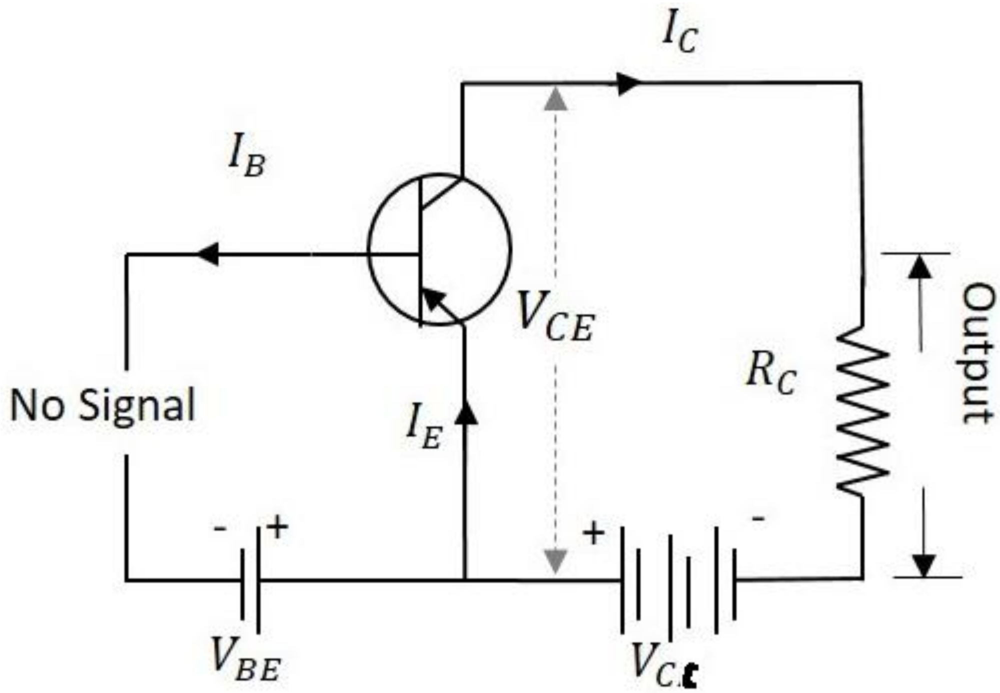
DC Load line

When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition, can be understood as **DC** condition. Here there will be no amplification as the signal is absent. The circuit will be as shown below.

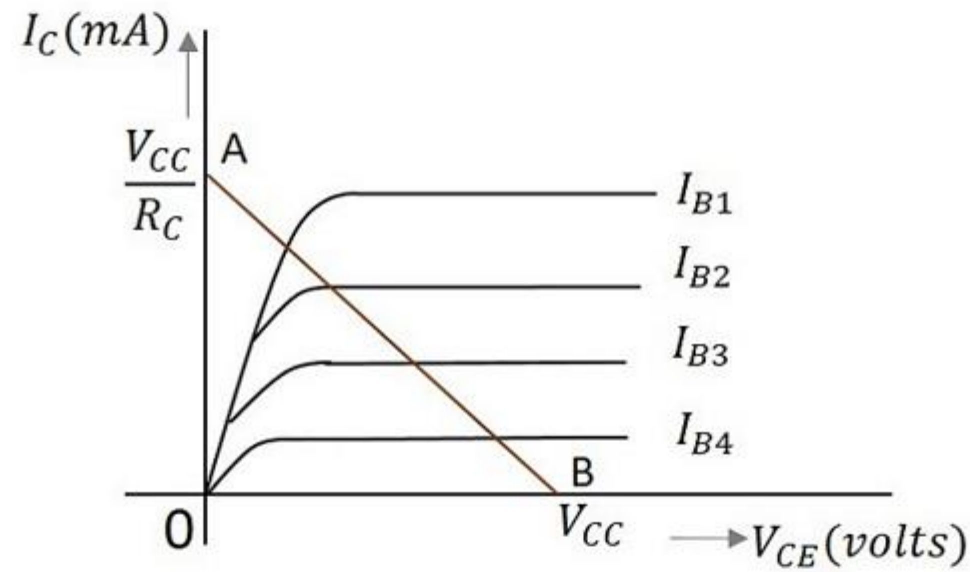


The value of collector emitter voltage at any given time will be

$$V_{CC} - I_C R_C - V_{CE} = 0 \quad \text{(Apply KVL)}$$

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

As V_{CC} and R_C are fixed values, the above one is a first degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**. The figure below shows the DC load line.



