Electronic Devices and Circuits

EME306

(Summer 2021-2022)

Lecture 10

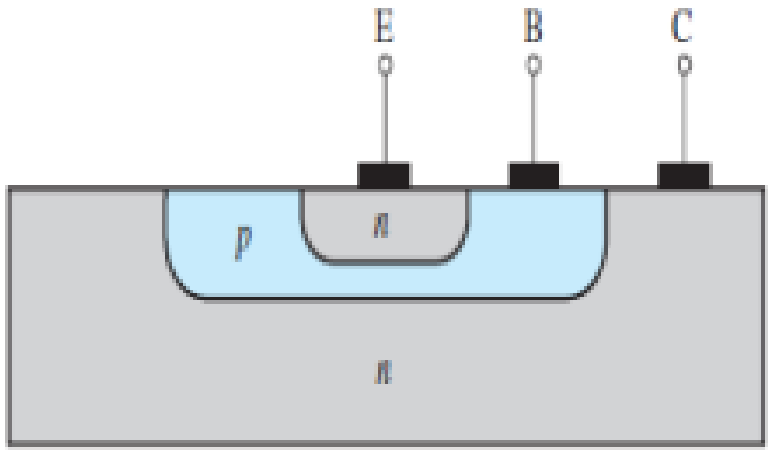
Bipolar Junction Transistors (BJTs)

INSTRUCTOR

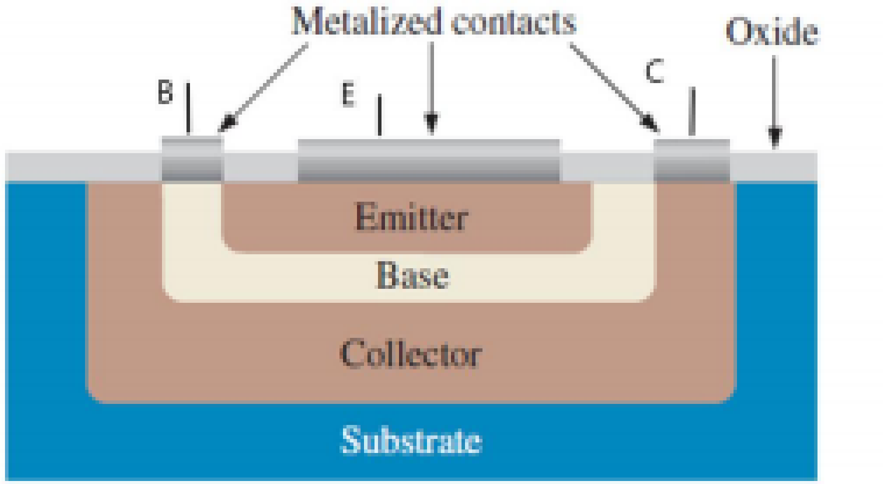
Dr / Ayman Soliman

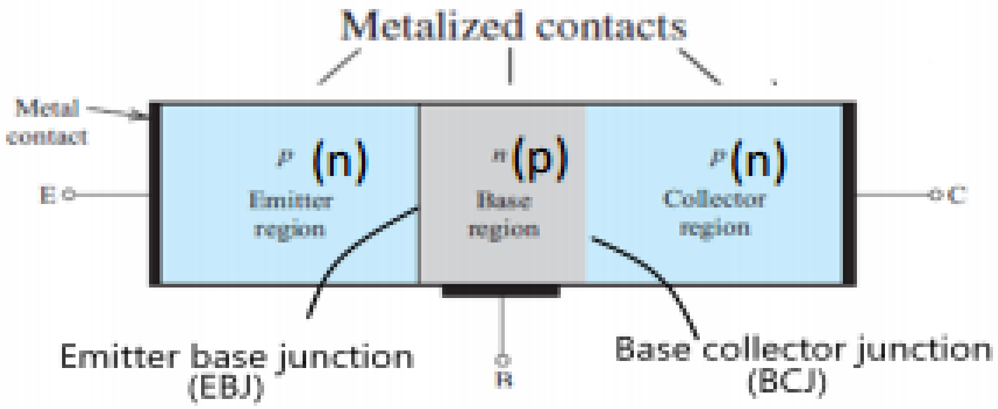
Contents

Simplified Structure

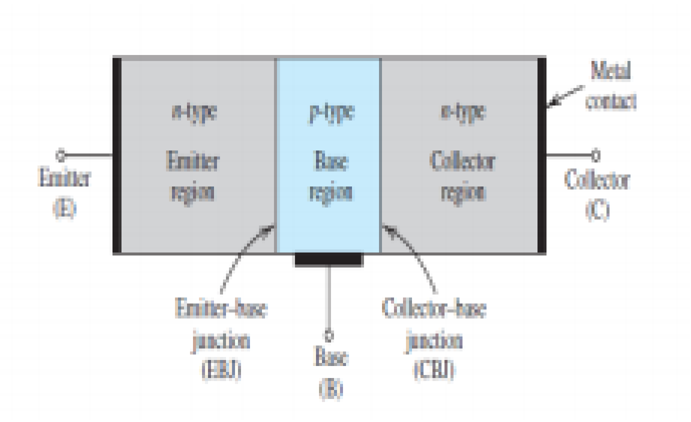


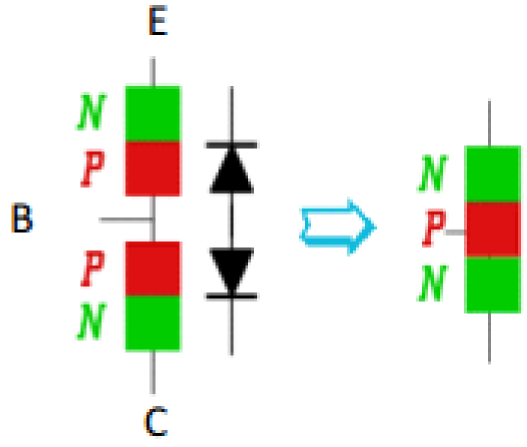
Cross section of an npn BJT.

