Engineering and Architecture Analog Electronics Fundamentals

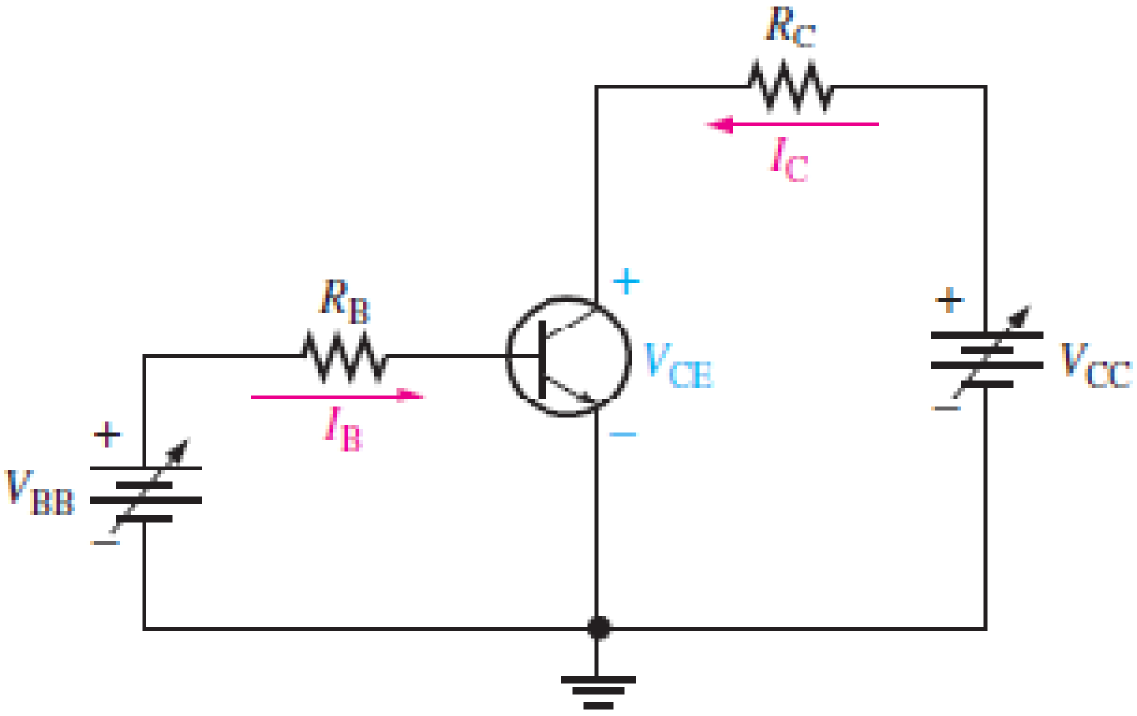
EEE223

Lec 10

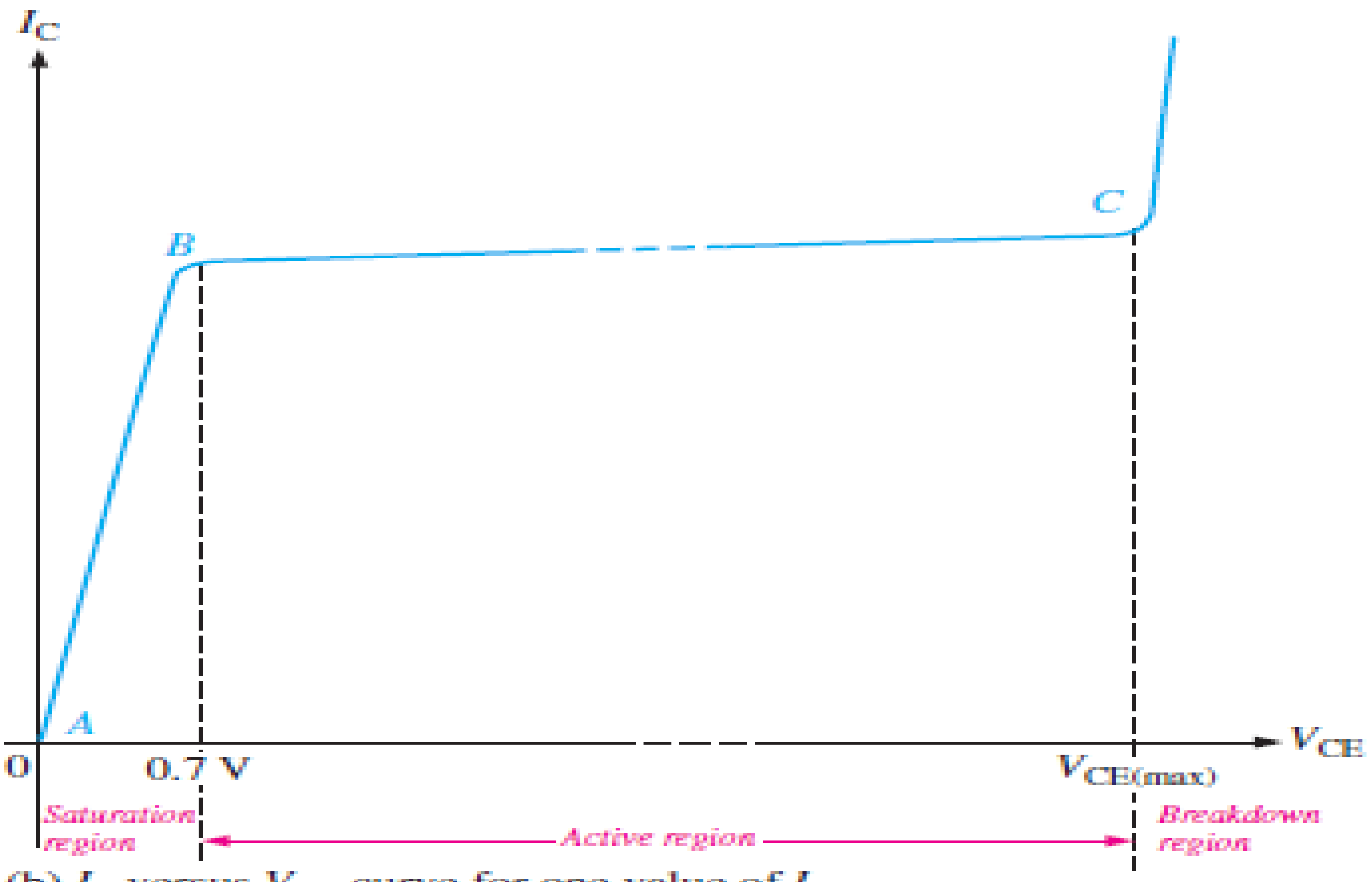
Bipolar Junction Transistor BJT

Lecturer Sally Adil

Collector Characteristic Curves



(a) Circuit

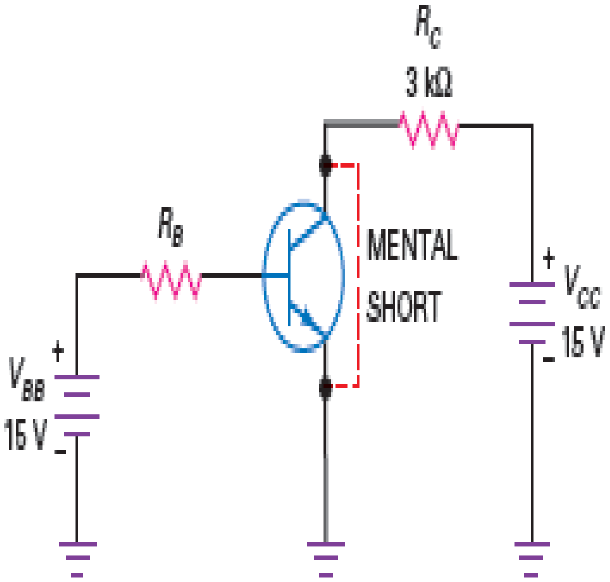


(b) I_C versus V_{CE} curve for one value of I_B

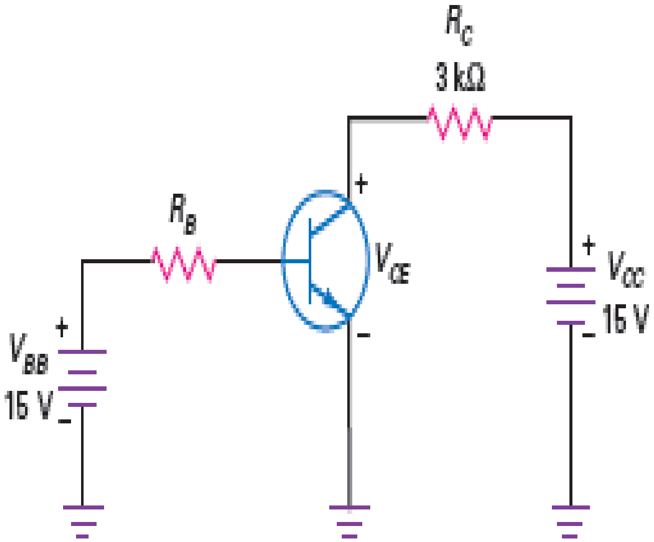
- I_C, varies with the collector-to emitter voltage, VCE, for specified values of base current, I_B.
- Notice in the circuit diagram that both V_{BB} and V_{CC} are variable sources of voltage.
- The Transistor has three regions of operations: Cutoff, Saturation and Linear Region.

