Bipolar Junction Transistor (BJT)

- Beside diodes, the most popular semiconductor devices is transistors. Eg: Bipolar Junction Transistor (BJT)
- Few most important applications of transistor are: as an amplifier, as an oscillator and as a switch.
- Amplification can make weak signal strong in general, provide function called Gain
- BJT is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device

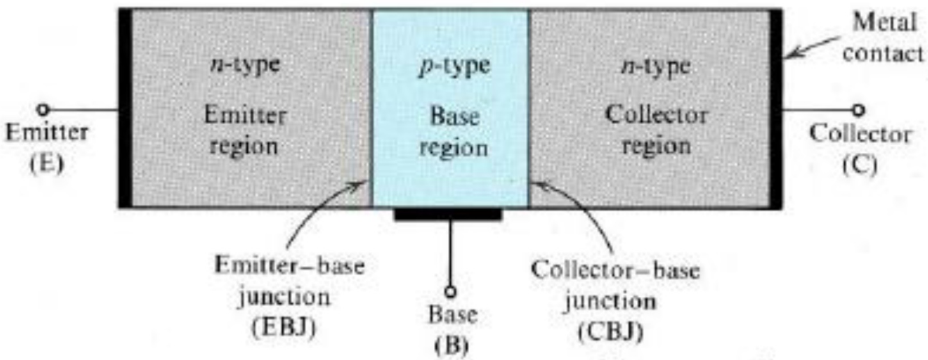
  N-type regions contains free electrons (negative carriers)

  P-type regions contains free holes (positive carriers)

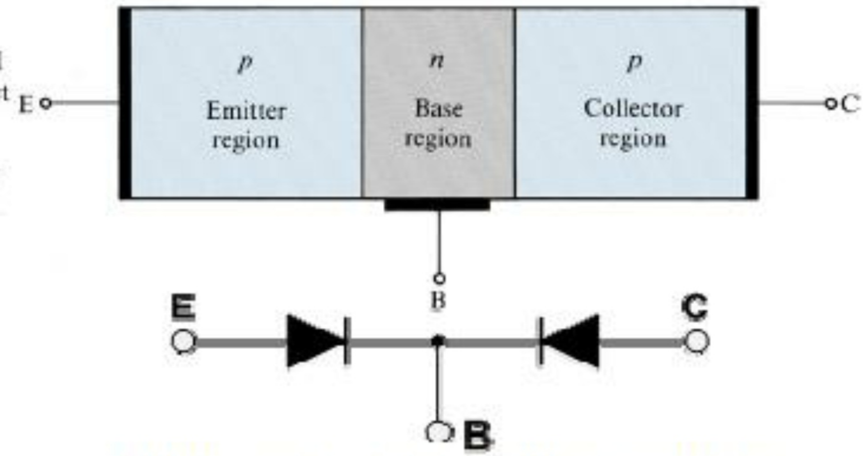
- The word Transistor is an acronym, and is a combination of the words **Trans**fer Var**istor** used to describe their mode of operation way back in their early days of development. There are two basic types of bipolar transistor construction, NPN and PNP, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.

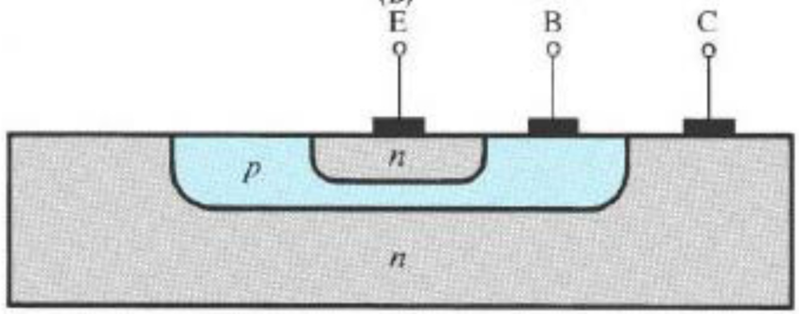
Bipolar Junction Transistor (BJT)

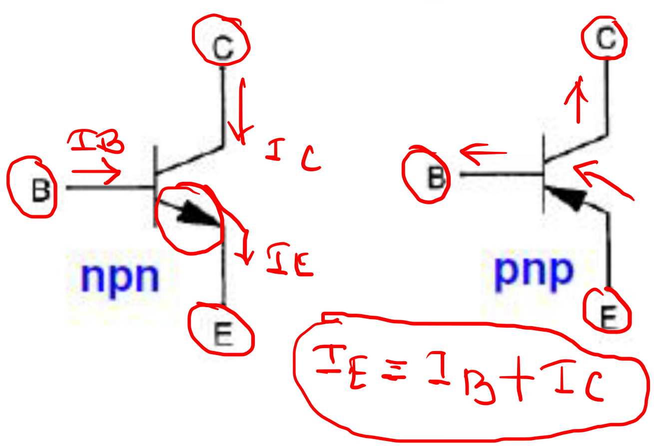
npnTransistor



pnpTransistor







- BJT is a 3 terminal device. namely- emitter, base and collector
- npn transistor: emitter & collector are n-doped and base is p-doped.
- Emitter is heavily doped, collector is moderately doped and base is lightly doped and base is very thin. i.e. $N_{DE} >> N_{DC} >> N_{AB}$

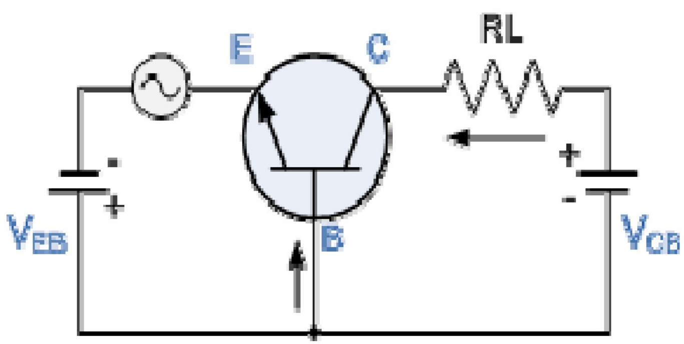
Mode of operation for BJT

Mode	V_{BE}	V_{BC}
Forward active	Forward bias	Reverse Bias
Reverse active	Reverse Bias	Forward Bias
Saturation	Forward bias	Forward bias
Cut off	Reverse Bias	Reverse Bias