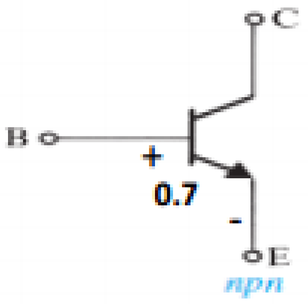


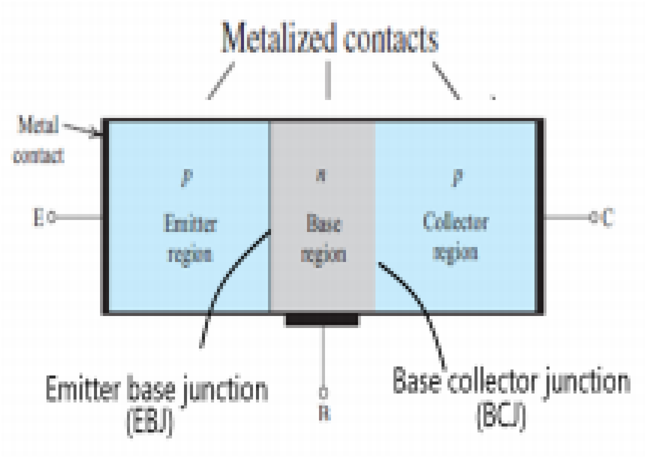


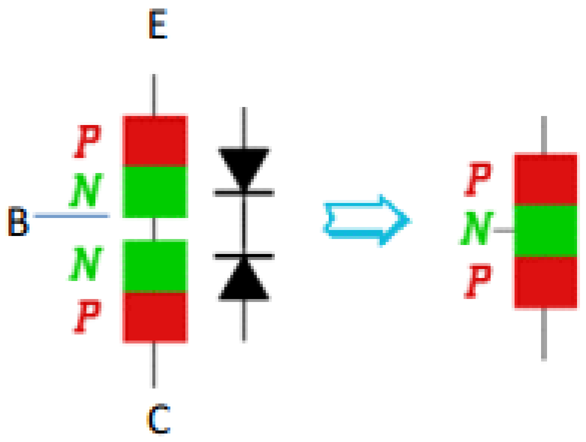
Transistors Types & symbols

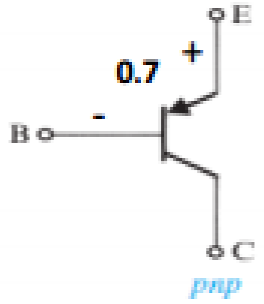






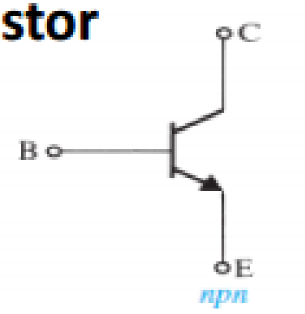


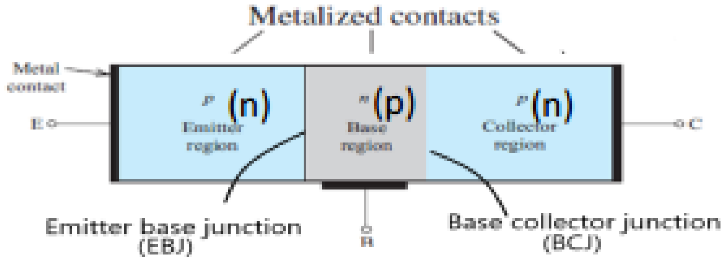


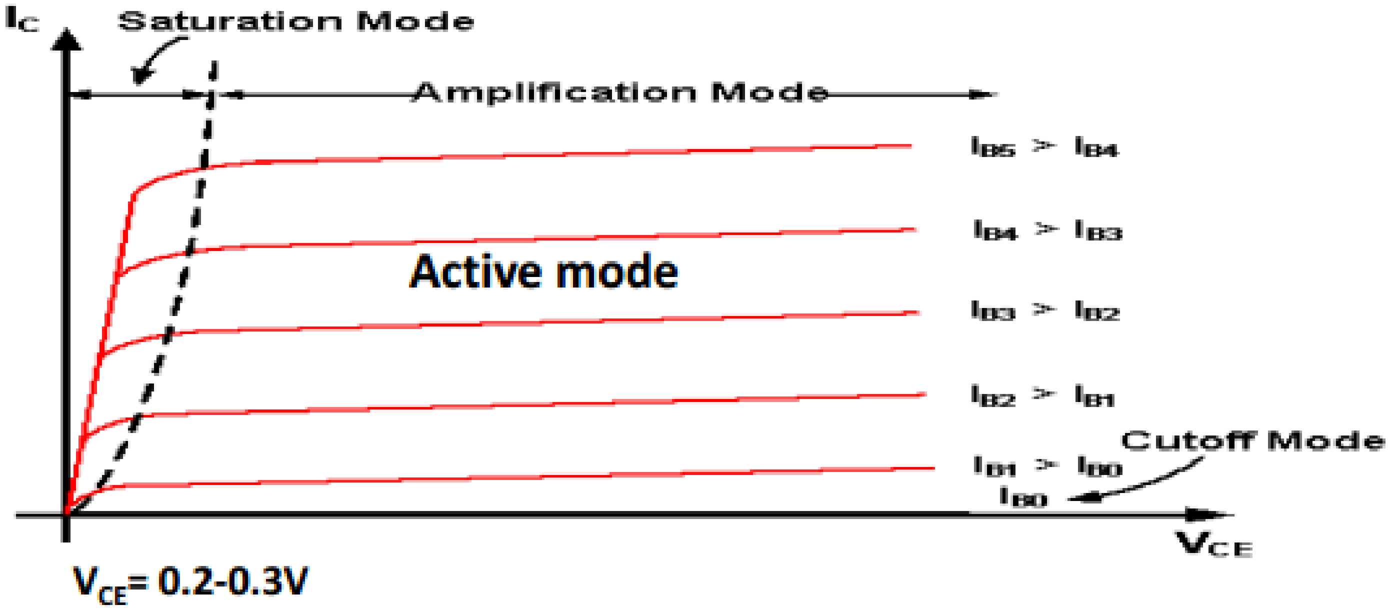


Modes of Operation

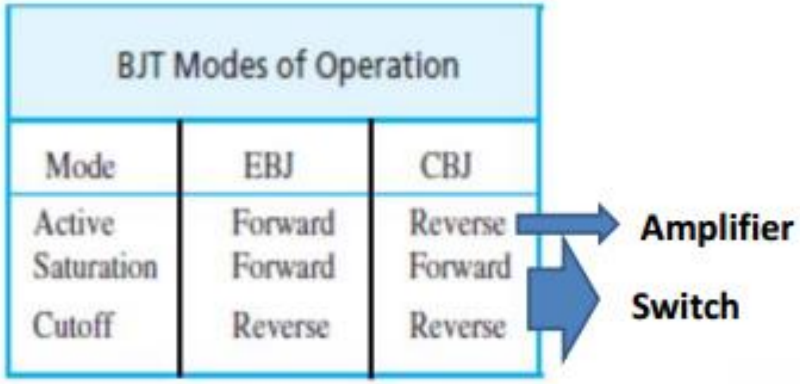
For NPN Transistor







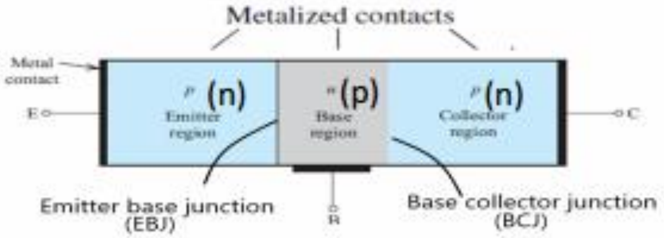
Modes of Operation

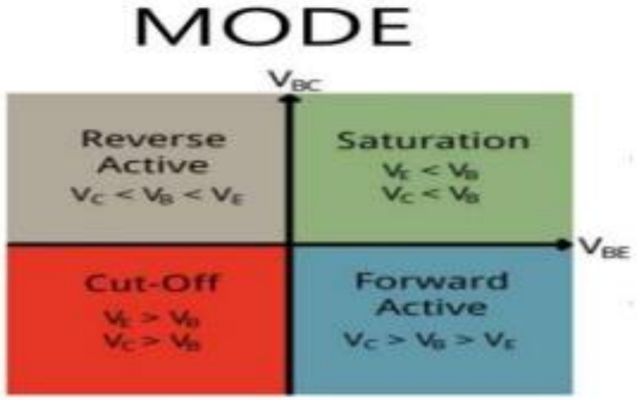


BJT Modes of Operation		
Mode	EBJ	CBJ
Active	Forward	Reverse
Saturation	Forward	Forward
Cutoff	Reverse	Reverse

