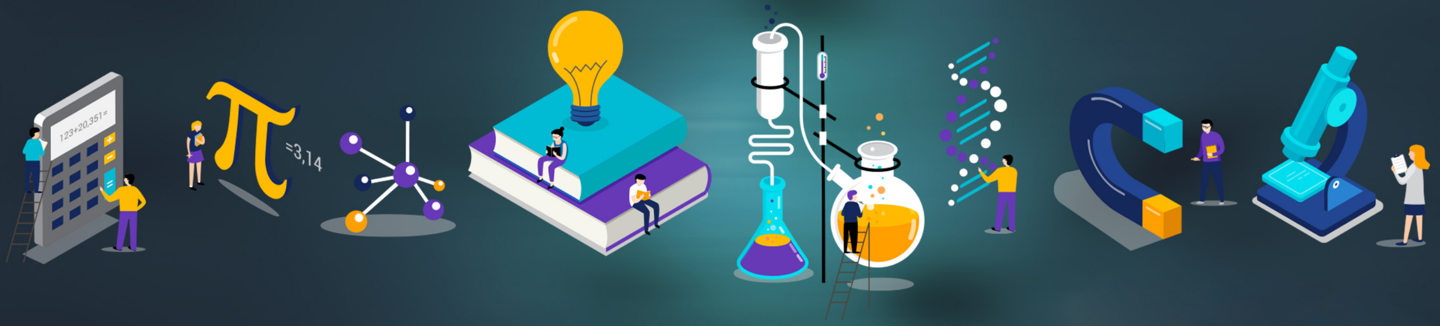


1. Bipolar Junction Transistor

The transistor is a three-layer semiconductor device consisting of either two n - and one p-type layers of material or two p - and one n-type layers of material. The former is called an npn transistor, and the latter is called a pnp transistor. The emitter layer is heavily doped, with the base and collector only lightly doped. The outer layers have widths much greater than the sandwiched p - or n-type material. The doping of the sandwiched layer is also considerably less than that of the outer layers (typically, 1 : 10 or less). This lower doping level decreases the conductivity (increases the resistance) of this material by limiting the number of "free" carriers.

The terminals have been indicated by the capital letters E for emitter, C for collector, and B for base. An appreciation for this choice of notation will develop when we discuss the basic operation of the transistor. The abbreviation BJT, from bipolar junction transistor, is often applied to this three-terminal device. The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material. If only one carrier is employed (electron or hole), it is considered a unipolar device.

1.1 Construction

The basic operation of the transistor will now be described using the pnp transistor The operation of the *npn* transistor is exactly the same if the roles played by the electron and hole are interchanged.
One p-n junction of transistor is forward biased, Where as the other is reverse biased.

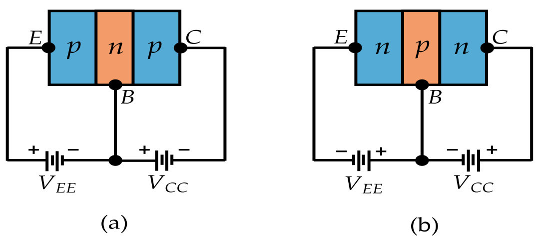


Figure 1.1: (a)pnp transistor (b)npn tranasistor

Both biasing potentials have been applied to a pnp transistor,large number of majority carriers will diffuse across the forwardbiased p-n junction into the n-type material. The question then is whether these carriers will contribute directly to the base current B or pass directly into the p-type material. Since the sandwiched n-type material is very thin and has a low conductivity, a very small number of these carriers will take this path of high resistance to the base terminal.The magnitude of the base current is typically on the order of microamperes, as

compared to milliamperes for the emitter and collector currents. The larger number of these majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal.The reason for the relative ease with which the majority carriers can cross the reverse-biased junction is easily understood if we consider that for the reverse-biased diode the injected majority carriers will appear as minority carriers in the n-type material. In other words, there has been an injection of minority carriers into the n-type base region material.Combining this with the fact that all the minority carriers in the depletion region will cross the reverse-biased junction of a diode.
Applying Kirchhoff's current law to the transistor as if it were a single node,we obtain

$$I_E = I + I_B$$

and find that the emitter current is the sum of the collector and base currents.
The collector current, however, comprises two components-the majority and the minority carriers.The minority-current component is called the leakage current and is given the symbol I_{co} (I_c current with emitter terminal Open). The collector current, therefore, is determined in total by

$$I_c = I_{c_{\text{majoily}}} + I_{co_{\text{minority}}}$$

For general-purpose transistors, I_c is measured in milliamperes and I_{CO} is measured in microamperes or nanoamperes. I_{co}, like I_s for a reverse-biased diode, is temperature sensitive and must be examined carefully when applications of wide temperature ranges are considered.

Note

- I_{co} for Germanium transisitor is μA range, Si transisitor is nA range.
- I_{co} doubles for every $10°C$ rise in temperature.
- For $1°C$,I_{co} approximately increases by 7%

$$I_{co(T_2)} = I_{co(T_1)} 2^{\left(\frac{T_2-T_1}{10}\right)}$$

- I_{co} is independent of collector supply voltage.
- The collector current is less than the emitter current.There are two reason for it.Firstly a part of the emitter current consists of holes that donot contribute to the collector current.secondly not all the electrons injected in to the base are successful in reaching the collector.

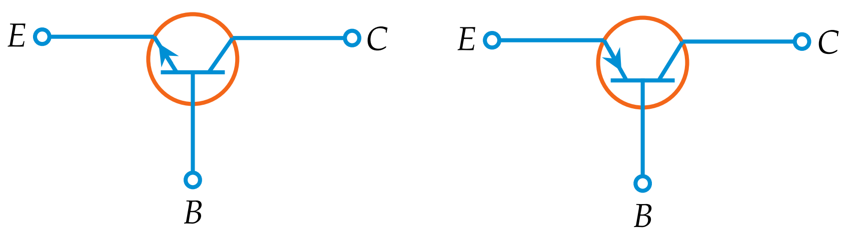
Equation of emitter current

In a transistor under active region emitter current is the forward current of emitter diode.

$$I_E = I_{co} e^{\frac{V_{BE}}{nV_T}}$$

The emitter current exponentially increases with base to emitter voltageV_{BE} of the transistor

Symbol



(n-p-n transistor symbol) (p-n-p transistor symbol)

Figure 1.2

Modes of operation

Modeof Operations	J_1 (B-E)	J_2 (C-B)	Applications
Active region	FB	RB	As an amplifier
Saturation region	FB	FB	As an electronic switch
Cut-off region	RB	RB	In digital circuit
Reverse active mode or inverted mode	RB	FB	As an amplifier with voltage and current gain to below (attenuator)

1.2 Transistor configurations

There are three leads in a transistor viz., emiter, base and collector terminals. However. when a transistor is to be connected in a circuit, we require four terminals; two for the input and two for the output. This difficulty is overcome by making one terminal of the transistor common to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. The output is obtained between the common terminal and the remaining terminal. Accordingly; a transistor can be connected in a circuit in the following three ways;

1. Common base configuration

2. Common emitter configuration

3. Common collector configuration

1.3 Common base configuration

In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base. Here, base of the transistor is common to both input and output circuits.

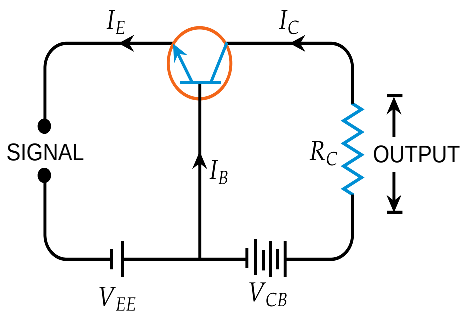


Figure 1.3

To fully describe the behaviour of a three terminal devices such as the common base amplirier,requires two set of characteristics one for the 'driving point' or input parameters and the other forthe output side.

1.3.1 Input characterestics

The input set for the common-base amplifier as shown in figure relates an input current (I_E) to an input voltage (V_{BE}) for various levels of output voltage V_{CB}.

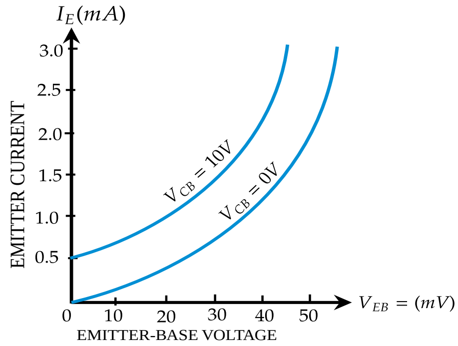


Figure 1.4

Input resistance.

It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) i.e. Input resistance

$$r_i = \frac{\Delta V_{EB}}{\Delta I_E} \text{at constant } V_{CB}$$

In fact, input resistance is the opposition offered to the signal current. As a very small V_{EB} is sufficient to produce a large flow of emitter current I_E, therefore, input resistance is quite small, of the order of a few ohms.

1.3.2 output characterestics

It relates I_C to V_{CB} for various levels input current I_E shown.

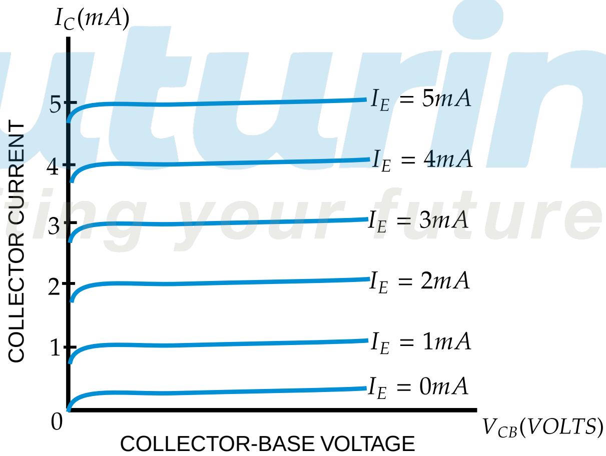


Figure 1.5

From the graph we can say that the emitter current which is approximately equal to collector current.

$$I_C \approx I_E$$

Output resistance.

It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current *i.e.* Output resistance,

$$r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant} I_E$$

The output resistance of *CB* circuit is very high, of the order of several tens of kilo-ohms. This is not surprising because the collector current changes very slightly with the change in V_{CB}.

1.3.3 Properties of CB configuration

- Lowest input resistance ($\mathrm{R_i} < 100\Omega$)
- Highest output resistance ($\mathrm{R_0} > 1\mathrm{M}\Omega$)
- Lowest current gain ($\alpha < 1$)
- Highest voltage gain
- Medium power gain (typical value 68)
- Output and input voltages are in phase i.e. phase shift is $0°$.
- In *CB* amplifier current gain is loss and therefore bandwidth is large and hence *CB* amplifier is widely used as high frequency.

1.3.4 Current amplification factor Alpha(α)

- In the dc mode the levels of I_C and I_E due to the majority carriers are related by a quantity called alpha and defined by the following equation.

$$\alpha_{dc} = \left| \frac{I_C}{I_E} \right|$$

  Where I_{CBO} is collector to base current when emitter terminal is open.

- For ac situations where the point of operation moves on the characteristic curve, an ac alpha is defined by.

$$\alpha_{ac} = \left. \frac{\Delta I_C}{\Delta I_E} \right|_{V_{CB-constant}}$$

- The alpha is formally called common base amplification factor on current gain of common base transistor. **Note**: The transistor's amplifying action is basically due to its capability of transfer its signal current from a low resistance circuit to high resistance circuit, contracting the two terms transfer and resistor results in the name transistor; i.e
  transfer+resistance $\rightarrow$ transistor

1.3.5 Expression for collector current

$$\alpha = \frac{I_C}{I_E}$$

$$I_C = \alpha I_E$$

The leakage current $I_{leakage}$ is due to the movement of minority carriers across base collector junction on account of it being reverse biased.This is much smaller than αI_E Total collector current

$$I_C = \alpha I_E + I_{leakage}$$

It is clear that if $I_E = 0$ (emitter circuit is open) a small leakage current still flows in the collector circuit.This leakage is abbreviated as I_{CBO} meaning collector base current with emitter open.Then

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_C + I_B$$

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

$$I_C(1-\alpha) = \alpha I_B + ICBO$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

1.4 Common emitter configuration

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter. Here, emitter of the transistor is common to both input and output circuits and hence the name common emitter connection.