Saturation:

- When **both** junctions are forward-biased, the transistor is in the saturation region of its operation.
- **Saturation is the state of a BJT in which the collector** current has reached a maximum and is independent of the base current.
- When VCE reaches its saturation value, VCE(sat), the base-collector junction becomes forward-biased and IC can increase no further even with a continued increase in IB.
- VCE(sat) for a transistor occurs somewhere below the knee of the collector curves.


R_C
3 kΩ
R_B
MENTAL
SHORT
+
V_{CC}
15 V
–
+
V_{BB}
15 V
–

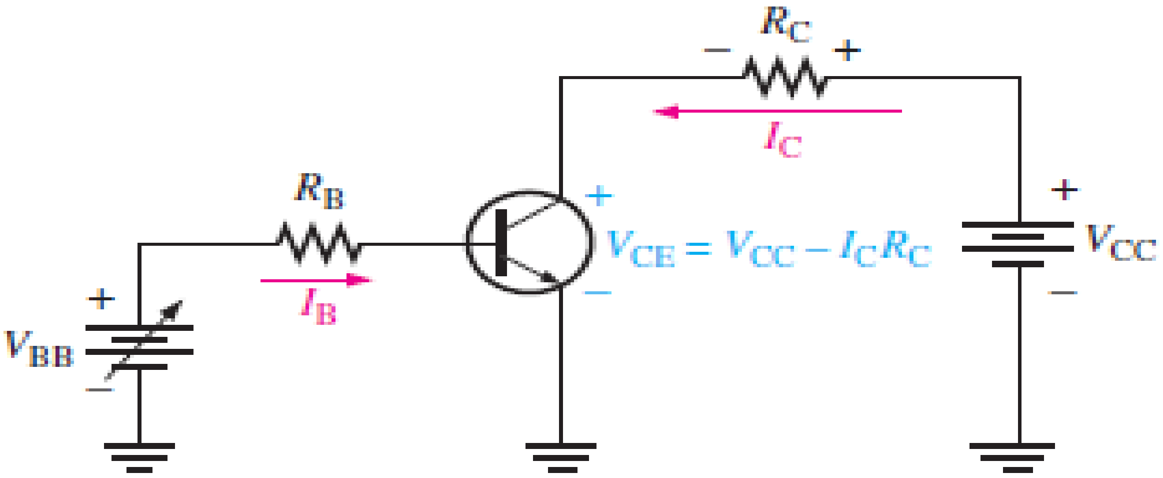
(b)


R_C
3 kΩ
R_B
+
V_{CE}
–
+
V_{CC}
15 V
–
+
V_{BB}
15 V
–

(a)

