COE/EE152: Basic Electronics

Lecture 5

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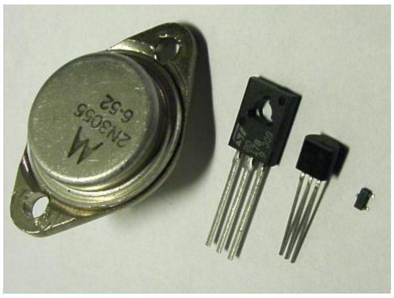
Outline

- 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

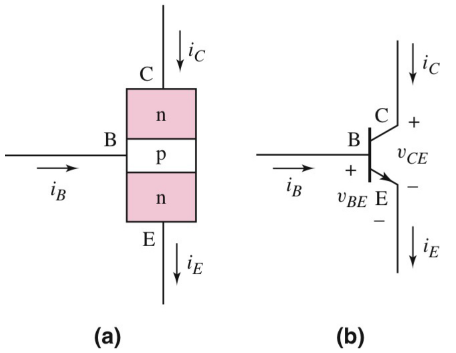
Bipolar Junction Transistors (BJTs)

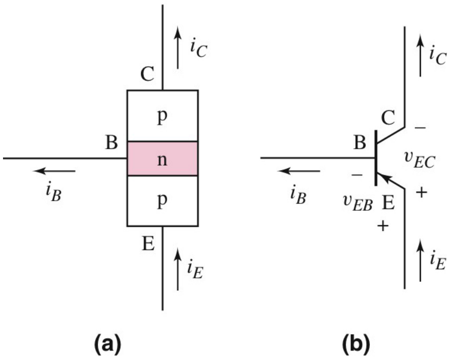
- The BJT is a nonlinear 3-terminal active device
- It can be thought of as a three layer sandwich with one type of doped semiconductor sandwiched between two oppositely doped ones
- Transistors are the basic building blocks of integrated circuits and can work as a switch on amplifier



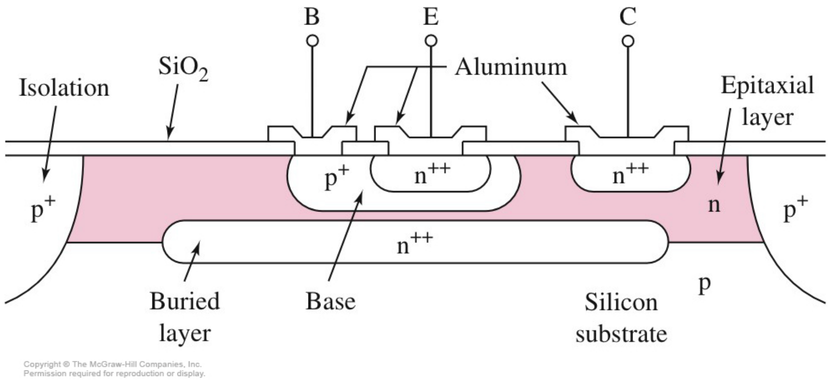
Physical Structure

- 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)

