# COE/EE152: Basic Electronics

## Lecture 5

Andrew Selasi Agbemenu

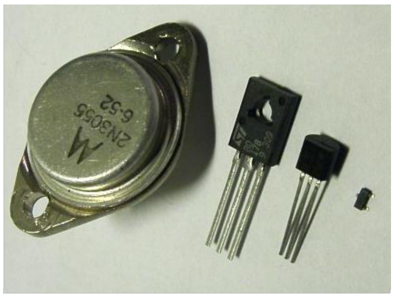


## Outline

- Physical Structure of BJT
- Two Diode Analogy
- Modes of Operation
- Forward Active Mode of BJTs
- BJT Configurations
- Early Effect
- Large Signal Model
- DC operating Point Determination

# Bipolar Junction Transistors (BJTs)

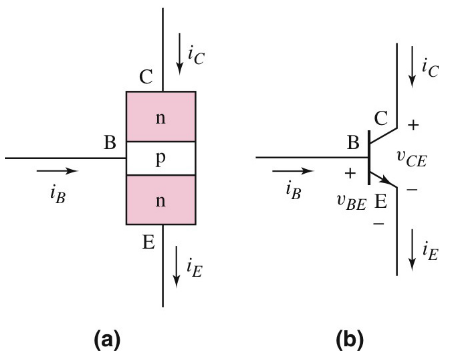
- The BJT is a nonlinear 3-terminal active device
- It can be thought of as a three layer sandwich with one type of doped semiconductor sandwiched between two oppositely doped ones
- Transistors are the basic building blocks of integrated circuits and can work as a switch on amplifier

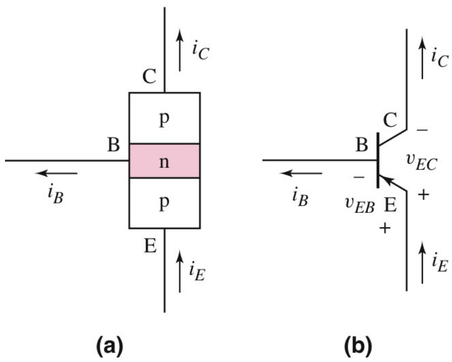





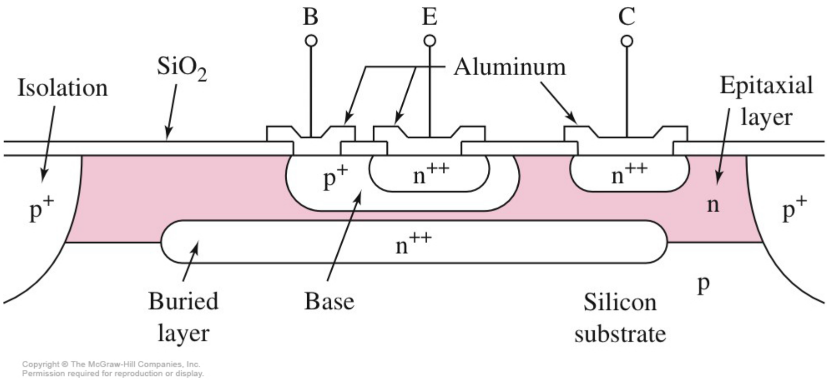
# Physical Structure

- The BJT can either be ***npn*** (an n-type semiconductor is sandwiched between two p-types) or a ***pnp*** ( a p-type semiconductor is sandwiched between two n-types)



