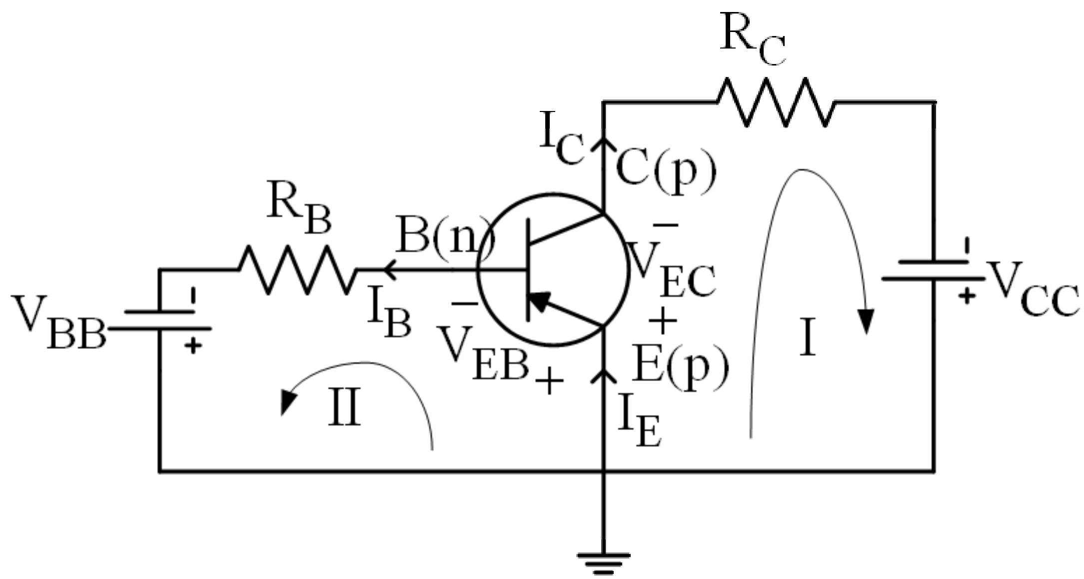
CLASS 21&22

STABILITY OF BJT BIASING CIRCUITS, BJT AS A SWITCH, SMALL-SIGNAL EQUIVALENT CIRCUIT OF THE BJT AND FETs

STABILITY OF THE BIASING CIRCUITS



KVL for loop I:

$V_{EC} + I_C R_C - V_{CC} = 0$

$V_{EC} + I_C R_C = V_{CC}$

KVL for loop II:

$V_{EB} + I_B R_B - V_{BB} = 0$

$V_{EB} + I_B R_B = V_{BB}$

$I_B = (V_{BB} - V_{EB}) / R_B$

Since V_{BB} , V_{EB} and R_B are fixed, I_B is also fixed.

If $T\uparrow$, $I_C\uparrow$; hence, $V_{EC}\downarrow$. The Q point will change as the Q point of the CE circuit is I_{CQ} and V_{ECQ} .

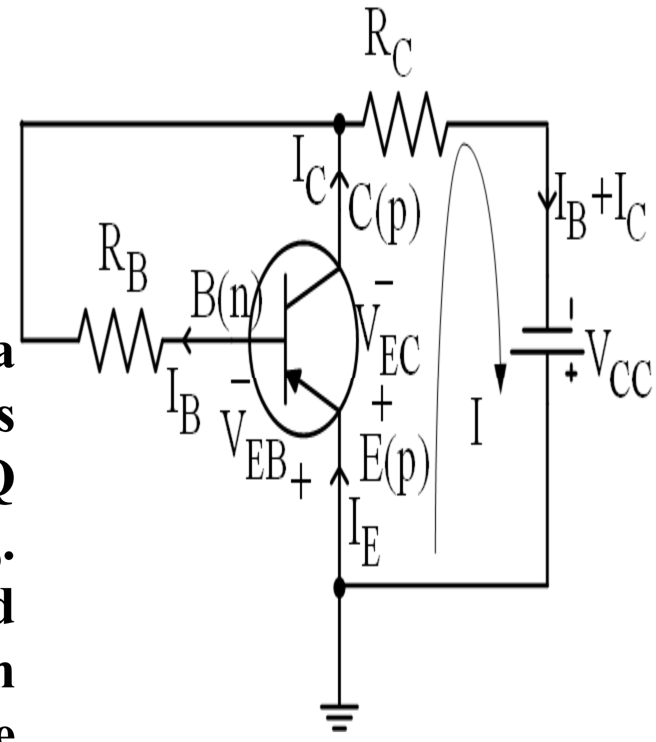
As the I_B is fixed, this condition does not help in stabilizing the Q point of the circuit when changes occur. Thus, fixed-current biasing circuit is said to be less stable in terms of its biasing performance.

KVL of loop I:

$V_{EC} + (I_B+I_C)R_C = V_{CC}$ (1)

KVL of loop II:

$I_B = (V_{EC} - V_{EB}) / R_B$ (2)



From $I_C = \beta_{DC} I_B + I_{CEO}$, T↑ then I_C↑ if I_B is a fixed current. From (1), V_{EC}↓ when I_C↑. If this happens, the Q point will change as the Q point of the CE circuit is I_{CQ} and V_{ECQ}. However, from (2), since V_{EB} and R_B are fixed values, I_B will ↓when V_{EC}↓. Again, from $I_C=\beta_{DC} I_B + I_{CEO}$, when T↑ I_{CEO}↑ but from the above, I_B will ↓. Hence, I_C will be maintained. This condition will also maintain the $(I_B+I_C)R_C$ term in (1). Hence, V_{EC} will be maintained at the quiescent value before the temperature change. Thus, collector feedback biasing circuit is said to be more stable in terms of its biasing performance.

KVL of loop I:

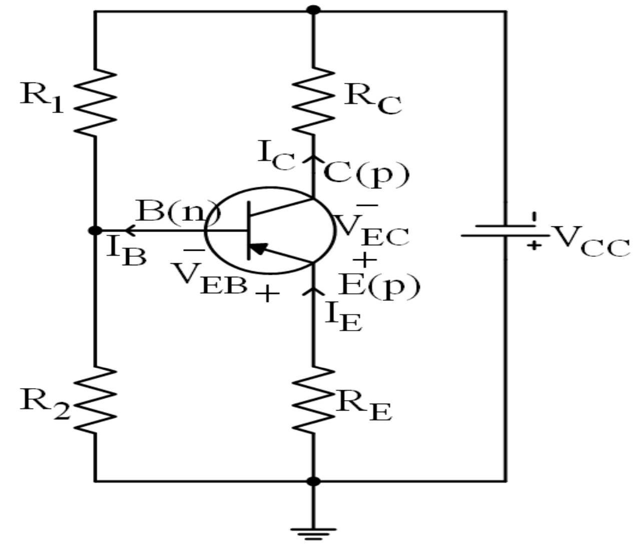
$I_E R_E + V_{EC} + I_C R_C = V_{CC}$ **(1)**