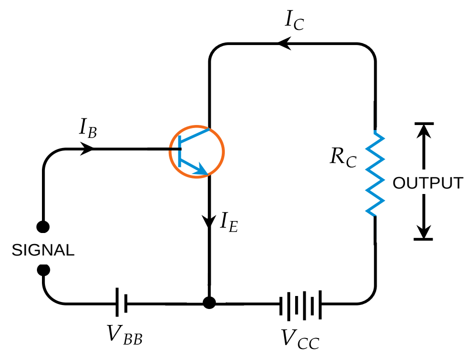


Figure 1.6

1.4.1 Input characterestics

It is the curve between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}

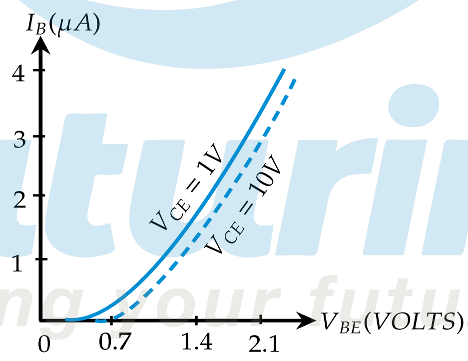


Figure 1.7

(i) The characteristic resembles that of a forward biased diode curve. This is expected since the base-emitter section of transistor is a diode and it is forward biased.
(ii) As compared to CB arrangement, I_B increases less rapidly with V_{BE}. Therefore, input resistance of a CE circuit is higher than that of CB circuit

Input resistance.

It is the ratio of change in base-emitter voltage (ΔV_{BE}) to the change in base current (ΔI_B) at constant V_{CE} i.e. Input resistance,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

The value of input resistance for a CE circuit is of the order of a few hundred ohms.

1.4.2 Output characterestics

It is the curve between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B.

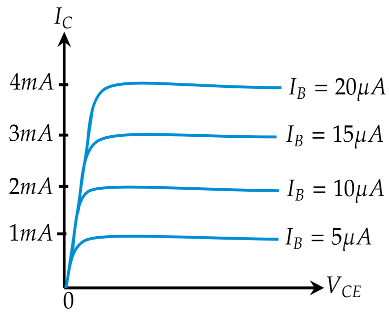


Figure 1.8

The following points may be noted from the characteristics:-
(i) The collector current I_C varies with V_{CE} for V_{CE} between 0 and 1 V only. After this, collector current becomes almost constant and independent of V_{CE}. This value of V_{CE} upto which collector current I_C changes with V_{CE} is called the knee voltage (V_{knee}). The transistors are always operated in the region above knee voltage.
(ii) Above knee voltage, I_C is almost constant. However, a small increase in I_C with increasing V_{CE} is caused by the collector depletion layer getting wider and capturing a few more majority carriers before electron-hole combinations occur in the base area.
(iii) For any value of V_{CE} above knee voltage, the collector current I_C is approximately equal to $\beta \times I_B$.
Output resistance It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at constant I_B i.e. Output resistance,

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C}$$

at constant I_B

- The output resistance of a common emitter configuration is less that of common base configuration.

1.4.3 Current amplification factor Beta (β)

- For dc

$$\beta_{dc} = \frac{I_C}{I_B} \quad (\beta > 1)$$

- For ac

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE=constant}}$$

- Range of β is 30 to 300.
- β is called the current gain of transistor in CE mode. It is the most important specification of the transistor.
- β is also denoted by h_{fe}
-

$$I_C = \beta I_B$$

$$\mathrm{I_E = I_C + I_B = \beta I_B + I_B} \quad I_E = (\beta + 1) I_B$$

- Thereia phase difference of $180°C$ between input and output voltage in a CE amplifie.
  when base voltage increase, base current increases. It causes an increase in collector current also. The collector current causes a voltage drop in the collector resistor. Because the output is situated below the collector resistance (with reference to Vcc) the output voltage will decrease as voltage drop across collector resistor increase. Thus it produces a 180 phase shift. (input positive, output negative and vice versa)

Relation between α and β
β in terms of α is $\beta = \frac{\alpha}{1-\alpha}$ $\quad \alpha = \frac{\beta}{1+\beta}$

1.4.4 Expression for collector current

In common emitter circuit, I_B is the input current and I_C is the output current. We know,

$$I_E = I_B + I_C$$

and

$$I_C = \alpha I_E + I_{CBO}$$

From above two equations we will get

$$I_C = \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$$

or

$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

From expression it is apparent that if $I_B = 0$ (i.e. base circuit is open), the collector current will be the current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

Then

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

$$I_C = \beta I_B + I_{CEO}$$

1.5 Common collector configuration

In this circuit arrangement, input is applied between base and collector while the output is taken between the emitter and collector. Here, collector of the transistor is common to both input and the output circuit. Hence the name common collector configuration.

1.5.1 Current amplification factor gamma (γ)

In common collector circuit, input current is the base current I_B and output current is the emitter current I_E. Therefore, current amplification in this circuit arrangement can be defined as under :

The ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B) is known as current amplification factor in common collector (CC) arrangement i.e.

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

This circuit provides about the same current gain as the common emitter circuit as $\Delta I_E \simeq \Delta I_C$. However, its voltage gain is always less than 1.

Relation between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in first expression we get,

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

Dividing the numerator and denominator on R.H.S. by ΔI_E, we get,

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E - \frac{\Delta I_C}{\Delta I_E}}} = \frac{1}{1-\alpha} \qquad (\because \alpha = \Delta I_C / \Delta I_E)$$

$$\therefore \quad \gamma = \frac{1}{1-\alpha}$$

1.5.2 Expression for collector current

$$\begin{aligned} I_C &= \alpha I_E + I_{CBO} \\ I_E &= I_B + I_C = I_B + (\alpha I_E + I_{CBO}) \\ I_E(1-\alpha) &= I_B + I_{CBO} \\ I_E &= \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{I-\alpha} \\ I_E &= *(\beta+1)I_B + (\beta+1)I_{CBO} \end{aligned}$$

1.5.3 Applications

The common collector circuit has very high input resistance (about 750 KΩ) and very low output resistance (about 25Ω). Due to this reason, the voltage gain provided by this circuit is always less than 1 . Therefore, this circuit arrangement is seldom used for amplification. However, due to relatively high input resistance and low output resistance, this circuit is primarily used for impedance matching i.e. for driving a low impedance load from a high impedance source.
This configuration is used in emitter follower circuits.

Comparison between CB, CE and CC amplifier

Characteristic	Amplifier		
	CB	CE	CC
Input resistance (R_i)	≈ 50 to 200Ω low	≈ 1 to 2kΩ medium	≈ 150 – 800kΩ high
Output resistance (R_o)	≈ 1 – 2kΩ high	≈ 50kΩ medium	≈ kΩ low
Current gain	0.8 – 0.9 low	20 – 200 high	20 – 200 high
Voltage gain	Medium	High	Low
Power gain	Medium	High	Low
Phase difference between input and output voltages	Zero	180°	Zero
Used as amplifier for	current	Power	Voltage

1.6 Modes of operation

A transistor can be operated in three mode.

- Saturation region
- Active region
- Cut off region

1.6.1 Load line analysis

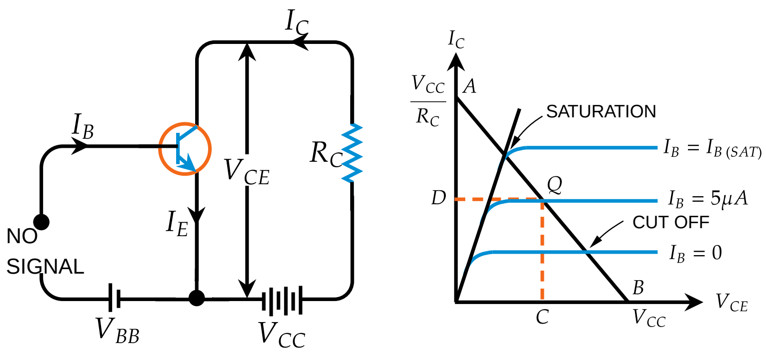


Figure 1.9

In general we need to determine the the collector current for various collector emitter voltages.One of the method is to plot the output characterestics.But we have another convenient method called load line method wich is used to solve such problems.Consider a circuit as shown in the figure.in this circuit we are not applying any input signal.Only dc conditions prevail in the circuit.
The value of collector emitter voltage at any time is given by

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

In this equation V_{CC} and R_C are constants.if we plot I_C against V_{CE}(Same as the case of output characterestics) we will get a straight line with end pointts as $\frac{V_C C}{R_C}$ at A on I_C axis and V_{CC} at B on V_{CE} axis.
This line AB is called load line.
The load line meet at some point on the output characterestics is called quiscent point or $Q-$point.
The corresponding value of I_c and V_{CE} ie(C,D) is called operating point.
It is called operating point because the variation of I_C and V_{CE} take place about this point when signal is applied.

1.6.2 Modes

(i)**Cut off** The point where th load line intersects the "$I_B = 0$" curve is known as *cut off*.
At this point $I_B = 0$ and only small collector current(ie the collector leakage I_{CEO} exists.
At cut off the base emitter junction no longer forward biased and normal transistor action is lost.
The collector emitter voltage is nearly equal to V_{CC}
(ii)**Saturation**
The points where the load line intersects the $I_B = I_B(sat)$ curve is called saturation
$I_B = I_B sat$ curve means it is the maximum base current when the collector base junction is not reverse biased.
At this point the transisitor will not work.
At this point I_C is approximately equal to $\frac{V_{CC}}{R_C}$
(iii)**Active region** The region between cut off and saturation is known as active region.
In the active region collector base junction remains reverse biased while base emitter junction remains forward biased.
Consequently the transisitor will function normally in this region.
CUT-OFF : Emitter diode and collector diode are OFF.
ACTIVE : Emitter diode is ON and collector diode is OFF.
SATURATED : Emitter diode and collector diode are ON.

1.7 Power rating of a transisitor

The maximum power that a transistor can handle without destruction is known as power rating of the transistor.
When a transistor is in operation, almost all the power is dissipated at the reverse biased collector-base junction.
The power rating (or maximum power dissipation) is given by:

$$P_{D(\max)} = \text{Collector current} \times \text{Collector-base voltage}$$

$$= I_C \times V_{CB}$$

$$\therefore \quad P_{D(\max)} = I_C \times V_{CE} \, [\because V_{CE} = V_{CB} + V_{BE} \cdot \text{ Since } V_{BE} \text{ is very small, } V_{CB} \simeq V_{CE}]$$

While connecting transistor in a circuit, it should be ensured that its power rating is not exceeded otherwise the transistor may be destroyed due to excessive heat.

1.8 Transisitor biasing

For faithfull amplification a transisitor amplifier must satisfy three basic conditions.namely
(i)Proper zero signal collector current
(ii)Proper base emitter voltage at any instant.
(iii)Proper collector emitter voltage at any instant.
The proper zerosignal collector current means that the applied signal that should be amplified must not cut off at any portion of the signal.Zero signal current must be greater than the maximum value of collector current due to signal alone.
The other two conidtions is to keep the base emitter junction properly forward biased and collector base junction properly reverse biased during the application of the signal.
All these conditions are fullfilled by transisitor biasing.

1.8.1 Methods of transister biasing

In the transistor amplifier circuits drawn so far biasing was done with the aid of a battery V_{BB} which was separate from the battery V_{CC} used in the output circuit. However, in the interest of simplicity and economy, it is desirable that transistor circuit should have a single source of supply-the one in the output circuit (i.e. V_{CC}). The following are the most commonly used methods of obtaining transistor biasing from one source of supply (i.e. V_{CC}):
(i) Base resistor method
(ii) Biasing with collector-feedback resistor
(iii) Voltage-divider bias

1.8.2 Base resistor method

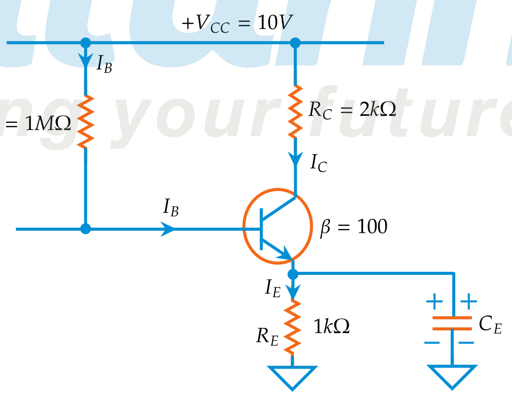


Figure 1.10

In this method, a high resistance R_B (several hundred kΩ) is connected between the base and +ve end of supply for *npn*. transistor and between base and negative end of supply for *pnp* transistor.
The required value of R_B that can be found out as

$$I_B = \frac{I_C}{\beta}$$

Considering the closed circuit *ABENA* and applying Kirchhoff's voltage law, we get,

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

$$\text{or } I_B R_B = V_{CC} - V_{BE}$$

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B}$$

V_{BE} is small compared to V_{CC} we can neglect it.Then

$$R_B = \frac{V_{CC}}{I_B}$$

Since the base bias current I_B is constant,the circuit is called fixed bias circuit.Applying KVL around the collector emitter circuit we get

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

Stability factor

Stability factor,

$$S = \frac{\beta + 1}{1 - \beta\left(\frac{dI_B}{dI_C}\right)}$$

In fixed-bias method of biasing, I_B is independent of I_C so that $dI_B/dI_C = 0$.
Putting the value of $dI_B/dI_C = 0$ in the above expression, we have,

$$\text{Stability factor } S = \beta + 1$$

This method provides poor stabilisation. It is because there is no means to stop a self-increase in collector current due to temperature rise and individual variations.The stability factor is very high. Therefore, there are strong chances of thermal runaway.
Due to these disadvantages, this method of biasing is rarely employed.