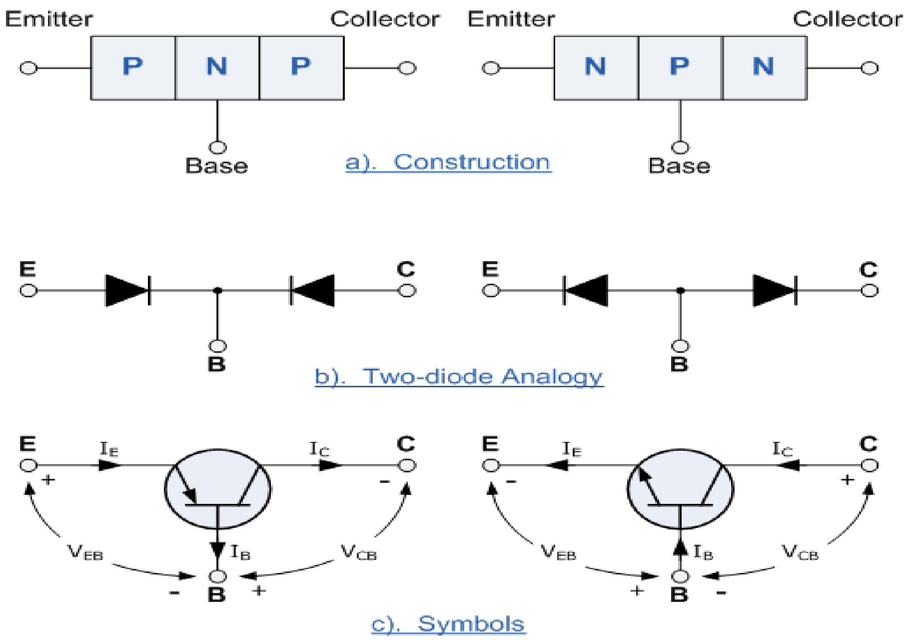



# Cross Section of Integrated Circuit npn Transistor






# Transistor Two-Diode Analogy



# Modes of Operation

- The BJT has two PN junctions which can either be forward biased or reverse biased
- The bias of these junctions determines the BJTs operation mode

Modes of Operation

| Mode | EBJ | CBJ | Applications |
|---|---|---|---|
| *Cutoff* | *Reverse* | *Reverse* | *Switching (Logic circuits): Assumed off and usually used for logic 'off' or '0'* |
| *Forward-Active* | *Forward* | *Reverse* | *Amplifier* |
| *Reverse-Active* | *Reverse* | *Forward* | *Not used* |
| *Saturation* | *Forward* | *Forward* | *Switching (Logic circuits): used for logic 'ON' or '1'* |



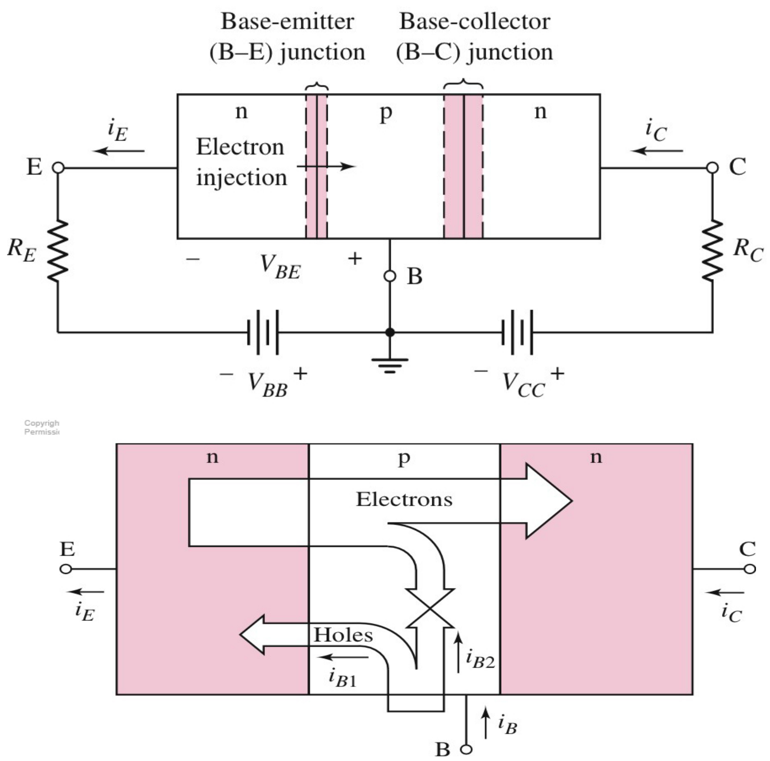
# Forward-Active Mode Operation of an NPN Transistor

- In the active region, the collector-base junction is reverse biased and the emitter-base junction is forward biased
- The emitter is heavily doped with high density of electrons
- The base is thin and lightly doped and therefore has how density of holes
- The collector is also heavily doped (lower than emitter) and large

