CLASS 18&19

BJT CONFIGURATIONS AND I-V CHARACTERISTICS

$$\gamma = \frac{I_{Ep}}{I_E}$$

$$= \frac{\frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT}}{qA\left\{\frac{D_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{D_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]\right\}}$$

$$= \frac{\frac{D_p p_{no}}{W}}{\left\{\frac{D_p p_{no}}{W} + \frac{D_E n_{Eo}}{L_E}\right\}}$$

$$= \frac{1}{\left\{1 + \frac{D_E}{D_p}\frac{n_{Eo}}{p_{no}}\frac{W}{L_E}\right\}}$$

$$n_{Eo} = \frac{n_i^2}{N_E}, p_{no} = \frac{n_i^2}{N_B}, \therefore \gamma = \frac{1}{\left\{1 + \frac{D_E}{D_p}\frac{N_B}{N_E}\frac{W}{L_E}\right\}}$$

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- **To increase the emitter efficiency, γ, N_B/N_E has to be low. This indicates that E has to be doped higher than B. This is the reason why E is represented by p^+ for the p^+-n-p transistor.**

- **To increase γ, the width of the B, W, should be small as compared to the diffusion length of the electrons in the E.**

BJT CIRCUIT CONFIGURATIONS

3 basic configurations:

1. **Common Emitter (CE)**
2. **Common Collector (CC)**
3. **Common Base (CB)**

All transistor circuits, no matter how complex they are, are based on either one or combinations of 2 or all of these configurations.

- **<u>Common Emitter (CE)</u>**

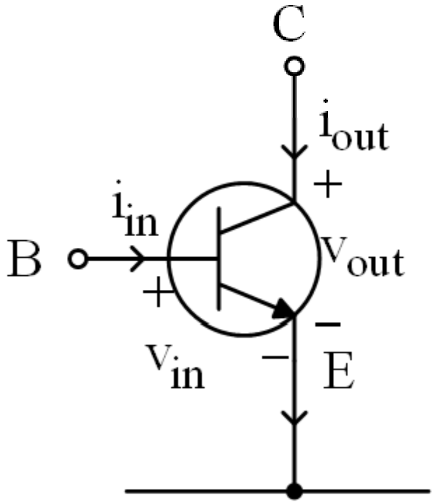
  E is the common point for both the input and output signals. Input signal is applied to B and output is at C. E is AC ground.

- **<u>Common Collector (CC)</u>**

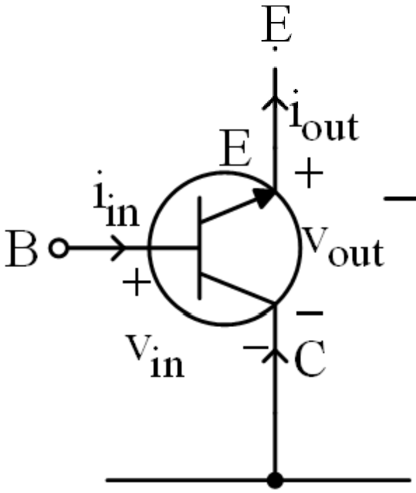
  C is the common point for both the input and output signals. Input signal is applied to B and output is at E. C is AC ground.

- **<u>Common Base (CB)</u>**

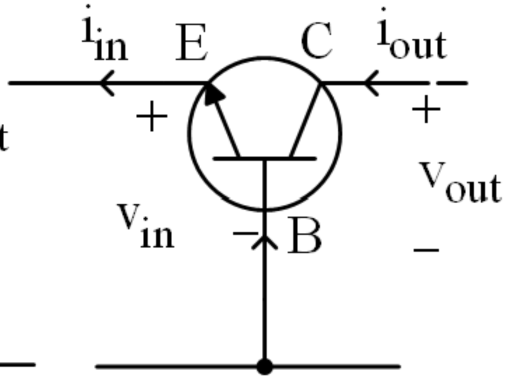
  B is the common point for both the input and output signals. Input signal is applied to E and output is at C. B is AC ground.