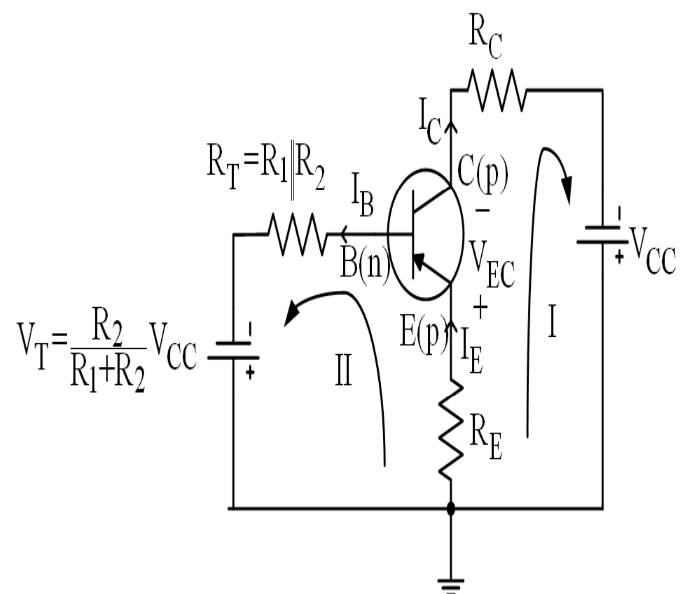
KVL of loop II:

$I_E R_E + V_{EB} + I_B R_T = V_T$

$I_E R_E + I_B R_T = V_T - V_{EB}$ **(2)**

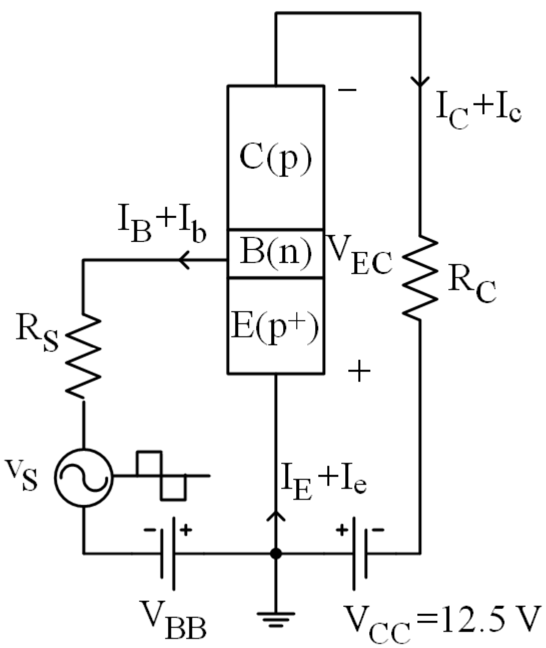
When T↑, then I_C↑. I_E will also ↑ as $I_C \approx \alpha I_E$. From (2), since V_{EB}, V_T, R_E and R_T are fixed values, when I_E↑, then I_B↓. From $I_C = \beta_{DC} I_B + I_{CEO}$, when T↑ I_{CEO} ↑ and will supposedly increase the $I_{C.}$ However, this will make I_B↓. Thus, I_C will be maintained. Therefore, I_B is helping to stabilize the circuit by maintaining the Q point. This circuit is the most popular amongst the 3 biasing circuits discussed.