Exercise 1.1 (i) A germanium transistor is to be operated at zero signal $I_C = 1mA$ .If the collector supply $V_{CC} = 12V$. what is the value of R_B in the base resisitor method ?Take $\beta = 100$
(ii) If another transisitor of the same batch with $\beta = 50$ is used.What will be the new value zero signal I_C for the same R_B ■

Solution: (i)

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

$$V_{BE} = 0.3V \quad V_{CC} = 12V \quad I_B = \frac{I_C}{\beta}$$

$$I_B = \frac{1mA}{100} = 0.01mA$$

$$R_B = \frac{12 - 0.3}{0.01mA} = \frac{11.7}{0.01mA} = 1170K\Omega$$

(ii) $\beta = 50$

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.3}{1170K\Omega} = 0.01mA$$

$$I_C = \beta I_B = 50 \times 0.01 = 0.5mA$$

Exercise 1.2 Calculate the values of three currents in the circuit shown in Figure?

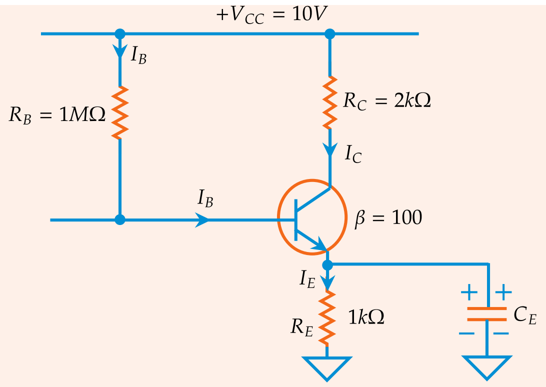


Figure 1.11

Solution: Applying Kirchhoff 's voltage law to the base side and taking resistances in kΩ and currents in mA, we have,

$$V_{CC} = I_B R_B + V_{BE} + I_E \times 1k\Omega$$

we can neglect V_{BE} which is small

$$10 = 1000k\Omega I_B + 0 + (I_C + I_B)$$
$$10 = 1000 I_B + (\beta I_B + I_B)$$
$$10 = 1000 I_B + (100 I_B + I_B)$$
$$10 = 1101 I_B k\Omega$$
$$I_B = 10/1101 = 0.0091 \text{ mA}$$
$$I_C = \beta I_B = 100 \times 0.0091 = 0.91 \text{ mA}$$
$$I_E = I_C + I_B = 0.91 + 0.0091 = 0.919 \text{ mA}$$

1.8.3 Biasing with feedback resistor

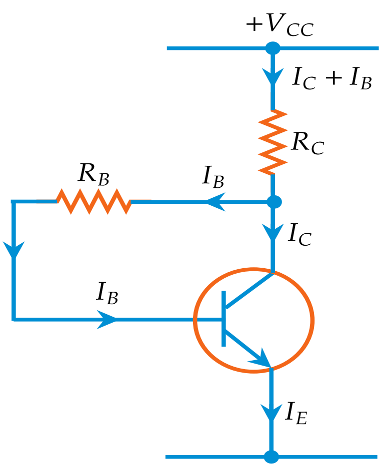


Figure 1.12

In this method, one end of R_B is connected to the base and the other end to the collector as shown in Figure. Here, the required zero signal base current is determined not by V_{CC} but by the collector base voltage V_{CB}.

The required value of R_B needed to give the zero signal current I_C can be determined as follows.

$$V_{CC} = *I_C R_C + I_B R_B + V_{BE}$$
$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B}$$
$$= \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B} \quad (\because I_C = \beta I_B)$$

Alternatively, $V_{CE} = V_{BE} + V_{CB}$ or

$$\text{or} \quad V_{CB} = V_{CE} - V_{BE}$$
$$\therefore \quad R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B}; \quad \text{where} \quad I_B = \frac{I_C}{\beta}$$

Stability factor

Stability factor, $S < (\beta + 1)$
Therefore, this method provides better thermal stability than the fixed bias.

Operating points I_C and V_{CE}

$$I_C = \frac{V_{CC} - V_{BE}}{R_B/\beta + R_C}$$
$$V_{CE} = V_{CC} - I_C R_C$$

Disadvantages

The circuit does not provide good stabilisation because stability factor is fairly high.Therefore, the operating point does change, although to lesser extent, due to temperature variations and other effects.
This circuit provides a negative feedback which reduces the gain of the amplifier.

1.8.4 Voltage divider bias method

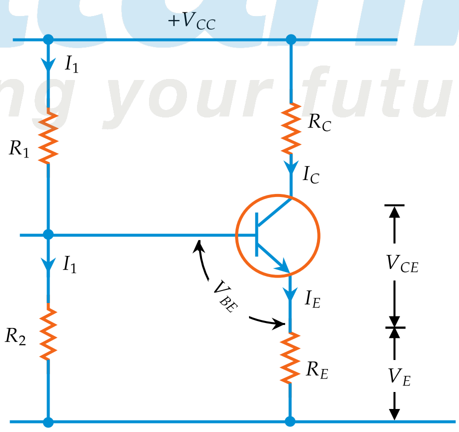


Figure 1.13

This is the most widely used method of providing biasing and stabilisation to a transistor. In this method, two resistances R_1 and R_2 are connected across the supply voltage V_{CC} and provide biasing. The emitter resistance R_E provides stabilisation. The name "voltage divider" comes from the voltage divider formed by R_1 and R_2. The voltage drop across R_2 forward biases the base-emitter junction. This causes the base current and hence collector current flow in the zero signal conditions.
Suppose that the current flowing through resistance R_1 is I_1. As base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1.
(i) **Collector current** I_C :

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

$\therefore$ Voltage across resistance R_2 is

$$V_2 = \left(\frac{V_{CC}}{R_1 + R_2}\right) R_2$$

Applying Kirchhoff's voltage law to the base circuit of Fig. 9.24, or

$$V_2 = V_{BE} + V_E$$
$$V_2 = V_{BE} + I_E R_E$$

or Since $I_E \simeq I_C$

$$\therefore I_C = \frac{V_2 - V_{BE}}{R_E}$$

It is clear from the above expression that I_C does not at all depend upon β. Though I_C depends upon V_{BE} but in practice $V_2 >> V_{BE}$ so that I_C is practically independent of V_{BE}. Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilisation is ensured. It is due to this reason that potential divider bias has become universal method for providing transistor biasing.
(ii) **Collector-emitter voltage V_{CE}**.
Applying Kirchhoff's voltage law to the collector side,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$
$$= I_C R_C + V_{CE} + I_C R_E$$
$$= I_C (R_C + R_E) + V_{CE}$$
$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

Stabilisation.
In this circuit, excellent stabilisation is provided by R_E
Consideration the equation

$$V_2 = V_{BE} + I_C R_E$$

Suppose the collector current I_C increases due to rise in temperature. This will cause the voltage drop across emitter resistance R_E to increase. As voltage drop across R_2 (i.e. V_2) is independent of I_C, therefore, V_{BE} decreases. This in turn causes I_B to decrease. The reduced value of I_B tends to restore I_C to the original value.

Stability factor

$$\text{Stability factor } = (\beta + 1) \times \frac{1}{\beta + 1} = 1$$

This is the smallest possible value of S and leads to the maximum possible thermal stability.

Operating points
We know that

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$
$$\text{when } I_C = 0 \quad V_{CE} = V_{CC}$$
$$\text{and when } V_{CE} = 0 \quad I_C = \frac{V_{CC}}{R_C + R_E}$$

Note Voltage drop across R_2

$$V_2 = \frac{V_{CC}}{R_1 + R_2} . R_2$$

And effective base resistance

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

Application of KVL around the base circuit yields,

$$V = I_B R_B + V_{BE} + I_E R_E$$

Exercise 1.3 A transistor uses potential divider method of biasing. $R_1 = 50\text{k}\Omega, R_2 = 10\text{k}\Omega$ and $R_E = 1\text{k}\Omega$. If $V_{CC} = 12$ V, find :
(i) the value of I_C; given $V_{BE} = 0.1$ V
(ii) the value of I_C; given $V_{BE} = 0.3$ V.

Solution: $R_1 = 50\text{k}\Omega, R_2 = 10\text{k}\Omega, R_E = 1\text{k}\Omega, V_{CC} = 12$ V
(i) When $V_{BE} = 0.1$ V,
Voltage across R_2

$$V_2 = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{10}{50+10} \times 12 = 2 \text{ V}$$

$$V_2 = V_{BE} + I_E R_E \quad I_E \approx I_C$$

$$\therefore \quad Collector current, I_C = \frac{V_2 - V_{BE}}{R_E} = \frac{2-0.1}{1\text{k}\Omega} = 1.9 \text{ mA}$$

(ii) When $V_{BE} = 0.3$ V, Collector current,

$$I_C = \frac{V_2 - V_{BE}}{R_E} = \frac{2-0.3}{1\text{k}\Omega} = 1.7 \text{ mA}$$

1.9 Transisitor amplifiers

A transistor raises the strength of a weak signal and thus acts as an amplifier. The weak signal is applied between emitter-base junction and output is taken across the log R_C connected in the collector circuit.
As the input circuit has low resistance, therefore, a small change in signal voltage causes an appreciable change in emitter current. This causes almost the same change in collector current due to transistor action. The collector current flowing through a high load resistance R_C produces a large voltage across it. Thus, a weak signal applied in the input circuit appears in the amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.

1.9.1 Single stage transistor amplifier

When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as single stage transistor amplifier.
Cicuit analysis

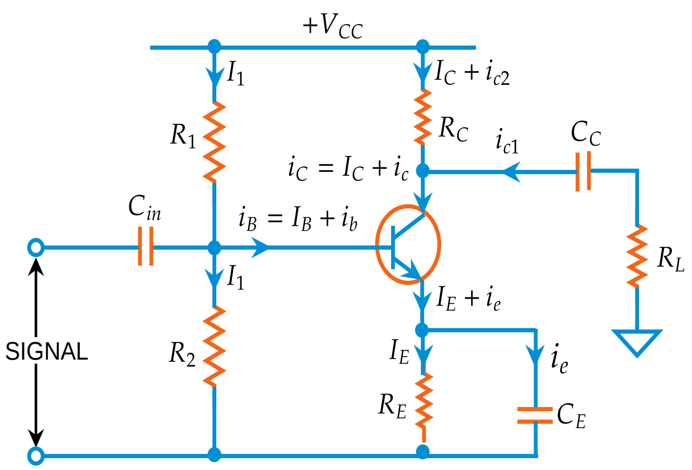


Figure 1.14

(i)**Biasing circuit**
The resistances R_1, R_2 and R_E form the biasing and stabilisation circuit. The biasing circuit must establish a proper operating point otherwise a part of the negative half-cycle of the signal may be cut off in the output.

(ii)**Input capacitor** C_{in}
An electrolytic capacitor $C_{in}(\simeq 10\mu\mathrm{F})$ is used to couple the signal to the base of the transistor. If it is not used, the signal source resistance will come across R_2 and thus change the bias. The capacitor C_{in} allows only a.c. signal to flow but isolates the signal source from R_2*
(iii)**Emitter bypass capacitor** C_E
An emitter bypass capacitor $C_E(\simeq 100\mu F)$ is used in parallel with R_E to provide a low reactance path to the amplified a.c. signal. If it is not used, then amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby reducing the output voltage.
(iv)**Coupling capacitor** C_C The coupling capacitor $C_C(\simeq 10\mu F)$ couples one stage of amplification to the next stage. If it is not used, the bias conditions of the next stage will be drastically changed due to the shunting effect of R_C. This is because R_C will come in parallel with the upper resistance R_1 of the biasing network of the next stage, thereby altering the biasing conditions of the latter. In short, the coupling capacitor C_C isolates the d.c. of one stage from the next stage, but allows the passage of a.c. signal.
(ii)**Phase reversal** In common emitter connection, when the input signal voltage increases in the positive sense, the output voltage increases in the negative direction and vice-versa. In other words, there is a phase difference of 180° between the input and output voltage in CE connection. This is called phase reversal.*

The phase difference of 180° between the signal voltage and output voltage in a common emitter amplifier is known as phase reversal.
(iii)**Voltage gain**

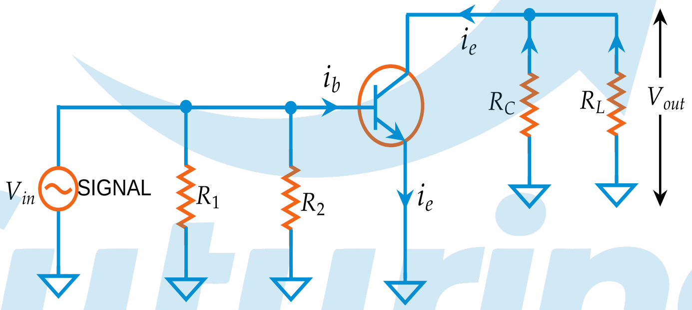


Figure 1.15

The basic function of an amplifier is to raise the strength of an a.c. input signal. The voltage gain of the amplifier is the ratio of a.c. output voltage to the a.c. input signal voltage. Therefore, in order to find the voltage gain, we should consider only the a.c. currents and voltages in the circuit. For this purpose, we should look at the a.c. equivalent circuit of transistor amplifier.
It is clear that as far as a.c. signal is concerned, load R_C appears in parallel with R_L.
Therefore, effective load for a.c. is given by:
a.c. load,

$$R_{AC} = R_C \| R_L = \frac{R_C \times R_L}{R_C + R_L}$$

Output voltage,

$$V_{\mathrm{out}} = i_c R_{AC}$$

Input voltage,

$$V_{in} = i_b R_{in}$$

$\therefore$ Voltage gain, $A_v = V_{oul}/V_{inn}$

$$= \frac{i_c R_{AC}}{i_b R_{in}} = \beta \times \frac{R_{AC}}{R_{in}} \quad \left(\mathrm{Q}\frac{i_c}{i_b} = \beta \right)$$

Incidentally, power gain is given by;

$$A_p = \frac{i_c^2 R_{AC}}{i_b^2 R_{in}} = \beta^2 \times \frac{R_{AC}}{R_{in}}$$

(iv)**Gian and transisitor configurations**

We know that the process of raising the strength of an a.c. signal is called amplification and the circuit used to preform this function is called an amplifier. There are three types of gain : current gain, voltage gain and power gain.
(i) The common emitter (CE) amplifier exhibits all there types gain. From input to output, current will increase, voltage will increase and power will increase.
(ii) The common base (CB) amplifier has voltage gain and power gain but no current gain. Note that the current gain of a CB circuit is less than 1 .
(iii) The common collector (CC) amplifier has current gain and power gain but no voltage gain.

