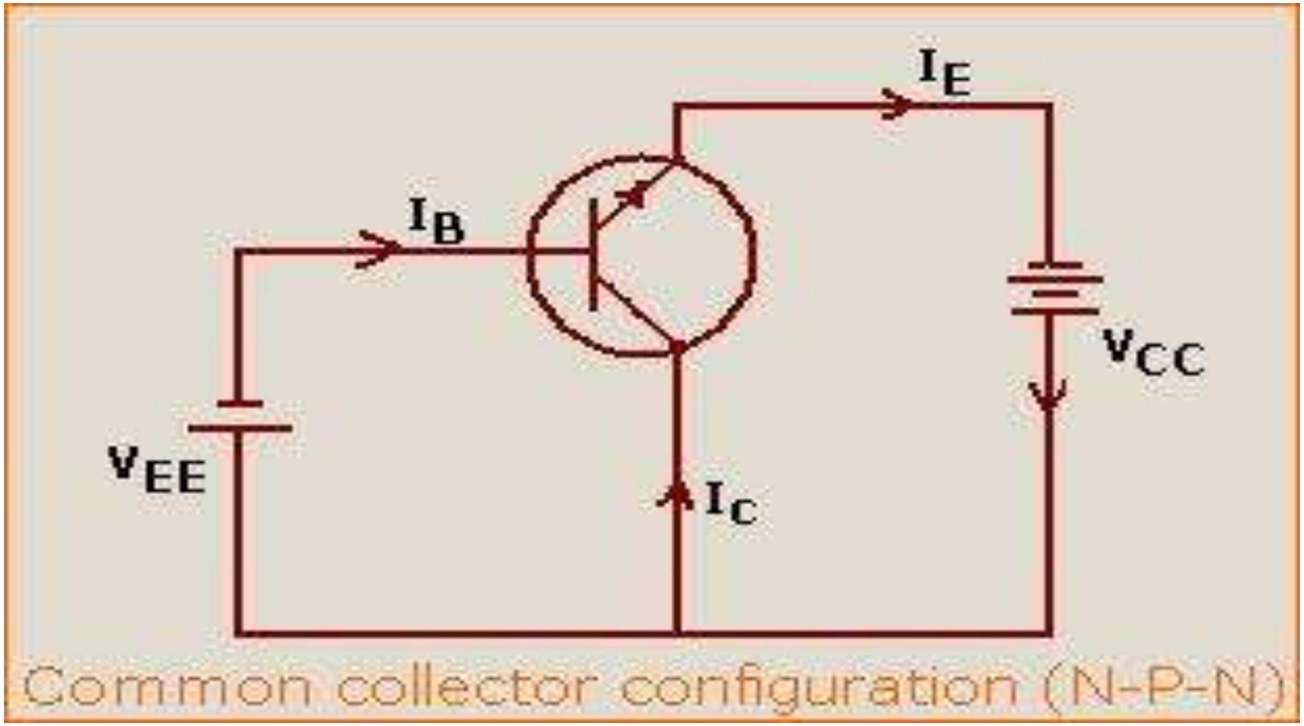
GAIN !!

$$\alpha_{DC} = \beta_{DC} / (1 + \beta_{DC})$$

$$I_C = \frac{\alpha_{DC} I_B + I_{CBO}}{1 - \alpha_{DC}}$$

$$I_{CEO} = I_{CBO} / (1 - \alpha_{DC})$$

Common Collector Amplifier



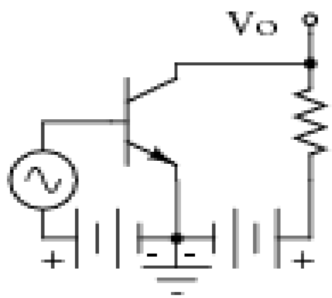
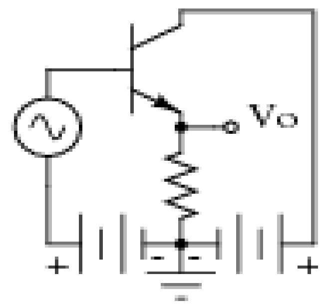
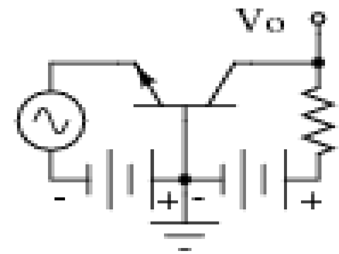
Common Collector Features

- Common Collector is also called emitter-follower (EF).
- It is called common-collector configuration since both the signal source and the load share the collector terminal as a common connection point.
- Output voltage is obtained at emitter terminal.
- Input characteristic of common-collector configuration is similar with common-emitter configuration.
- Common-collector circuit configuration is provided with the load resistor connected from emitter to ground.
- It is used primarily for impedance-matching purpose since it has high input impedance and low output impedance.

Characteristics of Different Transistor Configurations

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Angle	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

Comparison of Different Configuration

Basic circuit	Common emitter	Common collector	Common base
			
Voltage gain	high	less than unity	high, same as CE
Current gain	high	high	less than unity
Power gain	high	moderate	moderate
Phase inversion	yes	no	no
Input impedance	moderate ≈ 1 k	highest ≈ 300 k	low ≈ 50 Ω
Output impedance	moderate ≈ 50 k	low ≈ 300 Ω	highest ≈ 1 Meg

Problems

- **Example 2.1**

  A certain npn transistor has a base current of 80μA and a collector current of 2mA. Calculate α, β and I_E

  (α=.96, β=25, I_E=2.08mA)

- **Example 2.2**

  For a transistor α=.98,I_B=50μA.Find values of I_C, I_E and β

Summary

- Behavior can be described by the current gain, h_{FE} or by the transconductance, g_m of the device
- CE configuration will provide the current gain .
- Voltage gain is provided by CB configuration.

