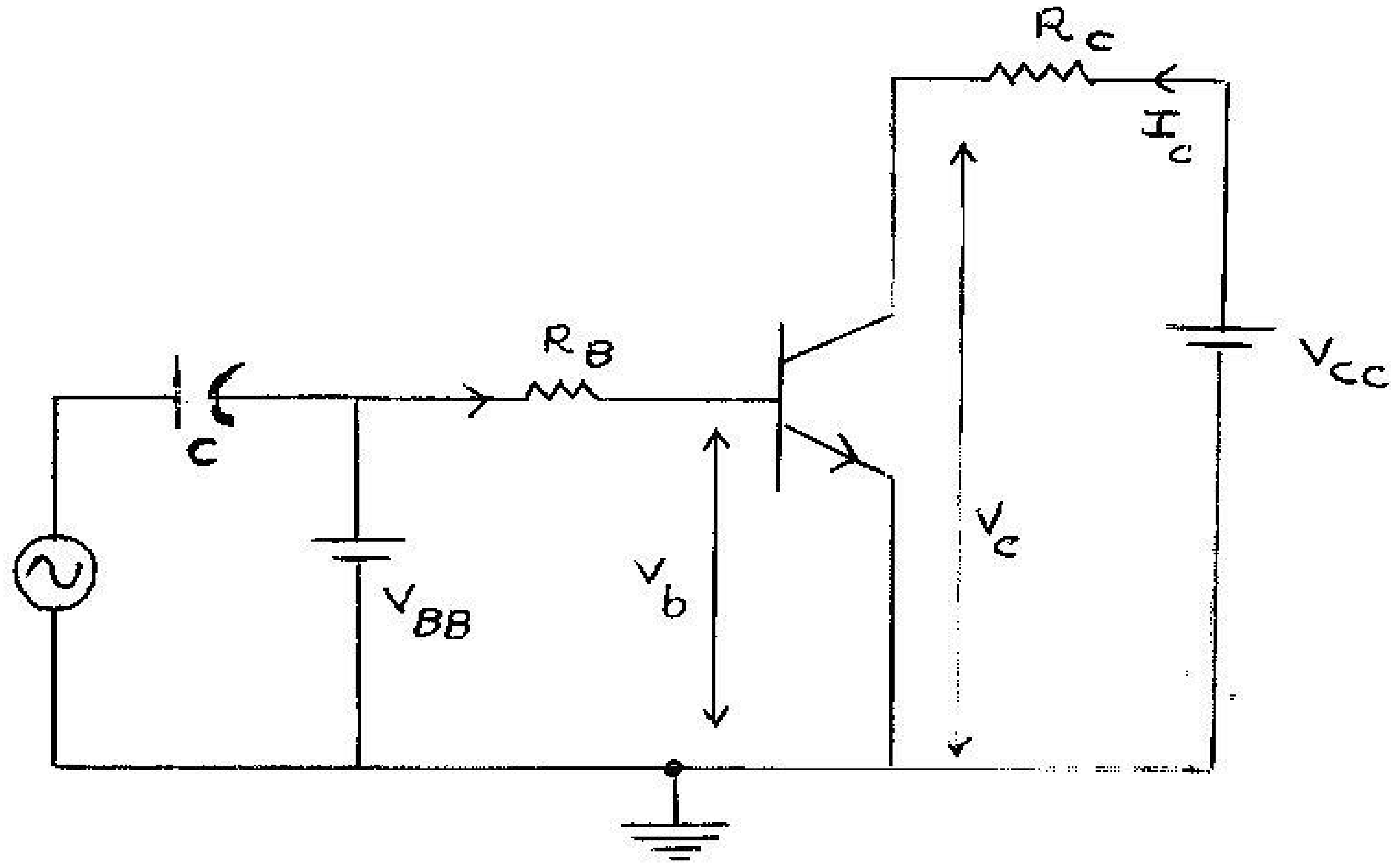
BJT Applications, Feedback Amplifiers and Oscillators

MODULE 04

The BJT as an amplifier :-

Amplification is a process of increasing the amplitude of an electrical signal. Figure below shows the circuit diagram of an amplifier using Bipolar Junction Transistor (BJT). For a BJT to work as an amplifier the emitter base junction should be forward biased and the collector base junction should be reverse biased.



An AC voltage V_s is applied at the input side of the transistor. The DC voltage V_{BB} is used to forward bias the emitter base junction and the DC voltage V_{cc} is used to reverse bias the collector base junction.

The AC input voltage produces an AC base current which results in much larger AC collector current I_c

This AC Collector current produces an AC voltage across R_c thus producing an amplified voltage V_c.

The forward biased emitter base junction presents a very low resistance to the AC signal. This internal AC resistance is denoted as r_e'. Thus we may write

$$V_b = I_e r_e'$$

The AC collector voltage V_c is equal to the AC voltage drop across R_c

$$V_c = I_c R_c$$

Since $I_e \simeq I_c$ the AC collector voltage is

$$V_c \simeq I_e R_c$$

V_b may be considered as the transistor AC input voltage and V_c can be considered as the transistor AC output voltage. Since the voltage gain is defined as the ratio of output voltage to the input voltage, the ratio of V_c to V_b is the AC voltage gain of the transistor given by

$$A_v = \frac{V_c}{V_b} \simeq \frac{I_e R_c}{I_e r_e'}$$

Cancelling I_e we have,

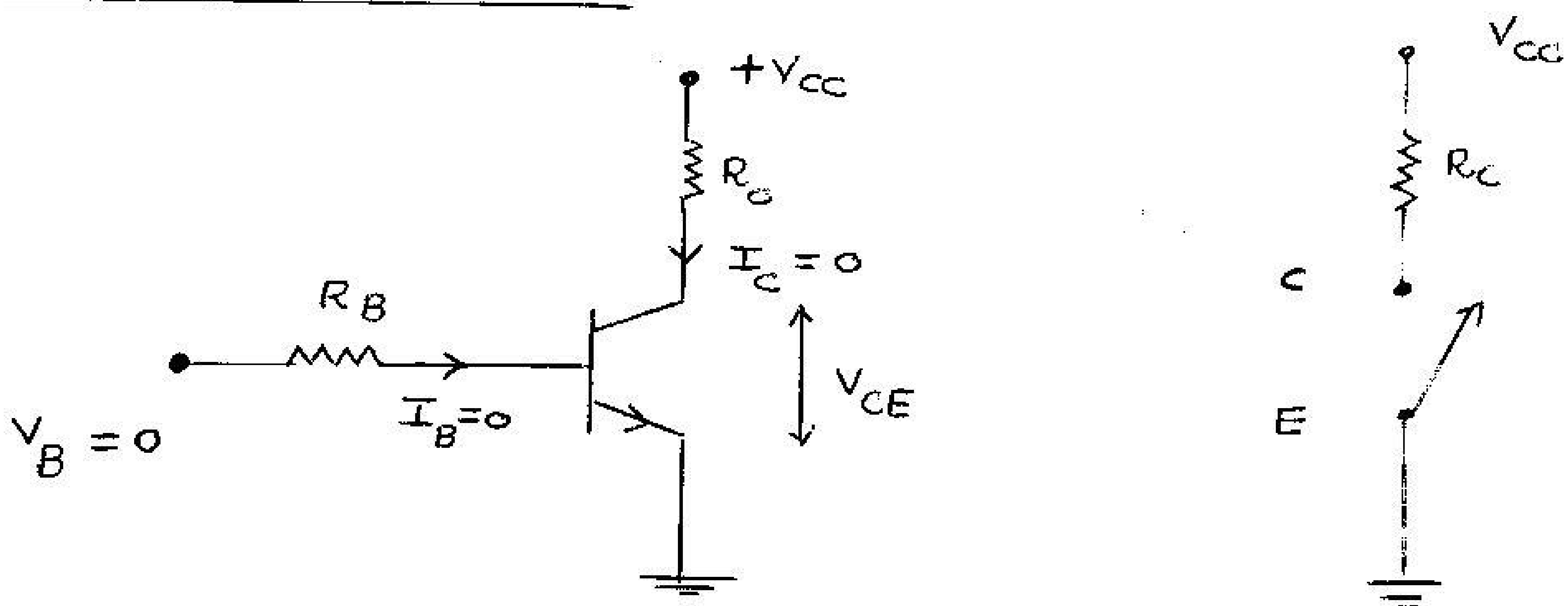
$$A_V \simeq \frac{R_C}{r_e'}$$

Since R_C is always considerably larger in value than r_e', the output voltage is greater than the input voltage.