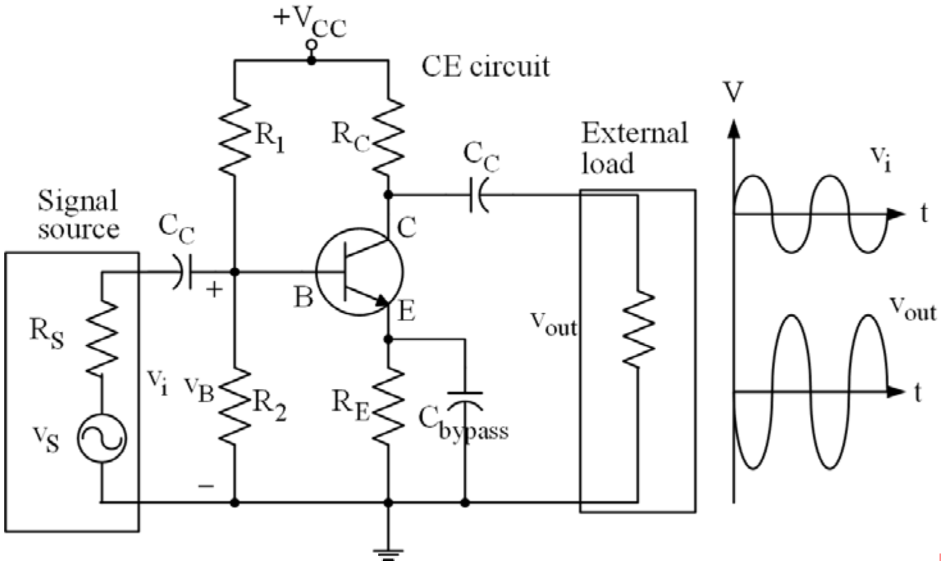
CE

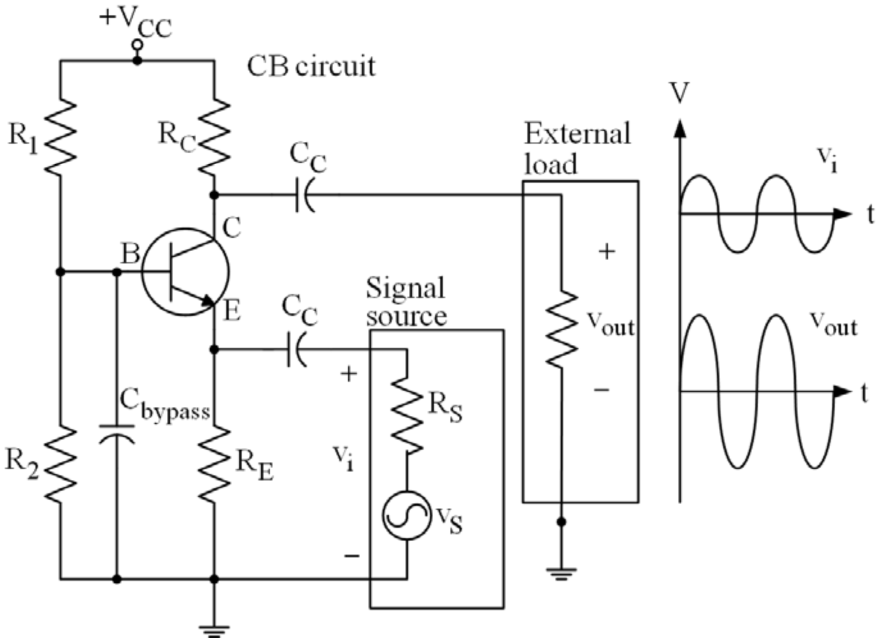


CC



CB


+VCC
CE circuit
R1
RC
CC
External load
Signal source
CC
+
B
C
E
RS
vi
vB
R2
RE
Cbypass
vS
–
vout
V
vi
t
vout
t


+VCC
CB circuit
R1
RC
CC
External load
B
C
E
CC
Signal source
+
RS
vi
vS
–
Cbypass
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vi
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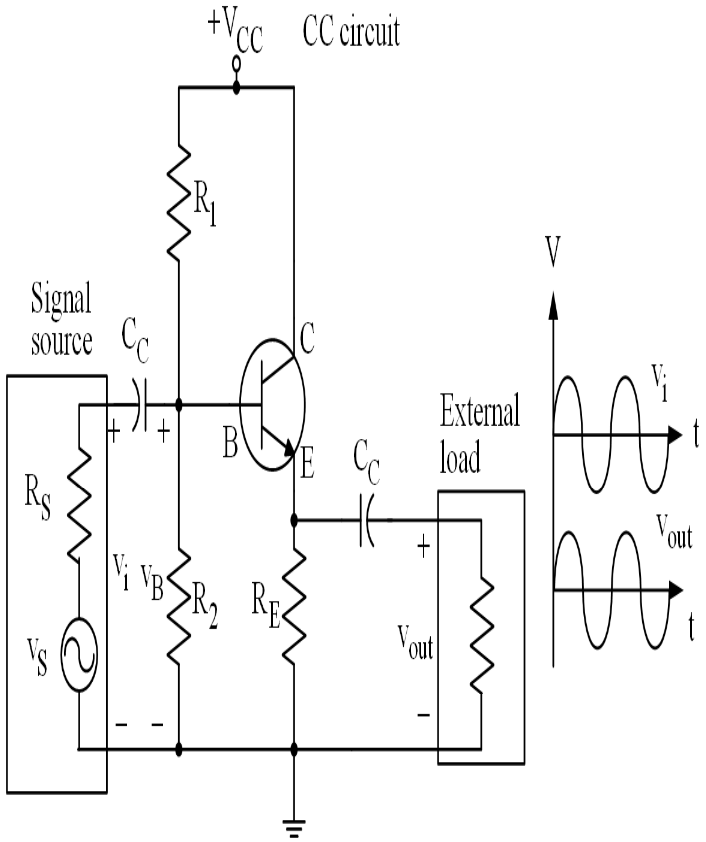
+VCC
CC circuit
R1
Signal source
CC
C
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– –
External load
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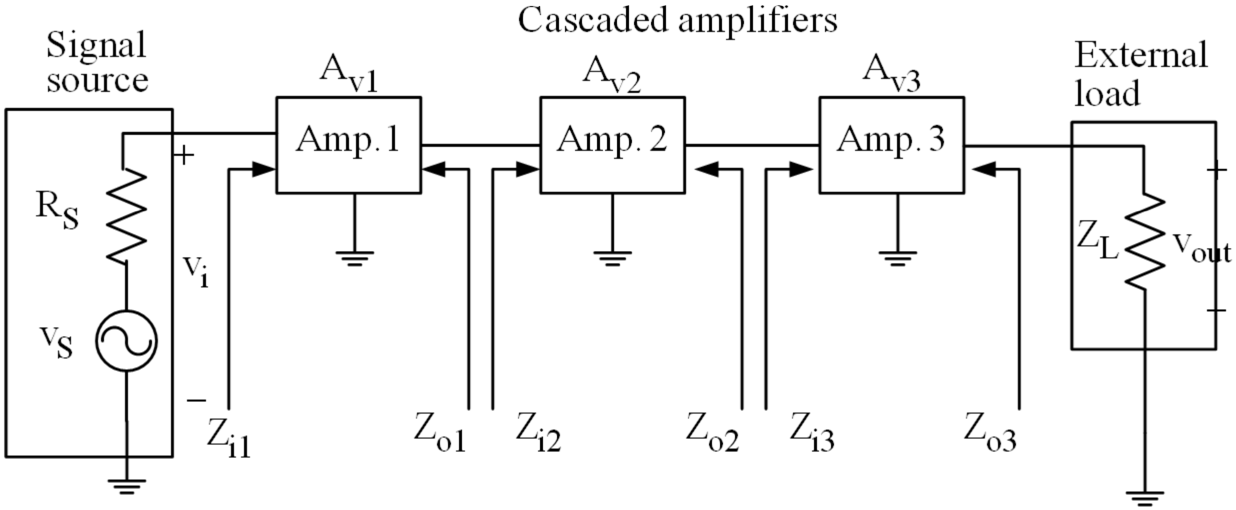
- **CE is the most typical configuration used. For this configuration, the voltage gain, $A_v = V_{out}/V_i$, is high. A high A_v means the amplifier is efficient. The input impedance, Z_i , and output impedance, $Z_o$of CE are also high. A high Z_i is required to optimize the A_v of a cascaded amplifier circuit.**