To obtain the load line, the two end points of the straight line are to be determined. Let those two points be A and B.

To obtain A

When collector emitter voltage V_{CE} = 0, the collector current is maximum and is equal to V_{CC}/R_C. This gives the maximum value of V_{CE}. This is shown as

$$VCE=VCC-ICRC$$

$$0=VCC-ICRC$$

$$IC=VCC/RC$$

This gives the point A (OA = V_{CC}/R_C) on collector current axis, shown in the above figure.

To obtain B

When the collector current IC = 0, then collector emitter voltage is maximum and will be equal to the VCC. This gives the maximum value of IC. This is shown as

$$VCE=VCC-ICRC$$

$$VCC=VCE$$

(As I_C = 0)

This gives the point B, which means (OB = V_{CC}) on the collector emitter voltage axis shown in the above figure.

Hence we got both the saturation and cutoff point determined and learnt that the load line is a straight line. So, a DC load line can be drawn.

The importance of this operating point is further understood when an AC signal is given at the input.

Biasing Of BJT: Biasing is the process of providing DC voltage which helps in the functioning of the circuit. A transistor is based in order to make the emitter base junction forward biased and collector base junction reverse biased, so that it maintains in active region, to work as an amplifier.

In the previous chapter, we explained how a transistor acts as a good amplifier, if both the input and output sections are biased.

Transistor Biasing

The proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of signal is known as **Transistor Biasing**. The circuit which provides transistor biasing is called as **Biasing Circuit**.

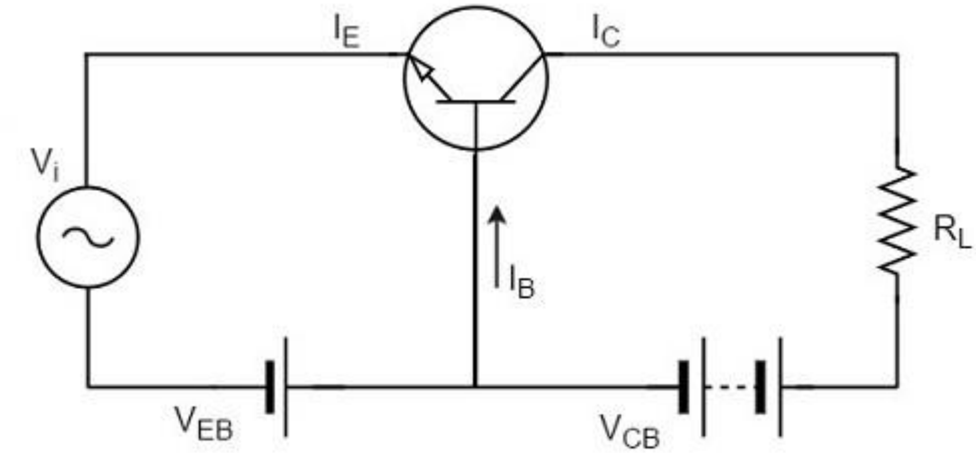
Need for DC biasing

If a signal of very small voltage is given to the input of BJT, it cannot be amplified. Because, for a BJT, to amplify a signal, two conditions have to be met.

- The input voltage should exceed **cut-in voltage** for the transistor to be **ON**.
- The BJT should be in the **active region**, to be operated as an **amplifier**.

If appropriate DC voltages and currents are given through BJT by external sources, so that BJT operates in active region and superimpose the AC signals to be amplified, then this problem can be avoided. The given DC voltage and currents are so chosen that the transistor remains in active region for entire input AC cycle. Hence DC biasing is needed.

The below figure shows a transistor amplifier that is provided with DC biasing on both input and output circuits.



For a transistor to be operated as a faithful amplifier, the operating point should be stabilized. Let us have a look at the factors that affect the stabilization of operating point.

Factors affecting the operating point

The main factor that affect the operating point is the temperature. The operating point shifts due to change in temperature.

As temperature increases, the values of I_{CE}, β, V_{BE} gets affected.

- I_{CBO} gets doubled (for every 10^o rise)
- V_{BE} decreases by 2.5mv (for every 1^o rise)

So the main problem which affects the operating point is temperature. Hence operating point should be made independent of the temperature so as to achieve stability. To achieve this, biasing circuits are introduced.

Stabilization

The process of making the operating point independent of temperature changes or variations in transistor parameters is known as **Stabilization**.

