Handout 2 for EE-203

Bipolar Junction Transistor (BJT)

Sheikh Sharif Iqbal

(Ref: Text book and
KFUPM Online course of EE-203)

(Remember to solve all the related examples, exercises problems as given in the Syllabus)

Chapter 5: Bipolar Junction Transistor (BJT)

***Text book**: "Microelectronic Circuits by Sedra and Smith*

5.1: Device Structure and Physical Operation

- BJT is a three terminal device that can operate as "Amplifier" or as "Switch"
- Voltage between the two terminals is used to control the current in the third terminal
- BJT consist of three semiconductor regions: NPN or PNP

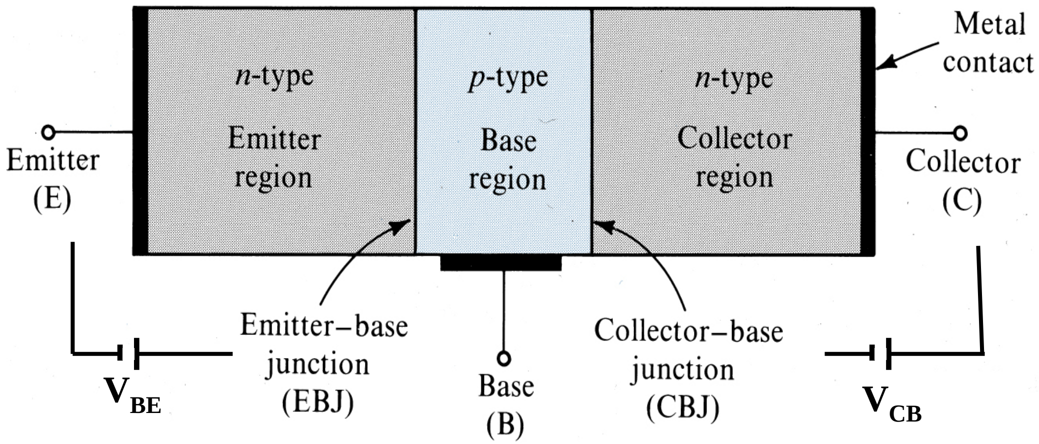
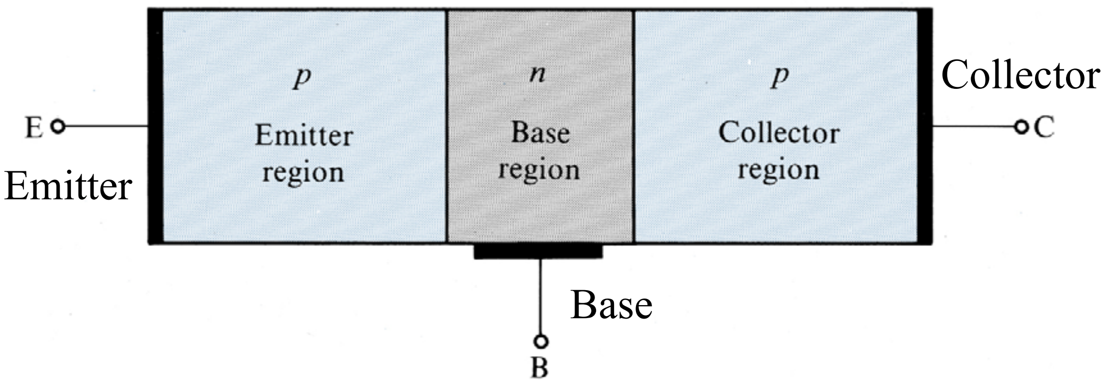
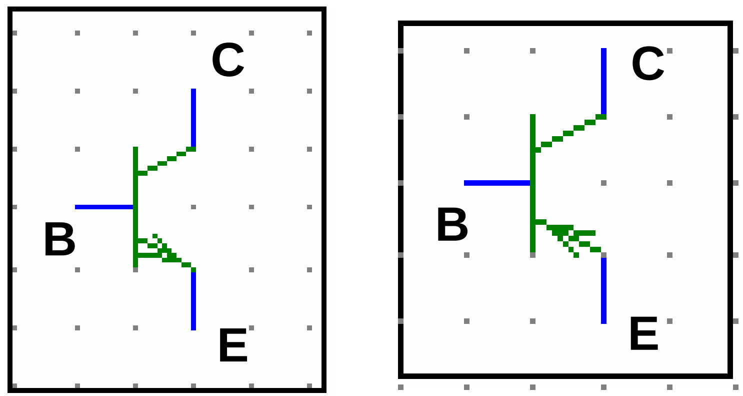


Table 5.1: BJT Modes of operation			
Application	Mode	EBJ	CBJ
Amplifier	**Active**	Forward	Reverse
Switch	Cutoff	Reverse	Reverse
	Saturation	Forward	Forward





Figures from text book

Symbols: NPN and PNP

Active Mode of Operation of an NPN transistor:

N-Type material: Arsenic, Antimony and Phosphorus (group V materials)

P-Type material: Aluminum, Boron and Gallium (group III materials)

Figure from text book

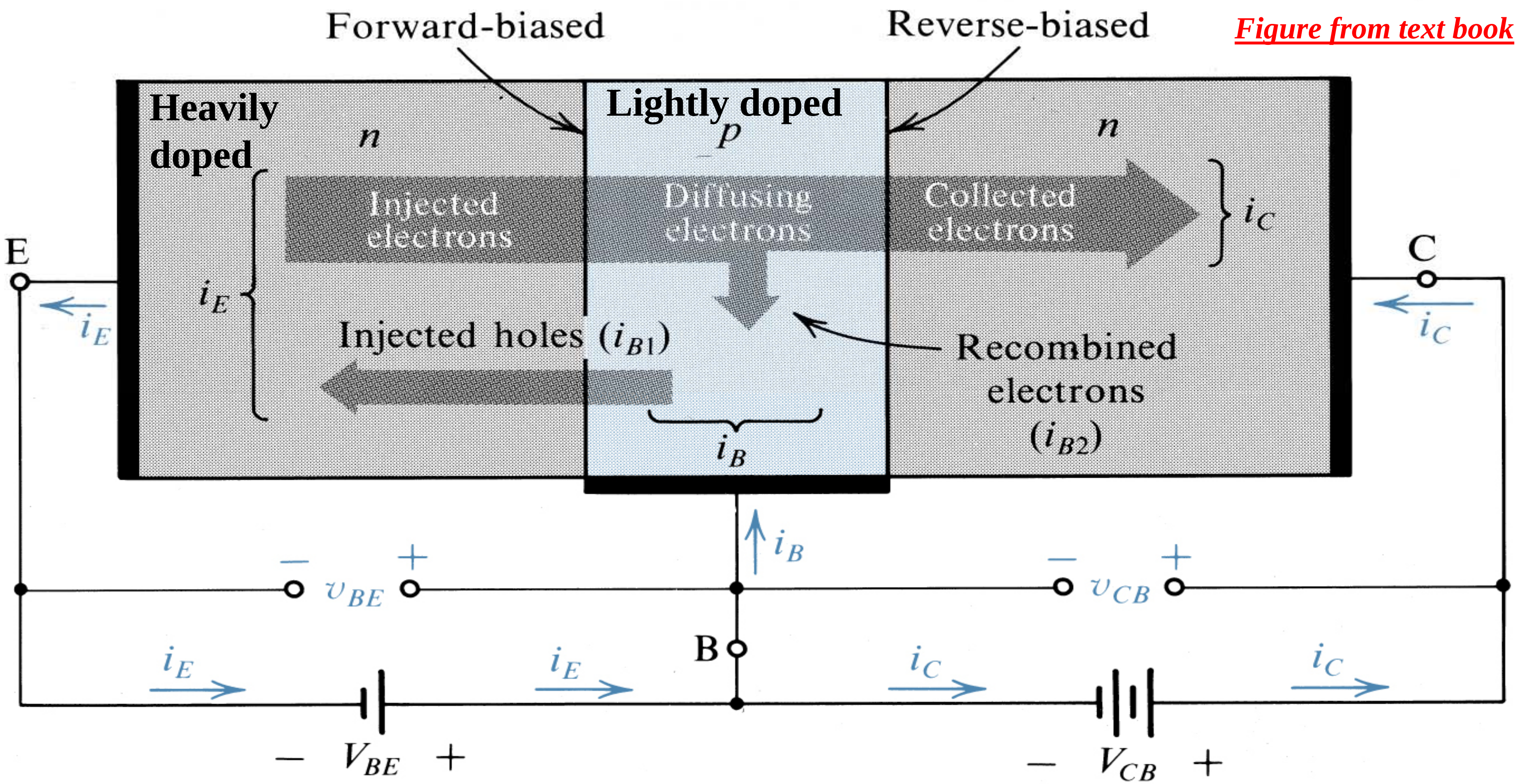
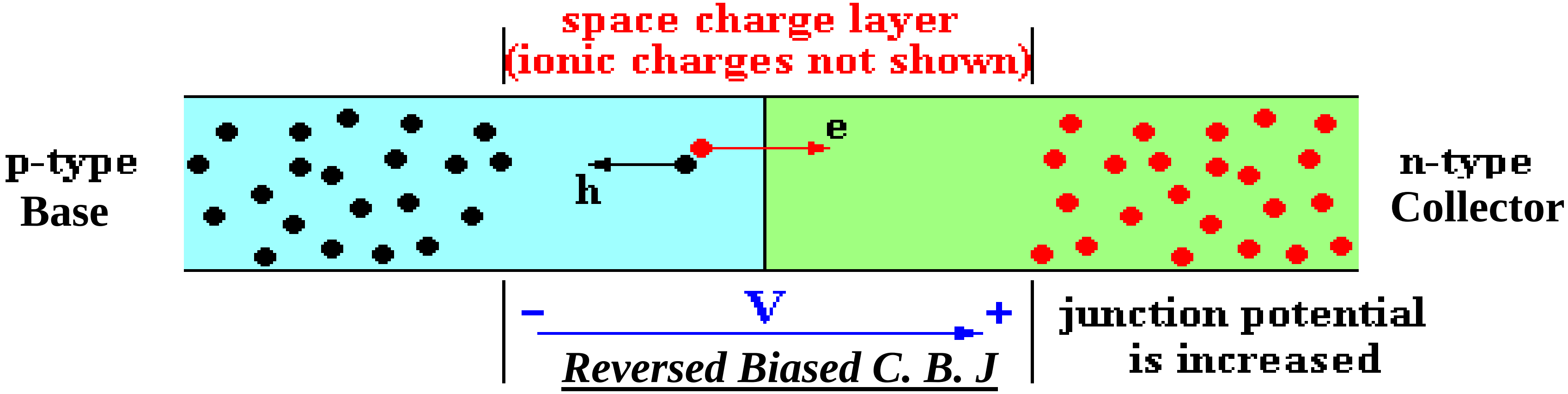


Fig 5.3: Forward current flow in an *NPN* transistor biased to operate in the active mode (Very small reverse current, due to drift of thermally generated minority carriers, are not shown.)

• The EMITTER is heavily doped and have high density of electrons. But the base is thin, lightly doped and has low density of holes. So, the current flow (i_E) between the forward biased emitter-base junction is mainly due to electronics flowing from emitter to base. This process emits free electrons into the base.

• Among the emitted electrons in BASE, around 5% **recombines** with available holes and escapes into external base lead as $\boldsymbol{i_{B2}}$, ($\boldsymbol{i_B = i_{B1} + i_{B2}}$ ➔ $\boldsymbol{i_{B1}}$ is due to majority holes) Remaining 95% base electrons acts as a minority carriers and are swept away to collector region by the electric field of reverse biased collector-base junc. (fig)

• These electrons are then collected by more positive collector terminal that constitute collector current (i_c). THUS: $(i_E) = (i_B) + (i_C)$



The Collector Current (i_C):

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

Base Current (i_B):

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

Emitter Current (i_E):

$$i_E = i_c + i_B$$

- Here, n = 1; Saturation current, $10^{-12} > I_S > 10^{-14}$ A <u>*and*</u> thermal voltage, V_T = 25 mV
- Note that 'i_C' is independent of V_{CB}, for $V_{CB} \geq 0$. So collector behaves as an ideal constant current source where the current is determined by V_{BE}. *(fig 2nd slide)*
- Since, $i_C = \alpha i_E$; $i_C = \beta i_B$ **and** $\alpha = \beta/(\beta+1)$,

  where "β" is common emitter current gain constant for a particular BJT

  "α" is common base current gain

- So the Emitter Current is given by:

$$i_E = i_C + i_B = \frac{\beta + 1}{\beta} \cdot i_C = \frac{\beta + 1}{\beta} \cdot \left(I_S \cdot e^{\frac{v_{BE}}{V_T}} \right)$$

<u>Exercise BJT-1</u>: For an NPN transistor having $I_s = 10^{-11}$ A, β=100 & V_T=25mV (at room temperature) **Calculate V_{BE} for i_C=1.5A**

(Solution: 0.643 V)

The PNP Transistor operation in Active mode:

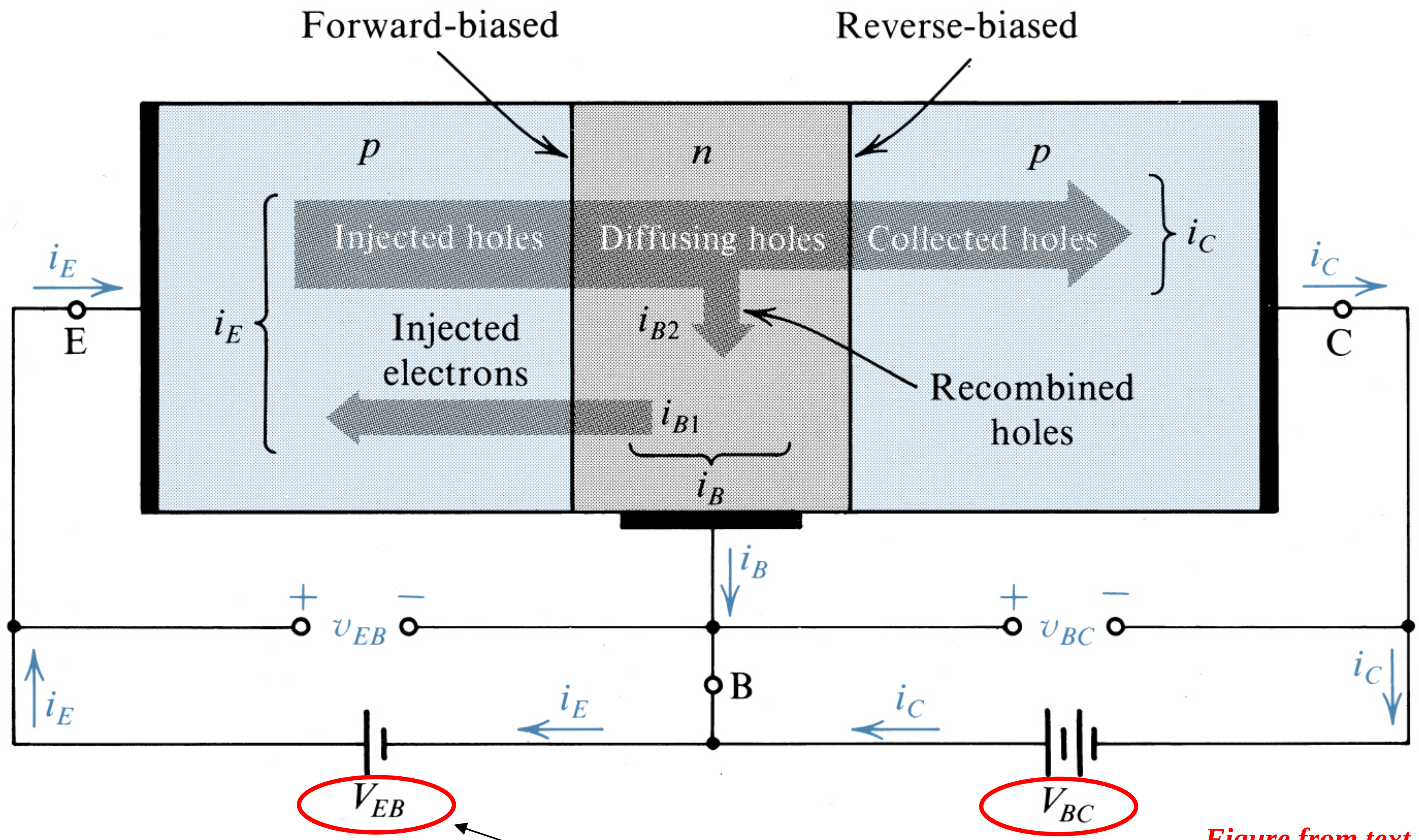
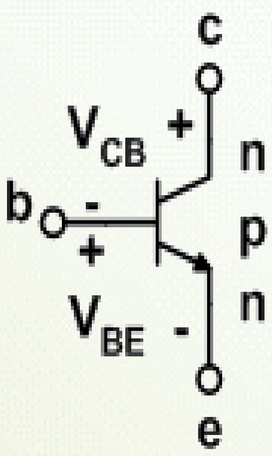