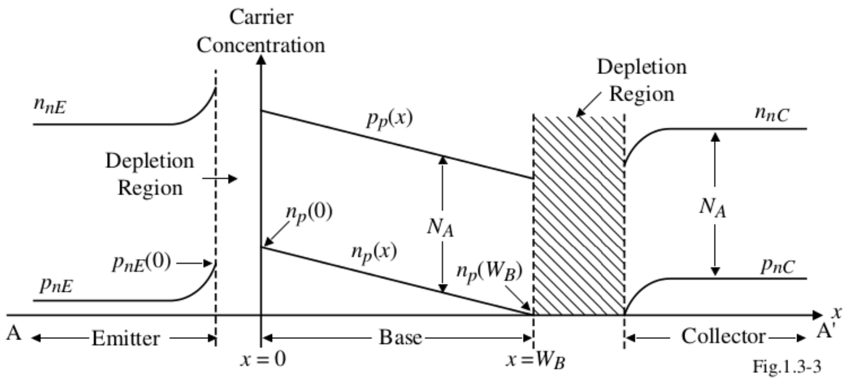
# NPN BJT in Forward Active Mode

- Electrons are injected from the emitter to the base through the forward biased EBJ
- About 5% of the electrons recombine with holes in the base because it is thin and lightly doped
- The rest of the electron acts as minority charge carriers and drift through the reverse biased CBJ due to the reverse biased voltage $V_{CB}$





# Profile of Carrier Concentrations of NPN




- This shows the profile of carrier concentration of an NPN transistor in the forward active mode



# Terminal Currents

*Collector Current* $(i_C)$:

$$i_C = I_S e^{\frac{v_{BE}}{V_T}}$$

$$i_C = \alpha i_E \quad ; \quad i_C = \beta i_B$$

*Base Current* $(i_B)$:

$$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{\frac{v_{BE}}{V_T}}$$

*Emitter Current* $(i_E)$:

$$i_E = i_C + I_B$$

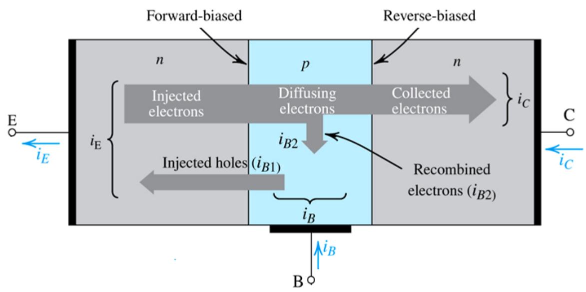
$$i_E = \frac{\beta+1}{\beta}\left(I_S e^{\frac{V_{BE}}{V_T}}\right)$$

*Where*:

$i_C$ *is the collector current*
$i_B$ *is the base current*
$i_E$ *is the emitter current*
$\beta$ *is the common emitter current gain*
$\alpha$ *is the common base current gain*

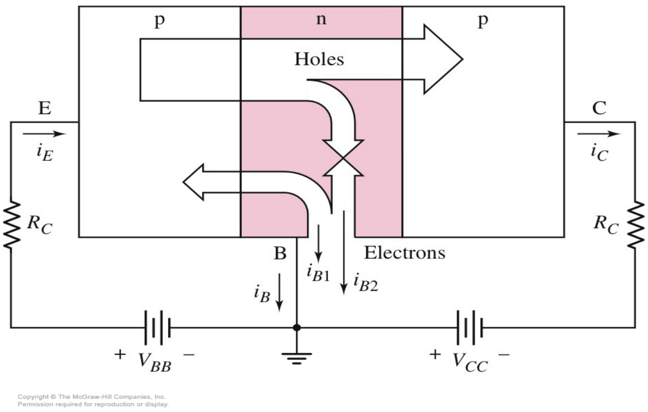
$$\alpha = \frac{\beta}{\beta+1}$$

Notice that $n = 1$ and $i_C$ is independent of $V_{CB}$
Therefore collector behaves like a current source
Whose magnitude is determined by $V_{BE}$



# Active Mode Operation of a PNP Transistor

- The emitter and collector are p-type and base n-type
- Operation of the PNP transistor is similar to the that of NPN
- The Active mode equations are the same
  - $V_{BE}$ in NPN changes to $V_{EB}$ in PNP