The BJT as a switch

The second major application of BJT is that it can be used an electronic switch. When used as an electronic switch, the BJT is operated alternately in cutoff mode and saturation.

BJT in cutoff mode :



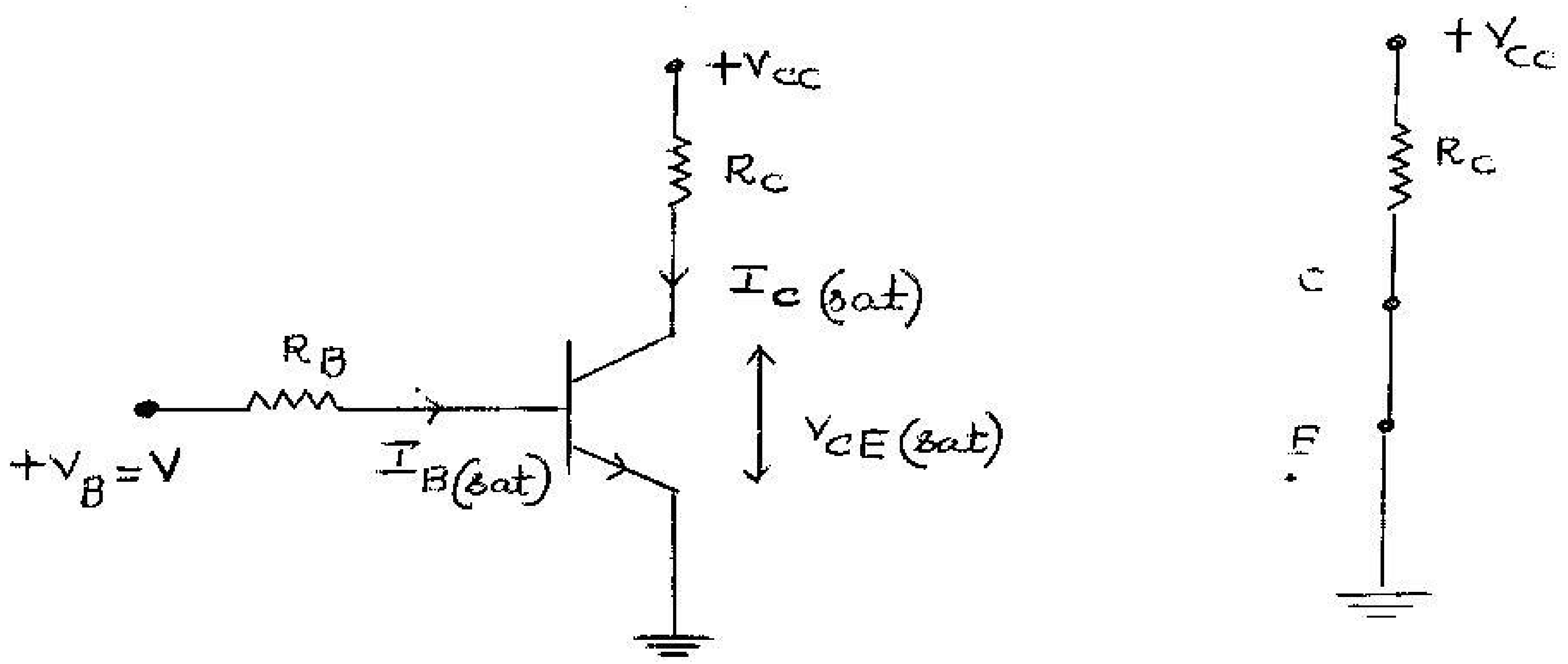
When $V_B = 0V$, the emitter base junction is reverse biased. This makes $I_B = 0$ and hence $I_C = \beta I_B = 0$. The transistor is now in the cutoff mode. Now the transistor acts as an open switch as shown in the figure above

Under cutoff we have

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

$$I_{C\,(cutoff)} = 0$$

BJT in saturation mode :



Here the $V_B = V$ and hence the emitter base junction is forward biased. The base current is made large enough to cause the collector current to reach its saturation value. The transistor is now in the saturation mode and acts as a closed switch as shown in the figure above.

Under saturation we have

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

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

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

The minimum value of base current required to maintain saturation is given by

$$I_{b(min)} = \frac{I_{c(sat)}}{\beta}$$

Transistor Switch Circuit to switch ON/OFF an LED

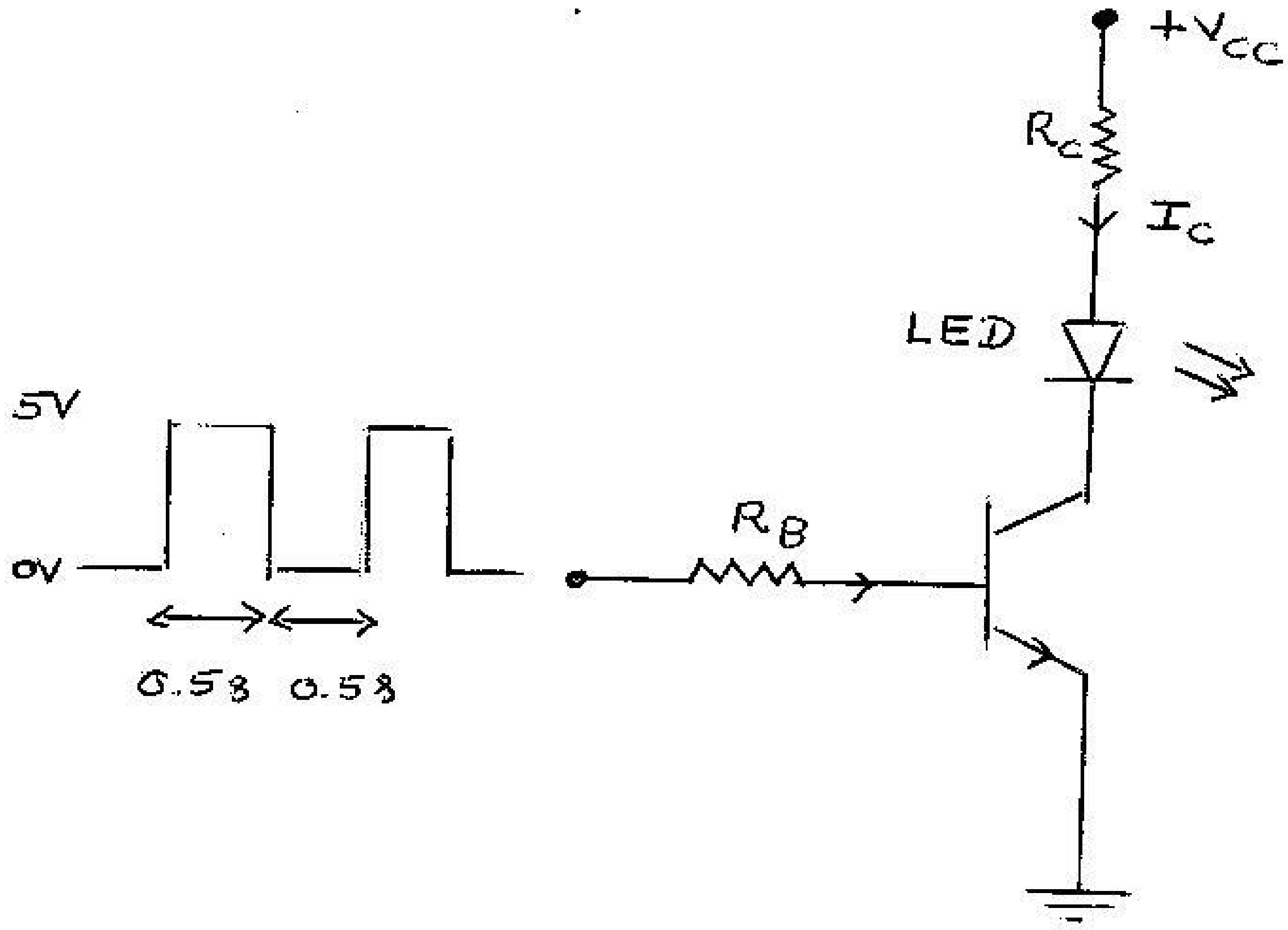


Figure shows the transistor switch circuit to switch the LED ON and OFF. A square wave with a period of 1s (0.5s 0 Volts and 0.5s 5V) is applied as input to the transistor.