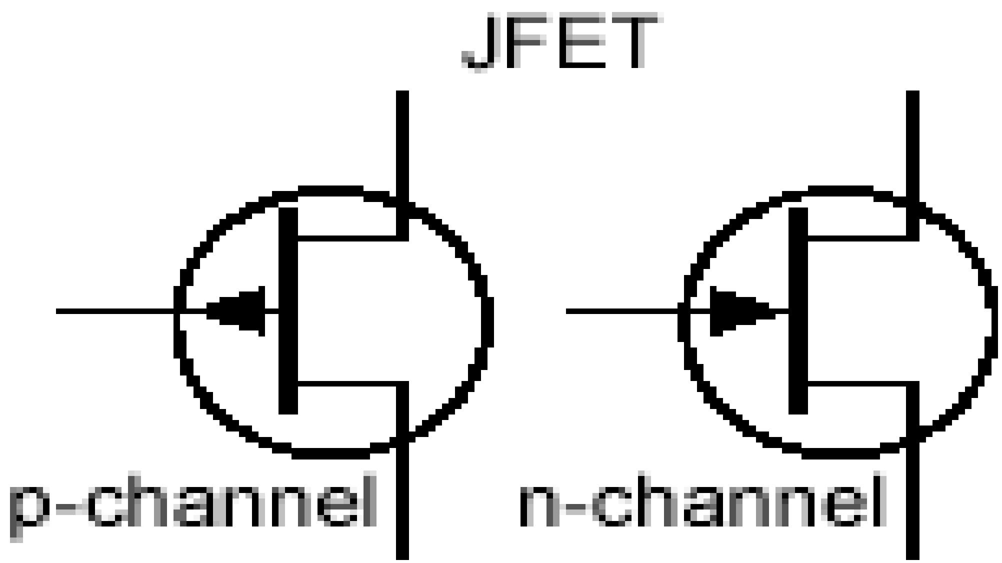
Junction Field Effect Transistor

- At the end of this lecture, student will be able to :
  - Define JFET
  - Explain the construction of JFET
  - Explain the operation of JFET
  - Classify JFET and BJT

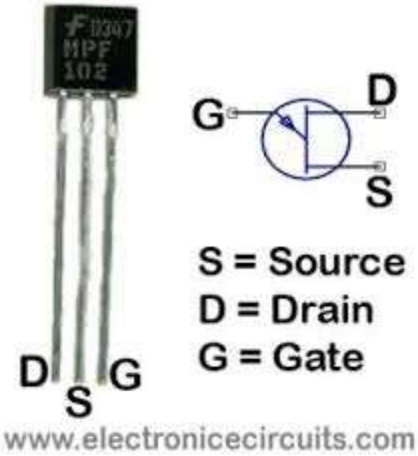
Topics

- JFET basics
- JFET construction
- JFET operation
- JFET characteristics

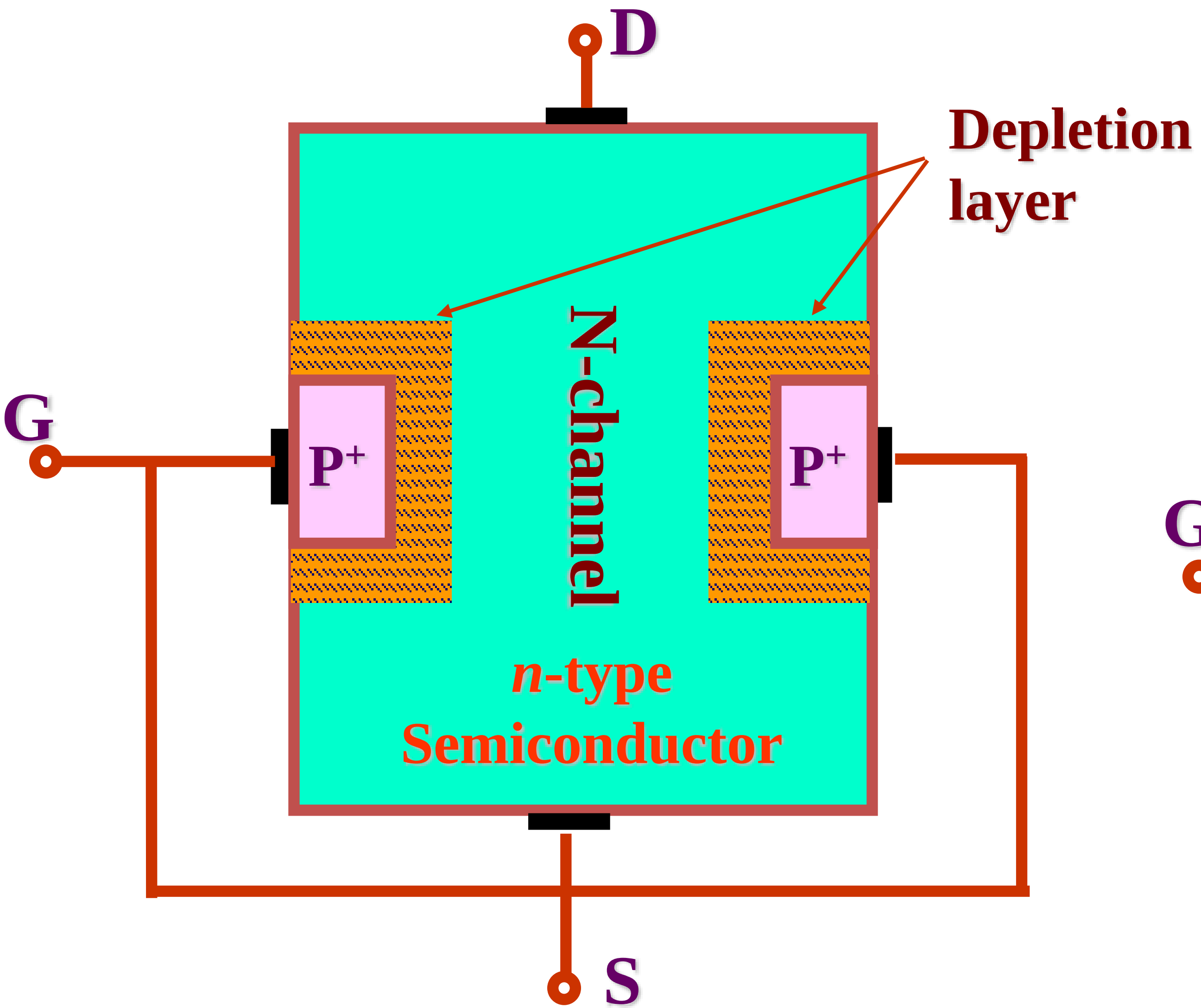
JFET (Junction Field Effect Transistor)

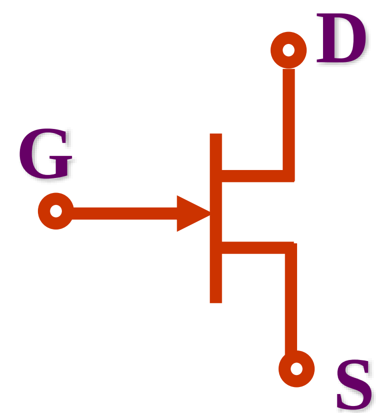


JFET continued..