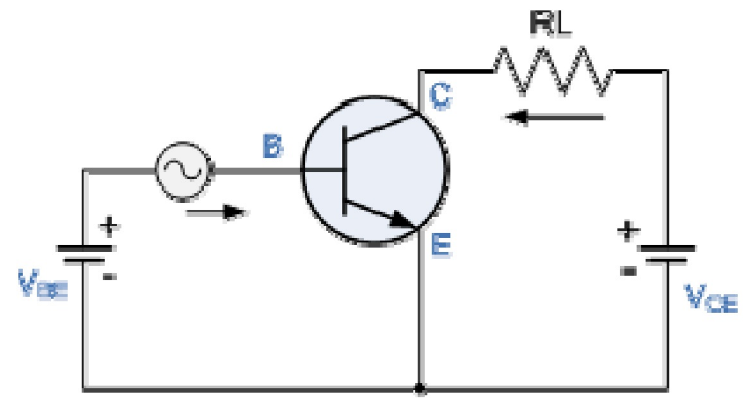
- **Forward active region is widely used and Reverse active region is rarely used**

Different configuration of BJT

Common base configuration

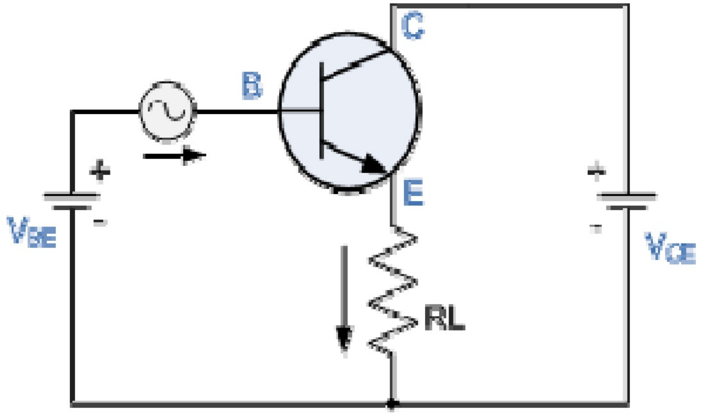


Non-inverting voltage amplifier circuit



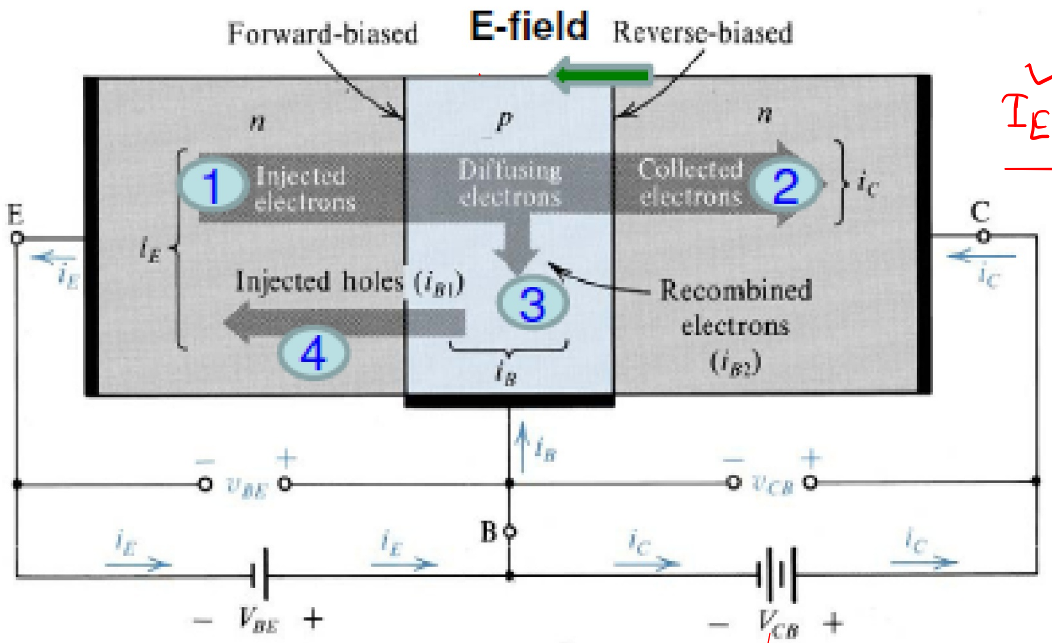
Common emitter configuration

Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

DC operation of npn BJT under forward active mode



$I_E = I_B + I_C$

- 1 . Forward bias of EBJ causes electrons to diffuse from emitter into base.
- 2. As base region is very thin, the majority of these electrons diffuse to the edge of the depletion region of CBJ, and then are swept to the collector by the electric field of the reverse-biased CBJ.
- 3. A small fraction of these electrons recombine with the holes in base region.
- 4. Holes are injected from base to emitter region. (4) << (1).

- The two-carrier flow from [(1) and (4)] forms the emitter current (I_E).

Current Relations (CE)