- **CC (known also as emitter follower) has $A_v = 1$, a high Z_i and a low Z_o . CC is typically employed as a buffer or impedance transformer.**
- **CB has high A_v but smaller Z_i . This configuration is used for high frequency of operation.**

BJT MODE OF OPERATION

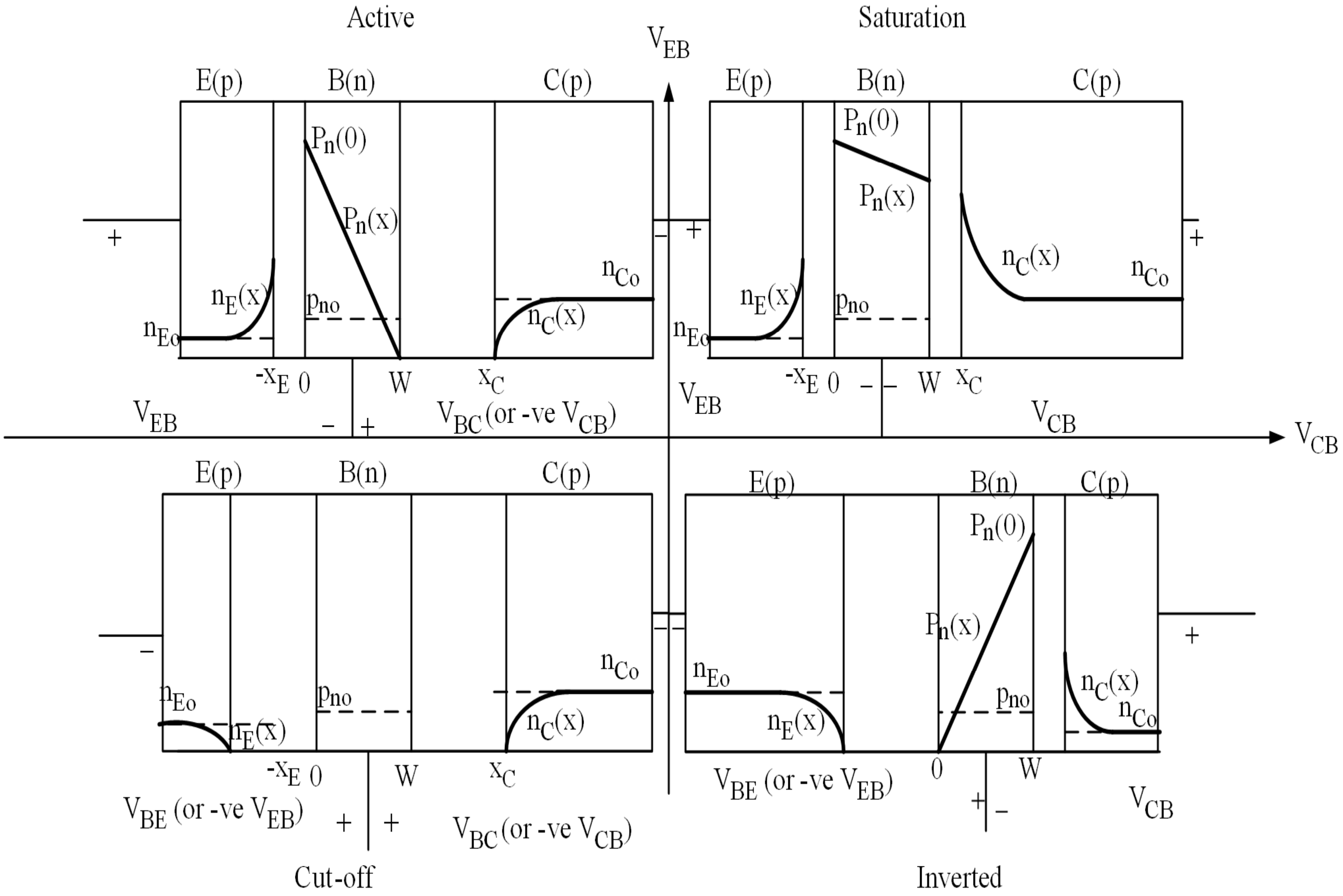
- **There are 4 modes of operation:**

1. **Active mode**
2. **Saturation mode**
3. **Cut-off mode**
4. **Inverted mode**

All the 4 modes are dependent on the biasing voltages, i.e. V_{EB} and V_{BC}.

Active mode: E-B junction fb, B-C junction rb
Saturation mode: E-B junction fb, B-C junction fb
Cut-off mode: E-B junction rb, B-C junction rb
Inverted mode: E-B junction rb, B-C junction fb

Junction polarity and minority carrier distribution for a pnp transistor in 4 different modes of operation.



Observations:

1. **Saturation Mode**

   Non-zero distribution of the minority carriers at the edges of both E-B and B-C depletion regions.

   $$P_n(W) = p_{no} e^{(qV_{CB})/kT}$$

   The bias voltage is small and the output current is large. The transistor is in the conducting state and function of the transistor is as a close (ON) switch.