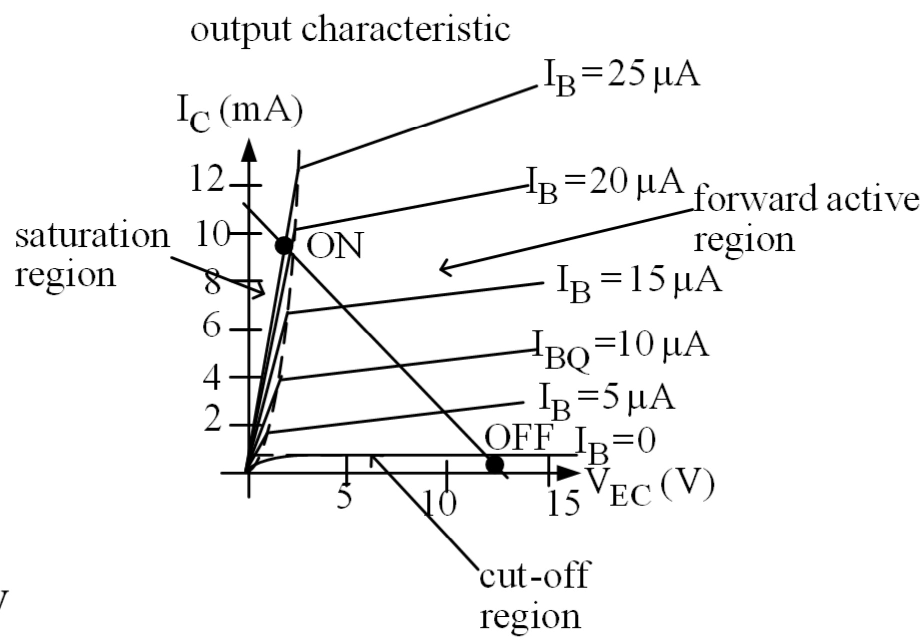




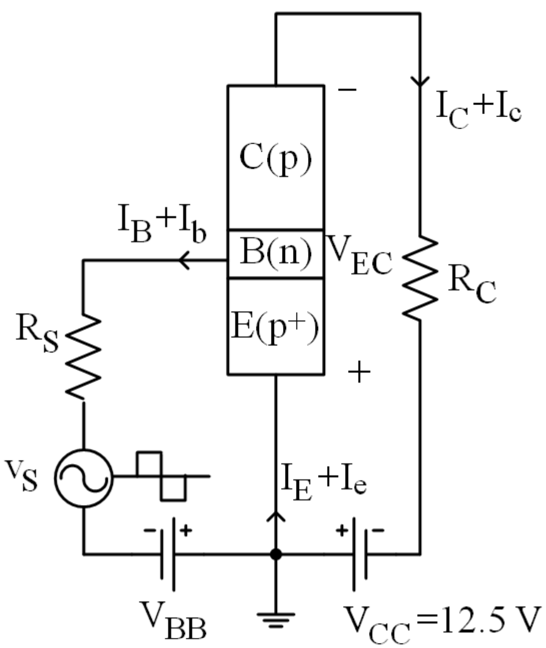
BJT AS A SWITCH

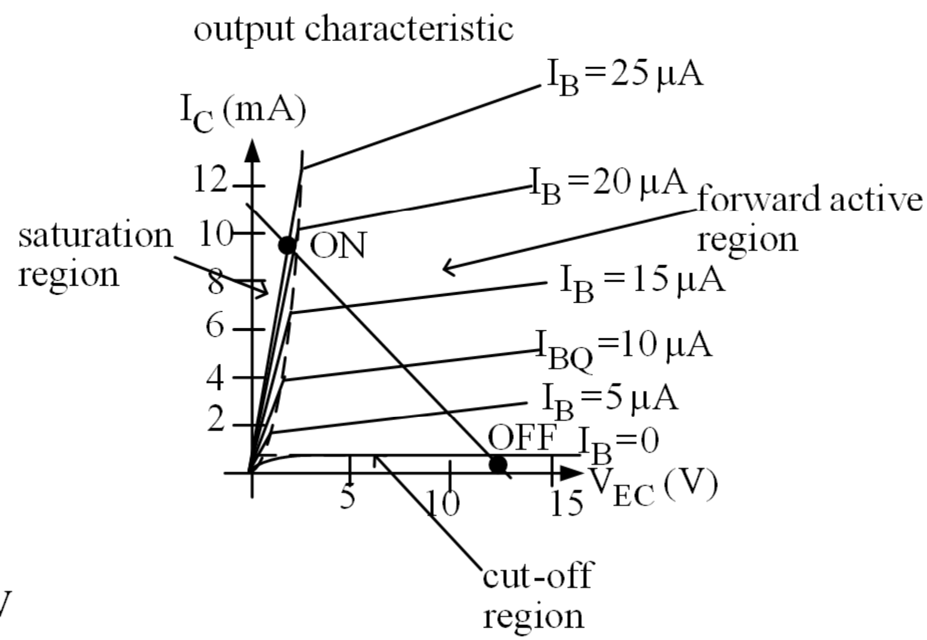
- In digital applications, the transistors are normally utilized as switches. As a switch, I_B is used to convert I_C from OFF to ON.
- OFF condition: high voltage and low current
- ON condition: low voltage and high current





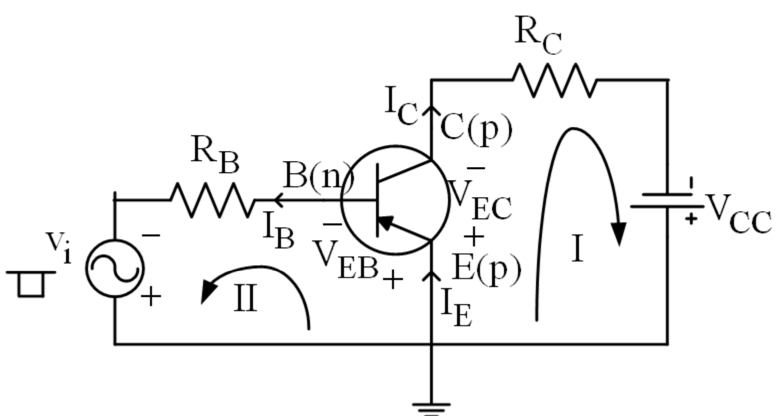
- **Transistor is an o/c between E and C in the OFF condition.**
- **Transistor is a s/c between E and C in the ON condition.**
- **Hence, the transistor's operation is like a switch.**

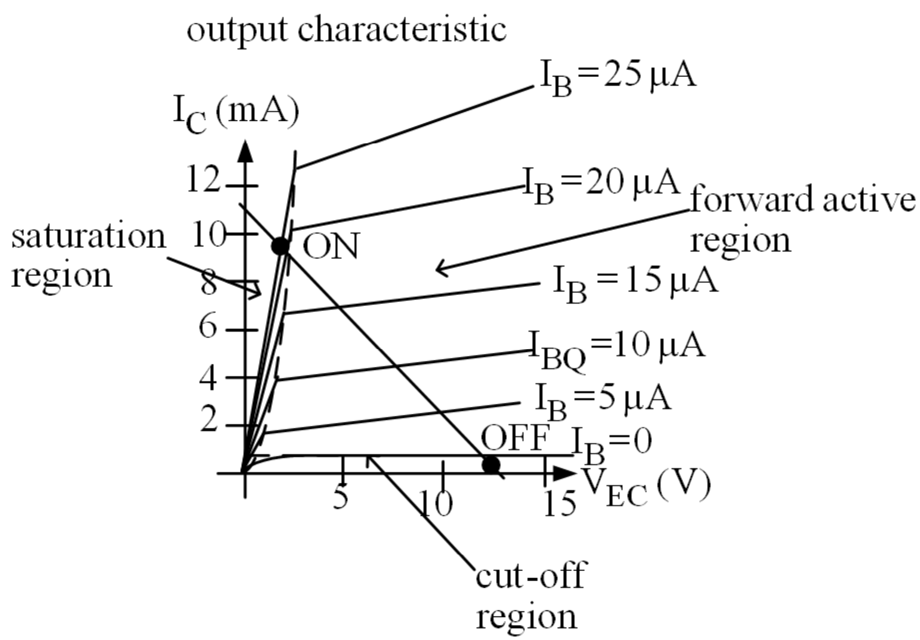




CUT-OFF

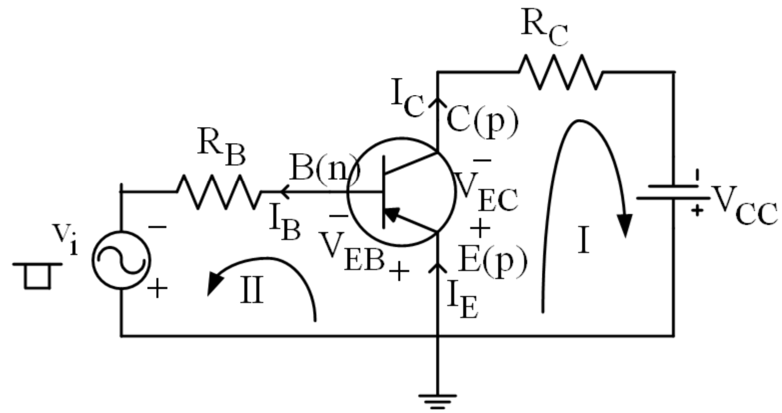
- **If $|v_i|$ is < 0.7, the E-B junction will let only a very small insignificant current to flow. Under this condition, the E-B junction is still considered as OFF. $I_B = I_C = I_E \approx 0$. $V_{EC} = V_{CC}$. B-C junction is also rb. The transistor is said to be in the cut-off condition (voltage is high, current is very small).**