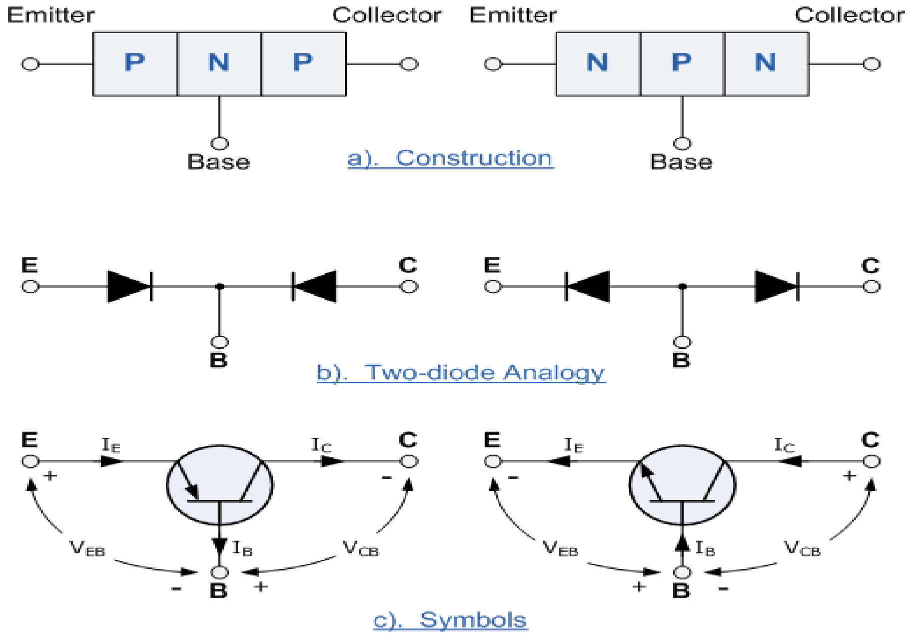




Cross Section of Integrated Circuit npn Transistor



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

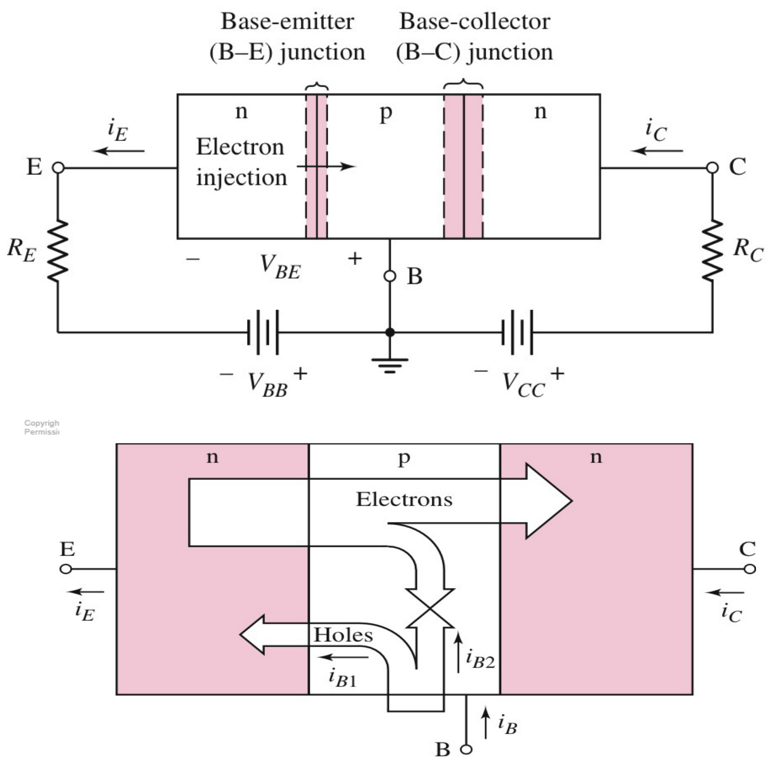
Mode	**EBJ**	**CBJ**	**Applications**
Cutoff	*Reverse*	*Reverse*	*Switching (Logic circuits): Assumed off and usually used for logic 'off' or '0'*
Forward-Active	*Forward*	*Reverse*	*Amplifier*
Reverse-Active	*Reverse*	*Forward*	*Not used*
Saturation	*Forward*	*Forward*	*Switching (Logic circuits): used 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 $\boldsymbol{V_{CB}}$



Profile of Carrier Concentrations of NPN

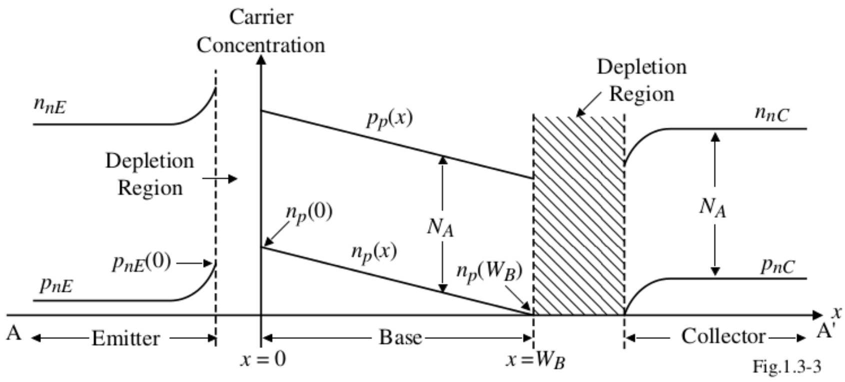


Fig.1.3-3

- 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):

$$i_E = i_C + I_B$$

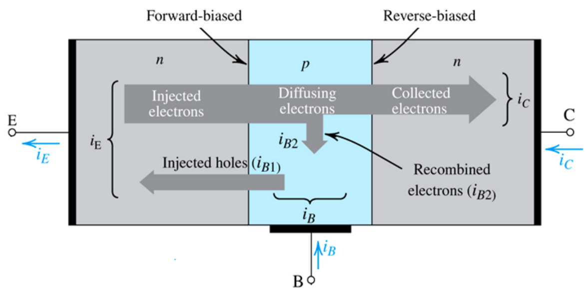
$$i_E = \frac{\beta+1}{\beta}\left(I_S e^{\frac{V_{BE}}{V_T}}\right)$$