# Example

1. Calculate the collector and emitter currents given $\beta = 150$ , $i_B = 15\mu A$

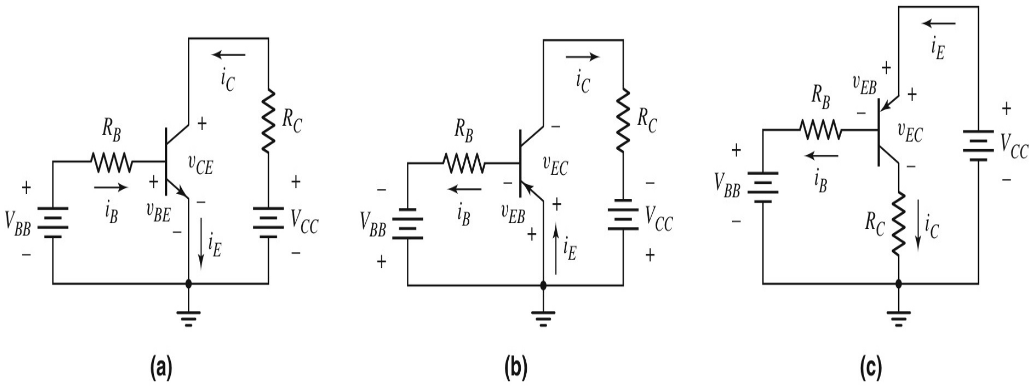
2. An npn transistor is biased in the forward-active mode. The base current $I_B = 8.50\mu A$ and the emitter current $I_E = 1.20mA$. Determine β, α and $I_C$

# BJT Configurations

- There are three possible ways in connecting a transistor in a circuit
  - Common Base Configuration
    - The base is common to both the input and output
  - Common Emitter Configuration
    - The emitter is common to both the input and the output
  - Common Collector Configuration
    - The collector is common to both the input and the output