① → $I_B + I_C = I_E$ ✓

$I_C \simeq I_E$ ✓

$I_C = \alpha I_E$ ✓

$I_B + \alpha I_E = I_E$

$I_B = (1-\alpha) I_E$

$I_B = (1-\alpha) \frac{I_C}{\alpha}$

$I_B = \left(\frac{1-\alpha}{\alpha}\right) I_C$

$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B$ ✓

$$\boxed{I_C = \beta \cdot I_B}$$

β = current gain of BJT

$\beta \Rightarrow 50$ to 400

$I_B + \beta I_B = I_E$

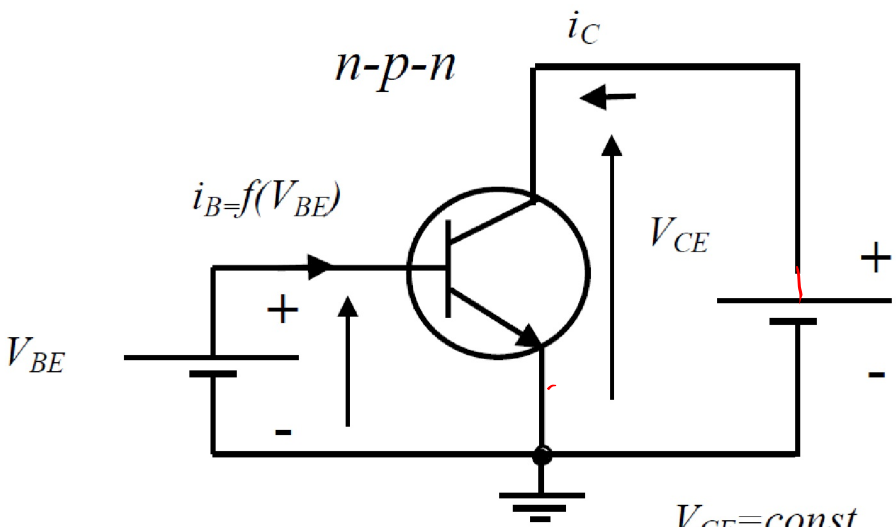
$I_E = (\beta + 1) I_B$

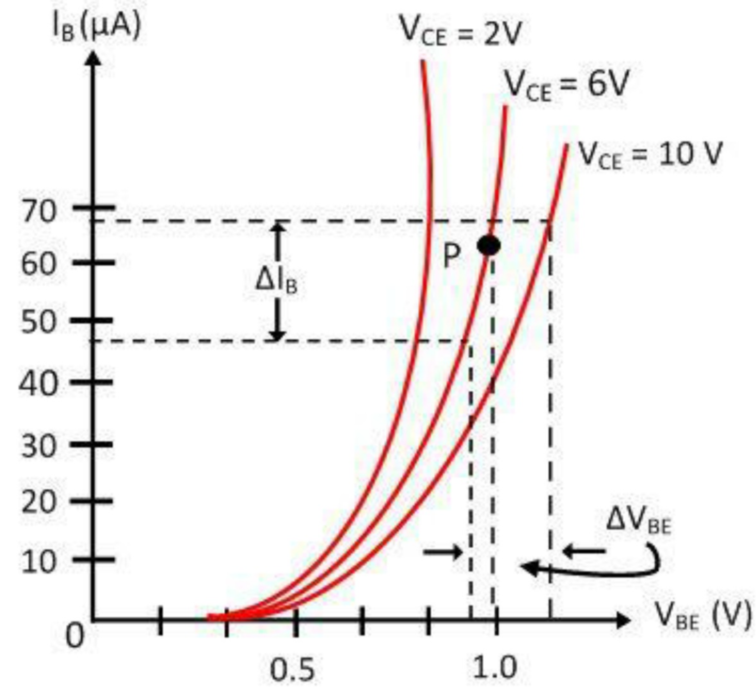
$I_C = \beta I_B$

BJT is current controlled device.

FET ⇒ Voltage controlled device

Input characteristics of BJT in Common Emitter configuration



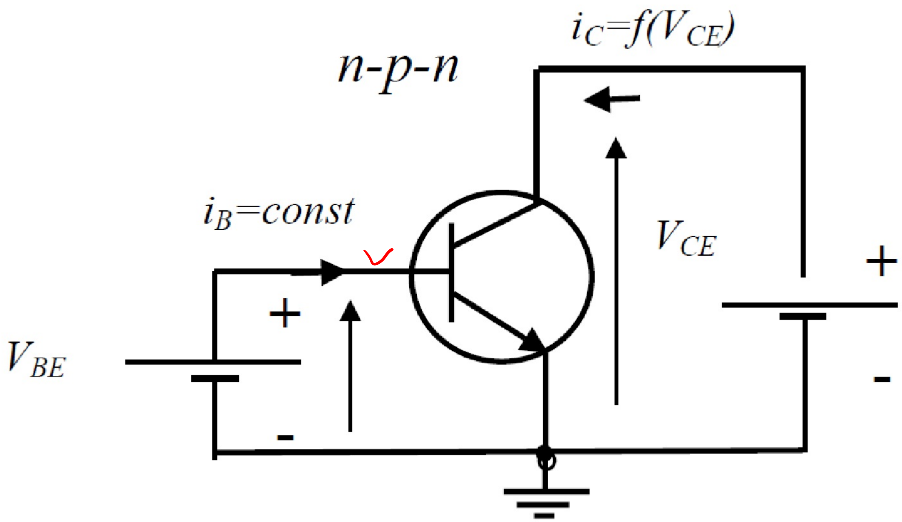


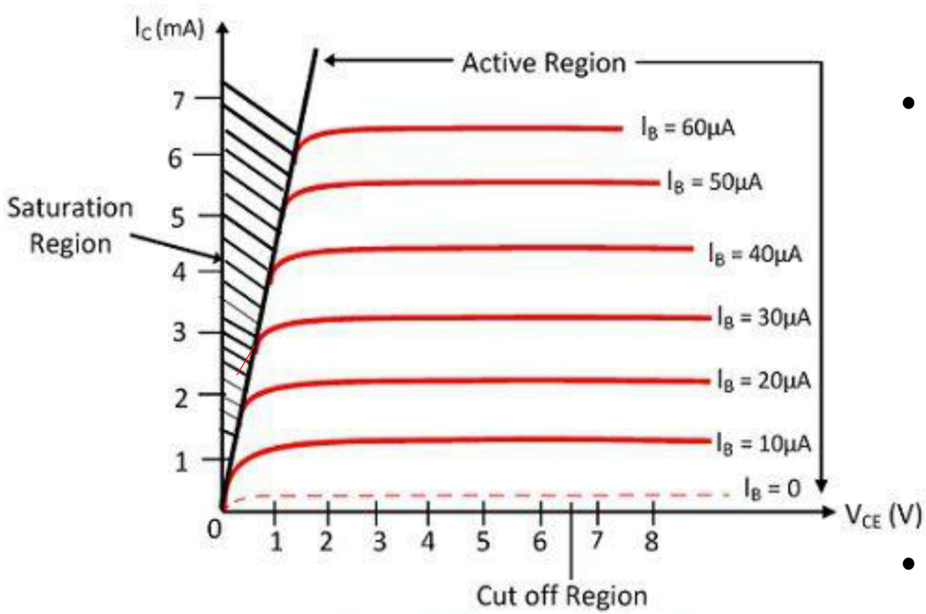
- Input characteristics are like a normal forward biased diode. As VBE increased IB also increased.
- iB(VBE) can be approximated as a step function at VBE ≈0.7V

- **Input Resistance:** The ratio of change in base-emitter voltage V_{BE} to the change in base current ΔI_B at constant collector-emitter voltage V_{CE} is known as input resistance, i.e.,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

Output characteristics of BJT in CE configuration





Output Characteristic Curve

- In the active region, the collector current increases slightly as collector-emitter VCE current increases. The slope of the curve is quite more than the output characteristic of CB configuration. Active region: iC is a weak function of VCE

- The value of the collector current IC increases with the increase in VCE at constant voltage IB, the value β of also increases.