Once the stabilization is achieved, the values of I_C and V_{CE} become independent of temperature variations or replacement of transistor. A good biasing circuit helps in the stabilization of operating point.

Need for Stabilization

Stabilization of the operating point has to be achieved due to the following reasons.

- Temperature dependence of I_C
- Individual variations

- Thermal runaway

Let us understand these concepts in detail.

Temperature Dependence of I_C

As the expression for collector current I_C is

$$IC=\beta IB+ICEO$$

$$=\beta IB+(\beta+1)ICBO$$

The collector leakage current I_{CBO} is greatly influenced by temperature variations. To come out of this, the biasing conditions are set so that zero signal collector current I_C = 1 mA. Therefore, the operating point needs to be stabilized i.e. it is necessary to keep I_C constant.

Individual Variations

As the value of β and the value of V_{BE} are not same for every transistor, whenever a transistor is replaced, the operating point tends to change. Hence it is necessary to stabilize the operating point.

Thermal Runaway

As the expression for collector current I_C is

$$IC=\beta IB+ICEO$$

$$=\beta IB+(\beta+1)ICBO$$

The flow of collector current and also the collector leakage current causes heat dissipation. If the operating point is not stabilized, there occurs a cumulative effect which increases this heat dissipation.

The self-destruction of such an unstabilized transistor is known as **Thermal run away**.

In order to avoid **thermal runaway** and the destruction of transistor, it is necessary to stabilize the operating point, i.e., to keep I_C constant.

Stability Factor

It is understood that I_C should be kept constant in spite of variations of I_{CBO} or I_{CO}. The extent to which a biasing circuit is successful in maintaining this is measured by **Stability factor**. It denoted by **S**.

By definition, the rate of change of collector current I_C with respect to the collector leakage current I_{CO} at constant β and I_B is called **Stability factor**.

$$S=dICdICOS \text{ at constant } I_B \text{ and } \beta$$

Hence we can understand that any change in collector leakage current changes the collector current to a great extent. The stability factor should be as low as possible so that the collector current doesn't get affected. S=1 is the ideal value.

The general expression of stability factor for a CE configuration can be obtained as under.

$$IC=\beta IB+(\beta+1)ICO$$

Differentiating above expression with respect to I_C, we get

$$1=\beta dIBdIC+(\beta+1)dICOdIC$$

Or

$$1=\beta dIBdIC+(\beta+1)S$$

$$\text{Since } dICOdIC=1SdICOdIC=1S$$

Or

$$S=\beta+11-\beta(dIBdIC)S$$

Hence the stability factor S depends on β, I_B and I_C.

we have seen different stabilization techniques. The stabilization occurs due to negative feedback action. The negative feedback, although improves the stability of operating point, it reduces the gain of the amplifier.

As the gain of the amplifier is a very important consideration, some compensation techniques are used to maintain excellent bias and thermal stabilization. Let us now go through such bias compensation techniques.

Diode Compensation for Instability

These are the circuits that implement compensation techniques using diodes to deal with biasing instability. The stabilization techniques refer to the use of resistive biasing circuits which permit I_B to vary so as to keep I_C relatively constant.

There are two types of diode compensation methods. They are −

- Diode compensation for instability due to V_{BE} variation
- Diode compensation for instability due to I_{CO} variation