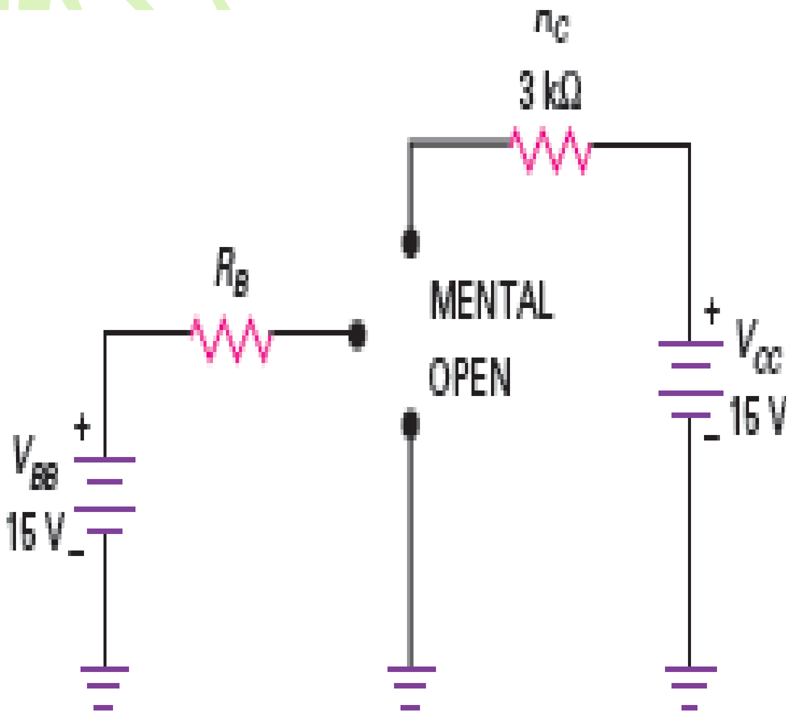
- **Saturation**: As I_B increases due to increasing V_{BB}, I_C also increases and V_{CE} decreases due to the increased voltage drop across R_C. When the transistor reaches saturation, I_C can increase no further regardless of further increase in I_B. **Base-emitter and base-collector junctions are forward-biased.**

$$I_{C(sat)} = \frac{V_{CC}}{R_C}$$

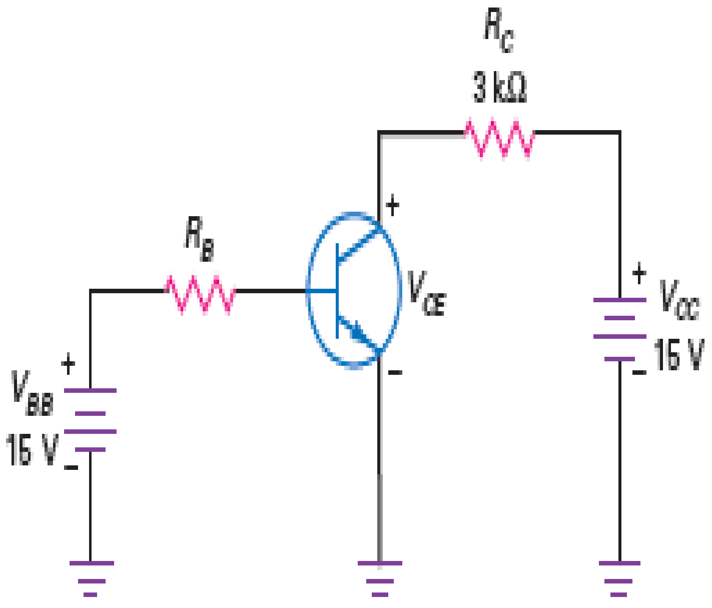


Cutoff

- when I_B =0, the transistor is in the cutoff region of its operation.
- This is shown in the figure with the base lead open, resulting in a base current of zero. Under this condition, there is a very small amount of collector leakage current, I_{CEO}, due mainly to thermally produced carriers.
- Because I_{CEO} is extremely small, it will usually be neglected in circuit analysis so that V_{CE}= V_{CC}.

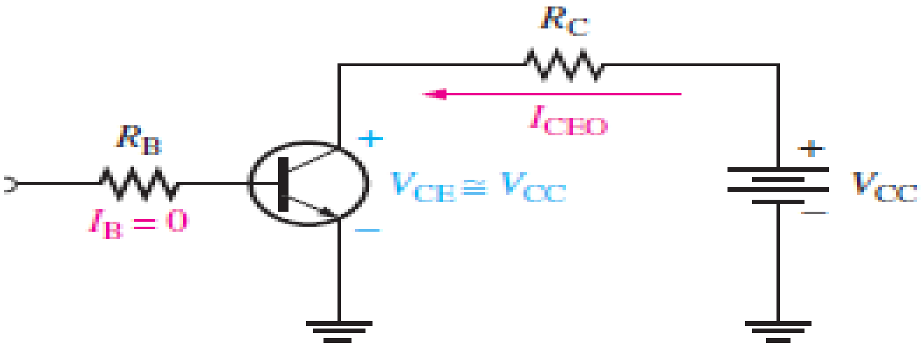

RC
3 kΩ
RB
MENTAL
OPEN
+
VBB
15 V
–
+
VCC
15 V
–

(c)

