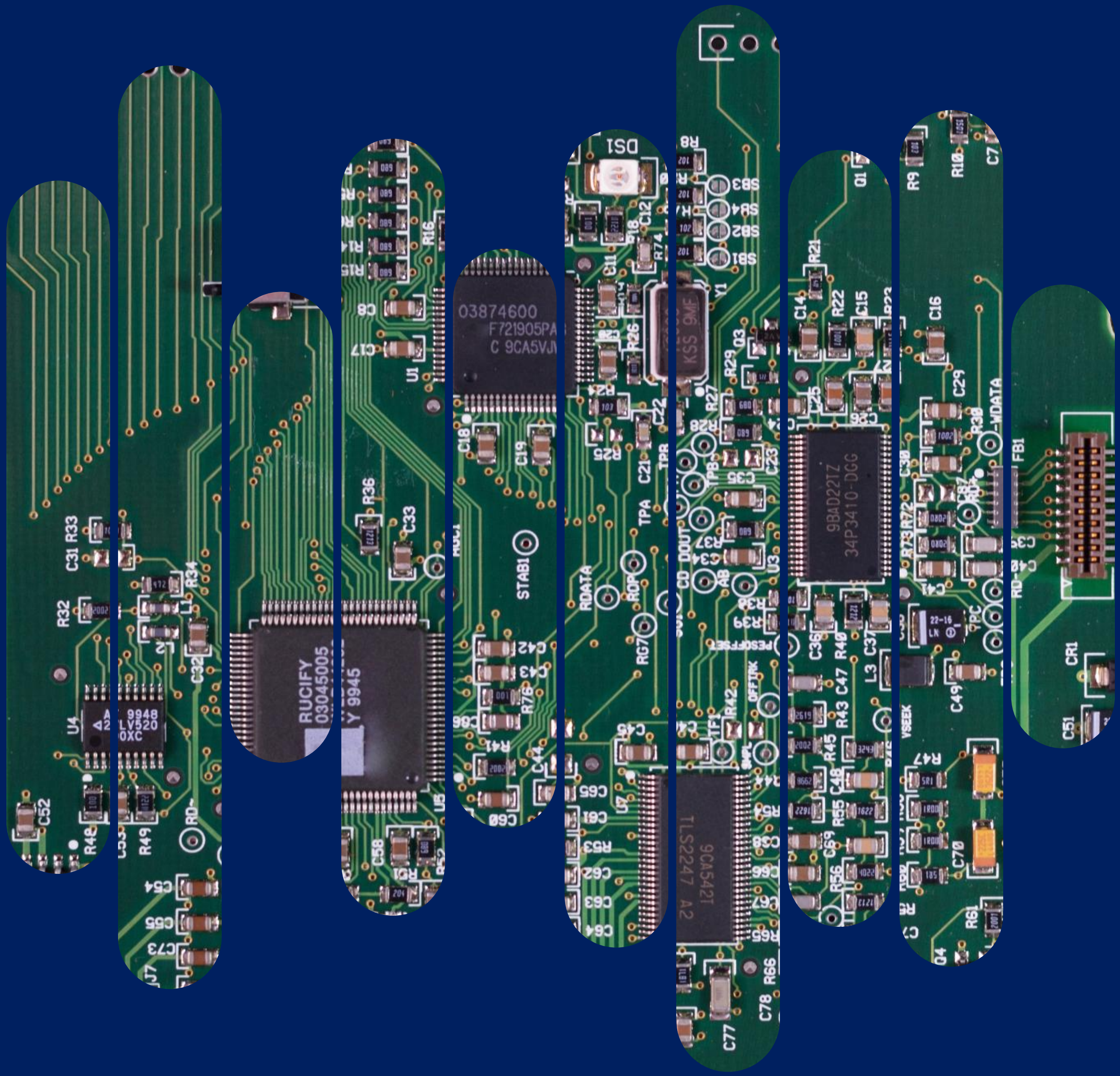
Electronic Devices

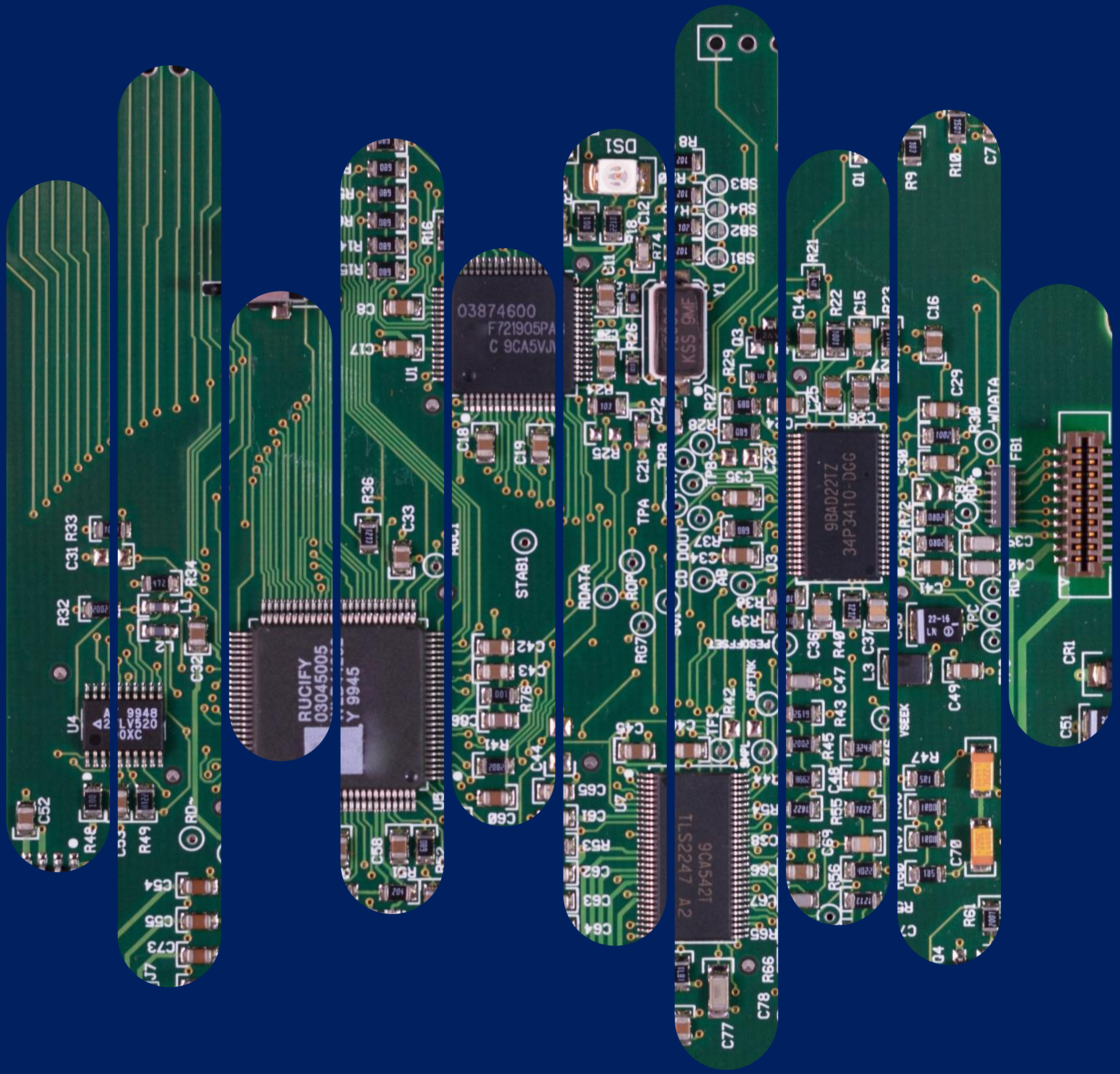


CHAPTER 2

Bipolar Junction Transistor

BJT

- An electronic device
- Uses both electrons and holes
- Consists 2 pn junctions
- Consists three layers of semiconductors
- Commonly used as amplifiers and switches



2.1 Introduction of bipolar junction transistor

Transistors basics

- The basic of electronic system nowadays is semiconductor device.
- The famous and commonly use of this device is BJTs
  (Bipolar Junction Transistors).
- It can be use as amplifier and logic switches.
- BJT consists of three terminal:
  - → collector : C
  - → base : B
  - → emitter : E
- Two types of BJT : pnp and npn

2.1 Introduction of bipolar junction transistor

Transistors Construction

- 3 layer semiconductor device consisting:
  - 2 n- and 1 p-type layers of material → npn transistor
  - 2 p- and 1 n-type layers of material →pnp transistor
- The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material
- A single pn junction has two different types of bias:
  - forward bias
  - reverse bias
- Thus, a two-pn-junction device has four types of bias.

2.1 Introduction of bipolar junction transistor

Terminals and symbol of BJT

- Base is located at the middle and more thin from the level of collector and emitter
- The emitter and collector terminals are made of the same type of semiconductor material, while the base of the other type of material

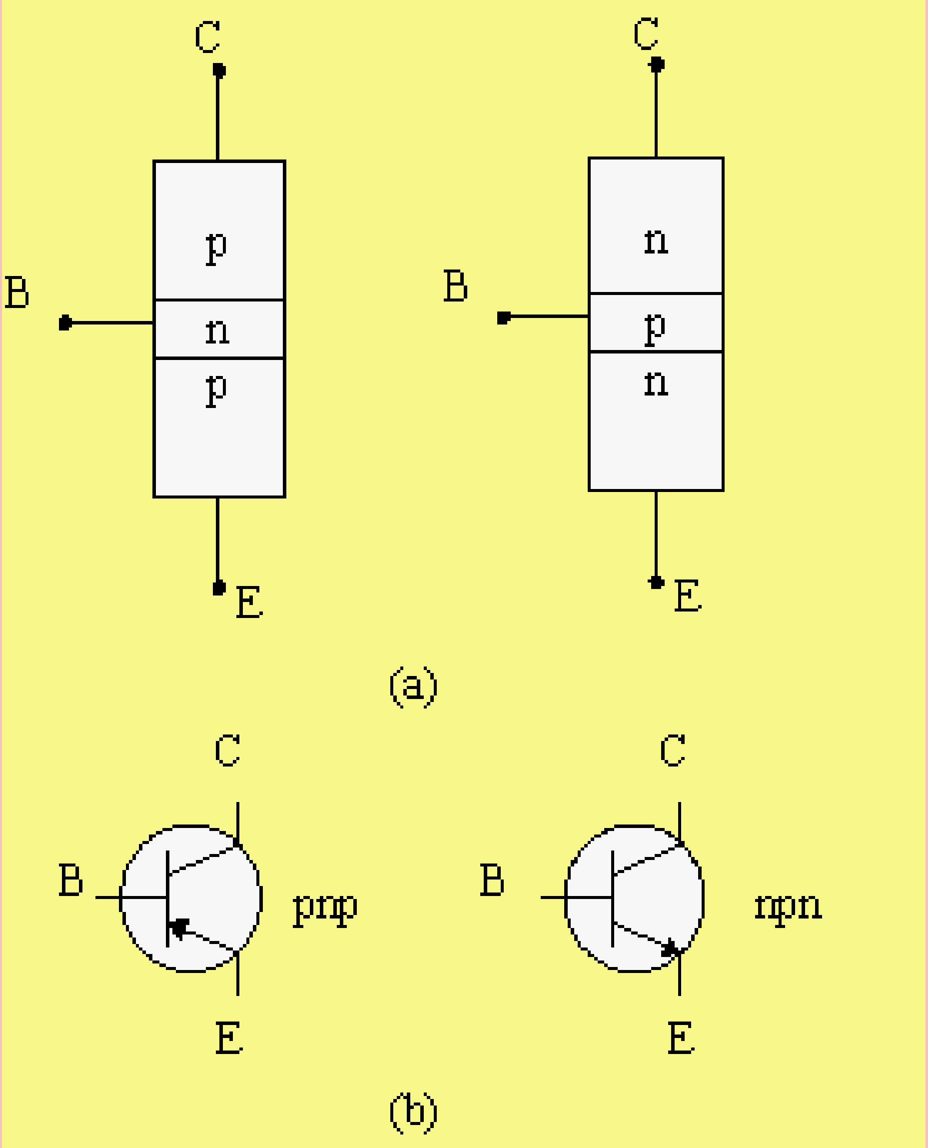
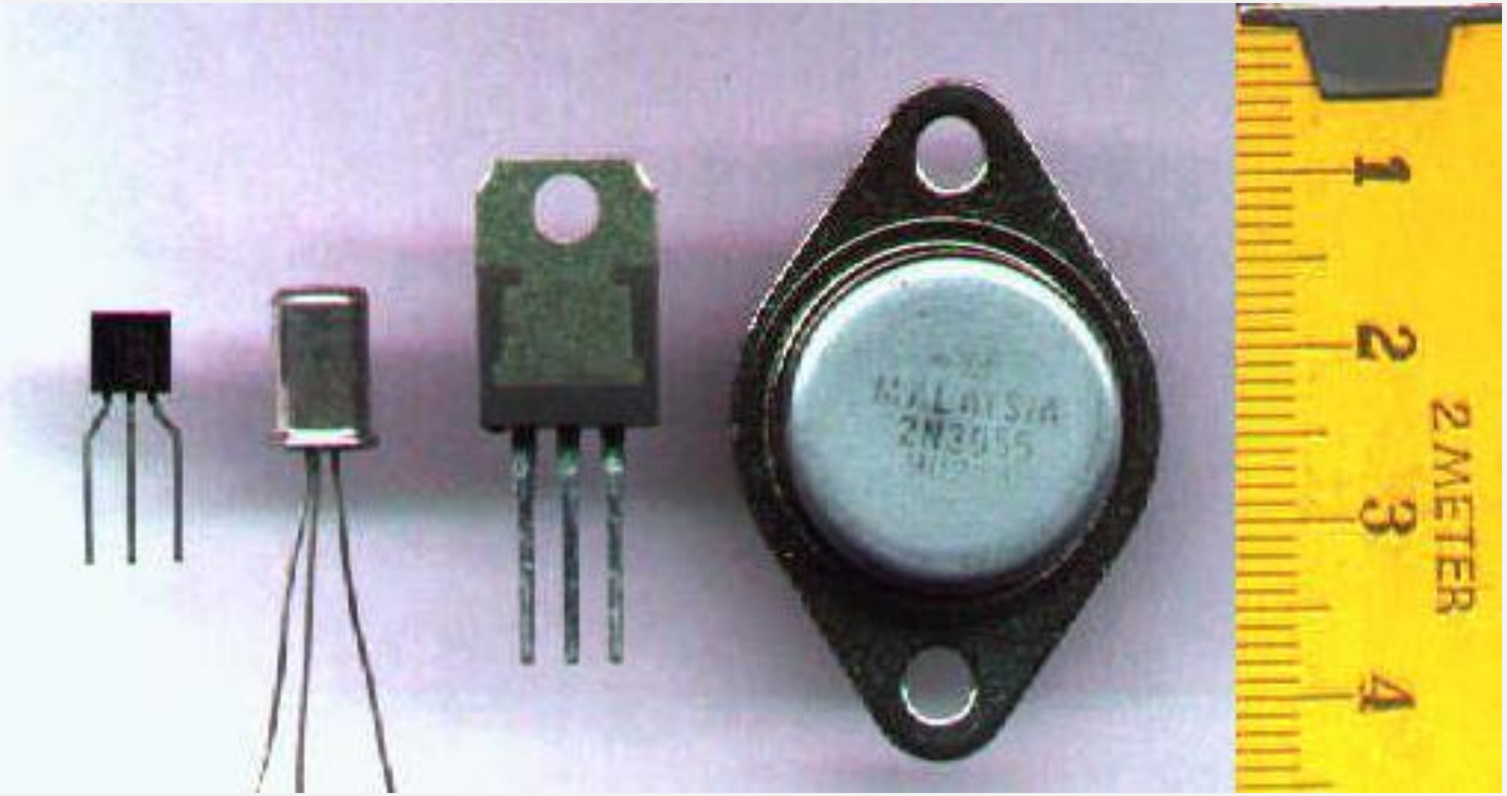


