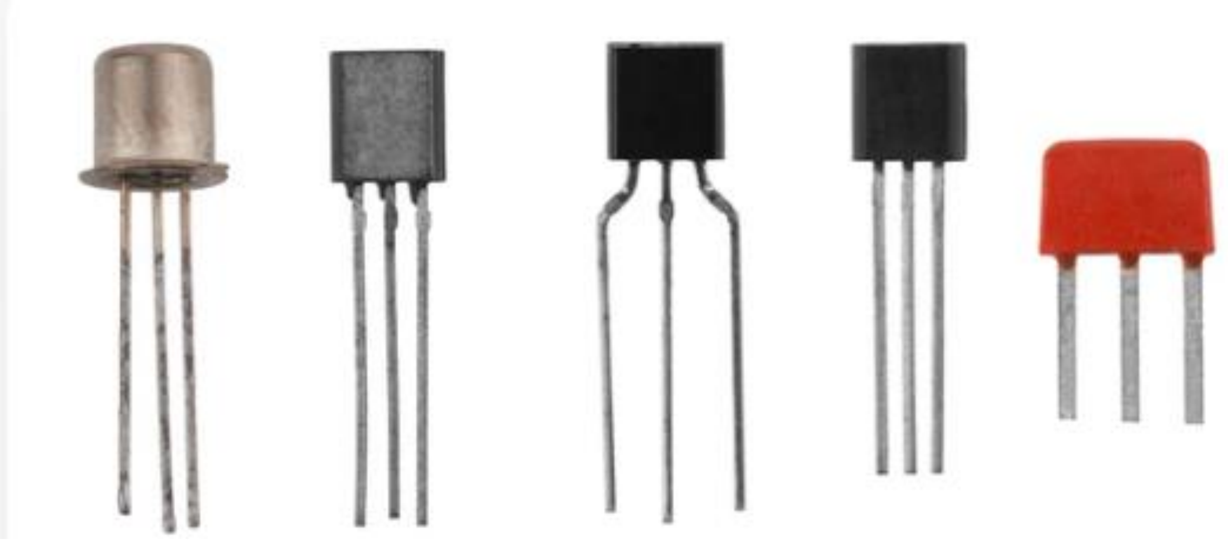
Electronic Circuits (1) EEC2103



LEC (1) Diode and BJT Revision

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هندسة الإلكترونيات والاتصالات الكهربية
الفرقة الثانية

الفصل الدراسي الأول

الرقم الكودي	المقرر الدراسي	عدد الساعات أسبوعيا			توزيع الدرجات				زمن الامتحان التحريري (ساعة)
		محاضرة	تمرين	إجمالي	أعمال فصل	عملي/ شفوي	تحريري	إجمالي	
PME2110	رياضيات هندسية (٣) أ	٣	٢	٥	٤٠		٨٥	١٢٥	٣
EEC2103	دوائر إلكترونية (١)	٣	٣	٦	٣٠	٣٠	٩٠	١٥٠	٣
EPM2142	مجالات كهرومغناطيسية	٣	٢	٥	٤٠		٨٥	١٢٥	٣
EEC2104	نظرية الاتصالات	٣	٣	٦	٥٠		١٠٠	١٥٠	٣
EEC2105	قياسات إلكترونية (١)	٣	٣	٦	٣٠	٣٠	٩٠	١٥٠	٣
EEC21H3	تقارير فنية	٢		٢	١٠		٤٠	٥٠	٢
المجموع		١٧	١٣	٣٠				٧٥٠	

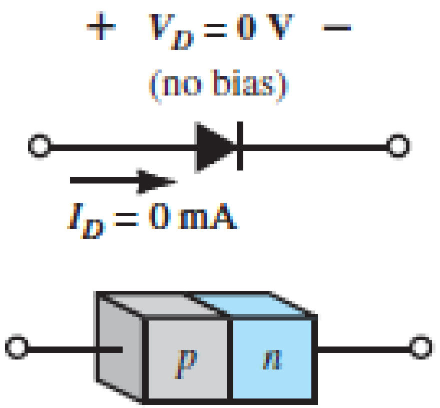
Course content

- BJT Revision
- BJT frequency response
- Operational amplifiers
- Power amplifiers

Diode (PN Junction) Biasing

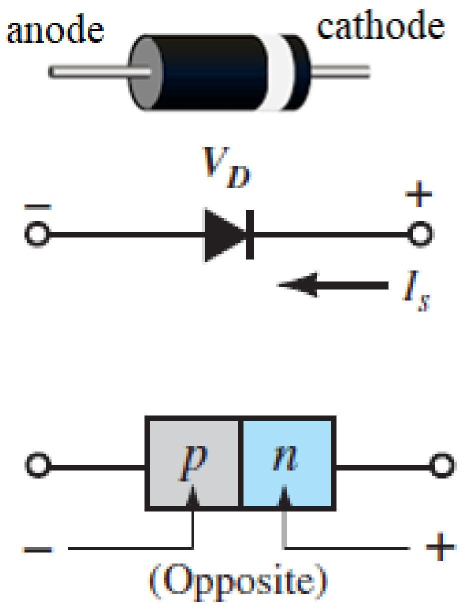
1) No applied Bias (V_D = 0 V).

- *The net carrier flow is zero at the external terminal of the device (I_D=0).*



2) Reverse Bias (V_D < 0 V).

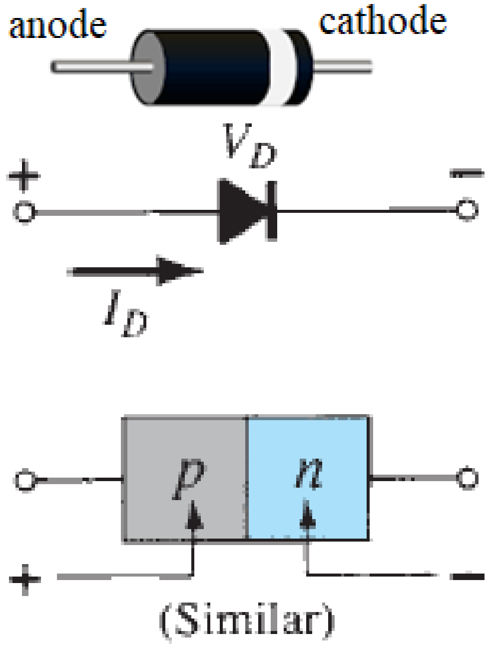
- *The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_s .*



Diode (PN Junction) Biasing

3) Forward Bias ($V_D > 0$ V).

As the applied bias increases in magnitude, the depletion region will continue to decrease in width until a flood of electrons can pass through the junction, resulting in an exponential rise in current.



Diode (PN Junction) Characteristic Curve

It can be demonstrated through the use of solid-state physics that the general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation, for the forward- and reverse-bias regions:

$$\boxed{I_D = I_s(e^{V_D/nV_T} - 1)} \quad \text{(A)} \qquad \textbf{(1.2)}$$

where I_s is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
n is an ideality factor, which is a function of the operating conditions and physical construction; it has a range between 1 and 2 depending on a wide variety of factors ($n = 1$ will be assumed throughout this text unless otherwise noted).