- When the VCE falls, the IC also decreases rapidly. The collector-base junction of the transistor always in forward bias. In the saturation region, the collector current becomes independent and free from the input current IB. Saturation region: VCE < 0.5V

- In the active region IC = βIB, a small current IC is not zero, and it is equal to reverse leakage current ICEO.

Biasing of Transistor

Transistor Operation regions:

Region of operation	Emitter Base Junction	Collector-Base Junction
Cut-off	Reverse Bias	Reverse Bias
Active	Forward Bias	Reverse Bias
Saturation	Forward Bias	Forward Bias

1. In order to operate transistor in desired region, external DC voltage (Bias) of correct polarity is applied to the two junctions of transistor.

2. With biasing a certain current and voltage conditions is established, called as DC operating or quiscent point.

3. Operating Point may shift becasue of changes in transistor parameters such as *Beta, ICo, and VBE.*

4. Beta, ICo, and VBE are temperature dependent.

Stability of operating POINT

--> Degree of change of operating point with temperature

① $S = \dfrac{\Delta I_C}{\Delta I_{CO}}\Bigg|_{V_{BE}\ \&\ \beta\ \text{Constant}}$ OR $S = \dfrac{\partial I_C}{\partial I_{CO}}$

② $S' = \dfrac{\Delta I_C}{\Delta V_{BE}}\Bigg|_{I_{CO}\ \&\ \beta\ \text{Constant}}$ → $S' = \dfrac{\partial I_C}{\partial V_{BE}}$

③ $S'' = \dfrac{\Delta I_C}{\Delta \beta}\Bigg|_{I_{CO}\ \&\ V_{BE}\ \text{Constant}}$ → $S'' = \dfrac{\partial I_C}{\partial \beta}$

Stability factor (S) for Common Emitter (CE) Configuration

$$S = \frac{\partial I_C}{\partial I_{CO}}$$

$$I_C = \beta I_B + I_{CEO}$$

$$I_C = \beta I_B + (\beta+1) I_{CBO}$$

Diff. w.r.t. I_C

$$1 = \beta \times \frac{\partial I_B}{\partial I_C} + (\beta+1)\frac{\partial I_{CBO}}{\partial I_C}$$

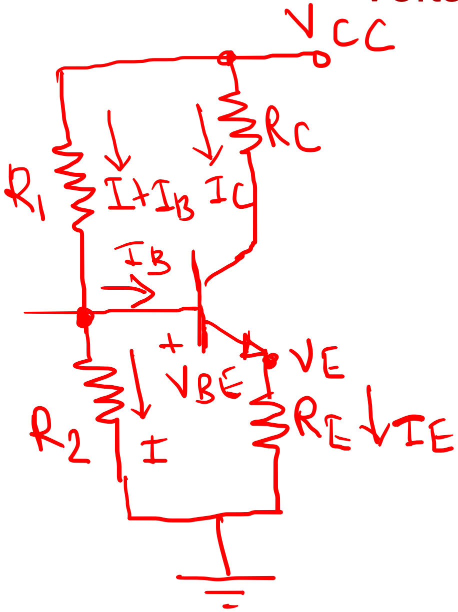
$$1 = \beta \times \frac{\partial I_B}{\partial I_C} + \beta \cdot \frac{\partial I_{CBO}}{\partial I_C} + \frac{\partial I_{CBO}}{\partial I_C}$$

$$1 - \beta \frac{\partial I_B}{\partial I_C} = (\beta+1)\frac{\partial I_{CBO}}{\partial I_C}$$

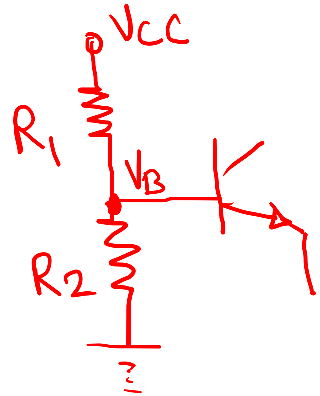
$$\frac{\partial I_{CBO}}{\partial I_C} = \frac{1 - \beta \cdot \frac{\partial I_B}{\partial I_C}}{1+\beta}$$

$$\boxed{S = \frac{1+\beta}{1 - \beta \cdot \frac{\partial I_B}{\partial I_C}}}$$