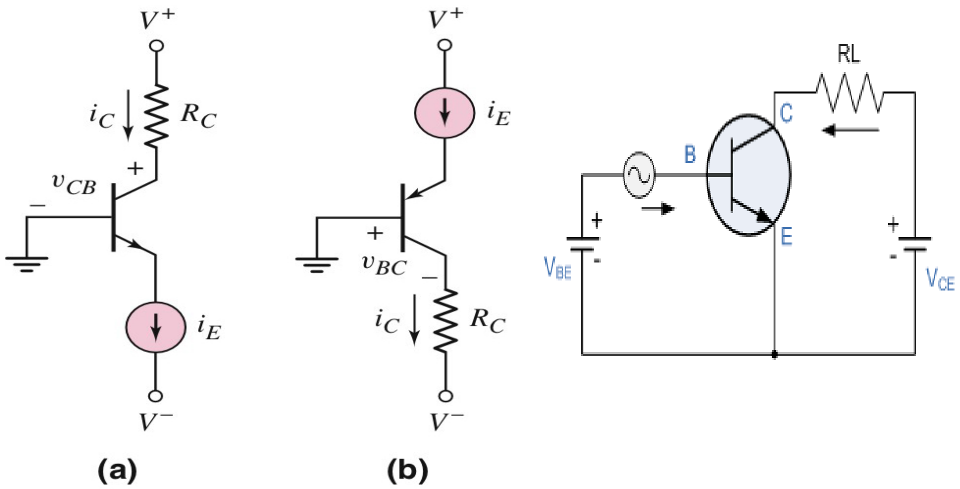
# Common Emitter Configuration






Notice emitter is common to both the base and the collector

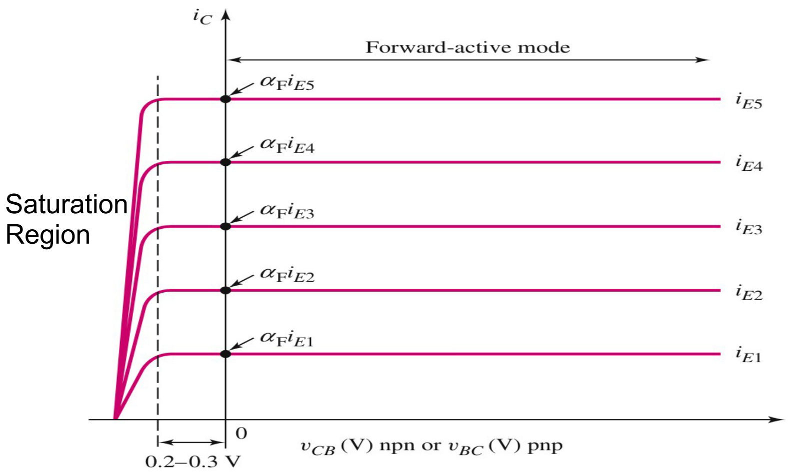
# Common-Base Configurtion







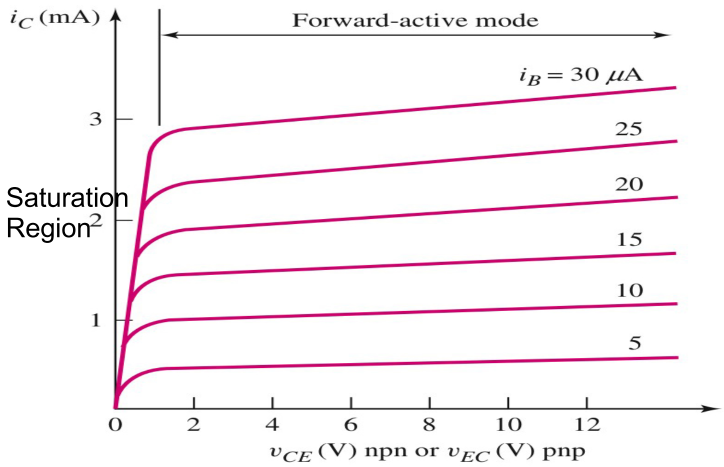

# I-V Characteristics of a Common-Base Circuit Configuration






Notice that $I_C = I_E$ which makes common base nearly a constant current source

# I-V Characteristics of a Common-Emitter Circuit Configuration



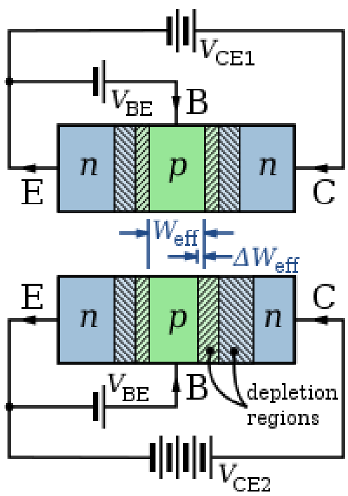

Notice that the common-emitter characteristics, collector current varies linearly with change in collector-emitter voltage at constant base current



# Early Effect

- It is the variation in the base width due to a variation in the applied collector- base voltage discovered by James M. Early

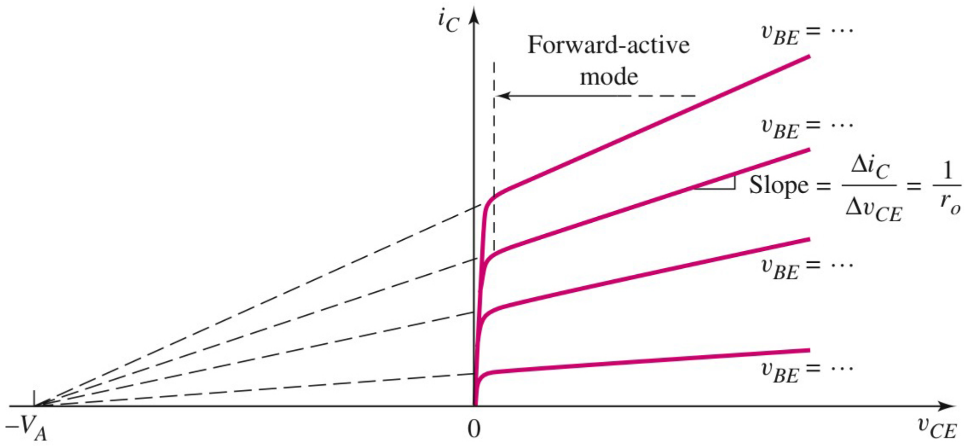
- A narrower base decreases the chance of recombination and therefore increases the number of minority charge carriers collected by the collector



# Early Voltage

- When the characteristics curve is extrapolated backwards they meet at a certain negative voltage ($-V_A$) on the voltage axis
- $V_A$ is the Early voltage
- Typical Values range $50V < V_A < 300V$








*Output Resistance of BJG*

$$\frac{1}{r_o} = \frac{\Delta i_C}{\Delta v_{CE}}$$

$$r_o \approx \frac{V_A}{\Delta I_C}$$

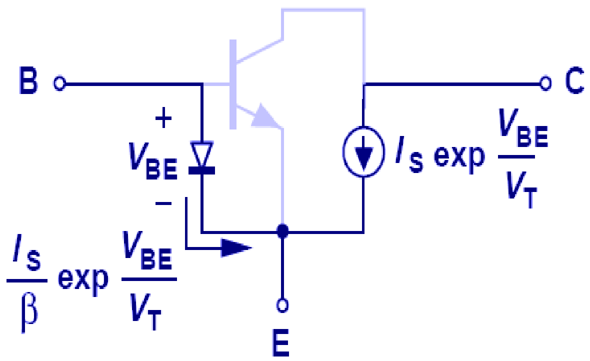
*Where $I_C$ is the $Q-$ point current at constant $v_{BE}$*