2. **Cut-off Mode**

   $P_n(0) = P_n(W) \approx 0$. The transistor functions as an open (OFF) switch.

   $I_E = I_B = I_C \approx 0$

3. **Inverted Mode**

   Known also as inverted active mode has C operating as E in the active mode and E operating as C in the active. The current gain for the inverted mode is normally lower than the active mode. This is because the "emitter efficiency" (in this case the C emits holes) is weaker since the doping of C is lower than the doping of B.

General equations for the currents in a BJT for all mode of operations:

$$I_E = qA\left[\frac{D_p p_{no}}{W} + \frac{D_E n_{Eo}}{L_E}\right]\left[e^{(qV_{EB})/kT} - 1\right] - \left[\frac{qAD_p p_{no}}{W}\right]\left[e^{(qV_{CB})/kT} - 1\right]$$

$$I_C = \frac{qAD_p p_{no}}{W}\left[e^{(qV_{EB})/kT} - 1\right] - qA\left[\frac{D_p p_{no}}{W} + \frac{D_C n_{Co}}{L_C}\right]\left[e^{(qV_{CB})/kT} - 1\right]$$

Equations for the BJT currents in the active mode:

$$I_E = \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{qAD_E n_{Eo}}{L_E}\left[e^{(qV_{EB})/kT} - 1\right]$$

$$I_C = \frac{qAD_p p_{no}}{W} e^{(qV_{EB})/kT} + \frac{qAD_C n_{Co}}{L_C}$$

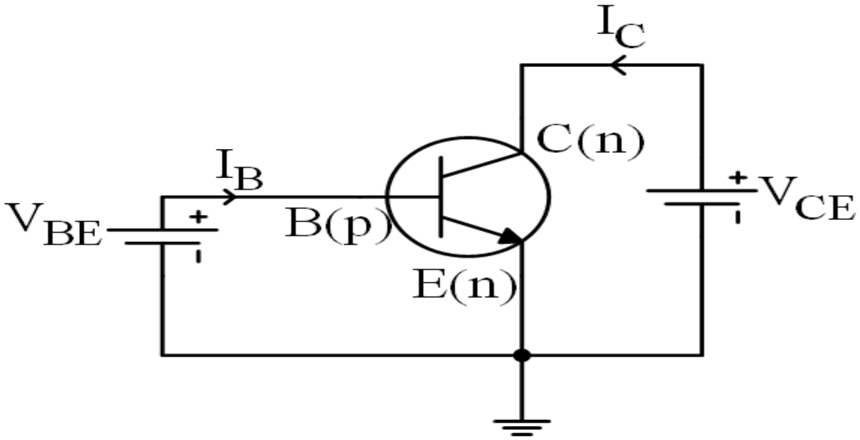
INPUT AND OUTPUT I-V CHARACTERSITICS

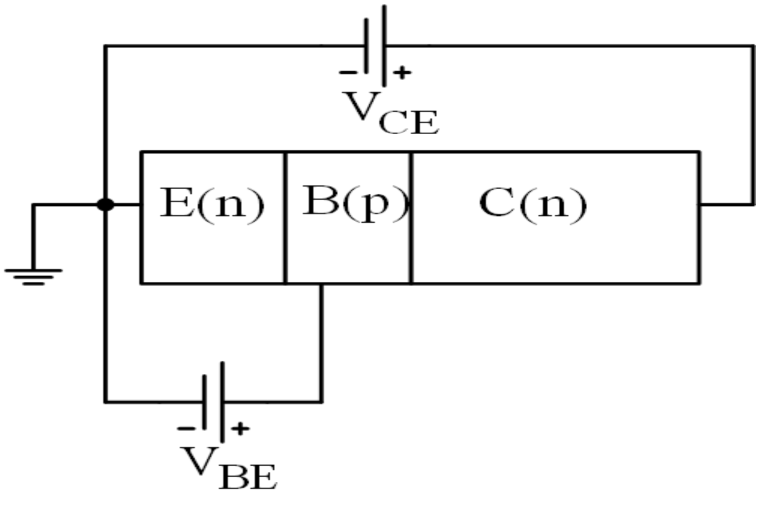
- **Each BJT configuration has its own input and output I-V characteristics. From these characteristics, the appropriate voltages and currents that will enable the BJT to be operated as an amplifier (active mode) can be determined.**

- **The input and output characteristics of the BJT is different for each configuration.**

- **Remember that to operate the BJT as an amplifier, the BJT has to be in the active mode i.e. E-B is fb and B-C is rb.**

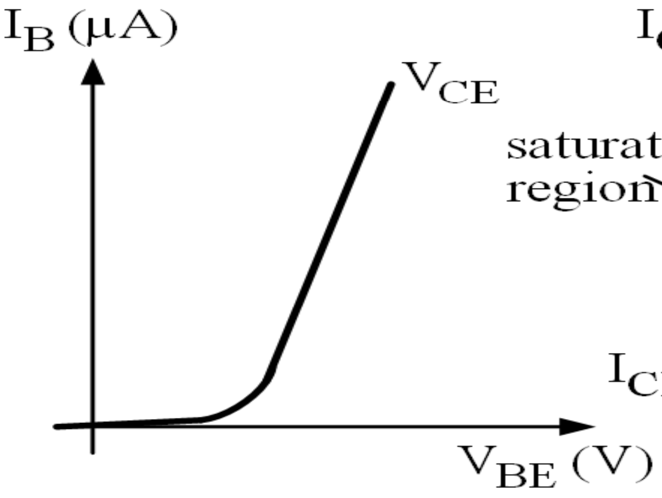
CE circuit (npn)