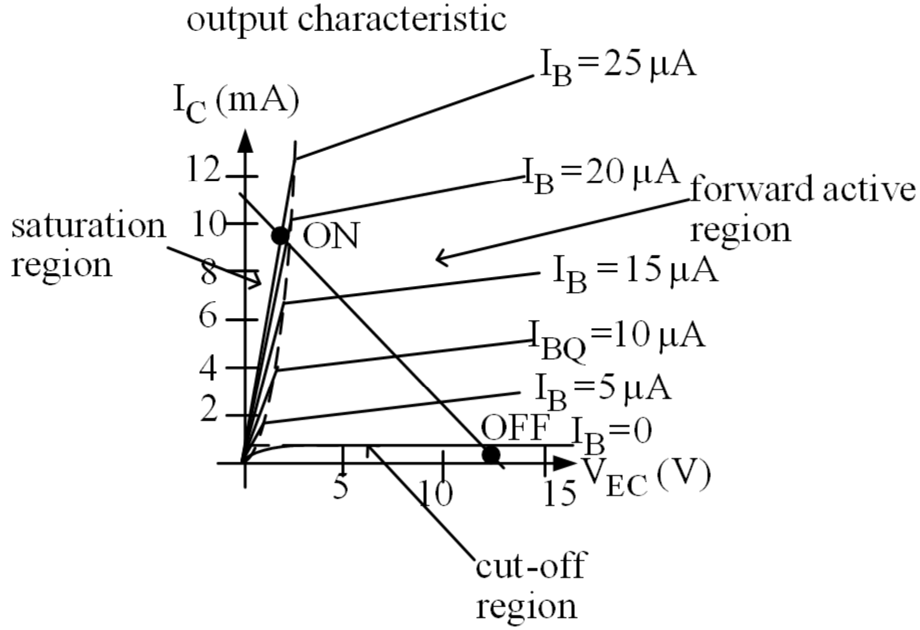




SATURATION

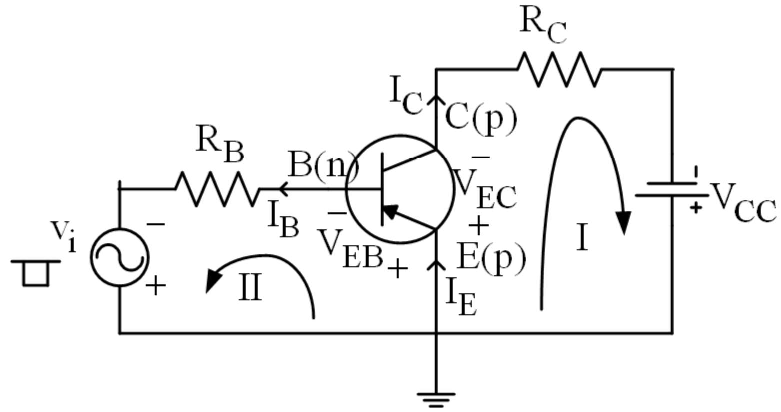
- **If $|v_i|\uparrow$, $I_B \uparrow I_C \uparrow$ and $V_{EC}\downarrow$ (from $V_{EC} + I_C R_C = V_{CC}$). If the $|V_{EC}| < 0.7$ V, the device will enter the saturation region as both E-B and B-C junctions are fb.**
- **Under this condition, $|V_C| < |V_B|$. The B-C junction will be fb as the C is more +ve than the B. The B-C junction can be fb by a forward voltage of 0.4 to 0.5 V. The forward voltage drop of the B-C junction is smaller than the forward voltage drop of the E-B junction (i.e. 0.7 V) because C is doped less than E. $[V_o=(kT/q)\ln(N_A N_D/n_i^2)]$.**



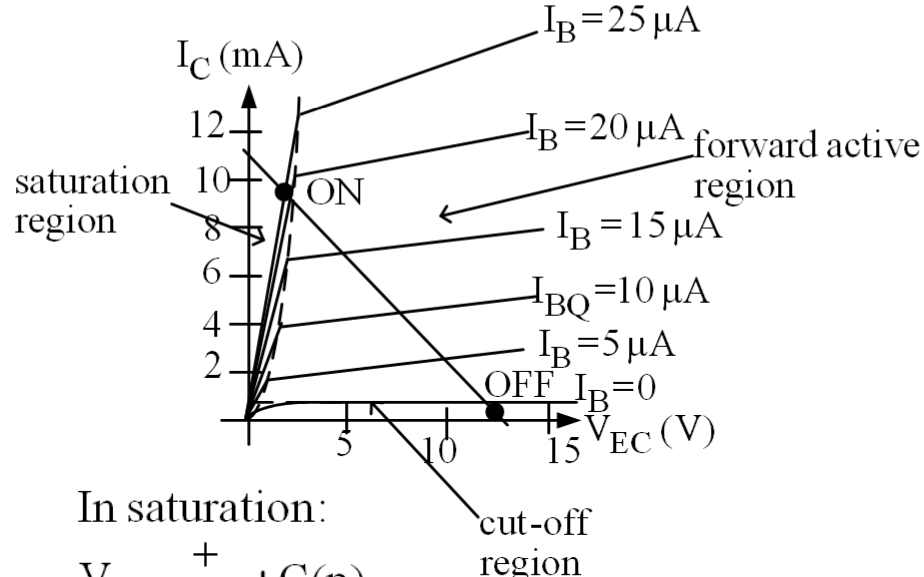


- **This condition is called saturation as any increment in the I_B will only cause the I_C to increase by a small amount and therefore, V_{EC} will also decrease by a small amount.**
- **The minimum rb of the BC junction is when $V_{BC} = 0$.**
- **In the saturation region, $\Delta I_C/\Delta I_B \neq \beta_{DC}$.**
- **As the forward voltage drop of the B-C junction is in the range 0.4 V to 0.5 V, then**
- **$V_{EB} - V_{CB} – V_{EC} = 0$. Under this condition, $V_{EC} = V_{EC(sat)} = 0.3$ V to 0.2 V.**
- **$V_{CC} = V_{EC(sat)} + I_{C(sat)}R_C$**

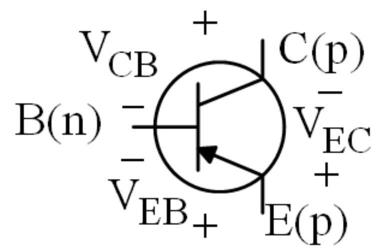
  $I_{C(sat)} = [V_{CC} - V_{EC(sat)}]/R_C$