Fig. 4.1: (a) Position of terminals (b) Type of BJT

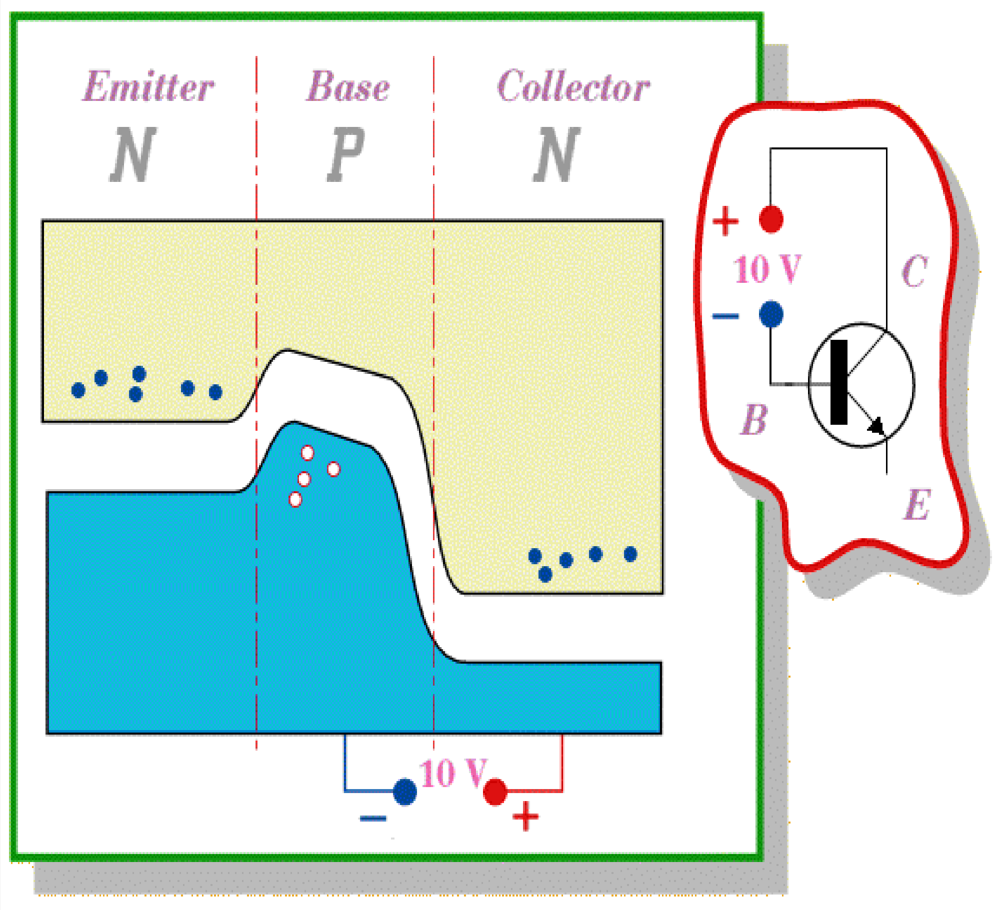
2.1 Introduction of bipolar junction transistor

Modern Transistors



2.2 Current flow mechanism in PNP and NPN transistors

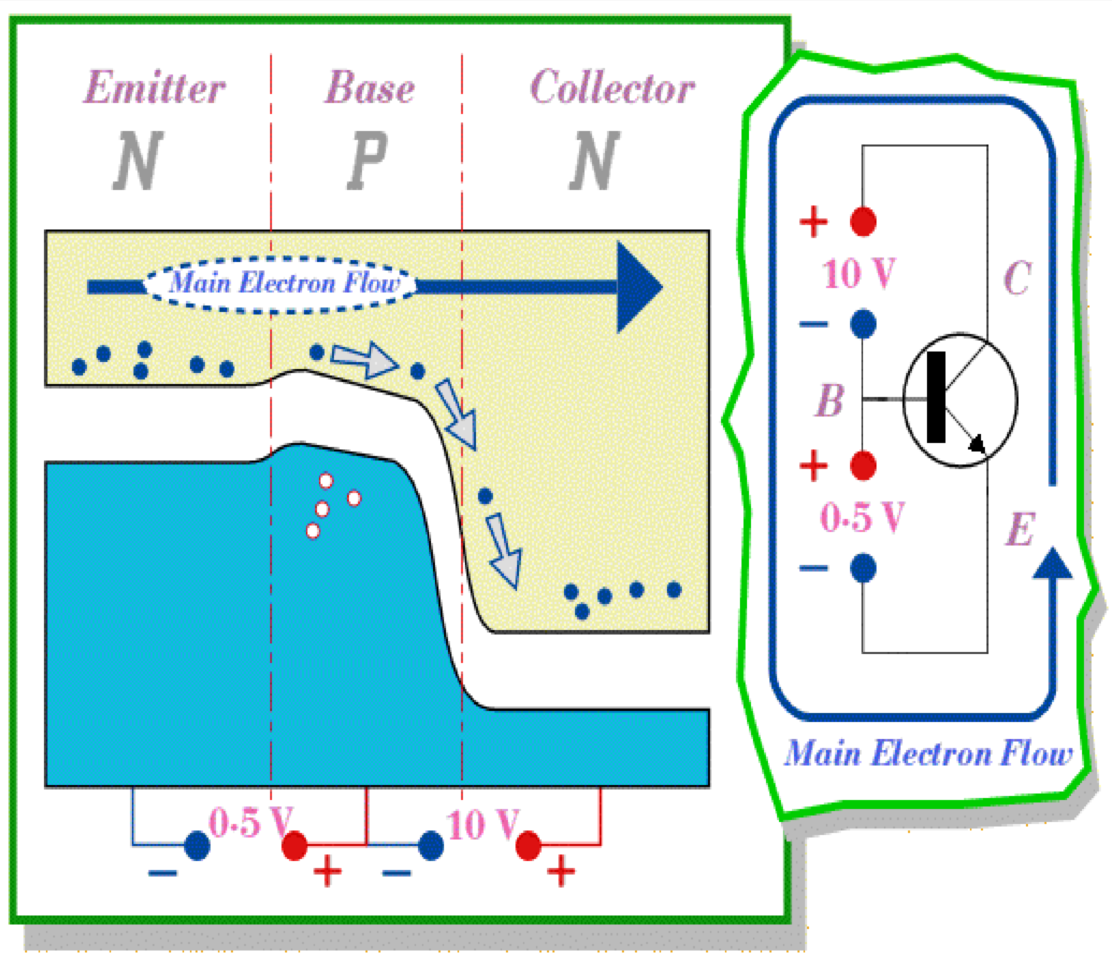
Transistors Operation



- What happens when we apply a moderate voltage between the collector and base parts.
- The polarity of the applied voltage is chosen to increase the force pulling the N-type electrons and P-type holes apart.
- This widens the depletion zone between the collector and base and so no current will flow.
- In effect we have reverse-biased the Base-Collector diode junction.

2.2 Current flow mechanism in PNP and NPN transistors

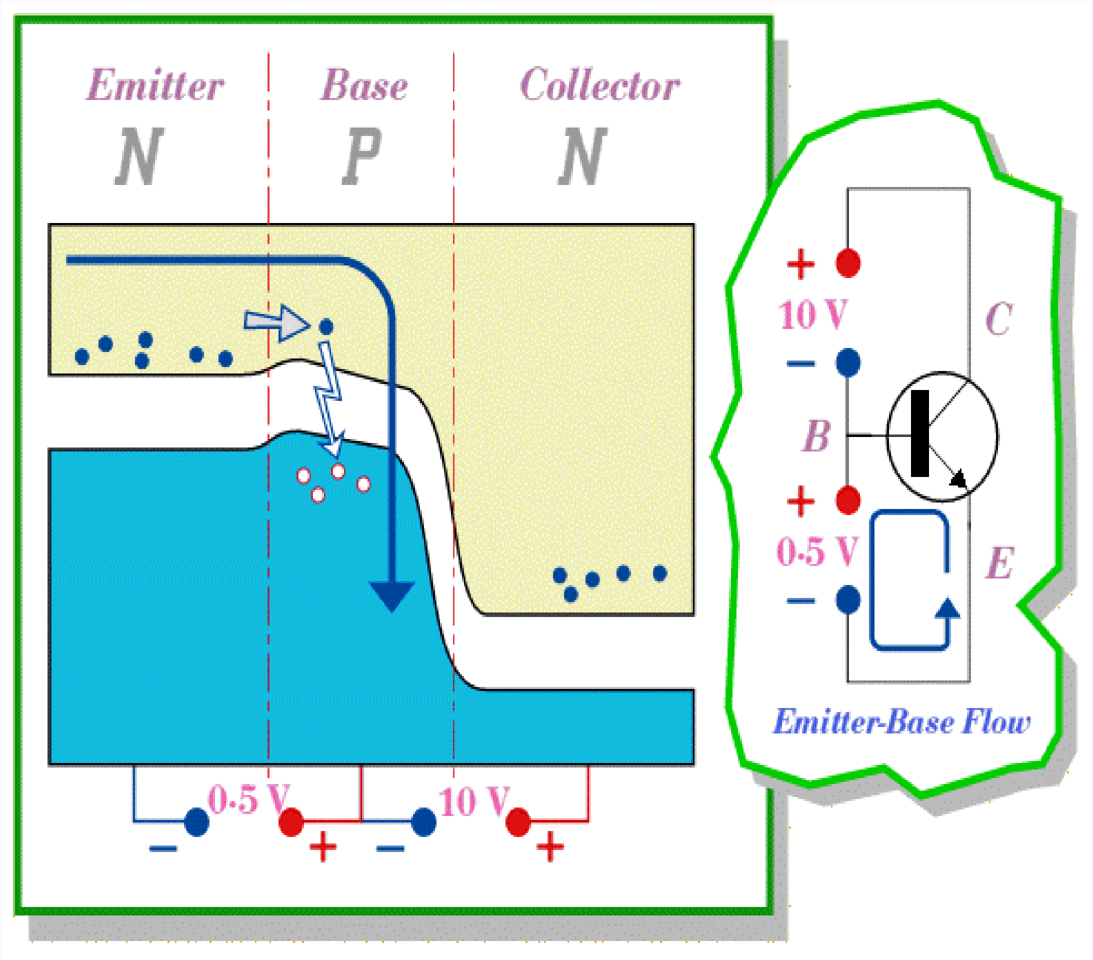
Transistors Operation



- What happens when we apply a relatively small Emitter-Base voltage whose polarity is designed to forward-bias the Emitter-Base junction.
- This 'pushes' electrons from the Emitter into the Base region and sets up a current flow across the Emitter-Base boundary.
- Once the electrons have managed to get into the Base region they can respond to the attractive force from the positively-biased Collector region.
- As a result the electrons which get into the Base move swiftly towards the Collector and cross into the Collector region.
- Hence a Emitter-Collector current magnitude is set by the chosen Emitter-Base voltage applied.
- Hence an external current flowing in the circuit.

2.2 Current flow mechanism in PNP and NPN transistors

Transistors Operation



- To prevent this happening we use the applied E-B voltage to remove the captured electrons from the base and maintain the number of holes.
- The effect, some of the electrons which enter the transistor via the Emitter emerging again from the Base rather than the Collector.
- For most practical BJT only about 1% of the free electrons which try to cross Base region get caught in this way.
- Hence a Base current, I_B, which is typically around one hundred times smaller than the Emitter current, I_E.