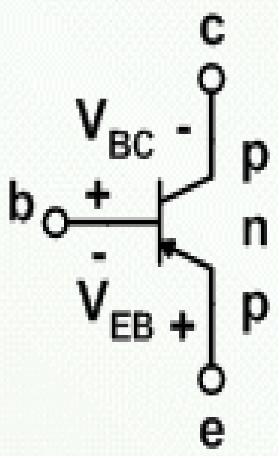
Figure from text book

Note that the PNP transistors have V_{EB} ; whereas the NPN transistors has V_{BE}

Summary of the BJT relationships in active & saturation modes

Active Mode

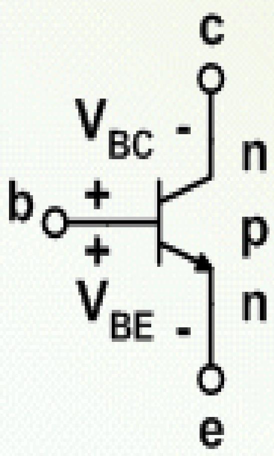


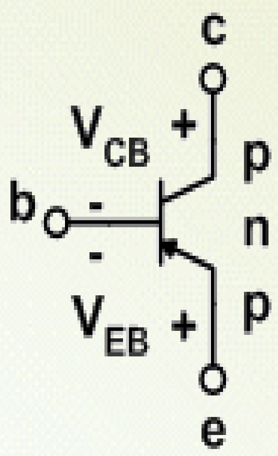


$i_C = I_S e^{v_{BE}/V_T}$	$i_E = \frac{\beta+1}{\beta} i_C$
$i_C = \beta i_B$	$i_C = \alpha i_E$
$i_E = i_C + i_B$	$\alpha = \frac{\beta}{\beta+1}$

For the pnp transistor, replace v_{BE} with v_{EB}

Saturation Mode





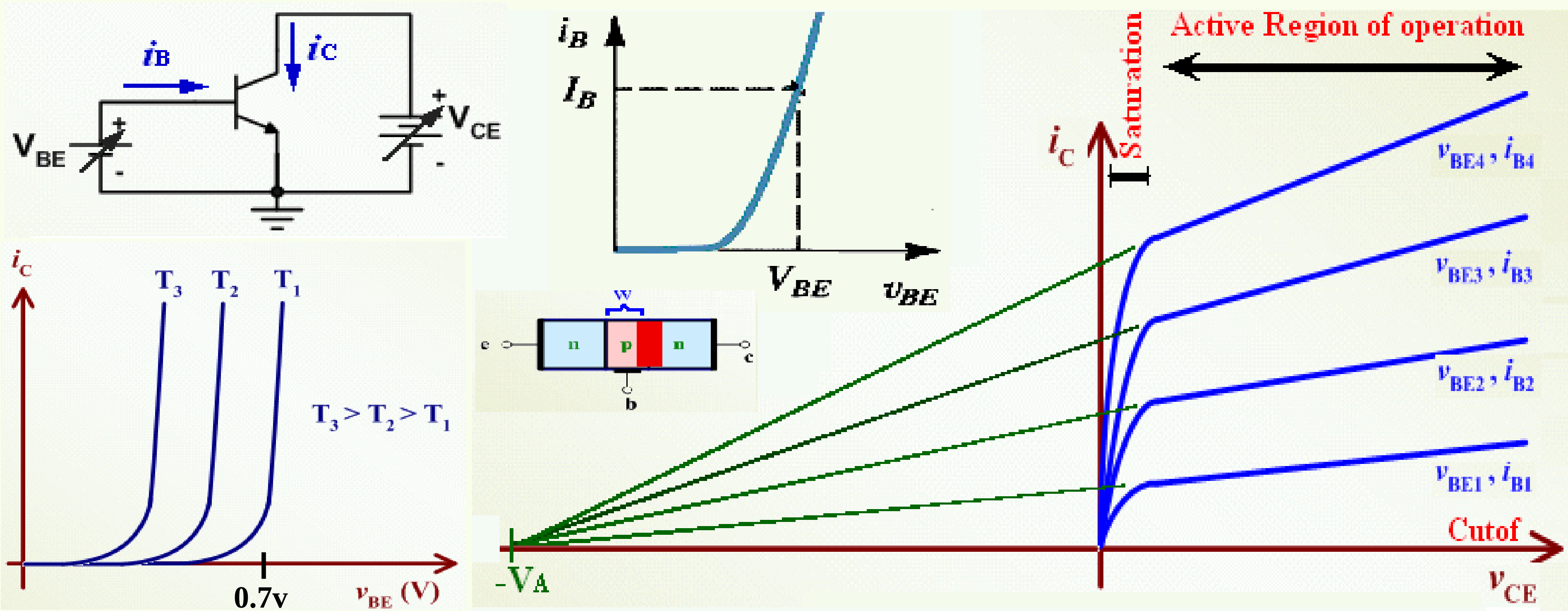
$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_C \neq \beta i_B \quad \text{but} \quad i_C < \beta i_B$$

$$i_E = i_C + i_B$$

$$v_{CE} \approx 0.2\text{V}$$

5.2.3: Dependence of current, voltage, temperature and the Early Effect:



- The collector current ic without the early voltage effect is given by $i_C = I_S e^{v_{BE}/V_T}$
- Increase in VCE causes the base width to decrease due to increased reverse biasing on collector-base junction.
- Since IS is inversely proportional to the base width, it increases with the decrease in base width.
- i_C is directly proportinal to Is and therefore increase in Is also increases the collector current.

This is called early voltage effect and the new equation for i_C is given by

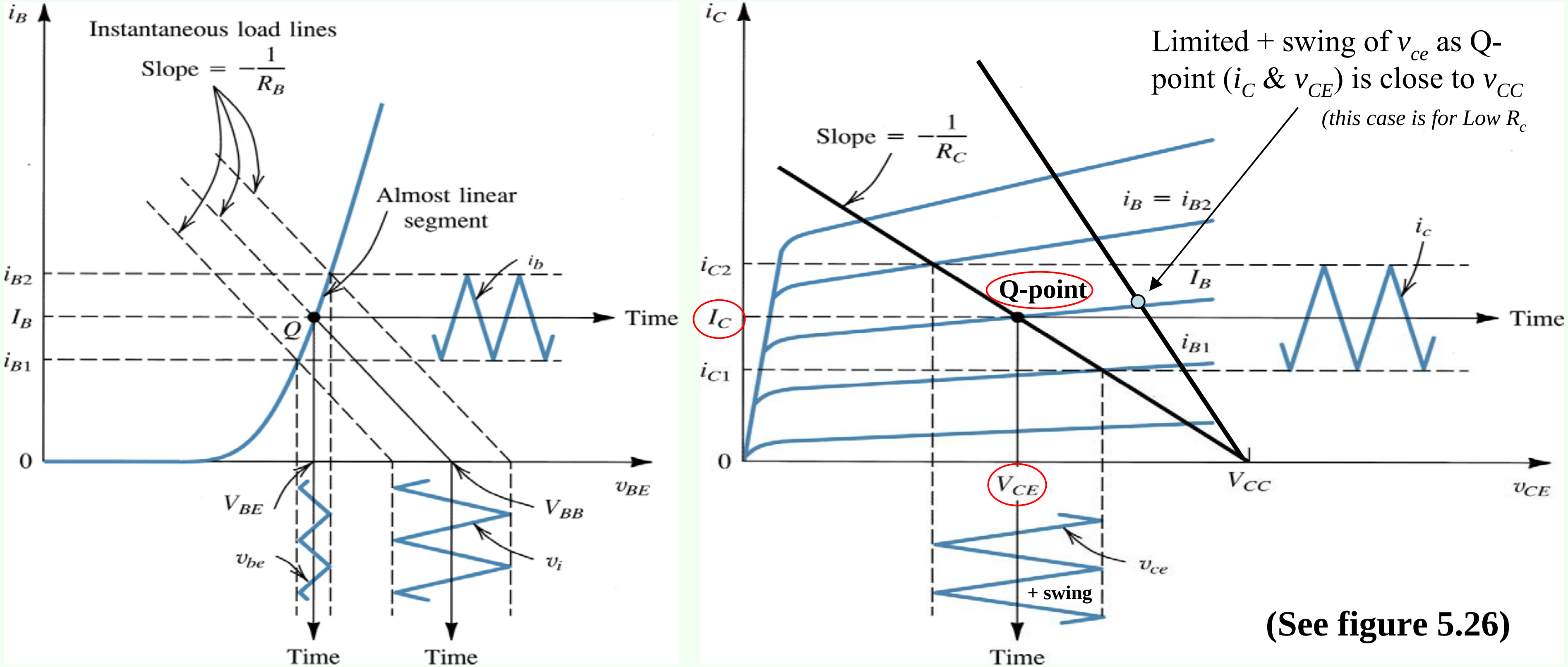
$$i_C = I_S e^{v_{BE}/V_T}\left(1 + \frac{v_{CE}}{V_A}\right) \qquad I_S = \frac{A_E q D_n n_i^2}{N_A W}$$

- Therefore the output resistance seen into the collector is defined and is given by

$$r_o = \left[\left.\frac{\partial i_C}{\partial v_{CE}}\right|_{v_{BE} = \text{constant}}\right]^{-1} \Rightarrow r_o \approx \frac{V_A}{I_C}$$

Exercise BJT-2: **If a BJT has V_A=100v and I_C=1mA, find r_0**

5.3.3: Q-point/Biasing point: Location of biasing point affects maximum allowable signal swing

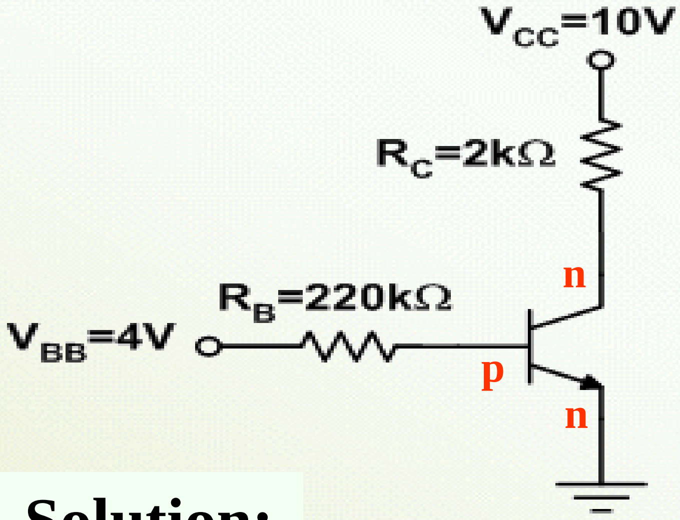


(See figure 5.26)

5.4: How to solve NPN or PNP BJT-DC circuits

- If not specified, assume that the transistor is working in active mode.
- Use the simple constant-V_{BE} model that is used for diode, i.e. take V_{BE}=0.7V for forward biased base-emitter junction.
- Analyze the circuit using current-voltage relationships for active mode operation.
- Check if the initial assumption of active mode operation was correct by verifying that the base-collector junction is reverse biased.
- If the active mode assumption was wrong than use the saturation mode current-voltage relationships for analysis.

Calculate Ic, IB, IE, Vc, VB of the following 'npn' circuit. β = 200

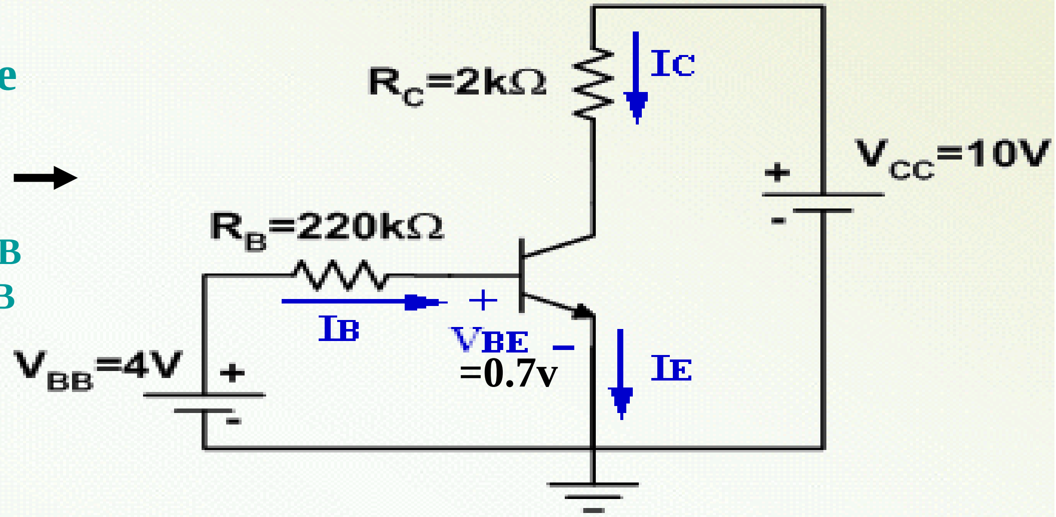


Assume Active mode

CBJ→RB

EBJ→FB

→



Solution:

Base current is found as

$$-4 + I_B R_B + V_{BE} = 0$$

$$\Rightarrow I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4 - 0.7}{220} = 15\mu A$$

Collector current is found as

$$I_C = \beta I_B = (200)(15\mu A) = 3mA$$

Emitter current is found as

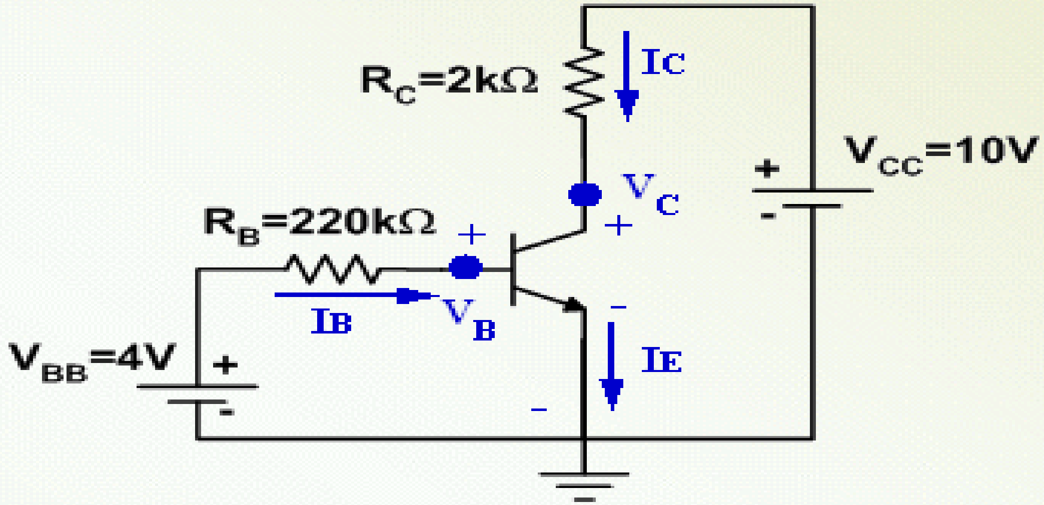
$$I_E = I_B + I_C = (\beta + 1)I_B = 3.02mA$$

Collector voltage is calculated as

$$V_{CC} - V_C - I_C R_C = 0 \Rightarrow V_C = V_{CC} - I_C R_C$$

$$V_C = 4V$$

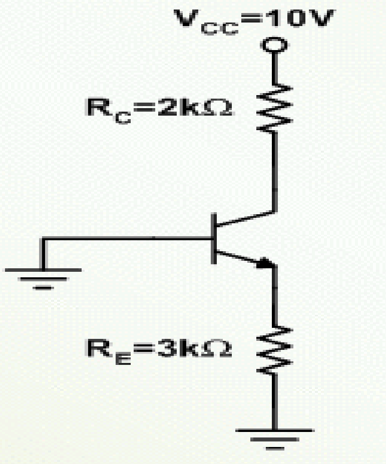
$$V_B = V_{BE} = 0.7V$$

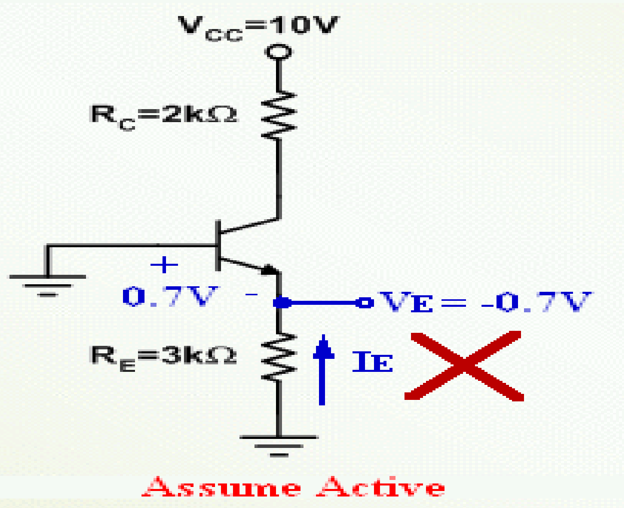


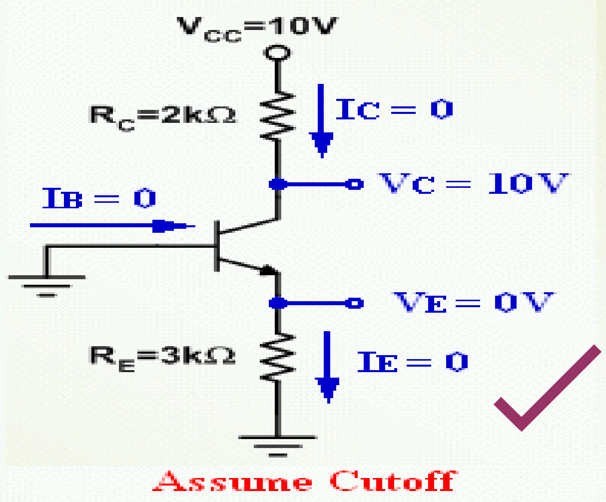
Since $V_C > V_B$ => Base-Collector junction is reverse biased