Voltage divider or self bias circuits



$\Rightarrow$

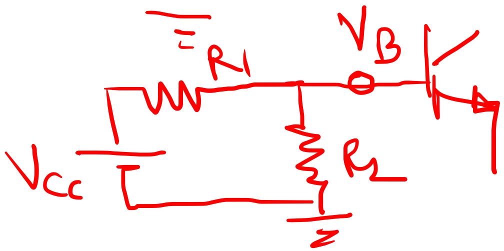


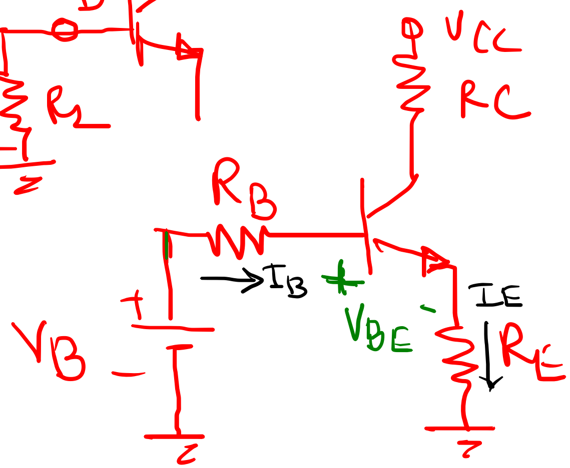
$\Rightarrow$

using voltage division formula

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

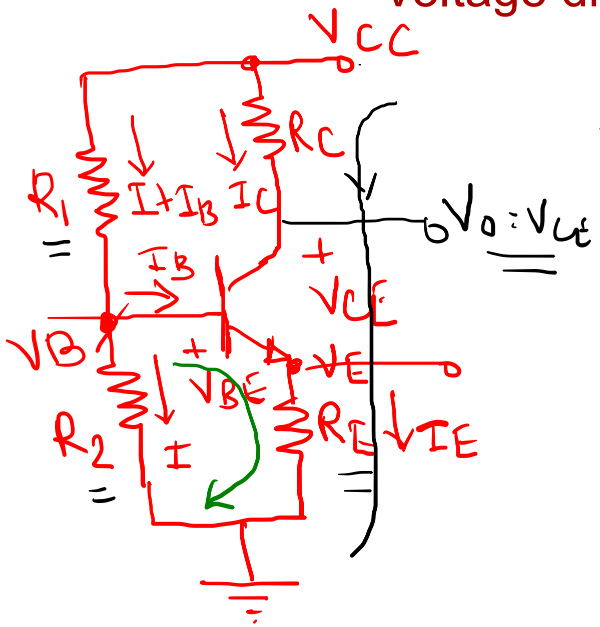
$$R_{th} = R_1 \| R_2 = R_B$$





$$V_B - I_B R_B - V_{BE} - I_E R_E = 0$$

Voltage divider or self bias circuits



$V_E = I_E \cdot R_E$

$V_B - V_{BE} - V_E = 0$

$V_E = V_B - V_{BE}$

$I_E R_E = V_B - V_{BE}$

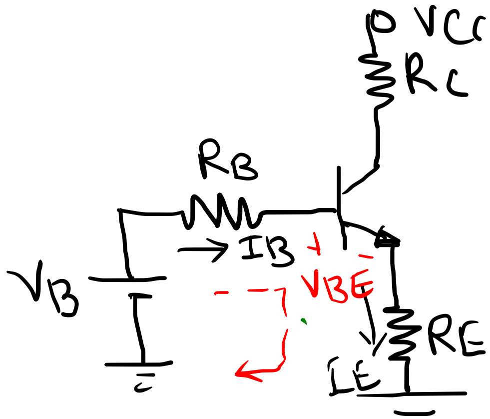
$I_E = \dfrac{V_B - V_{BE}}{R_E}$ ---- (1)

At collector side : KVL

$-I_C R_C - V_{CE} - I_E R_E + V_{CC} = 0$

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$ ---- (2)

Stability factor for voltage divider Bias circuit



$$V_B = \frac{R_2 V_{CC}}{R_1+R_2} \quad \& \quad R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$

$$V_B - I_B R_B - V_{BE} - I_E R_E = 0 \quad \text{—— (1)}$$

$$I_E = I_B + I_C$$

$$\boxed{V_{BE} = V_B - (R_B + R_E) I_B - I_C R_E}$$

$$\boxed{S = \frac{\partial I_C}{\partial I_{CBO}} = \frac{1+\beta}{1-\beta \frac{\partial I_B}{\partial I_C}}}$$

$$V_B = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

diff w.r.t. I_C

$$0 = \frac{\partial I_B}{\partial I_C} \cdot R_B + 0 + \frac{\partial I_B}{\partial I_C} R_E + R_E$$

$$\frac{\partial I_B}{\partial I_C} = -\frac{R_E}{(R_B+R_E)}$$

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_B+R_E}\right)}$$

$$S = \frac{(1+\beta)(R_B+R_E)}{R_B+R_E+\beta R_E}$$

$$S = \frac{(1+\beta)\left(1+\frac{R_B}{R_E}\right)}{(1+\beta)+\frac{R_B}{R_E}}$$

$$\frac{R_B}{R_E} << 1 \simeq 0$$

$R_E \uparrow$

$$\boxed{S = 1}$$

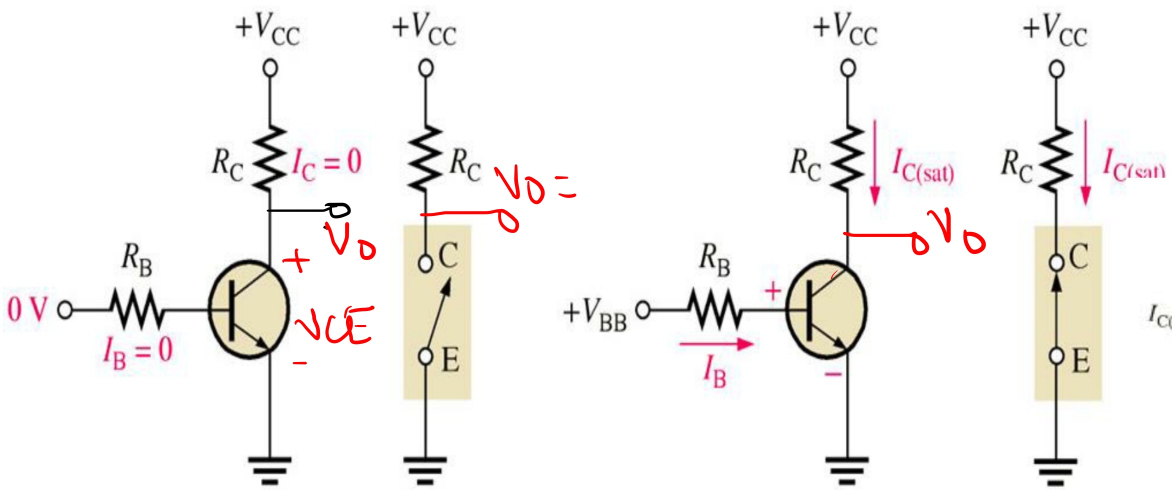
R_B, R_E

Common Emitter Configuration applications

1. Transistor as (Electronic)Switch

A transistor when used as a switch is simply being biased so that it is in cut-off (switched off) or saturation (switched on). Remember that the VCE in cut-off is VCC and 0 V in saturation.