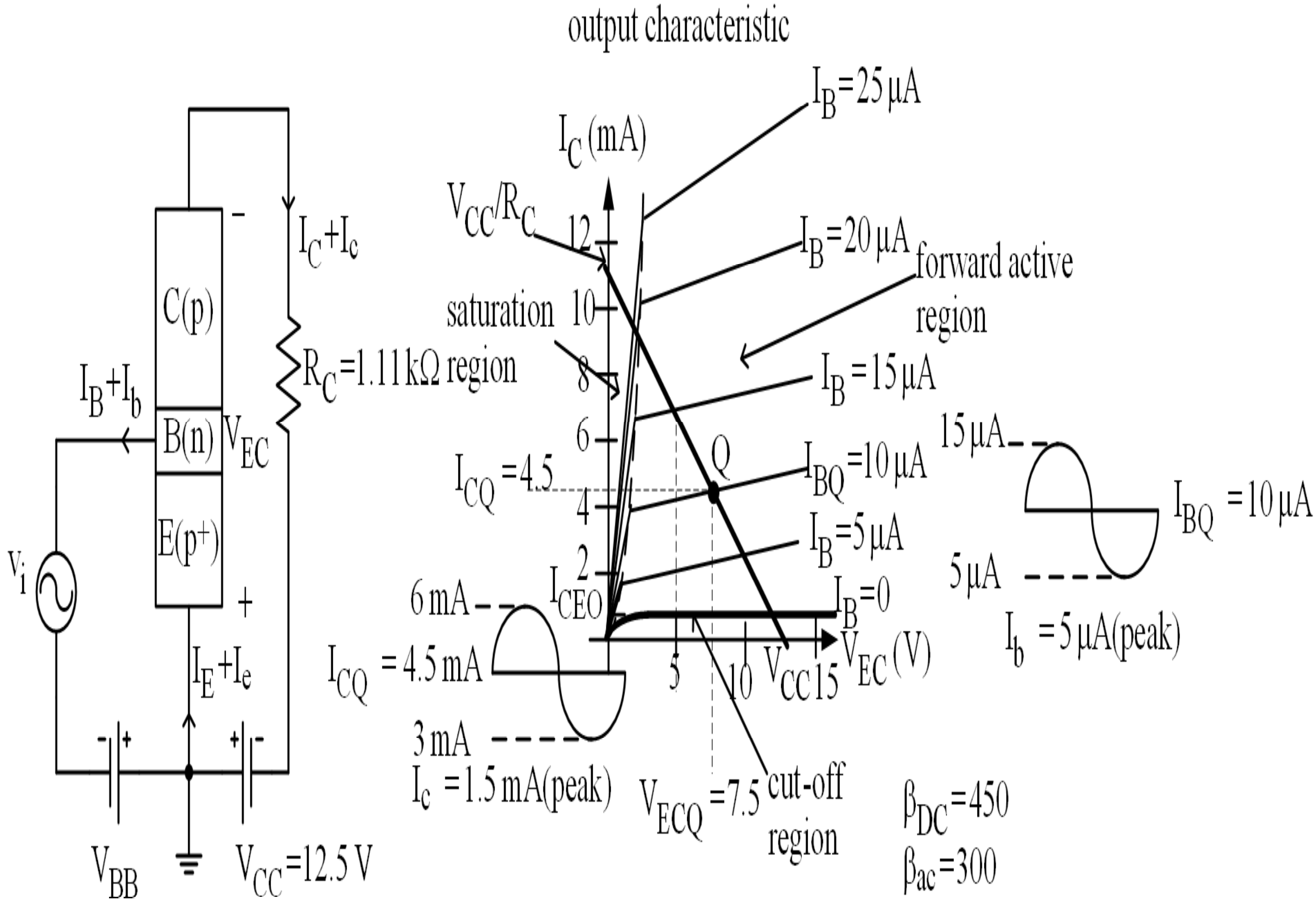
output characteristic



In saturation:

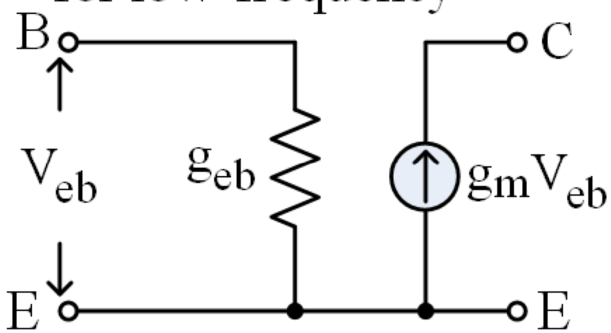


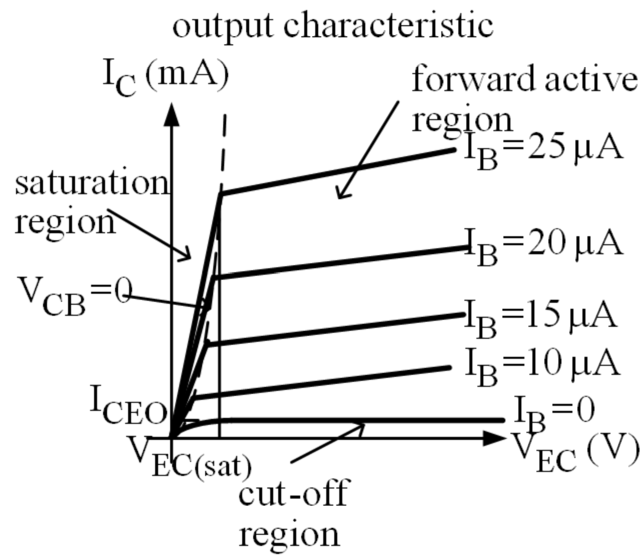
- **BJT has 4 modes of operation, i.e. forward active, saturation, cut-off and inverted. The mode of operation is dependent on the biasing condition of the BE and BC junctions.**
- **In analogue circuits, transistors normally operate in the active mode.**
- **In digital circuits, all 4 modes might be involved.**
- **So far, we had seen the static (or DC) characteristics of the BJT. Now we will learn about the AC characteristics of the BJT when a small-signal voltage or current is superimposed on its DC signal. Small-signal means the peak AC voltage and current are smaller than their DC values.**


output characteristic
I_B=25 μA
I_C (mA)
V_CC/R_C
12
I_C+I_c
I_B=20 μA
forward active region
C(p)
saturation region
10
R_C=1.11 kΩ
8
I_B =15 μA
I_B+I_b
B(n)
V_EC
6
15 μA
Q
I_BQ=10 μA
I_CQ =4.5
4
I_BQ =10 μA
E(p+)
I_B=5 μA
v_i
2
5 μA
I_CEO
I_B=0
6 mA
I_b =5 μA(peak)
V_EC (V)
I_CQ = 4.5 mA
5
10
V_CC
15
I_E+I_e
3 mA
I_c =1.5 mA(peak)
V_ECQ =7.5
cut-off region
β_DC=450
β_ac=300
V_BB
V_CC=12.5 V

SMALL-SIGNAL EQUIVALENT CIRCUIT OF BJT

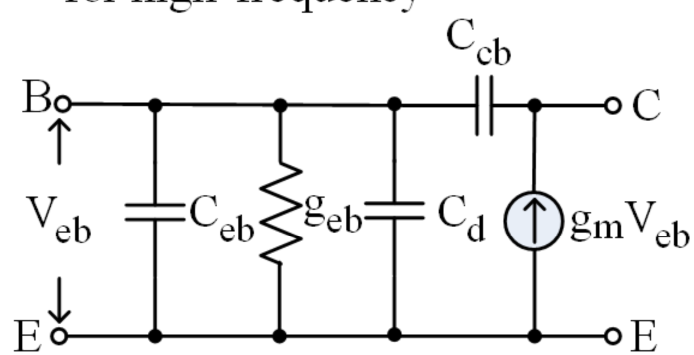
Basic equivalent circuit for low-frequency





- **$g_m = I_c/V_{eb}$ is the transconductance.**
- **$g_{eb} = I_b/V_{eb}$ is the i/p conductance. This conductance must be included as we are considering the current that is flowing through the fb E-B junction.**
- **At higher frequencies, when E-B is fb, there exist a depletion capacitance, C_{eb}, and diffusion capacitance, C_d. For the rb B-C junction, there exist only the depletion capacitance, C_{cb}.**

Basic equivalent circuit for high-frequency



Depletion capacitance:

Independent of whether the junction is forward or reverse biased, there exist the depletion region on both sides of the junction. The p-depletion region-n structure is similar to the structure of the capacitor. Due to the depletion region, depletion capacitance, C_j, exist.

