BJT Applications

Topics Covered from Module 4: *BJT as an amplifier, BJT as a switch, Transistor switch circuit to switch ON/OFF an LED and a lamp in a power circuit using a relay.*

BJT as an Amplifier

Amplification is the process of linearly increasing the amplitude of an electrical signal. It is one of the major properties of a bipolar junction transistor (BJT).

A BJT is a current controlled device. It amplifies current because the collector current is equal to the base current multiplied by the current gain, β. The base current in a transistor is very small compared to the collector and emitter currents. Because of this, the collector current is approximately equal to the emitter current.

Fig. 1 shows a basic transistor amplifier circuit. An ac voltage, V_S, is superimposed on the dc bias voltage V_{BB} by capacitive coupling as shown. The dc bias voltage V_{CC} is connected to the collector through the collector resistor, R_C.

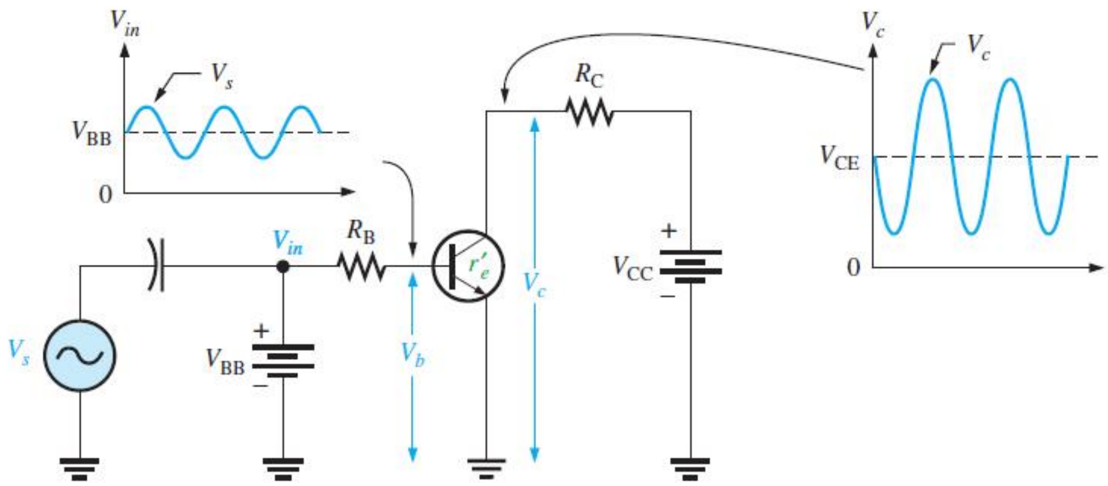


Fig. 1 Basic transistor amplifier circuit

The ac input voltage produces an ac base current I_b, which results in a much larger ac collector current I_c. The ac collector current I_c produces an ac voltage across R_C, thus producing an amplified, but inverted, reproduction of the ac input voltage as shown in Fig. 1.

The forward-biased base-emitter junction presents a very low resistance to the ac signal. This internal ac emitter resistance is designated r'_e and appears in series with R_B. The ac base voltage is

$$V_b = I_e r'_e$$

The ac collector voltage, V_c, equals the ac voltage drop across R_C.

$$V_c = I_c R_C$$

Since $I_c \cong I_e$, the ac collector voltage is

$$V_c \cong I_e R_C$$

V_b can be considered the transistor ac input voltage where $V_b = V_s - I_b R_B$. V_C can be considered the transistor ac output voltage.

Since *voltage gain* is defined as the ratio of the output voltage to the input voltage, the ratio of V_c to V_b is the ac voltage gain, A_v, of the transistor.

$$A_v = \frac{V_c}{V_b}$$

Substituting $I_e R_C$ for V_c and $I_e r'_e$ for V_b yields

$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r'_e}$$

Therefore,

$$\boldsymbol{A_v \cong \frac{R_C}{r'_e}}$$

This equation shows that the transistor in Fig. 1 provides amplification in the form of voltage gain, which is dependent on the values of R_C and r'_e. Since R_C is always considerably larger in value than r'_e, the output voltage for this configuration is greater than the input voltage.