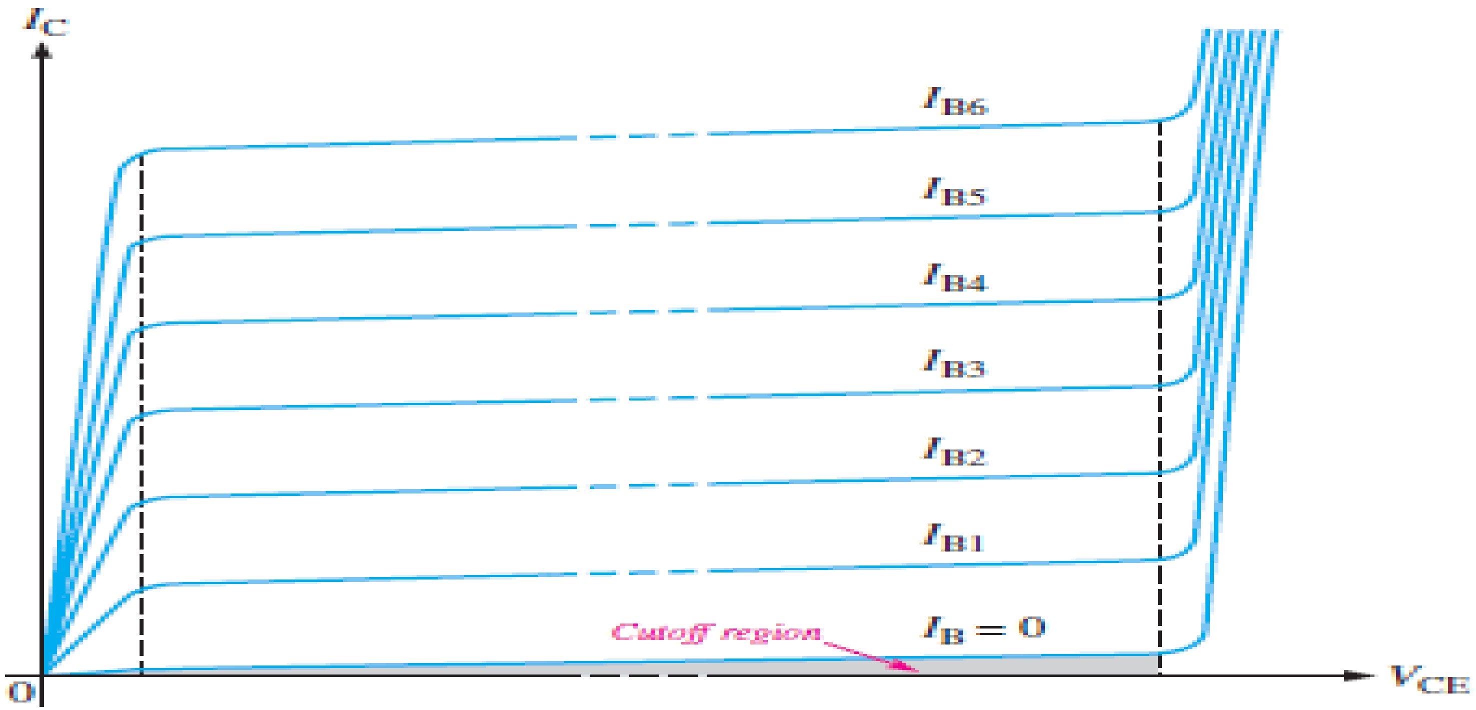

RC
3 kΩ
RB
+
VCE
–
+
VBB
15 V
–
+
VCC
15 V
–

(a)

- **In cutoff**, neither the base-emitter nor the base-collector junctions areforward-biased.
  The subscript CEO represents collector to- emitter with the **base open.**



Cutoff: Collector leakage current (ICEO) is extremely small and is usually neglected. **Base-emitter (BE) and base-collector junctions(BC) are reverse-biased.**



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

Linear or Active Region

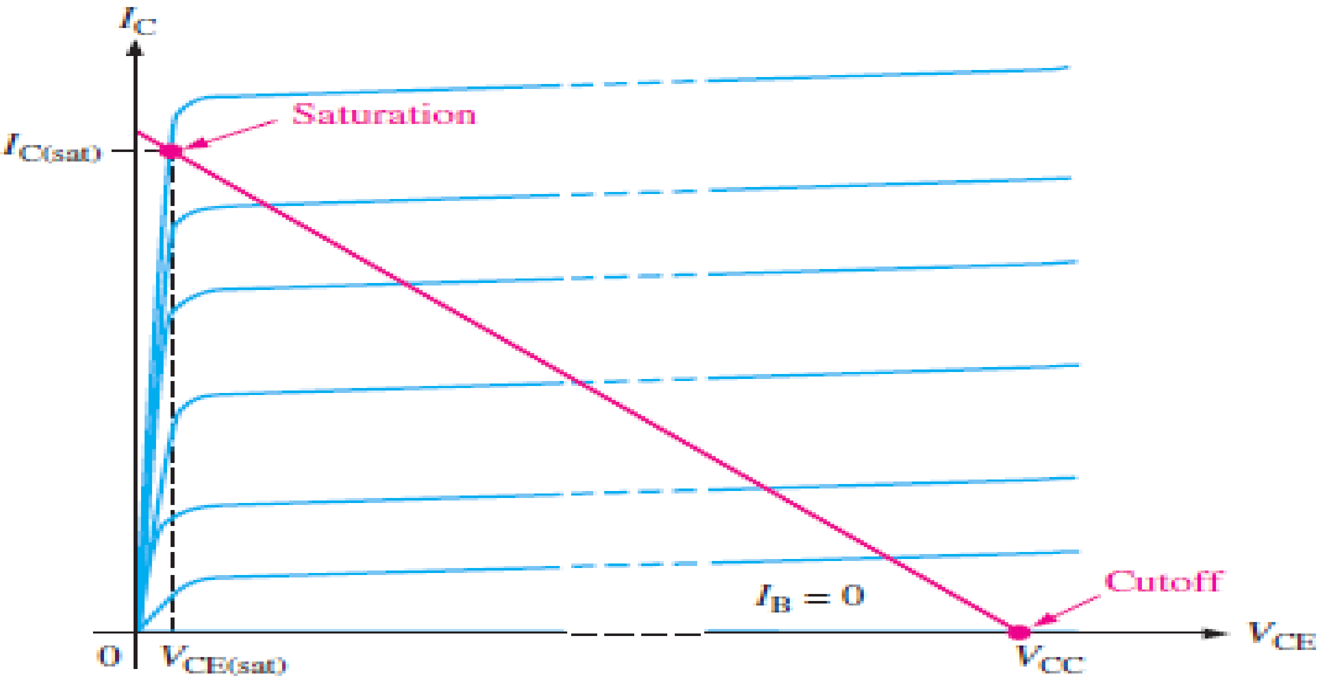
- As V_{CC} is increased, V_{CE} increases as the collector current increases. This is indicated by the portion of the characteristic curve between points A and B in Figure (b).
- I_C increases as V_{CC} is increased because V_{CE} remains less than 0.7 V due to the forward-biased base-collector junction.
- Ideally, when VCE exceeds 0.7 V, the base-collector junction becomes reverse-biased and the transistor goes into the active, or **linear, region of its operation.**

- Once the base collector junction is reverse-biased, I_C remains essentially constant for a given value of I_B as V_{CE} continues to increase.
- This is shown by the portion of the characteristic curve between points B and C in Figure (b).
- For this portion of the characteristic curve, the value of I_C is determined only by the relationship expressed as $I_C=\beta_{DC}I_B$.

- When V_{CE} reaches a sufficiently high voltage, the reverse-biased base-collector junction goes into breakdown; and the collector current increases rapidly as indicated by the part of the curve to the right of point C in Figure (b). A transistor should never be operated in this breakdown region.

DC Load Line

- Cutoff and saturation can be illustrated in relation to the collector characteristic curves by the use of **a load line.**
- **The bottom** of the load line is at ideal **cutoff** where IC =0 and VCE =VCC. The top of the load line is at **saturation** where IC =IC(sat) and VCE VCE(sat).
- In between cutoff and saturation along the load line is the **active region** of the transistor’s operation.