Exercise 1.4 In a transistor amplifier, when the signal changes by 0.02 V, the base current changes by 10μA and collector current by 1 mA. If collector load $R_C = 5\text{k}\Omega$ and $R_L = 10\text{k}\Omega$, find: (i) current gain (ii) input impedance (iii) a.c. load (iv) voltage gain (v) power gain.

Solution: $\Delta I_B = 10\mu\text{A}, \Delta I_C = 1\text{ mA}, \Delta V_{BE} = 0.02\text{ V}, R_C = 5\text{k}\Omega, R_L = 10\text{k}\Omega$
(i) Current gain, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{1mA}{10\mu A} = \mathbf{100}$

(ii) Input impedance, $R_{in} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{0.02V}{10\mu A} = 2\text{k}\Omega$

(iii) a.c. load, $R_{AC} = \frac{R_C \times R_L}{R_C + R_L} = \frac{5\times 10}{5+10} = 3.3\text{k}\Omega$

(iv) Voltage gain, $A_v = \beta \times \frac{R_{AC}}{R_{in}} = 100 \times \frac{3.3}{2} = 165$

(v) Power gain, $A_p =$ current gain $\times$ voltage gain $= 100 \times 165 = 16500$

1.9.2 classificaton of transistor amplifiers

The transistor amplifiers may be classified as to their usage, frequency capabilities, coupling methods and mode of operation.

1. **According to use:**
   The classifications of am-plifiers as to usage are basically voltage amplifiers and power amplifiers.
2. **According to frequency capabilities:**
   According to frequency capabilities, amplifiers are clas-sified as audio amplifiers, radio frequency amplifiers.
3. **According to coupling methods:**
   The output from a single stage amplifier is usually insuf- ficient to meet the practical requirements. Additional amplification is often necessary. To do this, the output of one stage is coupled to the next stage. Depending upon the coupling device used, the amplifiers are classified as R-C coupled amplifiers, transformer coupled amplifiers etc.
4. **According to mode of operation:**
   The amplifiers are frequently classified according to their mode of operation as class A, class B and class C amplifiers.

1.9.3 Multi stage transistor amplifier

A transistor circuit containing more than one stage of amplification is known as multistage transistor amplifier. In a multistage amplifier, a number of single amplifiers are connected in cascade arrangement i.e. output of first stage is connected to the input of the second stage through a suitable coupling device and so on. The purpose of coupling device ($e.g.$ a capacitor, transformer etc.) is,

- To transfer a.c. output of one stage to the input of the next stage.
- To isolate the d.c. conditions of one stage from the next stage.

There are mainly three type of coupling present.

1. **RC coupling**
   A capacitor is used as the coupling device. The capacitor connects the output of one stage to the input of the next stage in order to pass the a.c. signal on while blocking the d.c. bias voltages

2. **In transformer coupling,**
   transformer is used as the coupling device. The transformer coupling provides the same two functions (viz. to pass the signal on and blocking d.c.) but permits in addition impedance matching.

3. **In direct coupling or d.c. coupling.**

The individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for d.c. isolation.

Important terms

1. **Gain**
   The ratio of the output electrical quantity to the input one of the amplifier is called its gain. The gain of a multistage amplifier is equal to the product of gains of individual stages. For instance, if G_1, G_2 and G_3 are the individual voltage gains of a three-stage amplifier, then total voltage gain G is given by :

$$G = G_1 \times G_2 \times G_3$$

2. **Frequency response**
   The voltage gain of an amplifier varies with signal frequency. It is because the reactance of the capacitors in the circuit changes with signal frequency and hence affects the output voltage. The curve between voltage gain and signal frequency of an amplifier is known as frequency re- sponse. The gain of the amplifier increases as the frequency increases from zero till it becomes maximum at f_r , called resonant frequency. If the frequency of signal increases beyond f_r , the gain decreases.

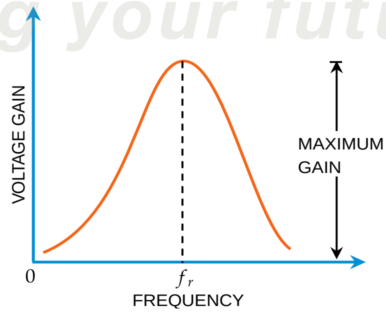


Figure 1.16

3. **Decibel gain**
   The unit assigned for gain is bel or decibel (db). The common logarithm (log to the base 10) of power gain is known as bel power gain i.e.

$$\text{Power gain } = \log_{10} \frac{P_{\text{out}}}{P_{\text{in}}} \text{ bel}$$

$$1 \text{ bel } = 10\text{db}$$

$$\therefore \quad \text{Power gain } = 10 \log_{10} \frac{P_{out}}{P_{in}} db$$

If the two powers are developed in the same resistance or equal resistances, then,

$$P_1 = \frac{V_{in}^2}{R} = I_{in}^2 R$$

$$P_2 = \frac{V_{\text{out}}^2}{R} = I_{\text{out}}^2 R$$

$$\therefore \quad \text{Voltage gain in } db = 10\log_{10}\frac{V_{\text{out}}^2/R}{V_{\text{in}}^2/R} = 20\log_{10}\frac{V_{\text{out}}}{V_{\text{in}}}$$

$$\text{Current gain in } db = 10\log_{10}\frac{I_{\text{out}}^2 R}{I_{\text{in}}^2 R} = 20\log_{10}\frac{I_{\text{out}}}{I_{\text{in}}}$$

4. **Bandwidth.** The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as bandwidth.
In the figure $f_2 - f_1$ is called bandwidth.
The former (f_1) is called lower cut-off frequency and the latter (f_2) is known as upper cut-off frequency.

The bandwidth of an amplifier can also be defined in terms of db. Suppose the maximum voltage gain of an amplifier is 100 . Then 70.7% of it is 70.7. $\therefore$ Fall in voltage gain from maximum gain

$$= 20\log_{10}100 - 20\log_{10}70.7$$

$$= 20\log_{10}\frac{100}{70.7}db$$

$$= 20\log_{10}1.4142db = 3db$$

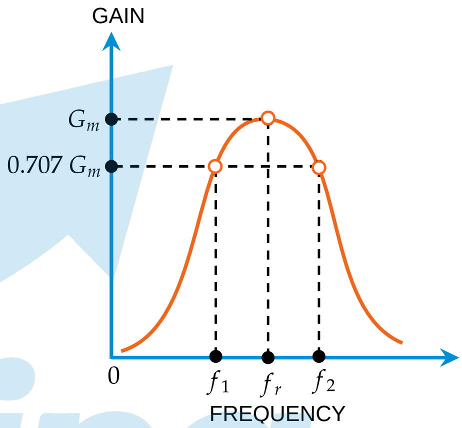


Figure 1.17

Hence bandwidth of an amplifier is the range of frequency at the limits of which its voltage gain falls by 3 db from the maximum gain.
The frequency f_1 or f_2 is also called 3-db frequency or half-power frequency.
The $3-db$ designation comes from the fact that voltage gain at these frequencies is $3db$ below the maximum value. The term half-power is used because when voltage is down to 0.707 of its maximum value, the power (proportional to V^2) is down to $(0.707)^2$ or one-half of its maximum value.

Exercise 1.5 A three-stage amplifier has a first stage voltage gain of 100 , second stage voltage gain of 200 and third stage voltage gain of 400 . Find the total voltage gain in db. ■

Solution:

$$\text{First-stage voltage gain in } db = 20\log_{10}100 = 20\times 2 = 40$$

$$\text{Second-stage voltage gain in } db = 20\log_{10}200 = 20\times 2.3 = 46$$

$$\text{Third-stage voltage gain in } db = 20\log_{10}400 = 20\times 2.6 = 52$$

$$\text{Total voltage gain } = 40+46+52 = 138\text{db}$$

Exercise 1.6 A certain amplifier has voltage gain of 15db. If the input signal voltage is 0.8 V, what is the output voltage? ■

Solution:

$$db \text{ voltage gain } = 20\log_{10} V_2/V_1$$
$$15 = 20\log_{10} V_2/V_1$$
$$15 = 20\log_{10} V_2/0.8V$$
$$V_2 = 10^{\frac{3}{4}} \times 0.8V$$
$$V_2 = 4.5V$$

1.9.4 RC Coupled Transistor Amplifier

This is the most popular type of coupling because it is cheap and provides excellent audio fidelity over a wide range of frequency. It is usually employed for voltage amplification. Figure shows two stages of an *RC* coupled amplifier. A coupling capacitor C_C is used to connect the output of first stage to the base (i.e. input) of the second stage and so on. As the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called resistance - capacitance coupled amplifiers.

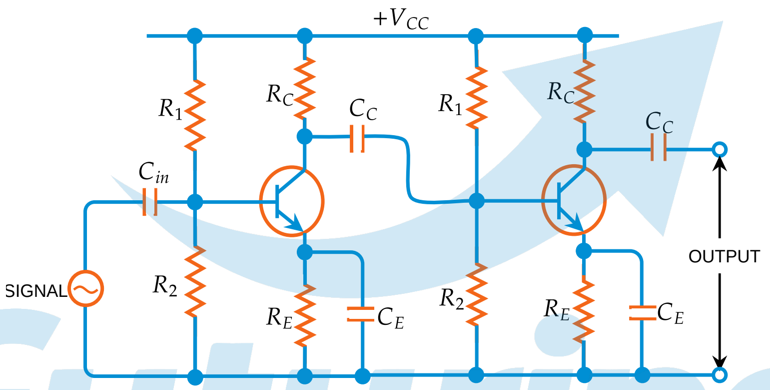


Figure 1.18

The resistances R_1, R_2 and R_E form the biasing and stabilisation network. The emitter bypass capacitor offers low reactance path to the signal. Without it, the voltage gain of each stage would be lost. The coupling capacitor C_C transmits a.c. signal but blocks d.c. This prevents d.c. interference between various stages and the shifting of operating point.

Operation

When a.c. signal is applied to the base of the first transistor, it appears in the amplified form across its collector load R_C. The amplified signal developed across R_C is given to base of next stage through coupling capacitor C_C. The second stage does further amplification of the signal. In this way, the cascaded (one after another) stages amplify the signal and the overall gain is considerably increased.

It may be mentioned here that total gain is less than the product of the gains of individual stages. It is because when a second stage is made to follow the first stage, the effective load resistance of first stage is reduced due to the shunting effect of the input resistance of second stage. This reduces the gain of the first stage.

Frequency response.

The frequency response of a typical RC coupled amplifier.

1. **At low frequencies** (< 50 Hz) the reactance of coupling capacitor C_C is quite high and hence very small part of signal will pass from one stage to the next stage. Moreover, C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies. These two factors cause a falling of voltage gain at low frequencies.

2. **Athigh frequencies** ($>$ 20kHz)The reactance of C_C is very small and it behaves as a short circuit. This increases the loading effect of next stage and serves to reduce the voltage gain. Moreover, at high frequency,

capacitive reactance of base-emitter junction is low which increases the base current. This reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at high frequency.

3. **At mid-frequencies** (50 Hz **to** 20kHz **)**, the voltage gain of the amplifier is constant. The effect of coupling capacitor in this frequency range is such so as to maintain a uniform voltage gain. Thus, as the frequency increases in this range, reactance of C_C decreases which tends to increase the gain. However, at the same time, lower reactance means higher loading of first stage and hence lower gain. These two factors almost cancel each other, resulting in a uniform gain at mid-frequency.