2.2 Current flow mechanism in PNP and NPN transistors

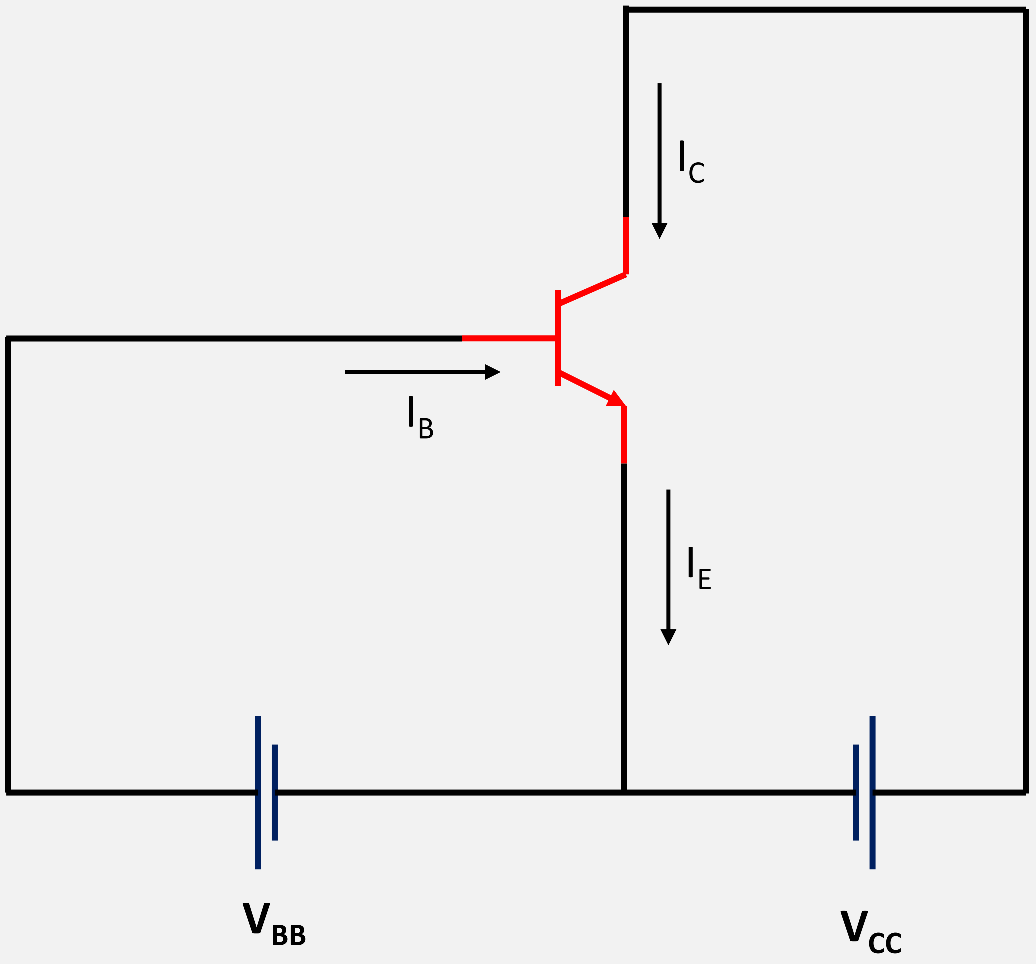
Transistors Operation Mode

Operation mode	Biasing polarity BE junction	Biasing polarity BC junction
Active	Forward	Reverse
Saturation	Forward	Forward
Cut off	Reverse	Reverse

- Active: Most widely encountered operation eg. as amplifiers. Large signal gain, small signal distortion
- Saturation: Equivalent to an on state when BJT is used as a switch. High current flow, Low voltage
- Cutoff: Equivalent to an off state when BJT is used as a switch. Low current flow, High voltage.

2.3 Input and Output characteristics

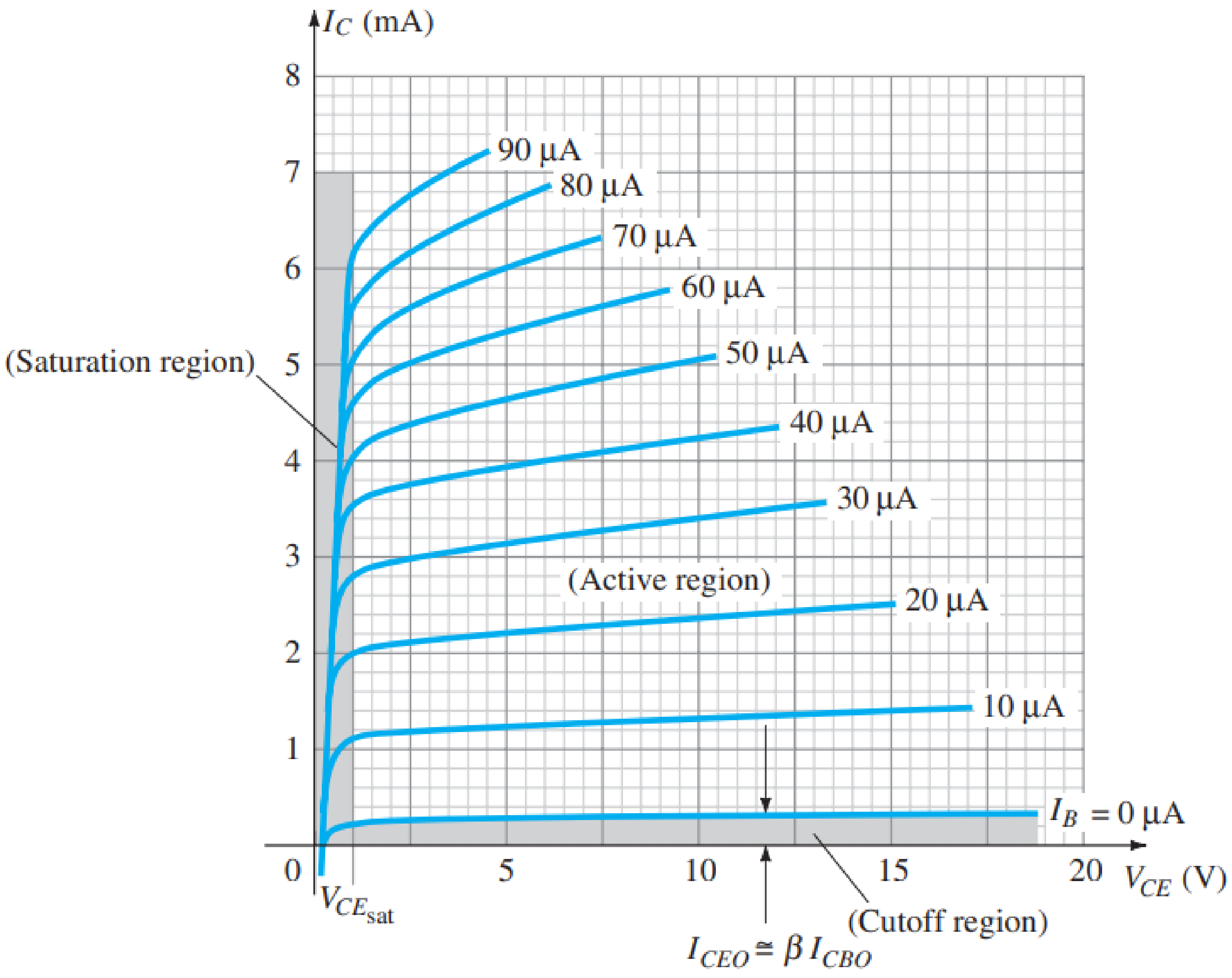
Transistors Operation Mode (Common Emitter Configuration)



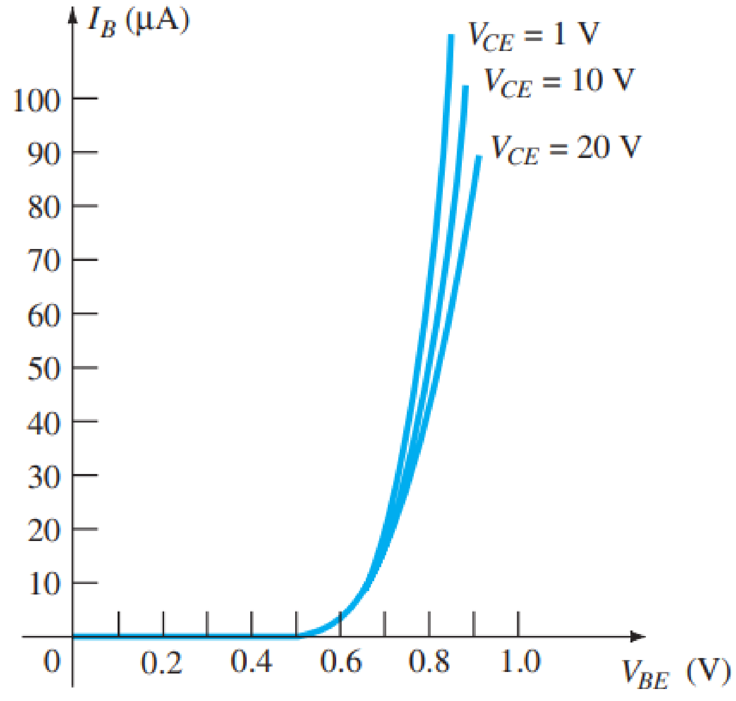
Emitter terminal is common

2.3 Input and Output characteristics

Transistors Operation Mode (Common Emitter Configuration)



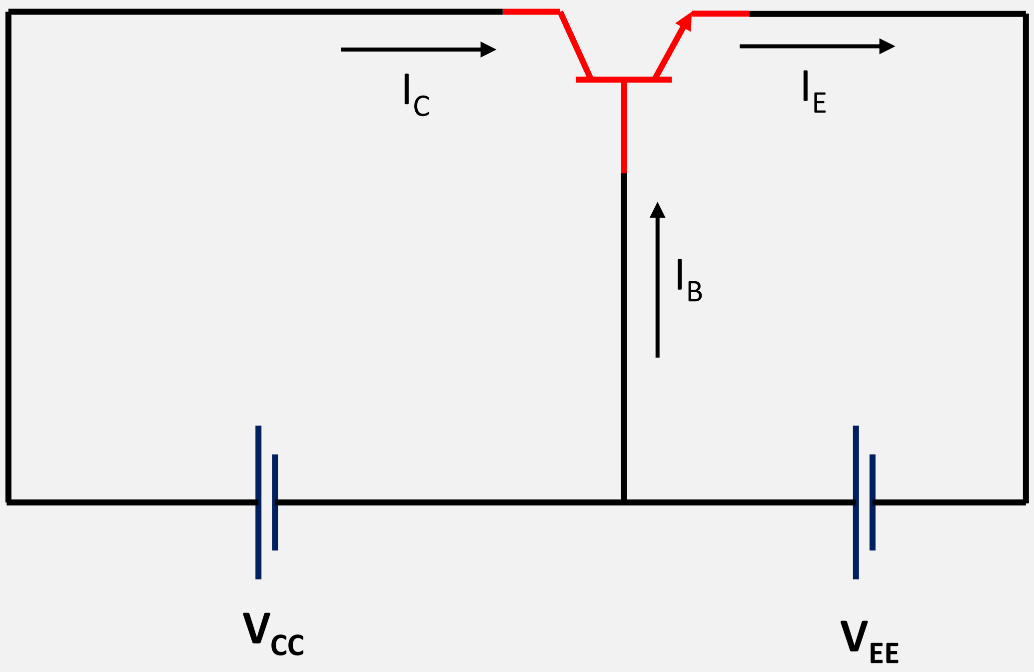
(a)



(b)

2.3 Input and Output characteristics

Transistors Operation Mode (Common Base Configuration)



Base terminal is common

2.3 Input and Output characteristics

Transistors Operation Mode (Common Base Configuration)

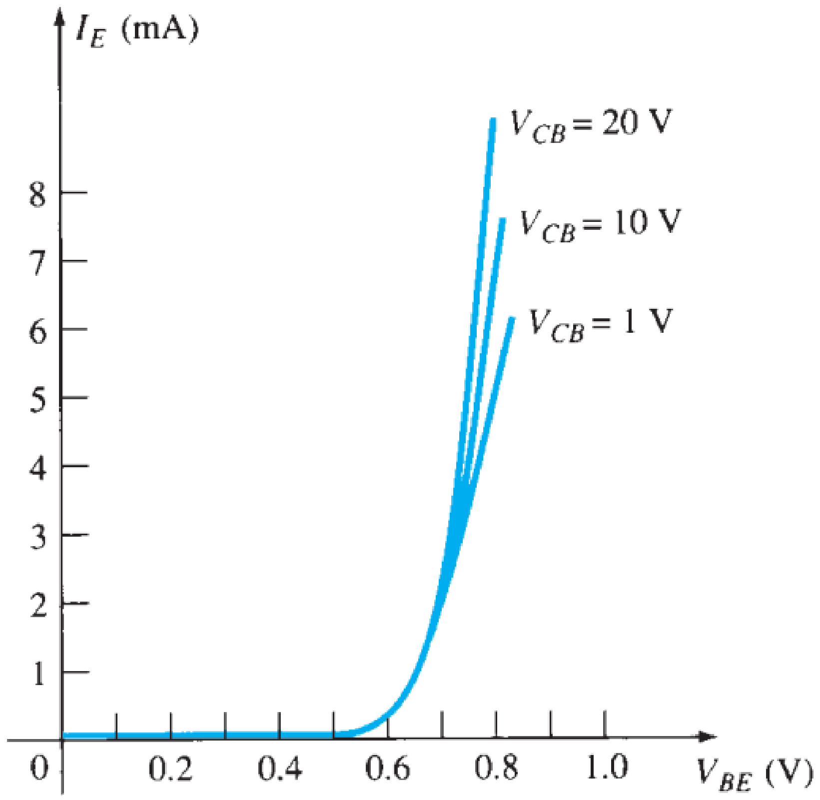


FIG. 3.7
Input or driving point characteristics for a common-base silicon transistor amplifier.