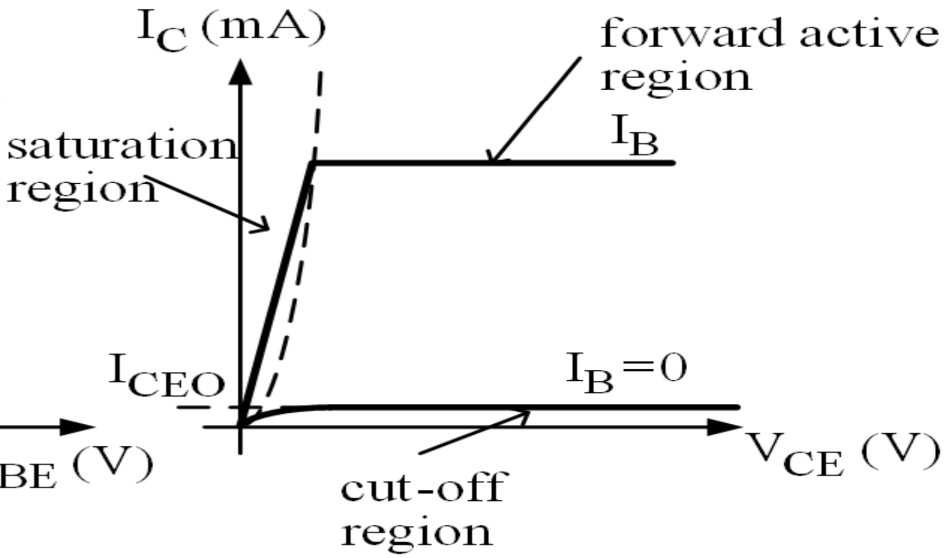


$|V_{CE}| > |V_{BE}|$

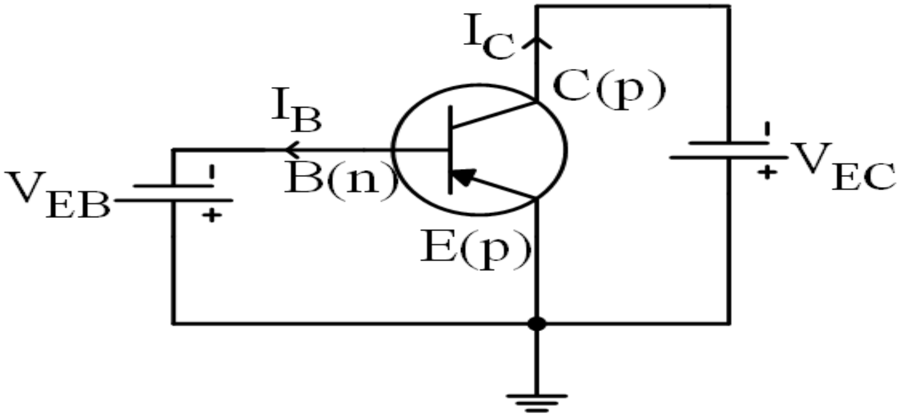
input characteristic

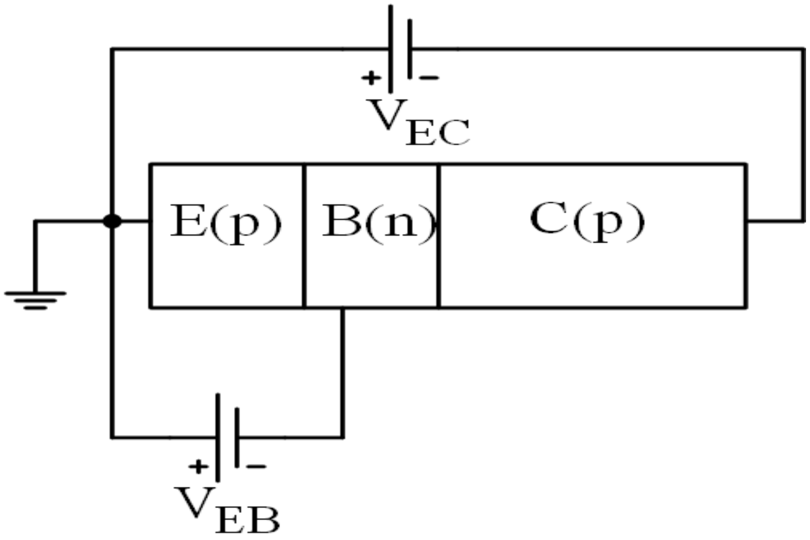


output characteristic

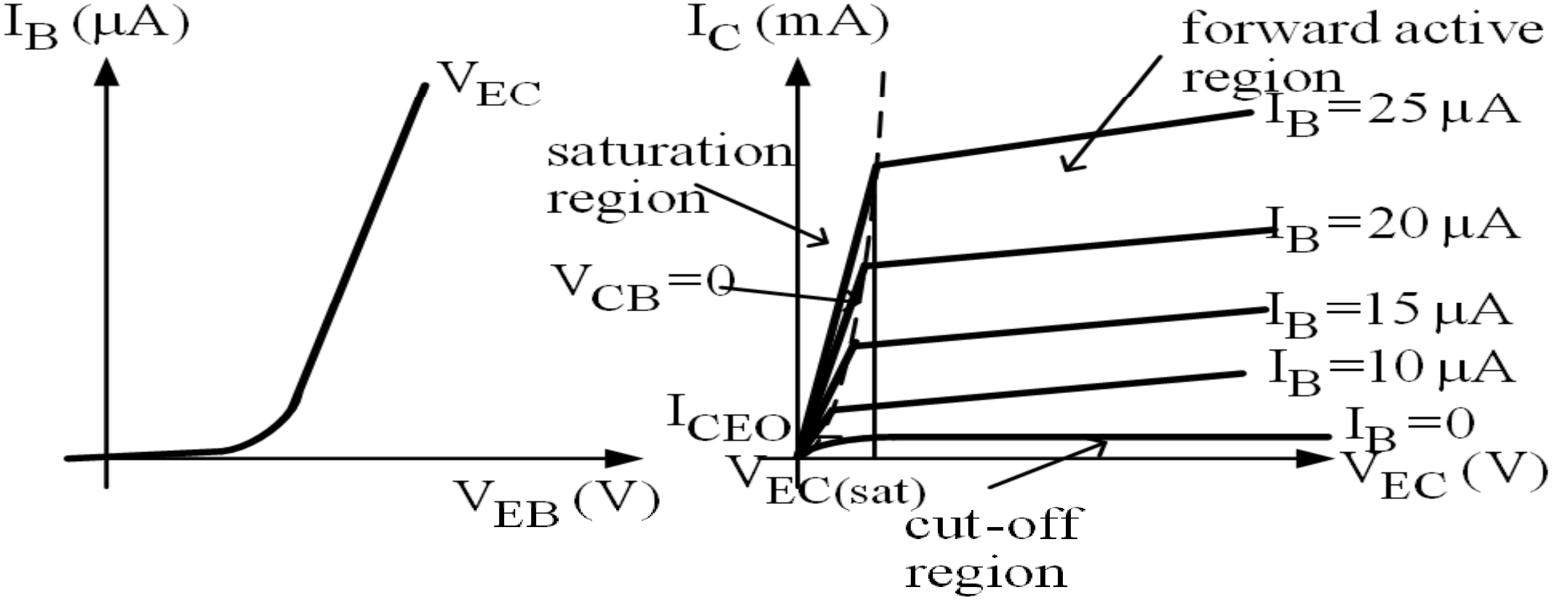