TRANSISTOR IN ACTIVE MODE

Find I_C, I_B, I_E, V_C, V_E of the following 'npn transistor' circuit. $\beta = 200$

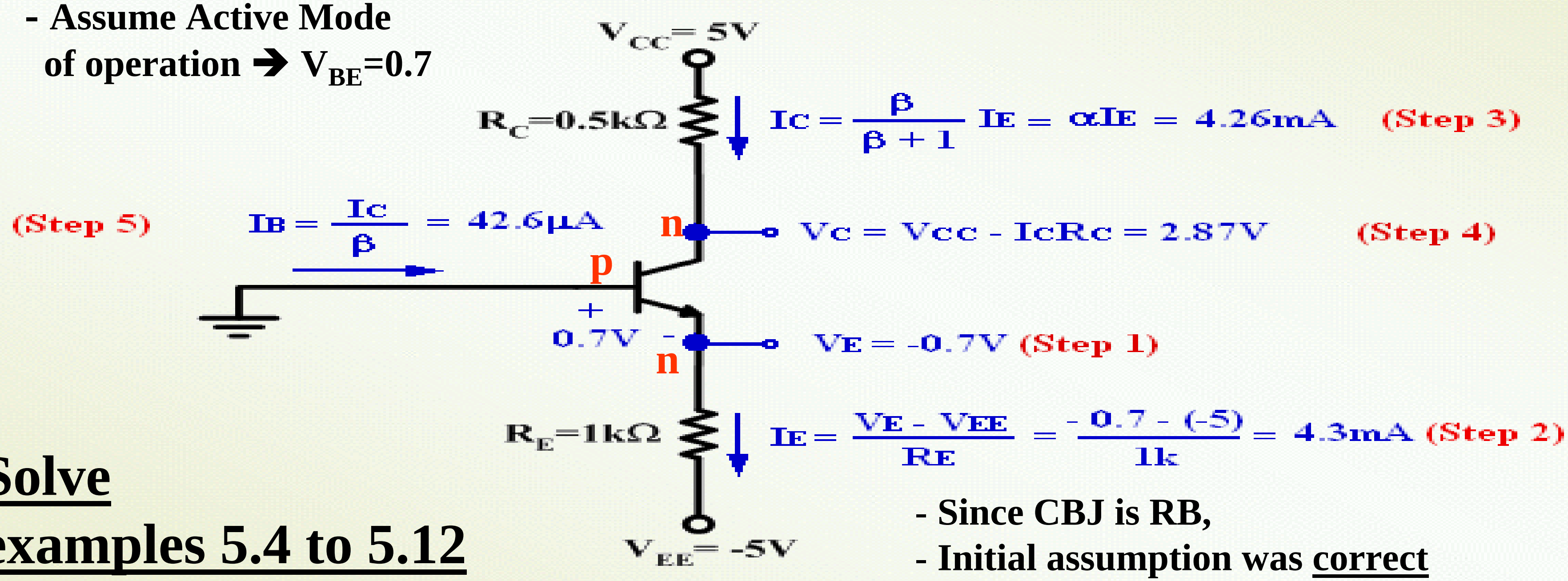






Find the bias point detail of the following npn circuit, take $\beta = 100$

- Assume Active Mode of operation ➔ V_{BE}=0.7

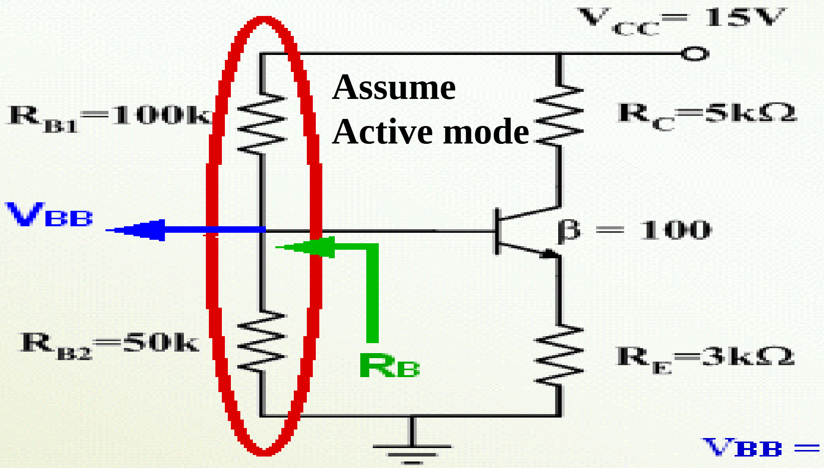


- Since CBJ is RB,
- Initial assumption was <u>correct</u>

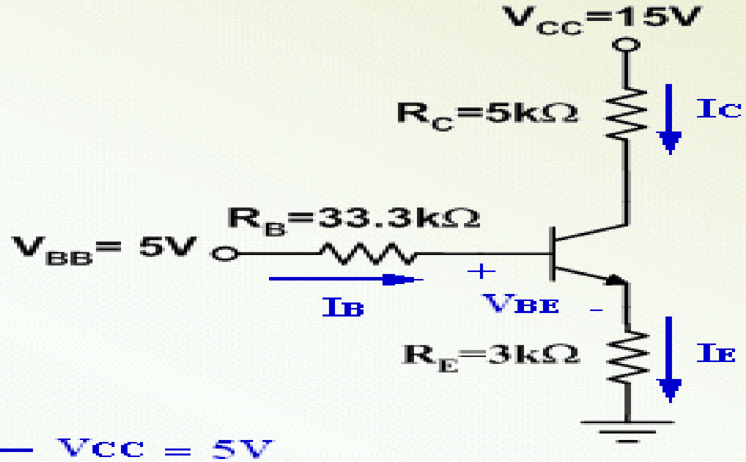
<u>Solve examples 5.4 to 5.12</u>

5.5: Biasing single stage BJT Amplifiers: - *Operating point* or *Q-point* (i_C and v_{CE})

Find the dc bias point (operating point) of the following circuit



Voltage Divider Biasing



$$V_{BB} = \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC} = 5V$$

$$R_B = R_{B1} // R_{B2} = 33.3k$$

Applying KVL around the base emitter loop

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E \qquad \text{Since } I_B = \frac{I_E}{\beta + 1}$$

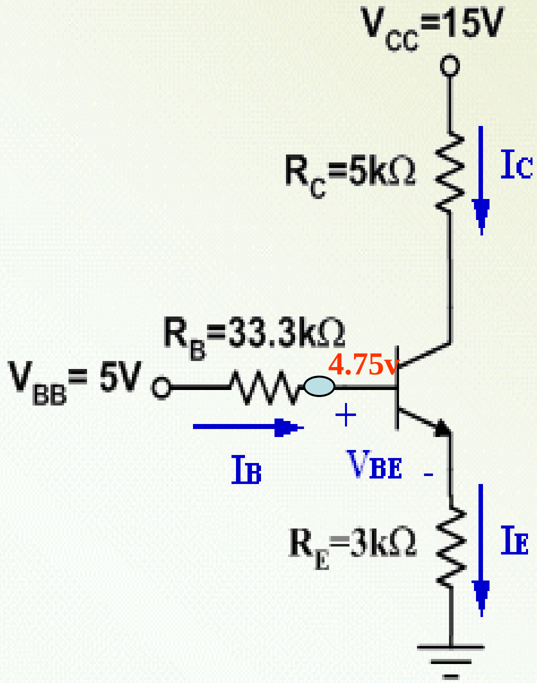
$$\text{Since } I_E = \frac{V_{BB} - V_{BE}}{R_E + [R_B/(\beta + 1)]} = 1.29\text{mA}$$

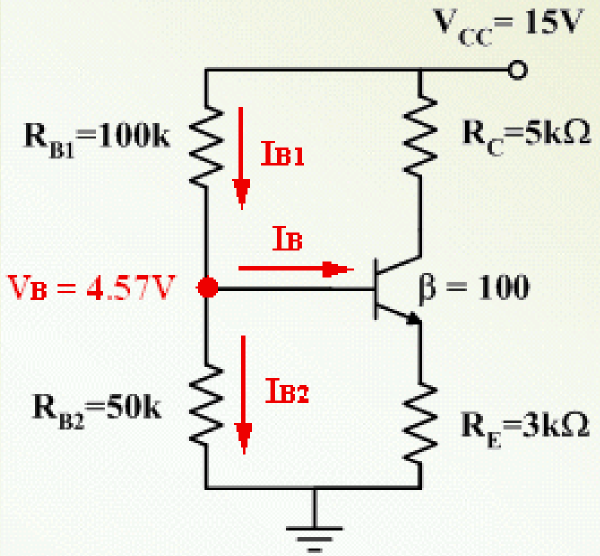
$$\text{Now } I_B = \frac{I_E}{\beta + 1} = 0.0128 \text{ mA}$$

$$\text{Now } I_C = \beta I_B = 1.28 \text{ mA}$$

$$V_B = V_{BE} + I_E R_E = 4.57V$$

$$V_C = V_{CC} - I_C R_C = 8.6V$$



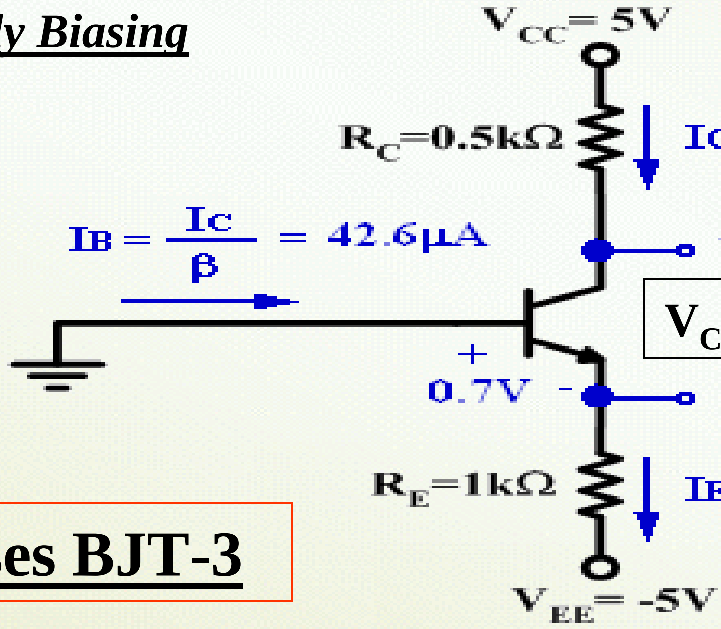


$I_{B1} = (V_{CC} - V_B) / R_{B1} = 0.103\text{mA}$

$I_{B2} = (V_B - 0) / R_{B2} = 0.09\text{mA}$

Find the bias point detail of the following npn circuit, take $\beta = 100$

Two supply Biasing



$V_E = -0.7V$ (Step 1)

$$I_E = \frac{V_E - V_{EE}}{R_E} = \frac{-0.7-(-5)}{1k} = 4.3mA \text{ (Step 2)}$$

$$I_C = \frac{\beta}{\beta+1} I_E = \alpha I_E = \boxed{4.26mA} \text{ (Step 3)}$$

$V_C = V_{CC} - I_C R_C = 2.87V$ (Step 4)

$$\boxed{V_{CE}=3.57\text{ v}}$$

(Step 5) $$I_B = \frac{I_C}{\beta} = 42.6\mu A$$

Exercises BJT-3

Design pnp BJT circuit such that $V_{EC} = 2.5V$. Take $\beta = 60$

Applying KVL around the emitter collector loop

$V_{CC} = I_E R_E + V_{EC}$

$\Rightarrow I_E = 1.25mA$

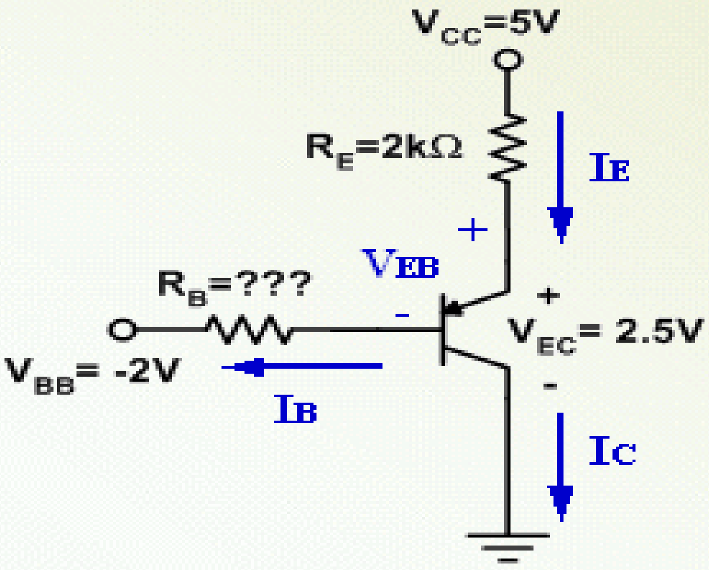
$$I_C = \frac{\beta}{\beta+1} I_E = \alpha I_E = 1.23mA$$

$$I_B = \frac{I_C}{\beta} = 20.5\mu A$$

Applying KVL around the emitter base loop

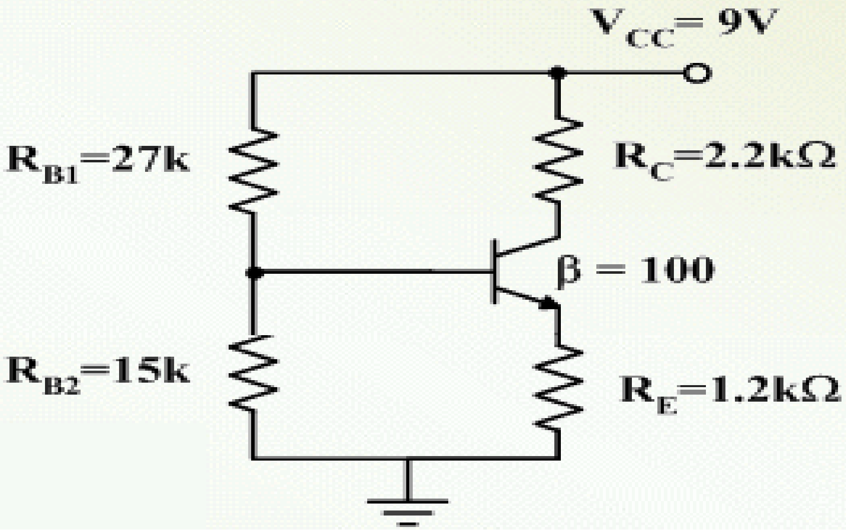
$V_{CC} = I_E R_E + V_{EB} + I_B R_B + V_{BB}$

$\Rightarrow R_B = 190k\Omega$



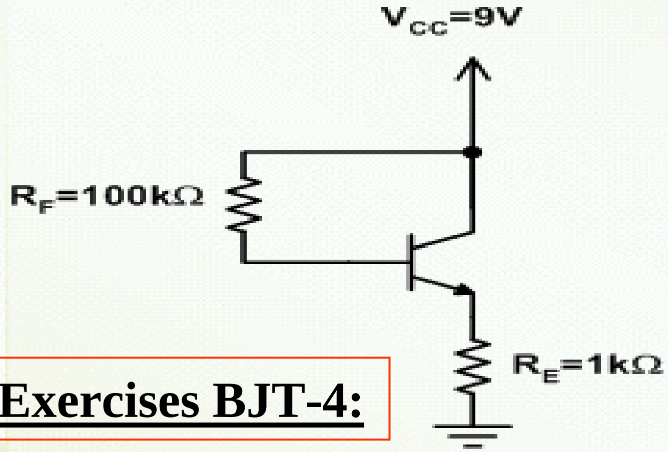
Exercises BJT-3:

Solve the given circuit to find
(a) I_C, I_E and I_B
(b) Prove that the transistor is working in active mode.
(Hint : Find V_C and V_B and if $V_C > V_B$, the transistor is working in active mode)



Answer: $I_E = 3.21mA$
$I_C = 3.178mA$
$I_B = 31.78\mu A$

For the collector feedback circuit, the BJT used is specified to have β values in the range of 20 to 200. For the two extreme values of β (β =20 and β =200) find I_E, V_E and V_B.
(Hint : Apply KVL in the loop starting from V_{CC} to R_F to V_{BE} to R_E to ground)