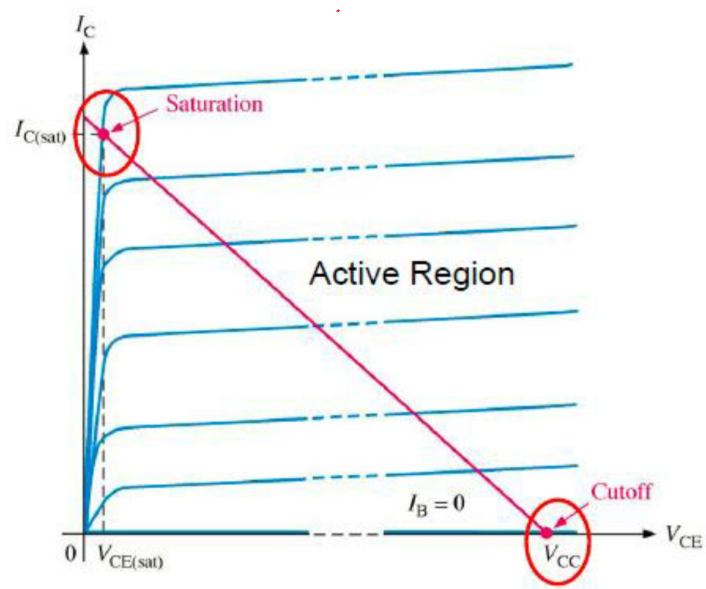
The dc load line graphically illustrates IC(sat) and cut-off for a transistor.



(a) Cutoff — open switch   (b) Saturation — closed switch

KVL(Collector-Emitter)

$$\boxed{V_{CE}=V_{CC}-I_CR_C}$$



$V_{CC} - I_C R_C - V_{CE} = 0$ ✓

$I_B = 0 \quad I_C = \beta I_B = 0$

$$\boxed{V_{CE} = V_o = V_{CC}}$$

Common Emitter Configuration applications

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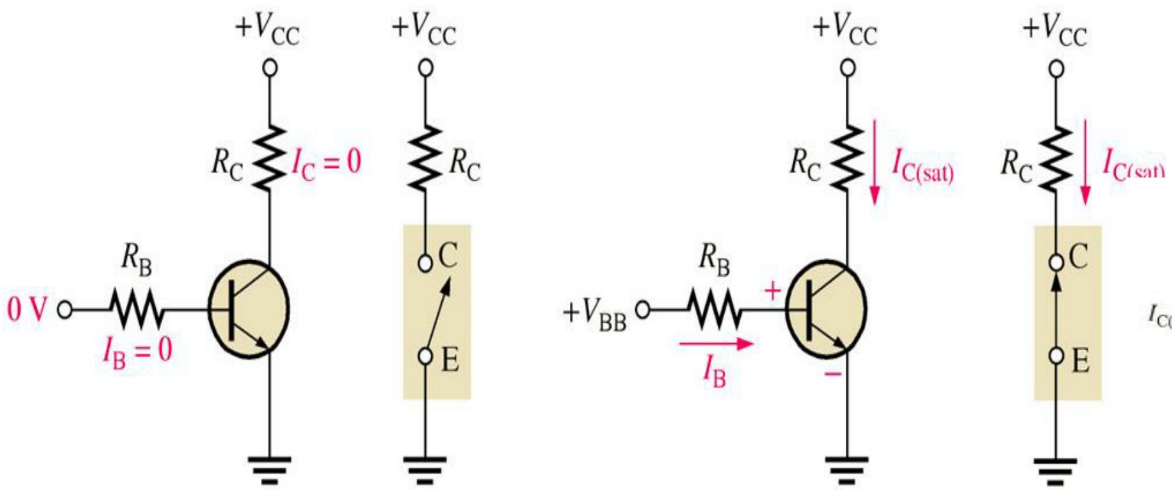

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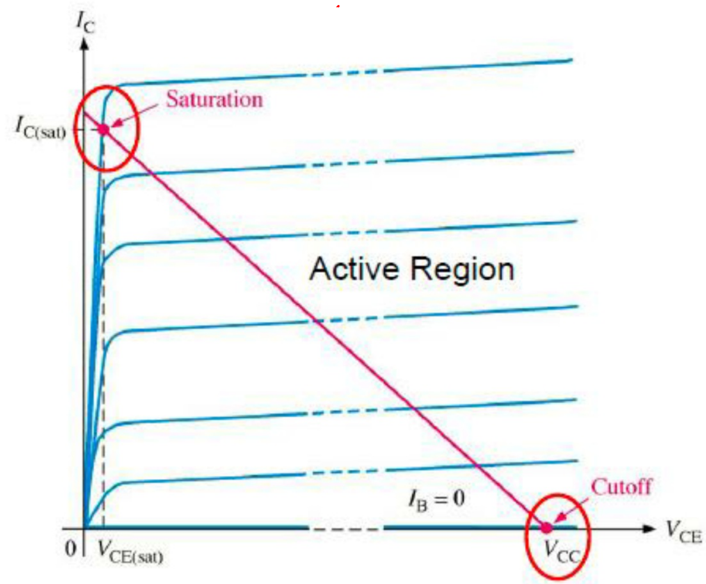