I_C
Saturation
$I_{C(sat)}$
$I_B = 0$
Cutoff
V_{CE}
0
$V_{CE(sat)}$
V_{CC}

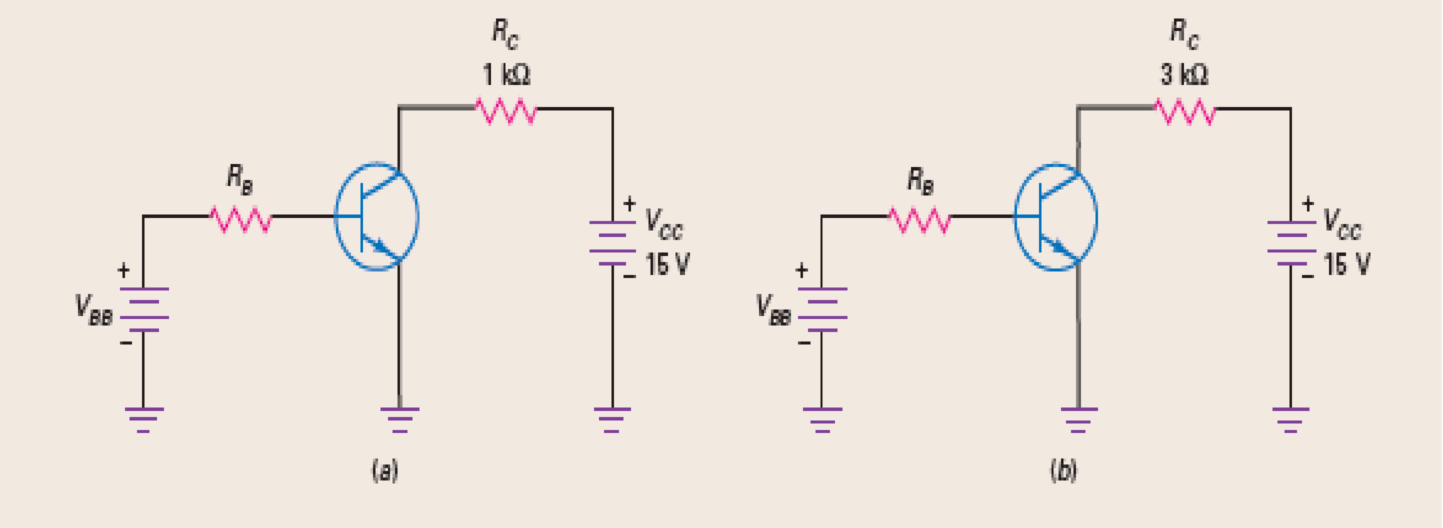
Why is the load line useful?

Because it contains every possible operating point for the circuit. Stated another way, when the base resistance varies from zero to infinity, it causes *IB* to vary, which makes *IC* and *VCE* vary over their entire ranges.

If you plot the *IC* and *VCE* values for every possible *IB* value, you will get the load line. Therefore, the load line is a visual summary of *all possible transistor operating points*

Example

- What are the saturation current and the cutoff voltage in Fig. *a* *and* Fig. *b*? Then, compare the load lines for both



solution

Fig a

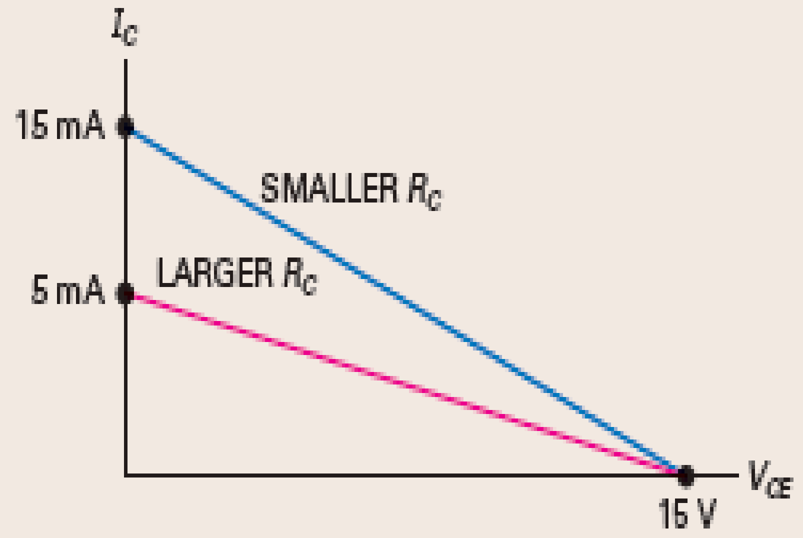
$$V_{CE(cutoff)} = 15\text{ V}$$

$$I_{C(sat)} = \frac{15\text{ V}}{1\text{ k}\Omega} = 15\text{ mA}$$

Fig b

$$V_{CE(cutoff)} = 15\text{ V}$$

$$I_{C(sat)} = \frac{15\text{ V}}{3\text{ k}\Omega} = 5\text{ mA}$$



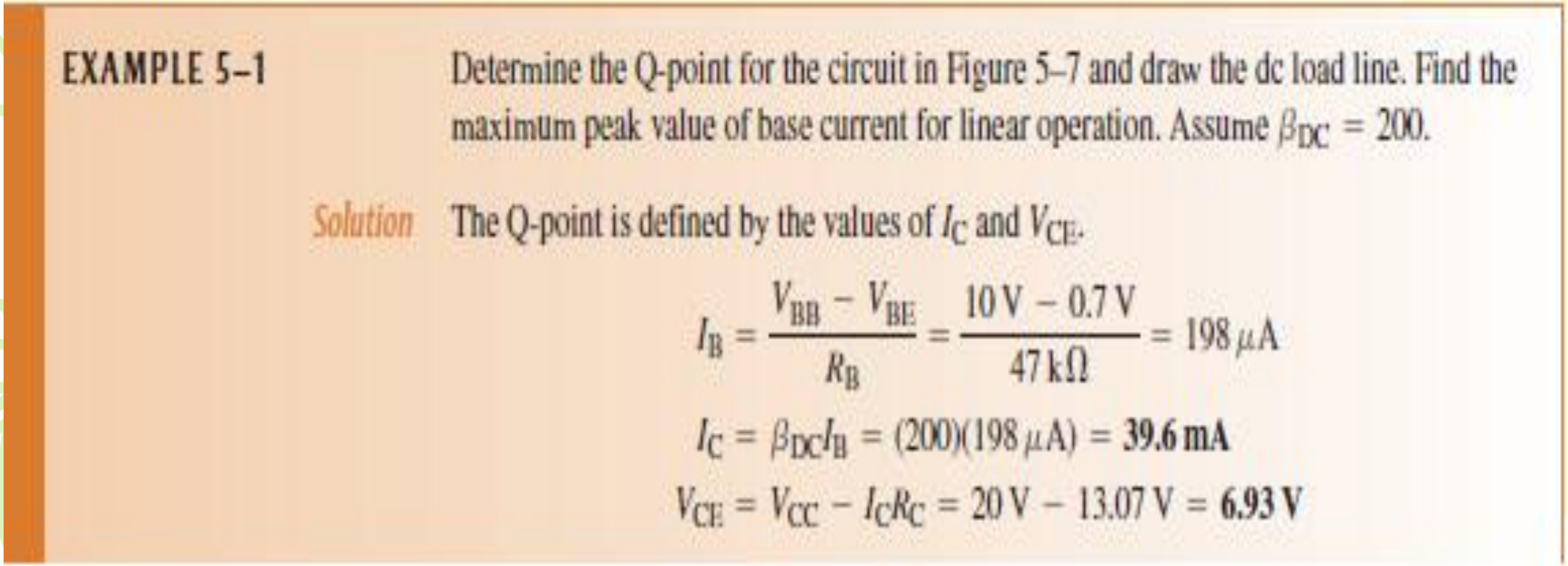
(c)