The voltage V_T in Eq. (1.1) is called the *thermal voltage* and is determined by

$$\boxed{V_T = \frac{kT_K}{q}} \quad \text{(V)} \qquad \textbf{(1.3)}$$

where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

Diode (PN Junction) Characteristic Curve

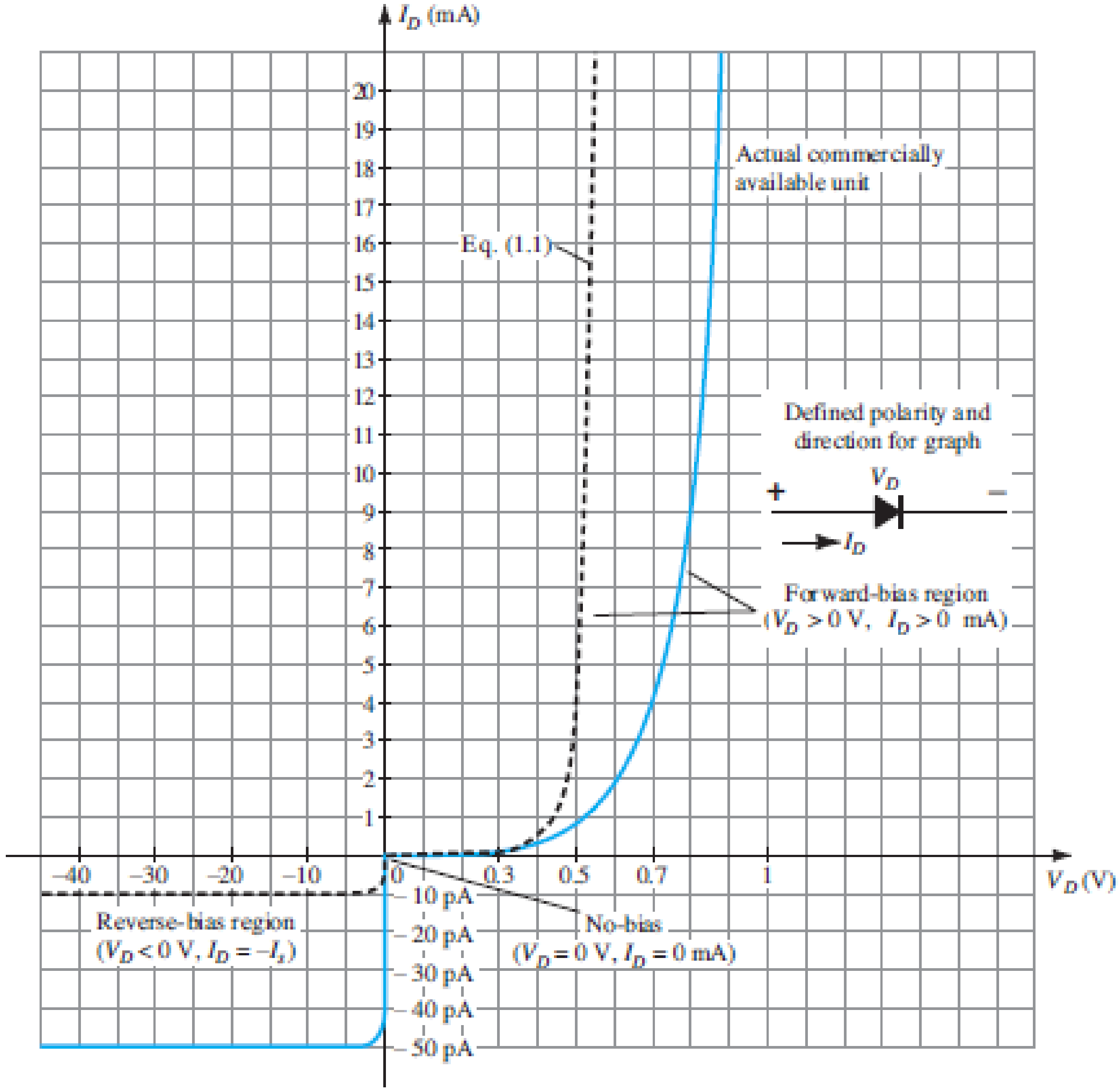
- The slope of the curve is equal to:

- $1/r_d = \Delta I_D / \Delta V_D$

- Where r_d is the *dynamic resistance* of the PN junction

$$\boxed{r_d = \frac{26\ \text{mV}}{I_D}}$$

Note: r_d can be obtained by differentiating Eq (1.2) w.r.t. V_D

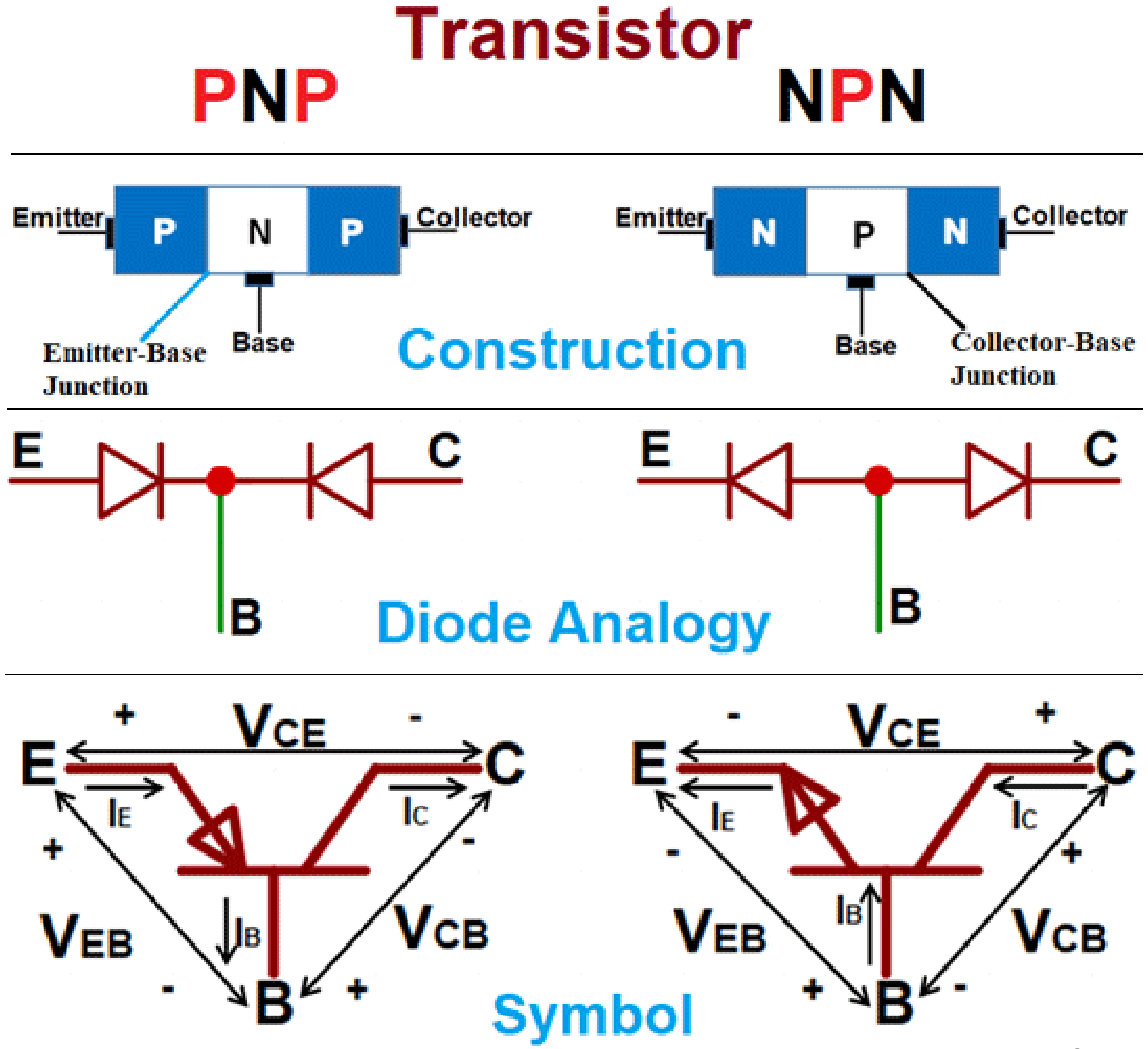


BJT

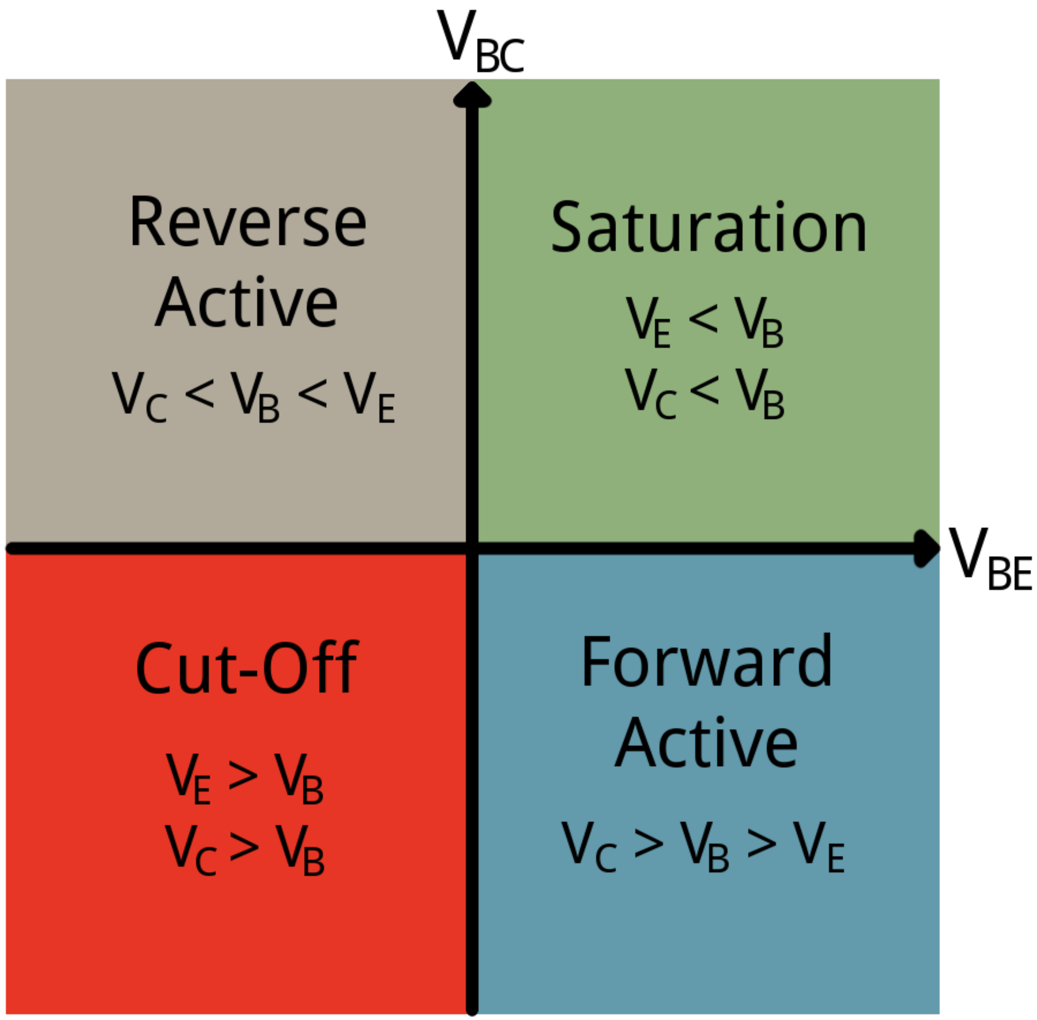
- What is meant by BJT?
- Bipolar junction transistor
- bipolar transistor is so named **because its operation involves two kinds of charge carriers, holes and electrons**
- It is **a three-terminal semiconductor device**
- It consists of **two p-n junctions which are able to amplify or magnify a signal**.
- It is **a current controlled device**.
- The three terminals of the BJT are **the base, the collector, and the emitter.**

Construction / Types /symbol

- PNP 2N3905 - 2N3906
- NPN 2N3903 -2N3904

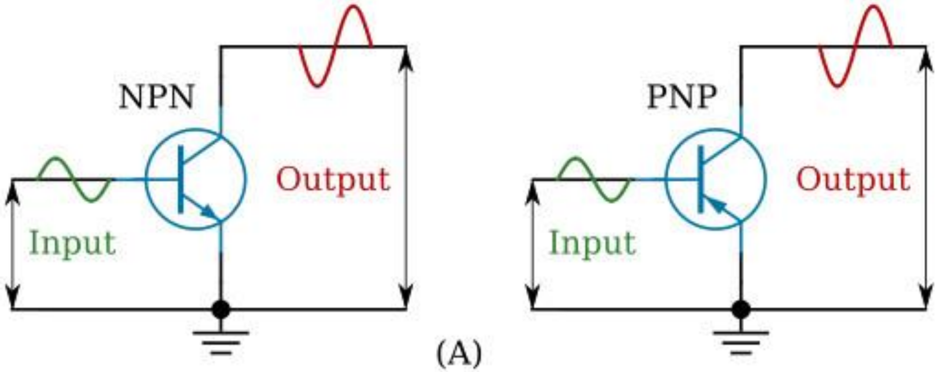


Modes of operation

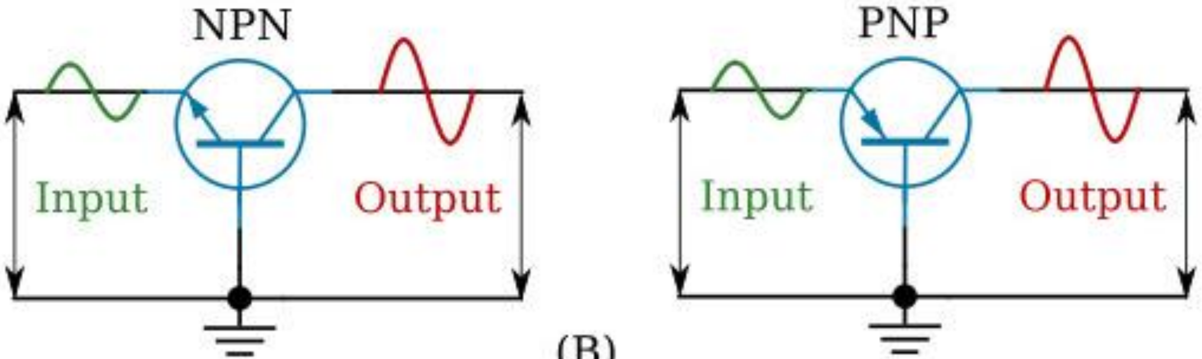


Modes	EBJ	CBJ	Application
Cutoff	Reverse	Reverse	Switching application in digital circuits
Saturation	Forward	Forward	
Active	Forward	Reverse	Amplifier
Reverse active	Reverse	Forward	Performance degradation