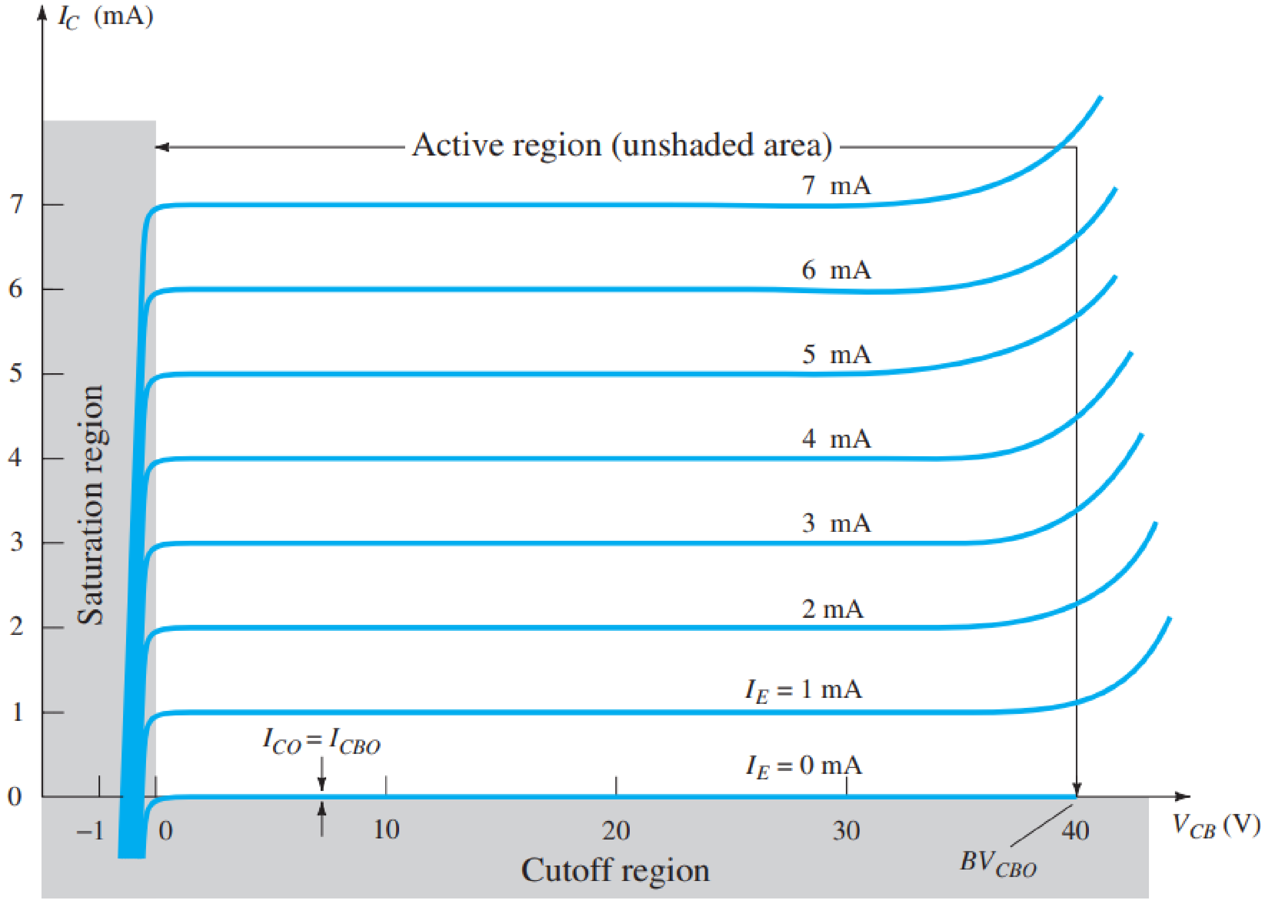


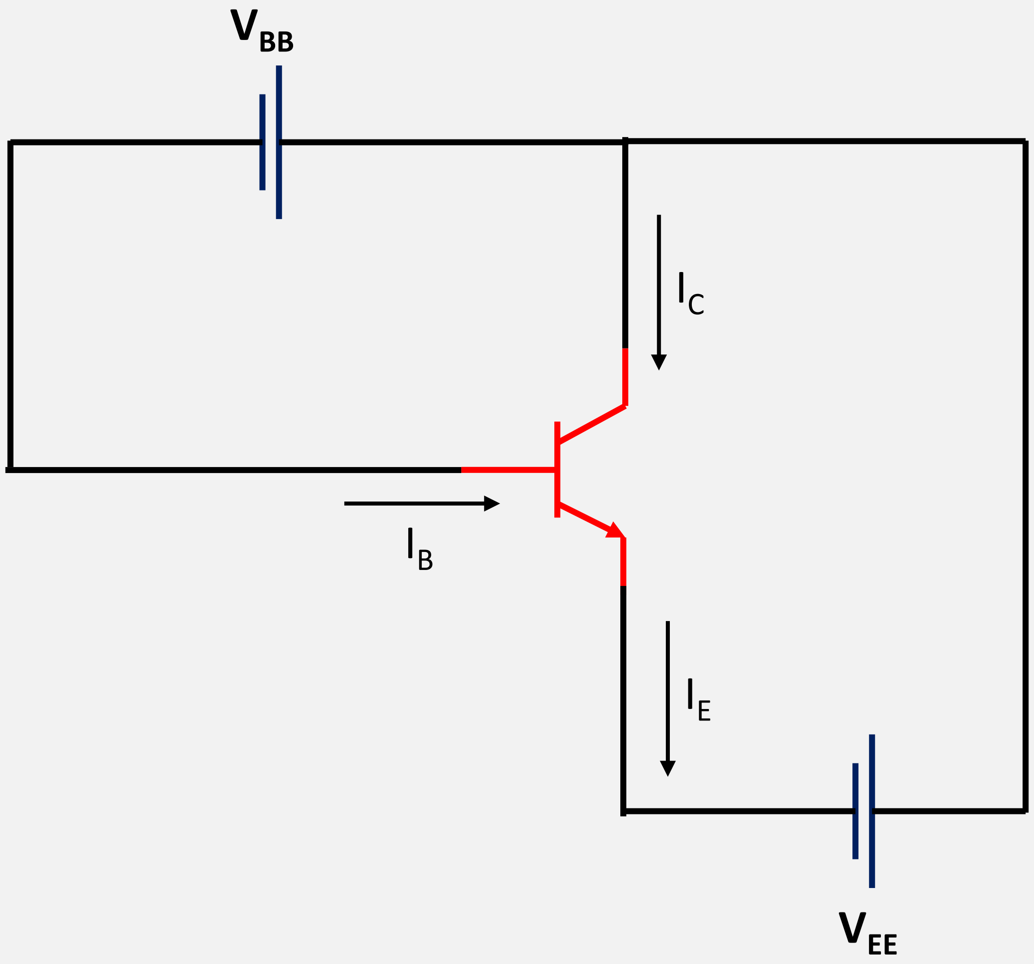
FIG. 3.8
Output or collector characteristics for a common-base transistor amplifier.

2.4 Reach through or Punch through

As we increase the reverse bias voltage of base collector junction depletion width increases and effective base width decreases (since base is less doped compared to collector, depletion layer protrudes more into the base the collector hence effective base width gets affected), at some point effective base width approaches zero and transistor will breakdown .This phenomenon is called reach through or punch through.

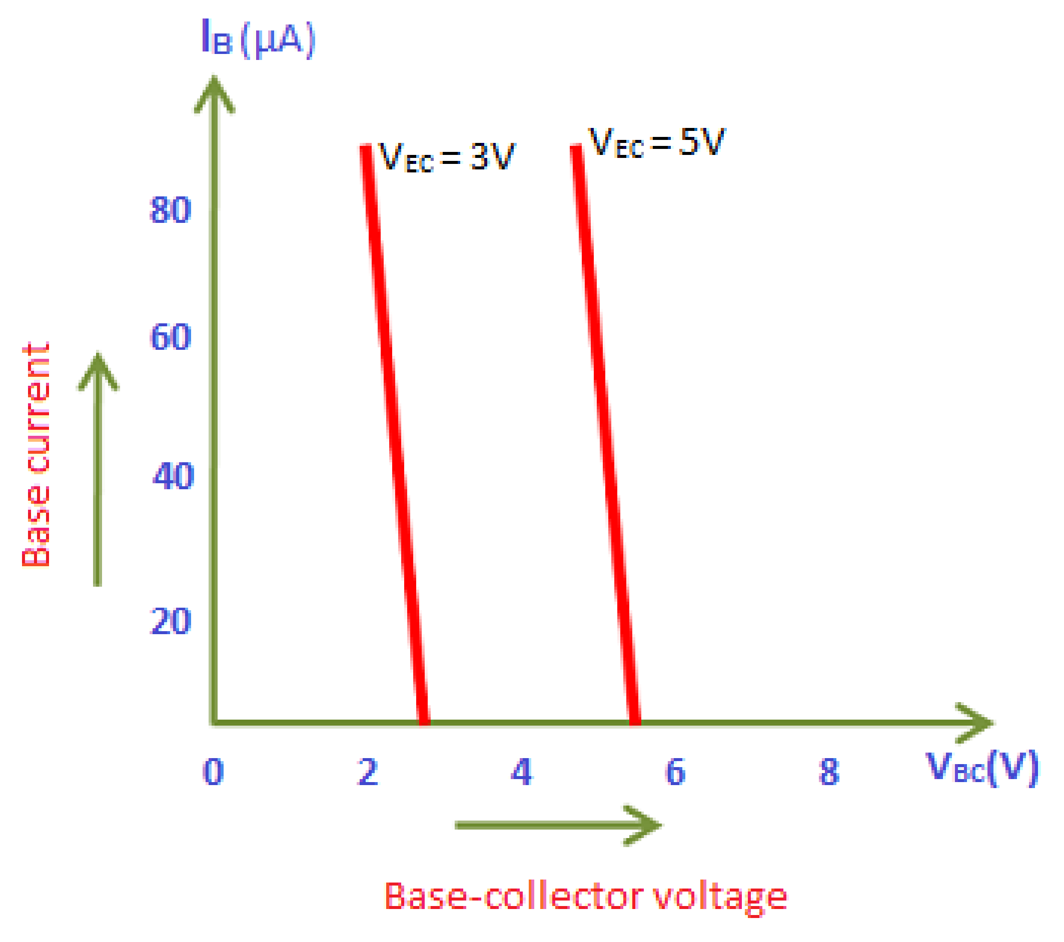
2.3 Input and Output characteristics

Transistors Operation Mode (Common Collector Configuration)

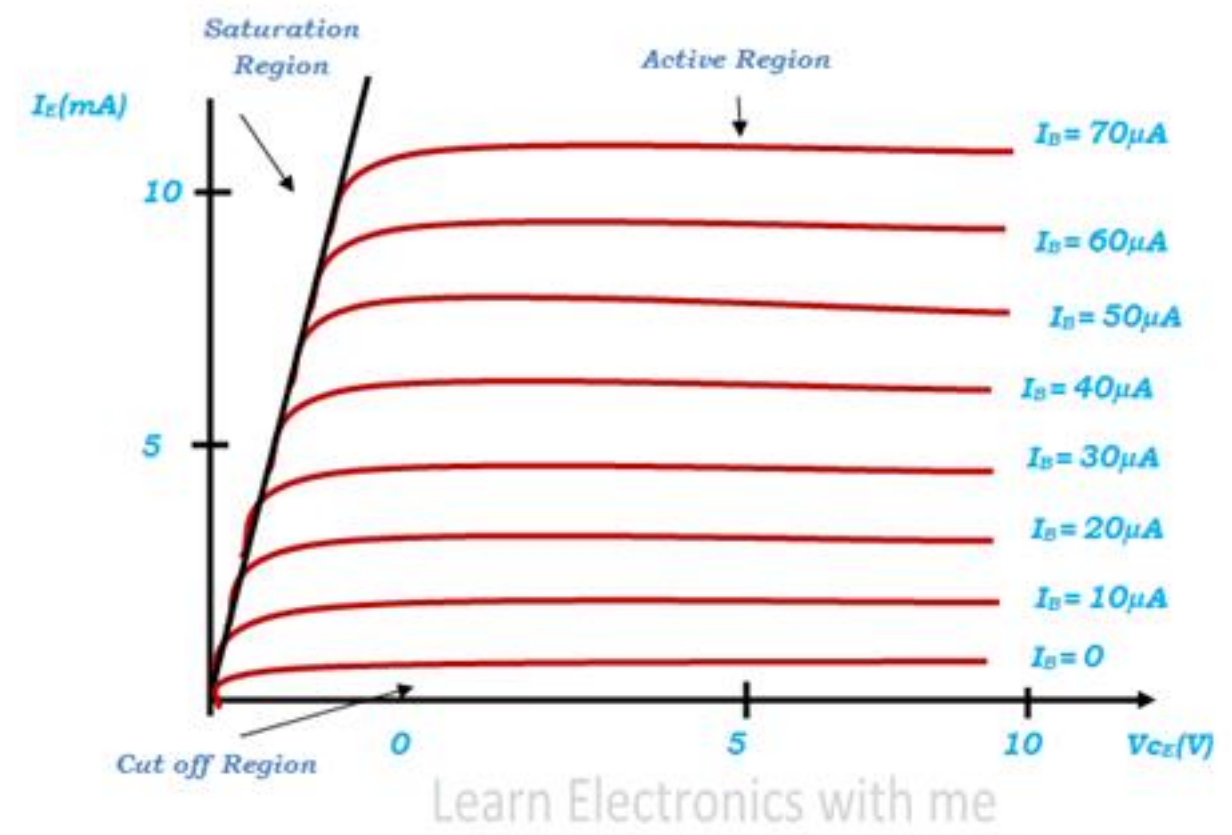


2.3 Input and Output characteristics

Transistors Operation Mode (Common Collector Configuration)