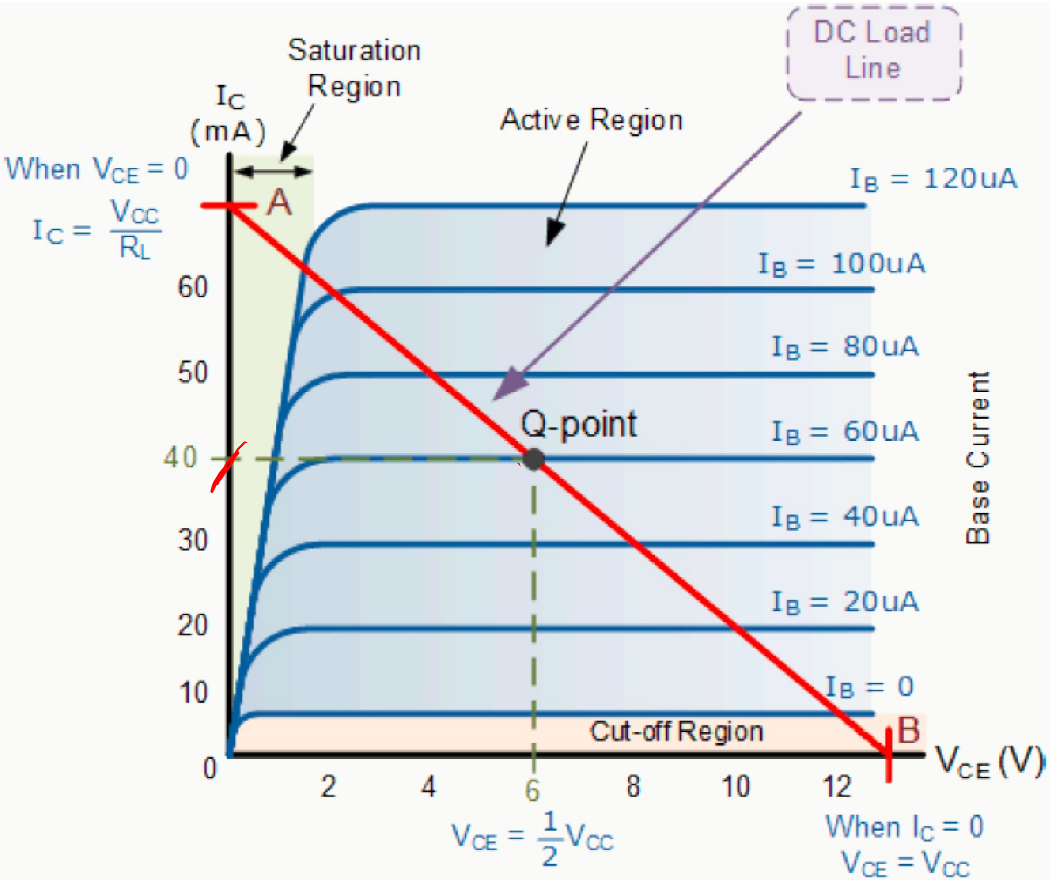
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

- BJT used as a semiconductor switch to turn load currents "ON" or "OFF" by controlling the Base signal to the transistor in ether its saturation or cut-off regions.
- Transistors can also be used in its active region to produce a circuit which will amplify any small AC signal applied to its Base terminal with the Emitter grounded. If a suitable DC "biasing" voltage is firstly applied to the transistors Base terminal thus allowing it to always operate within its linear active region, an inverting amplifier circuit called a single stage common emitter amplifier is produced.
- One such Common Emitter Amplifier configuration of the transistor is called a Class A Amplifier. A "Class A Amplifier" operation is one where the transistors Base terminal is biased in such a way as to forward bias the Base-emitter junction. The result is that the transistor is always operating halfway between its cut-off and saturation regions, thereby allowing the transistor amplifier to accurately reproduce the positive and negative halves of any AC input signal superimposed upon this DC biasing voltage. Without this "Bias Voltage" only one half of the input waveform would be amplified.
- A DC "Load Line" can also be drawn onto the output characteristics curves to show all the possible operating points when different values of base current are applied. It is necessary to set the initial value of Vce correctly to allow the output voltage to vary both up and down when amplifying AC input signals and this is called setting the operating point or Quiescent Point, **Q-point**

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



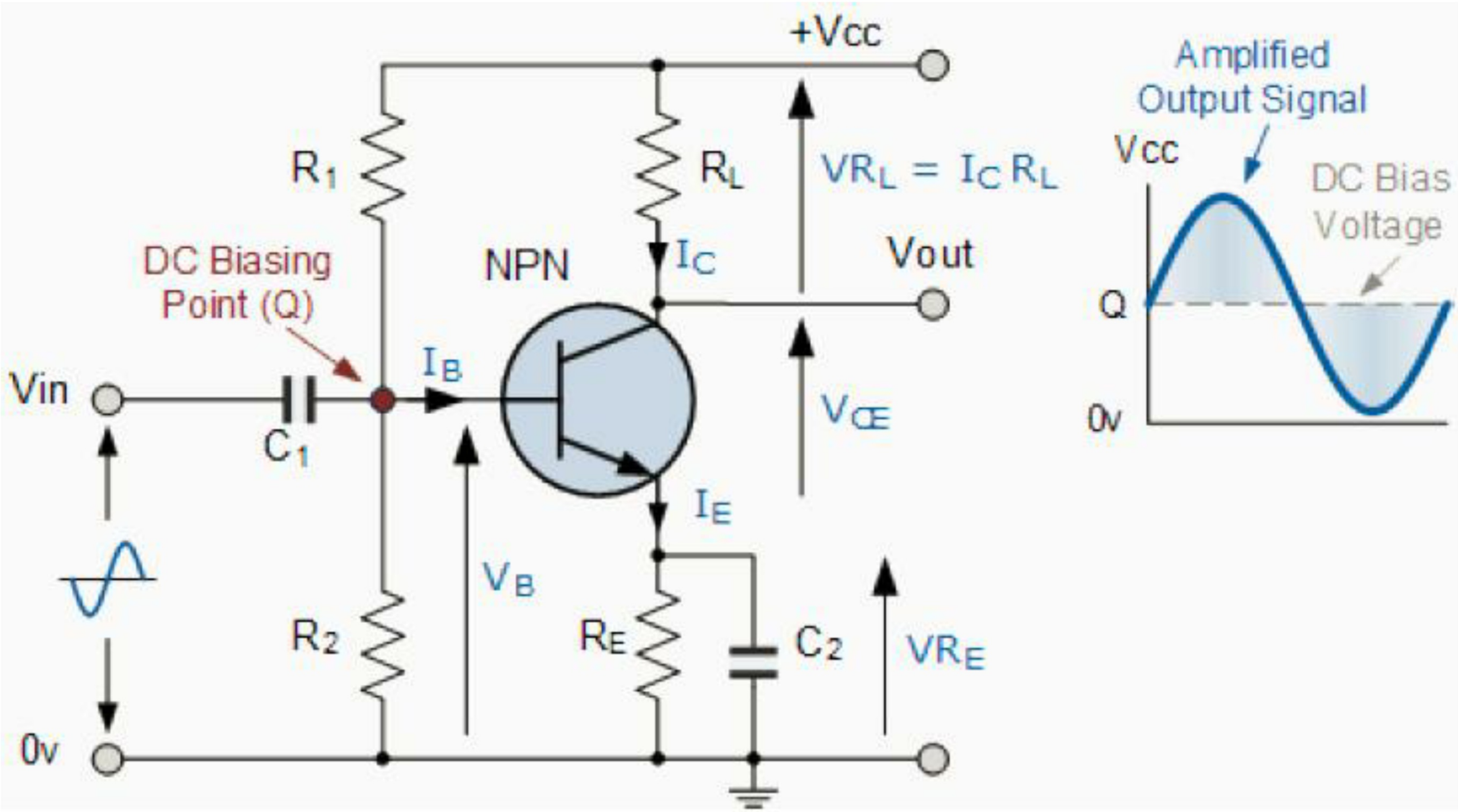
- Using the output characteristics curves and Ohm´s Law, the current flowing through the load resistor, (RL), is equal to the collector current, Ic entering the transistor which in turn corresponds to the supply voltage, (Vcc) minus the voltage drop between the collector and the emitter terminals, (Vce) and is given as:

$$\text{Collector Current, } I_C = \frac{V_{CC} - V_{CE}}{R_L}$$

- A straight line representing the Load Line of the transistor can be drawn directly onto the graph of curves above from the point of "Saturation" (A) when Vce = 0 to the point of "Cut-off" (B) when Ic = 0 thus giving us the "Operating" or Q-point of the transistor. These two points are joined together by a straight line and any position along this straight line represents the "Active Region" of the transistor.

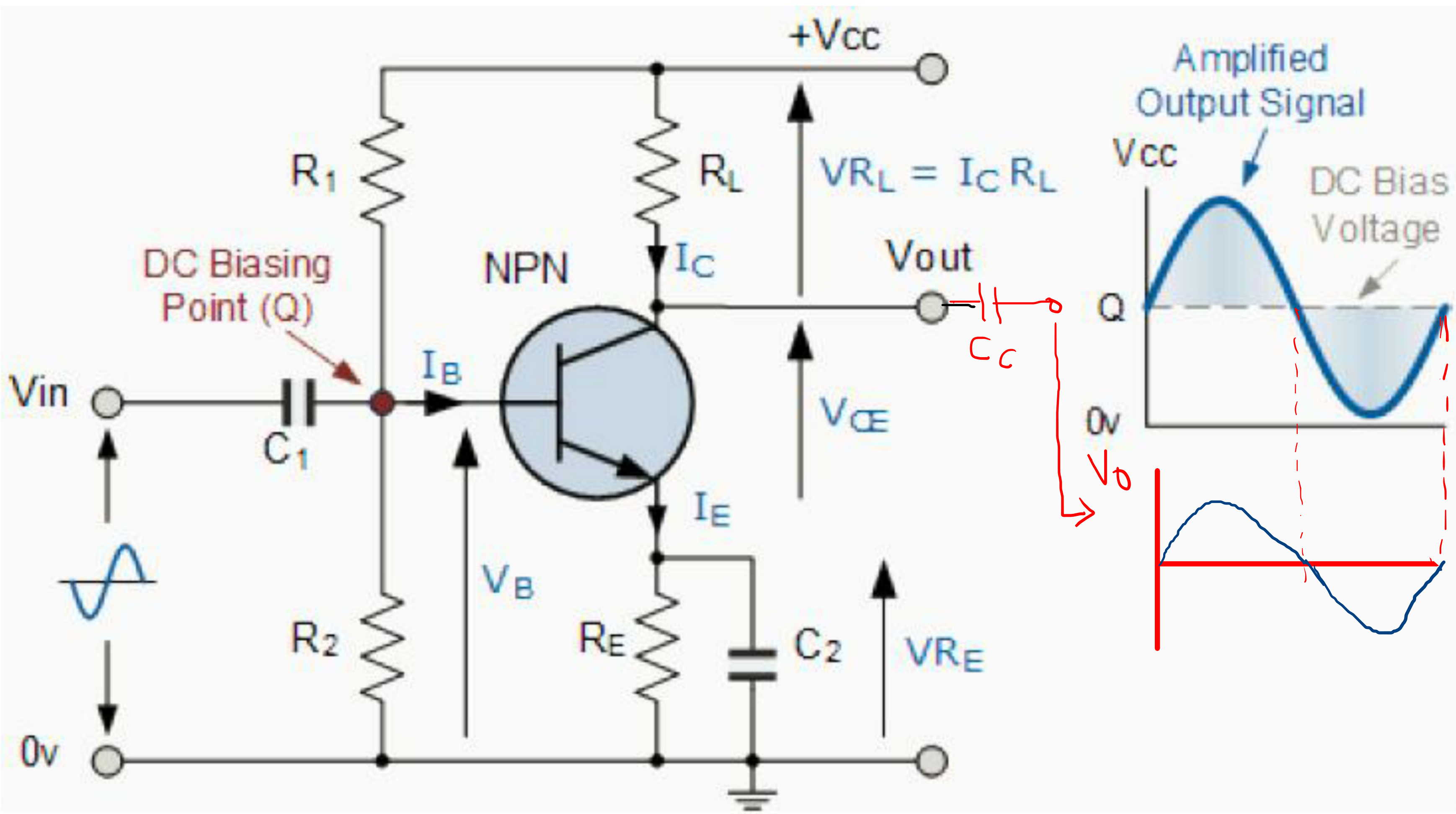
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

The actual position of the load line on the characteristics curves can be calculated as follows

$$\text{When}: \left(V_{CE} = 0\right) \quad I_C = \frac{V_{CC} - 0}{R_L}, \quad I_C = \frac{V_{CC}}{R_L}$$

$$\text{When}: \left(I_C = 0\right) \quad 0 = \frac{V_{CC} - V_{CE}}{R_L}, \quad V_{CC} = V_{CE}$$

- Then, the collector or output characteristics curves for Common Emitter Transistors can be used to predict the Collector current, Ic, when given Vce and the Base current, Ib. A Load Line can also be constructed onto the curves to determine a suitable Operating or Q-point which can be set by adjustment of the base current.

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

Design Steps: Approximate Formulae

1. Choose supply voltage Vcc
2. Choose collector current (IC)
3. Choose transistor (hfe or β=??)
4. Find collector Resistor Rc≈ (Vcc/Ic)/2
5. Find emitter resistance RE≈ 0.1Vcc/(Ic/2)
6. Choose emitter bypass capacitor CE= (1/2.π.f.RE)
7. Find base current IB=IC/ β
8. Base voltage VBB= VE(0.1Vcc)+VBE(0.7V)
9. Find R1 and R2

   VBB=(VccxR2/R1+R2)

   choose R1 /R2 and find R2/R1 using above equation