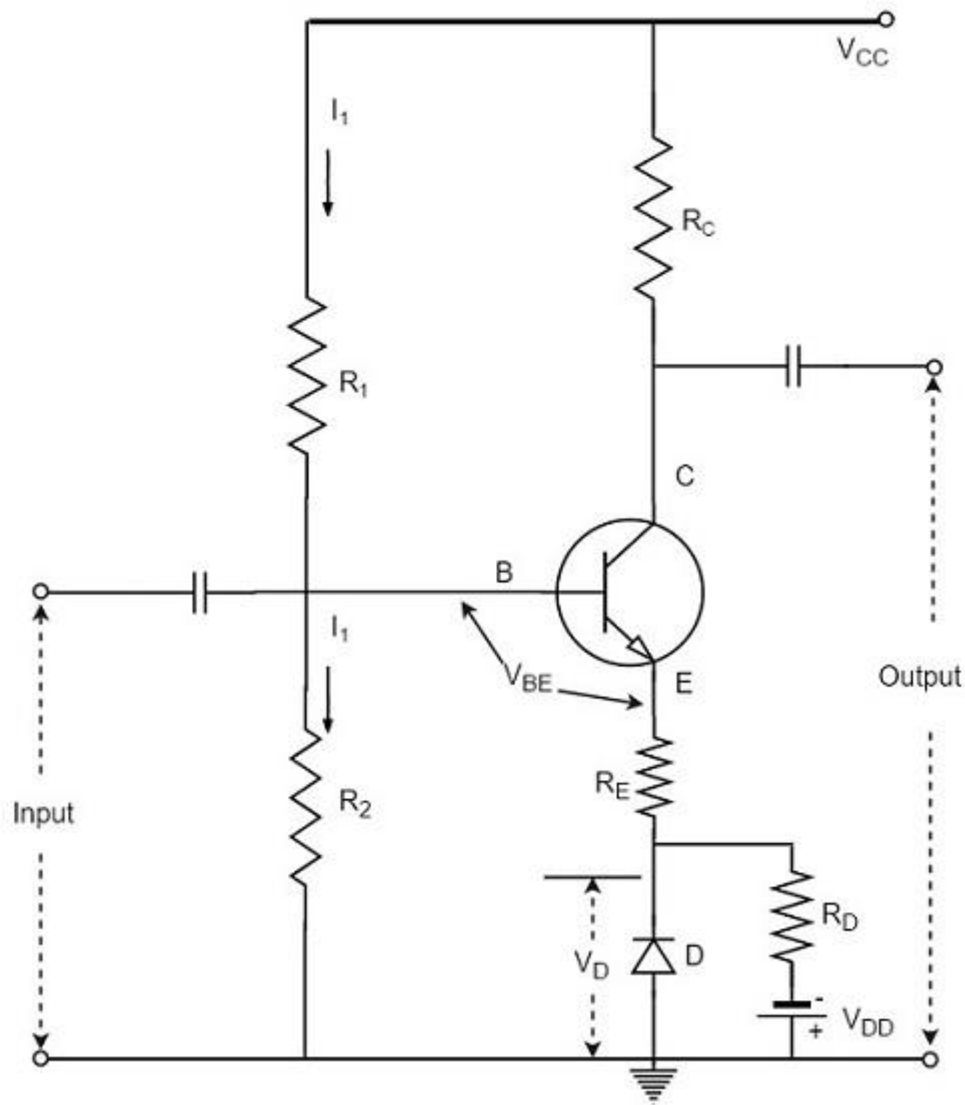
Let us understand these two compensation methods in detail.

Diode Compensation for Instability due to V_{BE} Variation

In a Silicon transistor, the changes in the value of V_{BE} results in the changes in I_C. A diode can be employed in the emitter circuit in order to compensate the variations in

V_{BE} or I_{CO}. As the diode and transistor used are of same material, the voltage V_D across the diode has same temperature coefficient as V_{BE} of the transistor.