JFET Construction





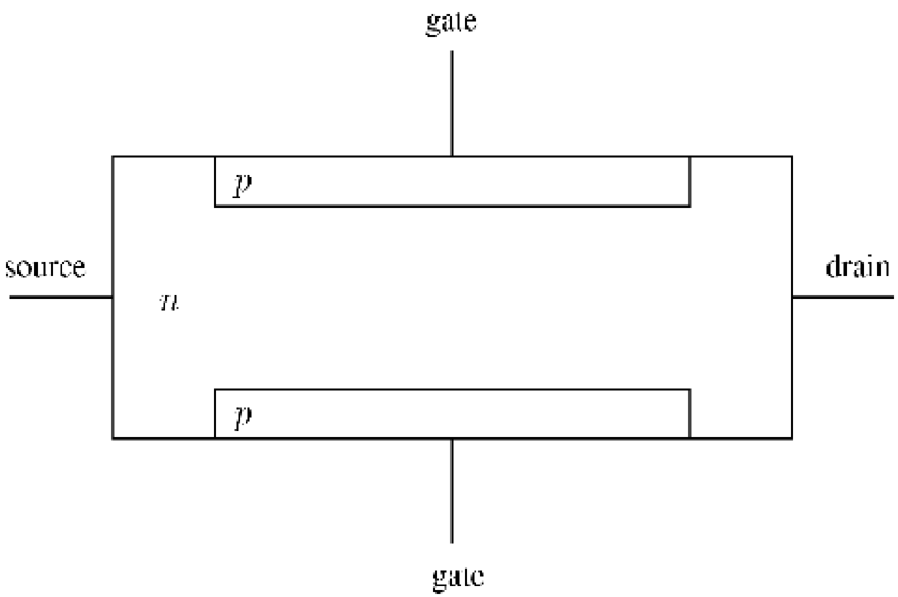
JFET Construction Continued..

- An n- channel is formed between two p-type layers which are connected to the gate.

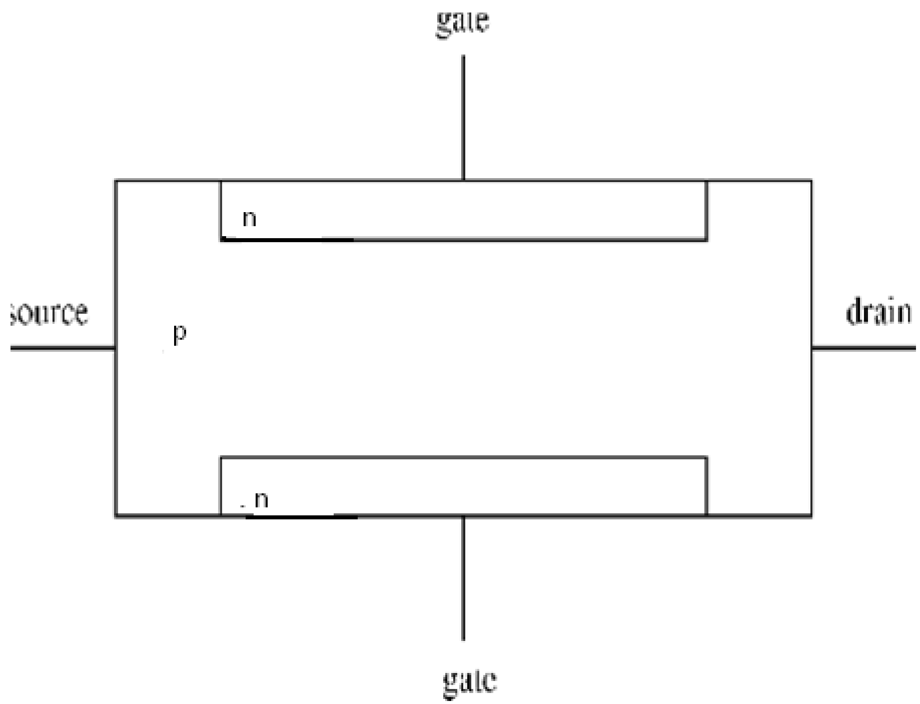
- Majority carrier electrons flow from the source and exit the drain, forming the drain current.

- The pn junction is reverse biased during normal operation, and this widens the depletion layers which extend into the n channel only (since the doping of the p regions is much larger than that of the n channel). As the depletion layers widen, the channel narrows, restricting current flow.