Amplifier

Switch



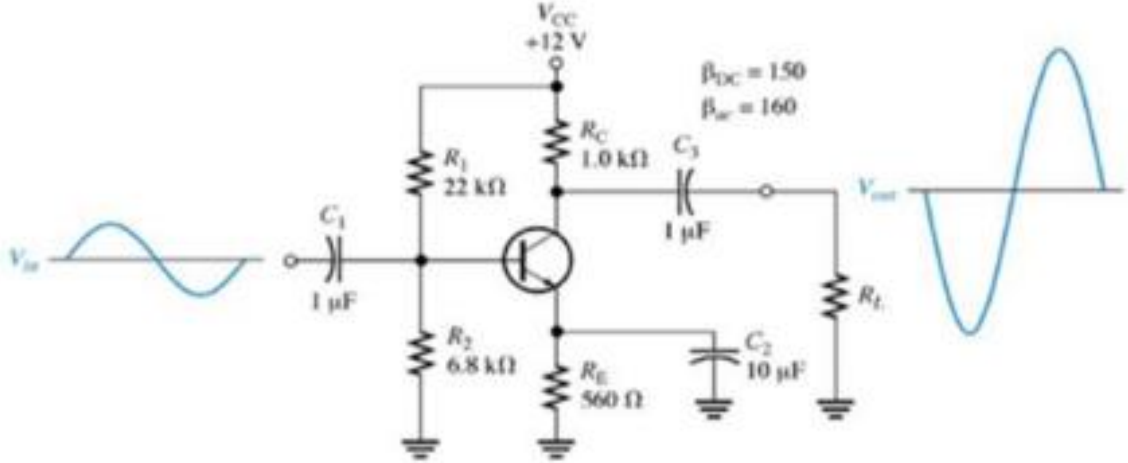


MODE

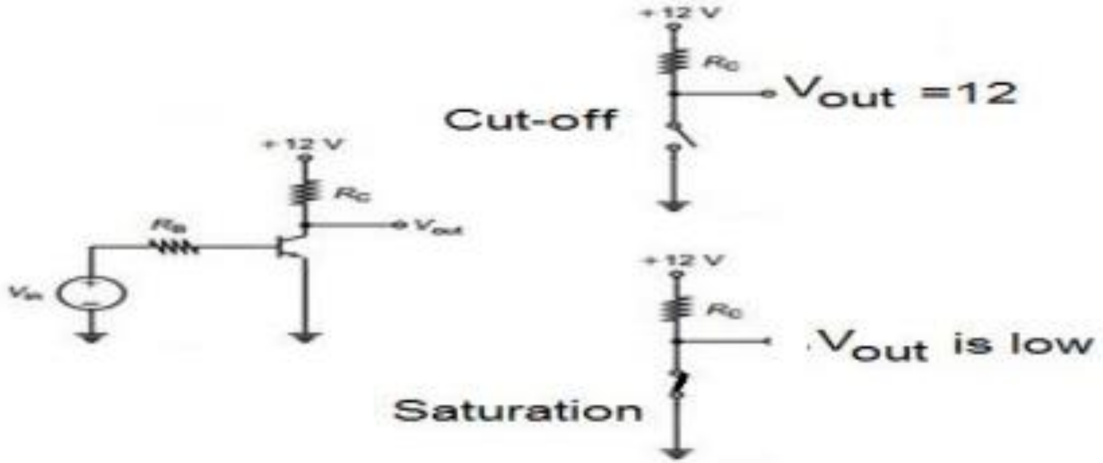
Reverse Active $V_C < V_B < V_E$	Saturation $V_E < V_B$ $V_C < V_B$
Cut-Off $V_E > V_B$ $V_C > V_B$	Forward Active $V_C > V_B > V_E$

Applications of regions of operations

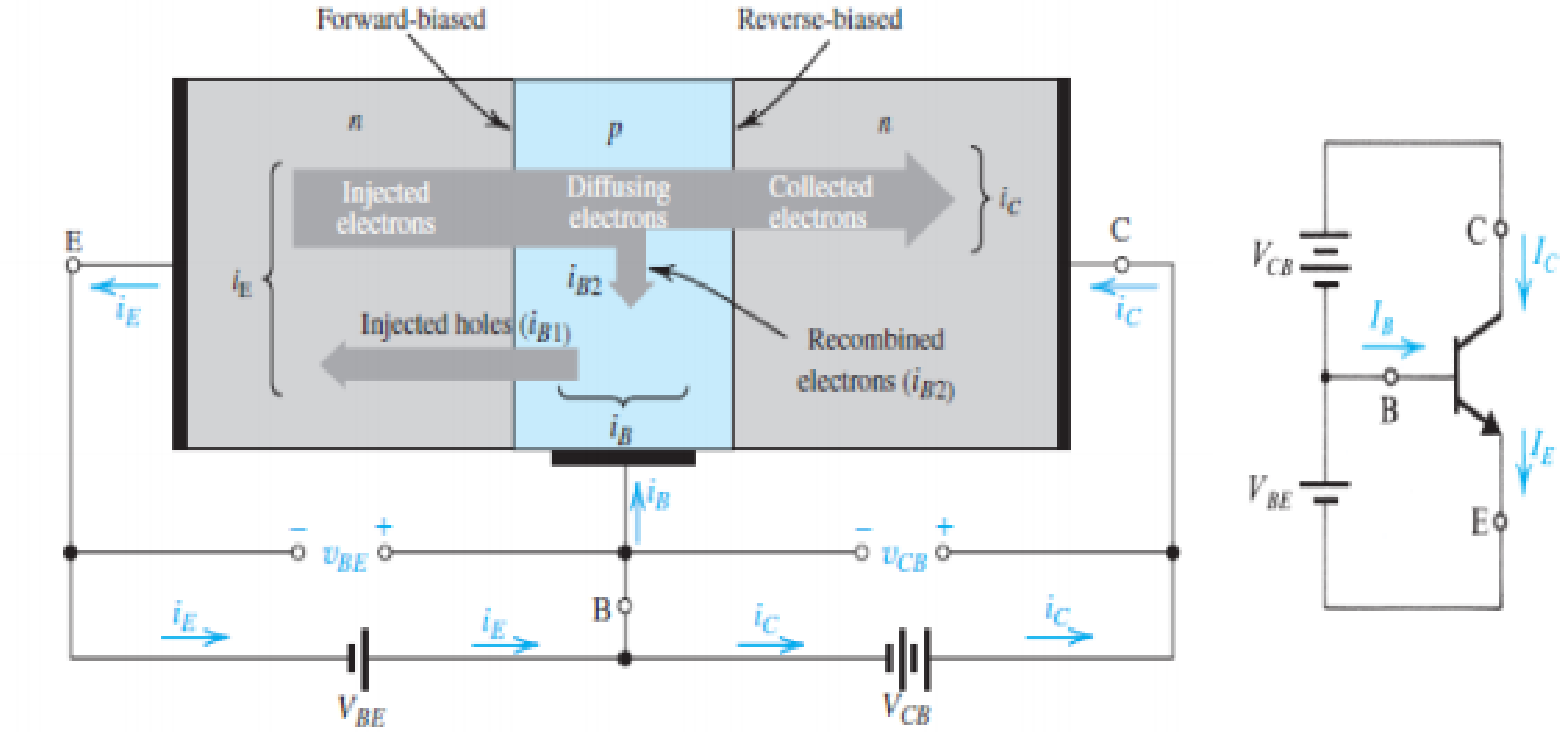
Amplifier



Switch



Operation of the NPN Transistor in the Active Mode



The Emitter Current

- the emitter current IE is equal to the sum of the collector current IC and the base current IB

$$i_E = i_B + i_C = i_B + \beta i_B = (1+\beta) i_B = i_C / \alpha$$

$$i_E = \frac{i_C}{\alpha} = \frac{I_s}{\alpha} e^{V_{BE}/V_T}$$

$$I_E > I_C > I_B$$

$$I_C = \beta I_B$$

$$I_E = I_B + I_C = (1+\beta) I_B$$

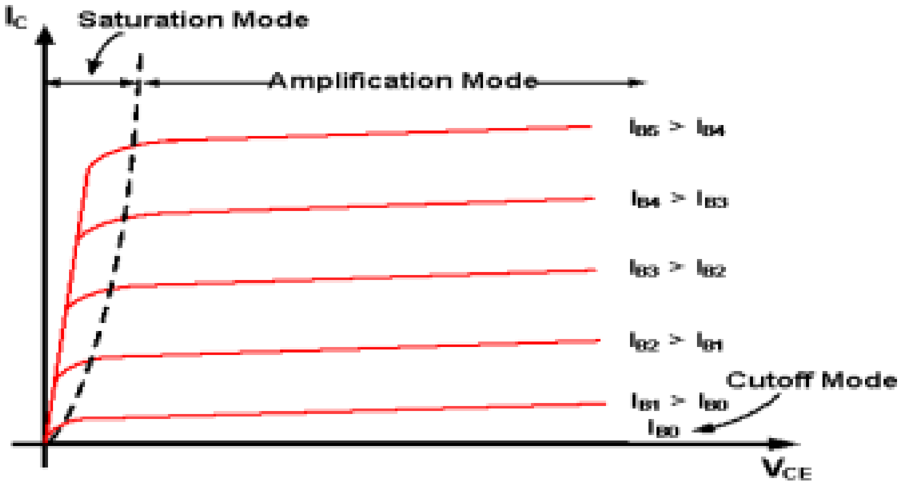
$$I_C = \alpha I_E$$

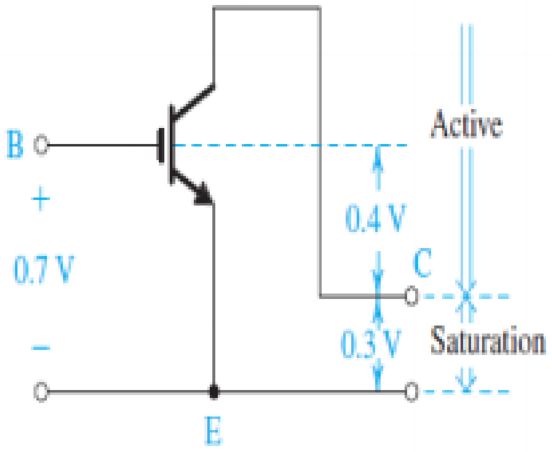
$$\beta = \frac{\alpha}{1-\alpha}, \qquad \beta >> 1$$