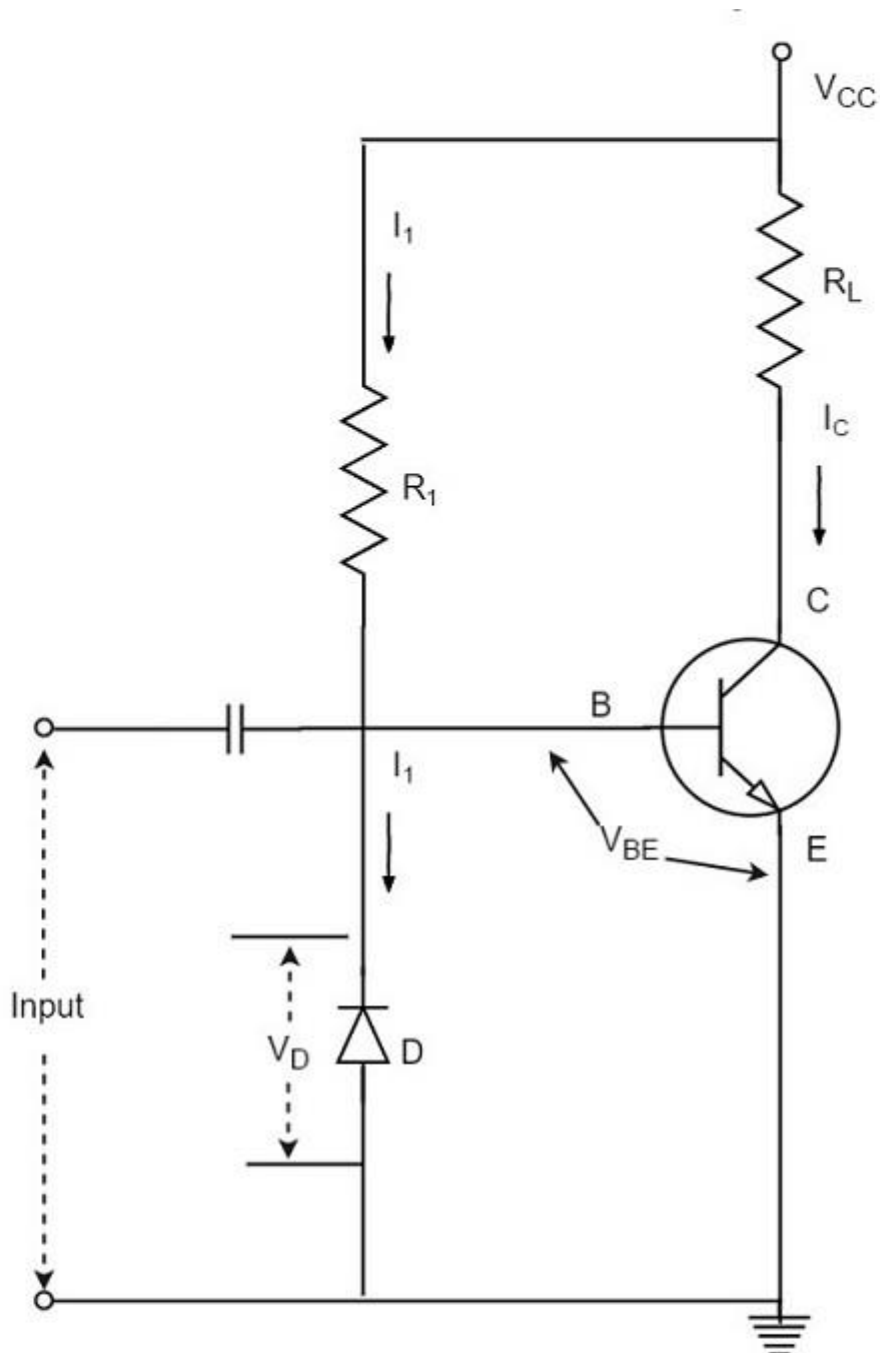
The following figure shows self-bias with stabilization and compensation.



The diode D is forward biased by the source V_{DD} and the resistor R_D. The variation in V_{BE} with temperature is same as the variation in V_D with temperature, hence the quantity ($V_{BE} - V_D$) remains constant. So the current I_C remains constant in spite of the variation in V_{BE}.

Diode Compensation for Instability due to I_{CO} Variation

The following figure shows the circuit diagram of a transistor amplifier with diode D used for compensation of variation in I_{CO}.



So, the reverse saturation current I_O of the diode will increase with temperature at the same rate as the transistor collector saturation current I_{CO}.

$$I=VCC-VBER\cong VCCR=Constant$$

The diode D is reverse biased by V_{BE} and the current through it is the reverse saturation current I_O.

Now the base current is,

$$I_B = I - I_O$$

Substituting the above value in the expression for collector current.

$$I_C = \beta(I - I_O) + (1+\beta)I_{CO}$$

If $\beta \gg 1$,

$$I_C = \beta I - \beta I_O + \beta I_{CO}$$

I is almost constant and if I_O of diode and I_{CO} of transistor track each other over the operating temperature range, then I_C remains constant.