$C_j = dQ/dV = dQ/(WdQ/\varepsilon A) = \varepsilon A/W$
(unit for C_j is F/cm^2)

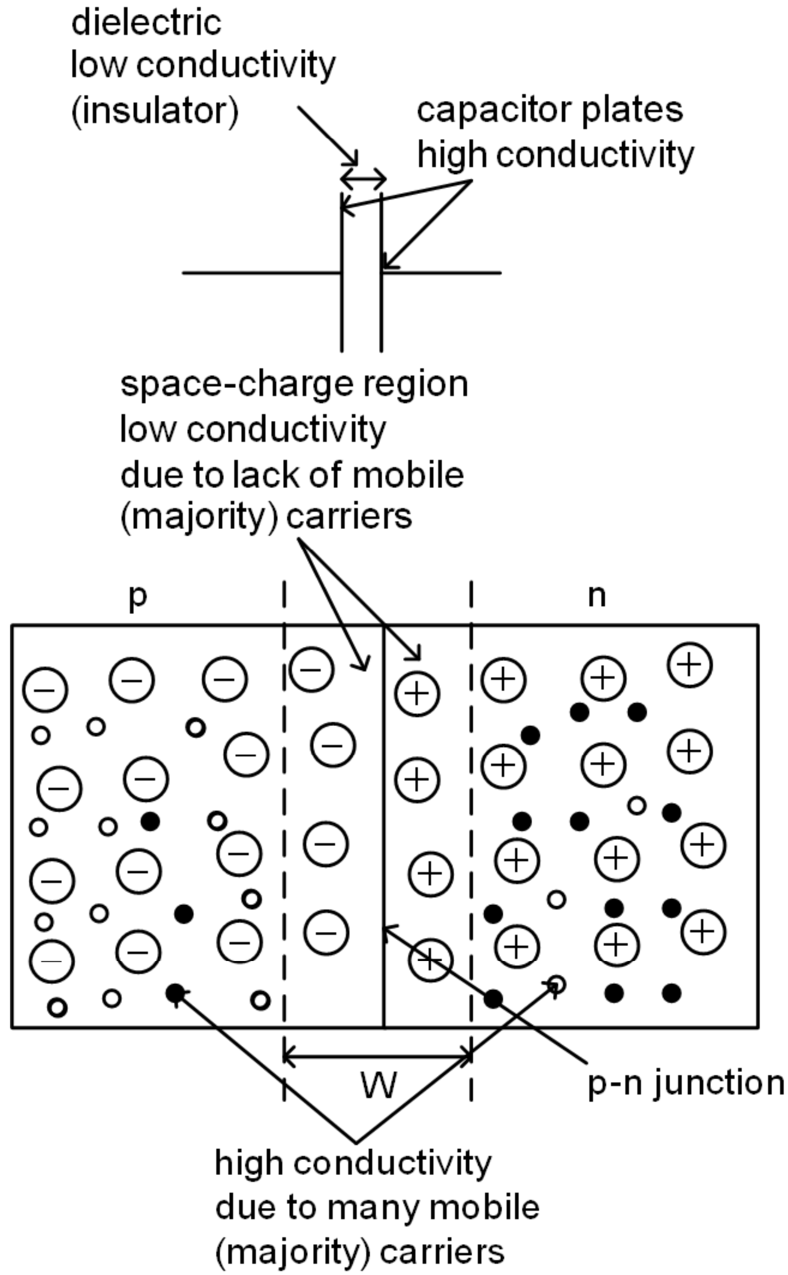
dQ = change of charge per unit area of the depletion layer.

dV = change of voltage applied.

A = cross-section area.

ε = permittivity of Si

W = width of the depletion region



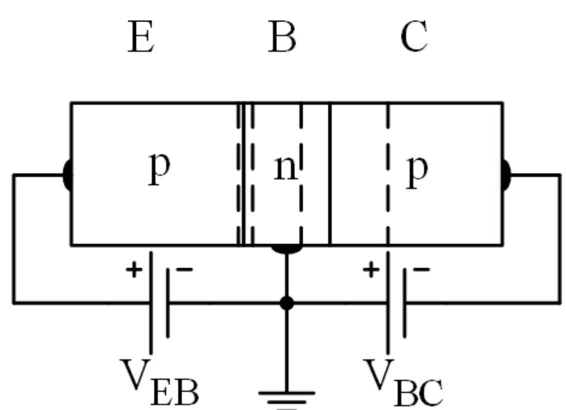
<u>Diffusion capacitance</u>

- **When the p-n junction is fb, large current flows through the junction. This will result in many mobile carriers to be in the neutral B. The change in the mobile carriers corresponding to the change in the biasing voltage will result in the diffusion capacitance, C_d.**
- **$C_d = (Aq^2 L_p p_{no}/kT)e^{qV/(kT)}$**