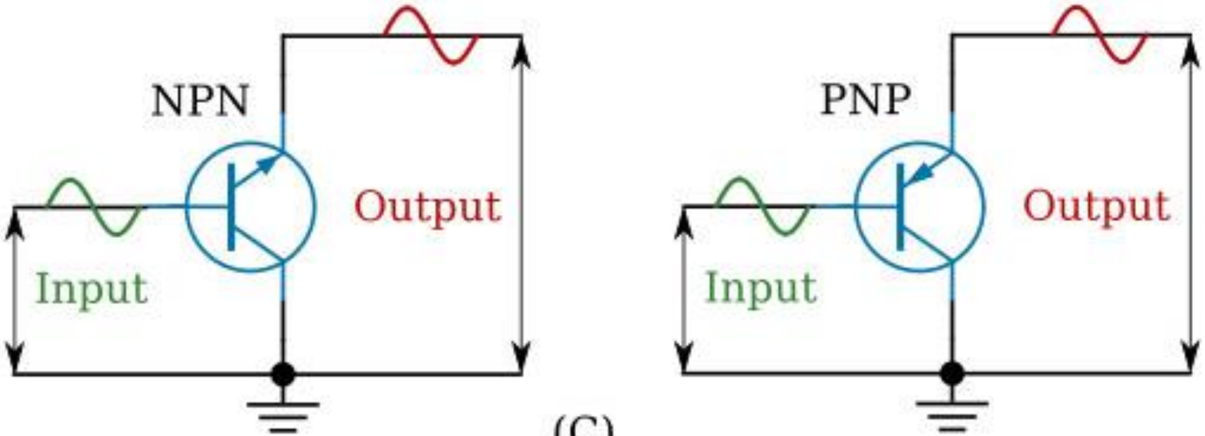
Configurations



(A)
Common emitter



(B)
Common base



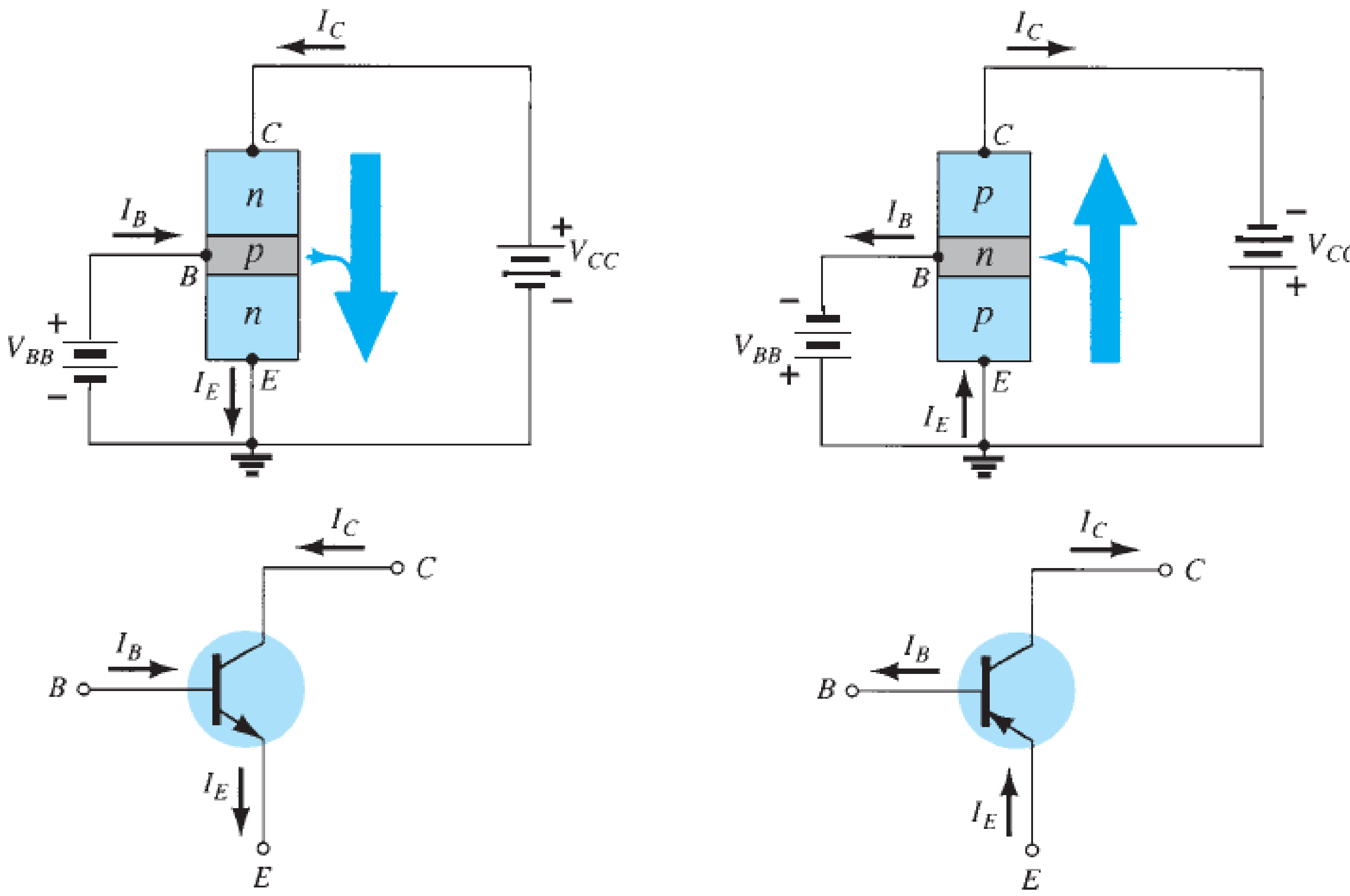
(C)
Common collector

Characteristic Curves

- Since we no longer deal with two-terminal devices, equations involve at least three variables.
- Therefore, ***parametric curves*** are usually used to describe transistor behavior.
- To fully describe the behavior of a three-terminal device (BJT) requires **two sets of characteristics**—one for the *driving point or input* parameters and the other for the *output* parameters.
- There is a set of curves for each transistor configuration (CE, CB, CC).