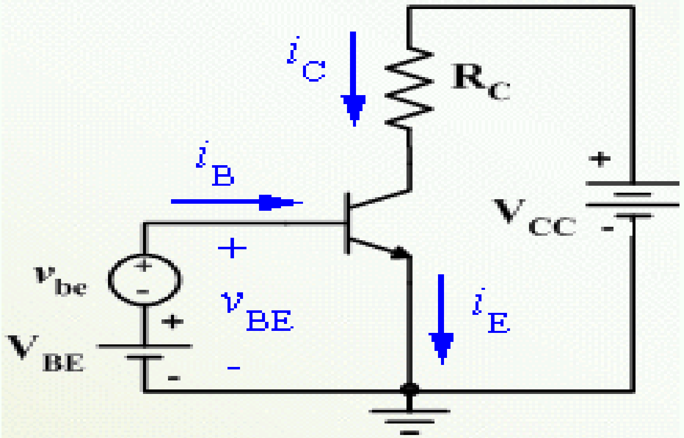
Answer:	For β=20	For β=200
	$I_E = 1.44mA$;	$I_E = 5.54mA$
	$V_E = 1.44V$;	$V_E = 5.54V$
	$V_B = 2.14V$	$V_B = 6.24V$

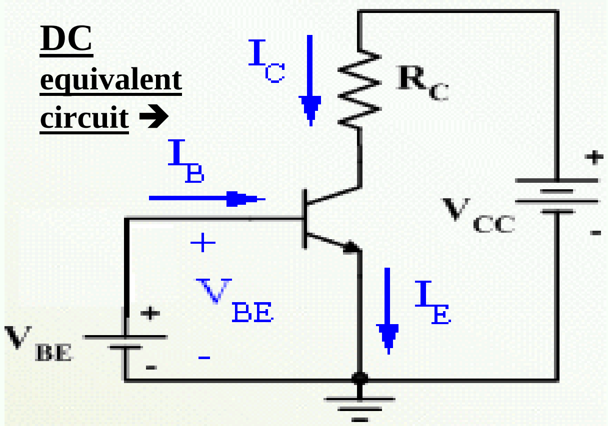
Exercises BJT-4:

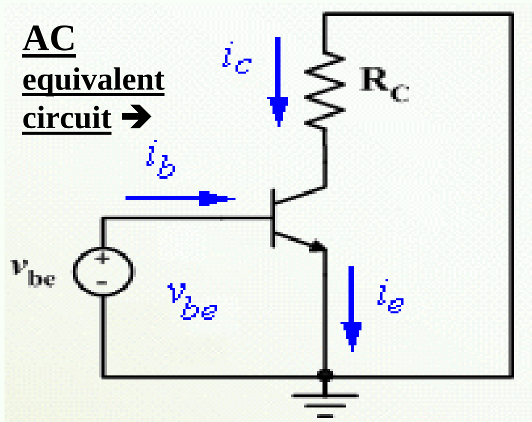
Solve example 5.13 & related exercises

5.6: BJT Amplifiers, Small-Signal Operation and Models :

- In linear amplifier the output signal is equal to the input signal multiplied by a constant. The value of this constant is usually greater than unity.
- To operate as an amplifier, the transistor must be biased in the active mode.
- The biasing problem is that of establishing a proper value of constant dc current in the emitter or collector of transistor.
- The operation of transistor as an amplifier is highly influenced by the value of the bias current also called operating point







Variable	Meaning
I_C, V_{CE}	DC values
i_c, v_{ce}	Instantaneous ac values
i_C, v_{CE}	Total instantaneous values

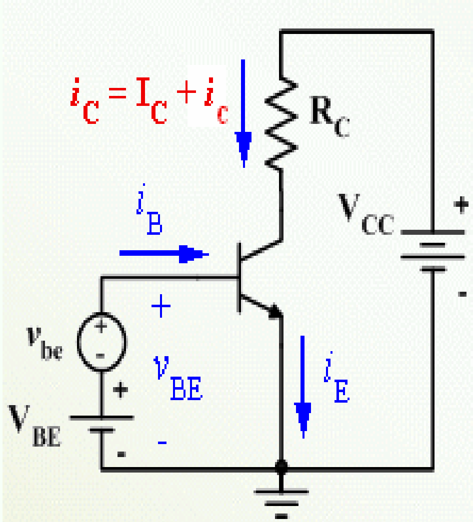
DC Analysis

$$I_C = I_S e^{V_{BE}/V_T}$$

$$I_E = \frac{I_C}{\alpha}$$

$$I_B = \frac{I_C}{\beta}$$

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



$$v_{BE} = V_{BE} + v_{be}$$

$$i_C = I_S e^{v_{BE}/V_T} = I_S e^{(V_{BE}+v_{be})/V_T}$$

$$= I_S e^{V_{BE}/V_T} e^{v_{be}/V_T} = I_C e^{v_{be}/V_T}$$

DC bias current I_C

Using Taylor series expansion for e^x

$$i_C = I_C\left(1+\frac{v_{be}}{V_T}+\left(\frac{v_{be}}{V_T}\right)^2+\left(\frac{v_{be}}{V_T}\right)^3+\dots\dots\right)$$

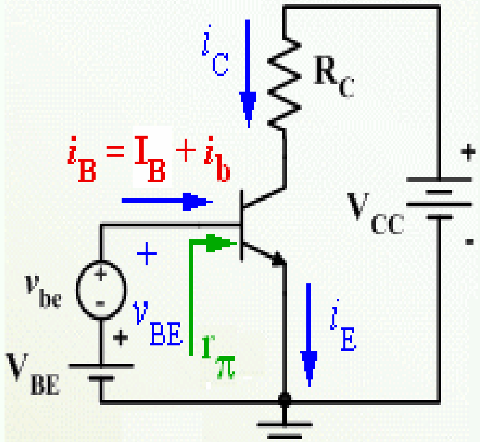
If vbe<<V_T (small signal approximation) valid for v_{be}<10mV

$$i_C = I_C\left(1+\frac{v_{be}}{V_T}\right) = I_C + \frac{I_C}{V_T}v_{be}$$

DC bias current I_C ac signal current i_c

$$i_c = \frac{I_C}{V_T}v_{be} = g_m v_{be}$$

where gm is transconductance, $g_m = \frac{i_c}{v_{be}} = \frac{I_C}{V_T}$



The total base current is therefore given by

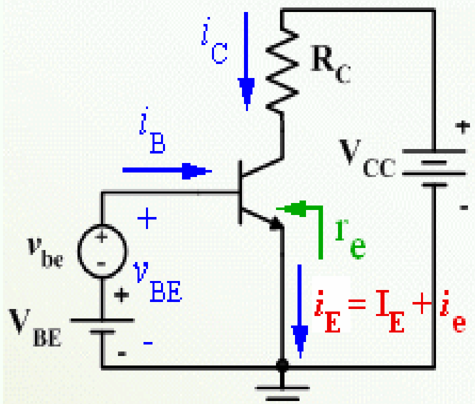
$$i_B = \frac{i_C}{\beta} = \frac{I_C}{\beta} + \frac{1}{\beta}\frac{I_C}{V_T}v_{be}$$

DC bias current I_B ac signal current i_b

Thus, $i_b = \frac{1}{\beta}\frac{I_C}{V_T}v_{be} = \frac{g_m}{\beta}v_{be} = \frac{1}{r_\pi}v_{be}$

as $r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{V_T}{I_B}$

where r_π is the small signal input resistance between base and emitter, looking into the base



The total emitter current is therefore given by

$$i_E = \frac{i_C}{\alpha} = \frac{I_C}{\alpha} + \frac{1}{\alpha}\frac{I_C}{V_T}v_{be}$$

DC bias current I_E ac signal current i_e

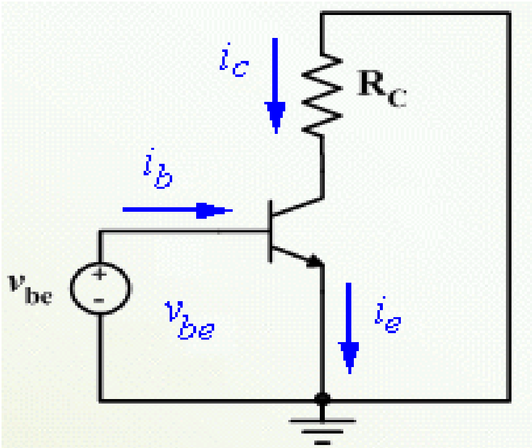
Thus, $i_e = \frac{1}{\alpha}\frac{I_C}{V_T}v_{be} = \frac{g_m}{\alpha}v_{be} = \frac{1}{r_e}v_{be}$

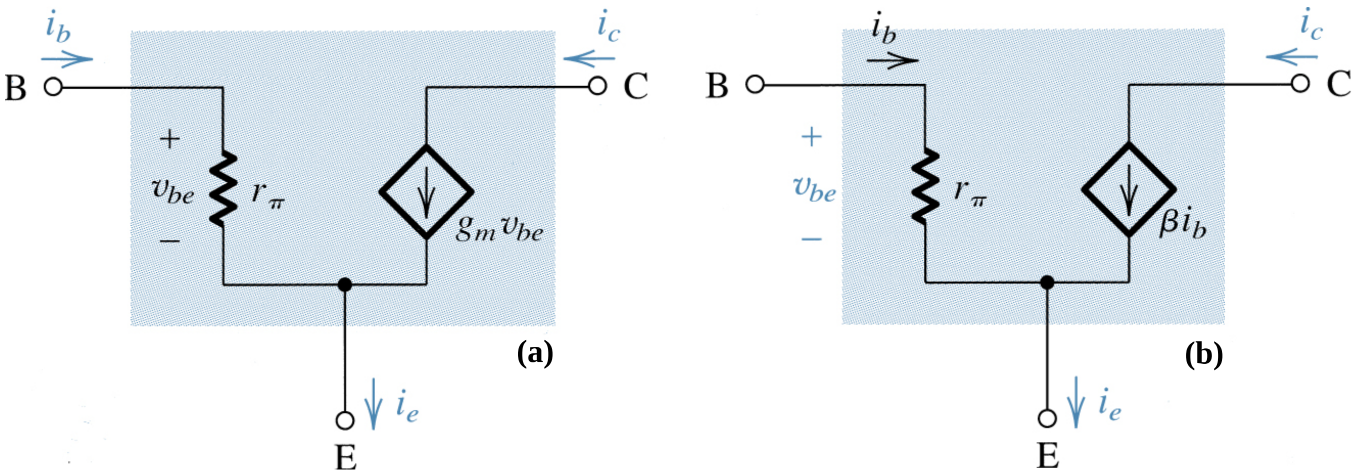
$$r_e = \frac{v_{be}}{i_e} = \frac{\alpha}{g_m} = \frac{V_T}{I_E}$$

where r_e is the small signal input resistance between base and emitter, looking into the emitter

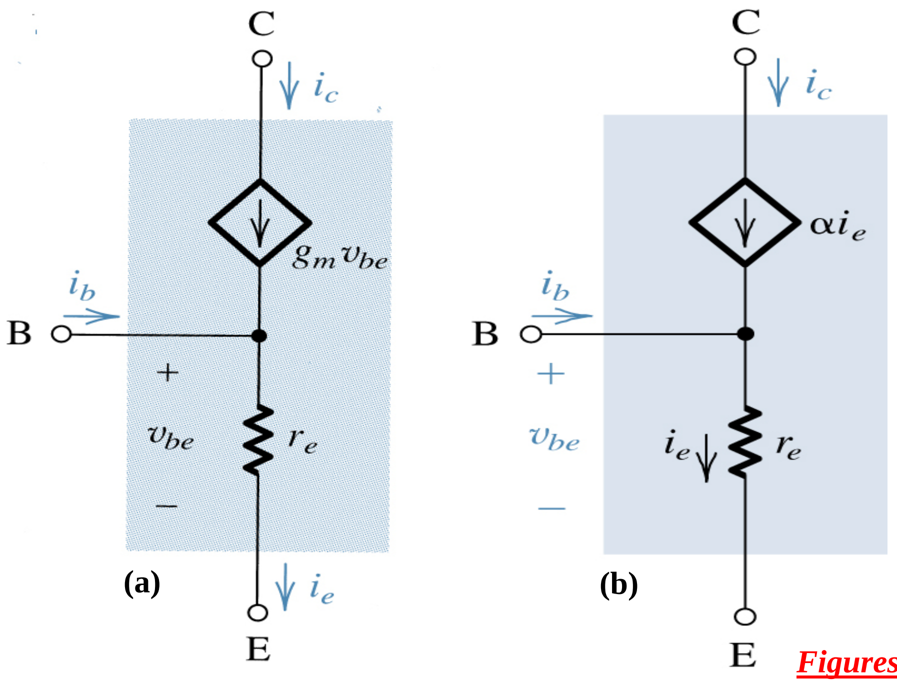
Since $\alpha \cong 1$ => $r_e \cong \frac{1}{g_m}$

<u>5.6.6 and 5.6.7: Small-Signal Equivalent Circuit Models</u>:





Two different versions of simplified **<u>hybrid-Π model</u>** for the small-signal operation of the BJT.
(a) represents the BJT as a voltage-controlled current source (a transconductance amplifier)
(b) represents the BJT as a current-controlled current source (a current amplifier).

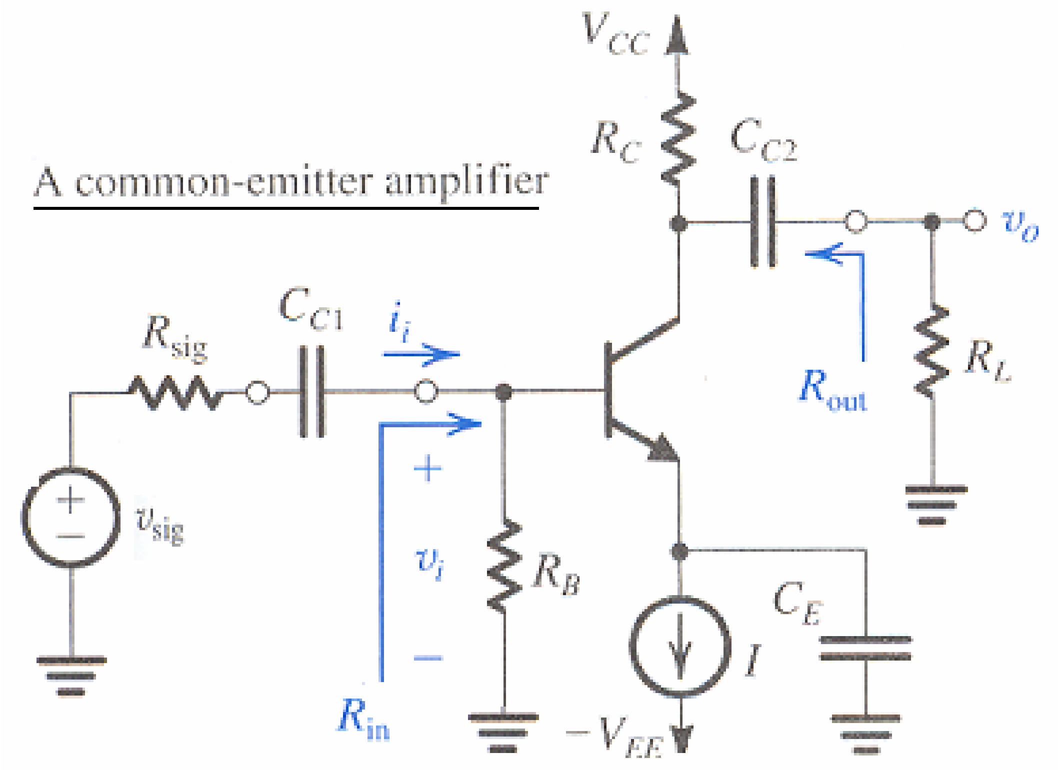


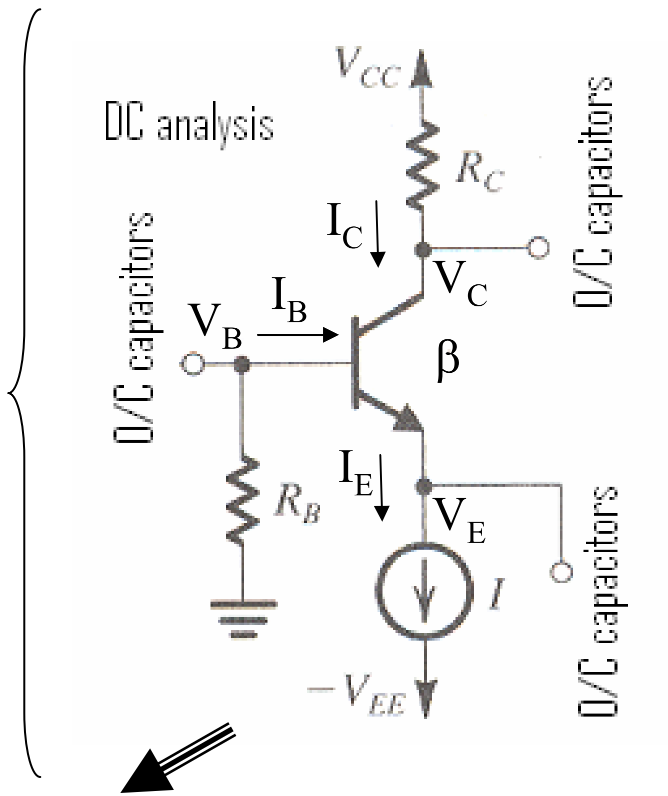
Two slightly different versions of what is known as the ***<u>T model</u>*** of the BJT. The circuit in **(a)** is a voltage-controlled current source representation and that in **(b)** is a current-controlled current source representation. These models explicitly show the emitter resistance r_e rather than the base resistance r_Π featured in the hybrid-π model.