n- Channel and p-Channel JFET

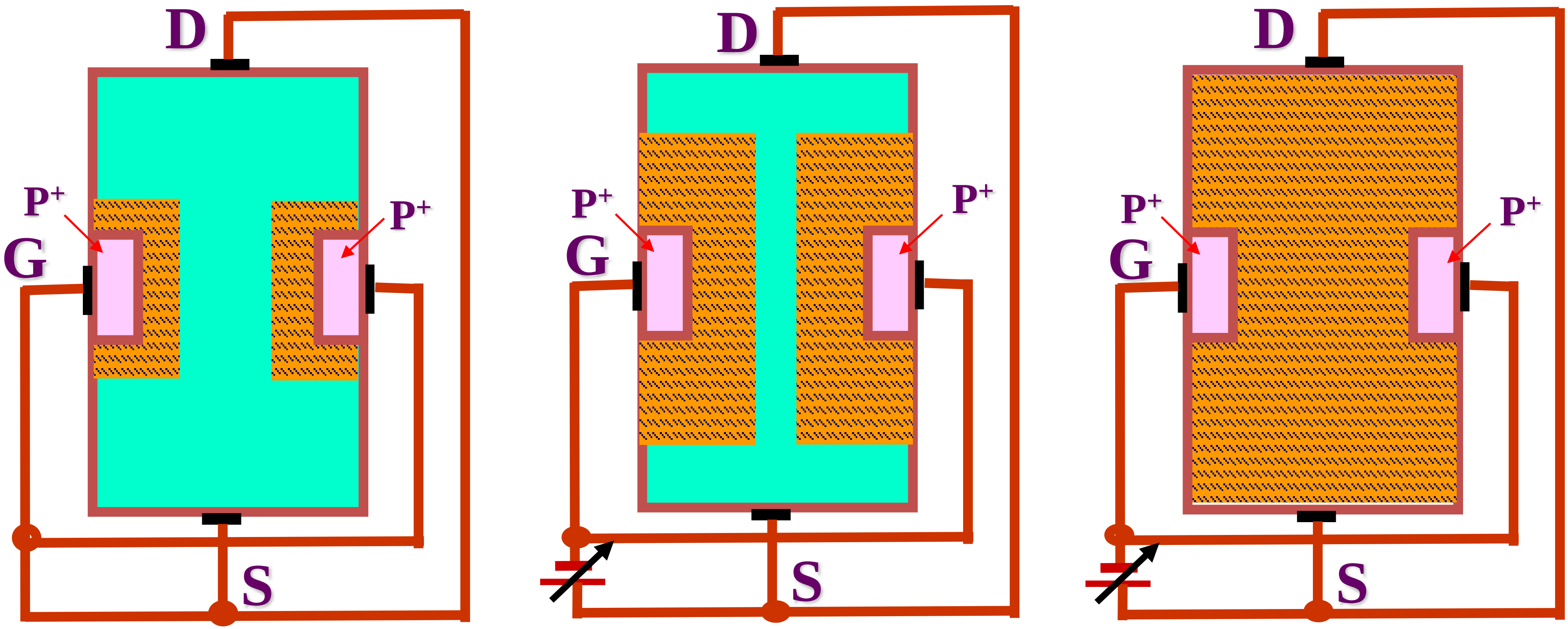


***n*- channel JFET**



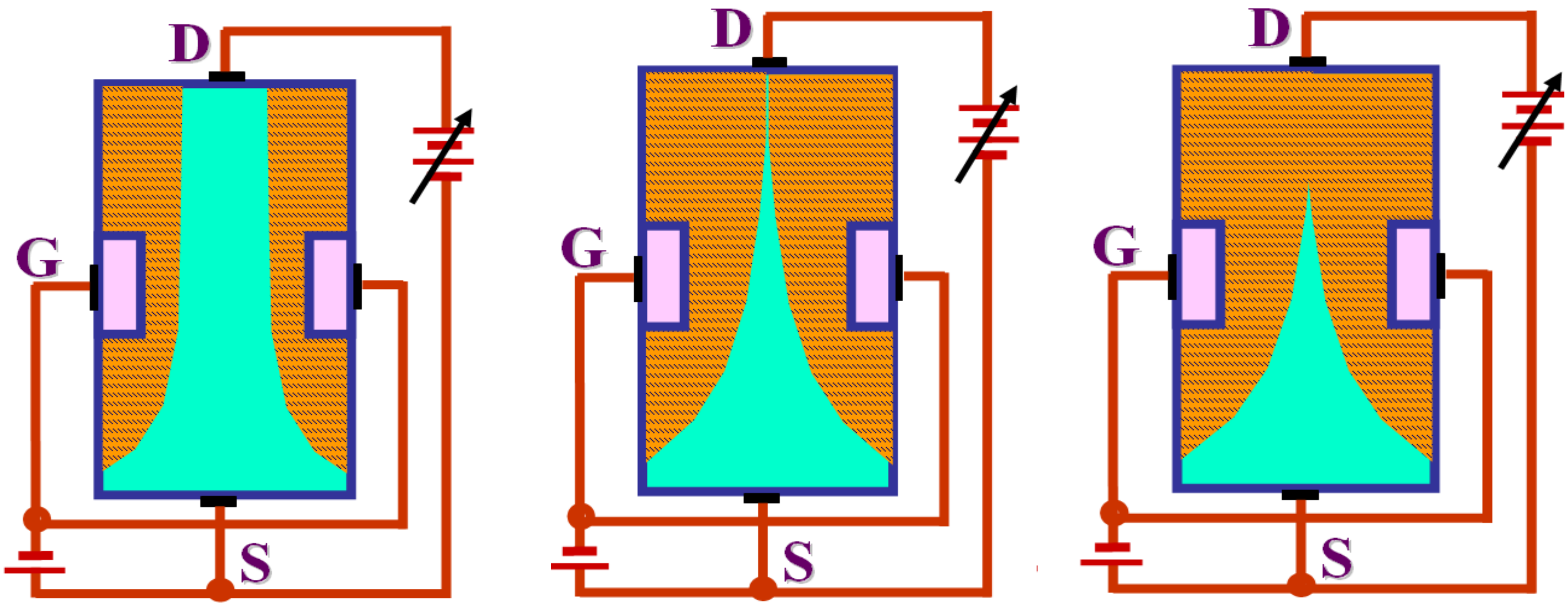
***p*- channel JFET**

JFET operation under v_{DS}=0



$V_{GS} = 0$ $\qquad$ $V_{GS} < 0$ $\qquad$ $V_{GS} = V_{GS(off)}$

Effect of V_{DS} on I_D for $V_{GS(off)} < V_{GS} < 0$



$V_{GD} > V_{GS}$

Triode region

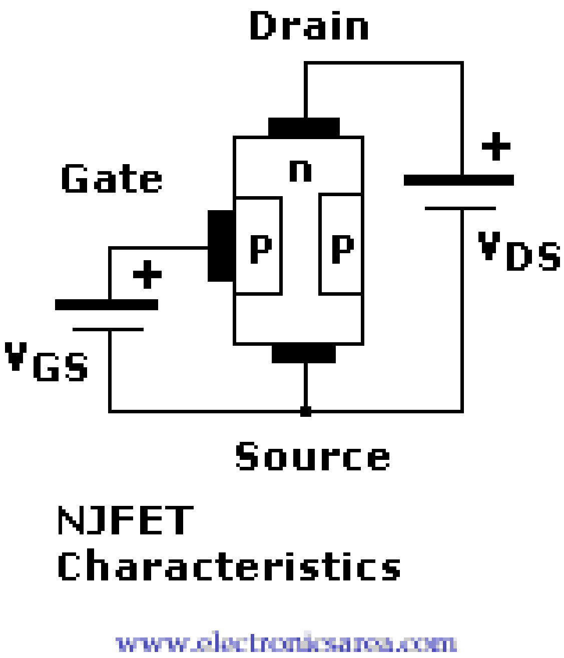
$V_{GD} = V_{GS(off)}$

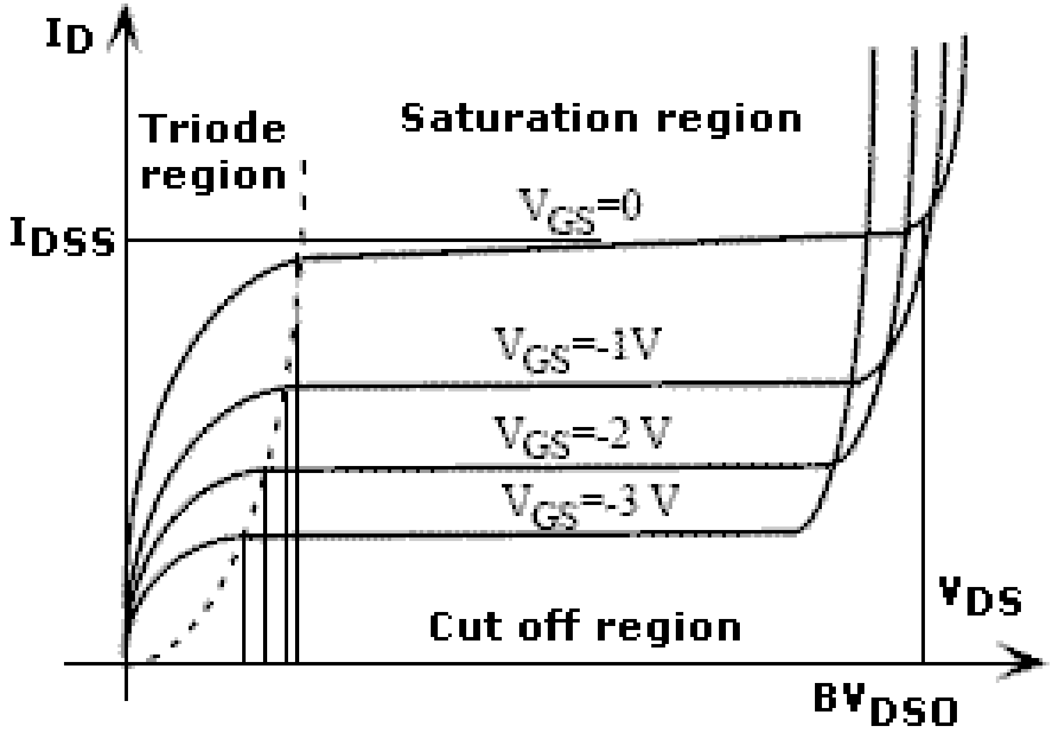