The Operating Point (Q-POINT)

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

$$I_C = \beta_{\mathrm{dc}} I_B$$

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



EXAMPLE 5–1 Determine the Q-point for the circuit in Figure 5–7 and draw the dc load line. Find the maximum peak value of base current for linear operation. Assume $\beta_{DC} = 200$.

Solution The Q-point is defined by the values of I_C and V_{CE}.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{47\text{ k}\Omega} = 198\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (200)(198\ \mu\text{A}) = \mathbf{39.6\ mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 20\text{ V} - 13.07\text{ V} = \mathbf{6.93\ V}$$

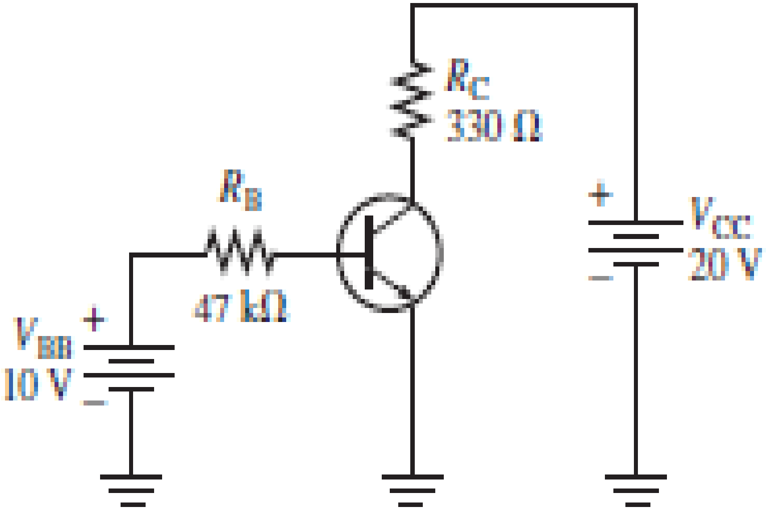
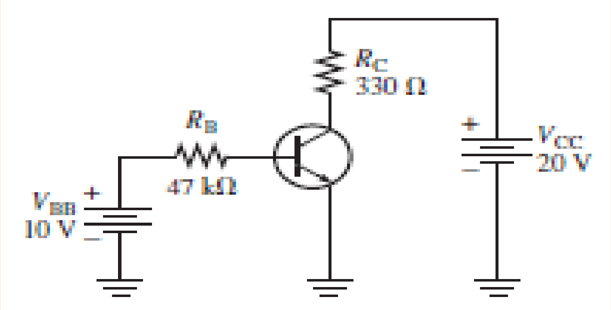


FIGURE 5–7



The Q-point is at $I_C = 39.6$ mA and at $V_{CE} = 6.93$ V.

Since $I_{C(cutoff)} = 0$, you need to know $I_{C(sat)}$ to determine how much variation in collector current can occur and still maintain linear operation of the transistor.

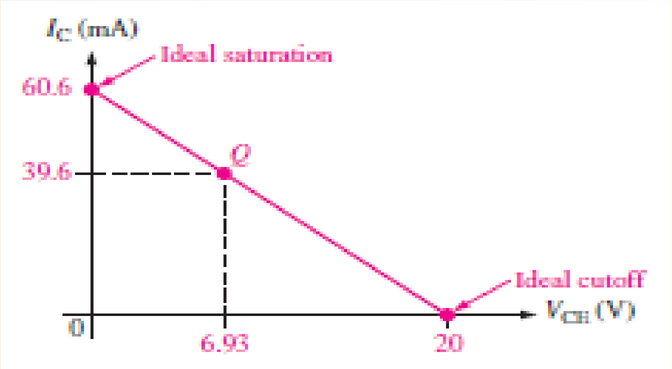
$$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{20\text{ V}}{330\ \Omega} = 60.6\text{ mA}$$

The dc load line is graphically illustrated in Figure 5–8, showing that before saturation is reached, I_C can increase an amount ideally equal to