Advantages

1. It has excellent frequency response. The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.

2. It has lower cost since it employs resistors and capacitors which are cheap.

3. The circuit is very compact as the modern resistors and capacitors are small and extremely light.

Disadvantages

1. The *RC* coupled amplifiers have low voltage and power gain. It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.

2. They have the tendency to become noisy with age, particularly in moist climates.

3. Impedance matching is poor. It is because the output impedance of *RC* coupled amplifier isseveral hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

1.10 Transistor oscillators

Sinusoidal Oscillator

An electronic device that generates sinusoidal oscillations of desired frequency is known as a sinusoidal oscillator. A transistor amplifier with proper positive feedback can act as an oscillator *i.e.*, it can generate oscillations without any external signal source.A positive feedback amplifier is one that produces a feedback voltage (V_F) that is in phase with the original input signal.

A phase shift of 180° is produced by the amplifier and a further phase shift of 180° is introduced by feedback network. Consequently,the signal is shifted by 360° and fed to the input i.e., feedback voltage is in phase with the input signal.

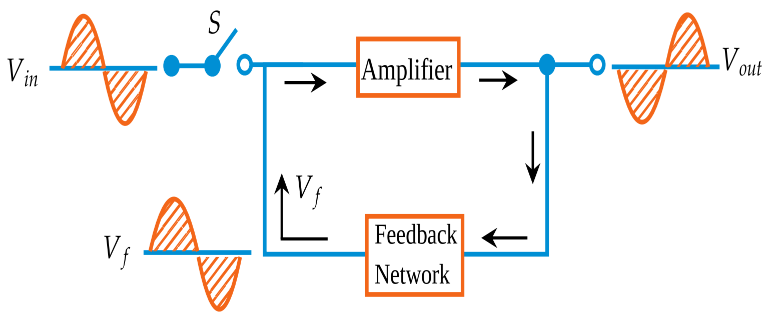


Figure 1.19

When we open the switch S the input signal (V_{in}) is removed. However, V_f (which is in phase with the original signal) is still applied to the input signal. The amplifier will respond to this signal in the same way that it did to V_{in} i.e., V_f will be amplified and sent to the output. The feedback network sends a portion of the output back to the input. Therefore, the amplifier receives another input cycle and another output cycle is produced. This process will continue so long as the amplifier is turned on. Therefore, the amplifer will produce sinusoidal output with no external signal source.

The circuit needs only a quick trigger signal to start the oscillations. Once the oscillations have started, no external signal source is needed. In order to get continuous undamped output from the circuit, the following condition must be met :

$$m_v A_v = 1$$

$$A_v = \text{ voltage gain of amplifer without feedback}$$

$$m_v = \text{ feedback fraction}$$

This relation is called **Barkhausen criterion.**
Explanation. The voltage gain of a positive feedback amplifier is given by;

$$A_{vf} = \frac{A_v}{1 - m_v A_v}$$

If $m_v A_v = 1$, then $A_{vf} \rightarrow \infty$. We know that we cannot achieve infinite gain in an amplifier. It means that a vanishing small input voltage would give rise to finite (i.e., a definite amount of) output voltage even when the input signal is zero. Thus once the circuit receives the input trigger, it would become an oscillator, generating oscillations with no external signal source.

1.10.1 Essentials of a transistor oscilltor

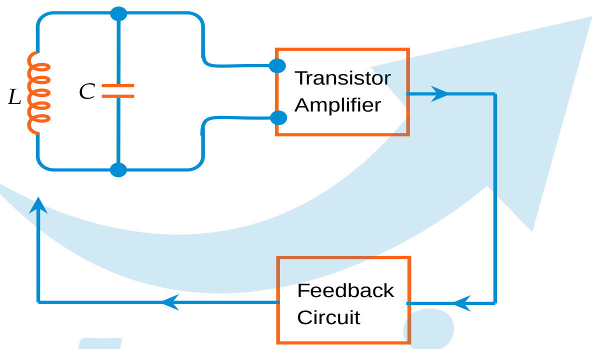


Figure 1.20

1. **Tank circuit**
   It consists of inductance coil (L) connected in parallel with capacitor (C). The frequency of oscillations in the circuit depends upon the values of inductance of the coil and capaci-tance of the capacitor.

2. **Transistor amplifier** The transistor amplifier receives d.c. power from the battery and changes it into a.c. power for supplying to the tank circuit. The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations.

3. **Feedback circuit.** The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations i.e. it provides positive feedback.

1.10.2 Different Types of Transistor Oscillators

The major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses. The following are the transistor oscillators commonly used at various places in electronic circuits:

1. Tuned collector oscillator
2. Colpitt's oscillator
3. Hartley oscillator
4. Phase shift oscillator
5. Wien Bridge oscillator
6. Crystal oscillator

1.10.3 Tuned collector oscillator

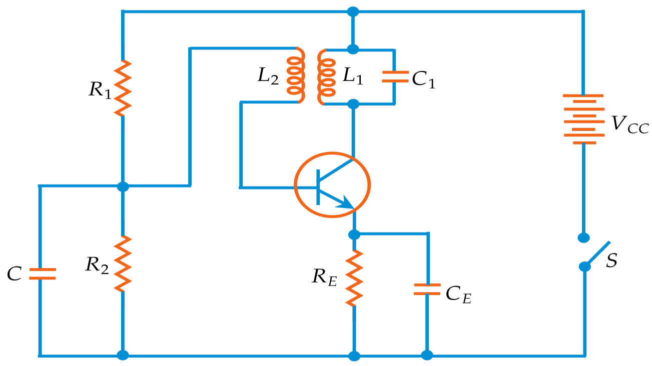


Figure 1.21

Figure shows the circuit of tuned collector oscillator. It contains tuned circuit $L_1 - C_1$ in the collector and hence the name. The frequency of oscillations depends upon the values of L_1 and C_1 and is given by:

$$f = \frac{1}{2\pi\sqrt{L_1C_1}}$$

The feedback coil L_2 in the base circuit is magnetically coupled to the tank circuit coil L_1. In practice, L_1 and L_2 form the primary and secondary of the transformer respectively. The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.

1.10.4 Colpitt's Oscillator

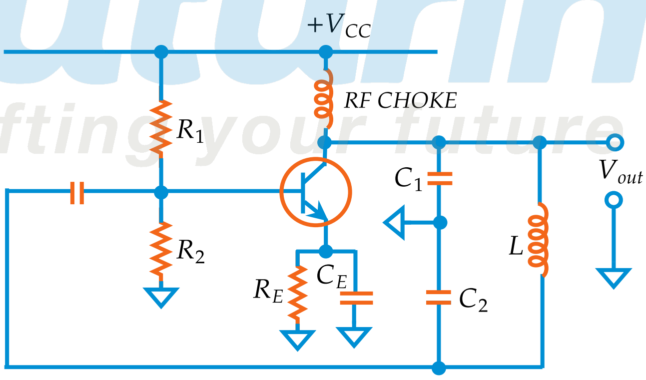


Figure 1.22

Figure shows a Colpitt's oscillator. It uses two capacitors and placed across a common inductor L and the centre of the two capacitors is tapped. The tank circuit is made up of C_1, C_2 and L. The frequency of oscillations is determined by the values of C_1, C_2 and L and is given by ;

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

Note that $C_1 - C_2 - L$ is also the feedback circuit that produces a phase shift of 180°.

1.10.5 Hartley Oscillator

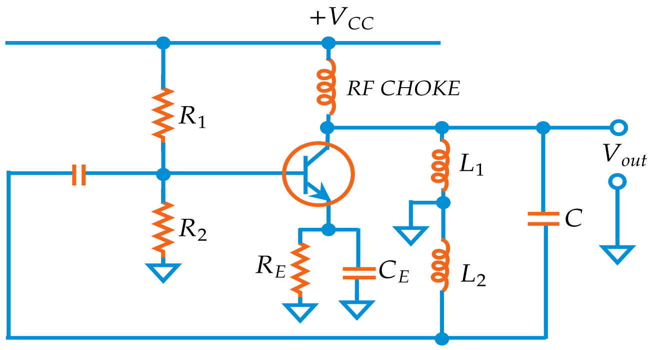


Figure 1.23

The Hartley oscillator is similar to Colpitt's oscillator with minor modifications. Instead of using tapped capacitors, two inductors L_1 and L_2 are placed across a common capacitor C and the centre of the inductors is tapped as shown in Figure. The tank circuit is made up of L_1, L_2 and C. The frequency of oscillations is determined by the values of L_1, L_2 and C and is given by : where

$$f = \frac{1}{2\pi\sqrt{CL_T}}$$
$$L_T = L_1 + L_2 + 2M$$
$$M = \text{ mutual inductance between } L_1 \text{ and } L_2$$

Note that $L_1 - L_2 - C$ is also the feedback network that produces a phase shift of 180°.

1.10.6 Phase Shift Oscillator

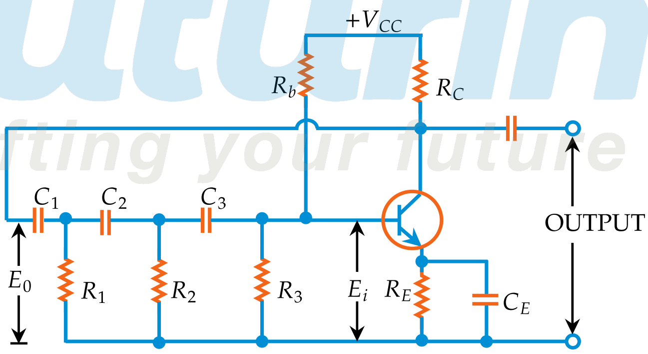


Figure 1.24

Figure shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a RC phase shift network. The phase shift network consists of three sections R_1C_1, R_2C_2 and R_3C_3. At some particular frequency f_0, the phase shift in each RC section is 60° so that the total phase-shift produced by the RC network is 180°. The frequency of oscillations is given by:

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$
$$R_1 = R_2 = R_3 = R$$
$$C_1 = C_2 = C_3 = C$$

1.10.7 Wien Bridge Oscillator

The Wien-bridge oscillator is the standard oscillator circuit for all frequencies in the range of 10 Hz to about 1MHz. It is the most frequently used type of audio oscillator as the output is free from circuit fluctuations and ambient temperature. Figure shows the circuit of Wien bridge oscillator. It is essentially a two-stage amplifier with R - C bridge circuit.

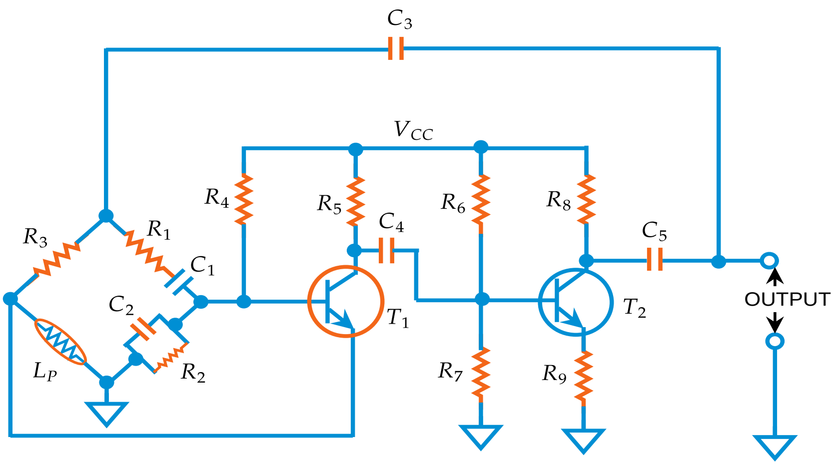


Figure 1.25

The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and tungsten lamp L_p. Resistances R_3 and L_p are used to stabilise the amplitude of the output. The transistor T_1 serves as an oscillator and amplifier while the other transistor T_2 serves as an inverter (i.e. to produce a phase shift of 180°). The circuit uses positive and negative feedbacks. The positive feedback is through R_1C_1, C_2R_2 to the transistor T_1. The negative feedback is through the voltage divider to the input of transistor T_2. The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then,

$$f = \frac{1}{2\pi RC}$$

Advantages

- it gives costant output due to using temperature sensitive tungston lamp L_p
- The overall gain is high because of two transistors.
- The frequency of oscillation can be easily changed by a potentiometer.
- The circuit work quite easily.

Disadvantages

- It cannot generate very high frequency.
- The circuit requires two transistors and a number of component

1.10.8 Limitations of L-C and R-C

- Due to some limitations of $L-C$ and RC oscillators ,we need crystal oscillators.
- LC oscillators are not used at low frequencies because inductor become bulky and costly.
- RC oscillators have not constant frequency and Q factor because of temperature variations.

1.10.9 Crystal oscillator

- Electrical oscillator cicuits are replaced by mechanical variations circuit that is called crystal oscillator.
- Certain crystalline materials ,namely ,roschelle salt,quartz and fourmaline exhibit the piezoelectric effect.
- Of the various piezoelectric crystals,quartz is most commonly used because it is inexpensive and their great mechanical strength.