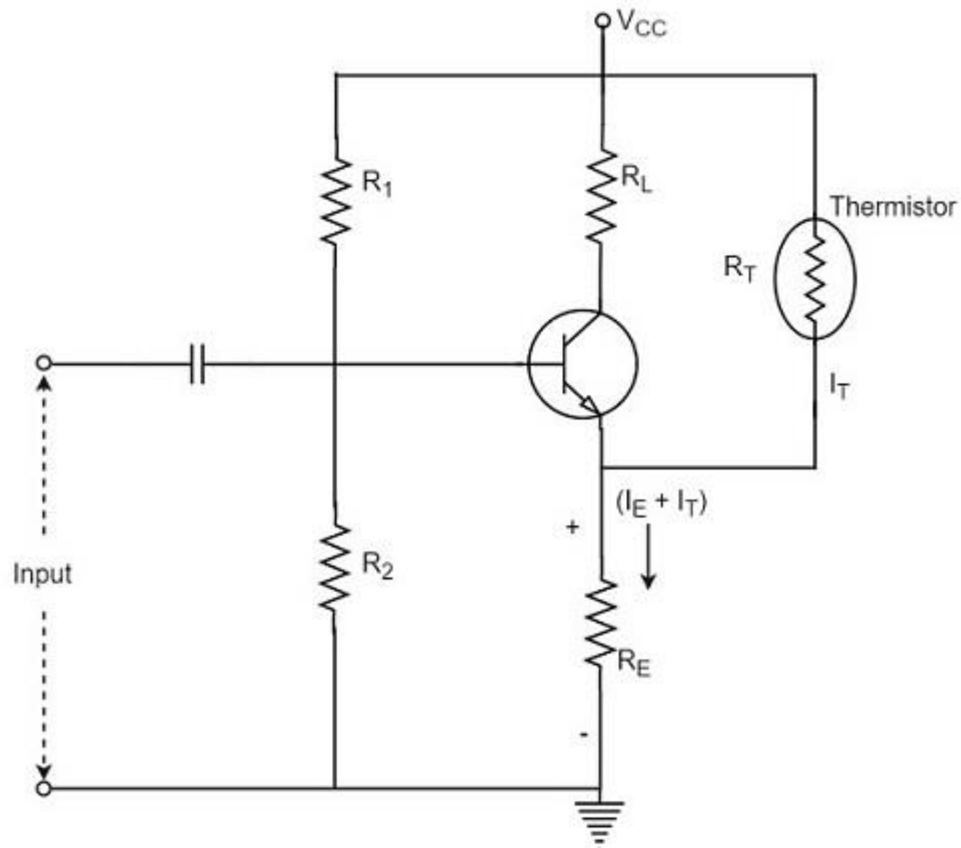
Other Compensations

There are other compensation techniques which refer to the use of temperature sensitive devices such as diodes, transistors, thermistors, Sensistors, etc. to compensate for the variation in currents.

There are two popular types of circuits in this method, one using a thermistor and the other using a Sensistor. Let us have a look at them.

Thermistor Compensation

Thermistor is a temperature sensitive device. It has negative temperature coefficient. The resistance of a thermistor increases when the temperature decreases and it decreases when the temperature increases. The below figure shows a self-bias amplifier with thermistor compensation.



In an amplifier circuit, the changes that occur in I_{CO}, V_{BE} and β with temperature, increases the collector current. Thermistor is employed to minimize the increase in collector current. As the temperature increases, the resistance R_T of thermistor decreases, which increases the current through it and the resistor R_E. Now, the voltage developed across R_E increases, which reverse biases the emitter junction. This reverse bias is so high that the effect of resistors R_1 and R_2 providing forward bias also gets reduced. This action reduces the rise in collector current.

Thus the temperature sensitivity of thermistor compensates the increase in collector current, occurred due to temperature.