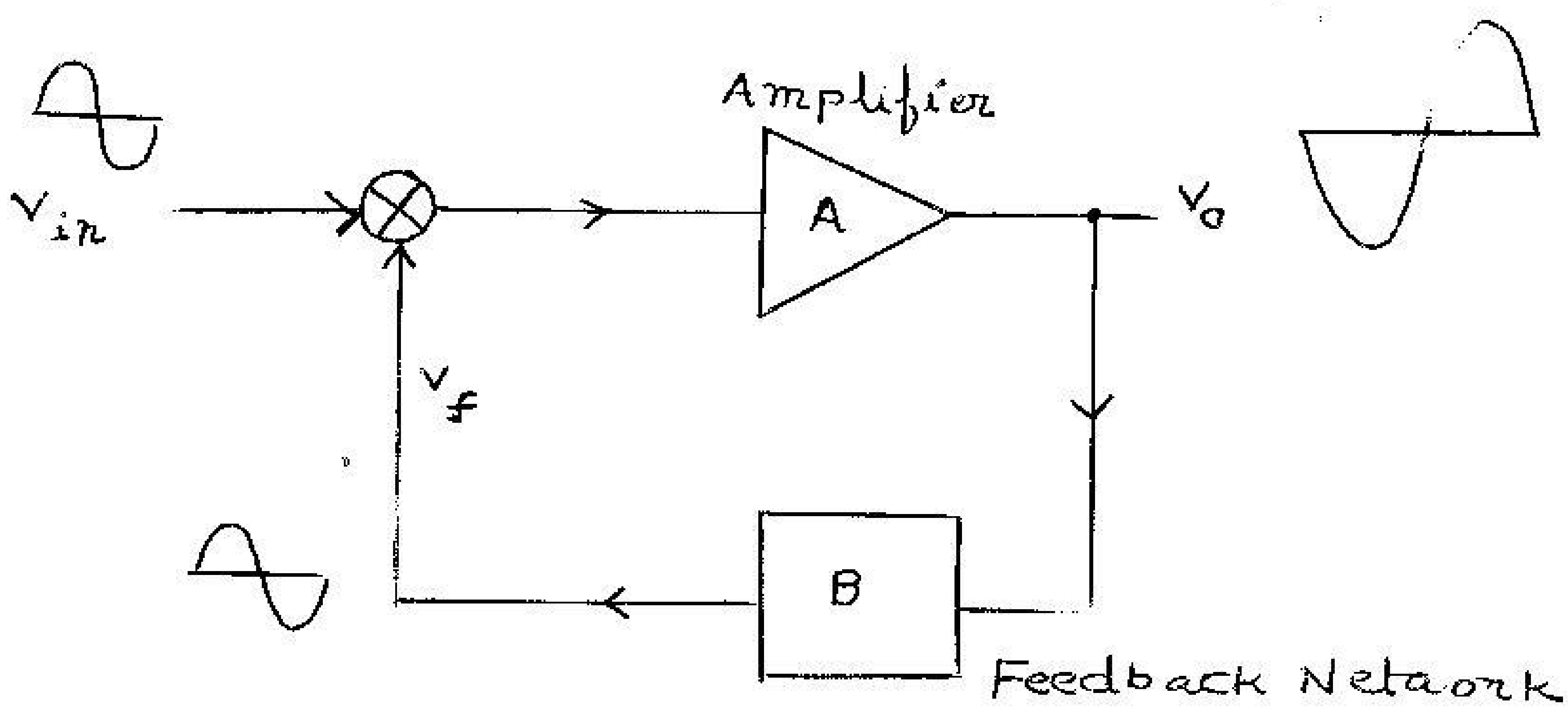
When the square wave is at 0 Volts, the emitter base junction is reverse biased and the transistor will be cutoff and acts an open switch. As a result, the collector current is zero and the LED is switched OFF.

When the square wave is at 5V, the emitter base junction is forward biased and the transistor enters into saturation region. As a result sufficient collector current flows through the LED and hence the LED is switched ON.

Positive and Negative Feedback :-

The process of injecting a fraction of output energy of some device back to the input is known as feedback. There are two types of feedback with respect to electronic amplifiers

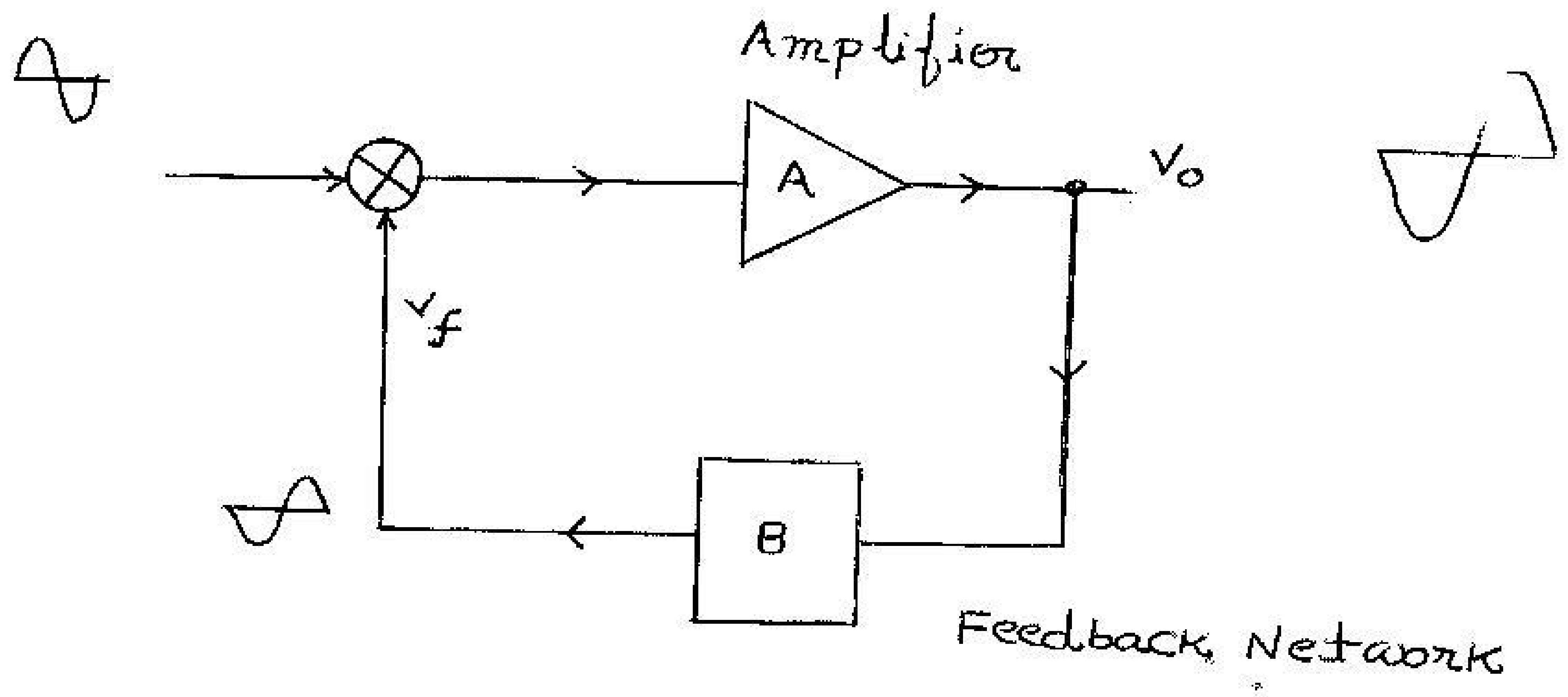
1. Positive feedback amplifier :-



When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback. Both amplifier and feedback network introduce a phase shift of 180°. This results in a 360° phase shift around the loop causing the feedback voltage V_f to be in phase with the input signal V_{in}.

The positive feedback increases the gain of the amplifier. The positive feedback makes the output distorted and causes the system to be unstable.