- When the circuit is not vibrating, it is equivalent to capacitance C_{in} because it has two metal plates separated by a dielectric.
- When a crystal vibrates, it is equivalent R-L-C series circuit.
- Therefore, the equivalent circuit of a vibrating crystal is R-L-C series circuit shunted by the mounting capacitance C_m as shown in figure
- Q factor of crystal $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$
- Q factor of crystal is very high
- The extremely high Q of a crystal leads to frequency stability.

Frequency response of crystal:

- **Case-I:** When $X_C = X_L$ at series resonant

  Impedance of the crystal is very low $Z = R$
  Series resonant frequency $f_S = \frac{1}{2\pi\sqrt{LC}} Hz$

- **Case-II:** At a slightly higher frequency, the net reactance of branch $R-L-C$ inductive and equal to X_{cm}

$$X_L - X_{cm}$$

  The crystal now acts as a parallel resonant circuit Impedance of crystal is very high
  Parallel resonant frequency

$$f_P = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

  where,

$$C_{eq} = \frac{C \times C_m}{C + C_m}, C_{eq} < C$$

Advantages:
- It has a high order of frequency stability.
- The quality factor (Q) of the crystal is very high.

Disadvantages:
- Hardly tunned
- It is fragile and consequently can only be used in low power circuit.

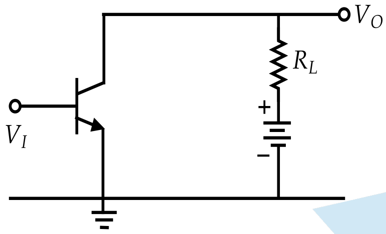
Note At f_S, the crystal will acts as a series resonant circuit.
At f_P, the crystal will acts as a parallel resonant circuit.

Practice Set-1

1. The transistor in the given circuit has $h_{fe} = 35\Omega$ and $h_{ie} = 1000\Omega$. If the load resistance $R_L = 1000\Omega$, the voltage and current gain are, respectively.

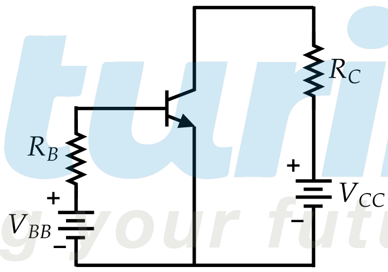
[NET/JRF(JUNE-2012)]

A. -35 and $+35$
B. 35 and -35
C. 35 and -0.97
D. 0.98 and - 35

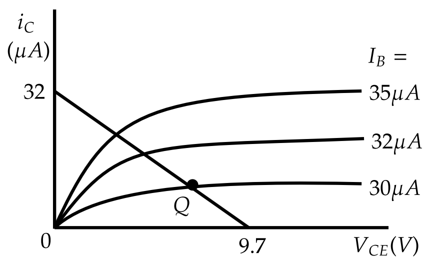


2. A silicon transistor with built-in voltage 0.7 V is used in the circuit shown, with $V_{BB} = 9.7V, R_B = 300k\Omega, V_{CC} = 12V$ and $R_C = 2k\Omega$. Which of the following figures correctly represents the load line and quiescent Q point?

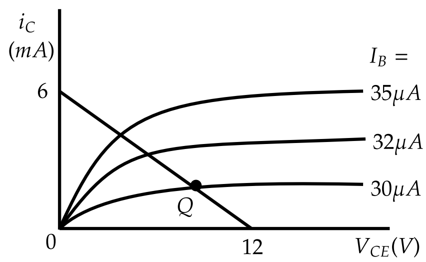
[NET/JRF(JUNE-2013)]



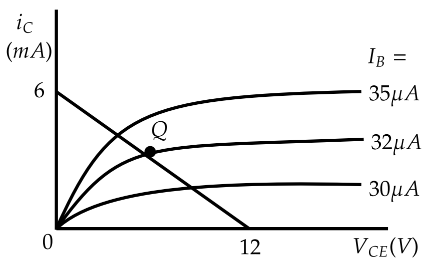
A.



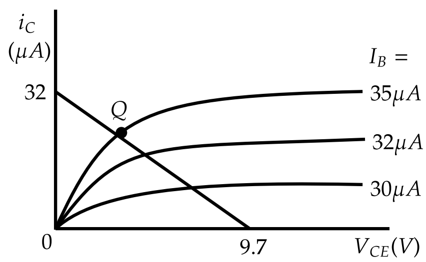
B.



C.



D.



3. The input to a lock-in amplifier has the form $V_i(t) = V_i \sin(\omega t + \theta_i)$ where V_i, ω, θ_i are the amplitude, frequency and phase of the input signal respectively. This signal is multiplied by a reference signal of the same frequency ω, amplitude V_r and phase θ_r. If the multiplied signal is fed to a low pass filter of cut-off frequency ω, then the final output signal is

[NET/JRF(JUNE-2013)]

A. $\frac{1}{2} V_i V_r \cos(\theta_i - \theta_r)$

B. $V_i V_r \left[\cos(\theta_i - \theta_r) - \cos\left(\frac{1}{2}\omega t + \theta_i + \theta_r\right)\right]$

C. $V_i V_r \sin(\theta_i - \theta_r)$

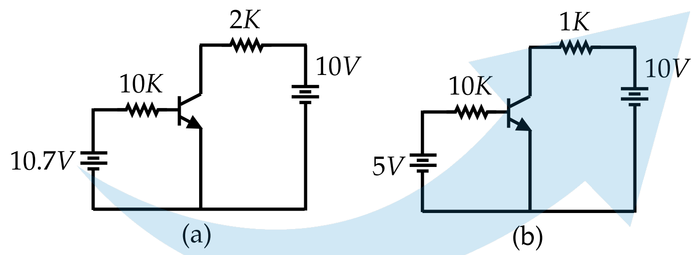
D. $V_i V_r \left[\cos(\theta_i - \theta_r) + \cos\left(\frac{1}{2}\omega t + \theta_i + \theta_r\right)\right]$

4. An RC network produces a phase-shift of 30°. How many such RC networks should be cascaded together and connected to a Common Emitter amplifier so that the final circuit behaves as an oscillator?

[NET/JRF(JUNE-2014)]

A. 6 **B.** 12 **C.** 9 **D.** 3

5. Consider the circuits shown in figures (a) and (b) below



If the transistors in Figures (a) and (b) have current gain (β_{dc}) of 100 and 10 respectively, then they operate in the

[NET/JRF(JUNE-2015)]

A. Active region and saturation region respectively

B. Saturation region and active region respectively

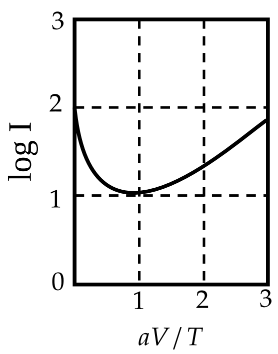
C. Saturation region in both cases

D. Active region in both cases

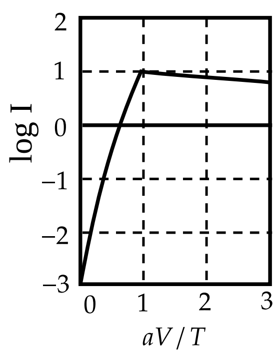
6. The $I - V$ characteristics of a device can be expressed as $I = I_s\left[\exp\left(\frac{aV}{T}\right) - 1\right]$, where T is the temperature and a and I_s are constants independent of T and V. Which one of the following plots is correct for a fixed applied voltage V ?

[NET/JRF(DEC-2016)]

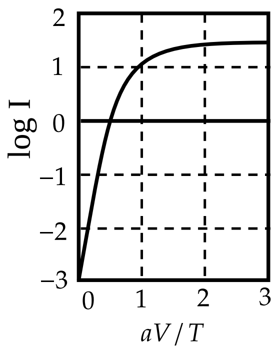
A.



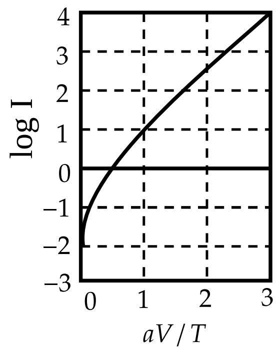
B.



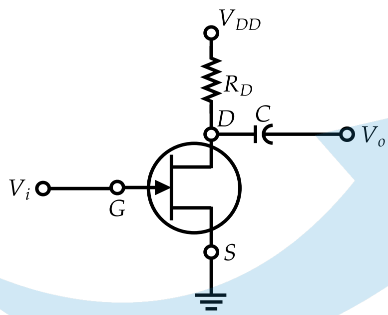
C.



D.



7. In the n-channel JFET shown in figure below, $V_i = -2V, C = 10pF, V_{DD} = +16$ V and $R_D = 2k\Omega$



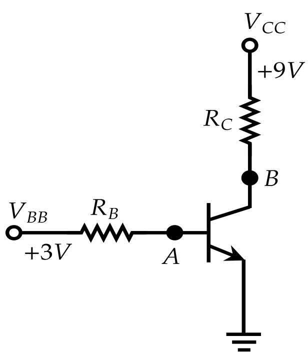
If the drain D - source S saturation current I_{DSS} is $10mA$ and the pinch-off voltage V_P is $-8V$, then the voltage across points D and S is

[NET/JRF(JUNE-2017)]

A. 11.125 V **B.** 10.375 V **C.** 5.75 V **D.** 4.75 V

8. In the circuit below the voltages V_{BB} and V_{CC} are kept fixed, the voltage measured at B is a constant, but that measured at A fluctuates between a few μV to a few mV.
From these measurements it may be inferred that the

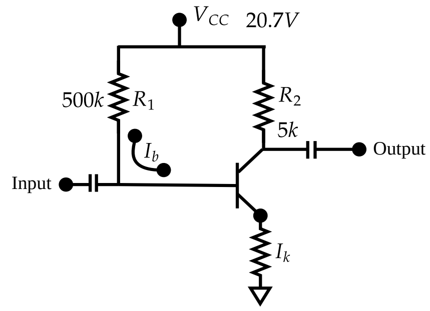
[NET/JRF(DEC-2017)]



A. Base is open internally **B.** Emitter is open internally

C. Collector resistor is open **D.** Base resistor is open

9. In the following circuit, the value of the common-emitter forward current amplification factor β for the transistor is 100 and V_{BE} is 0.7 V.

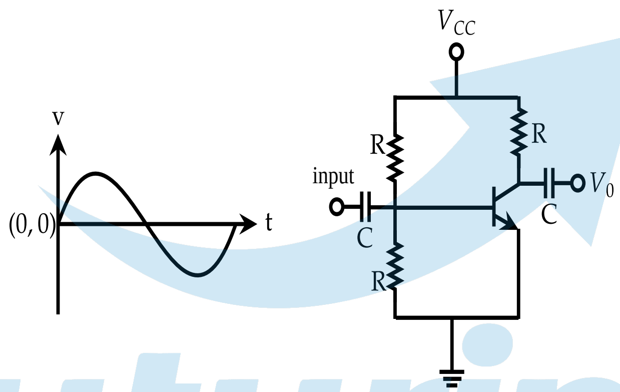


The base current I_B is

[NET/JRF(JUNE-2018)]

A. 40μA **B.** 30μA **C.** 44μA **D.** 33μA

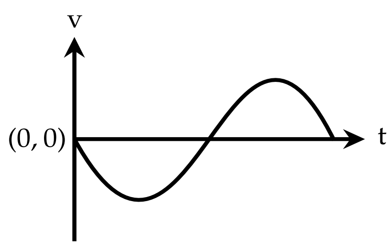
10. A sinusoidal signal is an input to the following circuit



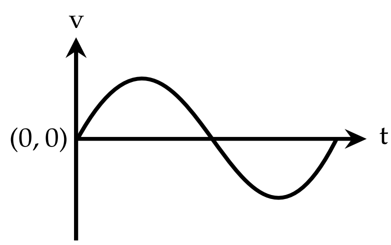
Which of the following graphs best describes the output wave function?

[NET/JRF(DEC-2018)]

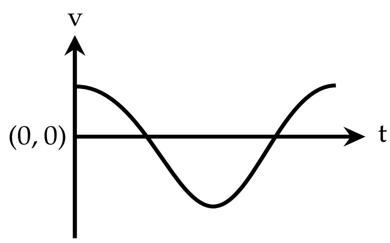
A.



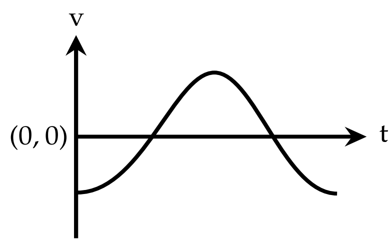
B.



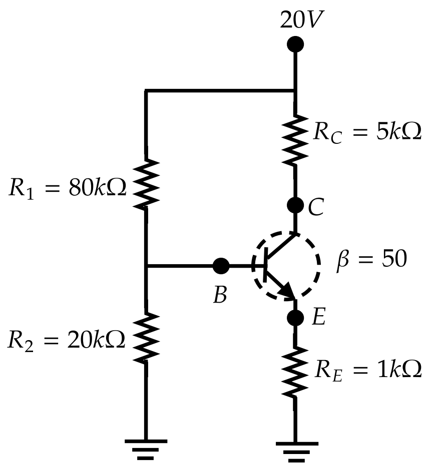
C.