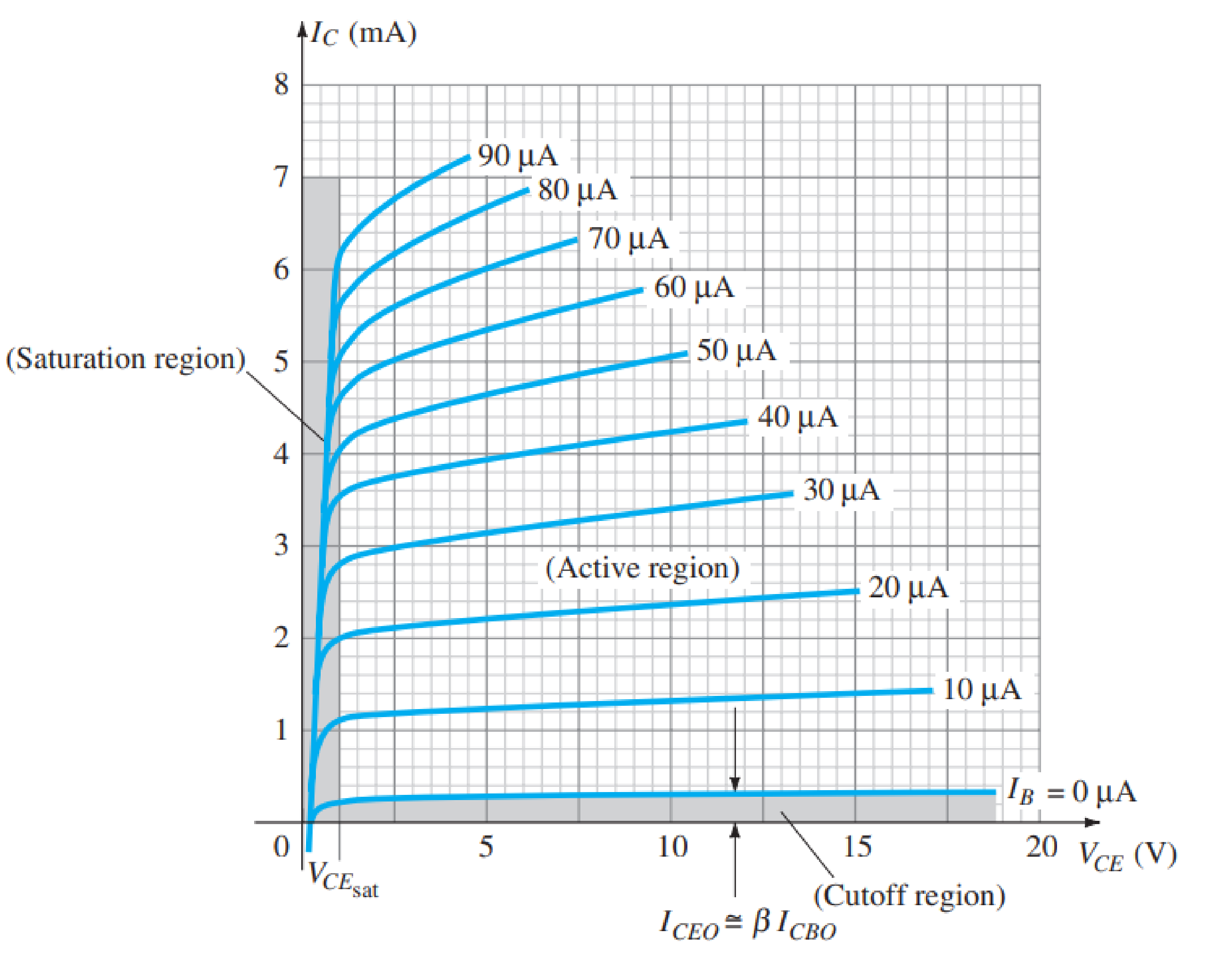
Input characteristics

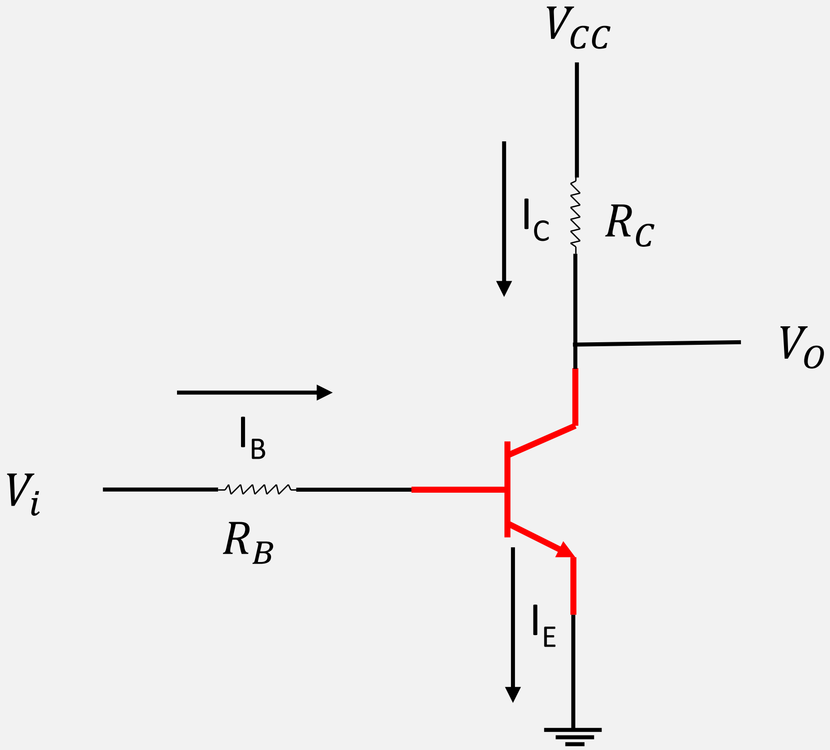


Output characteristics of common Collector configuration

2.6 BJT as switch

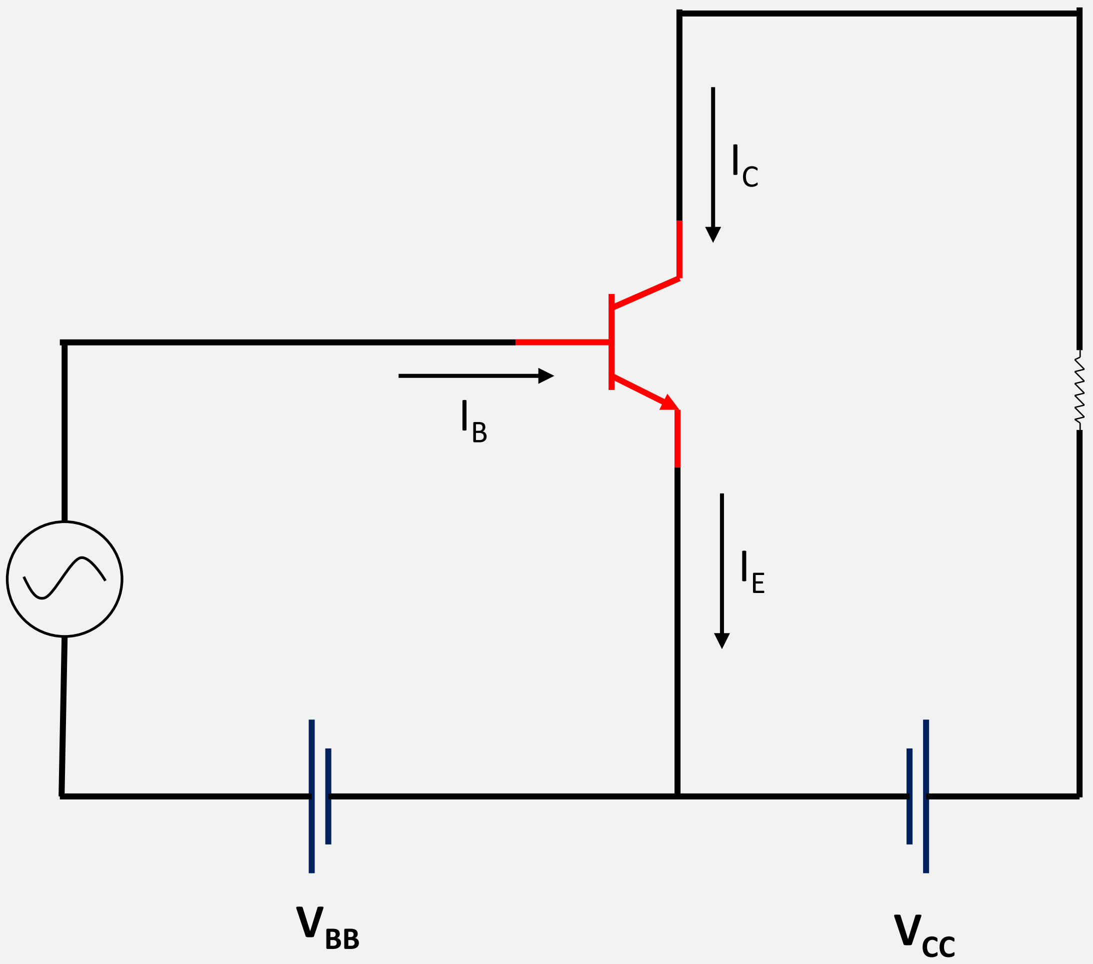
Transistor as inverter





2.5 BJT switching time

Transistor as an Amplifier



Current Gain in Transistors

1. Common Base Current Gain (α)

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

2. Common Emitter Current Gain (β)

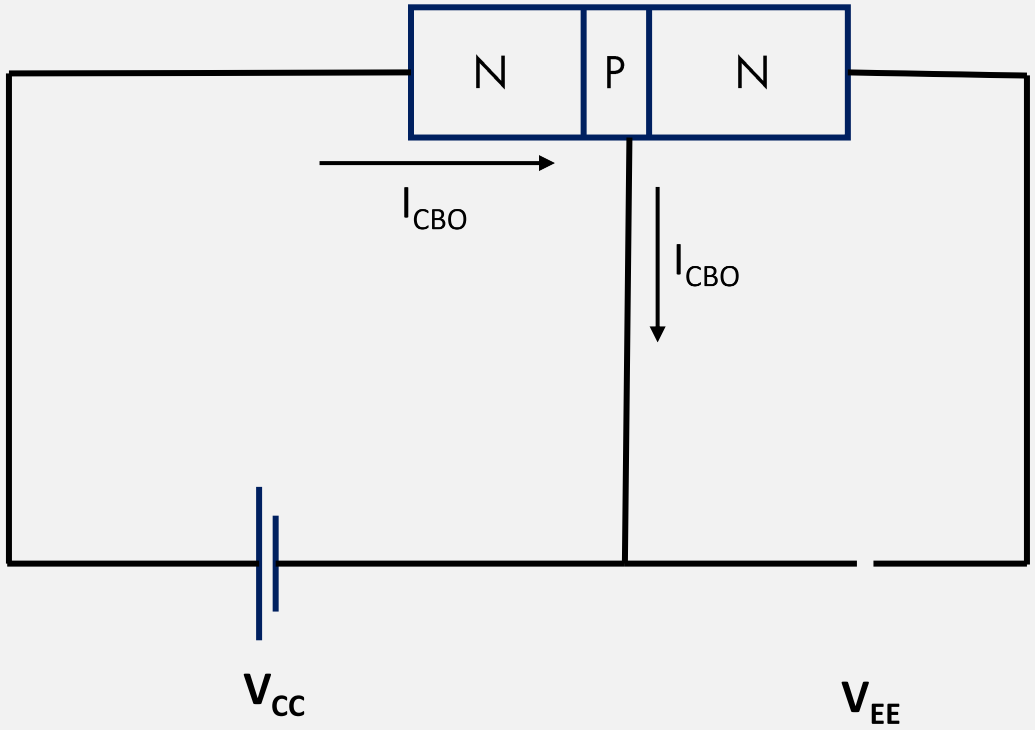
$$\beta = \frac{I_C}{I_B}$$

3. Common Collector Current Gain (β)

$$\gamma = \frac{I_E}{I_B}$$

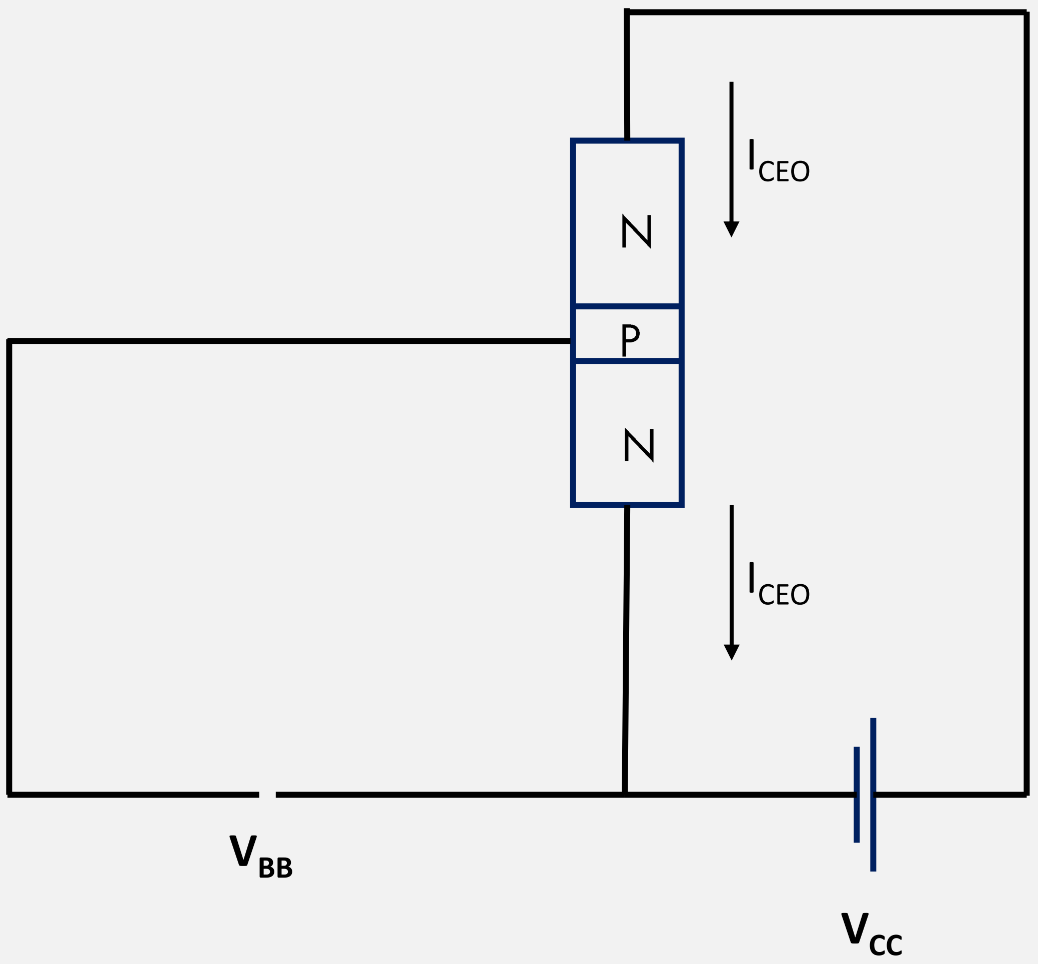
Leakage Current in Transistor

1. Collector Base Leakage Current (I_{CBO})



Leakage Current in Transistor

2. Collector Emitter Leakage Current (I_{CEO})



Relationship between α and β

$$I_E = I_C + I_B$$