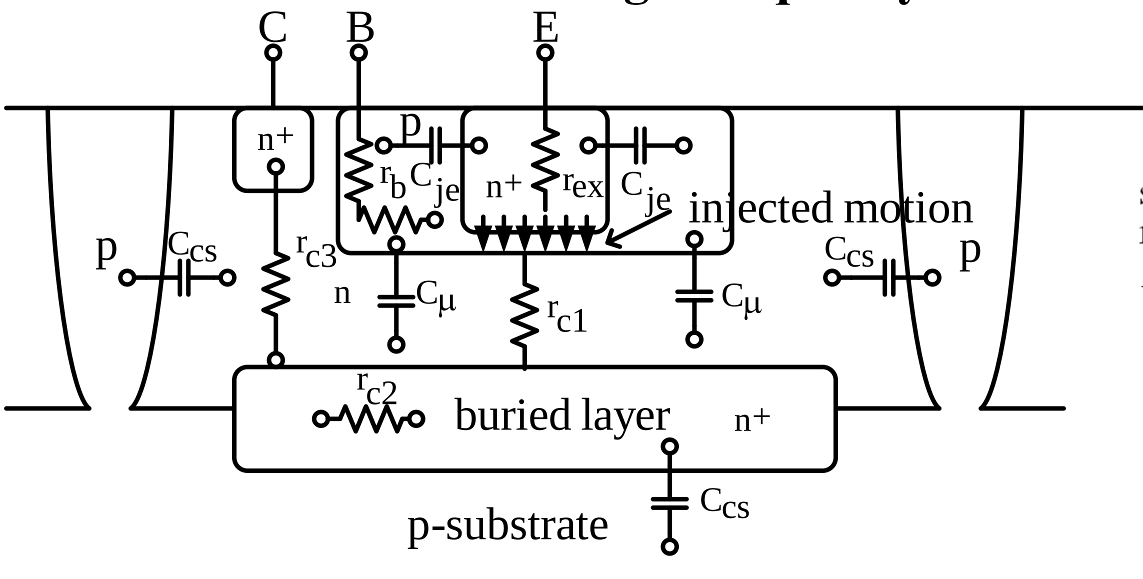
  where

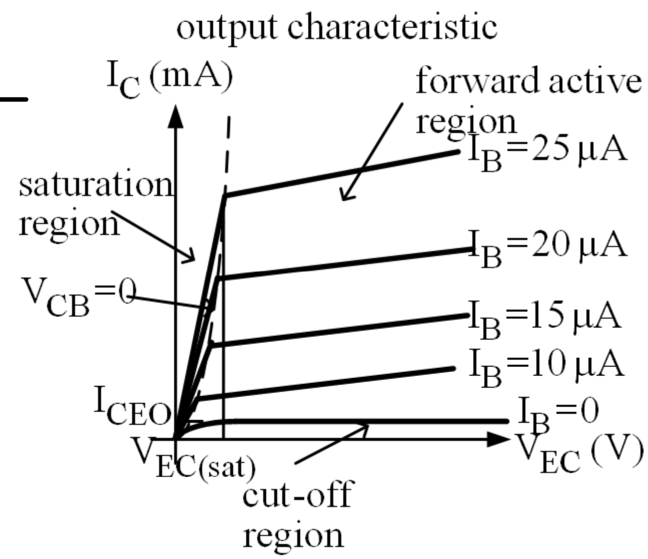
  L_p = diffusion length of hole in the n material

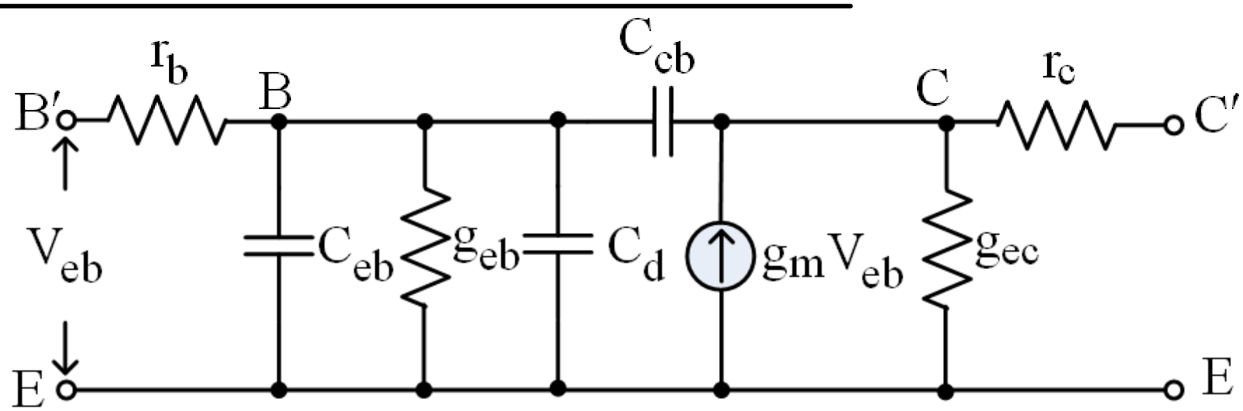
  p_{no} = equilibrium hole density in the n



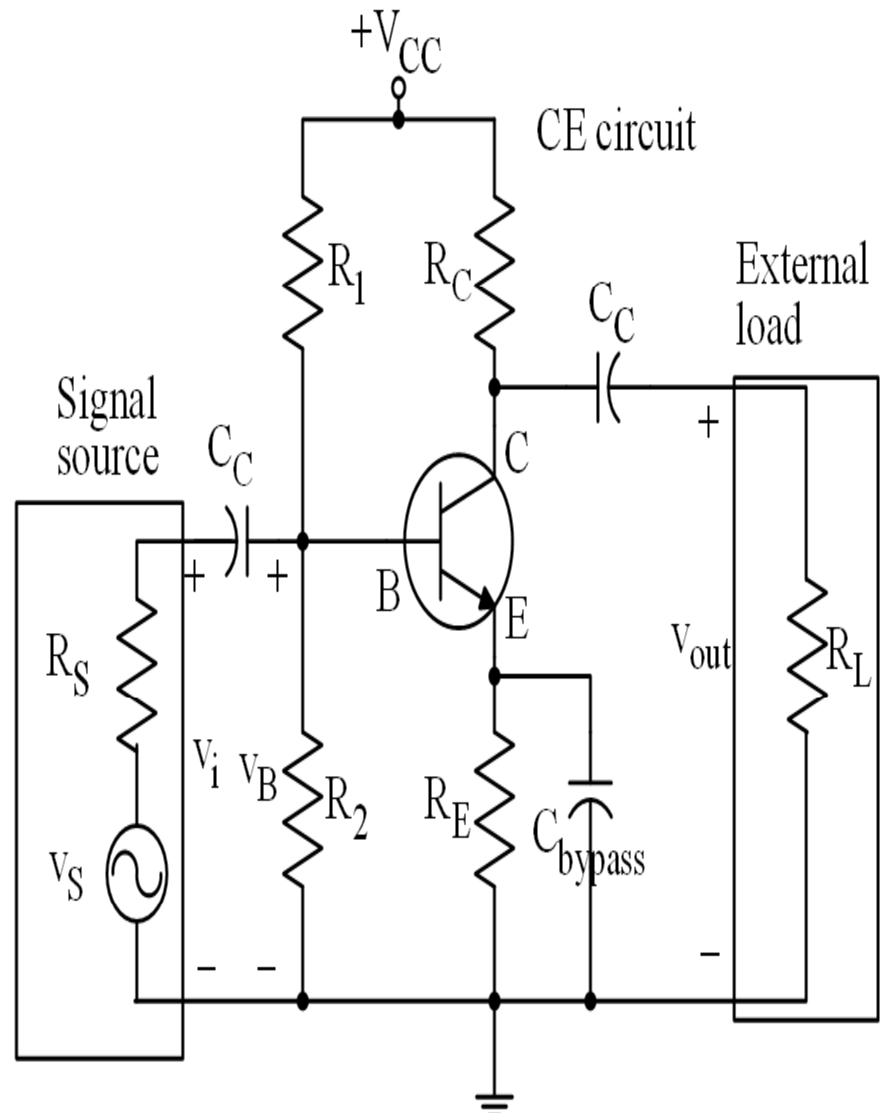
- **If the Early Effect (or base width modulation effect) is to be considered, the output conductance, $g_{ec} = I_c/V_{ce}$, has to be included.**
- **If the resistance of the B and C are to be included, the equivalent circuit of the BJT at high-frequency becomes:**