<u>Figures from text book</u>

<u>Solve example 5.14</u>

5.7.3: Common emitter Amplifier: DC analysis to find I_B, I_C, I_E, V_B, V_C and V_E





Lets assume the BJT is operating in Active Mode. Thus, $I_C = \alpha . I_E$, $I_C = \beta . I_B$ and $\alpha = \beta/(\beta+1)$

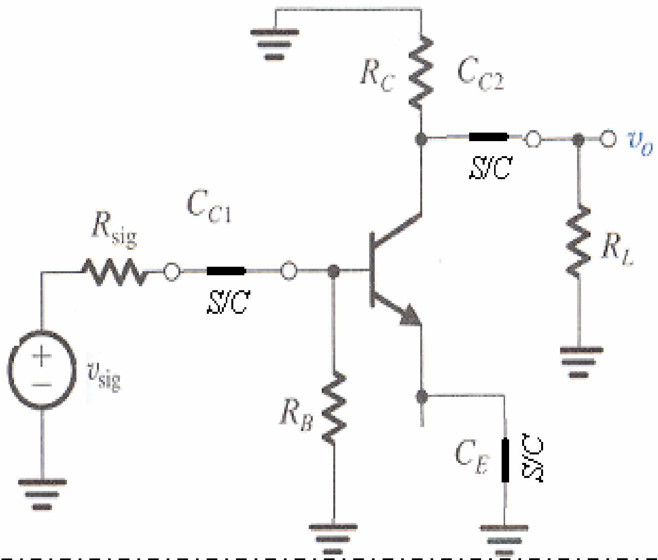
Since $I_E = \boldsymbol{I}$ mA ; $I_B = I_E / (\beta+1)$ mA ; $V_B = 0 - I_B.R_B$; $V_E = V_B - 0.7$;

Now $I_C = \alpha . I_E = (\beta . I_E) / (\beta+1)$; $V_C = V_{CC} - I_C.R_C$ and if CBJ remains RB then assumption is OK

Exercise-5: Find the operating point if $V_{CC}=V_{EE}=10$V, $R_C=8$ kΩ, $R_B=100$ kΩ, $\boldsymbol{I}=1$mA & $\beta=100$

Solution: Q or operating point is, $I_C=0.99$ mA ; $V_{CE}=0.3$ v *(as $V_B= -1v$, $V_C = 2v$, $V_E = -1.7v$)*

5.7.3:Common emitter Amplifier: AC analysis to find Gain, Input & output Impedances



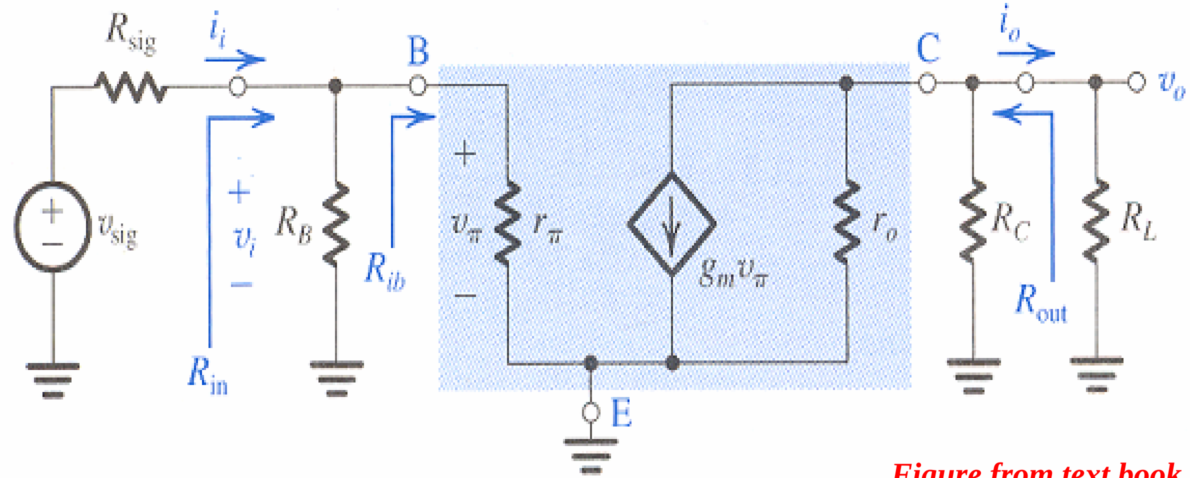


Figure from text book

AC analysis: short circuit capacitors, GND all DC voltage sources and O/C all DC current sources

$$R_{in} = \frac{v_i}{i_i} = R_B \parallel R_{ib} \quad , \quad R_{ib} = r_\pi \quad , \quad R_{in} = R_B \parallel r_\pi$$

$$v_i = v_{sig}\frac{R_{in}}{R_{in} + R_{sig}} = v_{sig}\frac{(R_B \parallel r_\pi)}{(R_B + r_\pi) + R_{sig}} \cong v_{sig}\frac{r_\pi}{r_\pi + R_{sig}} = v_\pi$$

since $v_\pi = v_i$ and $v_o = -g_m v_\pi (r_o \parallel R_C \parallel R_L)$

The voltage gain, $A_v = \frac{v_o}{v_i} = -g_m(r_o \parallel R_C \parallel R_L)$

The output resistance, $R_{out} = R_C \parallel r_o$

overall voltage gain, $G_v = -\frac{(R_B \parallel r_\pi)}{(R_B \parallel r_\pi) + R_{sig}} g_m(r_o \parallel R_C \parallel R_L)$

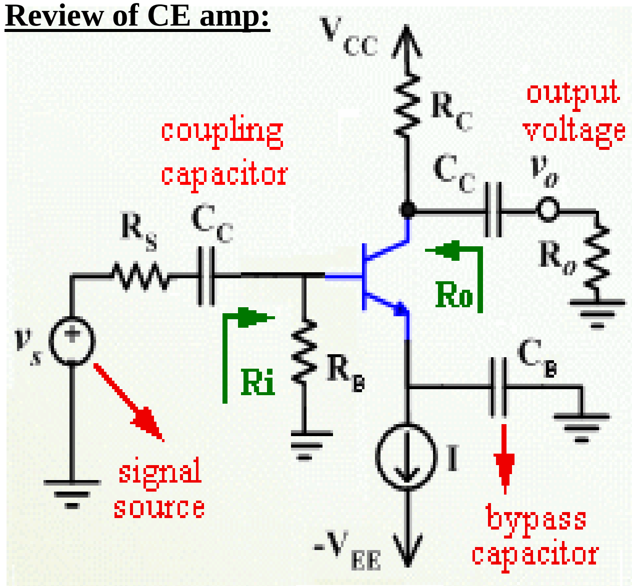
For $R_B \gg r_\pi$, $G_v \cong -\frac{\beta(R_C \parallel R_L \parallel r_o)}{r_\pi + R_{sig}}$ $\left[\text{as } G_v = A_v * \frac{v_i}{v_{sig}}\right]$

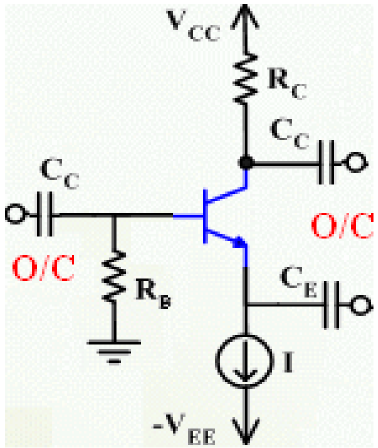
Remember,
$r_0 = |V_A|/I_C$
$g_m = I_C/V_T$
$r_\pi = V_T/I_B$

Exercise-6: Find R_{in}, R_{out}, A_v & G_v; if $R_{sig}=R_L=5k\Omega$, $R_B=100k$, $R_C=8k$; $I_C=1mA$, $I_B=0.01mA$, $V_A=100V$, $V_T=25mV$

Solution: $R_i=2.43\ k\Omega$; $R_{out}=7.4\ k\Omega$, $A_v=-119$ V/V, $G_v=-39$ V/V *(as $r_\pi=2.5K$, $g_m=40\ mA/V$, $r_0=100k$)*

Review of CE amp:

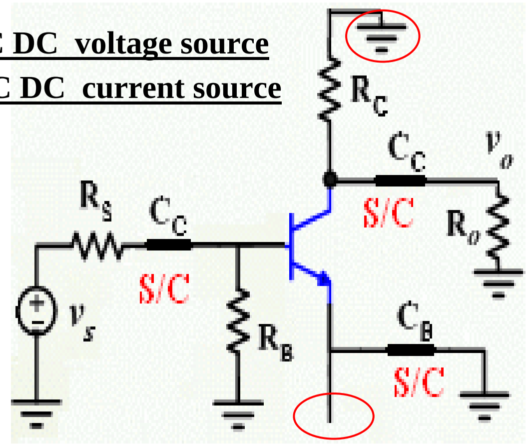




Find model parameters (r_π, r_e, g_m)

- S/C DC voltage source

- O/C DC current source



DC analysis: O/C capacitors & find I_B, I_C, I_E, V_B, V_C, V_E

AC analysis: S/C capacitors & find ➔ R_{in}, R_{out}, A_V, A_i

---

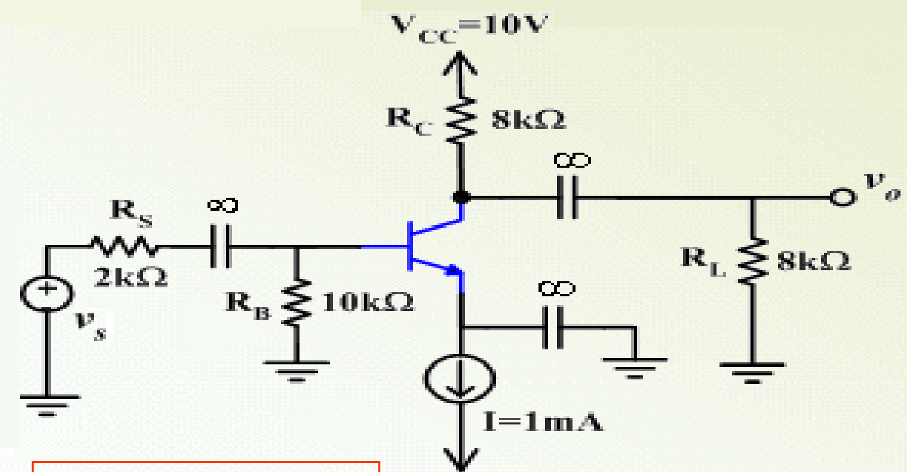
The transistor shown has β=100 and V_A=100V.

(a) Find the dc voltages at the base, emitter, and collector.

(b) Find g_m, r_π, and r_o.

(c) Draw the small signal equivalent circuit using hybrid-π model (with r_o) and find the voltage gain

(d) Neglect r_o and again find the voltage gain and find the percentage error between (c) and (d).



Exercises-7:

Hint : When performing dc analysis open circuit all the capacitors. Notice that I_E=I=1mA. When performing small signal analysis short circuit all the capacitors and open circuit the dc current source I.

Answer : (a) -0.1V, -0.8V, +2V (b) 40mA/V, 2.5kΩ, 100kΩ (c) -77 (d) -80 +3.9%

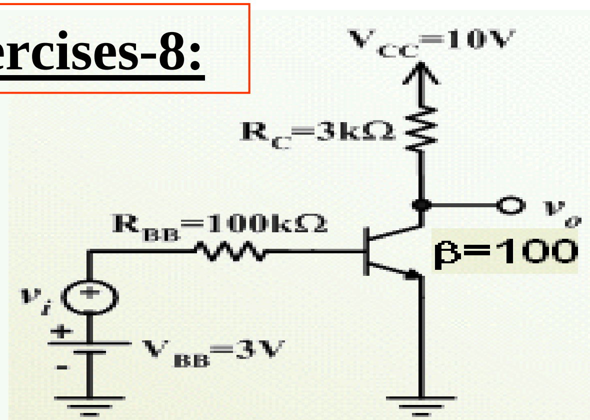
The transistor shown has β=100 and V_A=100V.

(a) Find the dc voltages at the base, emitter, and collector.

(b) Find g_m, r_π, and r_e

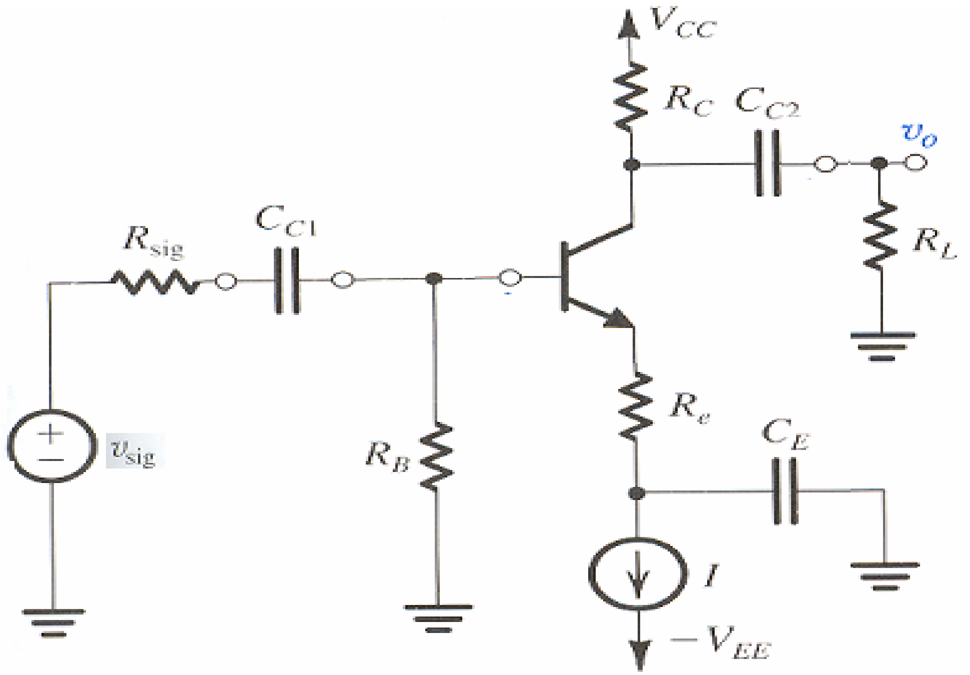
(c) Draw the small signal equivalent circuit using hybrid-π model and find the voltage gain $Av=v_o/v_i$

Exercises-8:

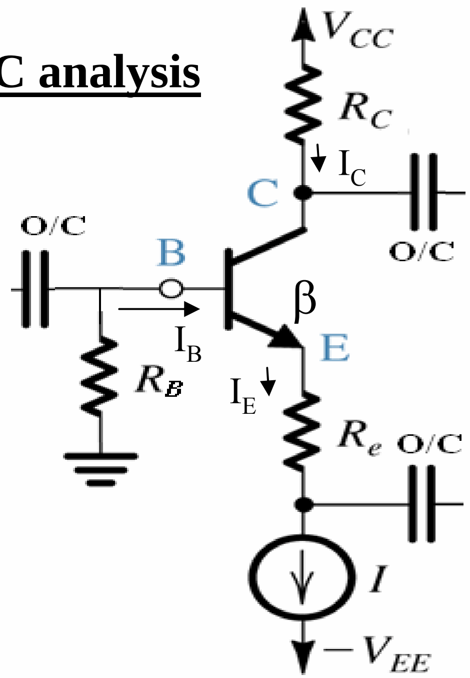


Answer: (a) 0.7v, 0v, 3.1v, (b) 92 mA/v, 1.09 KΩ , 10.8Ω (c) -3.04

5.7.4:Common emitter Amplifier with R_e (emitter resistor): Controlled voltage amp