# Comparison of BJT Configuration Modes

| Characteristics | Common Base | Common Emitter | Common Collector |
|---|---|---|---|
| Input resistance $(R_i)$ | Low | Low | High |
| Output resistance $(R_o)$ | High | High | Low |
| Current amplification factor | $\alpha = \frac{\beta}{1+\beta}$ | $\beta = \frac{\alpha}{1-\alpha}$ | $\gamma = \frac{\alpha}{1-\alpha}$ |
| Phase relationship between input and output | In phase | Out of phase | In phase |
| Application | High frequency applications | Audio frequency application | Impedance matching |
| Current gain | Less than Unity | Greater than unity | Very high |
| Voltage gain | High | Greater than unity | Less than unity |



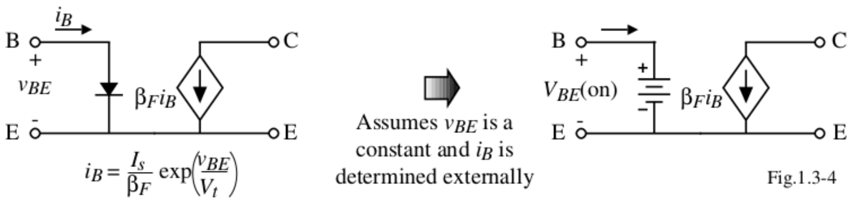
# BJT Large Signal Model in Active Mode



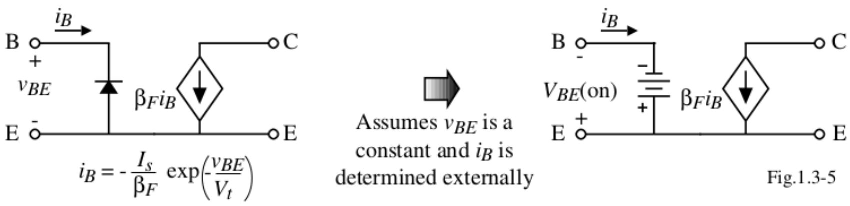

- In the active mode, the EBJ is forward and behaves like a diode in the forward biased mode.
  - A forward biased diode is placed between the base and diode terminals
- A voltage controlled current source is placed between the collector terminal and the emitter

# Large Signal Model in active Mode

Large-signal model for a *npn* transistor:



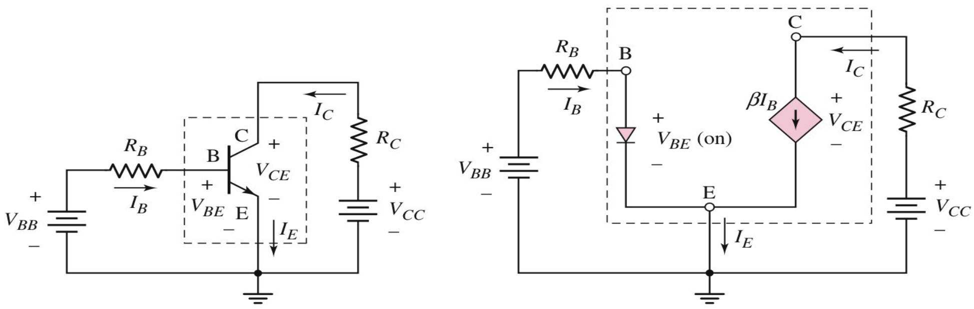

Large-signal model for a *pnp* transistor:




In this representation $\beta_F = \beta$ , the common emitter current gain

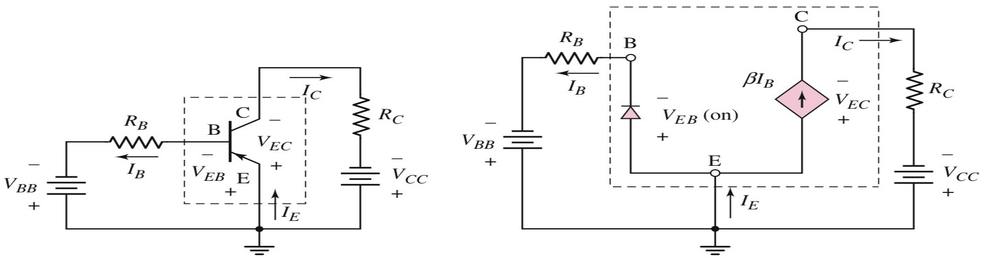


# DC Operating Point Determination




npn CE Mode






pnp CE Mode

# Next Lecture

- Load Line Analysis and Operating Point Determination
- Small Signal Model
- Transistor as Amplifier
- Operational amplifiers