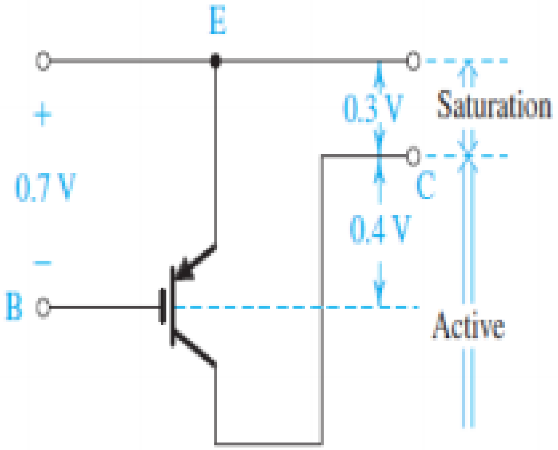
$$\alpha = \frac{\beta}{1+\beta}, \qquad \alpha << 1$$

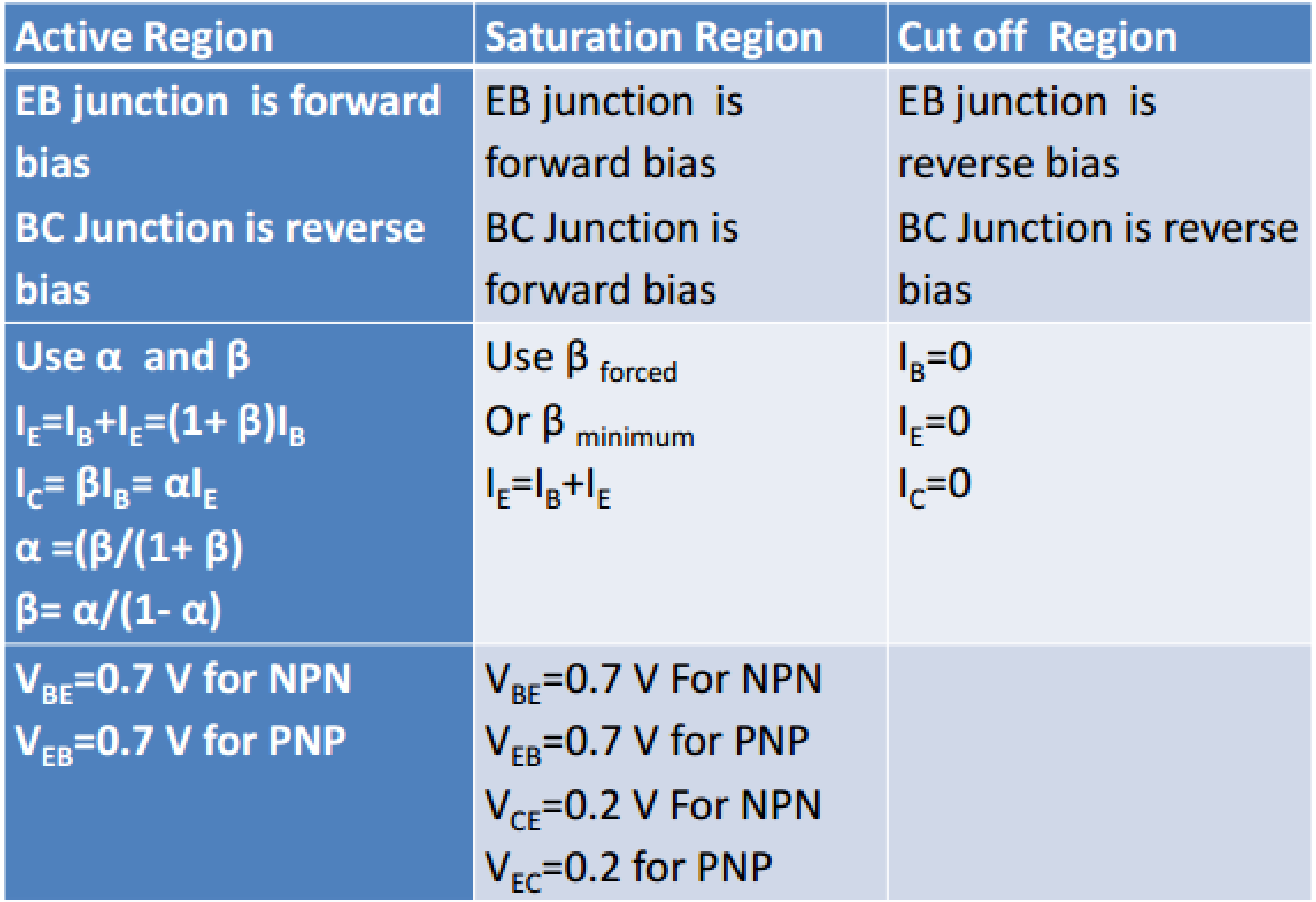
α, β are current gain

V_{EB} and V_{CE} for Active and saturation





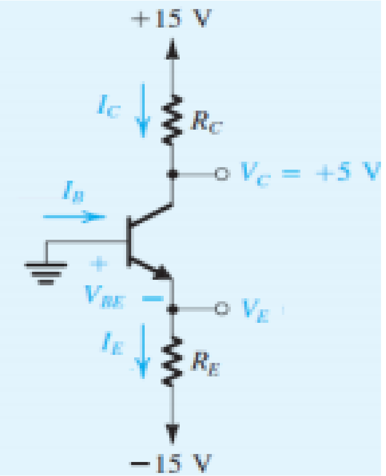




Active Region	Saturation Region	Cut off Region
EB junction is forward bias BC Junction is reverse bias	EB junction is forward bias BC Junction is forward bias	EB junction is reverse bias BC Junction is reverse bias
Use α and β $I_E=I_B+I_E=(1+\beta)I_B$ $I_C=\beta I_B=\alpha I_E$ $\alpha=(\beta/(1+\beta)$ $\beta=\alpha/(1-\alpha)$	Use β_{forced} Or β_{minimum} $I_E=I_B+I_E$	$I_B=0$ $I_E=0$ $I_C=0$
$V_{BE}=0.7$ V for NPN $V_{EB}=0.7$ V for PNP	$V_{BE}=0.7$ V For NPN $V_{EB}=0.7$ V for PNP $V_{CE}=0.2$ V For NPN $V_{EC}=0.2$ for PNP	

Example

The transistor shown in Fig. has β =100 and v_{BE} of 0.7 V at I_C =1 mA. Design the circuit so that a current of 2 mA flows through the collector and a voltage of +5 V appears at the collector



Assume transistor operates in Active region

$$R_C = \frac{15 - V_C}{I_C} = \frac{15-5}{2mA} = 5K\Omega$$

Since I_C=1 mA at V_{BE}=0.7 , then

$$V_{BE2} - V_{BE1} = V_T * \ln({}^{I_{C2}}\!/\!{}_{I_{C1}})$$

$$V_{BE2} - 0.7 = 0.025 * \ln(2/1) \qquad V_{BE2} = 0.717V \quad V_E = -0.717V$$

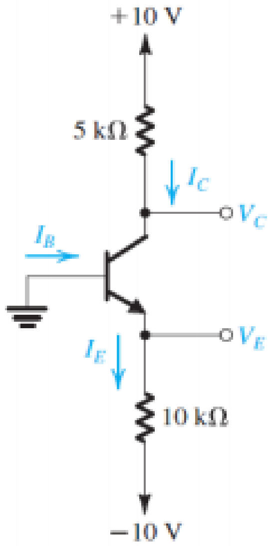
$$I_E = {}^{I_C}\!/\!{}_{\alpha} = {}^{2mA}\!/\!{}_{100/101} = 2.02mA$$

$$R_E = \frac{V_E - V_{EE}}{I_E} = \frac{-0.717+15}{2.02} = 7.07K\Omega$$

Check
V_E= - 0.717 , V_B=0, V_c = 5
Since V_B > V_E Then EB_j is Forward
Sine V_C > V_B Then BC_j is reverse
Then Transistor operates in Active Region