D.



11. An *npn* -transistor is connected in a voltage divider configuration as shown in the figure below



If the resistor R_2 is disconnected, the voltages V_B at the base and V_C at the collector change as follows. **[NET/JRF(JUNE-2019)]**

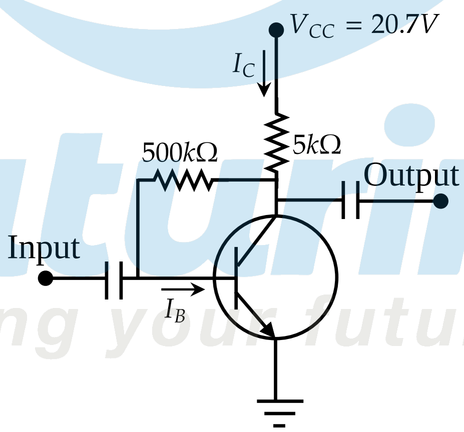
A. Both V_B and V_C increase

B. Both V_B and V_C decrease

C. V_B decreases, but V_C increases

D. V_B increases, but V_C decreases

12. In a collector feedback circuit shown in the figure below, the base emitter voltage $V_{BE} = 0.7V$ and current gain $\beta = \frac{I_C}{I_B} = 100$ for the transistor



The value of the base current I_B is

[NET/JRF(DEC-2019)]

A. $20\mu A$ **B.** $40\mu A$ **C.** $10\mu A$ **D.** $100\mu A$

Answer key			
Q.No.	Answer	Q.No.	Answer
1	**A**	2	**B**
3	**A**	4	**A**
5	**B**	6	**D**
7	**D**	8	**D**
9	**D**	10	**A**
11	**D**	12	**A**

Practice set-2

1. Which of the following statements is CORRECT for a common emitter amplifier circuit? **[GATE 2011]**

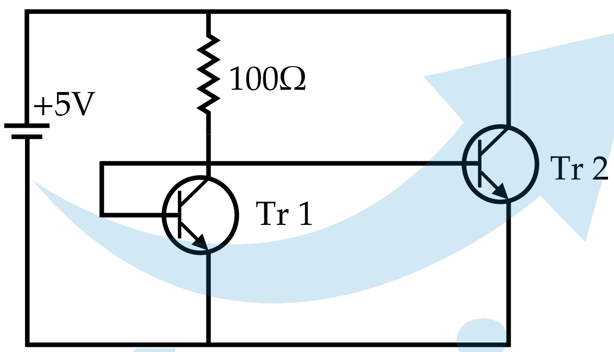
   A. The output is taken from the emitter

   B. There is 180° phase shift between input and output voltages

   C. There is no phase shift between input and output voltages

   D. Both $p-n$ junctions are forward biased

2. In the following circuit, Trl and Tr2 are identical transistors having $V_{BE}=0.7$ V. The current passing through the transistor Tr2 is **[GATE 2011]**

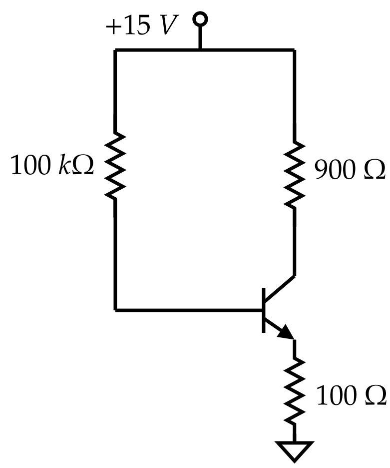


   A. 57 mA **B.** 50 mA **C.** 48 mA **D.** 43 mA

3. If the peak output voltage of a full wave rectifier is 10 V, its d.c. voltage is **[GATE 2012]**

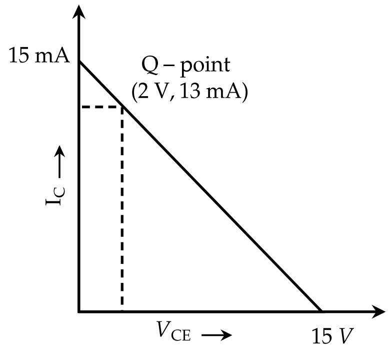
   A. 10.0 V **B.** 7.07 V **C.** 6.36 V **D.** 3.18 V

4. Consider the following circuit in which the current gain β_{dc} of the transistor is 100 .

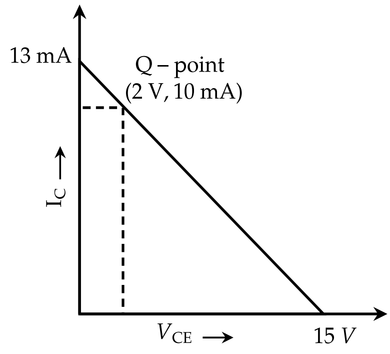


   Which one of the following correctly represents the load line (collector current I_C with respect to collector-emitter voltage V_{CE}) and Q-point of this circuit? **[GATE 2012]**

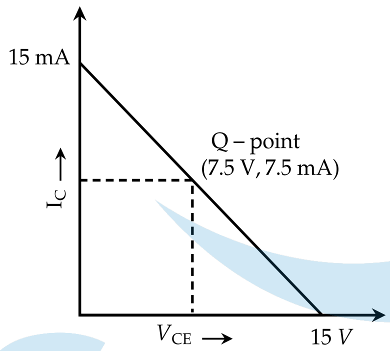
A.



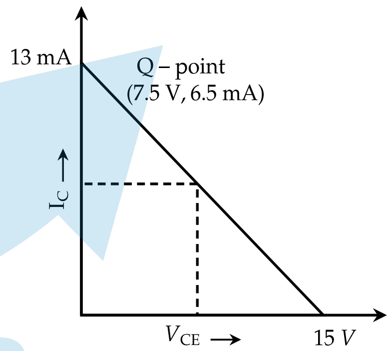
B.



C.

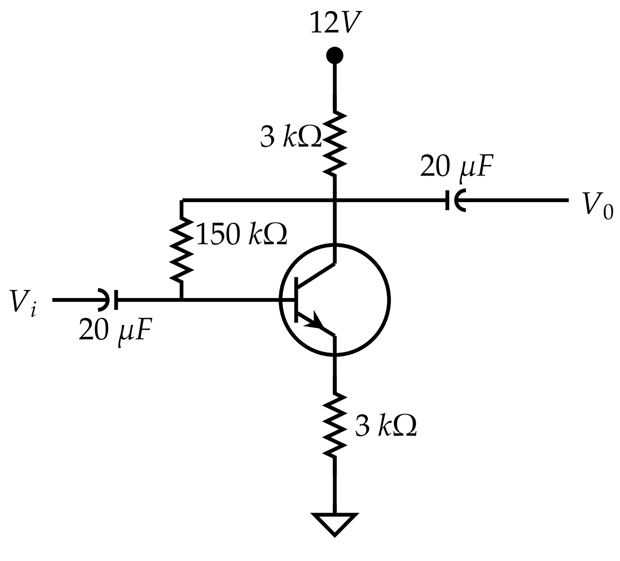


D.

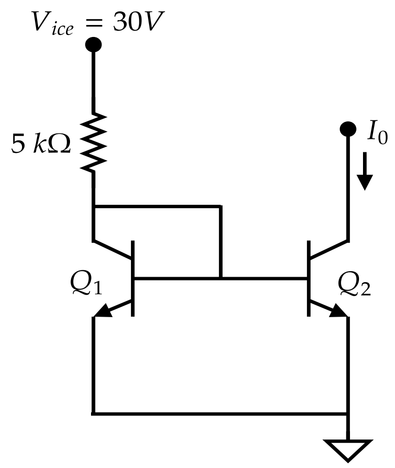


5. The current gain of the transistor in the following circuit is $\beta_{dc} = 100$. The value of collector current I_C is———— mA

[GATE 2014]



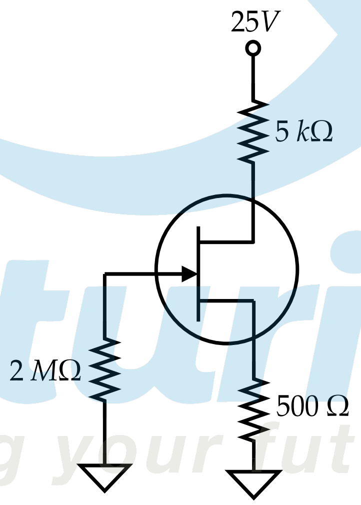
6. In the simple current source shown in the figure, Q_1 and Q_2 are identical transistors with current gain $\beta = 100$ and $V_{BE} = 0.7$ V



The current I_0(in mA) is ———(upto two decimal places)

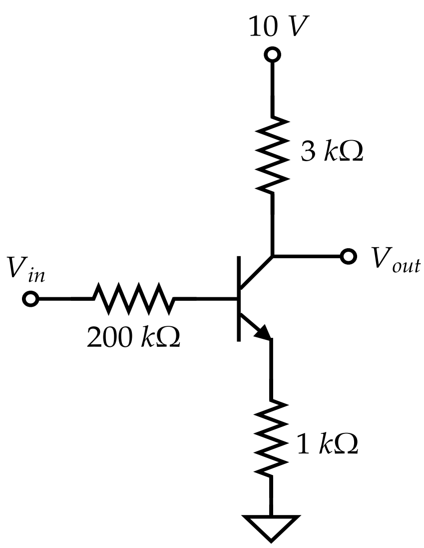
[GATE 2015]

7. In the given circuit, the voltage across the source resistor is $1V$. The drain voltage (in V) is———— **[GATE 2015]**



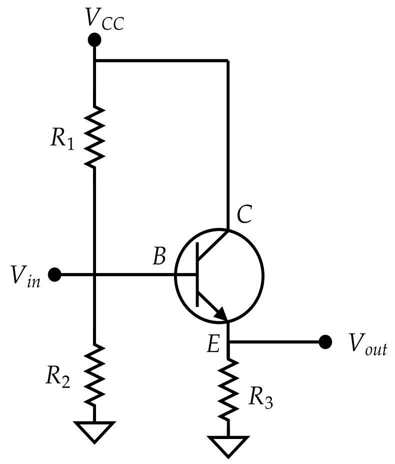
8. For the transistor shown in the figure, assume $V_{BE} = 0.7V$ and $\beta_{dc} = 100$. If $V_{\text{in}} = 5V, V_{\text{out}}$ (in Volts) is ———(Give your answer upto one decimal place)

[GATE 2016]



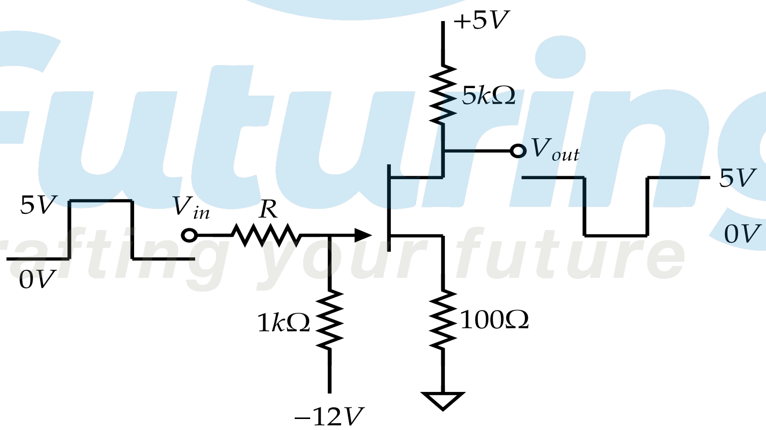
9. For the transistor amplifier circuit shown below with $R_1 = 10\text{k}\Omega, R_2 = 10\text{k}\Omega, R_3 = 1k\Omega$, and $\beta - 99$. Neglecting the emitter diode resistance, the input impedance of the amplifier looking into the base for small ac signal is............ $k\Omega$. (up to two decimal places)

[GATE 2017]



10. An n - channel FET having Gate-Source switch-off voltage $V_{GS(\text{OFF})} = -2V$ is used to invert a $0 - 5V$ square-wave signal as shown. The maximum allowed value of R would be——— $k\Omega$ (up to two decimal places).

[GATE 2018]



11. A transistor in common base configuration has ratio of collector current to emitter current β and ratio of collector to base current α. Which of the following is true?