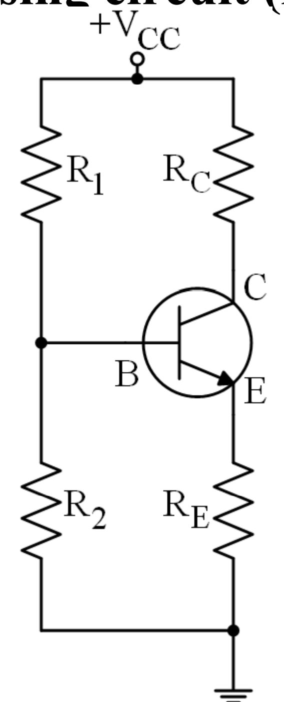




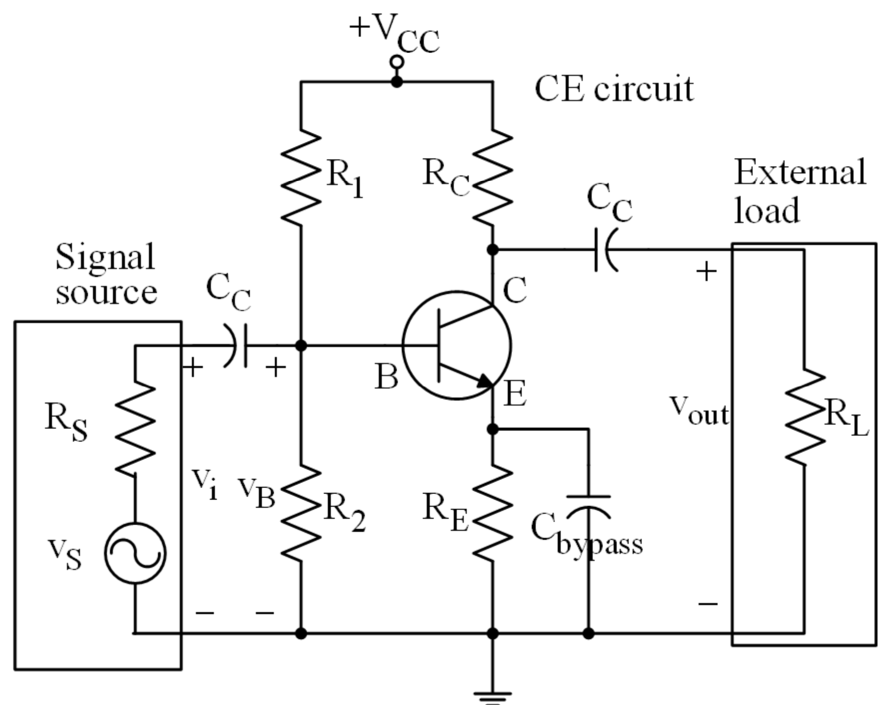
- C_C is a coupling capacitor. It limits the DC signal to the transistor and the biasing circuit only. The DC signal cannot reach the signal source and the external load as capacitor to a DC is an open circuit [$X_C = 1/(2\pi fC)$].
- C_{bypass} is a bypass capacitor. It takes out R_E (the emitter resistor that can reduce the amplifier's gain) from the AC signal's path but let R_E plays its part in stabilizing the biasing of the transistor. To the AC signal, the capacitor is a short circuit.



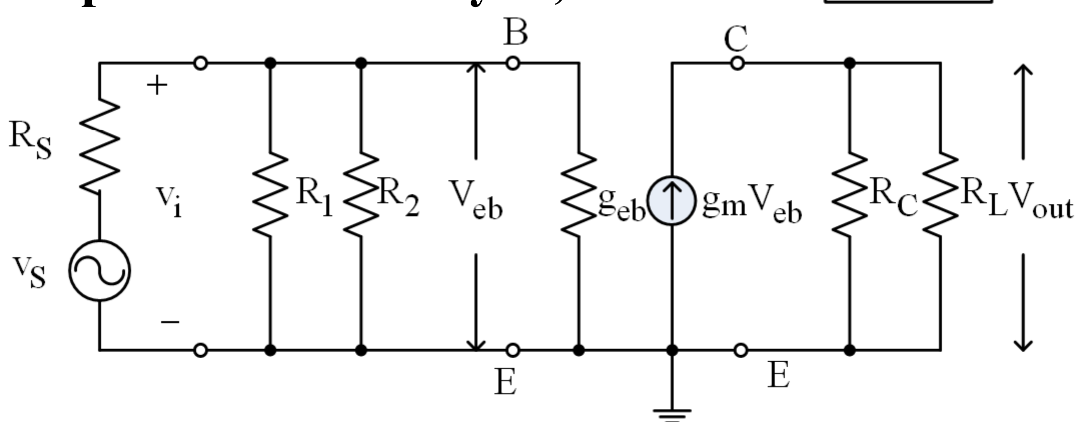
To analyze the biasing circuit (i.e. DC analysis),



CE Amplifier circuit



To perform AC analysis,



Field Effect Transistors (FET) and Bipolar Junction Transistors (BJT) Differences

	BJT	FET
1.	**Bipolar device** Both current carriers (electrons and holes) contribute to the current flow.	**Unipolar device** One current carrier (majority carrier) influences the current flow.
2.	**Current controlled device** Base current (I_B) controls Collector current (I_C).	**Voltage controlled device** Gate to Source voltage (V_{GS}) controls the amount of current (I_D) flowing.
3.	**Z_i of BJTs < Z_i of FETs** Depending on the configuration: CE - A_V is high, Z_i is quite high. CC - A_V is 1, Z_i is high. CB - A_V is high, Z_i is low.	**High input impedance** Z_i = hundreds of MΩ.
4.	Not as stable as the FET towards temperature variation.	More stable towards temperature variation.
5.	Larger and more complex than FET.	Smaller in size and easier to fabricate as compared to the BJT.

Due to 4 and 5, FET can be found in many digital ICs.

FIELD EFFECT TRANSISTORS

1. **Junction Field Effect Transistor (JFET)**
2. **Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET)**

Generally known as:

1. **Metal-Insulator-Semiconductor FET (MISFET) where the insulator may not be silicon dioxide (SiO_2) and semiconductor may not be Silicon (Si).**
2. **Insulated Gate FET (IGFET) symbolizing the device which Gate is insulated from the Body by the SiO_2.**

The insulated Gate from Body causes the gate current (I_G) to be considered as 0 in many analysis and calculation. In reality, this current is in the femto (10^{-15}A) range.

Differences between JFET and MOSFET

- **The Gate of the MOSFET is insulated from the channel (and Body) by a layer of SiO_2.**
- **MOSFET does not have a p-n junction that controls the width of the channel and consequently the current.**

MOSFET Application

- **In Very-Large-Scale-Integrated (VLSI) circuits. Examples: microprocessor and memory chips.**
- **At present, even the RF analog integrated circuits are implementing MOSFETs as these devices have smaller dimensions and cheaper to fabricate.**

  To summarize, the MOSFETs are typically used in IC design.

Types of MOSFET

- **Depletion-enhancement (typically known as DE-MOSFET)**
- **Enhancement-only MOSFET (typically known as E-MOSFET)**