$$\frac{I_E}{I_C} = \frac{I_C}{I_C} + \frac{I_B}{I_C}$$

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

2.5 BJT switching time

BJT switching time

t_r is rise time

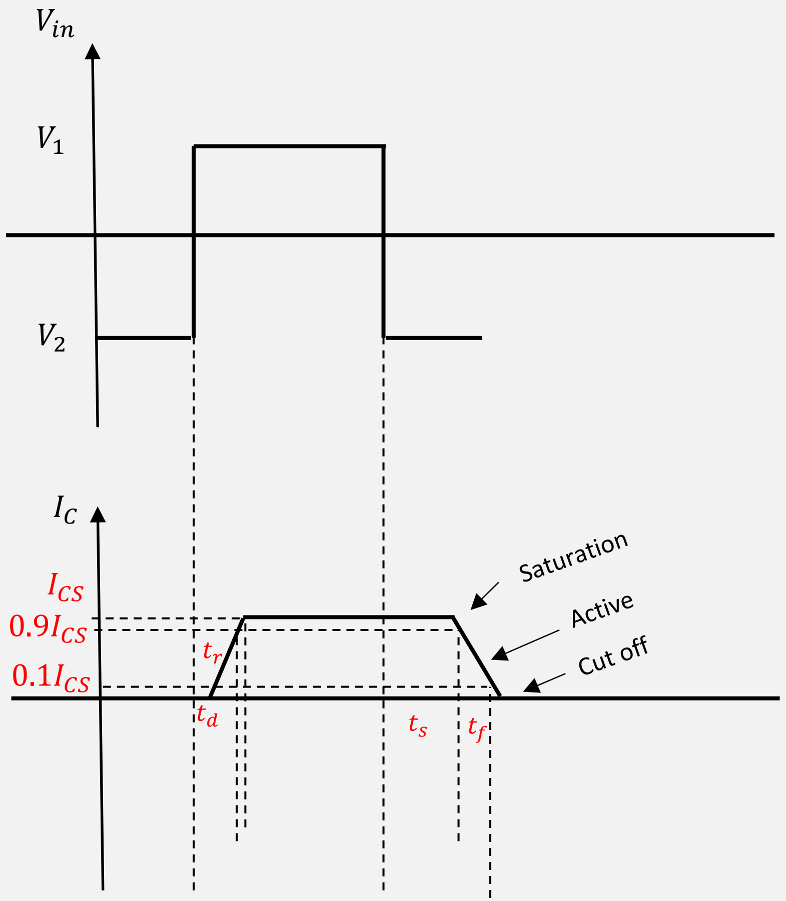
t_d is delay time

t_s is storage time

t_f is fall time

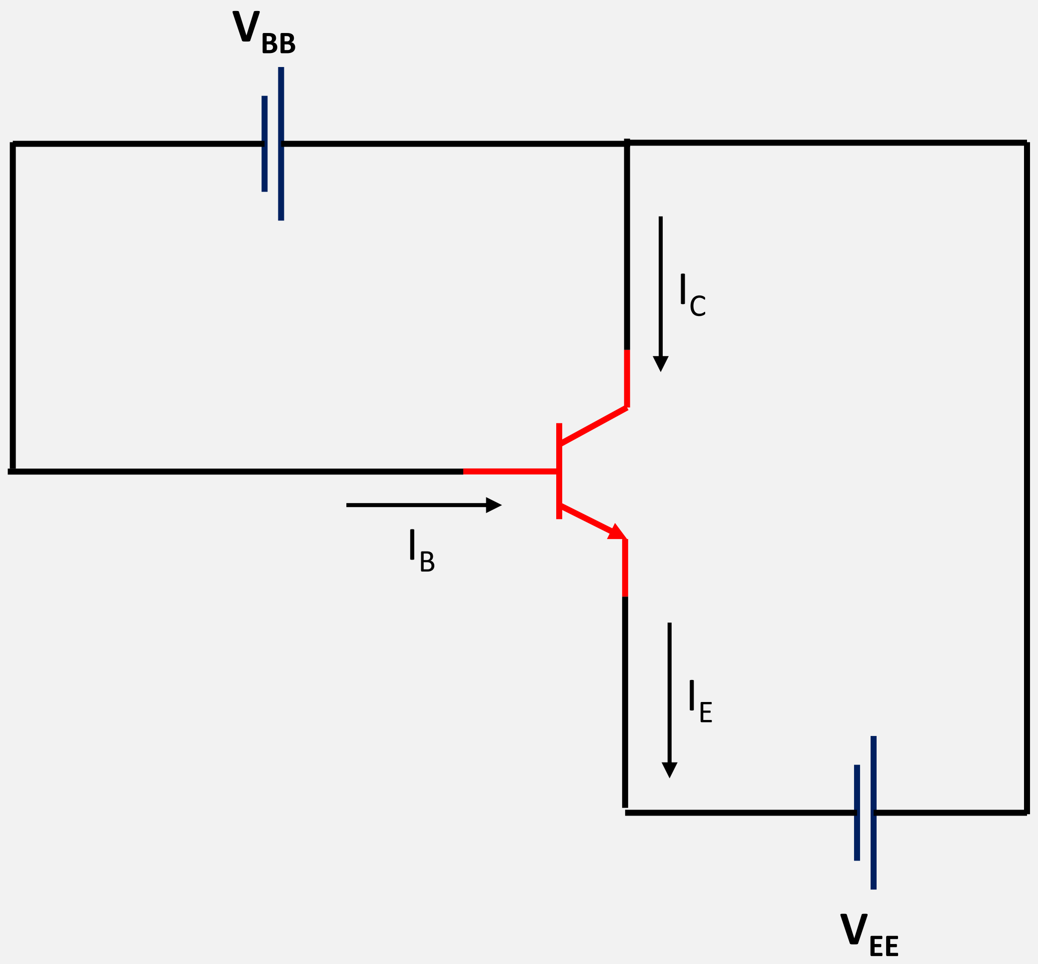
t_{on} is on time $(t_d + t_r)$

t_{off} is off time$(t_s + t_f)$



2.7 Comparison of CB, CE and CC configuration

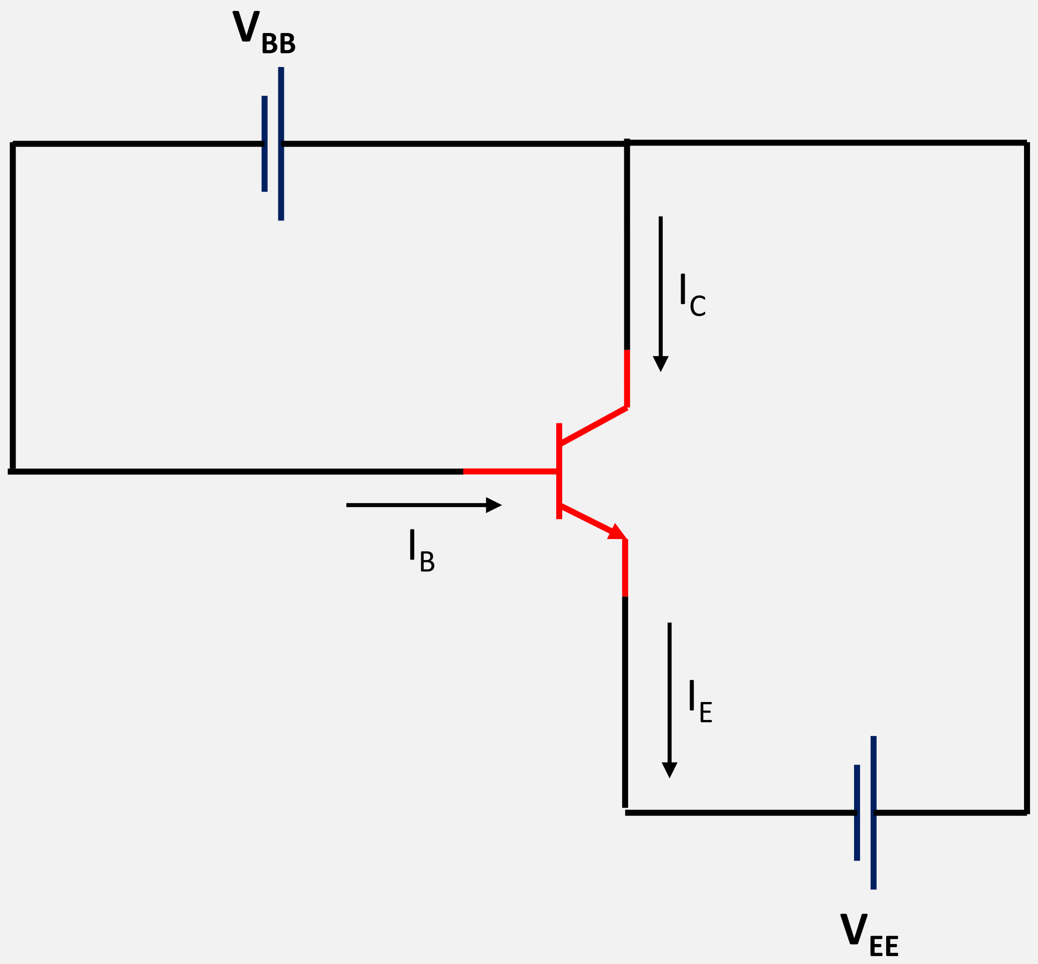
Transistors Operation Mode (Common collector Configuration)



Collector terminal is common

2.7 Comparison of CB, CE and CC configuration

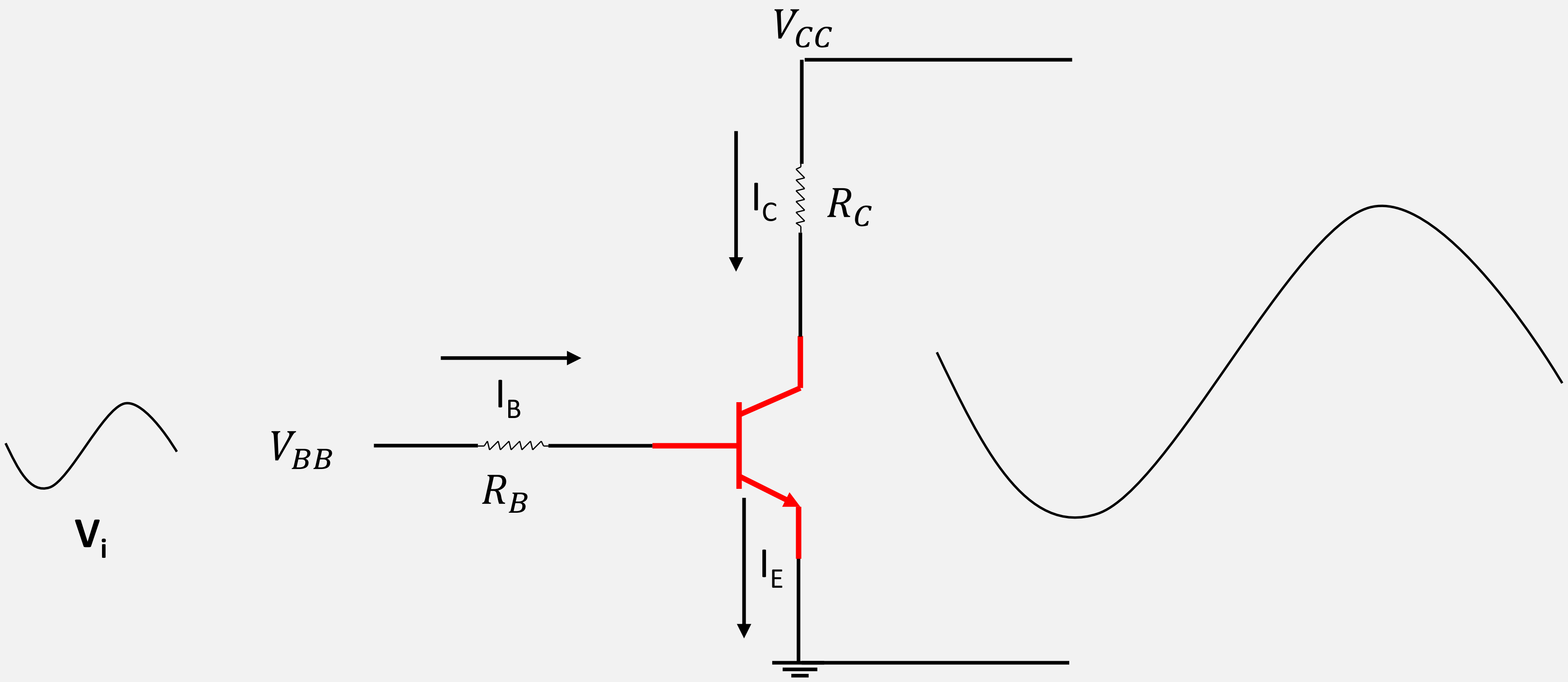
Transistors Operation Mode (Common collector Configuration)



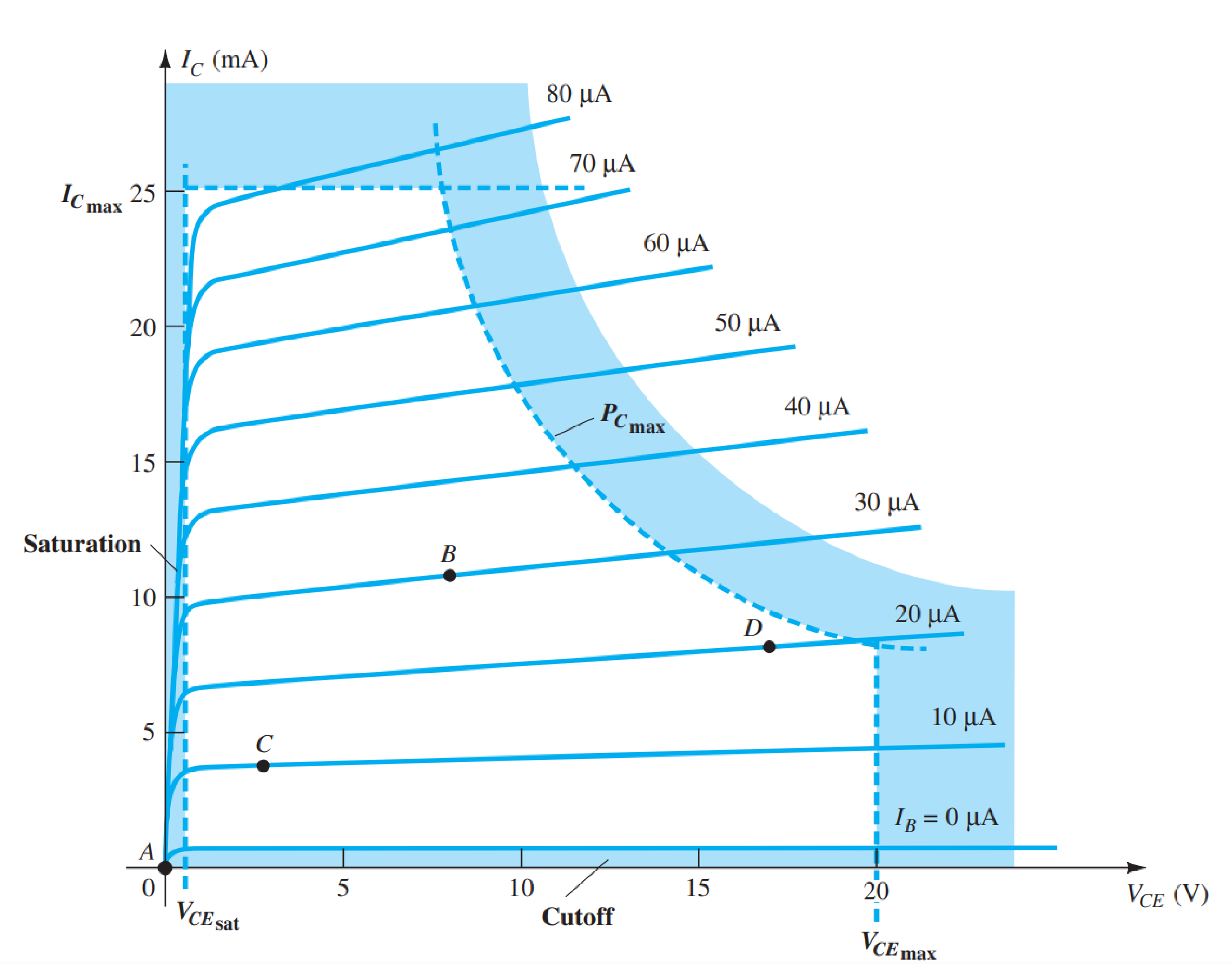
Collector terminal is common

2.8 Transistor Biasing

Biasing is the process of providing DC voltage which helps in the functioning of the circuit.