Example

For the circuit shown, given β=50, find all currents and voltages



Assume operate in active

$V_B=0$, $V_E= - 0.7$ V

$I_E=(-0.7-(-10))/10=0.93$mA

$I_C=\alpha\ I_E=(50/51)*0.93=0.911764$ mA

$I_B=I_E/(1+\beta)=0.93/51=0.0182353$mA

$V_C=10-I_C*R_C=10- 0.911764*5=5.4412$V

Check

$V_E= - 0.7$v , $V_B=0$v, $V_c = 5.44$v

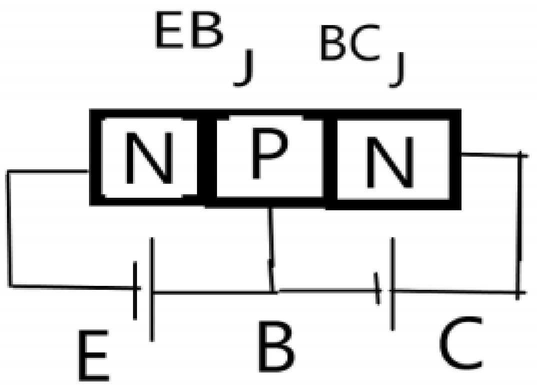
Since $V_B > V_E$

Then EB_J is Forward

Sine $V_C > V_B$

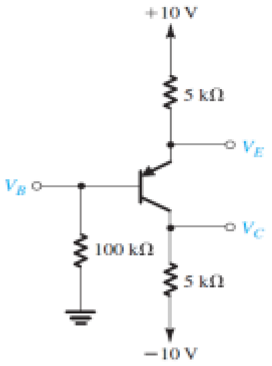
Then BC_J is reverse

Then Transistor operates in Active Region as assumed



Example

In the circuit shown , measurement indicates V_B to be +1.0 V. What are α and β for this transistor? What voltage V_C do you expect at the collector



Assume operate in active

V_B=1, V_E= V_B+ 0.7=1.7 V

I_E=(10- V_E)/5=(10-1.7)/5=1.66 mA

I_B= V_B/R_B= 1.0/100=0.01mA

I_C= I_E –I_B =1.66-0.01=1.65 mA

β= I_C / I_B =1.65/0.01=165

α=(β/1+ β)=165/166=0.99397

V_C=I_C*R_C-10= 1.65*5-10=-1.75v

Check

V_E= 1.7v , V_B=1v, V_c = -1.75v

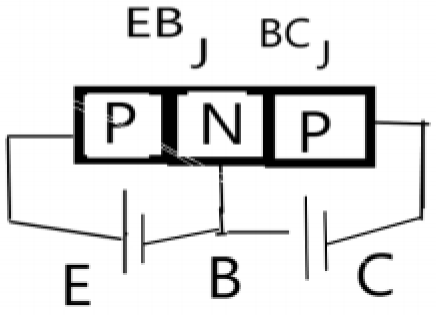
Since V_E > V_B

Then EB_J is Forward

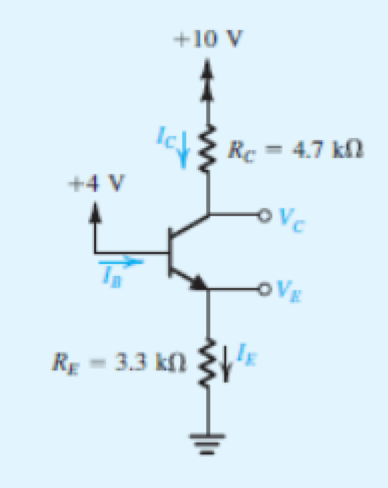
Sine V_B > V_C

Then BC_J is reverse

Then Transistor operates in Active Region as assumed



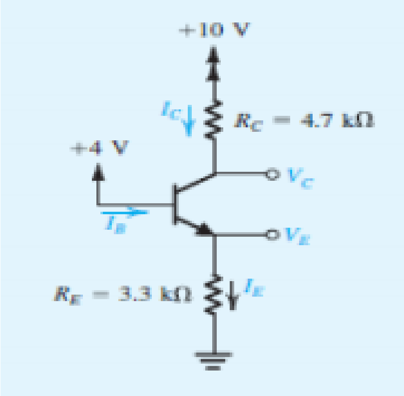
Example
Consider the circuit shown, β is specified to be 100.find all node voltages and currents



Assume operate in active

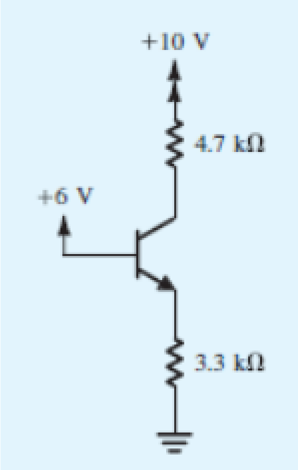
V_B=4v, V_E= 4- 0.7=3.3 V
I_E=(3.3-0)/3.3=1.0 mA
I_C=α I_E=(100/101)*1.0=0.9901 mA
I_B=I_E/(1+β)=1.0/101=0.009901mA
V_C=10-I_C*R_C=10- 0.9901*4.7=5.34653V

Check
V_E= 3.3 v , V_B=4v, V_c = 5.34653v
Since V_B > V_E
Then EB_J is Forward
Sine V_C > V_B
Then BC_J is Reverse
Then Transistor operates in active region as assumed



Example

Consider the circuit shown, β is specified to be 100.find all node voltages and currents



Assume operate in active

V_B=6v, V_E= 6- 0.7=5.3 V

I_E=(5.3-0)/3.3=1.6061 mA

I_C=α I_E=(100/101)*1.6061=1.59016 mA

I_B=I_E/(1+β)=1.6061/101=0.015902mA

V_C=10-I_C*R_C=10- 1.59016*4.7=2.52625V

Check

V_E= 5.3 v , V_B=6v, V_c = 2.52625 v

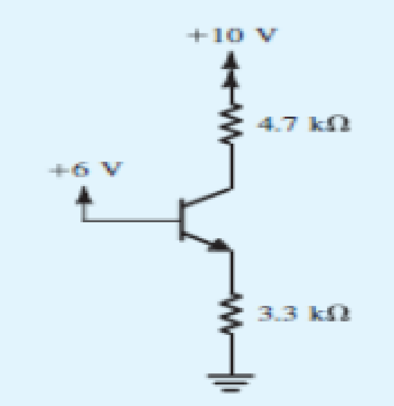
Since V_B > V_E

Then EB_J is Forward

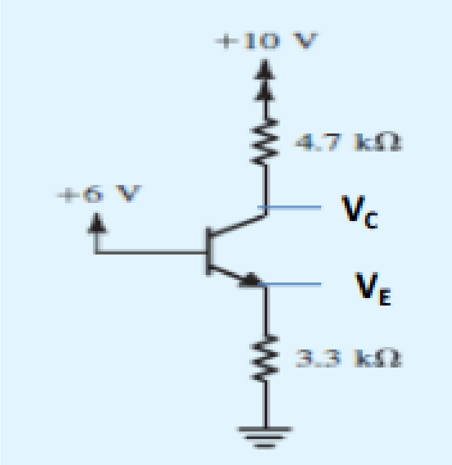
Sine V_B > V_C

Then BC_J is forward

Then Transistor operates in saturation Region



So, the transistor operates in Saturation region



V_B=6v, V_E= 6- 0.7=5.3 V

I_E=(5.3-0)/3.3=1.6061 mA

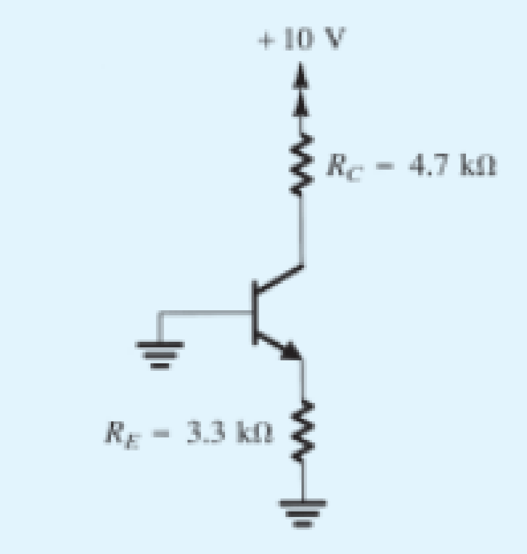
Sine V_{CE}=0.2 V, then V_C = V_E+0.2=5.3+0.2=5.5V