BJT as a Switch

The second major application area of BJT 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.

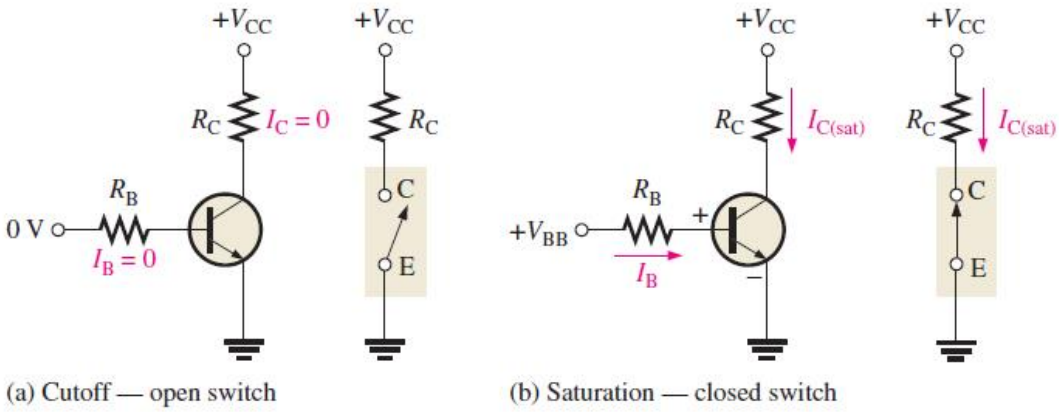


Fig. 2 Switching action of an ideal transistor

Fig. 2 illustrates the basic operation of a BJT as a switching device.

In Fig. 2 (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, as indicated by the switch equivalent.

In Fig. 2 (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. Actually, a small voltage drop across the transistor of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$.

Conditions in Cutoff

A transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}.

$$V_{CE(cutoff)} = V_{CC}$$

Conditions in Saturation

When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

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

Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can usually be neglected.

The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Normally, I_B should be significantly greater than $I_{B(min)}$ to ensure that the transistor is saturated.

A Simple Application of a Transistor Switch

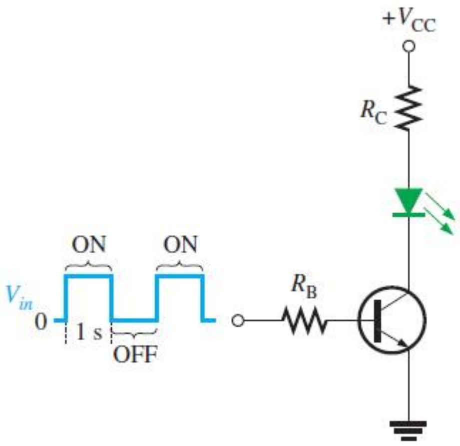


Fig. 3 A transistor used to switch an LED on and off

The transistor in Fig. 3 is used as a switch to turn the LED on and off.

For example, a square wave input voltage with a period of 2 s is applied to the input as indicated. When the square wave is at 0 V, the transistor is in cutoff; and since there is no collector current, the LED does not emit light. When the square wave goes to its high level, the transistor saturates. This forward-biases the LED, and the resulting collector current through the LED causes it to emit light. Thus, the LED is on for 1 second and off for 1 second.

Numerical Examples

1. What is the voltage gain of a transistor amplifier that has an output of 5 V rms and an input of 250 mV rms?

   Solution:

   Given $V_{in} = 250\ mV,\ V_{out} = 5\ V$

   We know that,
   The voltage gain

   $$A_V = \frac{V_{out}}{V_{in}} = \frac{5\ V}{250 \times 10^{-3}\ V}$$

   $$A_V = 20$$

2. In a transistor amplifier circuit, determine the voltage gain and the ac output voltage if $V_b = 100$ mV, $R_C = 1$ kΩ and $r'_e = 50$ Ω.