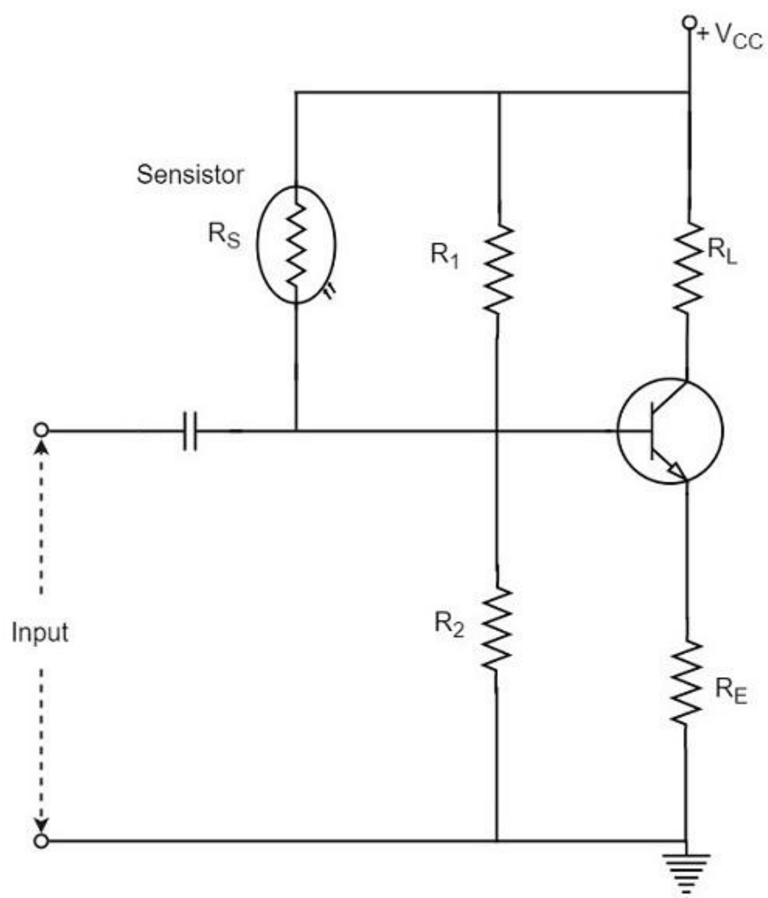
Sensistor Compensation

A Sensistor is a heavily doped semiconductor that has positive temperature coefficient. The resistance of a Sensistor increases with the increase in temperature and decreases with the decrease in temperature. The figure below shows a self-bias amplifier with Sensistor compensation.

The table below lists the four **h-parameters** for the **BJT** in common base and common collector (emitter follower) mode.

...

Hie	**input impedance (Ω)**
h$_{re}$	reverse voltage ratio (dimensionless)
h$_{fe}$	forward current transfer ratio (dimensionless)
h$_{oe}$	output admittance (Siemen)



In the above figure, the Sensistor may be placed in parallel with R_1 or in parallel with R_E. As the temperature increases, the resistance of the parallel combination, thermistor and R_1 increases and their voltage drop also increases. This decreases the voltage drop across R_2. Due to the decrease of this voltage, the net forward emitter bias decreases. As a result of this, I_C decreases.

Hence by employing the Sensistor, the rise in the collector current which is caused by the increase of I_{CO}, V_{BE} and β due to temperature, gets controlled.

Thermal Resistance

The transistor is a temperature dependent device. When the transistor is operated, the collector junction gets heavy flow of electrons and hence has much heat generated. This heat if increased further beyond the permissible limit, damages the junction and thus the transistor.

In order to protect itself from damage, the transistor dissipates heat from the junction to the transistor case and from there to the open air surrounding it.

Let, the ambient temperature or the temperature of surrounding air = $T_A{}^oC$

And, the temperature of collector-base junction of the transistor = $T_J{}^oC$

As $T_J > T_A$, the difference $T_J - T_A$ is greater than the power dissipated in the transistor P_D will be greater. Thus,

$$TJ-TA\propto PD$$

$$TJ-TA=HPD$$

There H is the constant of proportionality, and is called as **Thermal resistance**.

Thermal resistance is the resistance to heat flow from junction to surrounding air. It is denoted by H.

$$H=TJ-TAPD$$

The unit of H is ^oC/watt.

If the thermal resistance is low, the transfer of heat from the transistor into the air, will be easy. If the transistor case is larger, the heat dissipation will be better. This is achieved by the use of Heat sink.

Heat Sink

The transistor that handle larger powers, dissipates more heat during operation. This heat if not dissipated properly, could damage the transistor. Hence the power transistors are generally mounted on large metal cases to provide a larger area to get the heat radiated that is generated during its operation.

The metal sheet that helps to dissipate the additional heat from the transistor is known as the **heat sink**. The ability of a heat sink depends upon its material, volume, area, shape, contact between case and sink, and the movement of air around the sink.

The heat sink is selected after considering all these factors. The image shows a power transistor with a heat sink.

A tiny transistor in the above image is fixed to a larger metal sheet in order to dissipate its heat, so that the transistor doesn’t get damaged.

Thermal Runaway

The use of heat sink avoids the problem of **Thermal Runaway**. It is a situation where an increase in temperature leads to the condition that further increase in temperature, leads to the destruction of the device itself. This is a kind of uncontrollable positive feedback.

Heat sink is not the only consideration; other factors such as operating point, ambient temperature, and the type of transistor used can also cause thermal runaway

The table below lists the four **h**-**parameters** for the **BJT** in common base and common collector (emitter follower) mode.
...