I_C=(10-5.5)/4.7=0.95744mA
I_B= I_E -I_C=1.6061-0.95744= 0.64866mA

B_{forced}= I_C / I_B =0.95744/0.64855=1.476

Example

Consider the circuit shown, β is specified to be 100.find all node voltages and currents



Assume operate in active

V_B=0 v,

V_E= 0- 0.7= -0.7 V

I_E=(-0.7-0)/3.3= - 0.5263 mA

The current pass in reverse direction, so transistor is in cut off

Then I_C=0, I_B=0, I_E=0

V_C=10.0 V

V_B=0.0 V

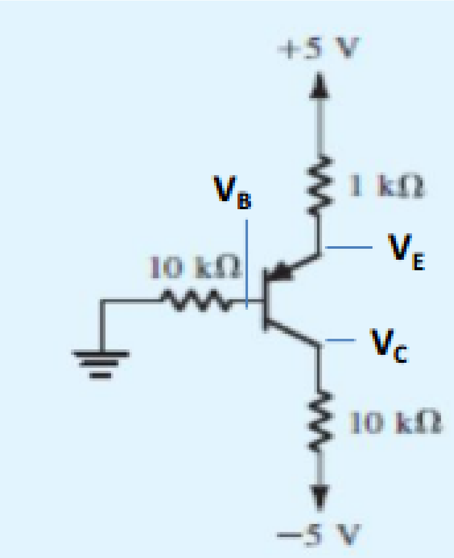
V_E=0.0 V

Example

Consider the circuit shown,

$\beta_{minimum}$ =30

.find all node voltages and currents



Assume operate in saturation

V_{EC}=0.2V, V_{EB}=0.7

V_E =V_C +0.2, V_B=V_E-0.7= V_C -0.5

I_E=I_B+I_C

$$\frac{5-V_E}{1}=\frac{V_B-0}{10}+\frac{V_C+5}{10}$$

$$\frac{5-V_c-0.2}{1}=\frac{V_C-0.5}{10}+\frac{V_C+5}{10}$$

V_c= 3.625V, V_B= 3.125V, V_E= 3.825V

I_c= 0.8625mA, I_B= 0.3125mA, I_E=1.175mA

V_c= 3.625V, V_B= 3.125V, V_E= 3.825V

Check

V_E= 3.825 v , V_B=3.125v,

V_c = 3.625v

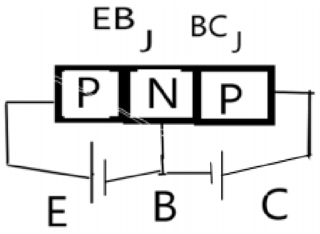
Since V_E > V_B

Then EB_J is Forward

Sine V_C > V_B

Then BC_J is forward

Then Transistor operates in saturation Region



B_{forced}= I_C / I_B =0.8625/0.3125=2.76

Which is much smaller than $B_{minimum}$ given

Example

Determine the voltages at all nodes and the currents through all branches. Assume β = 100