   Solution:

   Given, $V_b = 100\ mV = 100 \times 10^{-3}\ V$
   $R_c = 1\ k\Omega = 1 \times 10^3\ \Omega$, $r_e' = 50\ \Omega$

   We know that,
   The voltage gain

   $$A_V = \frac{V_c}{V_b}$$

   $$A_V = \frac{R_c}{r_e'} = \frac{1 \times 10^3}{50}$$

   $$\boxed{A_V = 20}$$

Since $A_v = \frac{V_c}{V_b}$,

The ac output voltage

$$V_c = A_v V_b$$

$$= 20 \times 100 \times 10^{-3} \text{ V}$$

$$V_c = 2\text{V}$$

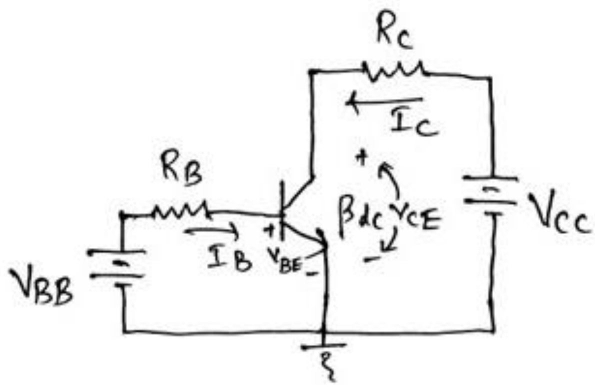
3. Determine the value of the collector resistor in an npn transistor amplifier with $\beta_{dc} = 250$, $V_{BB} = 2.5$ V, $V_{CC} = 9$ V, $V_{CE} = 4$ V and $R_B = 100$ kΩ.

Solution:

Given $\beta_{dc} = 250$, $V_{BB} = 2.5\text{V}$, $V_{CC} = 9\text{V}$,

$V_{CE} = 4\text{V}$, $R_B = 100\text{ k}\Omega$

We have the circuit of an npn transistor amplifier as



from the circuit,

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

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

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

Consider Si transistor,

Since Base-Emitter junction is forward biased $V_{BE} = 0.7\text{V}$

$$\therefore I_B = \frac{2.5-0.7}{100\times10^3}$$

$$I_B = \underline{18\ \mu A}$$

We know that

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

$$\therefore I_C = 250\times18\times10^{-6}$$

$$I_C = \underline{4.5\ mA}$$

From the circuit,

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

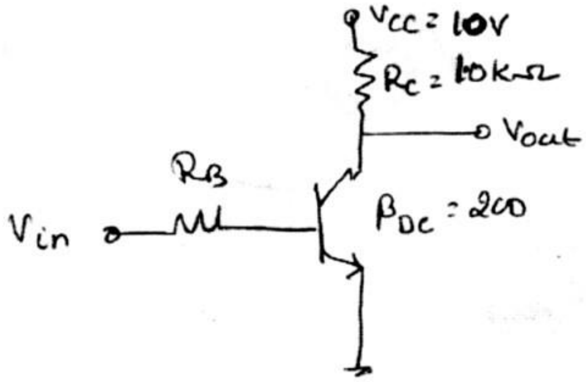
$$I_C R_C = V_{CC} - V_{CE}$$

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

$$R_C = \frac{9-4}{4.5\times10^{-3}}$$

$$R_C = \underline{1.11\ k\Omega}$$

4. The transistor in common emitter configuration is shown in figure, with $R_C = 1.0\ k\Omega$ and $\beta_{dc} = 200$. Determine (i) V_{CE} at $V_{in} = 0$ (ii) $I_{B(min)}$ to saturate the collector current (iii) $R_{B(max)}$ when $V_{in} = 5\ V$. $V_{CE(sat)}$ can be neglected.