Pinch off

$V_{GD} < V_{GS(off)}$

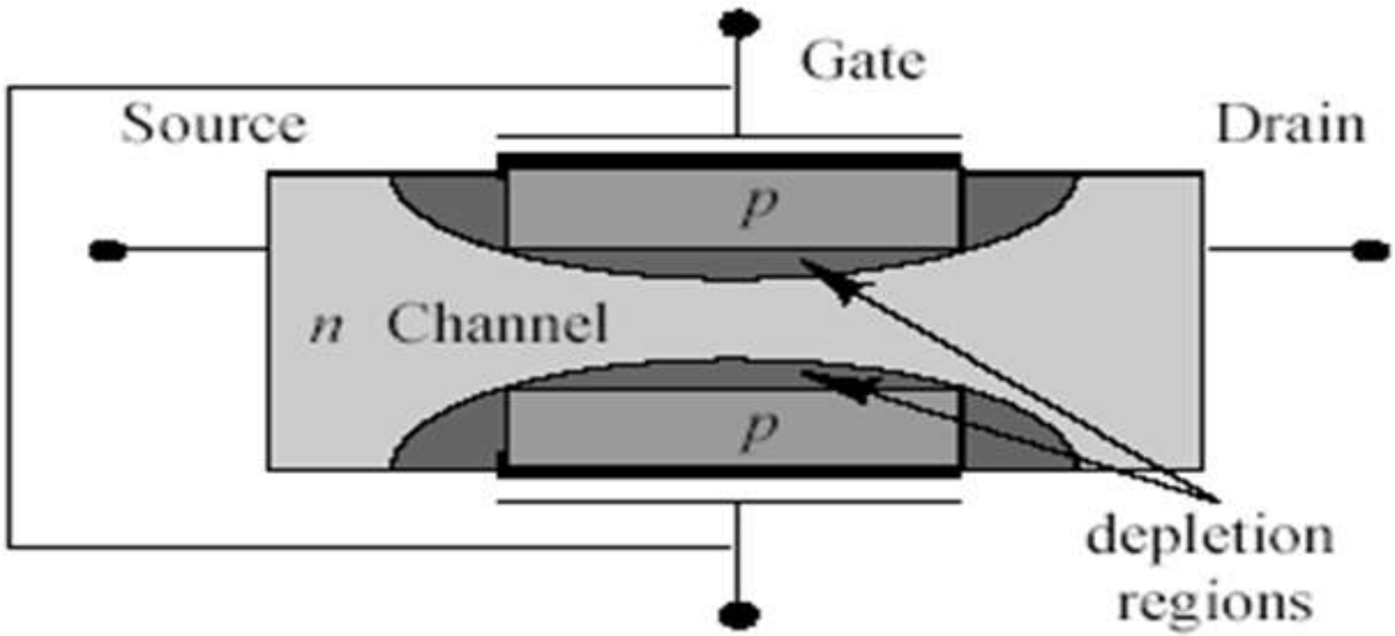
Saturation region

N-JFET Characteristics

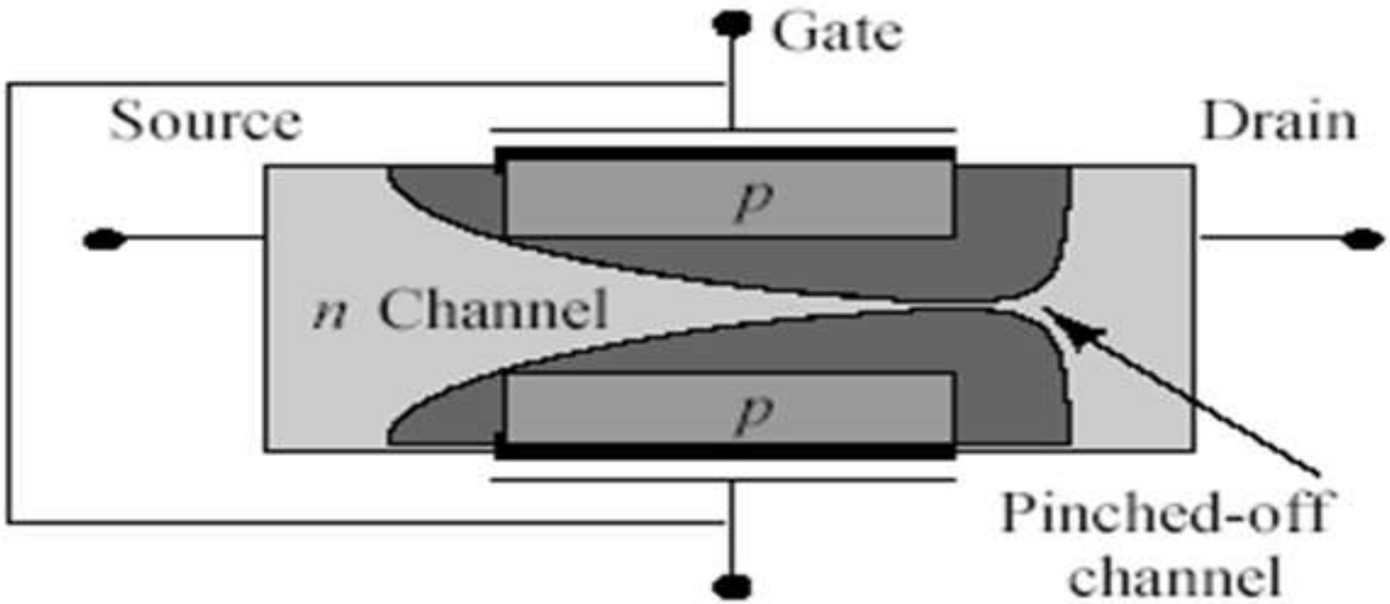




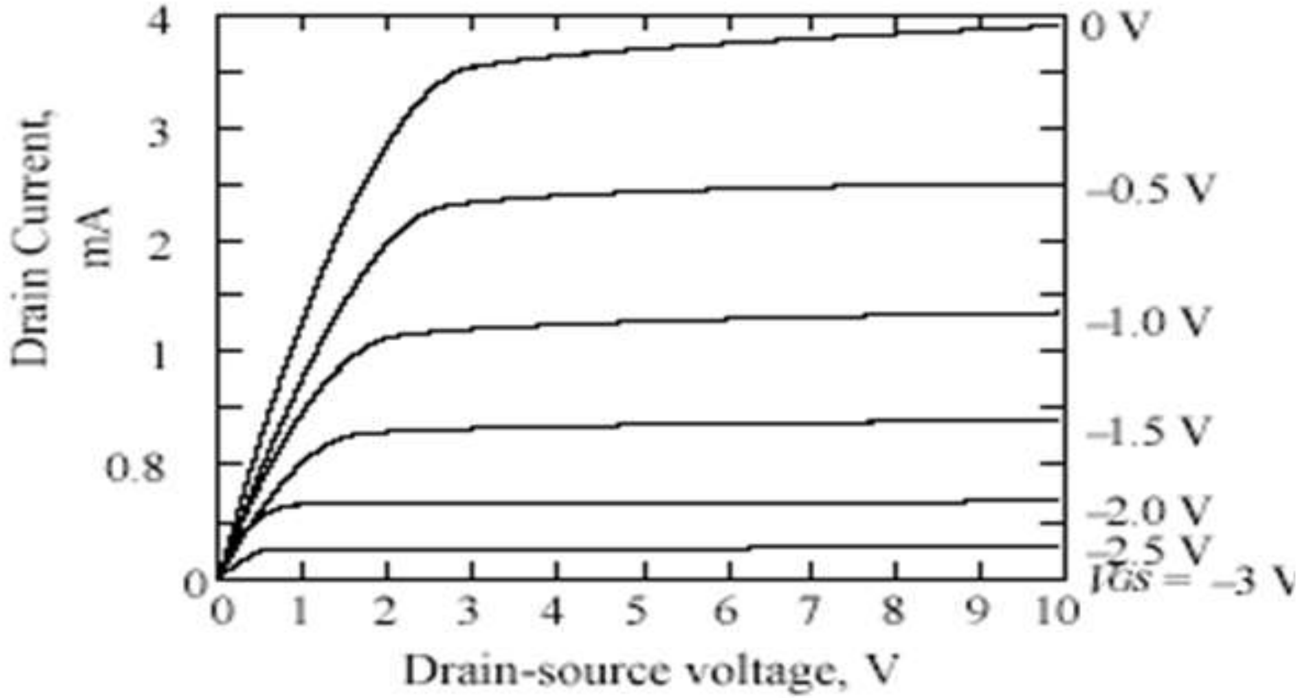
Operation of JFET: Ohmic Region



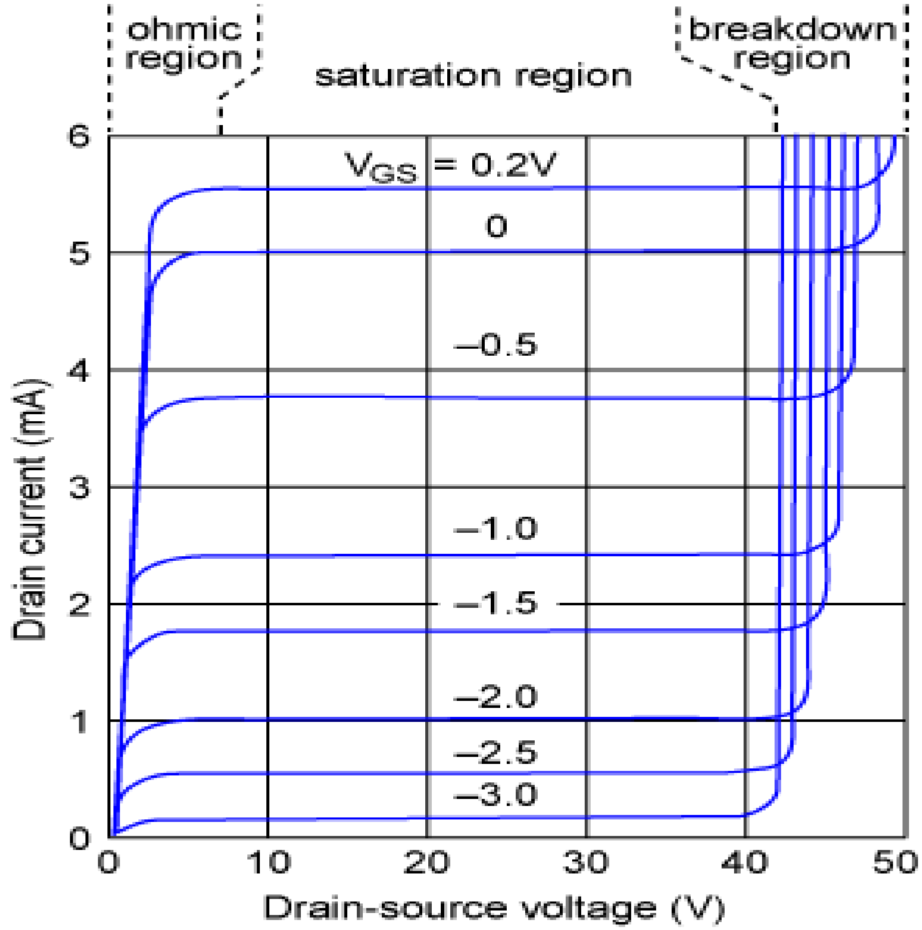
Operation of JFET: Saturation Region



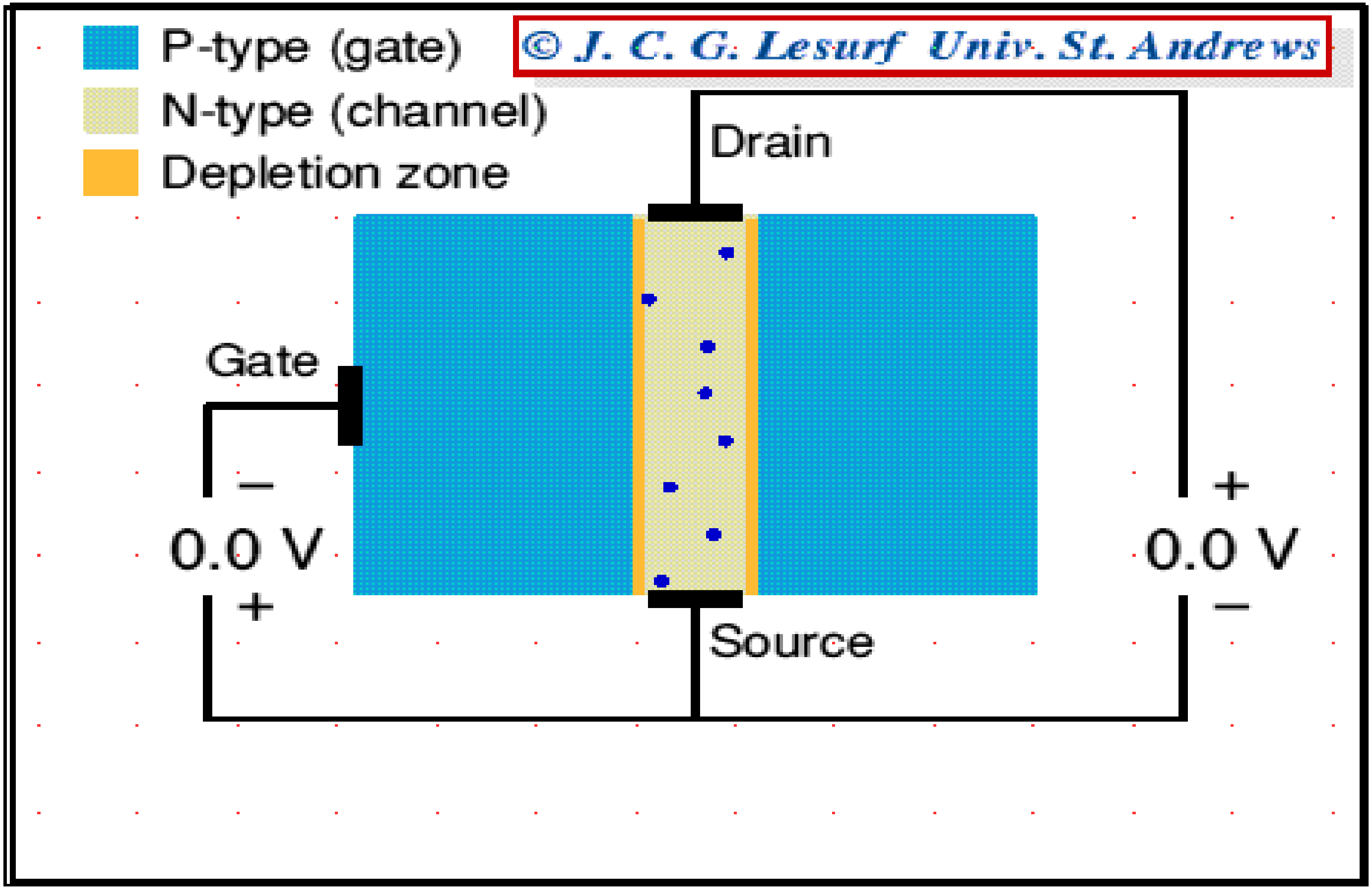
Operation of JFET: Breakdown Region



Characteristic Curve of N Channel JFET