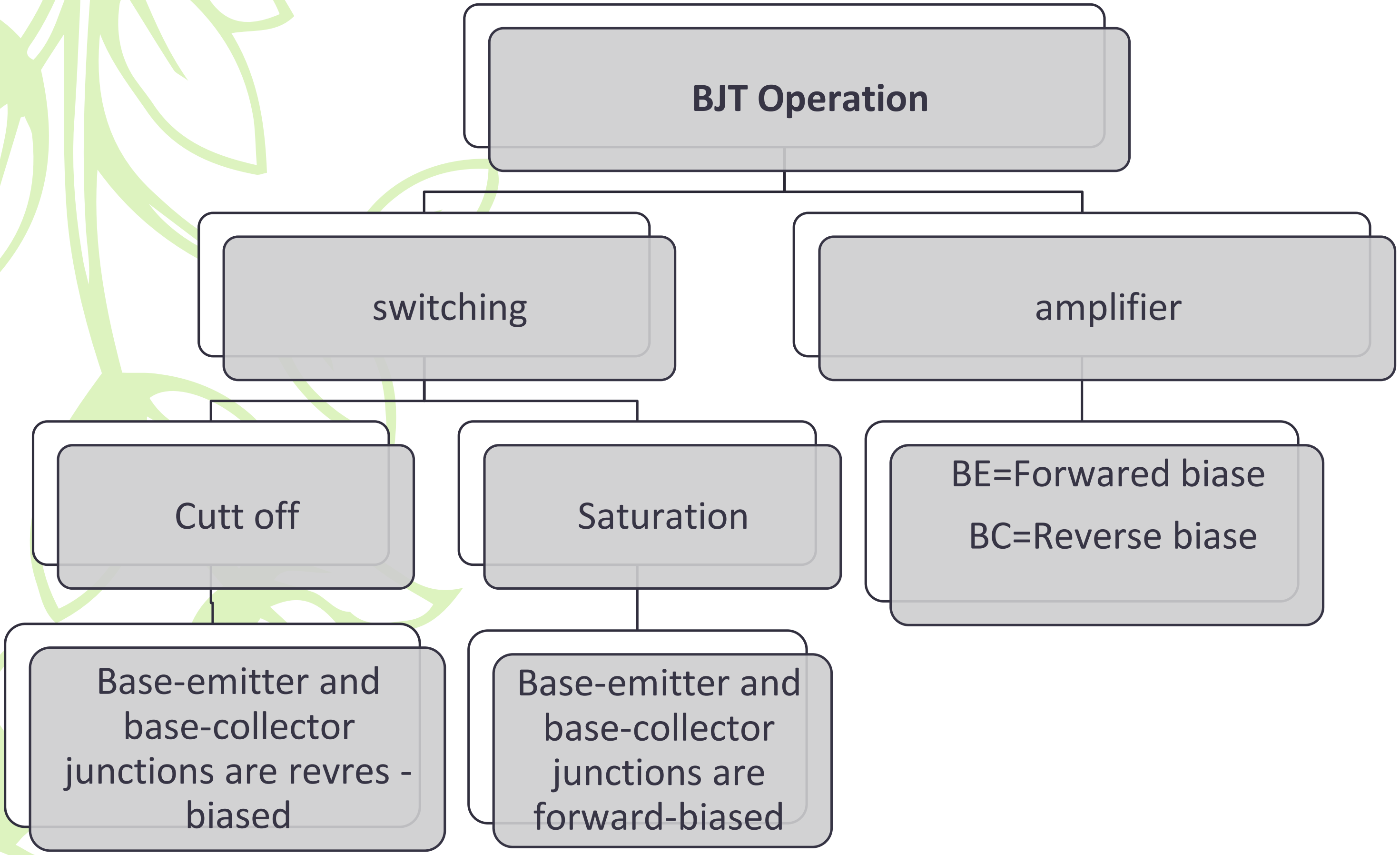
$$I_{C(sat)} - I_{CQ} = 60.6\text{ mA} - 39.6\text{ mA} = 21.0\text{ mA}$$

However, I_C can decrease by 39.6 mA before cutoff ($I_C = 0$) is reached. Therefore, the limiting excursion is 21 mA because the *Q-point is closer to saturation than to cutoff*. The 21 mA is the maximum peak variation of the collector current. Actually, it would be slightly less in practice because $V_{CE(sat)}$ is not quite zero.

FIGURE 5–8



BJT Operation



BJT Operation

switching

Cutt off

Base-emitter and base-collector junctions are revres - biased

Saturation

Base-emitter and base-collector junctions are forward-biased

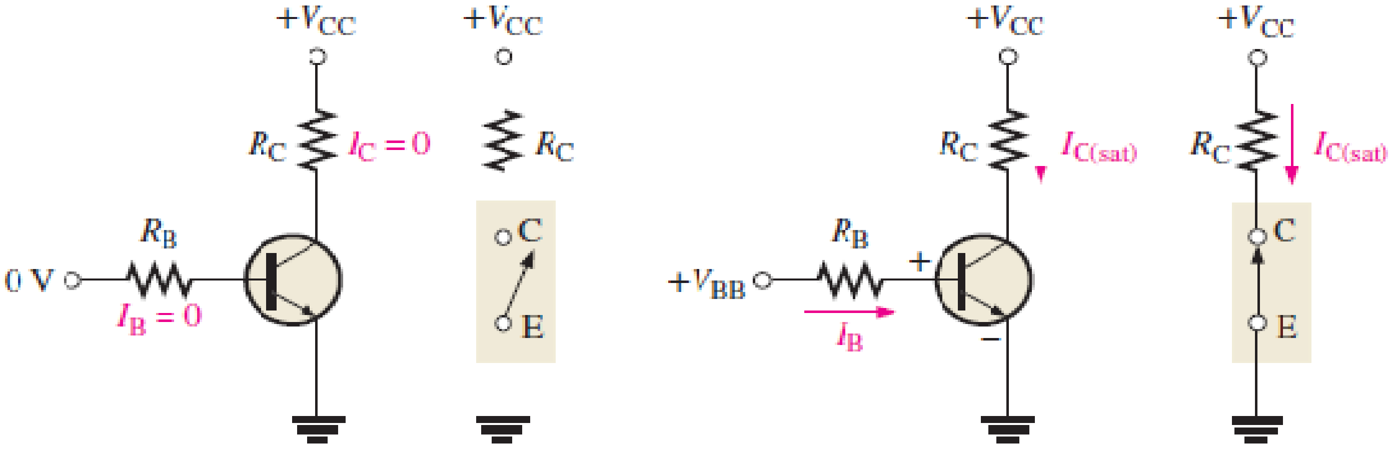
amplifier

BE=Forwared biase

BC=Reverse biase

The BJT as a switch

- The major application area is switching applications. When used as an electronic switch, a BJT is normally operated alternately in cutoff and saturation. Many digital circuits use the BJT as a switch



(a) Cutoff — open switch

(b) Saturation — closed switch

Switching Operation

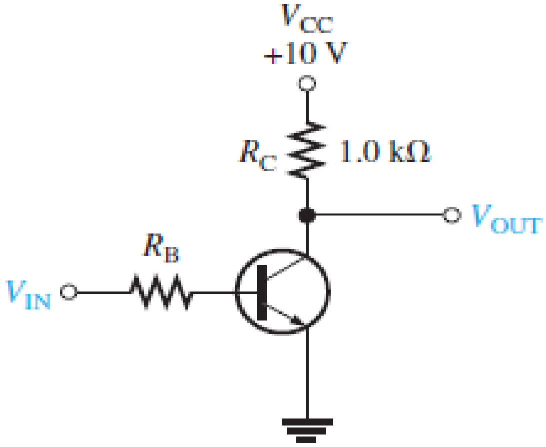
- In part (a), the transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an open between collector and emitter.
- In part (b), the transistor is in the saturation region because the base emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector current to reach its saturation value. In this condition, there is, ideally, a short between collector and emitter, as indicated by the switch equivalent.
- A small voltage drop across the transistor of up to a few tenths of a volt normally occurs, which is the saturation voltage, VCE(sat).