Solution:

i) When $V_{in} = 0V$, the transistor is in cutoff (acts as an open switch)

We know that,

$$V_{CE(cutoff)} = V_{CC} = \underline{10V}$$

ii)

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

Since $V_{CE(sat)}$ is neglected,

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

$$= \frac{10}{1 \times 10^{-3}} = \underline{10mA}$$

Then,

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{dc}}$$

$$= \frac{10 \times 10^{-3}}{200} = \underline{50\mu A}$$

iii) The voltage across R_B is

$$V_{RB} = V_{in} - V_{BE}$$

Assume $V_{BE} = 0.7V$ (ON state)

$$V_{RB} = 5 - 0.7 = 4.3V$$

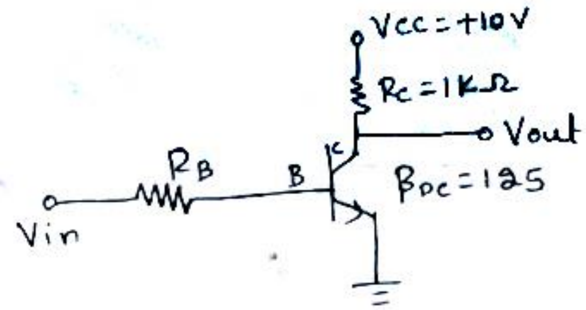
Then

$$R_{B(max)} = \frac{V_{RB}}{I_{B(min)}}$$

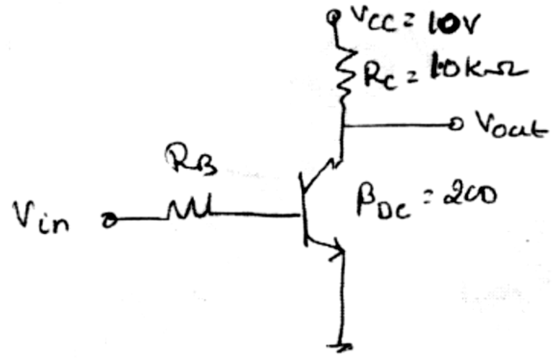
$$= \frac{4.3}{50 \times 10^{-6}} = \underline{86 k\Omega}$$

Questions

1. What is an amplifier? Explain the operation of transistor amplifier circuit. ***(MQP '18 – 8M)***
2. With neat circuit diagram, explain how transistor is used as a voltage amplifier. Derive an equation for voltage gain A_v. ***(Sep '20 – 8M, Jan '20 – 8M, Jul '19 – 6M, Jan '19 – 8M)***
3. Briefly explain how a transistor is used as an electronic switch. ***(MQP '18 – 6M)***
4. Explain the operation of BJT (transistor) as an amplifier and as a switch. ***(MQP '18 – 10M)***
5. With a neat circuit diagram, explain how transistor can be used to switch an LED ON/OFF and give the necessary equations. ***(Jan '19 – 8M)***
6. Determine the value of the collector resistor in an npn transistor amplifier with $\beta_{dc} = 250$, $V_{BB} = 2.5$ V, $V_{CC} = 9$ V, $V_{CE} = 4$ V and $R_B = 100$ kΩ.
7. In a transistor amplifier circuit, determine the voltage gain and the ac output voltage if $V_b = 100$ mV, $R_C = 1$ kΩ and $r'_e = 50$ Ω.
8. The transistor in CE configuration is shown in figure, with $R_C = 1$ kΩ and $\beta_{dc} = 125$. Determine (i) V_{CE} at $V_{in} = 0$ V (ii) $I_{B(min)}$ to saturate the collector current (iii) $R_{B(max)}$ when $V_{in} = 8$ V. $V_{CE(sat)}$ can be neglected. ***(Jan '20 – 4M)***



9. The transistor in common emitter configuration is shown in figure, with $R_C = 1.0$ kΩ and $\beta_{dc} = 200$. Determine (i) V_{CE} at $V_{in} = 0$ (ii) $I_{B(min)}$ to saturate the collector current (iii) $R_{B(max)}$ when $V_{in} = 5$ V. $V_{CE(sat)}$ can be neglected. ***(Jan '19 – 4M)***



References

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