CE circuit (pnp)





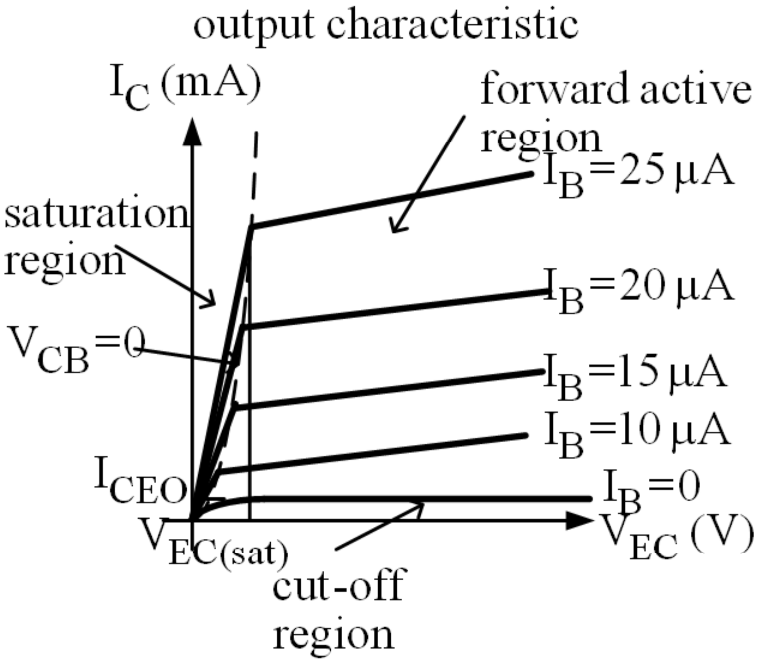
$|V_{EC}|>|V_{EB}|$

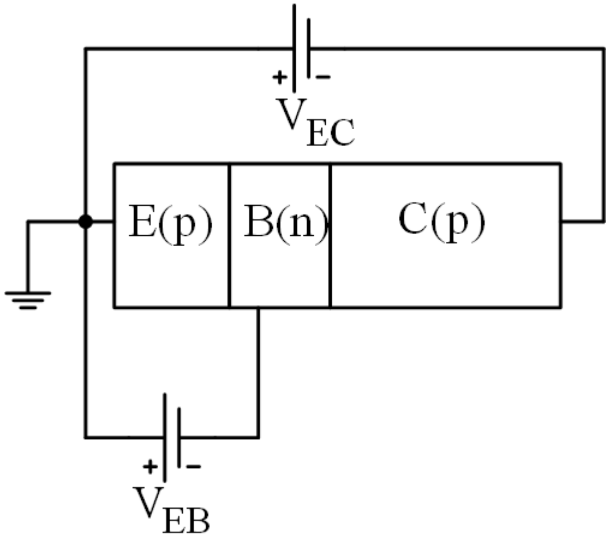

input characteristic

output characteristic

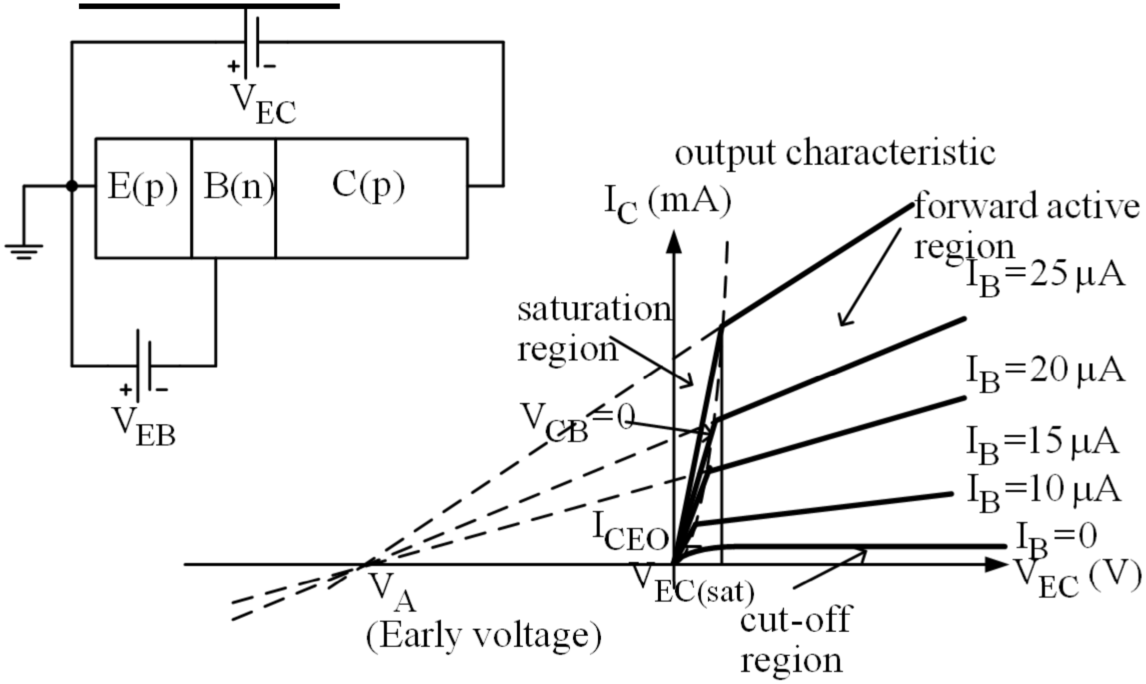
Observations:

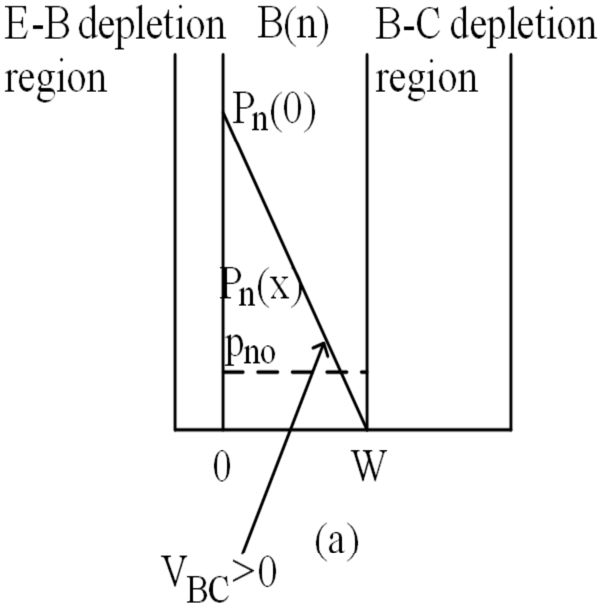
- **For an ideal transistor in the CE configuration, I_C for a fixed I_B is independent of V_{EC} for $V_{EC}>V_{EC(sat)}$. This condition is true if the effective width of the B is fixed.**
- **As the width of the depletion region in B of the B-C junction is dependent on V_{EC} , the effective width of B will also be dependent on V_{EC}. Therefore, I_C will be dependent on V_{EC} although $V_{EC}>V_{EC(sat)}$. For a fixed I_B and $V_{EC}>V_{EC(sat)}$, I_C ↑ when V_{EC} ↑. However, the increment is small when compared to the increment of I_C with the increase in V_{EC} when the transistor is in the saturation region.**



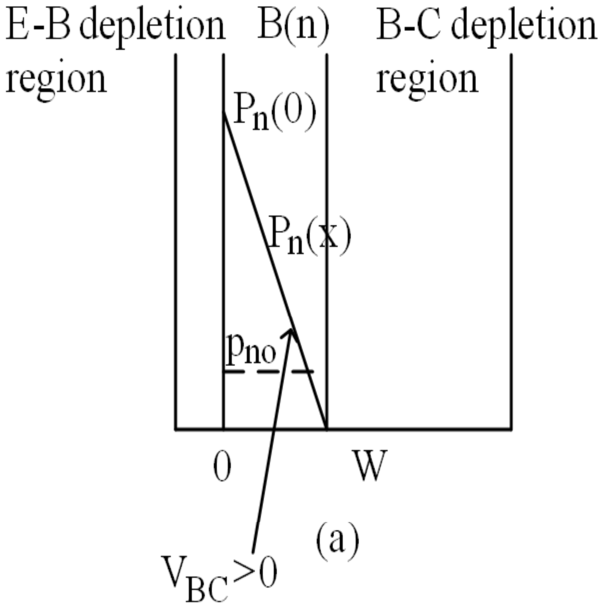


- When V_{EC} ↑, B-C junction becomes more rb, depletion region of B-C junction ↑ , effective width of B ↓. Less recombination happen in B (or the slope of the hole density in B ↑), and therefore I_C ↑.
- The phenomena where I_C ↑ when V_{EC} ↑ is called the <u>Early effect</u> or <u>base width modulation</u>.



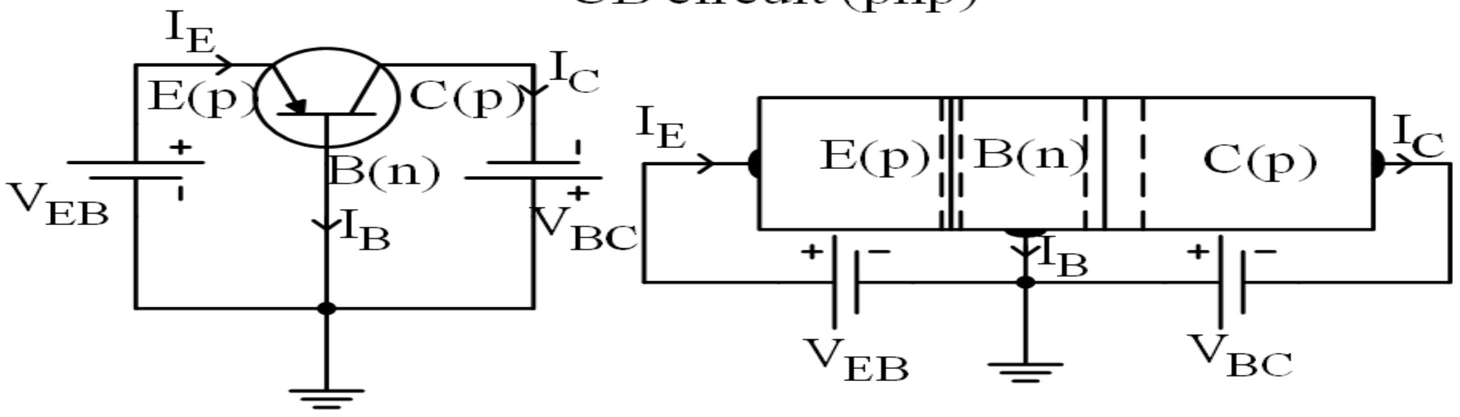


(a)