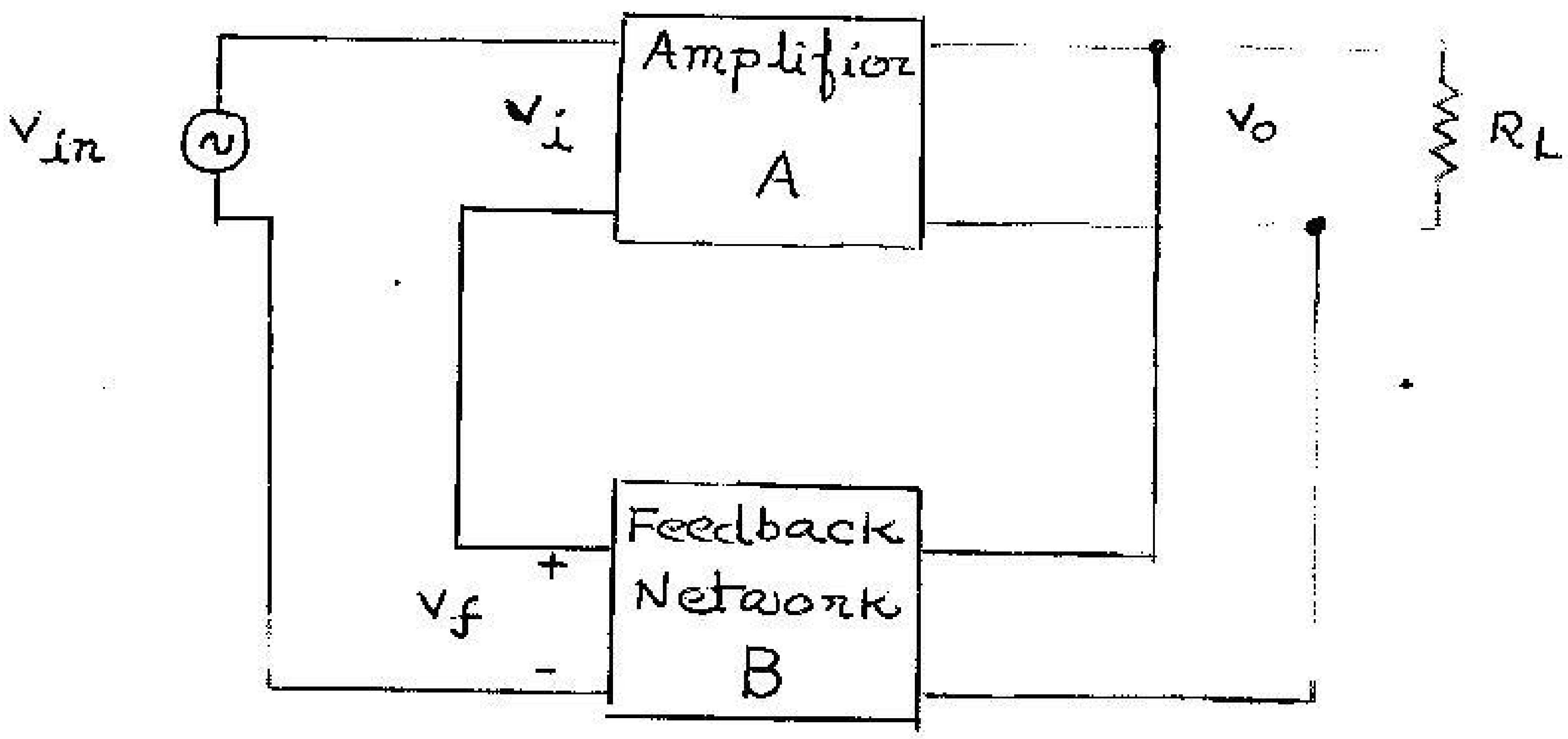
2. Negative feedback amplifier :-



When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called negative feedback. Here the amplifier introduces a phase shift of 180° while the feedback network is designed so that it introduces no phase shift. This results in a 180° phase shift around the loop causing the feedback voltage V_f to be 180° out of phase with the input signal V_{in}.

The negative feedback reduces the gain of the amplifier. However the negative feedback improves the performance of the circuit.

Voltage Series Negative Feedback Amplifier :-



Consider a voltage series feedback amplifier as shown in the figure above. Let A be the gain of the amplifier without feedback. Let B be the feedback fraction of the feedback network.

The output of the feedback network is given by

$$V_f = B V_o$$

The actual input to the amplifier is given by

$$V_i = V_{in} - V_f = V_{in} - BV_o$$

The amplifier output V_o is given by

$$V_o = A V_i$$

$$= A\left(V_{in} - BV_o\right)$$

$$\therefore \quad V_o = \left(\frac{A}{1+AB}\right) V_{in}$$

$$V_o = A_f V_{in}$$

where A_f is the gain of the amplifier with feedback and is given by

$$\boxed{A_f = \frac{A}{1+AB}}$$

It can be shown that the input impedance with feedback is given by

$$Z_{if} = Z_i \left(1+AB\right)$$

where Z_i is the input impedance of the amplifier without feedback. From the expression it is seen that, the input impedance increases due to feedback.

Similarly the output impedance with feedback is given by

$$Z_{of} = \frac{Z_o}{1+AB}$$

where Z_o is the output impedance of the amplier without feedback. From the expression it can be seen that, the output impedance reduces with feedback.

Considering the gain with feedback A_f we have,

$$A_f = \frac{A}{1+AB}$$

If $AB \gg 1$, then the above expression becomes

$$A_f \simeq \frac{A}{AB} = \frac{1}{B}$$

Now it can be seen that, the gain with feedback depends only on the feedback fraction. The feedback fraction is unaffected by changes in temperature, variation in transistor parameters and frequency. Hence the gain of the amplifier with feedback is extremely stable.

Gain Stability with Feedback :-

We know that, the amplifier with feedback has a gain

$$A_f = \frac{A}{1+AB}$$

Differentiating w.r.t A on both sides

$$\frac{dA_f}{dA} = \frac{1}{(1+AB)^2}$$

$$= \frac{1}{(1+AB)} \frac{A_f}{A}$$

On Rearranging,

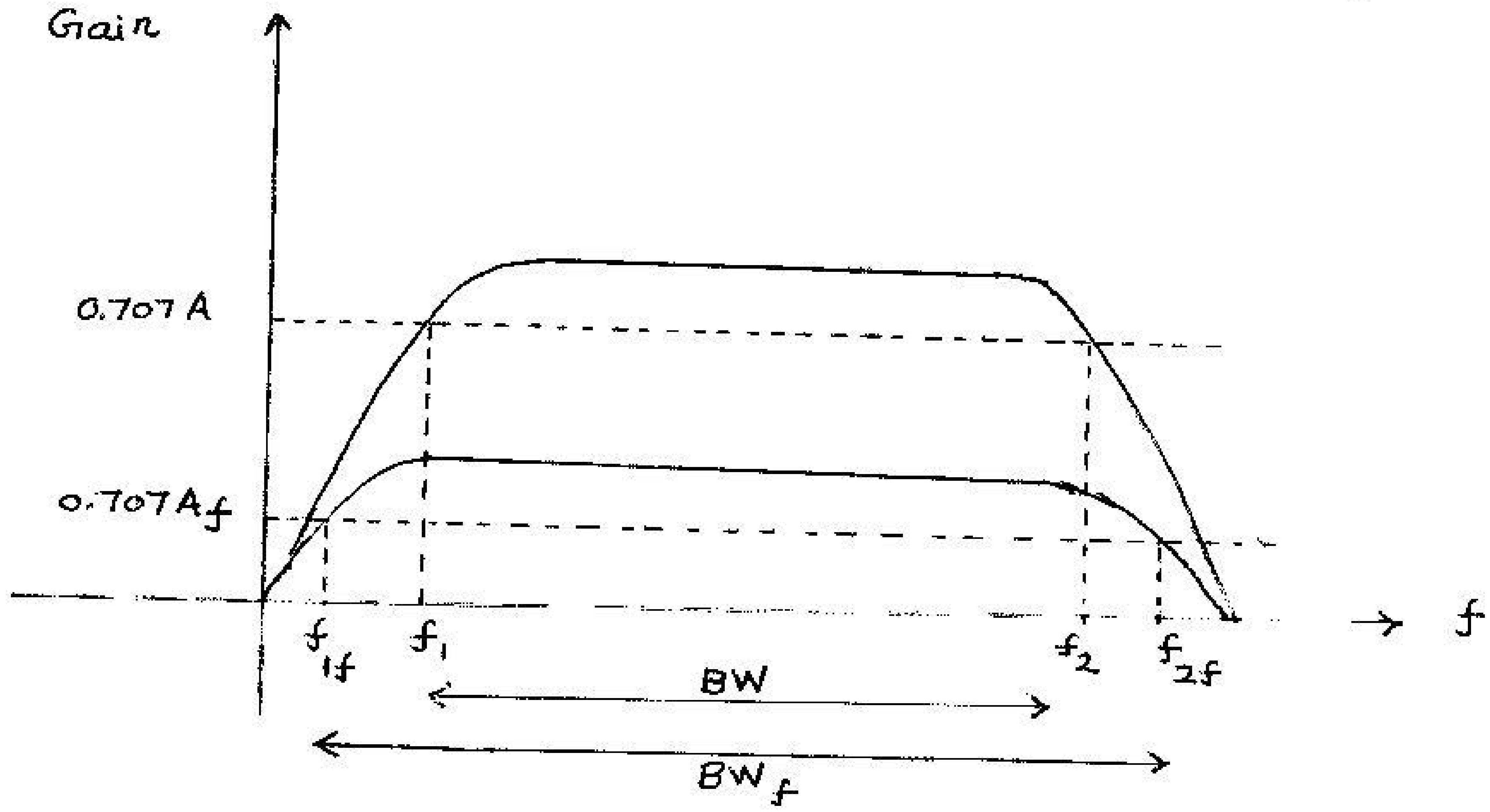
$$\frac{dA_f}{A_f} = \frac{1}{1+AB} \frac{dA}{A}$$

when $AB \gg 1$, we have,

$$\frac{dA_f}{A_f} = \frac{1}{AB}\left(\frac{dA}{A}\right)$$

This shows that the relative change $\frac{dA_f}{A_f}$ in the gain of the amplifier with feedback is reduced by a factor AB.