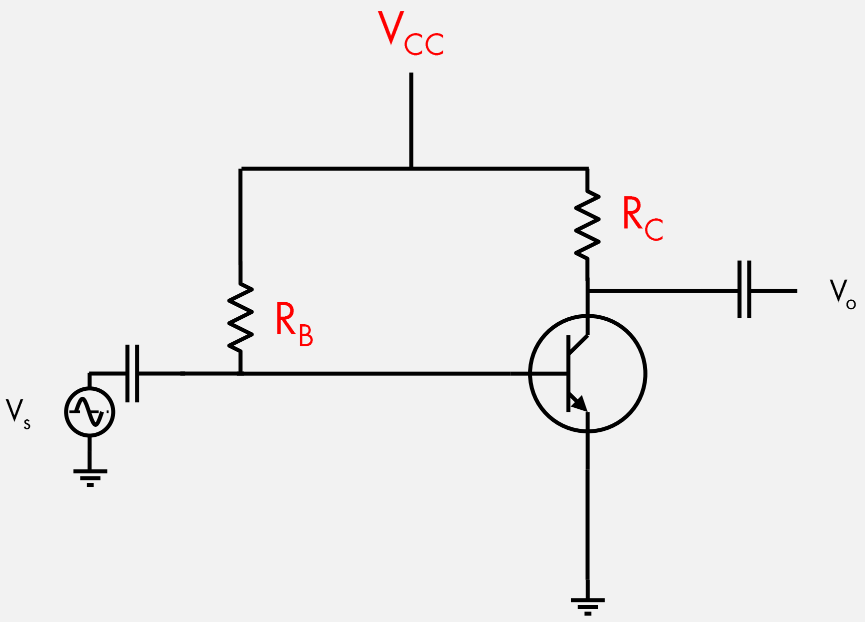


2.8 Transistor Biasing



2.8 Transistor Biasing

Fixed Bias



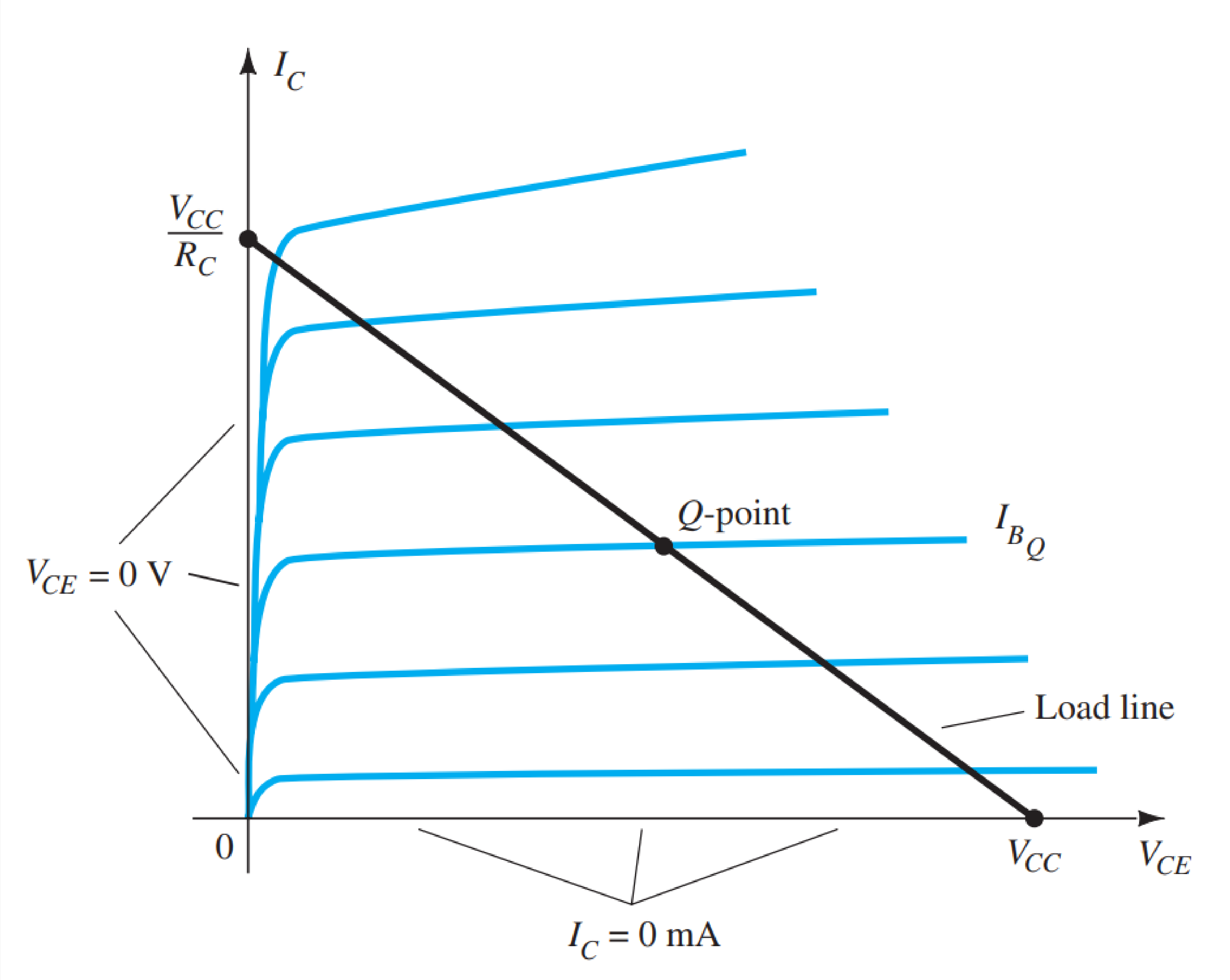
β

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

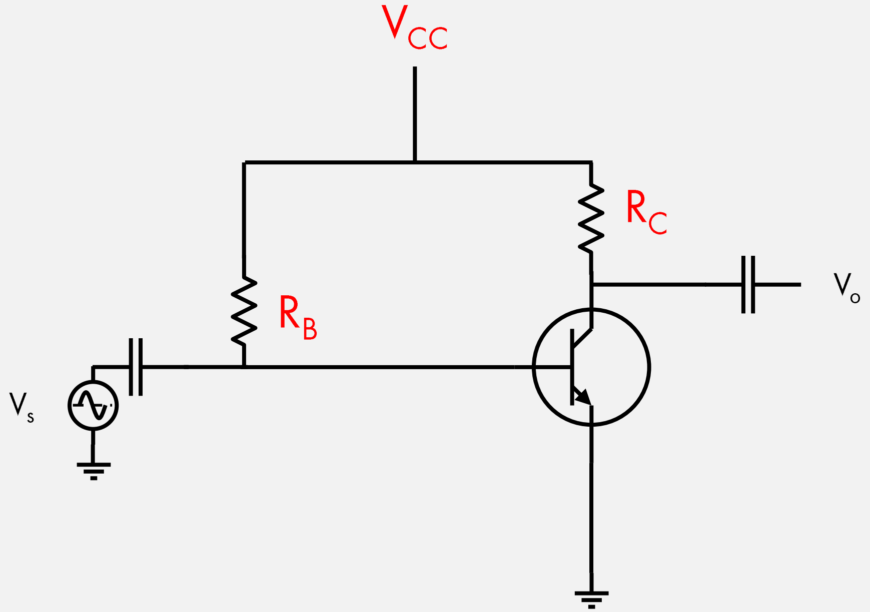
$$I_C = \beta I_B \, , I_E = (\beta + 1) I_B$$

$$V_{CE} = V_{CC} - \; I_C R_C$$

2.8 Transistor Biasing



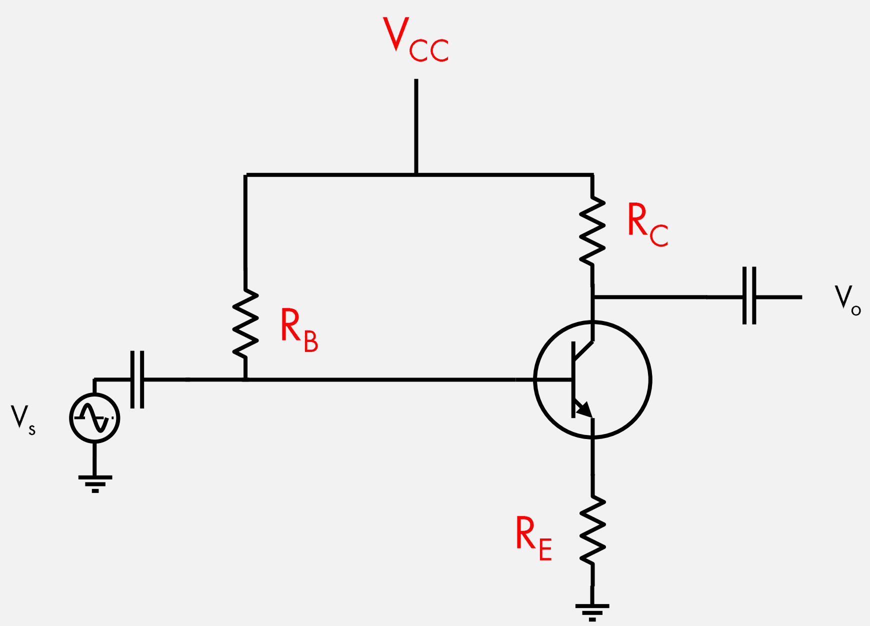
Fixed Bias



β

2.8 Transistor Biasing

Emitter Bias



β

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$$

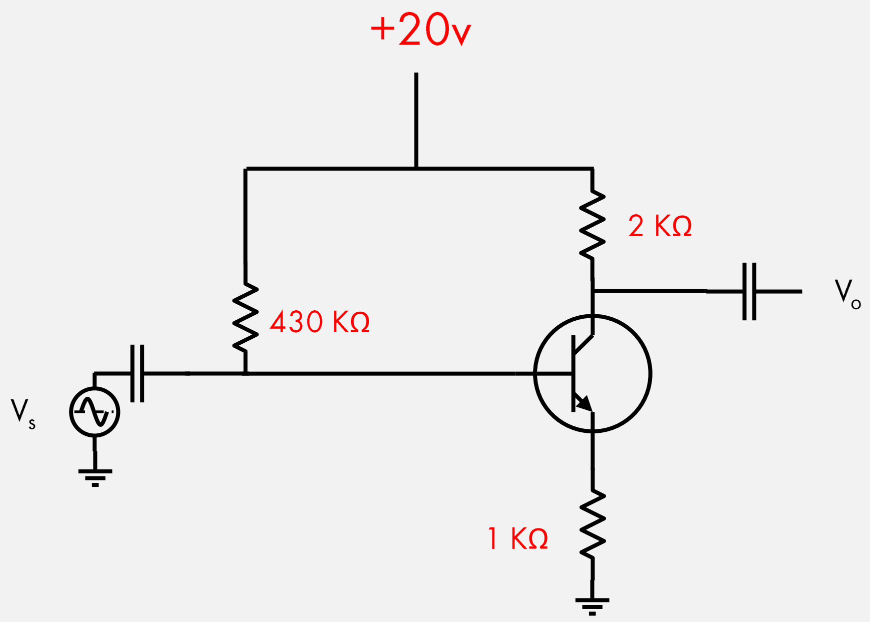
$$I_C = \beta I_B \,, I_E = (\beta + 1)I_B$$