Assume operate in active

V_{th} = 15*50/(100+50)=5 V

R_{th} = (100*50)/(100+50)=33.33KΩ

$5=I_B*R_B+0.7+I_E*R_E$

$5=I_B*R_B+0.7+I_B(1+\beta)*R_E$

$5=I_B*33.33+0.7+I_B(1+100)*3$

I_B = 0.012785 mA

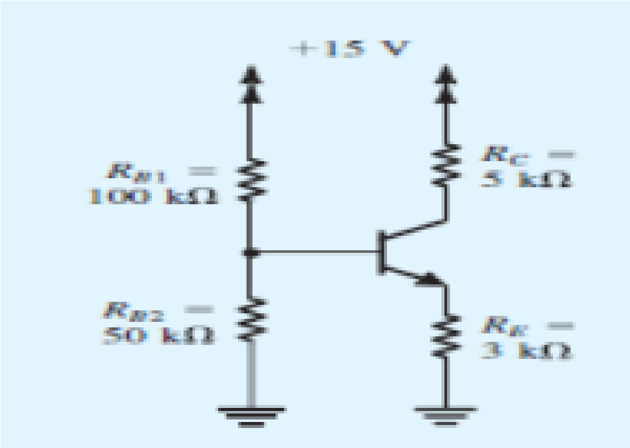
I_C = 1.2785 mA

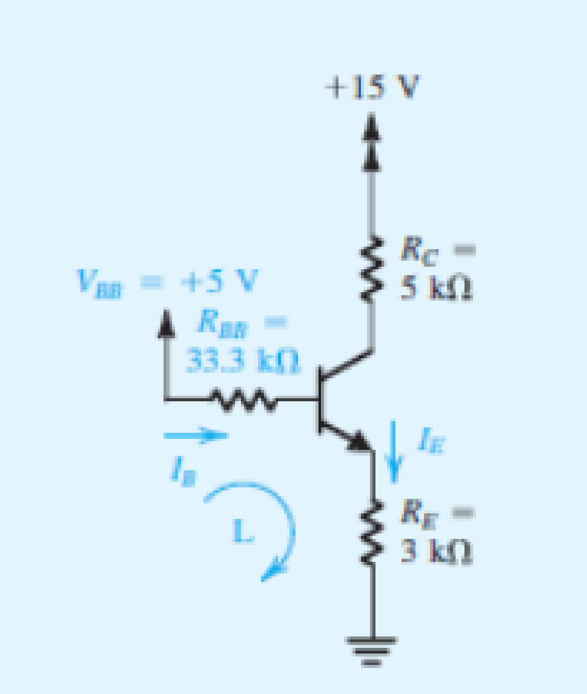
I_E = 1.29129 mA

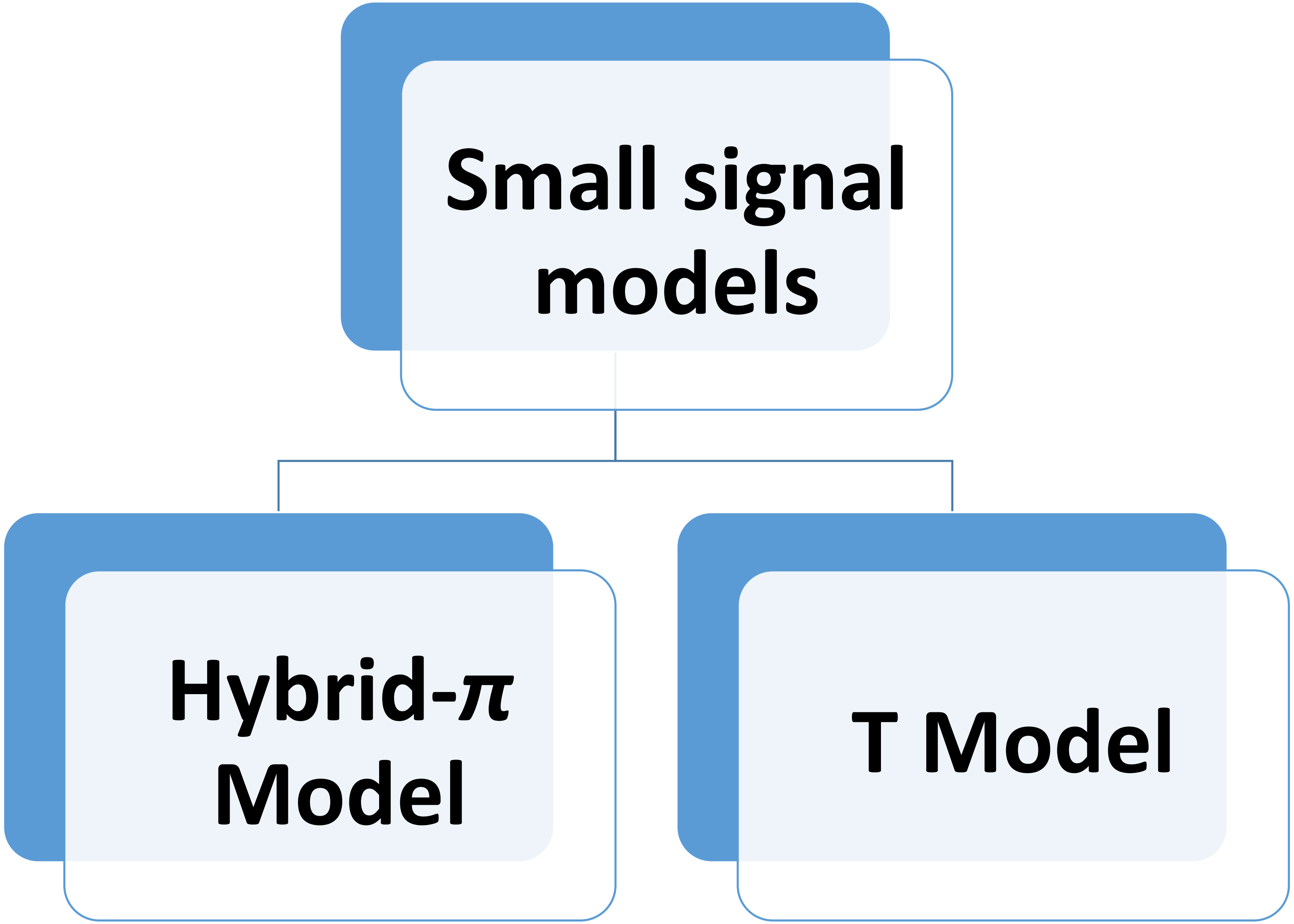
$V_E = I_E*R_E$= 3.87387 V

$V_B=V_E+0.7$=4.57387V

$V_C=15-I_C*R_C=15-1.2785*5$=8.61V





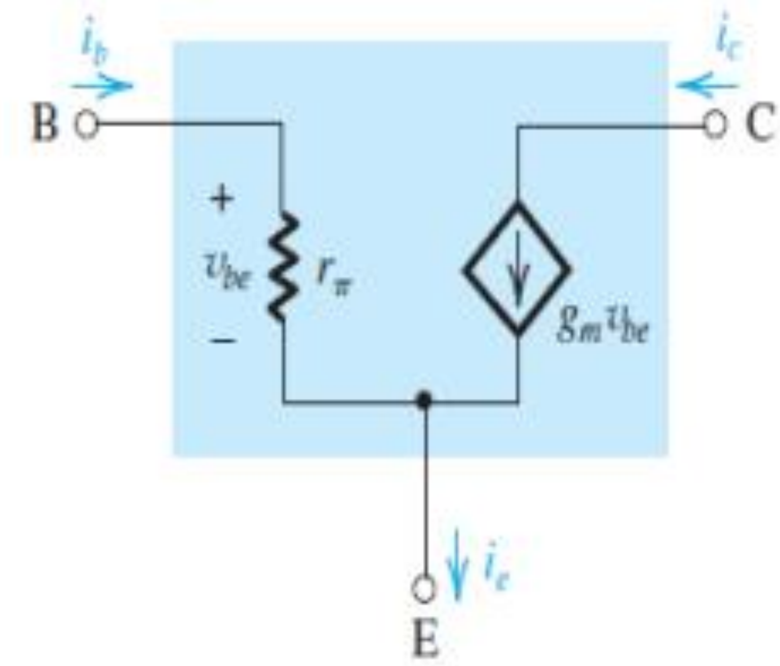


Small signal models

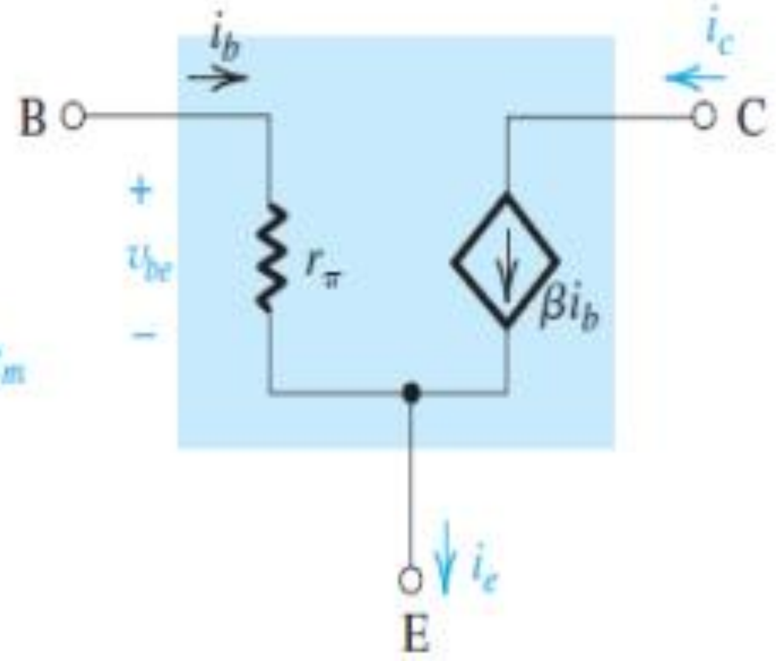
Hybrid-π Model

T Model

Hybrid-π Model

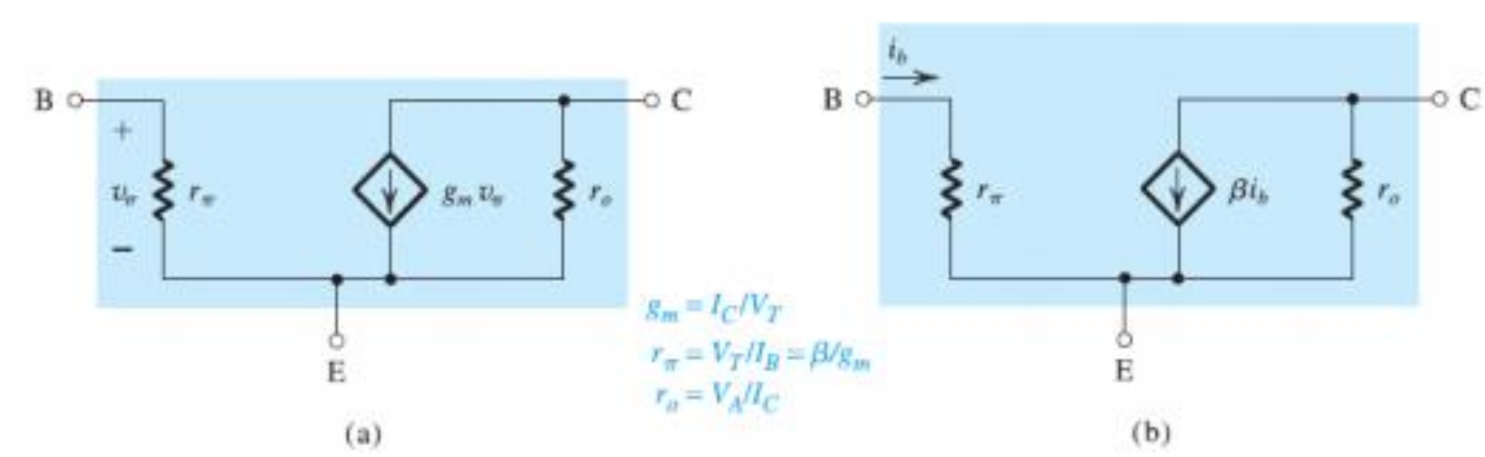


$$g_m = I_C/V_T$$
$$r_\pi = V_T/I_B = \beta/g_m$$

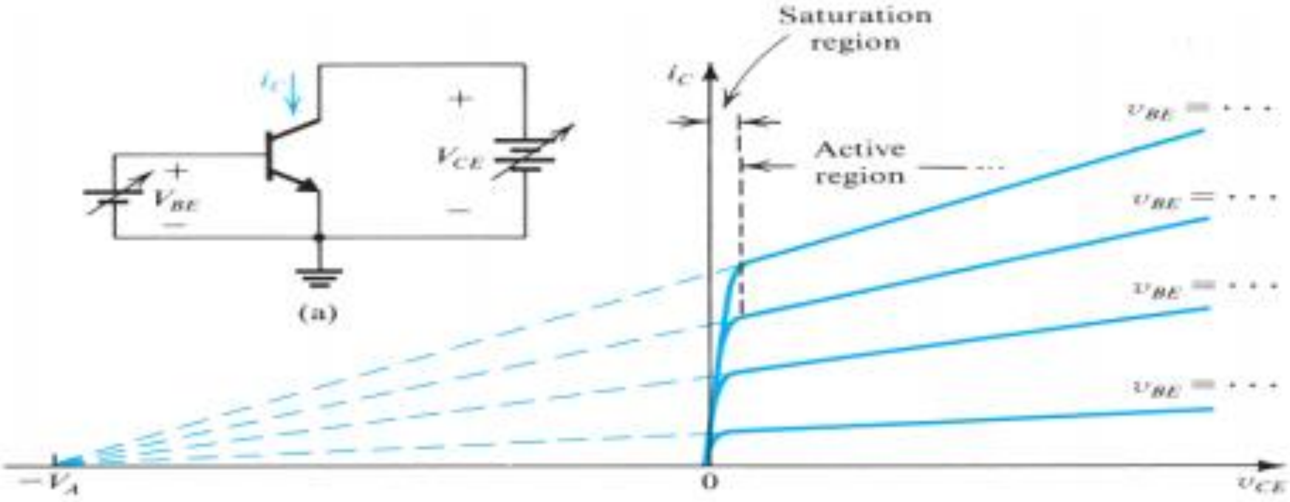


$$\begin{aligned} g_m v_{be} &= g_m(i_b r_\pi) \\ &= (g_m r_\pi) i_b = \beta i_b \end{aligned}$$