DC analysis

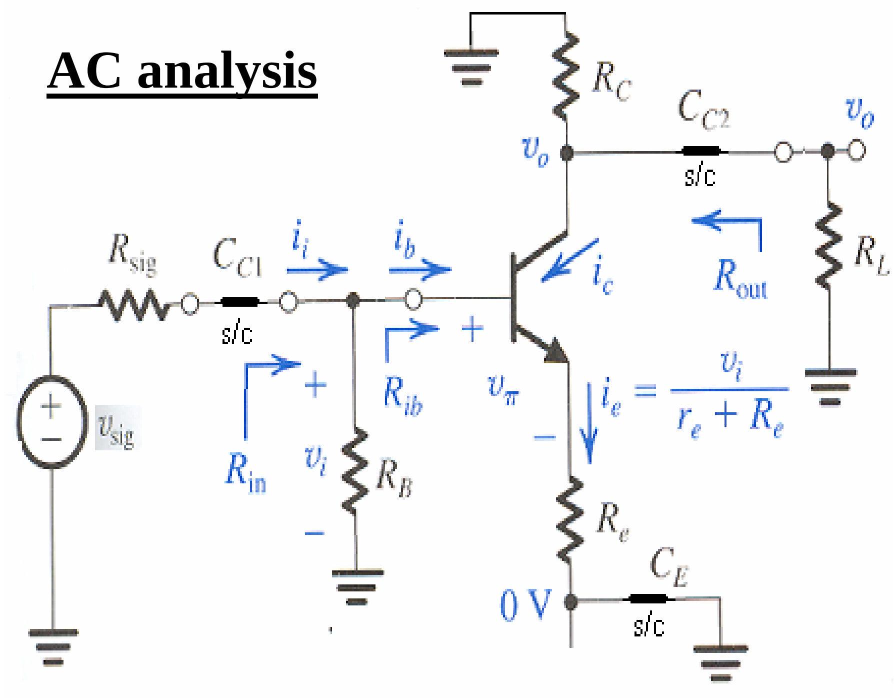


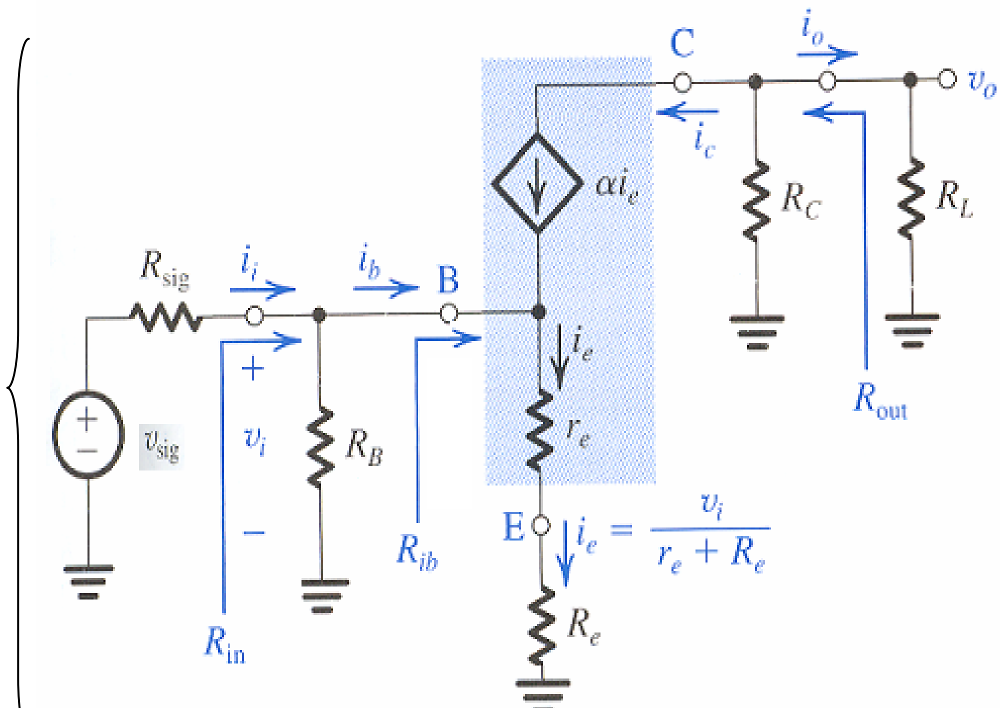
$I_C = \alpha . I_E$,
$I_C = \beta . I_B$
$\alpha = \beta/(\beta+1)$
and
$g_m = I_C/V_T$;
$r_e = V_T/I_E$;

Exercise-9: Find the operating point if $V_{CC}=V_{EE}$=10V, R_C=8 kΩ, R_B=100 kΩ, I=1mA & β=100

Solution: operating point, I_C=0.99 mA ; V_{CE}=3.7 v *(as I_E=1mA ; V_B= -1v, V_C = 2v, V_E = -1.7v)*

AC analysis





Figures from text book

The amplifier input resistance , $R_{in} = R_B \| R_{ib}$

– input resistance at the base , $R_{ib} \equiv \frac{v_i}{i_b}$, where $i_b = \frac{i_e}{\beta + 1}$, and $v_i = i_e\,(r_e + R_e)$

Thus, $R_{ib} = (\beta + 1)(r_e + R_e)$, **Remember,** $r_e = V_T/I_E$ **&** Resistance reflection rule➔ $R_{base} \approx (\beta+1) R_{emitter}$

– *input resistance looking into base is (β + 1) times the total resistance in emitter.*

Thus, $\frac{R_{ib}\,(\text{with } R_e \text{ included})}{R_{ib}\,(\text{without } R_e)} = \frac{(\beta+1)(r_e + R_e)}{(\beta+1) r_e} = 1 + \frac{R_e}{r_e} \cong 1 + g_m R_e$; ***Remember,*** $g_m = I_C/V_T$

The output resistance $R_{out} = R_C$ *(as r_o of T-model is neglected to ease solution process)*

5.7.3:Common Emitter (CE) with Emitter Resistance (R_e): AC analysis (cont'd…)

The voltage gain $A_v \equiv \frac{v_o}{v_i} = \frac{-i_c(R_C \parallel R_L)}{i_e(r_e + R_e)} = -\frac{\alpha i_e(R_C \parallel R_L)}{i_e(r_e + R_e)} = -\frac{\alpha(R_C \parallel R_L)}{r_e + R_e}$

$$A_v \cong -\frac{R_C \parallel R_L}{r_e + R_e} \quad , \text{ if } \alpha \cong 1$$

The current gain $A_{is} = \frac{i_{os}}{i_i} = \frac{-\alpha i_e}{v_i / R_{in}} = -\frac{\alpha R_{in} i_e}{v_i} = \frac{-\alpha(R_B \parallel R_{ib})}{r_e + R_e}$

$$A_{is} = -\beta \quad , \text{ if } R_B \gg R_{ib}, \alpha \cong 1 \text{ and } R_{ib} = (\beta + 1)(r_e + R_e)$$

The overall voltage gain $G_v = \frac{v_i}{v_{sig}} \cdot A_v = -\frac{R_{in}}{R_{sig} + R_{in}} \frac{\alpha(R_C \parallel R_L)}{r_e + R_e}$

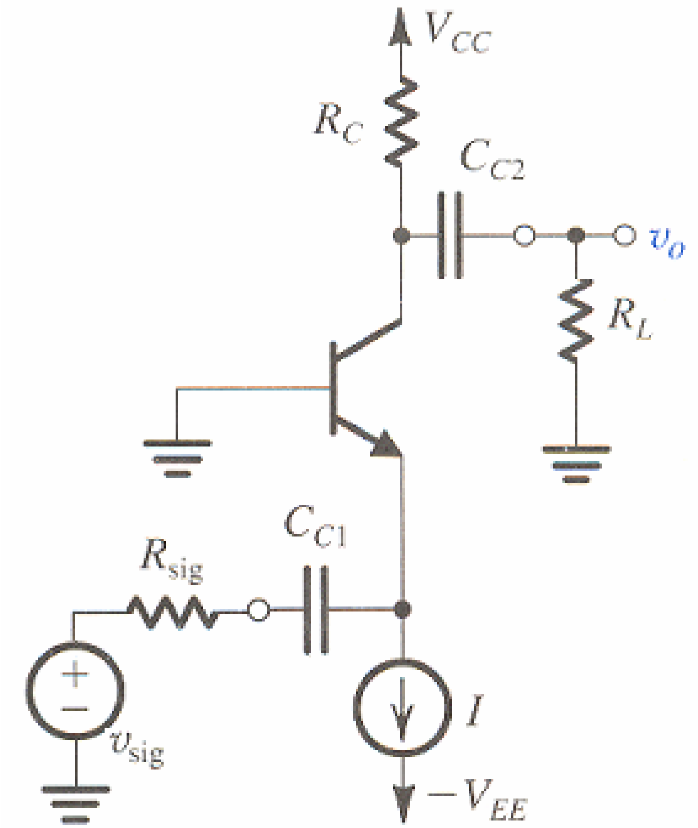
The resistance R_e in the emitter **introduce a negative feedback ➔ see pg 474**

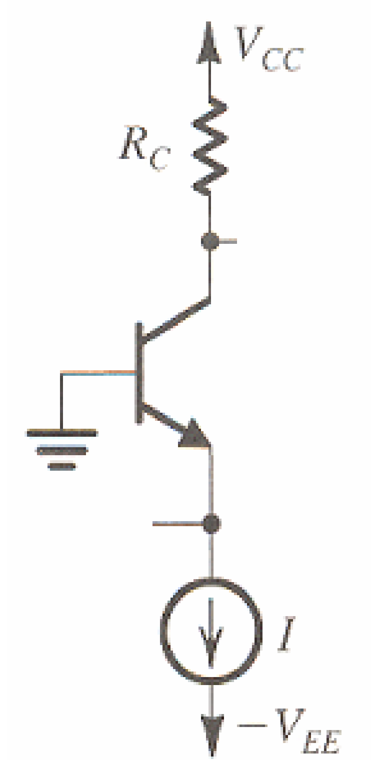
1. The input resistance R_{ib} is increased by the factor $(1 + g_m R_e)$.
2. The voltage gain from base to collector, A_v, is reduced by factor $(1 + g_m R_e)$.
3. For the same nonlinear distortion, the input signal v_i can be increased by the factor $(1 + g_m R_e)$.
4. The overall voltage gain is less dependant on the value of β.

Exercise-10: if I_E=1mA, I_C=0.99mA, R_e=225Ω, R_B=100kΩ, R_C=8kΩ, R_{sig}=R_L=5kΩ, β=100, V_T=25mV,

Neglect r_o to FIND R_{in}, R_{out}, A_v, G_v ➔ ***Sol:*** R_i=20.16 kΩ; R_{out}=8 kΩ, A_v= -12.18V/V, G_v=-9.76v/v

5.7.5:Common Base (CB) Amplifier: Unity-gain-current-amplifier or Current-buffer





DC analysis

Lets assume Active Mode.

$V_B = 0$; $V_E = V_B - 0.7$;

$I_E = \boldsymbol{I}$ mA ; $I_B = I_E / (\beta+1)$ mA;

$I_C = \alpha.I_E = (\beta.I_E) / (\beta+1)$;

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

if CBJ remains RB

then assumption is OK

AC analysis: For the AC equivalent circuit given in the figure in the next page,

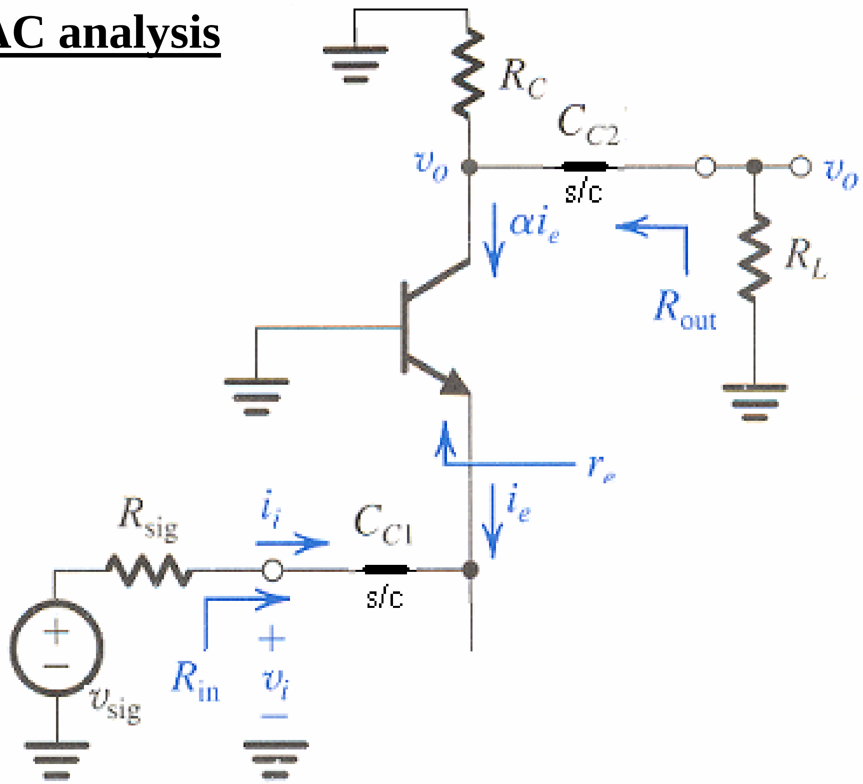
The input resistance $R_{in} = r_e$ and output resistance $R_{out} = R_C$ (with r_o neglected)

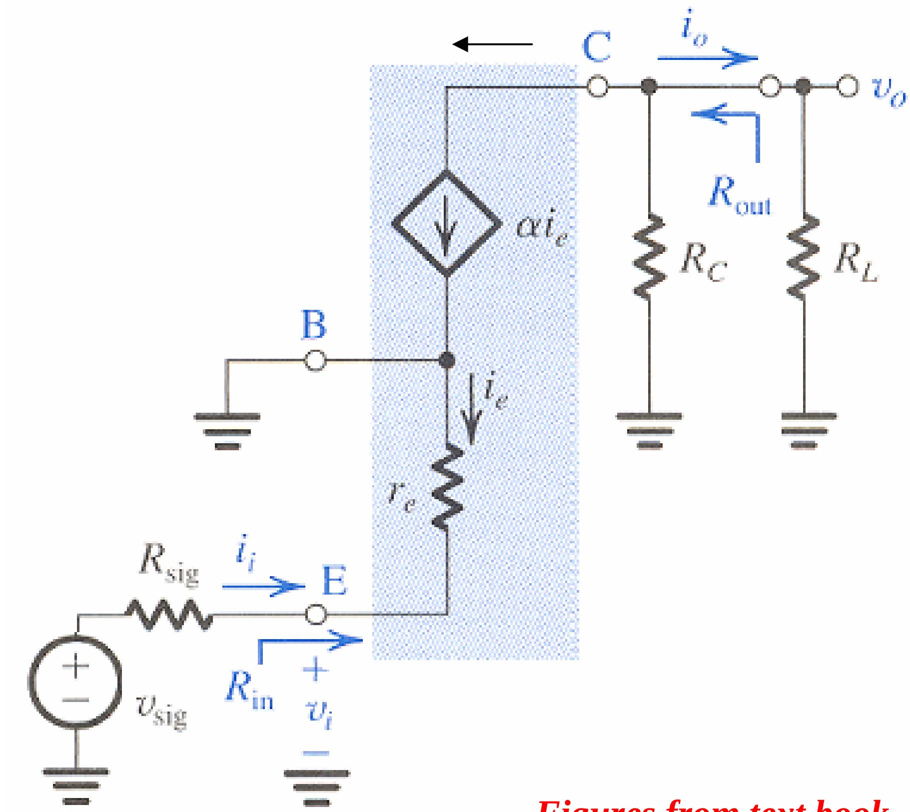
The low R_{in} cause the input signal to be severely attenuated,

as $$\frac{v_i}{v_{sig}} = \frac{R_i}{R_{sig} + R_i} = \frac{r_e}{R_{sig} + r_e}$$