Characteristic Curves \ CE configuration

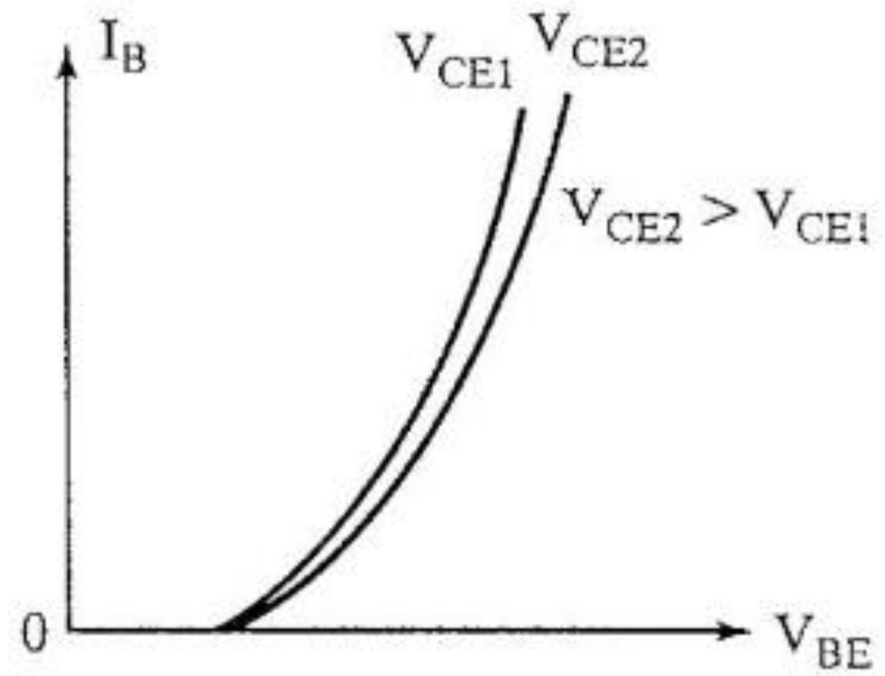
- All the current directions appearing in the figure are the actual directions as defined by the choice of conventional flow (which is indicated by the direction of hole flow).
- **Note in each case that $I_E = I_C + I_B$.**
- Note also that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.
- That is, compare the direction of I_B to the polarity of V_{BB} for each configuration.
- And the direction of I_C to the polarity of V_{CC}.



Characteristic Curves \ CE configuration \ Input

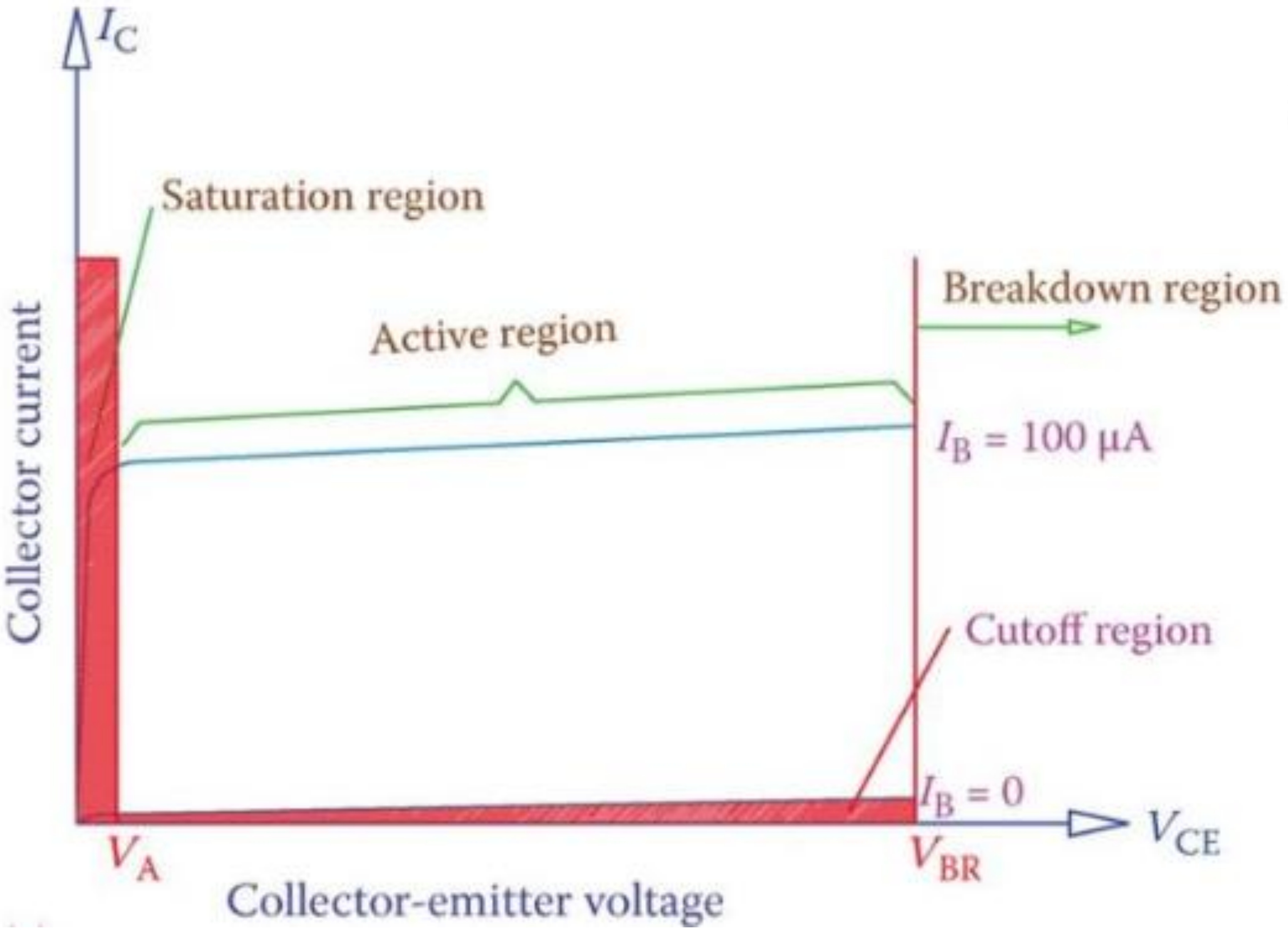
- **Input (Emitter-Base) Characteristic Curve. Similar to that of the diode.**