Example

(a) For the transistor circuit in the figure, what is VCE when VIN= 0 V?

(b) What minimum value of IB is required to saturate this transistor if βDC is 200? Neglect VCE(sat).

(c) Calculate the maximum value of RB when VIN = 5 V.



Solution

(a) When VIN = 0 V, the transistor is in cutoff (acts like an open switch) and

$$VCE = VCC = 10\text{ V}$$

(b) Since VCE(sat) is neglected (assumed to be 0 V),

$$IC(sat) = VCC/RC = 10\text{ V}/1.0\text{ k}\Omega = 10\text{ mA}$$

$$IB(min) = IC(sat)/\beta DC = 10\text{ mA}/200 = \mathbf{50\ \mu A}$$

This is the value of IB necessary to drive the to the point of saturation.

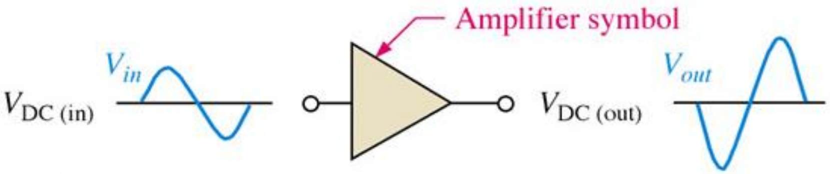
Any further increase in IB will ensure the transistor remains in saturation but there cannot be any further increase in IC.

Amplification

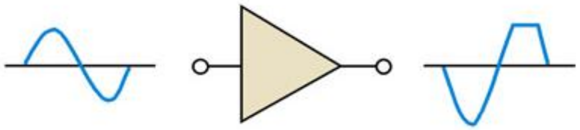
- The goal of amplification in most cases is to increase the amplitude of an ac signal without altering it.
- **Gain** The amount by which an electrical signal is increased or amplified
- Amplification is **the process of linearly increasing the amplitude of an electrical signal** and is one of the major properties of a transistor.
- When a BJT is biased in the active (or linear) region, as previously described, the BE junction has a low resistance due to forward bias and the BC junction has a high resistance due to reverse bias.

BJT as an Amplifier

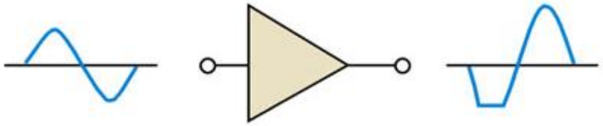
- A transistor amplifies current because the collector current is equal to the base current multiplied by the current gain β.



(a) Linear operation: larger output has same shape as input except that it is inverted

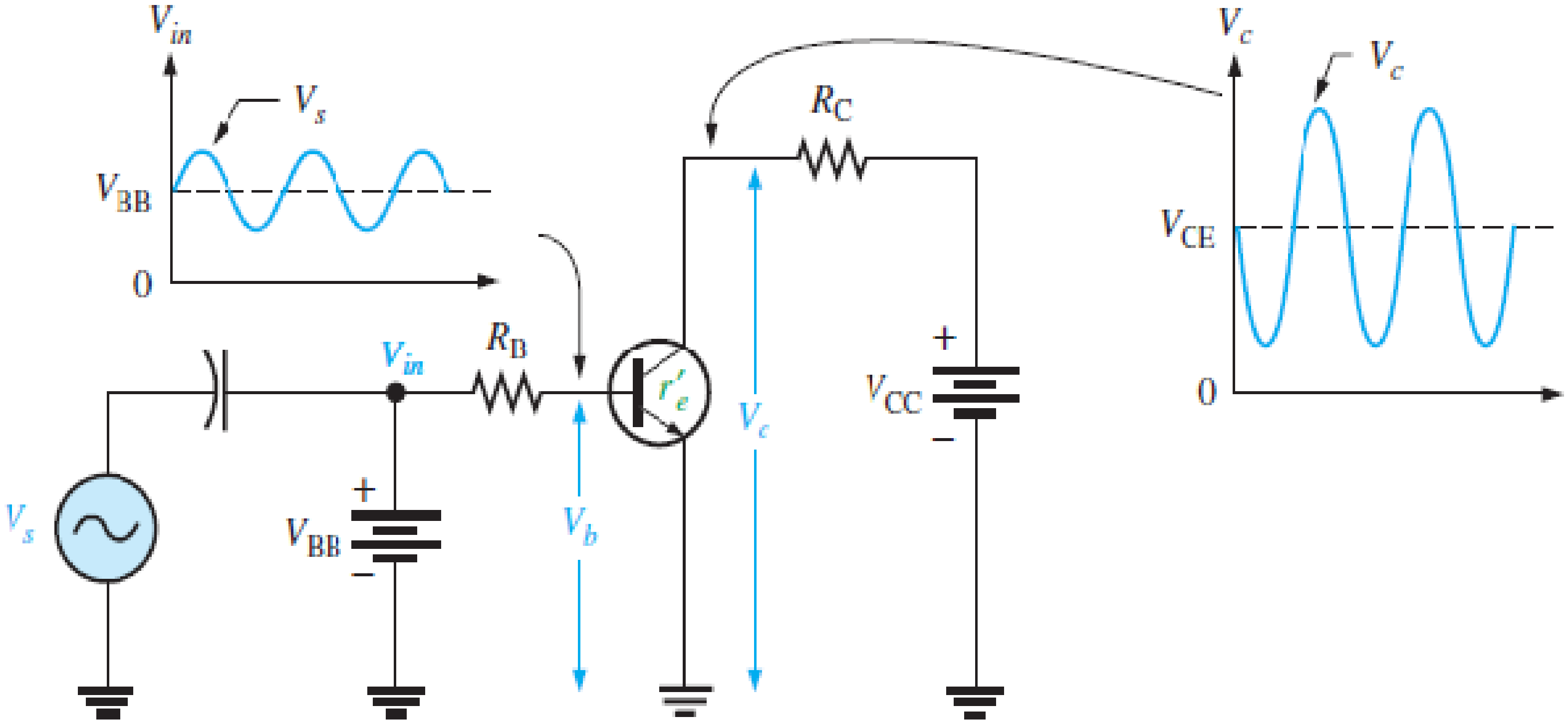


(b) Nonlinear operation: output voltage limited (clipped) by cutoff



(c) Nonlinear operation: output voltage limited (clipped) by saturation

Voltage Amplifier



Thank you