Gain and Bandwidth of feedback amplifier



Consider a frequency response (graph of gain versus frequency) of an amplifier with and without feedback. It can be seen that the bandwidth of the amplifier with feedback is large when compared with the amplifier without feedback. The increase in bandwidth comes at the cost of reduction in gain. Also it can be shown that the gain bandwidth product is constant for an amplifier with and without feedback. That is

$$A\,(BW) = A_f\,(BW)_f$$

Properties of Negative Feedback Amplifier

1. Desensitize the gain :- Negative Feedback brings stability to the amplifier by making the gain less sensitive to all variations.

2. Reduces Distortion :- Negative feedback makes the output proportional to the input.

3. Reduces the effect of the noise :- It minimizes the contribution by unwanted signals.

4. Controls the input and output impedance :- Negative feedback increases or decreases the input and output impedance.

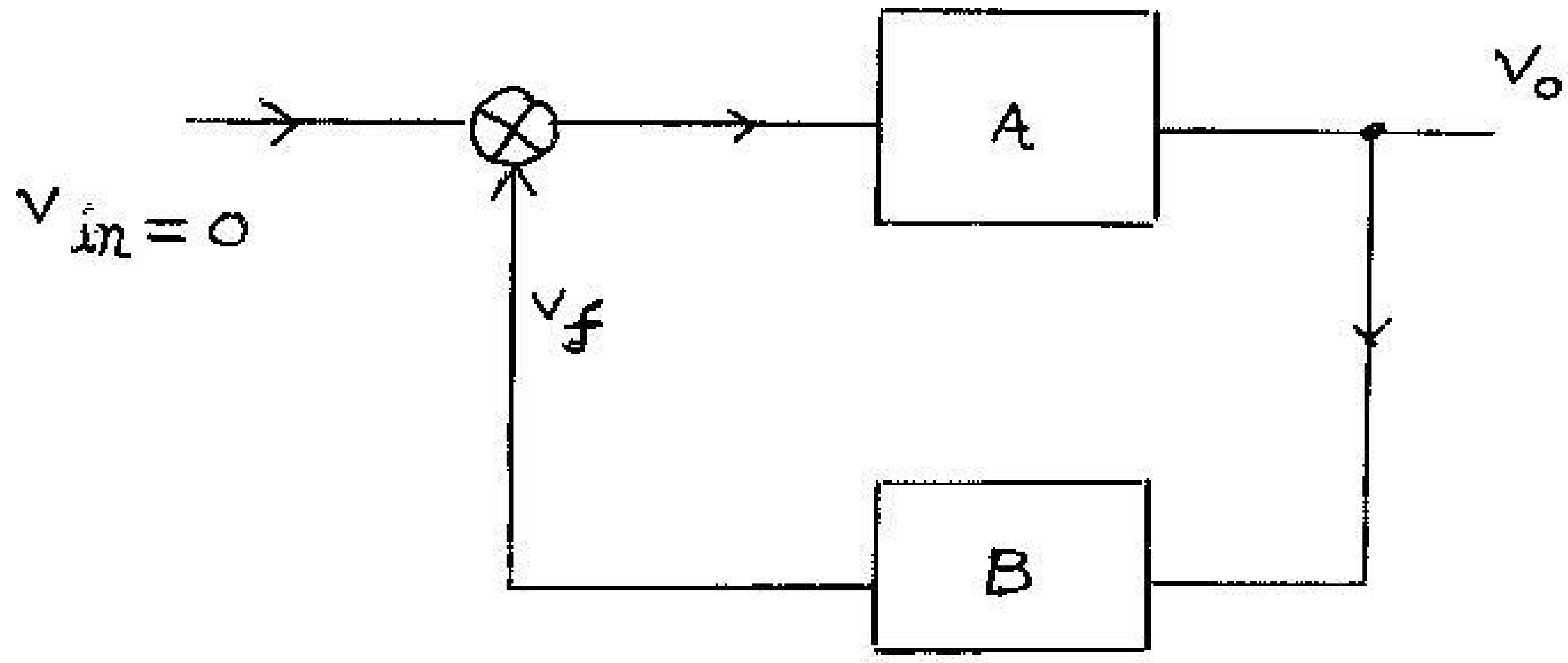
5. Extends the bandwidth of the amplifier :- By using the feedback, the bandwidth can be increased.

Advantages of negative Feedback :-

1. The amplifier gains stability
2. Significant extension of bandwidth
3. Very less distortions
4. Decreased output impedance
5. Reduces noise and other interferences.

Barkhausen Condition of oscillations :-

Consider the schematic of a positive feedback amplifier without input signal as shown below



A is the gain of the amplifier and B is the feedback fraction or attenuation of the feedback network. Since the amplifier and feedback network contains reactive elements, the values of A and B are complex values.

The product AB is called as loop gain. If the value of B is adjusted such that AB = 1, then the circuit becomes self oscillatory. That is the circuit generates sinusoidal oscillations without any input signal. The condition AB = 1 is called Barkhausen Criteria for oscillation. Accordingly to have a sustained oscillations the conditions are as follows:

1. The magnitude of loop gain should be equal to unity. $|AB| = 1$

2. The phase shift around the loop should be equal to 0° or 360° $\angle AB = 0°$ or $360°$

RC Phase Shift Oscillator :-

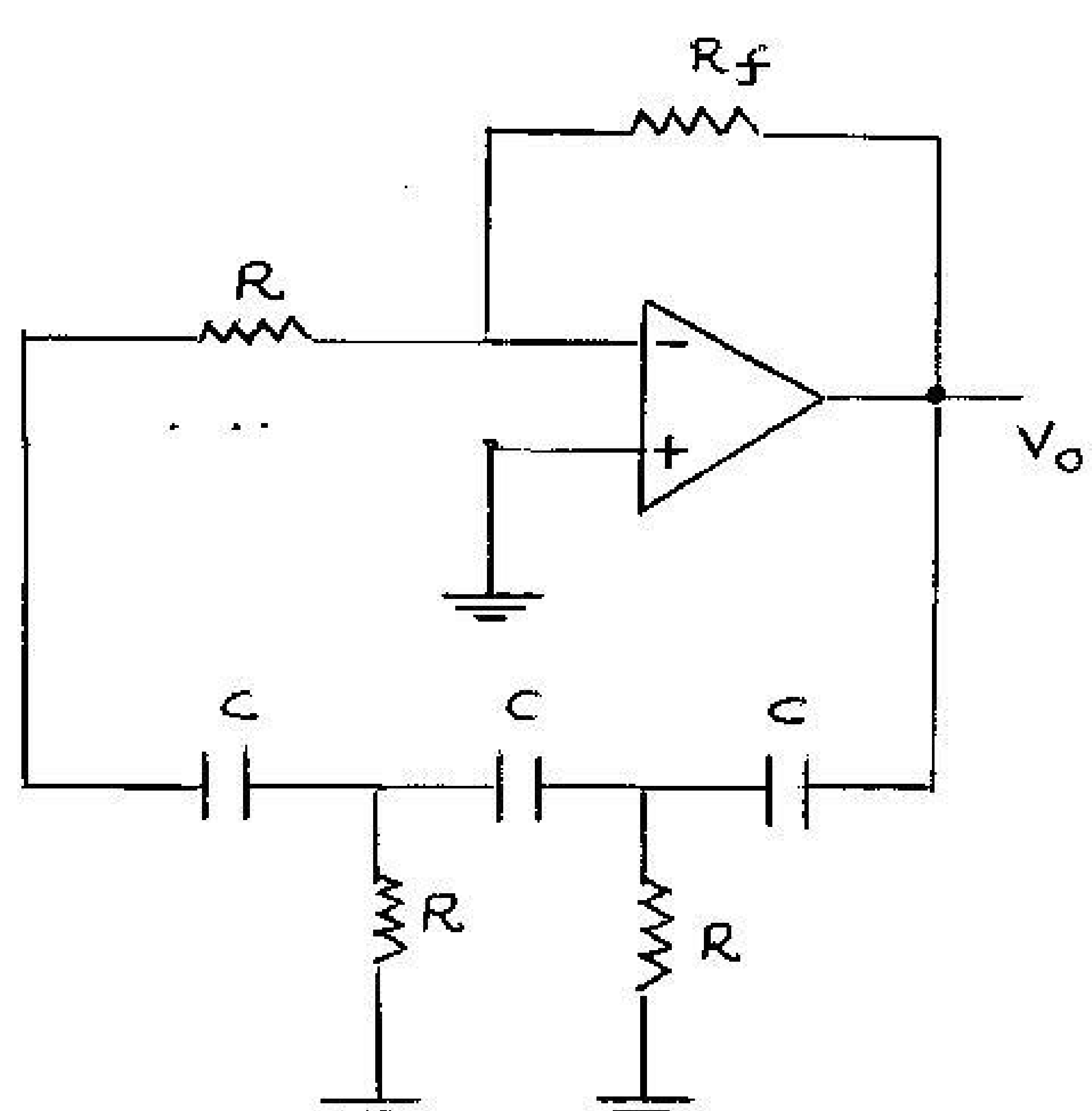


Figure shows the circuit diagram of RC phase shift oscillator, which consists of an inverting amplifier and an RC phase shift network. The amplifier produces a phase shift of 180° and the RC phase shift network produces a phase shift of 180° thus giving a total phase shift of 0° or 360°.

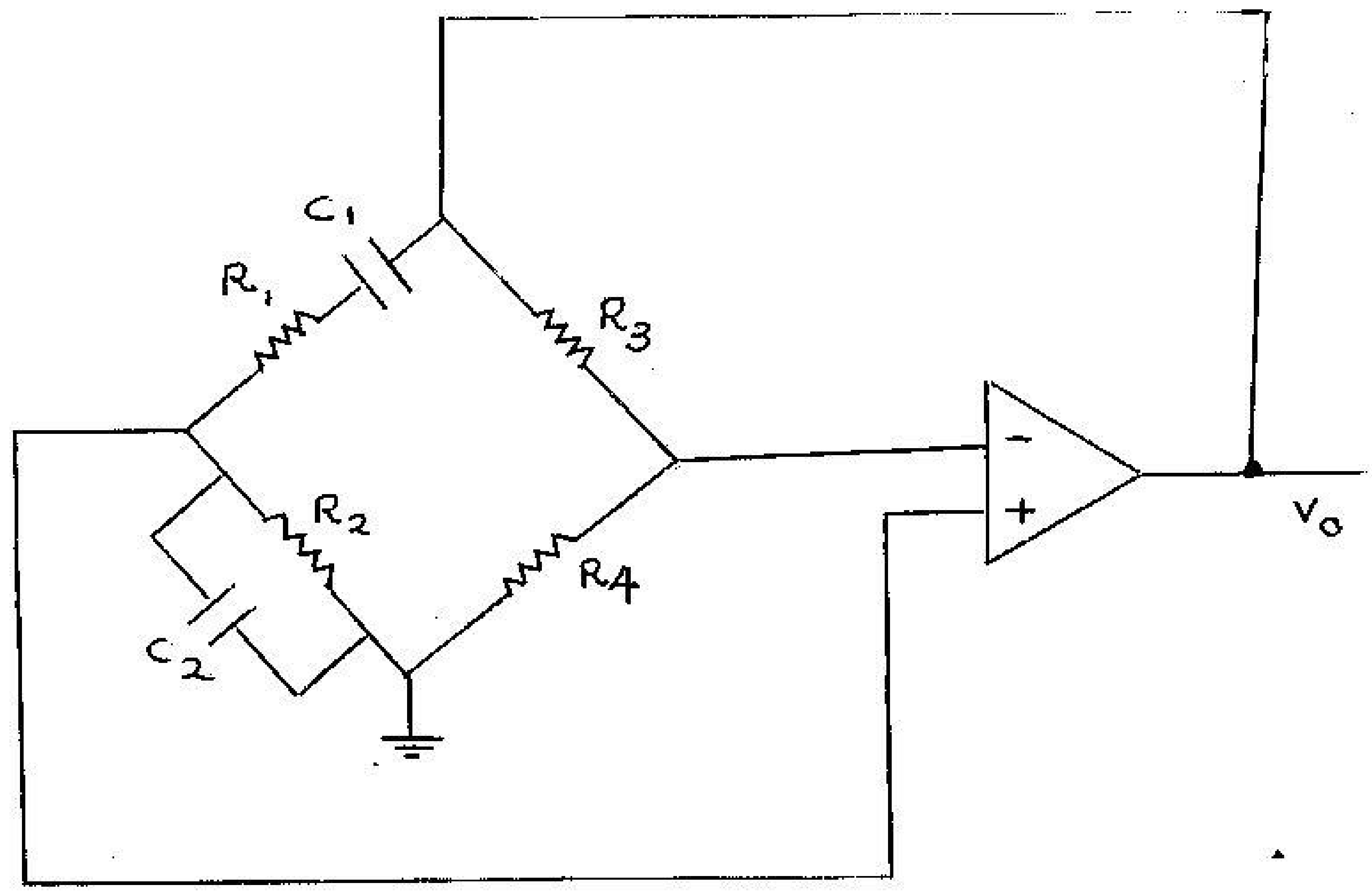
The frequency of the oscillator output depends upon the component values in the RC network. The frequency of oscillation is given by.

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

It can be shown that, when the feedback network produces a phase shift of 180°, the feedback factor B is equal to 1/29. This means, as per the Barkhausen's condition, the amplifier's gain A should be 29. For the inverting amplifier $A = \frac{R_f}{R}$. Thus we have

$$R_f = 29R$$

Wien Bridge Oscillator :-



The Wien Bridge is an AC bridge, that balances at a particular frequency. In the Wien bridge oscillator, two arms of the wien bridge is used as a feedback network. The Wien bridge oscillator is shown in the figure above where the op-amp together with resistors R_3 and R_4 Constitutes the non inverting amplifier. The feeback network is made up of Components C_1, R_1, C_2 and R_2.

At the balance frequency of the Wien bridge, the feedback Voltage is in phase with the amplifier output. Thus the Barkhausen criteria of 300 phase shift around the loop is satisfied.

The frequency of oscillations is given by

$$f = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

Practically the components are selected such that $R_1 = R_2$ and $C_1 = C_2$. Hence the frequency of oscillations is given by