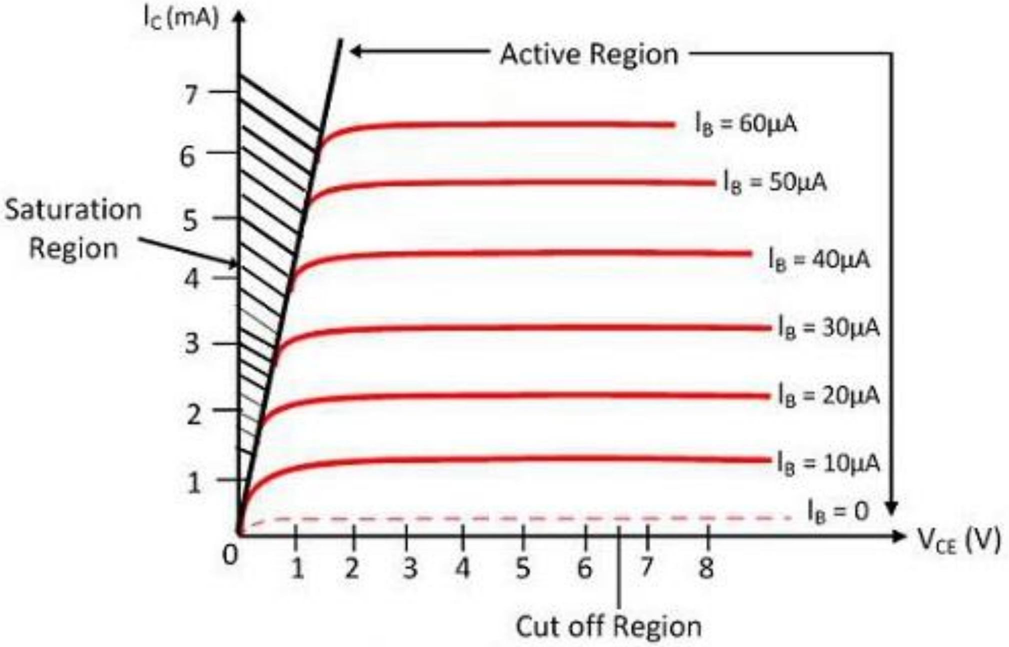
- As V_{CE} increases more V_{BE} is required to turn the BE junction on so that $I_B > 0$
- There is a small decrease in I_B with increasing V_{CE}. **Why?**
- As V_{CE} increases, V_{CB} increases
  - The effective width of the base region decreases (Early effect)
  - The depletion region increases
  - So, the base current (that depends on the minority carrier) decreases



Characteristic Curves \ CE configuration \Output

- Output (Emitter-Collector) Characteristic Curve





Characteristic Curves \ CE configuration \Output

1) Cutoff Region:

- *The area under the curve corresponding to I_B = 0 (i.e., the input current is disconnected),*
- *Shaded in the figure**,** represents the region where a transistor is cut off and is not conducting.*

2) Breakdown Region:

The voltage at which a semiconductor device changes behavior or gets damaged.

- This is due primarily to an **avalanche effect** similar to that described for the diode in when the reverse-bias voltage reached the breakdown region.

Characteristic Curves \ CE configuration \Output

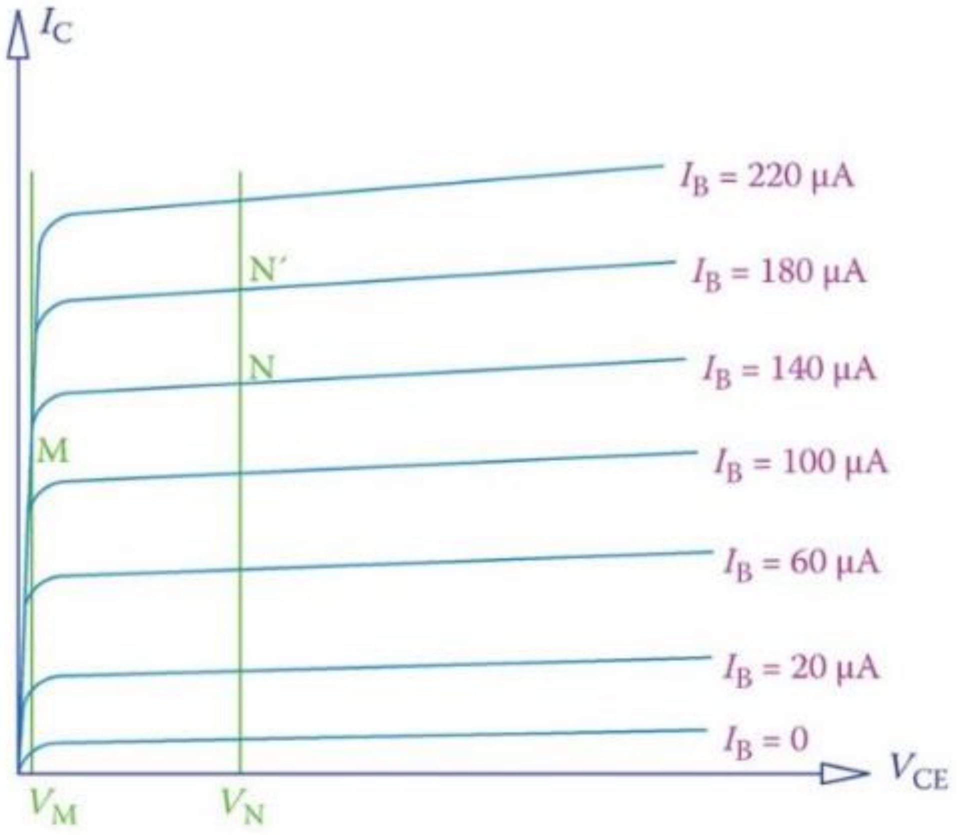
3) Active Region:

- *An area in the characteristic curve of a transistor, in terms of collector-emitter voltage ($V_A < V_{CE} < V_{BR}$) and collector current (IC>0) values that the transistor can function as an amplifier ($VA=V_{CEsat}$).*
- *If any of these values falls outside of its range a transistor falls in the saturation region, breakdown region, or cutoff region and cannot function as an amplifier.*

Characteristic Curves \ CE configuration \Output

4) Saturation Region:

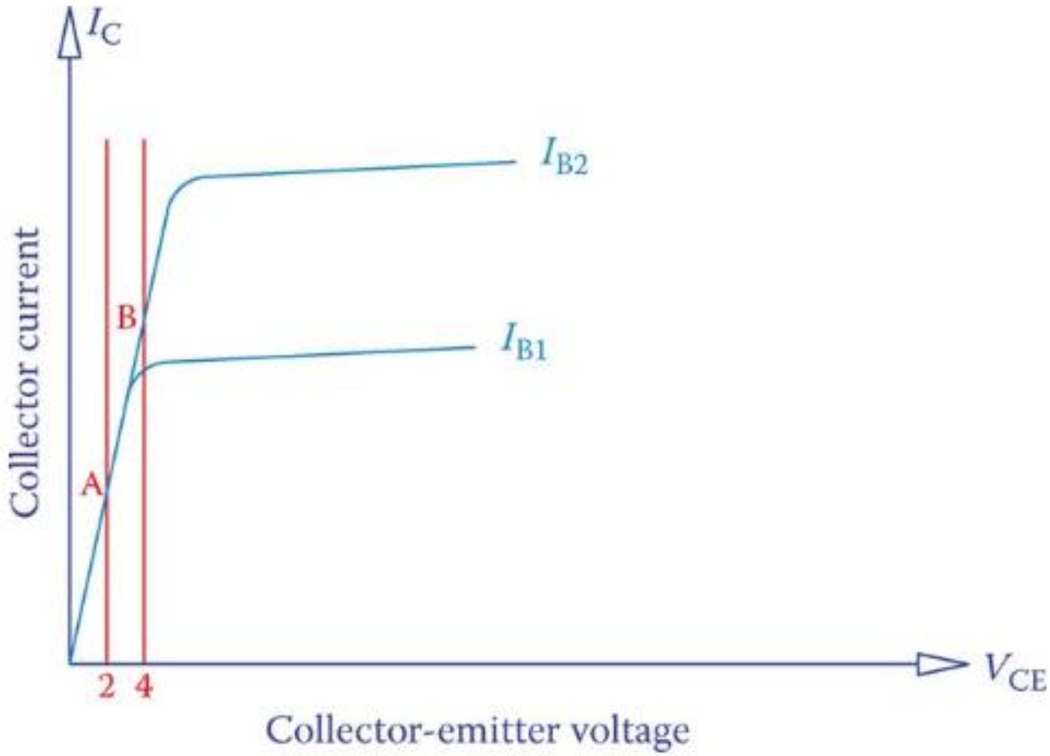
- **The state of a transistor at which the collector current I_C has reached its maximum value for the present collector-emitter voltage V_{CE}, *and cannot increase further by only increasing the base current I_B.***
- For example, consider point M corresponding to $V_{CE} = V_M$ in the figure. For this point, I_C has reached its maximum and cannot be increased by increasing I_B.
- In contrast, an increase in I_B can move point N to N′, both corresponding to a collector-emitter voltage V_N.