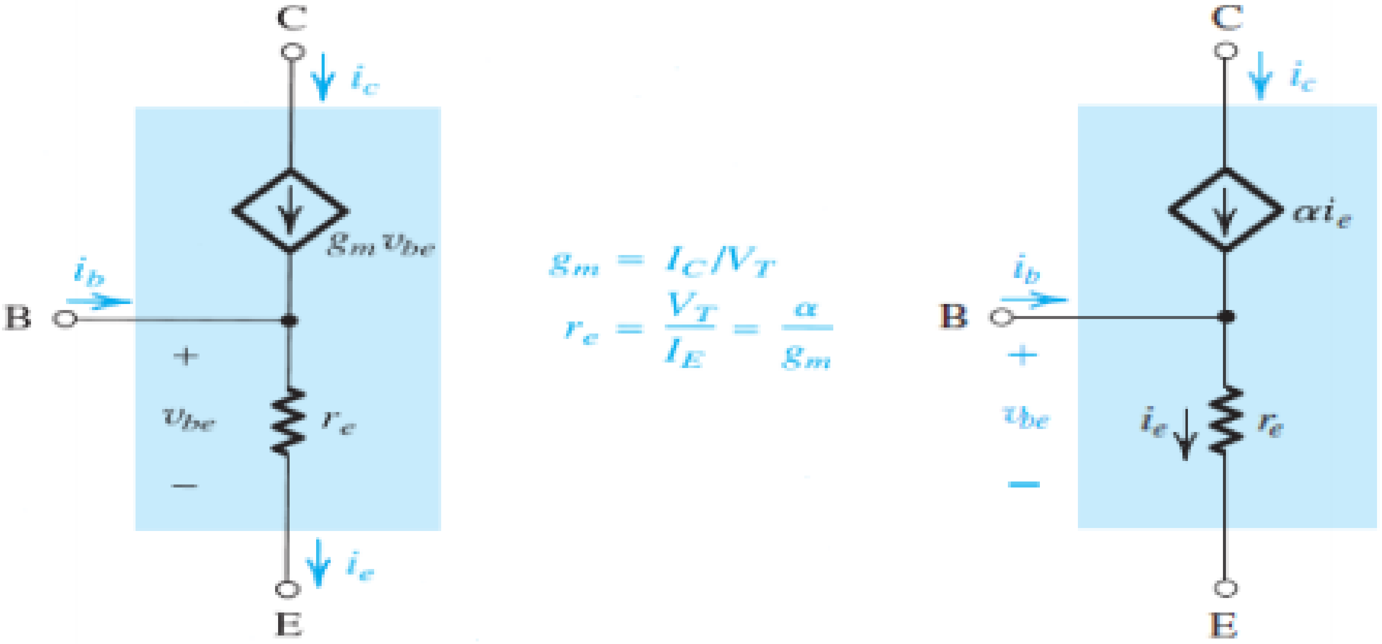
The Hybrid-π Model take ro into consideration



$$r_o = \frac{V_A}{I_C}$$



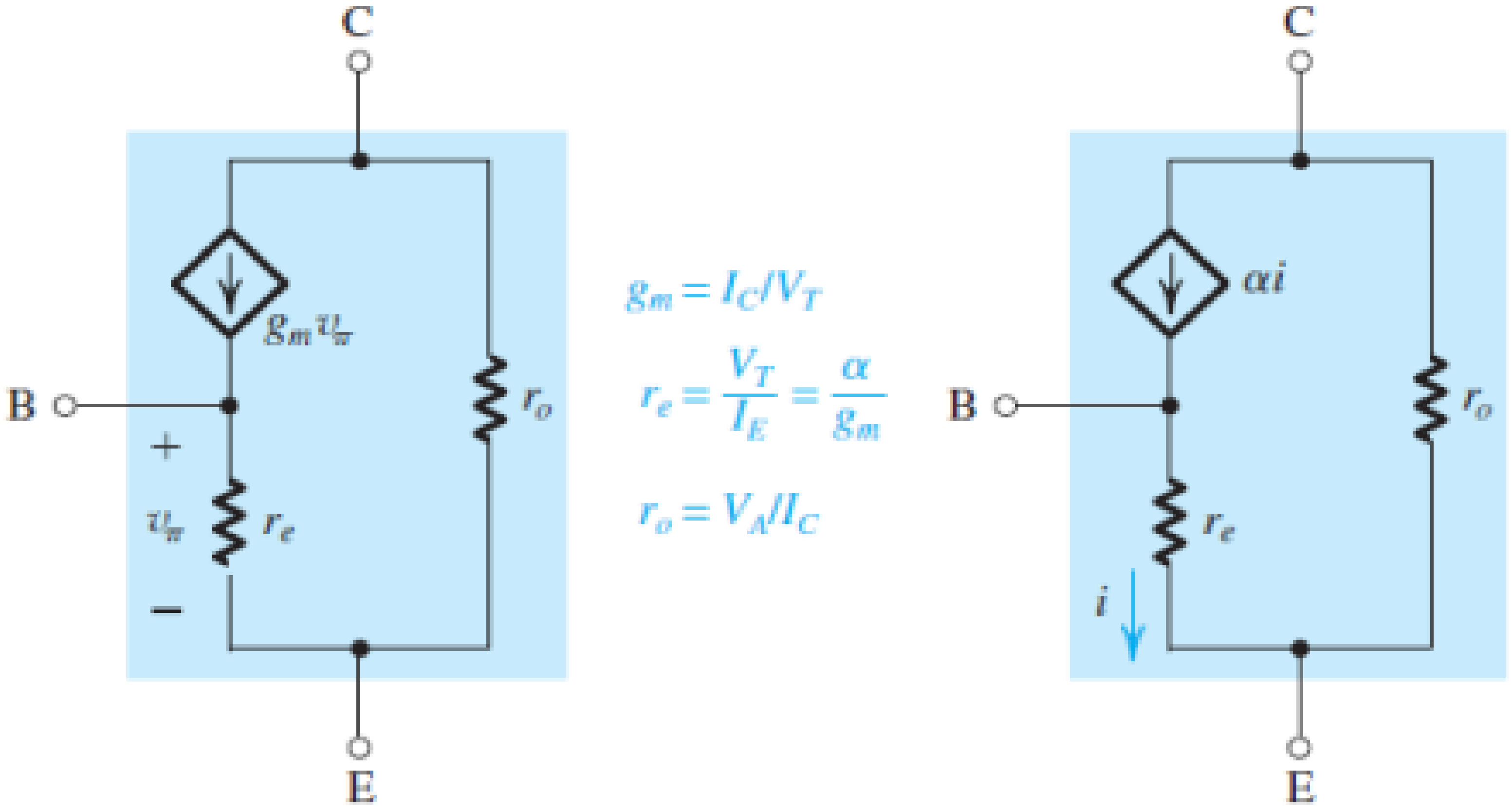
The T Model



$$g_m v_{be} = g_m(i_e r_e)$$

$$= (g_m r_e) i_e = \alpha i_e$$

The T Model take ro into consideration



$$g_m = I_C/V_T$$

$$r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m}$$

$$r_o = V_A/I_C$$


Thank
you