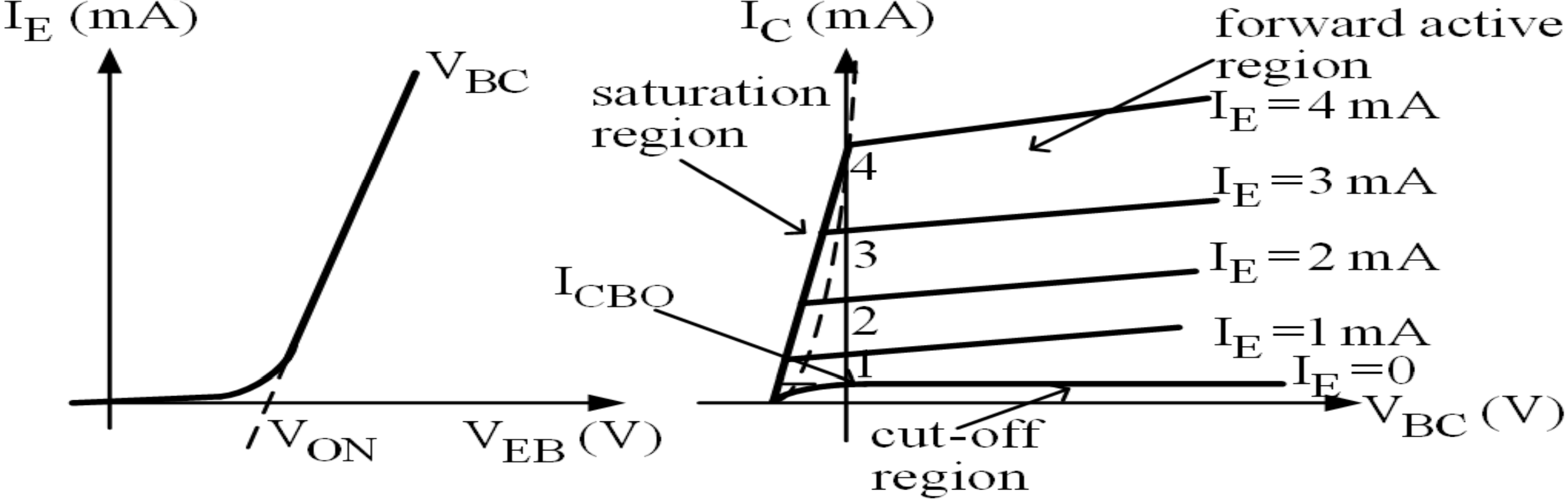
(a)

CB circuit (pnp)



input characteristic

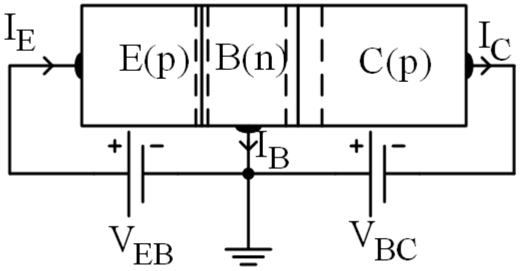
output characteristic



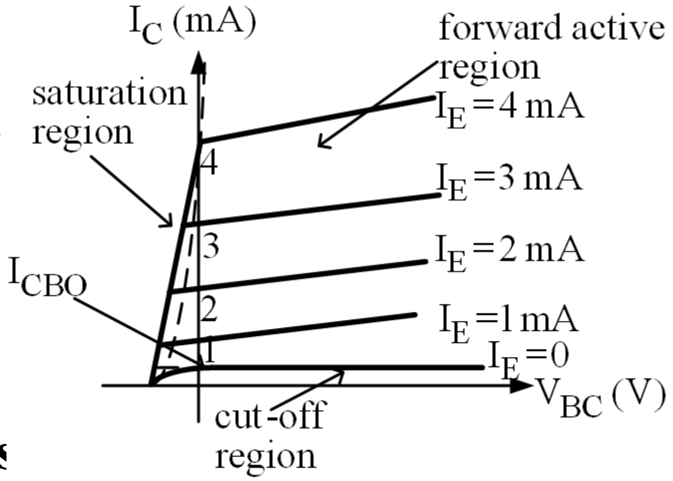
In the active region, $I_C \approx I_E$ and is independent of V_{BC}. $I_C \approx \alpha_o I_E$

Observations

- V_{BC}↑ I_C↑ because when V_{BC}↑, the B-C junction becomes more rb. The width of the effective B region (outside depletion) becomes smaller. Recombinations ↓. Hence, I_C↑.
- At a fixed V_{BC} , if I_E↑ I_C↑. As $I_C = \alpha_o I_E$ and $\alpha_o \approx 1$, $I_C \approx I_E$. Thus, I_E↑ I_C↑.
- If $V_{BC} = 0$, there still exists a depletion region at the B-C junction. Fixed –ve ions in the depletion region of the C can still manage to attract the holes from B to cross the B-C junction and enter C. I_C exists. If the V_{BC} becomes –ve (i.e. V_C is more +ve than V_B), the width of the depletion region↓ and I_C ↓. When $V_{CB} = V_{ON}$, the depletion region's width ≈ 0. At this time, the B-C junction becomes fb and $I_C = 0$.



output characteristic



input characteristic