$$f = \frac{1}{2\pi R_1 C_1}$$

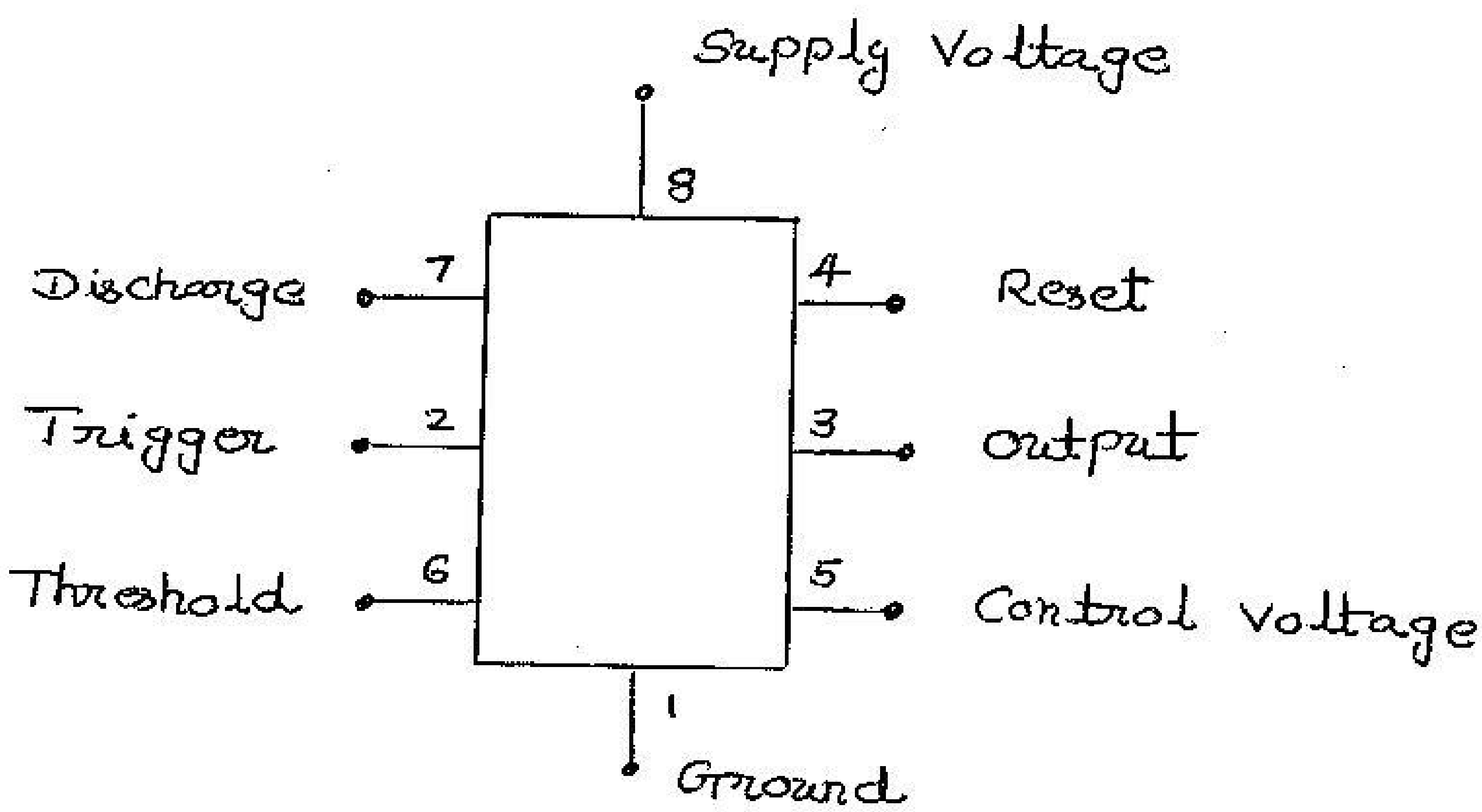
It can be found that the feedback fraction $B = \frac{1}{3}$. To satisfy the Barkhausen Condition of oscillations we have $A = 3$ so that $AB = 1$. Thus we have

$$A = 1 + \frac{R_3}{R_4} = 3$$

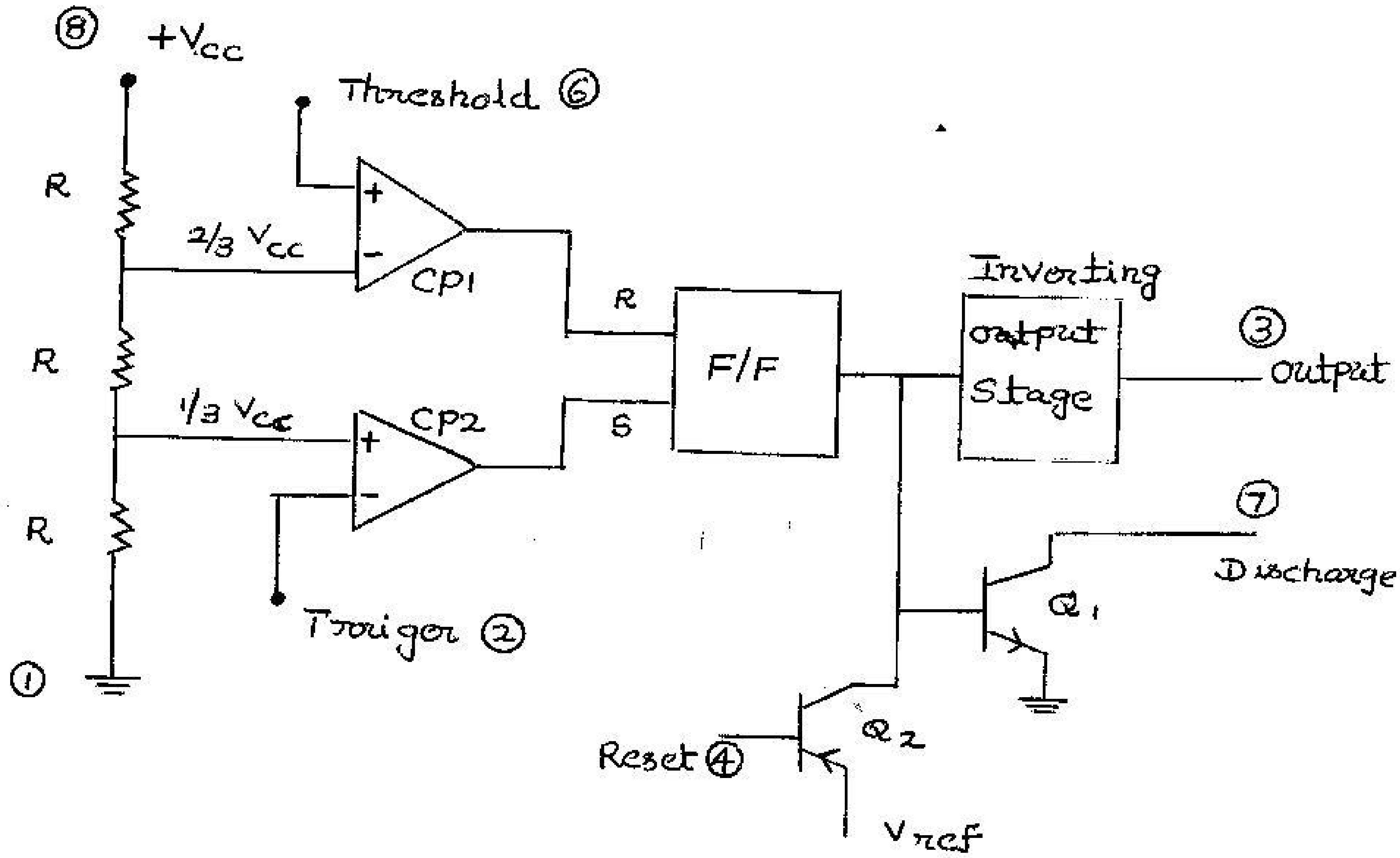
$$\therefore \quad R_3 = 2R_4$$

IC 555 Timer :-

The 555 Timer is a popular IC (Integrated Circuit) used to generate pulses of required width and frequency. The IC is available in a 8-pin package as shown below:



The detailed circuitry is shown below:



The component parts are as follows

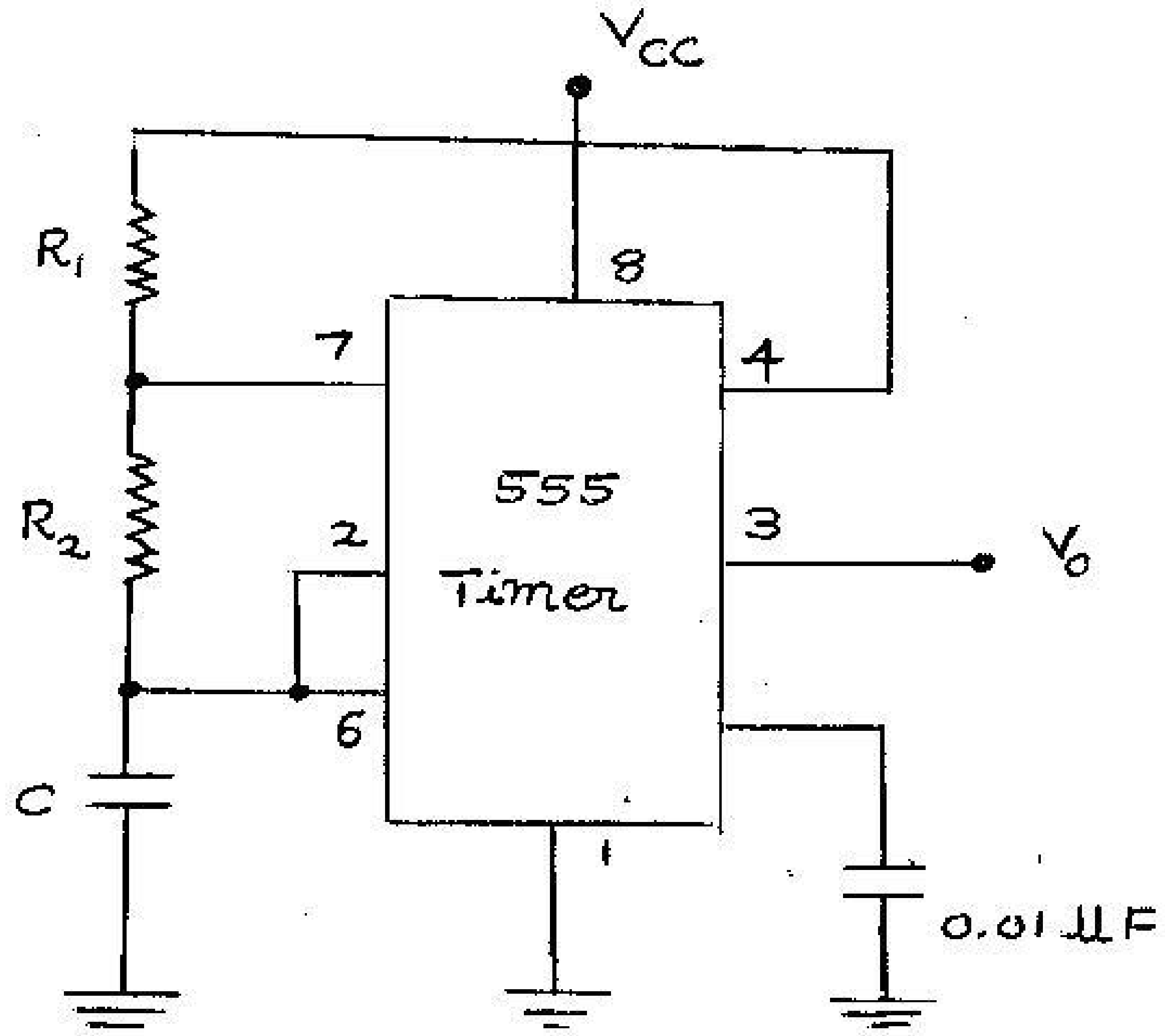
1. Voltage divider comprising of three 5k resistors
2. Voltage Comparator CP1
3. Voltage comparator CP2
4. RS Flip Flop
5. npn transistor Q1
6. pnp transistor Q2