[JEST 2016]

A. $\beta = \frac{\alpha}{(\alpha+1)}$

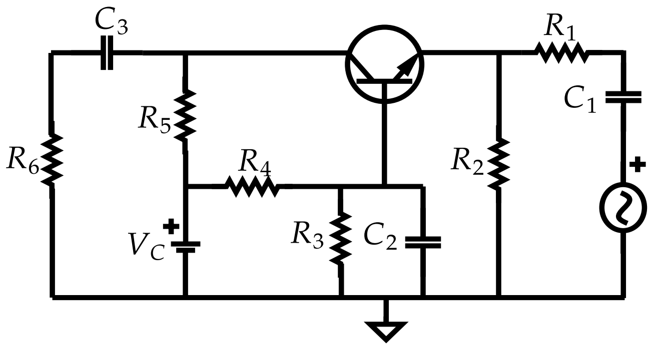
B. $\beta = \frac{(\alpha+1)}{\alpha}$

C. $\beta = \frac{\alpha}{(\alpha-1)}$

D. $\beta = \frac{(\alpha-1)}{\alpha}$

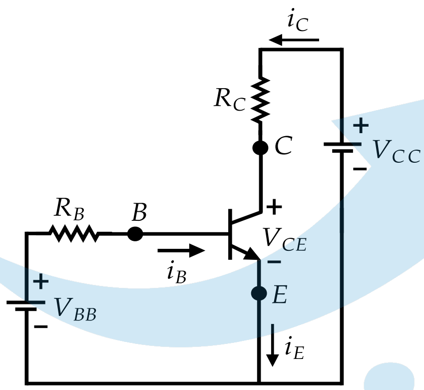
12. What is the DC base current (approximated to nearest integer value in μA) for the following $n-p-n$ silicon transistor circuit, given $R_1 = 75\Omega, R_2 = 4.0k\Omega, R_3 = 2.1k\Omega$, $R_4 = 2.6\text{k}\Omega, R_5 = 6.0\text{k}\Omega, R_6 = 6.8\text{k}\Omega, C_1 = 1\mu F, C_2 = 2\mu F, V_C = +15$ V$\beta_{dc} = 75$?

[JEST 2017]



A. 20 **B.** 24 **C.** 16 **D.** 32

13. Consider the transistor circuit shown in the figure. Assume $V_{BEQ} = 0.7V, V_{BB} = 6V$ and the leakage current is negligible. What is the required value of R_B in kilo-ohms if the base current is to be $4\mu A$?
[JEST 2019]



Answer key			
Q.No.	Answer	Q.No.	Answer
1	**B**	2	**D**
3	**C**	4	**A**
5	**1.6**	6	**5.86**
7	**15**	8	**5.7**
9	**4.75**	10	**0.70**
11	**A**	12	**A**
13	**1325**		

Practice set 3

1. A transistor-oscillator using a resonant circuit with an inductor L (of negligible resistance) and a capacitor C in series produce oscillations of frequency f. If L is doubled and C is changed to 4C, the frequency will be

Solution:

$$f = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$
$$f' = \frac{1}{2\pi}\frac{1}{\sqrt{2L4C}}$$
$$f' = \frac{f}{2\sqrt{2}}$$

2. The β of a transistor is 50 . The input resistance of the transistor when used in the common emitter configuration is 2kΩ. The peak value of the collector AC current for an AC input voltage of 0.02 V peak is

Solution:

$$R_i = 2k\Omega \quad \beta = 50 \quad V_i = 0.02V$$
$$i_b = \frac{0.02}{2\times 10^3} = 10^{-5}A$$
$$\beta = \frac{I_C}{I_B}$$
$$I_C = I_B \times \beta$$
$$= 50 \times 10^5 = 500\mu A$$

3. In CE transistor amplifier, the audio signal voltage across the collector resistance of 2kΩ is 2 V. If the base resistance is 1kΩ and the current amplification of the transistor is 100 , the input signal voltage is

Solution:

$$V_0 = 2V \quad R_C = 2\times 10^3\Omega \quad R_B = 1\times 10^3\Omega \quad v_i = ?$$
$$V_0 = I_C R_C = 2$$
$$I_C = \frac{2}{R_C} = \frac{2}{2\times 10^3} = 10^{-3}$$
$$\beta = \frac{I_C}{I_B} = 100$$
$$I_B = \frac{I_C}{100} = \frac{10^{-3}}{100} = 10^{-5}$$
$$V_i = R_B I_B = 1\times 10^3 \times 10^{-5} = 10mV$$

4. The input signal given to a a CE amplifier having a voltage gain of 150 is $\mathrm{V_i} = 2\cos\left(15\mathrm{t}+\frac{\pi}{3}\right)$. The corresponding output signal will be

Solution:

$$V_i = 2\cos\left(15t+\frac{\pi}{3}\right)$$

voltage gain $A_v = \frac{V_0}{V_i}$

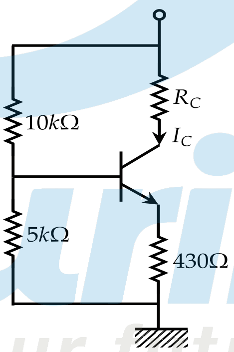
$$V_0 = A_v \times V_i$$

$$= 150 \times 2\cos\left(15t + \frac{\pi}{3}\right)$$
$$= 300\cos\left(15t + \frac{\pi}{3}\right)$$

Input and output are out of phase in CE configuration.So an additional π will come in output voltage

$$V_0 = 300\cos\left(15t + \frac{\pi}{3} + \pi\right)$$
$$= 300\cos\left(15t + \frac{4\pi}{3}\right)$$

5. In circuit shown, assume that the transistor is in active region. It has a large β and its base emitter voltage is 0.7 volts. The value of I_C is



Solution:

$$\beta = \frac{I_C}{I_B}$$
$$I_B = \frac{I_C}{\beta}$$

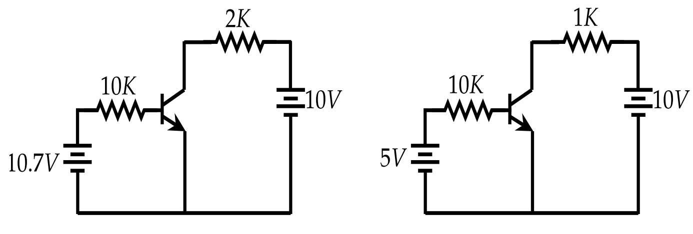
When β is large

$$I_B \approx 0$$

Consider the loop containing base emitter junction.Then

$$V_B = V_{BE} + I_E R_E$$
$$V_B = \frac{15}{10+5} \times 5$$
$$V_B = 5V$$
$$I_E = \frac{V_B - V_{BE}}{R_E}$$
$$I_E = \frac{5-0.7}{430}$$
$$= 10mA$$

6. Consider the circuits shown in figures (a) and (b) below



(a) (b)

If the transistors in Figures (a) and (b) have current gain (β_{dc}) of 100 and 10 respectively, then they operate in the

Solution: In both case input section is F.B.
For figure (a)

$$I_B = \frac{10.7-0.7}{10} = 1 \text{ mA}$$
$$I_C = BI_B = 100 \text{ mA}$$
$$\text{Thus } V_{CB} = V_C - V_B$$
$$= (10-2\times 100) - 0.7 = -ve$$
$$\Rightarrow \quad \text{output section is F.B.}$$

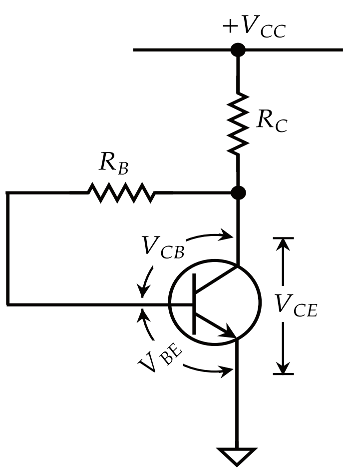
since both section are F.B. so it is in saturation region.

For Figure (b)

$$I_B = \frac{5-0.7}{10} = 0.43 \text{ mA}$$
$$I_C = BI_B = 4.3 \text{ mA}$$
$$\text{Thus } V_{CB} = V_C - V_B$$
$$= (10-4.3) - 0.7 = +ve$$
$$\Rightarrow \quad \text{out put section is R.B.}$$

Thus it is in active region

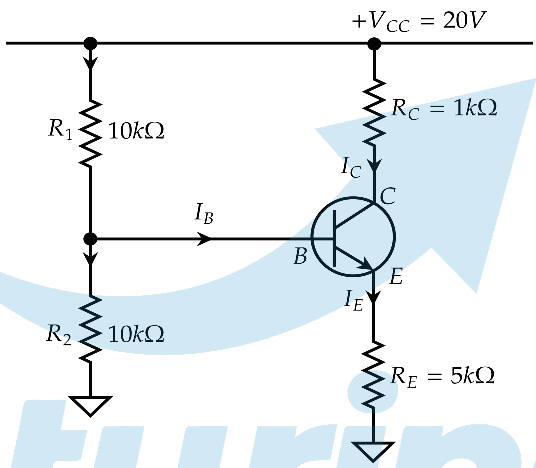
7. It is desired to set the operating point at 2 V, 1 mA by biasing a silicon transistor with collector feedback resistor RB. If $\beta = 100$, find the value of R_B



Solution:

$$I_C = 1mA \quad \beta = 100 \quad V_{CE} = 2V$$
$$\beta = \frac{I_C}{I_B}$$
$$I_B = \frac{I_C}{\beta} = \frac{1mA}{100 = 10} = 10\mu A$$
$$V_{CE} = V_{BE} + V_{CB}$$
$$2 = 0.7V + V_{CB}$$
$$V_{CB} = 2 - 0.7 = 1.3V$$
$$R_B = \frac{V_{CB}}{I_B} = \frac{1.3V}{10\mu A} = 130K\Omega$$

8. Calculate the emitter current in the voltage divider circuit shown in Figure?



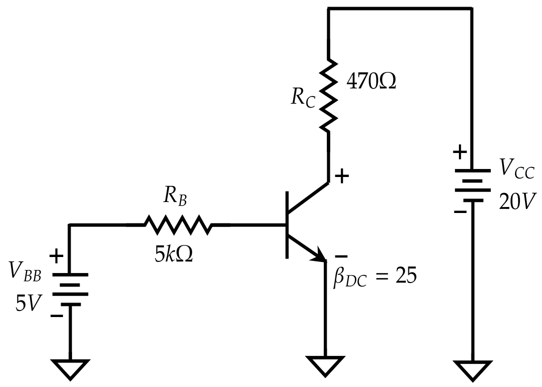
Also find the value of V_{CE} and collector potential V_C

Solution:

$$V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$
$$= \frac{20}{10 + 10} \times 10 = 10V$$
$$V_2 = V_{BE} + I_E R_E$$
$$V_2 = I_E R_E$$
$$I_E = \frac{V_2}{R_E} = \frac{10}{5k\Omega} = 2mA$$
$$I_E \approx I_C$$
$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$
$$V_{CC} = I_E R_C + V_{CE} + I_E R_E$$
$$V_{CC} = V_{CE} + I_E(R_C + R_E)$$
$$V_{CE} = V_{CC} - I_E(R_C + R_E)$$
$$V_{CE} = 20 - 2 \times 10^{-3}(1 + 5) \times 10^3$$
$$= 20 - 12 = 8V$$
$$V_C = V_{CC} - I_C R_C$$
$$= 20 - 2 \times 10^{-3} \times 1 \times 10^3$$

$$20-2=18V$$

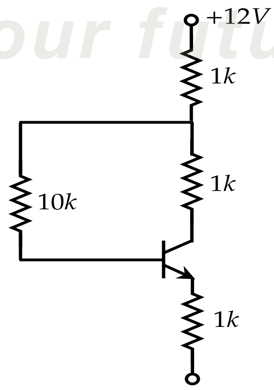
9. Refer to this figure. The value of V_{CE} is?



Solution: Consider the loop containing base resisitor and battery 5V.

$$V_2 = I_BR_B + V_{BE}$$
$$I_BR_B = V_2 - V_{BE}$$
$$5-0.7 = 4.3V$$
$$I_B = \frac{4.3}{5k\Omega} = 0.86mA$$
$$I_C = I_B \times \beta = 0.86\times 25 = 21.5mA$$
$$V_{CC} = I_CR_C + V_{CE}$$
$$V_{CE} = V_{CC} - I_CR_C$$
$$= 20-21.5\times 470\times 10^{-3} = 9.9V$$

10. A transistor having $\alpha = 0.99$ and $V_{BE} = 0.7$ volts, in the circuit shown, then the value of the collector current will be............



Solution: Consider the loop containing collector resisitor $R_C = 1k\Omega$

$$V_{CC} = (I_B+I_C)\times 10^3 + I_C\times 10^3 + V_{CE} + (I_B+I_C)\times 10^3$$
$$I_E = I_B + I_C$$
$$12 = 2I_B + 2I_C + I_C + 0.2V$$
$$11.8 = 3I_C + 2I_B$$

Suppose the transistor is at saturation then $V_{CE(sat)} = 0.2V \quad and \quad V_{BE(sat)} = 0.8V$

Consider the loop containing base resisitor$R_B = 10k\Omega$

$$V_{CC} = (I_B+I_C)1\times 10^3 + I_B\times 10\times 10^3 + V_{CE(sat)} + (I_B+I_C)\times 10^3$$

$$12 = 12I_B + 2I_C + 0.8$$
$$11.2 = 12I_B + 2I_C$$
$$11.8 = 3I_C + 2I_B$$

From these two equations we will get

$$I_C = 3.725mA$$

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