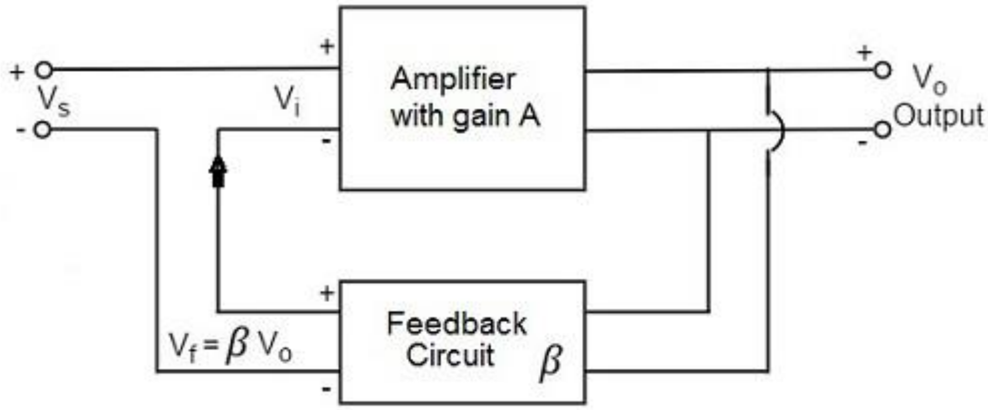
$\mathbf{h_{ie}}$	**input impedance (Ω)**
$\mathbf{h}_{re}$	reverse voltage ratio (dimensionless)
$\mathbf{h}_{fe}$	forward current transfer ratio (dimensionless)
$\mathbf{h}_{oe}$	output admittance (Siemen)

Feed Back Amplifier: An amplifier circuit simply increases the signal strength. But while amplifying, it just increases the strength of its input signal whether it contains information or some noise along with information. This noise or some disturbance is introduced in the amplifiers because of their strong tendency to introduce **hum** due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output, which is very undesirable.

The noise level in the amplifier circuits can be considerably reduced by using **negative feedback** done by injecting a fraction of output in phase opposition to the input signal.

Principle of Feedback Amplifier

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors. The concept of feedback amplifier can be understood from the following figure.



From the above figure, the gain of the amplifier is represented as A. the gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i. the feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s. Now,

$$Vi=Vs+Vf=Vs+\beta Vo$$

$$Vi=Vs-Vf=Vs-\beta Vo$$

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

Let us consider the case of negative feedback. The output V_o must be equal to the input voltage $(V_s - \beta V_o)$ multiplied by the gain A of the amplifier.

Hence,

$$(Vs-\beta Vo)A=Vo$$

Or

$$AVs-A\beta Vo=Vo$$

Or

$$\mathbf{AVs=Vo(1+A\beta)}$$

Therefore,

$$VoVs=A1+A\beta$$

Let A_f be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e., Af=OutputvoltageInputsignalvoltage=VoVsAf=OutputvoltageInputsignalvoltage=VoVs

So, from the above two equations, we can understand that,

The equation of gain of the feedback amplifier, with negative feedback is given by

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

The equation of gain of the feedback amplifier, with positive feedback is given by

$$A_f = \frac{A}{1-A\beta}$$

These are the standard equations to calculate the gain of feedback amplifiers.

Types of Feedbacks

The process of injecting a fraction of output energy of some device back to the input is known as **Feedback**. It has been found that feedback is very useful in reducing noise and making the amplifier operation stable.

Depending upon whether the feedback signal **aids** or **opposes** the input signal, there are two types of feedbacks used.

Positive Feedback

The feedback in which the feedback energy i.e., either voltage or current is in phase with the input signal and thus aids it is called as **Positive feedback**.

Both the input signal and feedback signal introduces a phase shift of 180^o thus making a 360^o resultant phase shift around the loop, to be finally in phase with the input signal.

Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as

- Increasing distortion
- Instability

It is because of these disadvantages the positive feedback is not recommended for the amplifiers. If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed. This concept will be discussed in OSCILLATORS tutorial.

Negative Feedback

The feedback in which the feedback energy i.e., either voltage or current is out of phase with the input and thus opposes it, is called as **negative feedback**.

In negative feedback, the amplifier introduces a phase shift of 180^o into the circuit while the feedback network is so designed that it produces no phase shift or zero phase shift. Thus the resultant feedback voltage V_f is 180^o out of phase with the input signal V_{in}.

Though the **gain** of negative feedback amplifier is **reduced**, there are many advantages of negative feedback such as

- Stability of gain is improved
- Reduction in distortion
- Reduction in noise
- Increase in input impedance
- Decrease in output impedance
- Increase in the range of uniform application

It is because of these advantages negative feedback is frequently employed in amplifier