Where:

i_C *is the collector current*
i_B *is the base current*
i_E *is the emitter current*
β *is the common emitter current gain*
α *is the common base current gain*

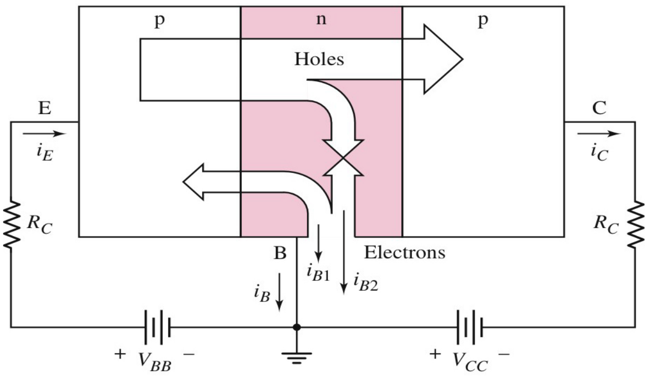
$$\alpha = \frac{\beta}{\beta+1}$$

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

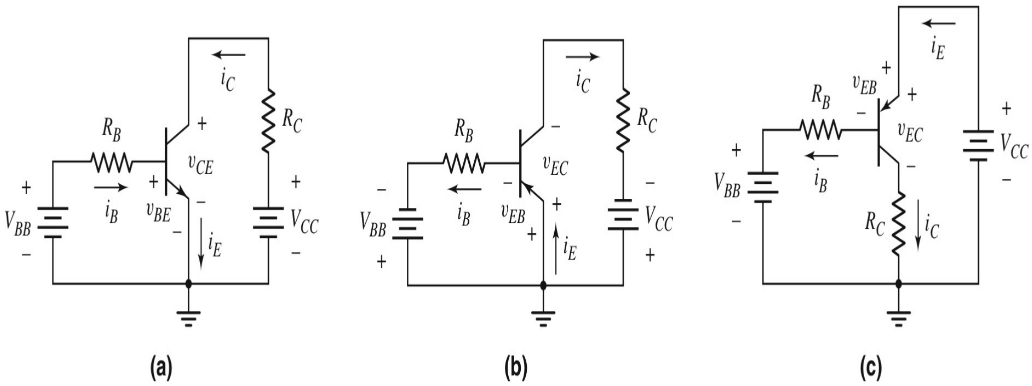
1. Calculate the collector and emitter currents given $\beta = 150$, $i_B = 15\mu A$

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

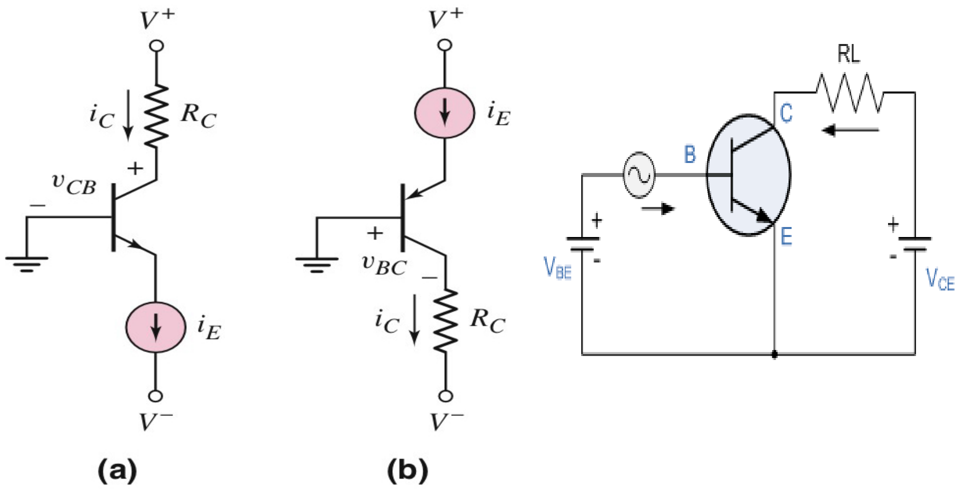
- There are three possible ways in connecting a transistor in a circuit
  - Common Base Configuration
    - The base is common to both the input and output
  - Common Emitter Configuration
    - The emitter is common to both the input and the output
  - Common Collector Configuration
    - The collector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