Characteristic Curves \ CE configuration \Output

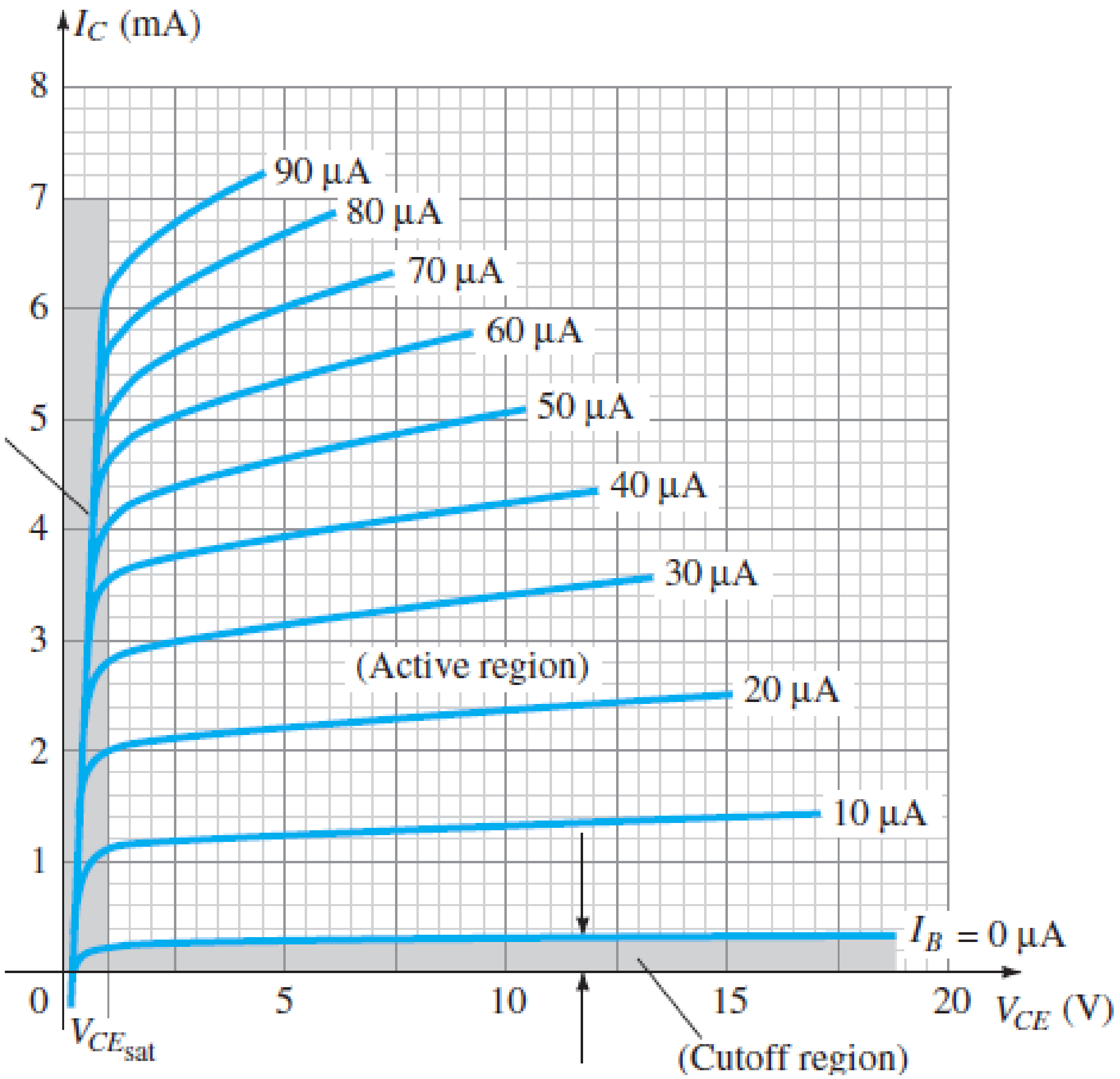
4) Saturation Region:

- Two characteristic curves, corresponding to two base currents I_{B1} and I_{B2} are shown. Suppose that the collector-emitter voltage is 2 V. On both curves the corresponding point is A.
- **This implies that if the base current is increased to I_{B2}, but the V_{CE} is still 2 V, the collector current does not change.**
- The collector current increases only if the V_{CE} increases, for instance, to 4 V, for which the operating point moves from A to B.



Characteristic Curves \ CE configuration \Output

- $V_{CE}\uparrow$ =>$V_{CB}\uparrow$ => depletion region around BC junction $\uparrow$ => effective width of the base region $\downarrow$ => carrier recombination decreases so more current carriers cross the BC junction => $I_C\uparrow$ (while I_B is kept the same)



Characteristic Curves \ CE configuration \Output

Beta (β)

DC Mode In the dc mode the levels of I_C and I_B are related by a quantity called *beta* and defined by the following equation:

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}} \tag{3.10}$$

- On specification sheets β_{dc} is usually included as h_{FE}
- With the italic letter ***h*** derived from an **ac *h*ybrid equivalent circuit**.
- The subscript ***FE*** is derived from ***f*orward-current** amplification and common-emitter configuration

The quiescent point (Q-point) of a BJT transistor

- The Q point is typically defined by the **DC voltages and currents at the transistor's terminals (base, emitter, and collector) when no AC signal is present**.
- It's essentially the point where **the transistor is biased to operate in the desired region (active, saturation, or cutoff) before any input signal is applied.**
- A DC operating point must be set so that **signal variations at the input terminal are amplified and accurately reproduced at the output terminal.**

DC Load Line

- Pages 229-234 (Floyd)