5.7.5:Common Base (CB) Amplifier: Low Z_{in} makes it not good voltage amplifier

AC analysis





Figures from text book

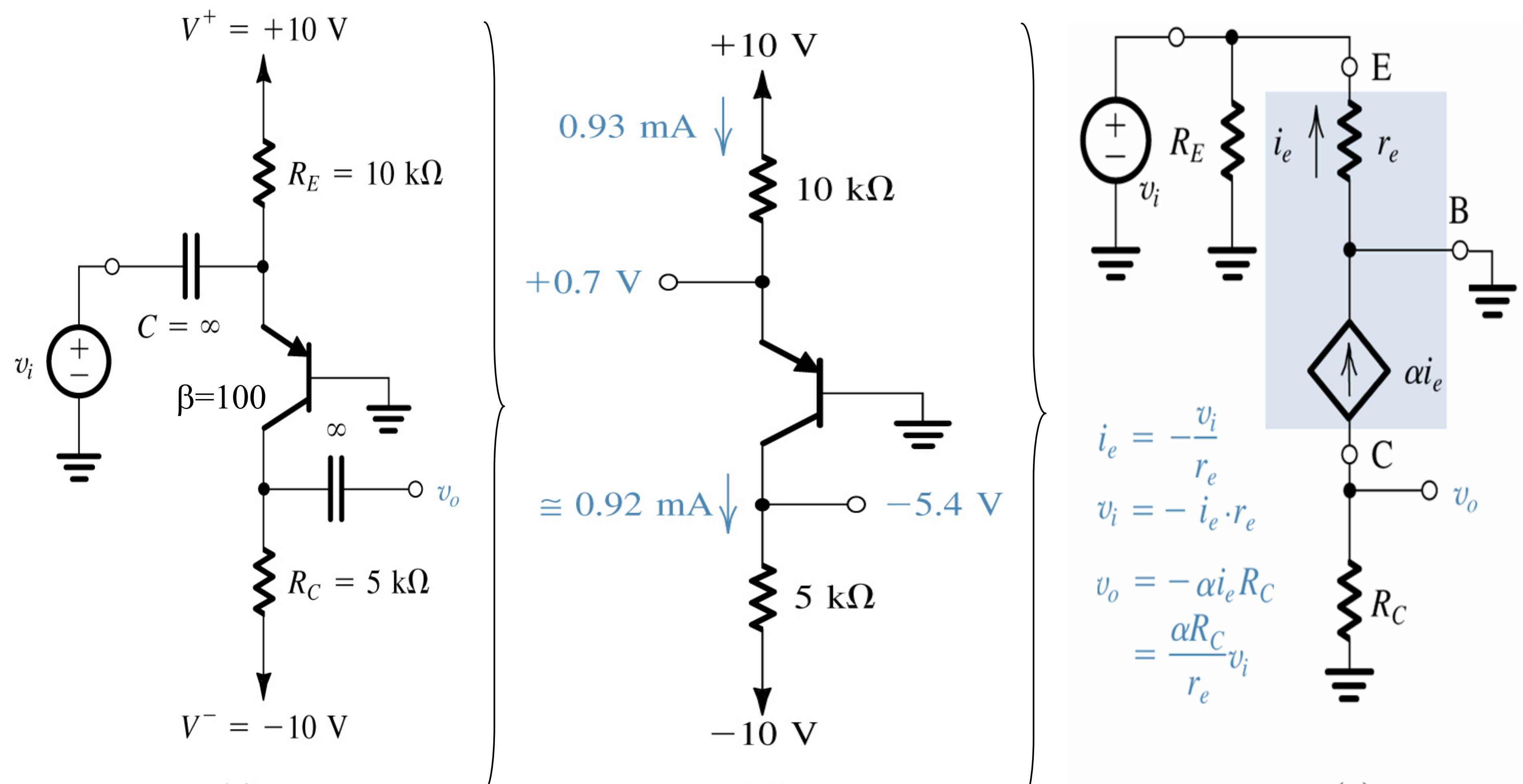
The voltage gain $A_v \equiv \dfrac{v_o}{v_i}$ as $v_o = -\alpha i_e(R_C \parallel R_L)$ and $v_i = -i_e \cdot r_e$

$$A_v \equiv \frac{v_o}{v_i} = \frac{\alpha}{r_e}(R_C \parallel R_L) = g_m(R_C \parallel R_L)$$

and the overall voltage gain $G_v = \dfrac{r_e}{R_{sig} + r_e} g_m(R_C \parallel R_L) = \dfrac{\alpha(R_C \parallel R_L)}{R_{sig} + r_e}$

Finally, a very significant application of the CB circuit is as a unity-gain current amplifier or **current buffer:** It accepts an input

Exercise-11: Determine the voltage gain of the circuit given in figure (a)



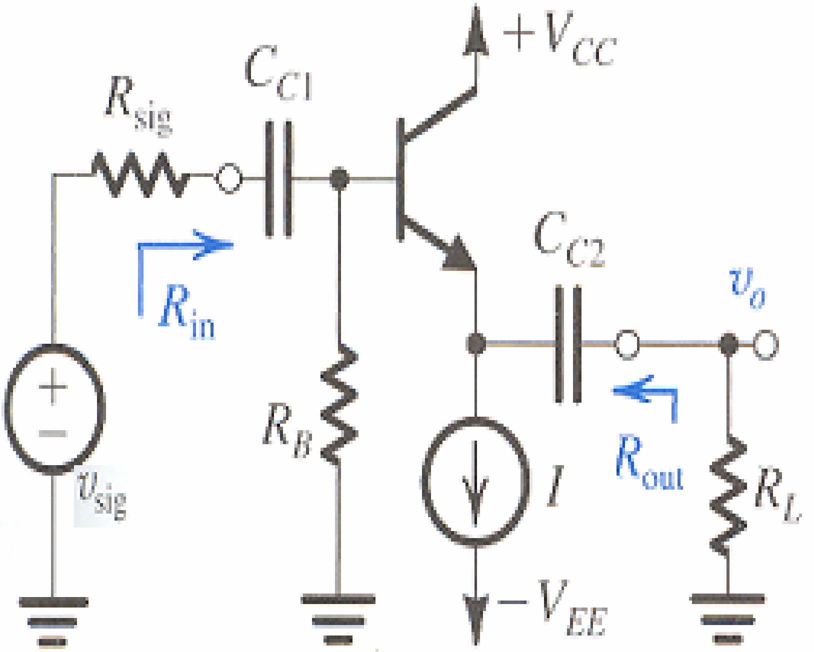
(a) (b) *Figures from text book* (c)

Hints: Draw the DC and AC (using T-model) equivalent circuits (as shown in figure)

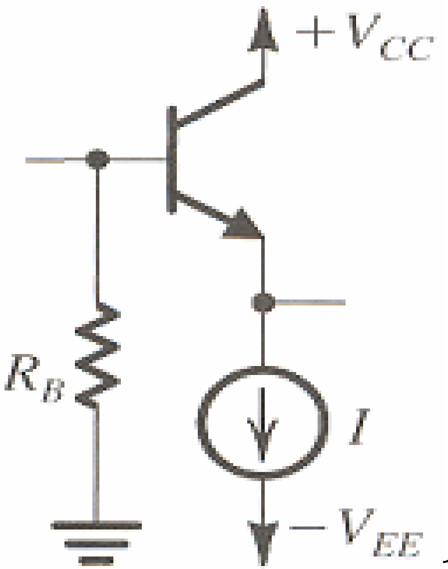
The DC solutions are also shown in figure (b). Calculated ➔ $r_e = 27\ \Omega$

The Gain of the circuit, calculated from figure (c) is, $A_v = v_o/v_i = 183.3$ V/V

5.7.5:Common Collector (CC) Amplifier: Emitter Follower



DC analysis



Assume Active Mode.

$I_E = \boldsymbol{I}$ mA; $I_B = I_E/(\beta+1)$mA

$V_B = 0 - (I_B)(R_B)$;

$V_E = V_B - 0.7$;

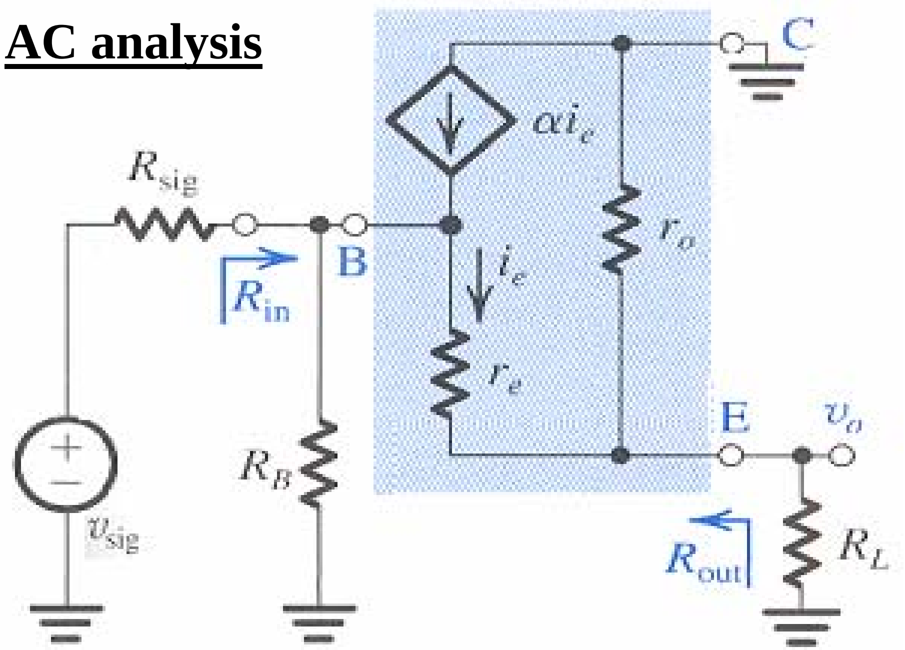
$I_C = \alpha.I_E = (\beta.I_E)/(\beta+1)$;

$V_C = V_{CC}$

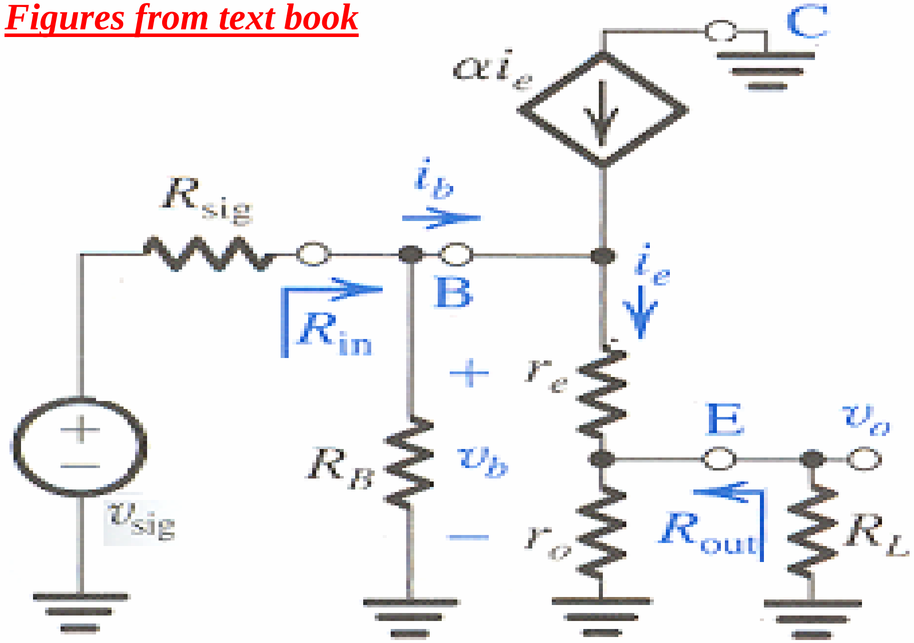
if CBJ remains RB

then assumption is OK

AC analysis

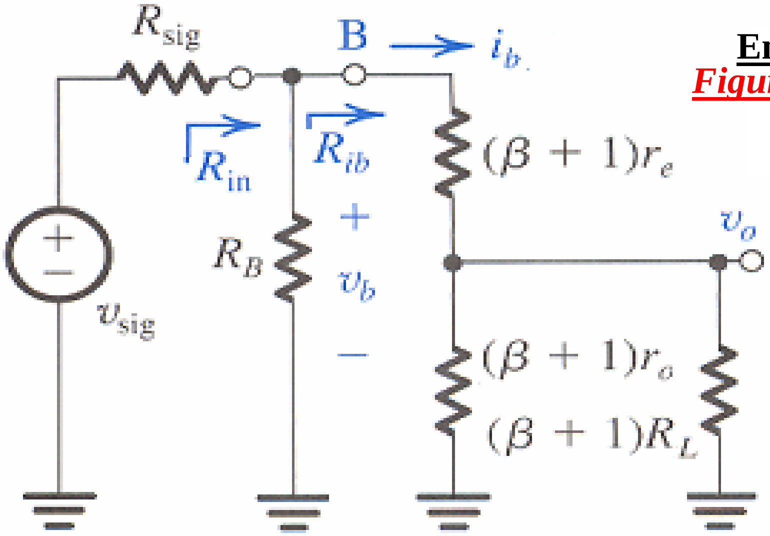


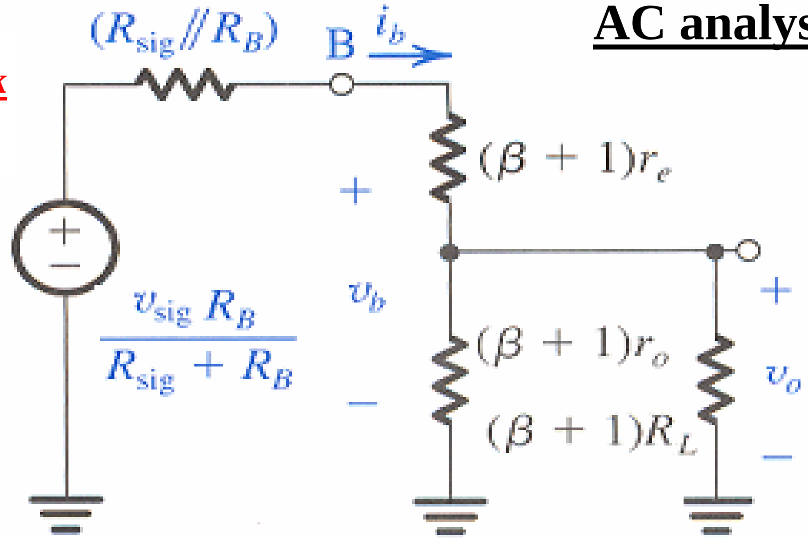
Figures from text book



AC analysis

Emitter to Base:
Figures from text book

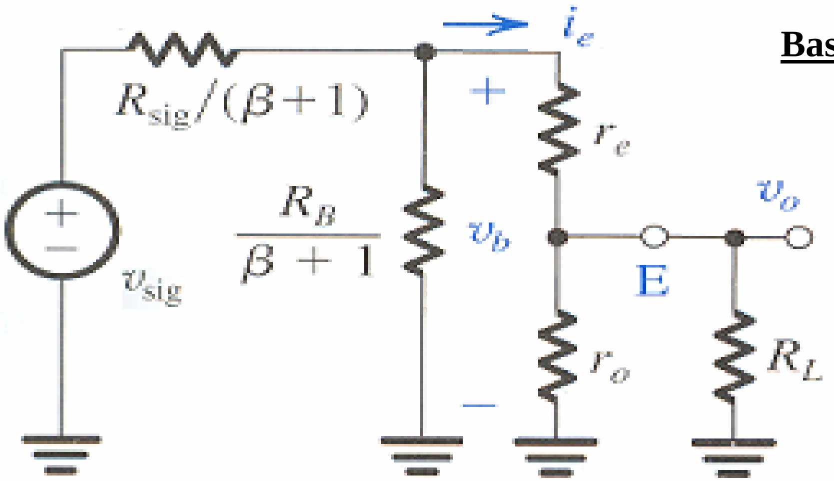


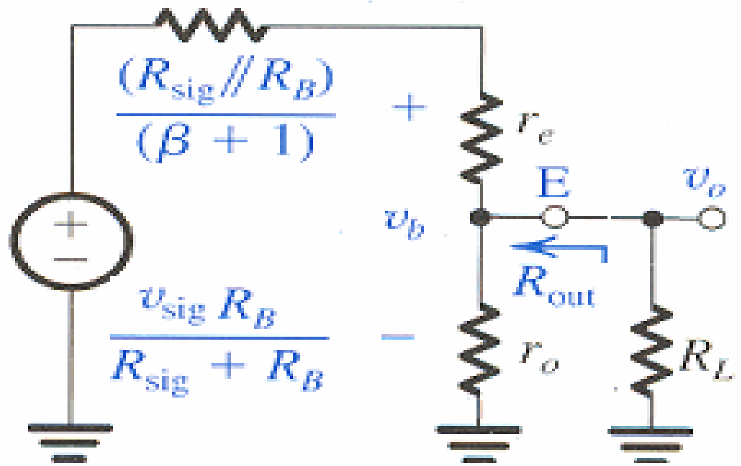


$$R_{in} = R_B // (\beta + 1)[r_e + (r_o // R_L)]$$

$$G_v = \frac{v_o}{v_{sig}} = \frac{R_B}{R_{sig} + R_B} \frac{(\beta + 1)(r_o // R_L)}{(R_{sig} // R_B) + (\beta + 1)[r_e + (r_o // R_L)]}$$

Base to Emitter

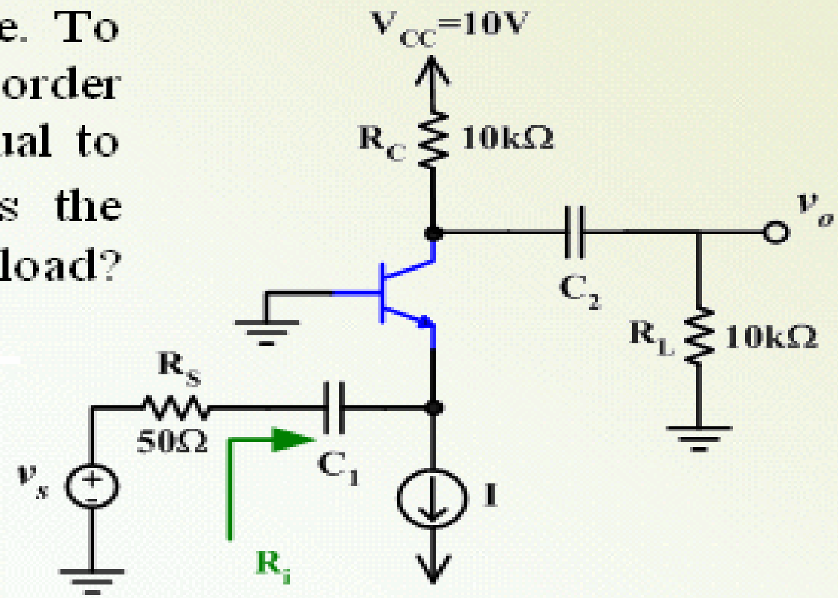




$$G_v = \frac{v_o}{v_{sig}} = \frac{R_B}{R_{sig} + R_B} \frac{(r_o // R_L)}{\frac{(R_{sig} // R_B)}{\beta + 1} + r_e + (r_o // R_L)}$$

$$R_{out} = r_o \parallel \left(r_e + \frac{R_{sig} \parallel R_B}{\beta + 1} \right)$$

Consider the CB amplifier shown in the figure. To what value must current source 'I' be set in order that the input resistance at emitter 'Ri' is equal to that of the source (namely 50Ω)? What is the resulting voltage gain from the source to the load? Assume α=1 and neglect early voltage effect.