Common Emitter Configuration

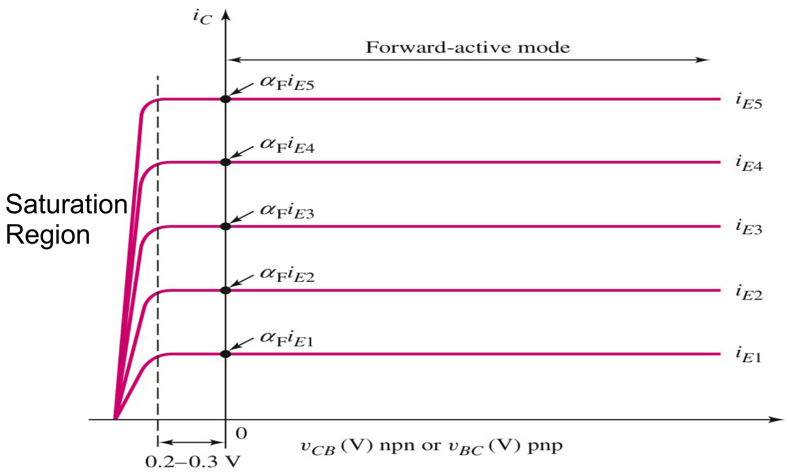


Notice emitter is common to both the base and the collector

Common-Base Configurtion

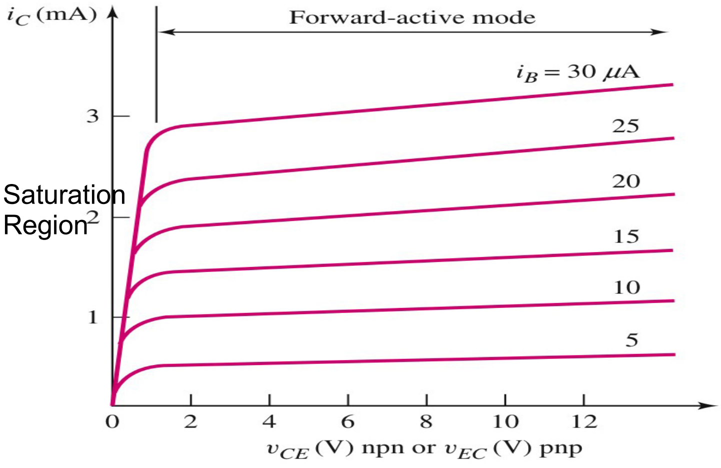


I-V Characteristics of a Common-Base Circuit Configuration



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

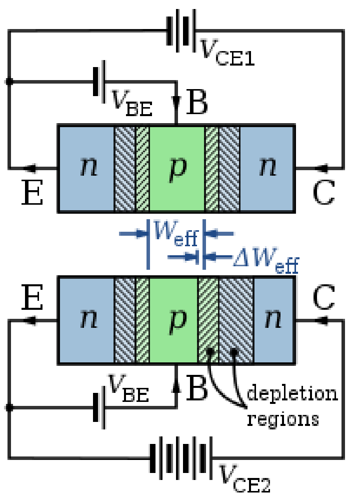
I-V Characteristics of a Common-Emitter Circuit Configuration