Voltage-Divider Bias

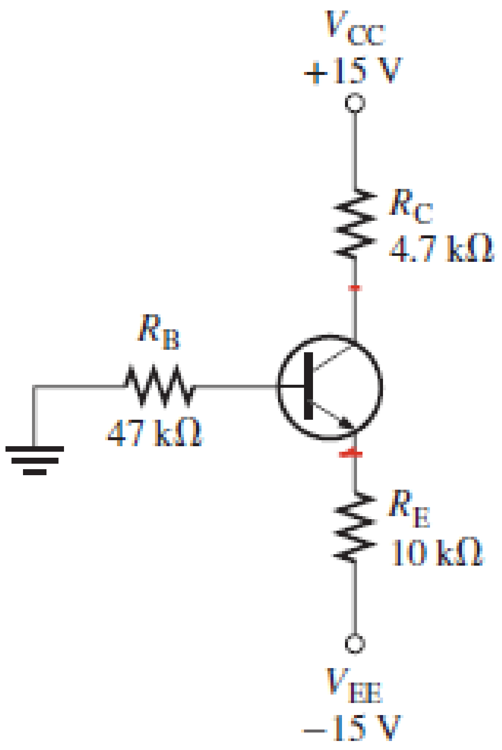
- Pages 235-241, will be discussed in the next section by Eng. Asmaa

Other Bias Methods

- **Analyze four more types of bias circuits**
- Discuss emitter bias
  - Analyze an emitter-biased circuit
- Discuss base bias
  - Analyze a base-biased circuit
  - Explain Q-point stability of base bias
- Discuss emitter-feedback bias
  - Define negative feedback
  - Analyze an emitter-feedback biased circuit
- Discuss collector-feedback bias
  - Analyze a collector-feedback biased circuit
  - Discuss Q-point stability over temperature

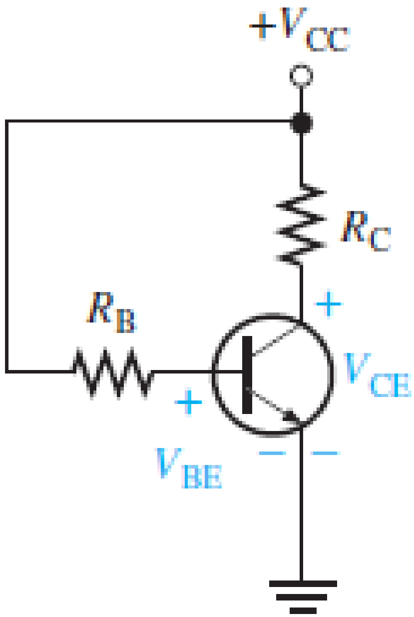
1- Emitter Bias

- **Emitter bias provides excellent bias stability** despite changes in β or temperature.
- It uses both **a positive and a negative supply voltage**.
- The small base current causes the base voltage to be slightly below ground.
- The emitter voltage is one diode drop less than this. ∴ ($V_E = V_B - V_{BE}$, $V_E \cong -1$ V).
- The combination of this small drop across R_B and V_{BE} forces the emitter at approximately -1 V.
- I_B is very small. ∴ $I_C \cong I_E$, $I_B \cong \frac{I_E}{\beta}$
- Pages (242-244).
- Study Example 5-7 (page 244)



2- Base Bias

- This method of biasing is common in **switching circuits.**
- The analysis of this circuit for the linear region shows that it is **directly dependent on β_{DC}**
- **Page 244**
- ***Q-Point Stability of Base Bias***
  - Notice that I_C is dependent on β_{DC}
  - The disadvantage of this is that a variation in β_{DC} causes I_C and, as a result, V_{CE} to change,
    thus, changing the Q-point of the transistor.
  - **This makes the base bias circuit extremely beta-dependent and unpredictable.**
  - Recall that β_{DC} varies with temperature and collector current.
  - In addition, there is a large spread of β_{DC} values from one transistor to another of the same type due to manufacturing variations.

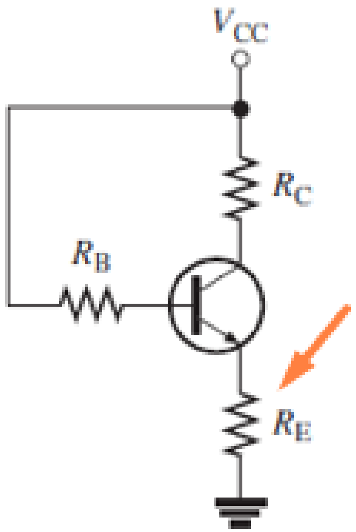


$$V_{CE} = V_{CC} - I_C R_C \qquad I_B = \frac{V_{CC} - V_{BE}}{R_B} \qquad I_C = \beta_{DC}\left(\frac{V_{CC} - V_{BE}}{R_B}\right)$$

- Study Example 5-8 (page 245)

3- Emitter-Feedback Bias

- The idea is to help make base bias more predictable with **negative feedback**, which cancels any attempted change in collector current with an opposing change in base voltage.
- $I_C \uparrow \Rightarrow I_E \uparrow (I_E = I_C + I_B) \Rightarrow V_E \uparrow \Rightarrow V_B \uparrow (V_B = V_E + V_{BE}) \Rightarrow V_{RB} \downarrow \Rightarrow I_B \downarrow$
- While this is **better for linear circuits than base bias**, it is still dependent on β_{DC} and is not as predictable as voltage-divider bias.
- Study Example 5-9 (page 246).



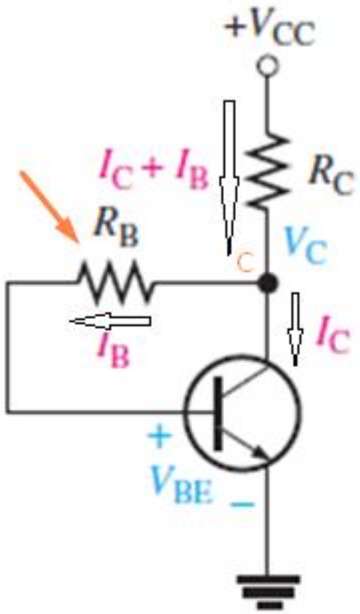
$$-V_{CC} + I_B R_B + V_{BE} + I_E R_E = 0$$

Substituting I_E/β_{DC} for I_B, you can see that I_E is still dependent on β_{DC}.

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}}$$

4- Collector-Feedback Bias

- The base resistor R_B is connected to the collector (C) rather than to V_{CC}.
- The negative feedback creates an "offsetting" effect that tends to keep the Q-point stable.
- $I_C \uparrow \Rightarrow V_{RC}\uparrow\ V_C\downarrow\ (V_C=V_{CC}-V_{RC}) \Rightarrow V_{RB}\downarrow\ (V_{RB}=V_C-V_{BE}) \Rightarrow I_B\downarrow$
- The decrease in I_B produces less I_C which, in turn, drops less voltage across R_C and thus offsets the decrease in V_C.
- Page 247
- Study Example 5-10.
- Compare the results of examples 5-7,8,9,10. (What is your comment)



$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{DC}}$$

Since the emitter is ground, $V_{CE} = V_C$.

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

Lecture References

- Electronic devices: electron flow version / Thomas L. Floyd.— 9th ed.