JFET Working



JFET Operation

JFET Equations

- The following equations describe the operation of n-channel JFETs (and of depletion-mode MOSFETs; those for enhancement-mode MOSFETs are slightly different). They also apply to p-channel JFETs by substituting v_{SG} for v_{GS} and v_{SD} for v_{DS}.

$$\text{Cut-off region:} \quad v_{GS} < -V_P$$

$$\text{Ohmic region:} \quad v_{DS} < 0.25(v_{GS} + V_P), \; v_{GS} > -V_P$$

$$R_{DS} = \frac{V_P^2}{2I_{DSS}(v_{GS} + V_P)} \quad \text{(equivalent drain-to-source resistance)}$$

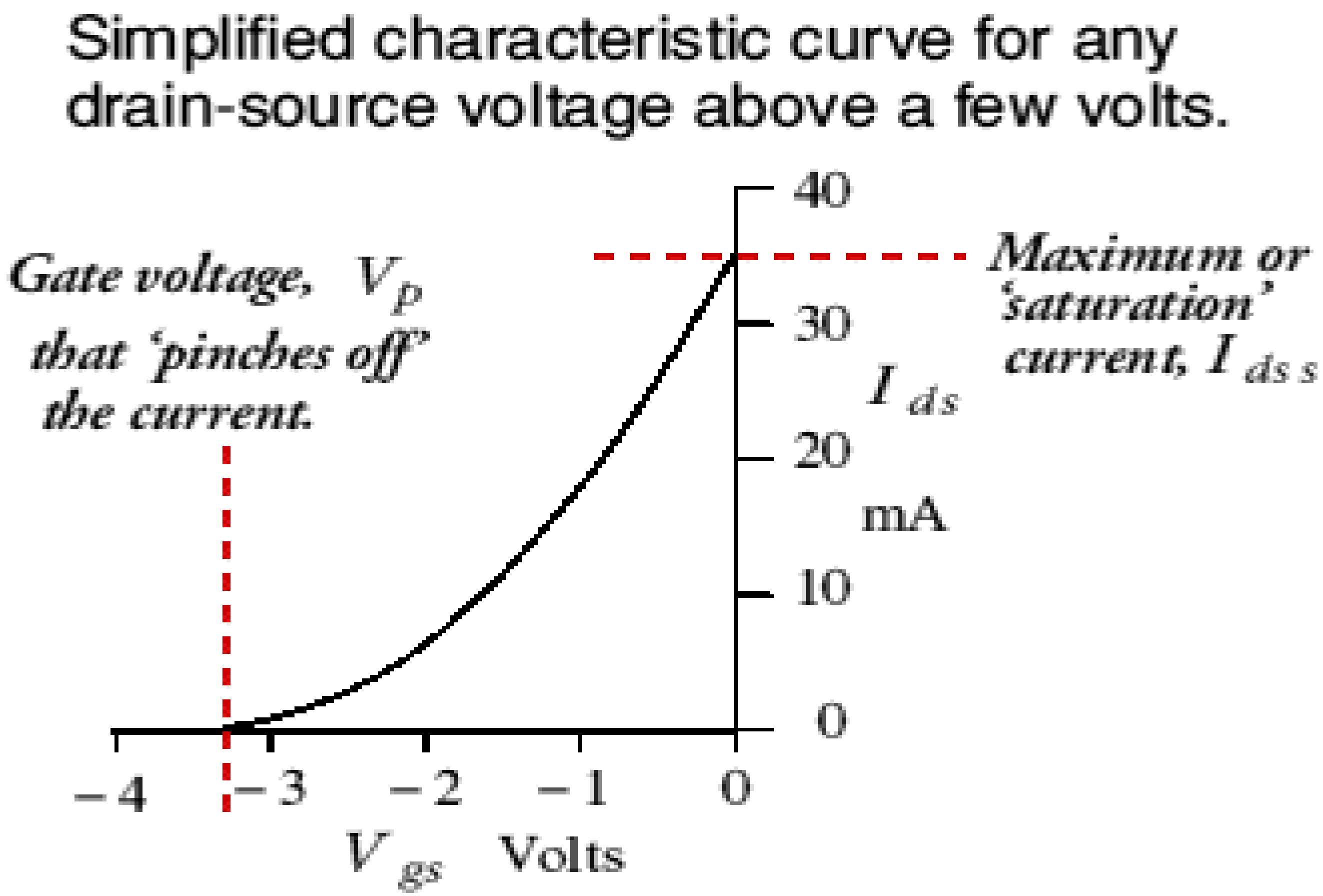
$$i_D \approx \frac{v_{DS}}{R_{DS}}$$

$$\text{Saturation region:} \quad v_{DS} \geq v_{GS} + V_P, \; v_{GS} > -V_P$$

$$i_D = \frac{I_{DSS}}{V_P^2}(v_{GS} + V_P)^2$$

$$\text{Breakdown region:} \quad v_{DS} > V_B$$

JFET Transfer characteristic



JFET Transfer characteristic continued..

Hence a large increase in drain-source:

- ‘pulls harder’, trying to drag the electrons more quickly from source to drain.
- ‘squeezes down’ the channel making it harder for the electrons to get through.
- These effects tend to cancel out, leaving the current the same at all high drain-source voltage.

Summary

- JFETS are unipolar devices.
- Gate, Drain and Source are the terminals of JFET
- JFET is a voltage controlled device.
- JFET can work in 3 regions which are Ohmic,saturation and cut off.