$$R_i = (\beta + 1)R_E$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

2.8 Transistor Biasing

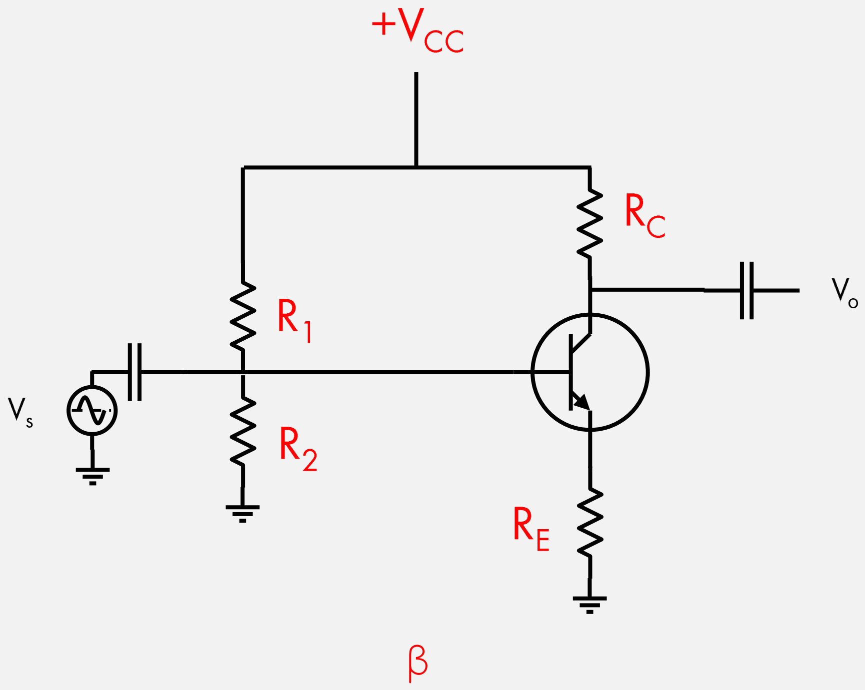
Emitter Bias

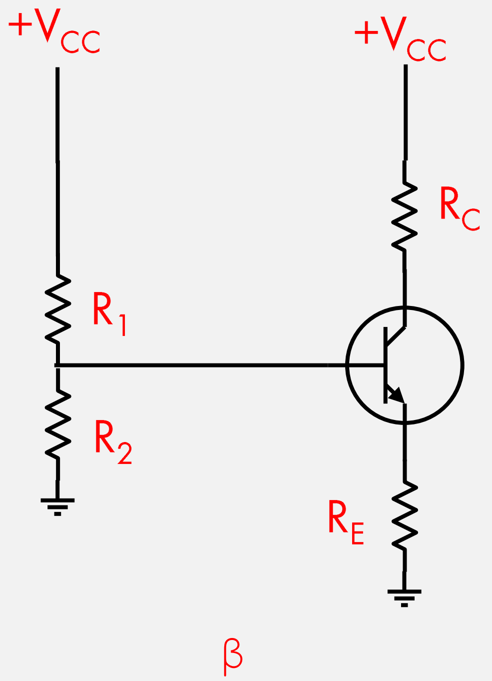


$\beta = 50$

2.8 Transistor Biasing

Voltage Divider

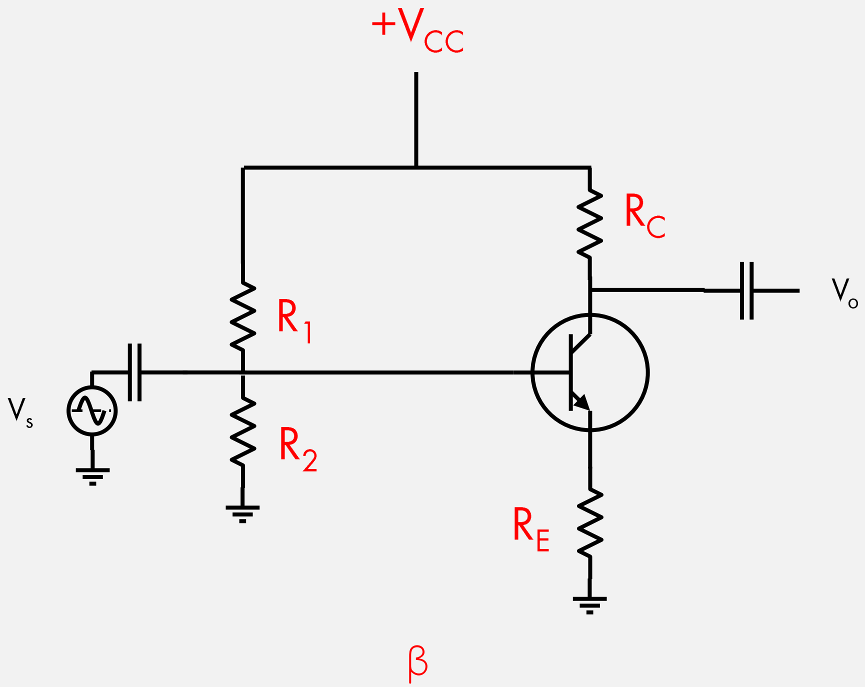




DC component of the voltage divider configuration

2.8 Transistor Biasing

Voltage Divider



$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1)R_E}$$

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

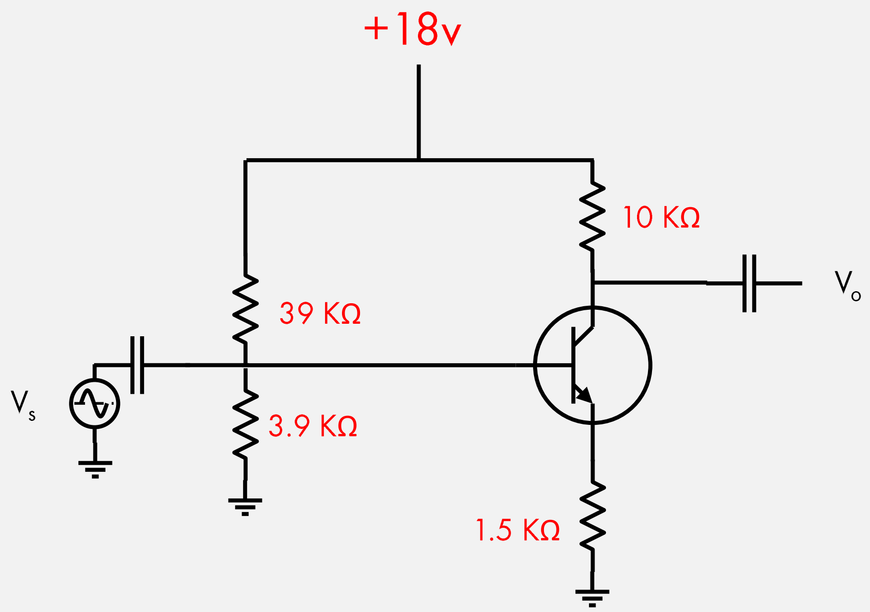
$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

$$R_{TH} = R_1 \, || R_2$$

$$V_{TH} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

2.8 Transistor Biasing

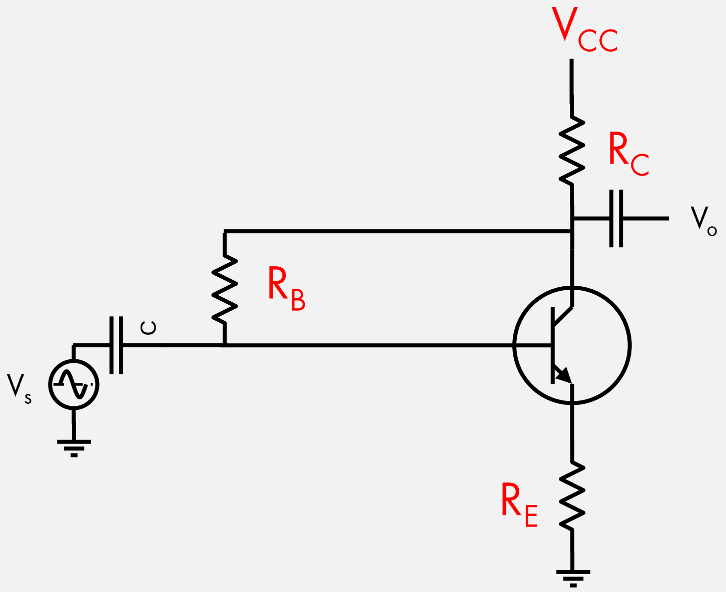
Voltage Divider



$\beta = 100$

2.8 Transistor Biasing

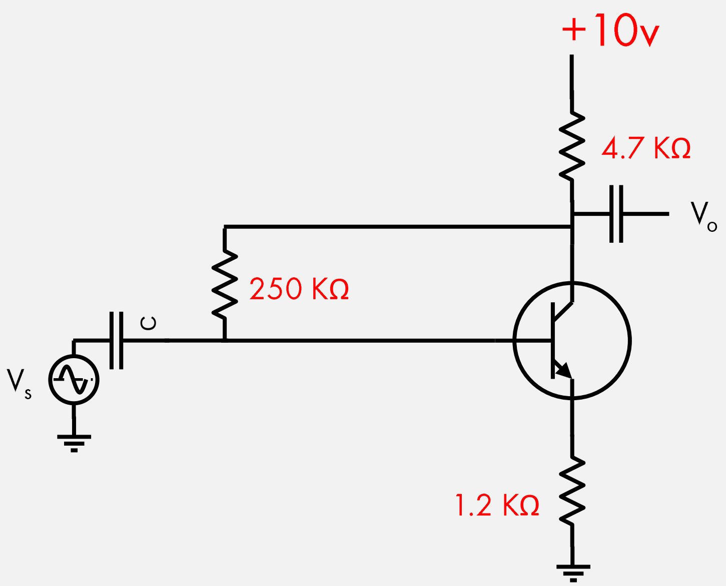
Collector Feedback



β

2.8 Transistor Biasing

Collector Feedback



$\beta = 90$

2.8 Transistor Biasing

Design a transistor biasing circuit with operating point of 12mA and 6V using fixed bias circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

Design a transistor biasing circuit with operating point of 12mA and 6V using voltage divider circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

2.8 Transistor Biasing

Design a transistor biasing circuit with operating point of 12mA and 6V using voltage divider circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

$I_B = \frac{I_C}{100} = 40\mu A$

While designing voltage divider bias, generally, $V_E = \frac{V_{CC}}{10} = \frac{15}{10} = 1.5V$ is set.

Therefore,

$$R_E = \frac{V_E}{I_E} = \frac{1.5}{4} = 0.375K\Omega$$

$$R_C = (V_{CC} - V_{CE})/I_C = (15 - 12)/4 = 0.75K\Omega$$

$$V_B = V_{BE} + V_E = 0.7 + 1.5 = 2.1V$$

2.8 Transistor Biasing

Design a transistor biasing circuit with operating point of 12mA and 6V using voltage divider circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

For the circuit to operate efficiently, it is assumed that the current through R1 and R2 should be approximately equal to and much larger than the base current (at least 10:1). This fact and the voltage-divider equation for the base voltage provide the two relationships necessary to determine the base resistors. That is,

$$R_2 \leq \frac{1}{10}\beta R_E$$

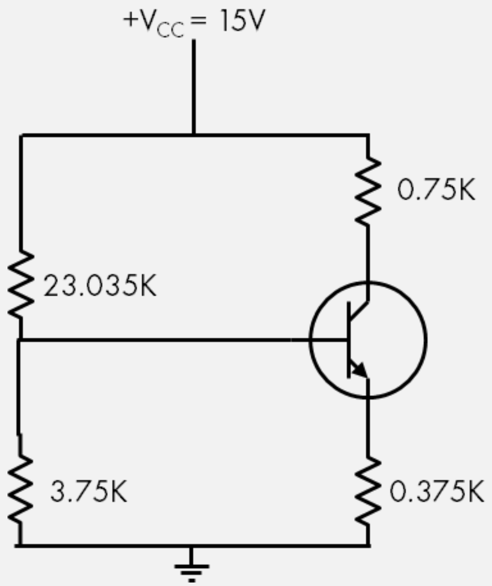
$$V_B = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$R_2 = \frac{1}{10}\beta R_E = \frac{1}{10} \cdot 100 \cdot 0.375 = 3.75K\Omega$$

$$2.1 = \frac{3.75}{(R_1 + 3.75)}\ 15$$

$$R_1 + 3.75 = 3.75 \cdot \frac{15}{2.1}$$

$$R_1 = 26.785 - 3.75 = 23.035K\Omega$$



2.8 Transistor Biasing

Fixed Bias

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

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

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

Emitter Bias

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E}$$

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

$$R_i = \ (\beta + 1) R_E$$

$$V_{CE} = V_{CC} - \ I_C (R_C + R_E)$$

Voltage divider Bias

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1) R_E}$$

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

$$V_{CE} = V_{CC} - \ I_C (R_C + R_E)$$

$$R_{TH} = R_1 \,||R_2$$

$$V_{TH} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

2.8 Transistor Biasing

Design a transistor biasing circuit with operating point of 12mA and 6V using emitter bias circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

Design a transistor biasing circuit with operating point of 12mA and 6V using collector feedback circuit. Use +15V as collector biasing voltage. Beta of given transistor is 100.

2.9 Stability

Measure of the sensitivity of the circuit to the variation in the external parameters

β: Increases with increase in temperature

V_{BE}: Decreases about 7.5 mV per degree Celsius increase in temperature

I_{CO}: Doubles in value for every 10^0C increase in temperature

$T\ (^0C)$	$I_{CO}\ (nA)$	β	$V_{BE}(V)$
-65	0.2×10^{-3}	20	0.85
25	0.1	50	0.65
100	20	80	0.48
175	3.3×10^{3}	120	0.3

2.9 Stability

Measure of the sensitivity of the circuit to the variation in the external parameters

$$S(I_{CO}) = \frac{\Delta I_C}{\Delta I_{CO}}$$

$$S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}}$$

$$S(\beta) = \frac{\Delta I_C}{\Delta \beta}$$

2.9 Stability

Measure of the sensitivity of the circuit to the variation in the external parameters

	$S(\beta)$	$S(I_{CO})$	$S(V_{BE})$
Fixed bias	$\frac{I_{C1}}{\beta_1}$	β	$\frac{-\beta}{R_B}$
Emitter-bias	$\frac{I_{C1}\left(1+\frac{R_B}{R_E}\right)}{\beta_1(\beta_2+\frac{R_B}{R_E})}$	$\frac{\beta\left(1+\frac{R_B}{R_E}\right)}{\beta+R_B/R_E}$	$\frac{-\beta/R_E}{\beta+R_B/R_E}$
Voltage divider	$\frac{I_{C1}\left(1+\frac{R_{TH}}{R_E}\right)}{\beta_1(\beta_2+\frac{R_{TH}}{R_E})}$	$\frac{\beta\left(1+\frac{R_{TH}}{R_E}\right)}{\beta+R_{TH}/R_E}$	$\frac{-\beta/R_E}{\beta+R_{TH}/R_E}$

2.7 Comparison between different configuration

	Common Base	Common Emitter	Common Collector
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	High	Medium
Input impedance	Low	Medium	High
Output impedance	High	Medium	Low