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

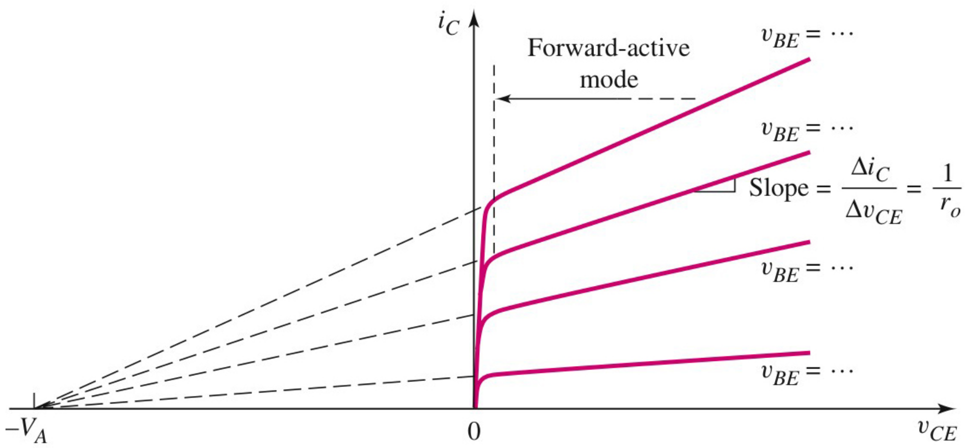
Early Effect

- 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

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

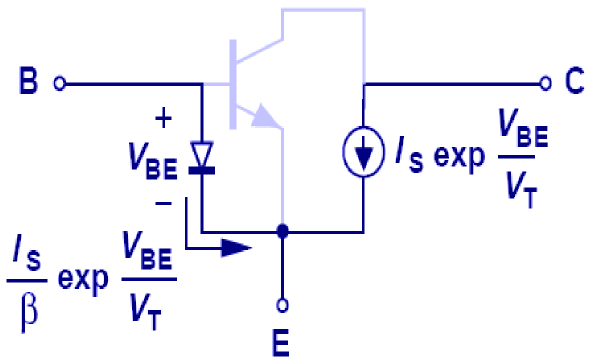
$$r_o \approx \frac{V_A}{\Delta I_C}$$

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

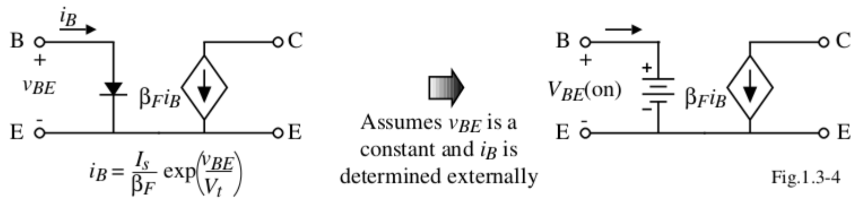
BJT Large Signal Model in Active Mode



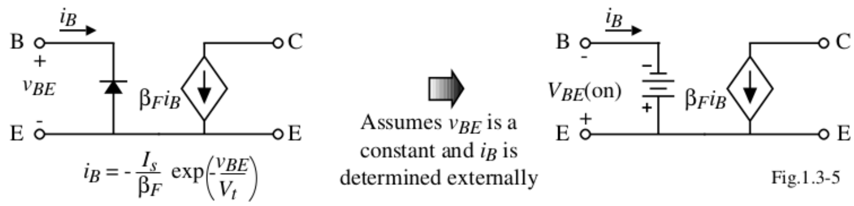
- In the active mode, the EBJ is forward and behaves like a diode in the forward biased mode.
  - A forward biased diode is placed between the base and diode terminals
- A voltage controlled current source is placed between the collector terminal and the emitter

Large Signal Model in active Mode

Large-signal model for a *npn* transistor:

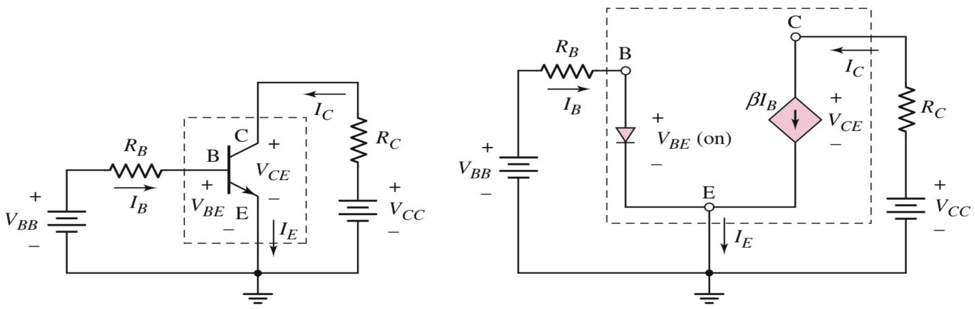


Large-signal model for a *pnp* transistor:

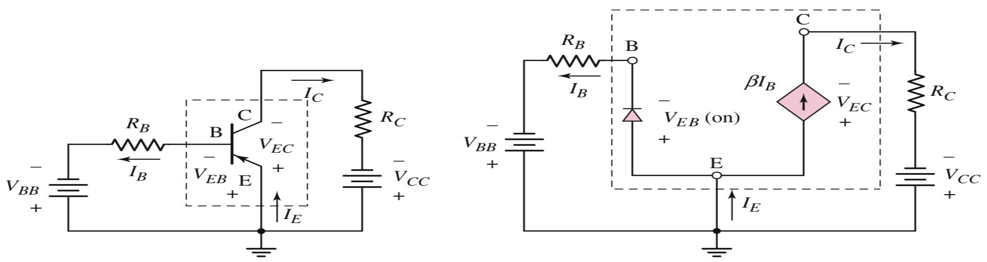


In this representation $\beta_F = \beta$, the common emitter current gain

DC Operating Point Determination



(a) npn CE Mode (b)



(a) pnp CE Mode (b)

Next Lecture

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