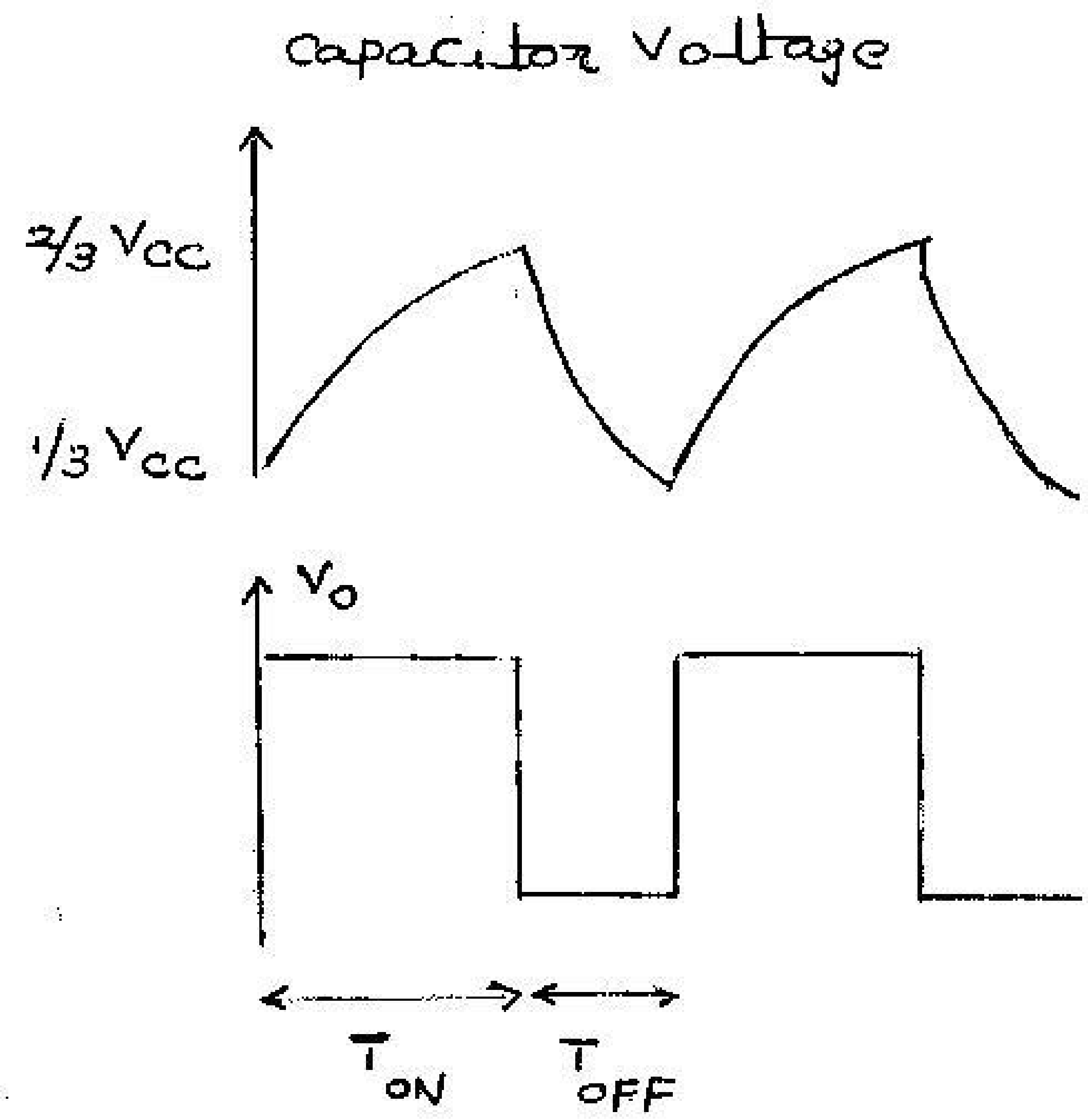
Voltage comparators compare the voltages at their inverting and non inverting inputs. When the non inverting input voltage is lower than the inverting input the output is low. The output switches from low to high when non inverting input is higher than the inverting input. The comparator CP1 has its inverting input biased at $2/3\ V_{cc}$ and the comparator CP2 has its non inverting input set at $1/3\ V_{cc}$. The output of CP1 & CP2 are inputs to RS. Flip Flop. The RS flip flop gives a high output when the inputs are R = 1 and S = 0. When the inputs are R = 0 and S = 1, the RS flip flop gives a low output.

The transistor Q_1 is controlled by the flipflop output. When the base of Q_1 is supplied with high voltage, the transistor acts as a closed switch, thus connecting pin number 7 to ground. When the base of Q_1 is driven low, the transistor acts as an open switch thus disconnecting pin number 7 from ground.

Astable operation :-

A common application of the 555 timer is astable multivibrator which is used to generate a train of pulses. Figure below shows the circuit diagram of a 555 astable multivibrator. The capacitor C and resistors R_1 and R_2 are the external components.





The capacitor begins to charge from the DC source V_{cc}. When the capacitor voltage tends to increase beyond $2/3\ V_{cc}$, the comparator CP1 will output a high voltage. This causes the RS flip flop output to go high. So the output at pin number 3 is low. At the same time, the transistor will act as short circuit causing the pin no 7 to discharge the capacitor through R_2.

As the capacitor voltage falls below $1/3\ V_{cc}$ the output of the comparator CP2 will be high. This causes the RS flipflop output to go low. So the output at pin number 3 is high. Now the transistor will act as open circuit. Now the capacitor begins to charge through R_1 and R_2. The process repeats continuously.

The T_{ON} and T_{OFF} are given by

$$T_{ON} = 0.7 (R_1 + R_2) C$$

$$T_{OFF} = 0.7 R_2 C$$

The oscillation period is $T = T_{ON} + T_{OFF}$

The oscillation frequency is $f = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2) C}$

Important Questions

1. What is an amplifier? Explain the operation of transistor amplifier circuit.

2. Explain briefly how a transistor is used as an electronic switch.

3. With a neat circuit diagram explain how a transistor is used an amplifier. Derive expressions for A_V.

4. With a neat circuit diagram explain how transistor can be used to switch an LED ON/OFF.

5. What is a feedback amplifier? What are the properties of negative feedback amplifier

The amplifier in which part of output is fed back to the input is called feedback amplifier.

6. Draw the block diagram of voltage series negative feedback amplifier and derive expression for its voltage gain.

7. List the advantages of negative feedback in an amplifier. Explain the voltage series feedback amplifier

8. Write a note on the following w.r.t feedback amplifier

(i) Gain stability with feedback

(ii) Gain and Bandwidth

9. Explain the Barkhausen's Criteria for oscillations.

10. Explain the operation of RC phase shift oscillator

11. With a neat circuit diagram, explain the working of Wien Bridge oscillator.

12. With a neat diagram explain the astable operation of IC 555 timer.