Hint : Since α=1, therefore $I_E=I_C=I$. Using T-model, its easy to see that $R_i=r_e$. Find r_e in terms of I and put it equal to 50 to find I. Find the voltage gain $Av=v_o/v_s$ from the T-model. Answer : I= 0.5mA ; Av = 50

Exercises-12

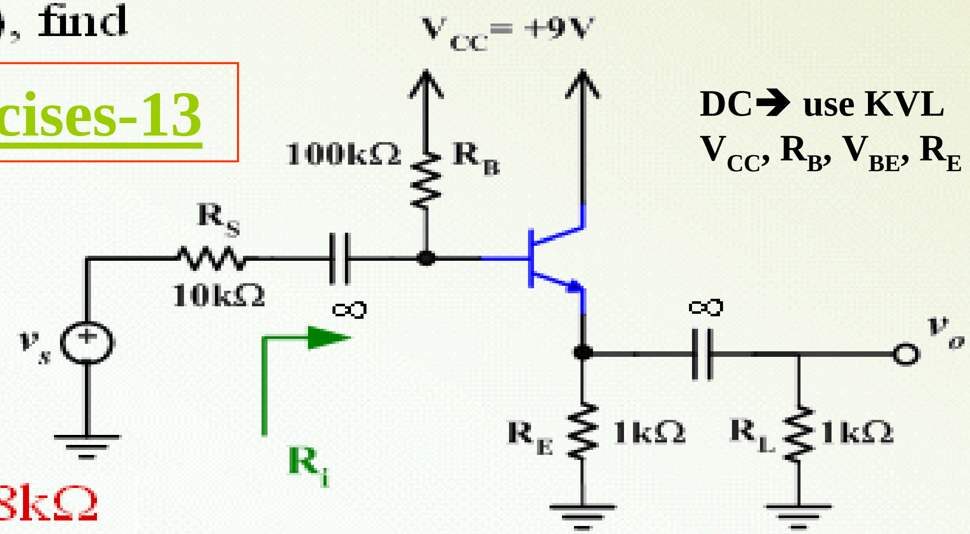
In the CC amplifier shown, the BJT used is specified to have β values in the range of 20 to 200 (a distressing situation for the circuit designer). For the two extreme values of β (β=20 and β=200), find

(a) the input resistance, Ri

(b) the overall voltage gain, G_v

Exercises-13

The result will show why electronic engineers want to design biasing circuits that are independent of variations in β

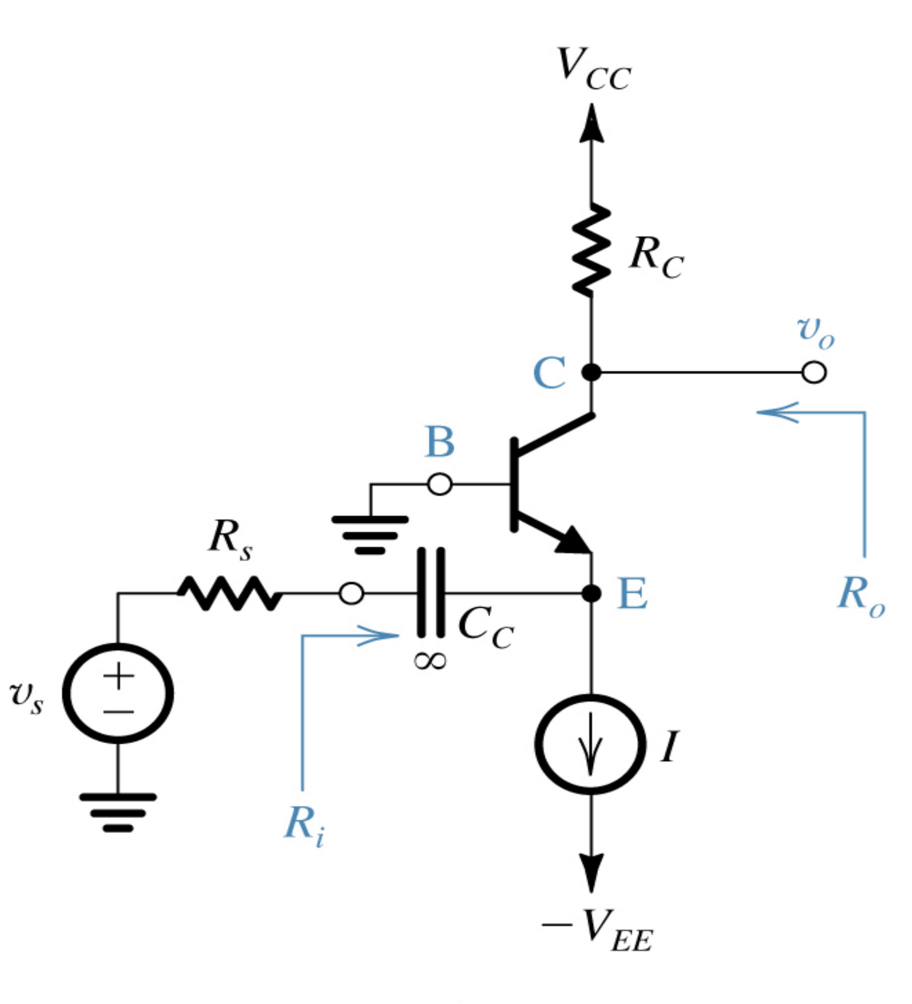


Answer:

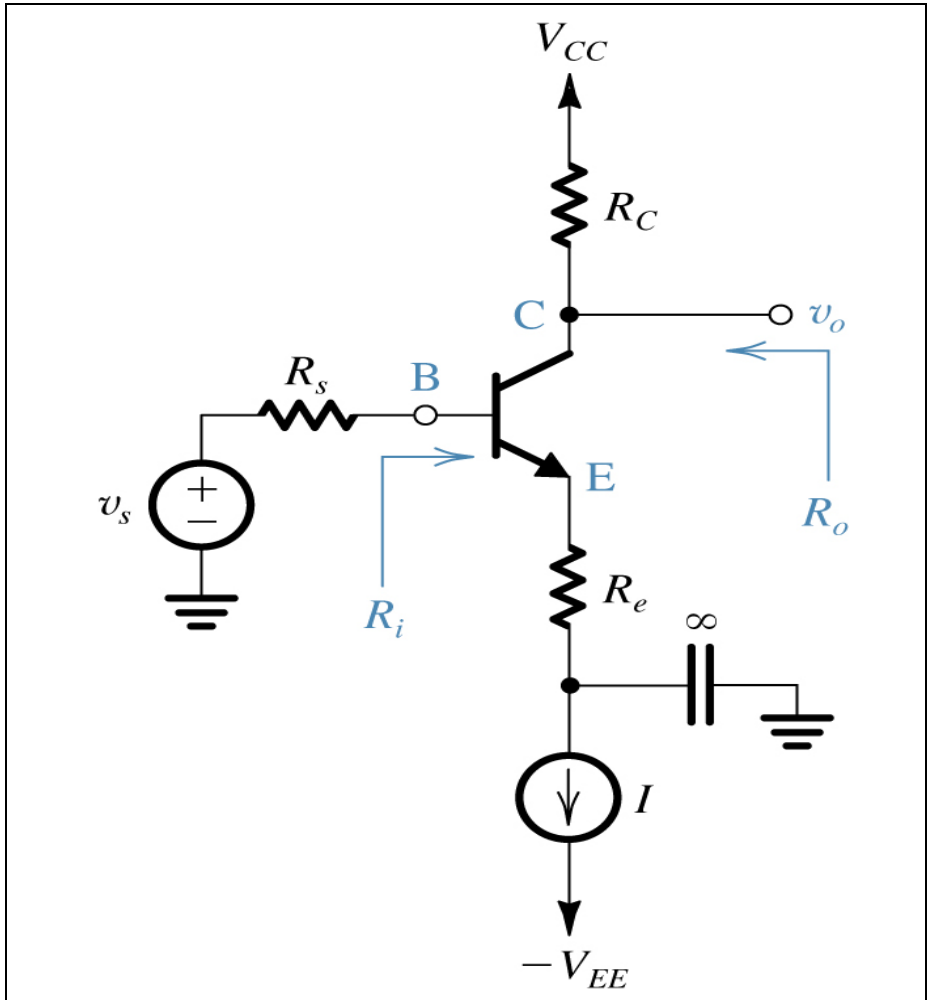
β=20 G_v $=v_o/v_s$=0.478 ; Ri=9.8kΩ

β=200 G_v $=v_o/v_s$=0.827 ; Ri=50.3kΩ

Exercise-14: For the following circuits, find the <u>expressions</u> for R_{in}, R_{out}, A_v



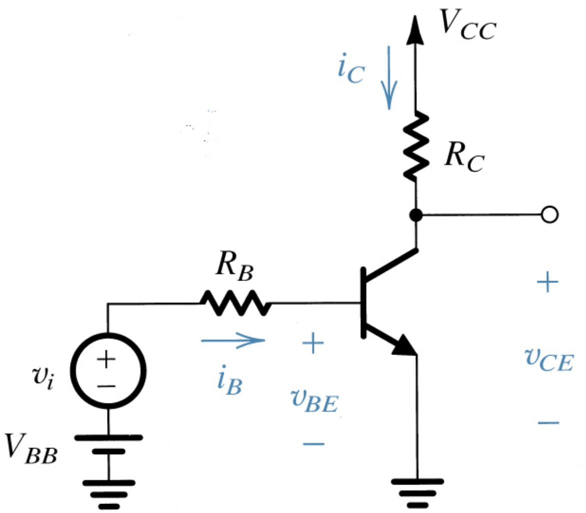
Circuit 1 configuration

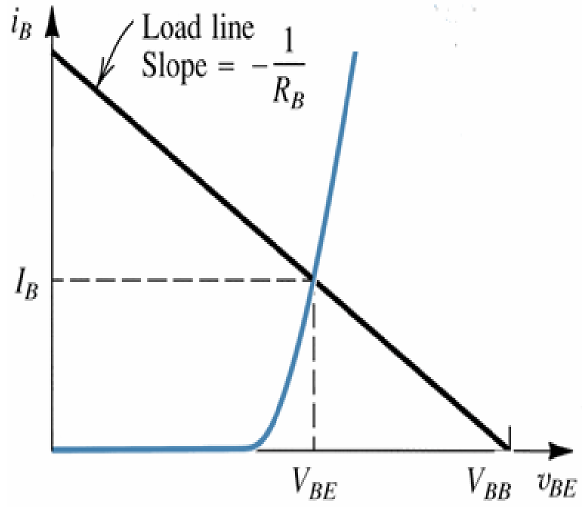


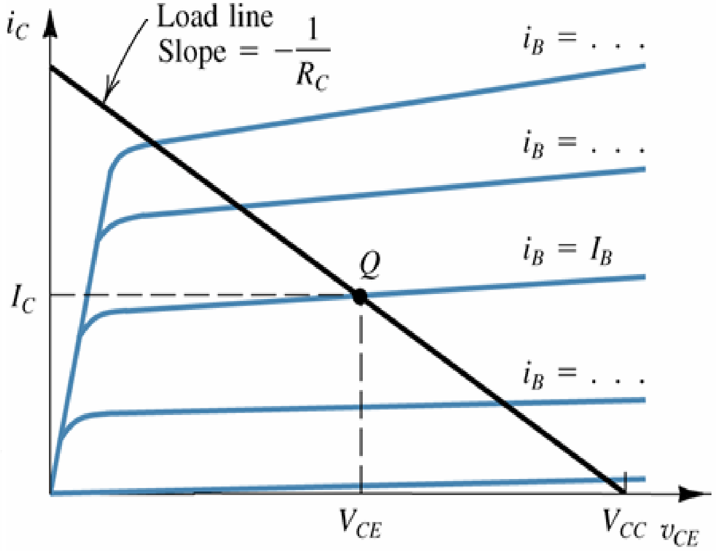
Circuit 2 configuration

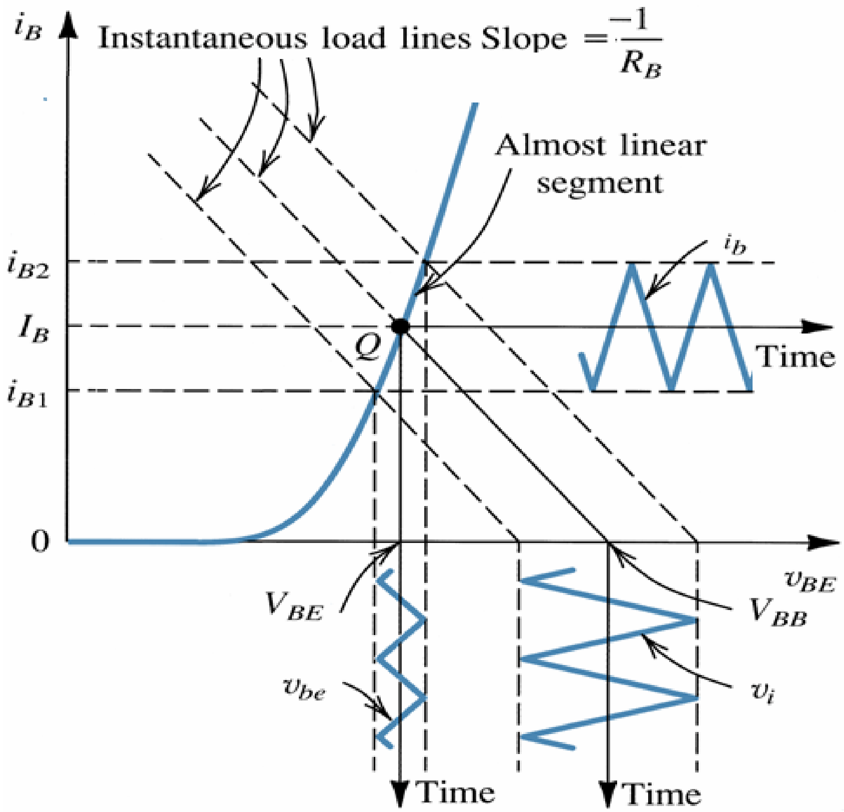
Assignment Problems: 5:21, 5.26, 5.72, 5.83(b), 5.130 ,5.134, 5.135, 5.143 and 5.141 ➔ Due on next week

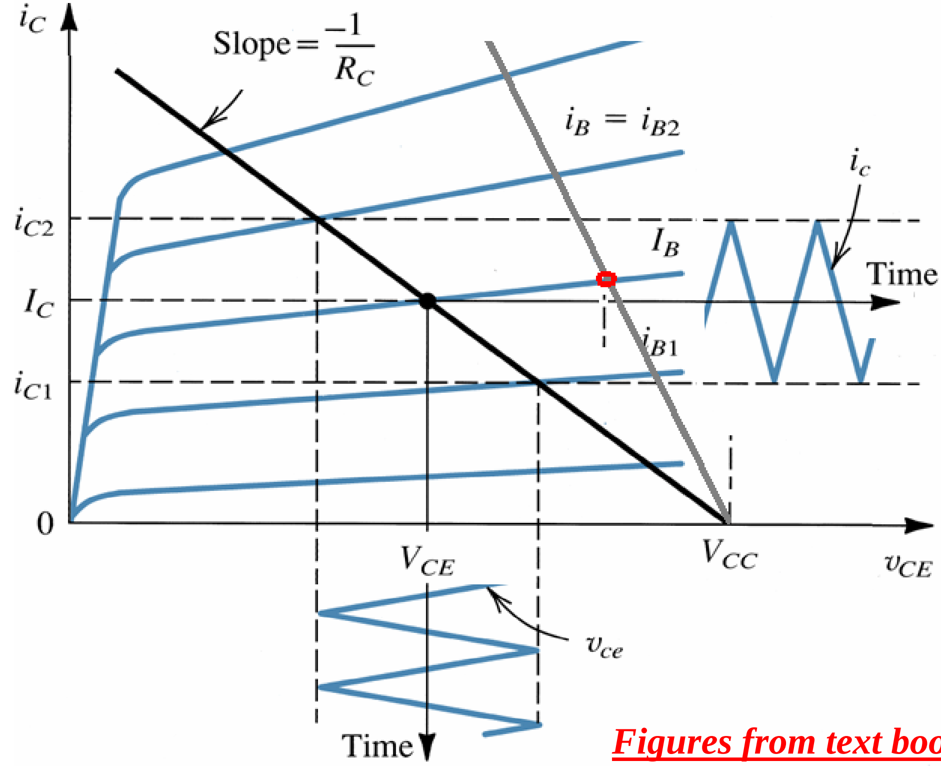
Design Criteria of a BJT Amplifier (review):











Figures from text book

Simulation Examples using the Spice software: