UNIT-IV TRANSISTOR BIASING AND STABILIZATION

1. What is the need for biasing?

   In order to produce distortion free output in amplifier circuits, the supply voltages and resistances establish a set of dc voltage V_{CEQ} and I_{CQ} to operate the transistor in the active region. These voltages and currents are called quiescent values which determine the operating point or Q-point for the transistor. The process of giving proper supply voltages and resistances for obtaining the desired Q-Point is called Biasing. The circuits used for getting the desired and proper operating point are known as biasing circuits. To establish the operating point in the active region biasing is required for transistors to be used as an amplifier. For analog circuit operation, the Q-point is placed so the transistor stays in active mode (does not shift to operation in the saturation region or cut-off region) when input is applied. For digital operation, the Q-point is placed so the transistor does the contrary - switches from "on" to "off" state. Often, Q-point is established near the center of active region of transistor characteristic to allow similar signal swings in positive and negative directions. Q-point should be stable. In particular, it should be insensitive to variations in transistor parameters (for example, should not shift if transistor is replaced by another of the same type), variations in temperature, variations in power supply voltage and so forth. The circuit must be practical: easily implemented and cost-effective.

2. **Explain Thermal Runaway.**

THERMAL RUN AWAY:

Collector current $I_C = \beta I_B + (\beta+1) I_{CBO}$

β, I_B, I_{CBO} all increases with temperature

I_{CBO} doubles for every 10°C rise in temperature

Collector current causes junction temperature to rise, which in term rises $I_{CBO} \rightarrow$ rise in Ic. This cumulative process leads to collector current to increase further and transistor may be destroyed. This phenomenon is called thermal Run away.

There are several approaches to mitigate bipolar transistor thermal runaway. For example,

- Negative feedback can be built into the biasing circuit so that increased collector current leads to decreased base current. Hence, the increasing collector current throttles its source.
- Heat sinks can be used that carry away extra heat and prevent the base–emitter temperature from rising.
- The transistor can be biased so that its collector is normally less than half of the power supply voltage, which implies that collector–emitter power dissipation is at its maximum value. Runaway is then impossible because increasing collector current leads to a decrease in dissipated power.

3. Define Stability factor?

STABILITY FACTOR (S)

The extent to which the collector current I_C is stabilized with varying Ico is measured by stability factor S.
It is defined as the rate of change of collector current to the change in Ico, keeping I_B and B as constant.

$S = \frac{\Delta I_C}{\Delta I_{CO}}, \beta \,\&\, I_B$ Constant Or $S = \frac{dI_C}{dI_{co}}$

Collector current Ic $= \beta I_B + (\beta+1) I_{CO}$ - (1)
Differencing eqn. (1) with repeat to Ic.

$$\frac{dI_c}{dI_c} = \frac{d\beta I_B}{dI_c} = \frac{d(\beta+1)I_{co}}{dI_c}$$

$$1 = \beta \frac{dI_B}{dI_C} + (\beta+1)\frac{DI_{CO}}{dI_C}$$

$$1 - \beta \frac{dI_B}{dI_c} = \frac{\beta+1}{S}$$

Or $$S = \frac{\beta+1}{1-\beta\left[\frac{dIB}{dIc}\right]}$$

'S' should be as small as possible to have better stability

Stability Factor S' and S".

$$S' = \frac{dI_c}{dV_{BE}} \approx \frac{\Delta I_c}{\Delta V_{BE}}, Ico \,\&\, \beta \text{ constant}$$

$$S'' = \frac{dI_c}{d\beta} \approx \frac{\Delta I_c}{\Delta \beta}, I_{co} \,\&\, V_{BE} \text{ constant}$$

4. Mention the methods of transistor biasing? Or what are the t ypes of bias circuits for BJT amplifiers

Five common biasing circuits are used with bipolar transistor amplifiers:

1 Fixed Bias or base resistor Bias
2 Emitter-feedback bias
3 Collector to Base bias or collector feet back bias
4 Collector-emitter feedback bias
5 Self-bias or emitter bias or potential divides Bias.

5. Explain Fixed Bias circuit.

1. Fixed bias (base bias)

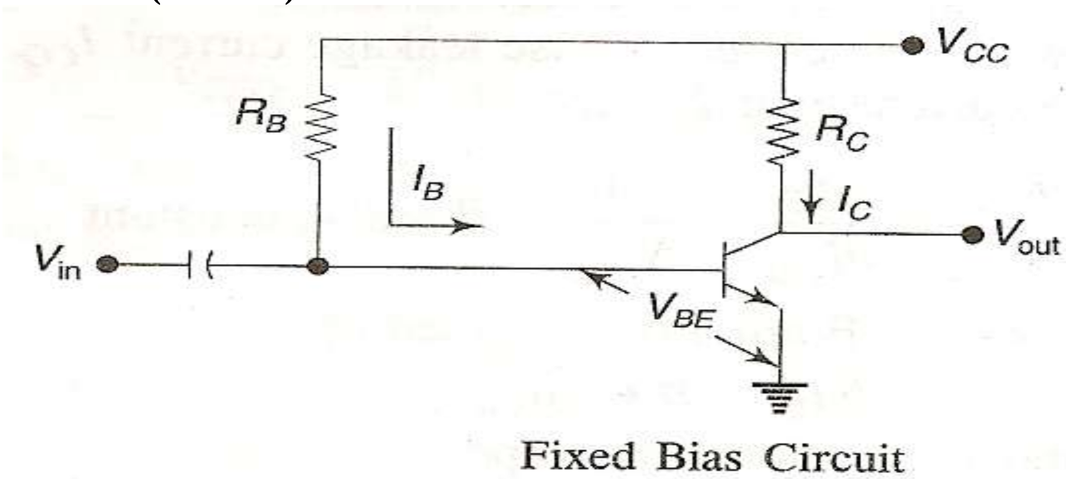


Fig.1 Fixed bias (Base bias)

In the given circuit,

$V_{CC} = I_B R_B + V_{BE}$…………………(1)

Therefore,

$I_B = (V_{CC} – V_{BE})/R_B$………………..(2)

For a given transistor, V_{BE} does not vary significantly during use. As V_{CC} is of fixed value, on selection of R_B, the base current I_B is fixed. Therefore this type is called *fixed bias* type of circuit.

Also for given circuit,

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

Therefore,

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

Stability Factor S = $\dfrac{1+\beta}{1-\beta\left(\dfrac{dIB}{dIC}\right)}$

Since IB is not depending on Ic as per equation (2).

$$S = \frac{1+\beta}{1-\beta(0)} = 1+\beta \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Since β is a large quality and varies from device to device. This is very poor circuit for stability for bias.The common-emitter current of a transistor is an important parameter in circuit design, and is specified on the data sheet for a particular transistor. It is denoted as β.

Because $I_C = \beta\, I_B$

we can obtain I_C as well. In this manner, operating point given as (V_{ce},I_C) can be set for given transistor.

Merits:

- It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).
- A very small number of components are required.

Demerits:

- The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.
- Changes in V_{be} will change I_B and thus cause R_B to change. This in turn will alter the gain of the stage.
- When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.
- For small-signal transistors (e.g., not power transistors) with relatively high values of β (i.e., between 100 and 200), this configuration will be prone to thermal runaway. In particular, the stability factor, which is a measure of the change in collector current with changes in reverse saturation current, is approximately β+1. To ensure absolute stability of the amplifier, a stability factor of less than 25 is preferred, and so small-signal transistors have large stability factors.

Usage:

Due to the above inherent drawbacks, fixed bias is rarely used in linear circuits (i.e., those circuits which use the transistor as a current source). Instead, it is often used in circuits where transistor is used as a switch. However, one application of fixed bias is to achieve crude automatic gain control in the transistor by feeding the base resistor from a DC signal derived from the AC output of a later stage.

6..Explain Emitter feedback bias method or Fixed bias with emitter resistor.

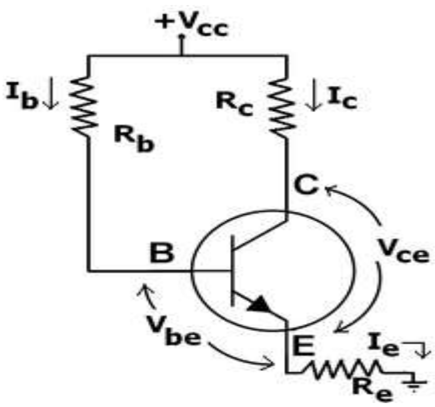


Fig. Fixed bias with emitter resistor

The fixed bias circuit is modified by attaching an external resistor to the emitter. This resistor introduces negative feedback that stabilizes the Q-point. From Kirchhoff's voltage law, the voltage across the base resistor is

$V_{Rb} = V_{CC} - I_eR_e - V_{be}$.

From Ohm's law, the base current is

$I_b = V_{Rb} / R_b$.

The way feedback controls the bias point is as follows. If V_{be} is held constant and temperature increases, emitter current increases. However, a larger I_e increases the emitter voltage $V_e = I_eR_e$, which in turn reduces the voltage V_{Rb} across the base resistor. A lower base-resistor voltage drop reduces the base current, which results in less collector current because $I_c = ß\ I_B$. Collector current and emitter current are related by $I_c = \alpha\ I_e$ with $\alpha \approx 1$, so increase in emitter current with temperature is opposed, and operating point is kept stable. Similarly, if the transistor is replaced by another, there may be a change in I_C (corresponding to change in β-value, for example). By similar process as above, the change is negated and operating point kept stable.

For the given circuit,

$I_B = (V_{CC} - V_{be})/(R_B + (\beta+1)R_E)$.

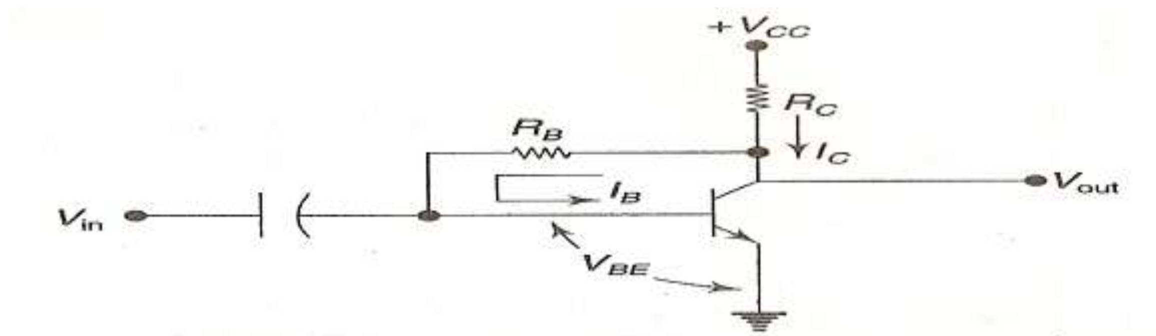
Stability Factor S = $\dfrac{1+\beta}{1-\beta\left(\dfrac{dIB}{dIC}\right)}$

dIB/dIC = -(Re/Re+Rb)

Hence stability factor for this method is

Stability Factor S = $\dfrac{1+\beta}{1+\beta\,(Re/Re+Rb)}$

7. Explain Collector-to-base bias method.



Collector-to-base Bias Circuit

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

- $I_B = \left(\dfrac{V_{CE} - V_{BE}}{R_B}\right)$

- If the collector current increases due to increase in temperature or the transistor is replaced by one with higher β, the voltage drop across R_C increases.

- So, less V_{CE} and less I_B, to compensate increase in Ic i.e., greater stability

$V_{CC} = I_B + I_C \;\; R_C + I_B R_B + V_{BE}$ - (1)

$= I_B R_C + I_C R_C + I_B R_B + V_{BE}$

$$= I_B \; R_C + R_B \; + I_C R_C + V_{BE}$$

Or $$I_B = \frac{V_{CC} - V_{BE} - I_C R_C}{RC + RB} \qquad - \qquad (2)$$

$$\frac{d_{IB}}{d_{IC}} = \frac{R_C}{R_C + R_B} \qquad - \qquad (3)$$

Stability Factor:

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

Putting the value of dI_B / dI_C from equation (3)

$$S = \frac{1+\beta}{1-\beta\left(\frac{-R_C}{R_C+R_B}\right)} = \frac{1+\beta}{1+\beta\left(\frac{R_C}{R_C+R_B}\right)}$$

Note: 1) Value of S is less than that of fixed bias (which is S = 1+β)

2. S can be made small and stability improved by making R_B small or R_C large. If Rc is small S = 1 + β, i.e., stability is poor.

Merits:

- Circuit stabilizes the operating point against variations in temperature and β (i.e. replacement of transistor)

Demerits:

- In this circuit, to keep I_c independent of β, the following condition must be met:

$$I_c = \beta I_b = \frac{\beta(V_{cc} - V_{be})}{R_b + R_c + \beta R_c} \approx \frac{(V_{cc} - V_{be})}{R_c}$$

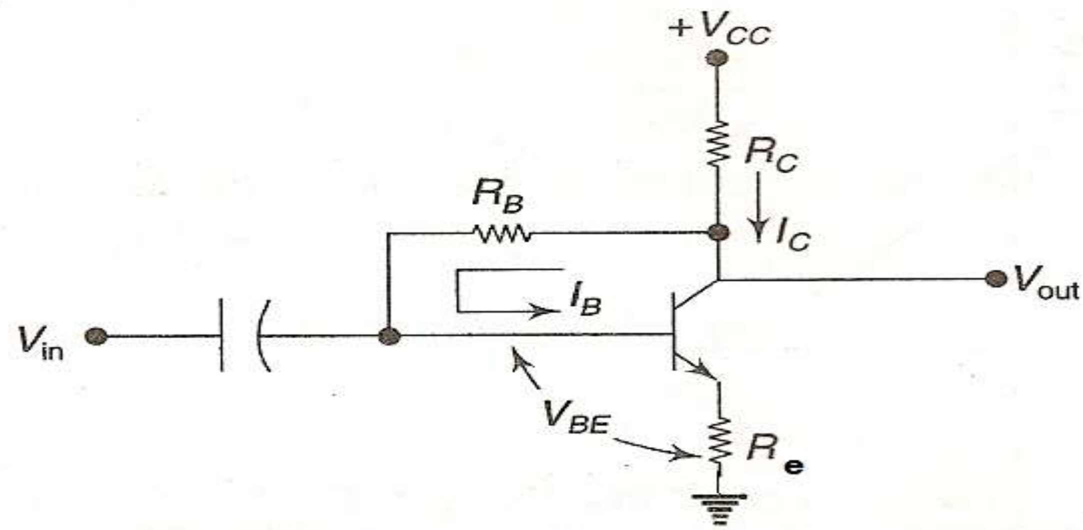
which is the case when

$$\beta R_c \gg R_b.$$

- As β-value is fixed (and generally unknown) for a given transistor, this relation can be satisfied either by keeping R_c fairly large or making R_b very low.
    - If R_c is large, a high V_{cc} is necessary, which increases cost as well as precautions necessary while handling.
    - If R_b is low, the reverse bias of the collector–base region is small, which limits the range of collector voltage swing that leaves the transistor in active mode.
- The resistor R_b causes an AC feedback, reducing the Voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

Usage: The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability is warranted.

8. Explain Collector-Emitter Feedback bias method.



Collector to emitter feedback bias

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

- $I_B = \left(\dfrac{V_{CE} - V_{BE}}{R_B}\right)$

- If the collector current increases due to increase in temperature or the transistor is replaced by one with higher β, the voltage drop across R_C increases.

- So, less V_{CE} and less I_B, to compensate increase in Ic i.e., greater stability

$$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE} + IeRe \quad - \quad (1)$$

$$= I_B R_C + I_C R_C + I_B R_B + V_{BE} + I_B R_E + I_C R_E$$

$$= I_B(R_C + R_B + R_E) + I_C R_C + V_{BE}$$

Or

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_C + RE\ Ic}{RC + RB + RE} \quad - \quad (2)$$

$$\frac{d_{IB}}{d_{IC}} = \frac{-R_C + Re}{R_C + R_B + Re} \quad - \quad (3)$$

Stability Factor:

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

Putting the value of dI_B / dI_C from equation (3)

$$S = \frac{1+\beta}{1-\beta\left(\frac{-R_C\ Re}{R_C + R_B + Re}\right)} = \frac{1+\beta}{1+\beta\left(\frac{R_C Re}{R_C + R_B + Re}\right)}$$

Note: - 1) Value of S is less than that of fixed bias (which is S = 1+β) and collector feedback bias.

1) S can be made small and stability improved by making R_B small or R_C ,R_E large.

- If Rc,R_E is small S = 1 + β, i.e., stability is poor.

9.Explain about Voltage divider bias or emitter bias or self bias method.

The voltage divider is formed using external resistors R_1 and R_2. The voltage across R_2 forward biases the emitter junction. By proper selection of resistors R_1 and R_2, the operating point of the transistor can be made independent of β. In this circuit, the voltage divider holds the base voltage fixed independent of base current provided the divider current is large compared to the base current .Required base bias is obtained from the power supply through potential divider R_1 & R_2.In this circuit voltage across Reverse biases base emitter junction. Whenever there is increase in this collector circuit voltage across R_E increases causing base current to diverse which compensate the increase in collector current. This circuit can be used with low collector resistance.

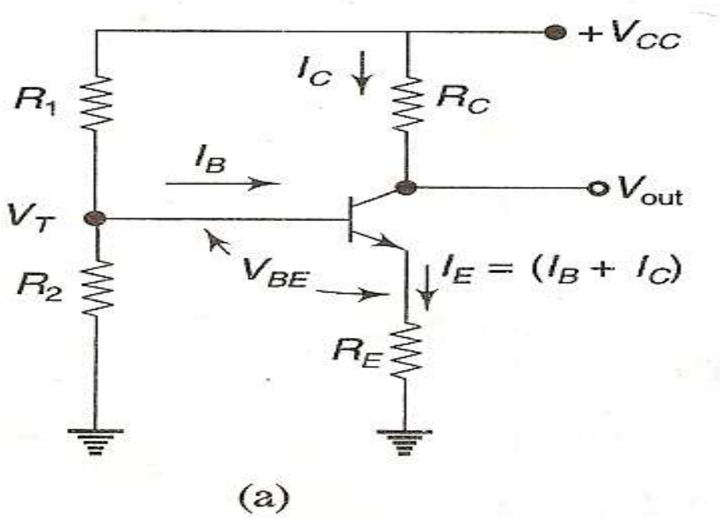
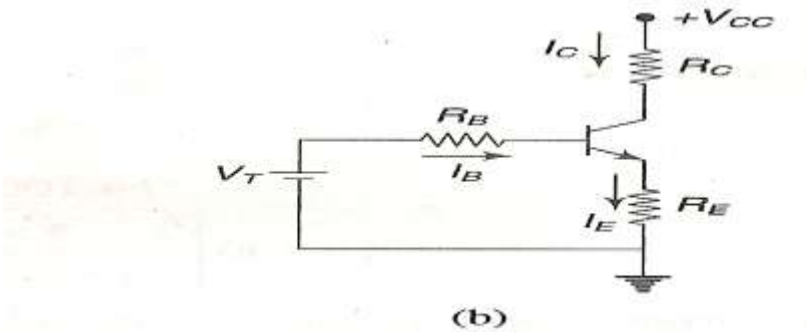


Fig. (a) Self Bias

$V_B = \dfrac{R_2 Vcc}{R_1 + R_2}$ By applying thevenins theorem, the cut can be replaced and

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



(b) Thevenin's Equivalent Circuit

.

Equivalent Circuit: writing loop equation for the basic loop shown

$= I_B R_B + V_{BE} + R_E(I_B+I_C)$

$= I_B R_B + V_{BE} + I_B R_E + I_C R_E$

$= I_B(R_B+R_E) + V_{BE} + I_C R_E$

Or $I_B(R_B+R_E) = V_B - V_{BE} - I_C R_E$

$I_C R_E$

Differencing wrt. Ic,

$$\frac{dI_B}{dI_C}\ R_B + R_E \ = \frac{dV_B}{dI_C} - \frac{dV_{BE}}{dI_C} - \frac{dI_C R_E}{dI_C}$$

Or $\frac{dI_B}{dI_c}(R_B + R_E) = 0 - 0 - R_E$

Or $\frac{dI_B}{dI_c} = \frac{-R_E}{R_B + R_E}$ - (1)

Stability Factor

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

Putting the value of dI_B / dI_C from equation (1)

$$S = \frac{1+\beta}{1-\beta\left(\frac{-R_E}{R_B+R_E}\right)} = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_B+R_E}\right)} = \frac{1+\beta}{\frac{R_B+R_E+\beta R_E}{R_B+R_E}}$$

Dividing N & D by R_E

$$S = \frac{1+\beta \; \frac{R_B+R_E}{R_E}}{\frac{R_B+R_E+\beta R_E}{R_E}} = (1+\beta)\frac{1+\frac{R_B}{R_E}}{1+\beta+\frac{R_B}{R_E}} \qquad \Rightarrow (2)$$

If $\quad \frac{R_B}{R_E}=0, \; S=(1+\beta)\frac{1+0}{1+\beta-0}=\frac{1+\beta}{1+\beta}=1 \quad \Rightarrow \quad (3)$

If $\quad \frac{R_B}{R_E}=\infty, \; S= \; 1+\beta \; \frac{1+\infty}{1+\beta+\infty} = \; 1+\beta$

So, (a) for smaller value of R_B stability is better, but large power will be wasted in R1 & R2. S is independent of β.

(b)For fixed RB/RE, S increases with β (see eqn. 2) i.e., stability decreases with increase in β.

Merits:

- Unlike above circuits, only one dc supply is necessary.
- Operating point is almost independent of β variation.
- Operating point stabilized against shift in temperature.

Demerits:

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E fairly large, or making $R_1||R_2$ very low.
  - If R_E is of large value, high V_{CC} is necessary. This increases cost as well as precautions necessary while handling.

- If $R_1 \parallel R_2$ is low, either R_1 is low, or R_2 is low, or both are low. A low R_1 raises V_B closer to V_C, reducing the available swing in collector voltage, and limiting how large R_C can be made without driving the transistor out of active mode. A low R_2 lowers V_{be}, reducing the allowed collector current. Lowering both resistor values draws more current from the power supply and lowers the input resistance of the amplifier as seen from the base.

- AC as well as DC feedback is caused by R_E, which reduces the AC voltage gain of the amplifier. A method to avoid AC feedback while retaining DC feedback is discussed below.

Usage:

The circuit's stability and merits as above make it widely used for linear circuits.

10.Explain about compensation methods.

Bias compensation

a) Diode bias compensation

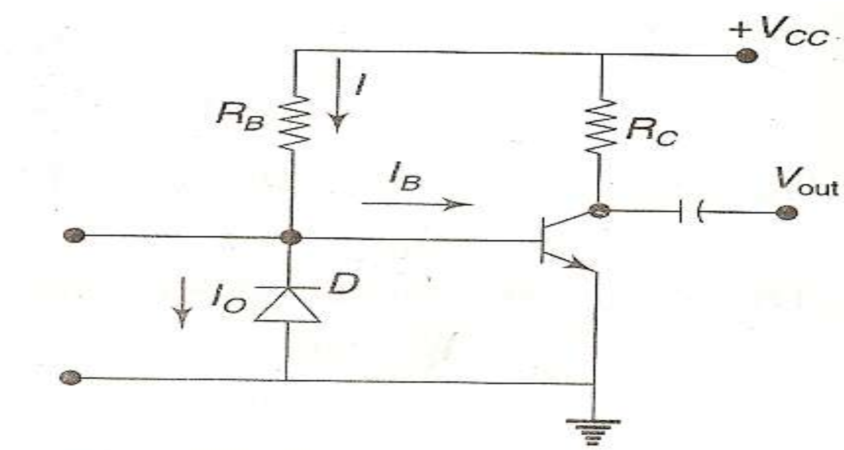


Fig. 5.12 Diode Bias Compensation

$I_R = I_D + I_B$ (I_D is reverse saturation Current increases with temp.)

When temperature increases, I_C increases at the time, I_D also increases,

making I_B to Reduce and controlling I_C.

b) Thermistor Bias compensation: -

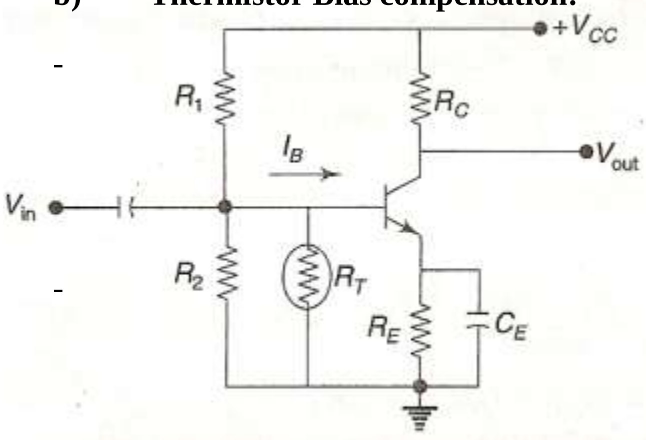


Fig. 5.13 Thermistor Bias Compensation

- RT is having negative temp. Coefficient

  i.e., temperature ↑ RT ↓.RT

- When temperature increases RT decreases thereby reducing base bias voltage & base current and hence collect to current.

c) Sensistor Bias compensation.

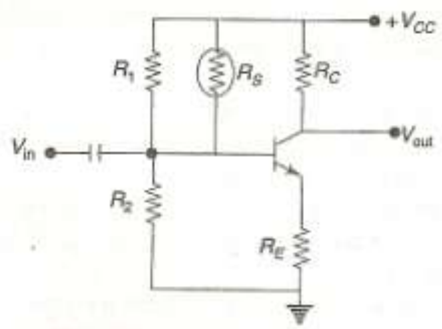


Fig. 5.14 Sensistor Bias Compensation

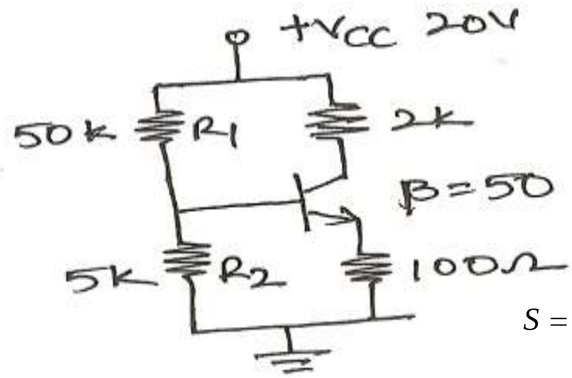
- Rs is sensistor (resistance) having positive temperature coefficient.
- When temp. ↑ Rs. ↑ VR_2 ↓

Base bias voltage ↓ Base current ↓. Collector current controlled.

Problems

1. Find out stability factor of the circuit given below:

   Stability factor of self-biased Circuit given by:



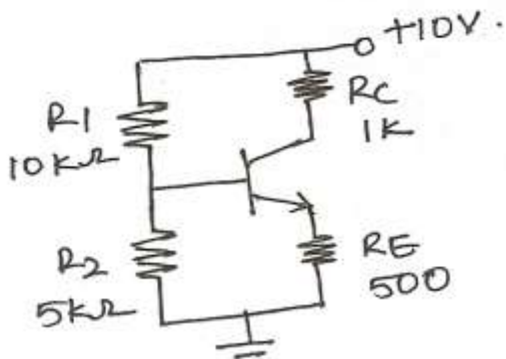
$$S = 1+\beta \frac{1+\frac{R_B}{R_E}}{1+\beta+\left(\frac{R_B}{R_E}\right)}$$

$$R_B = \frac{R_1 R_2}{R_1+R_2} = \frac{5\times 50}{5+50} = \frac{50}{11}k \approx 4.5k = 4500\Omega$$

$$\frac{R_B}{R_E} = \frac{4500}{100} = 45$$

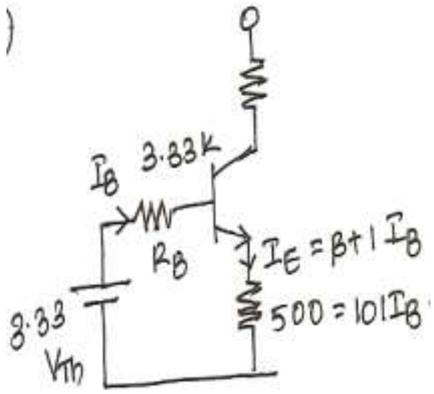
$$S = 50+1\left(\frac{1+45}{1+50+45}\right) = 24.54$$

2) For the circuit shown, determine the value of Ic and V_{CE}. Assume V_{BE} = 0.7V and β = 100



$$V_{in} = \frac{V_{cc}.R_2}{R_1+R_2} = \frac{10\times 5k}{10+5\ k} = \frac{50}{15} = 3.33volts$$

$$R^{th} = \frac{10\times 5}{10+5}k = \frac{50}{15}k = 3.33k.$$



V_{th} = $I_BR_B + V_{BE} + I_ER_E$

= $I_BR_B + V_{BE} + (\beta+1)I_BR_E$

$V_{th} – V_{BE} = I_B(R_B+(\beta + 1)R_E)$

Or $$I_B = \frac{V_{th} - V_{BE}}{R_B + \ \beta + 1\ R_E}$$

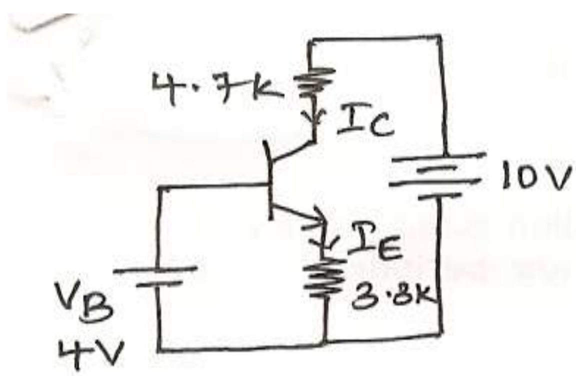
$$= \frac{3.33 - 0.7}{3.3K + 101 \times 500}$$

$$I_B = \frac{2.63}{3300 + 50500} = \frac{2.63}{53800} = 48.88\mu A.$$
$$I_C = \beta.I_B = 4888\mu A.$$

$$I_E = I_C + I_B = 4888 + 48.88 = 49.6\mu A$$

3. For the circuit shown, calculate V_E, I_E, Ic and Vc. Assume V_{BE} = 0.7V.

Solution:



$V_B = V_{BE} + V_E$ or $V_E = V_B – V_{BE}$ = 4 – 0.7 = 3.3V

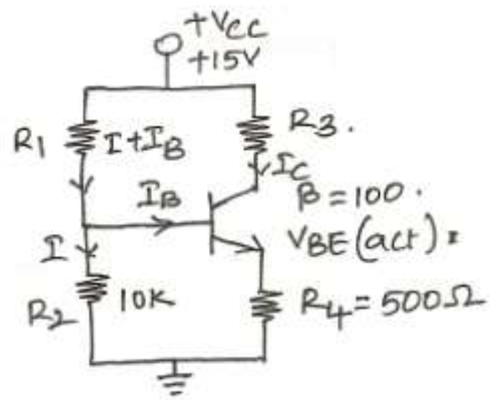
$$I_E = \frac{V_E}{R_E} = \frac{3.3}{3.3k} = 1mA$$

Since β is not given, assume Ic $\approx I_E$ = 1mA.

$V_C = V_{CC} – I_CR_L = 10 – 1 \times 10^{-3} \times 4.7 \times 10^3$ = 5.3 volts

4. In the circuit shown, if I_C = 2mA and V_{CE} = 3V, calculate R_1 & R_3

Solution:



$$I_B = \frac{Ic}{\beta} = \frac{2mA}{100} = 0.02mA$$

$$I_E = I_C + I_B = 2 + 0.02 = 2.02mA$$

$$V_E = I_E R_E = 2.02mA \times 500 = 1.01 volts$$

$$V_{R2} = V_E + V_{BE} = 1.01 + 0.6 = 1.61 volts$$

$$I = \frac{V_{R2}}{R_2} = \frac{1.61}{10k} = 0.161mA$$

$V_{R1} = V_{CC} – V_{R2} = 15 – 1.61 = 13.39$ volts

$$R_1 = \frac{V_{R1}}{I + I_B} = \frac{13.39}{0.161 + 0.02\ \ mA} = 73.97k\Omega$$

$V_{R3} = V_{CC} – V_E – V_{CE}$; $V_{CE} = 3V$

$V_R3 = 15 – 1.01 – 3 = 10.99$ volts

$$R_3 = \frac{V_{R3}}{I_C} = \frac{1099}{2mA} = 5.49k\Omega$$

Part (b) V_{CE} = ?

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

Or $V_{CE} = V_{CC} – I_C R_C – I_E R_E$

$= 10 – 4888 \times 10^{-6} \times 10^{3} – 4937 \times 10^{-6} \times 500$

$= 10 – 04.888 – 2.468$

$= 2.64$ volts

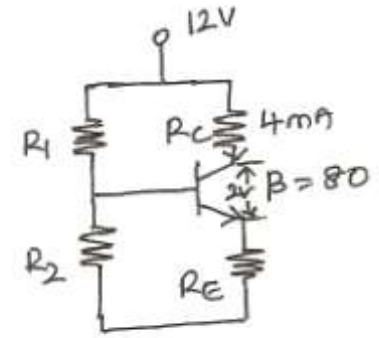
$I_C = 4.89$ mA

V_{CE} 2.64 Volts

5. Design a self-bias circuit for the following specifications.

$V_{CC} = 12V$, $V_{CE} = 2V$, $I_C = 4mA$, $h_{fc} = 80$.

Solution:



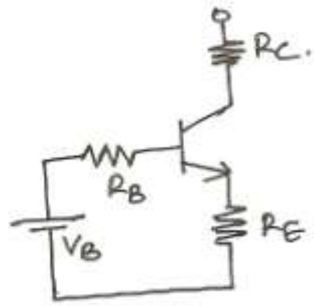
$I_B = \frac{I_C}{\beta}$ = 4mA / 80 = 0.05mA

$I_E = I_C + I_B$ = 4 + 0.05 = 4.05 mA

Let V_B = 4V.

R_2 = 4k and R_1 = 8K

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = \left(\frac{4 \times 8}{4+8}\right)k = \frac{32}{12}k = 2667\Omega$$



$V_B = I_B R_B + V_{BE} + V_{RE}$

Or $V_{RE} = V_B - I_B R_B - V_{BE} = 4 - 0.05 \times 10^{-3} \times 2667 - 0.7$

= 4 – 0.133 – 0.7 = 3.167 volts $R_E = \frac{V_{RE}}{I_E} = \frac{3.167}{4.05mA} = 7.82\Omega$

$V_{CC} = V_{RC} + V_{CE} + V_{RE}$ (OR)

$V_{RC} = V_{CC} - V_{CE} - V_{RE}$

= 12 – 2 – 3.167 = 6.833 volts

$R_c = \frac{V_{RC}}{I_C} = \frac{6.833}{4 \text{ mA}}$ = 1708Ω.

R_1 = 8kΩ, R_2 = 4kΩ, Rc = 1708Ω and Rc = 782 Ω.

But resistor of 1708Ω and 782Ω are not available commercially. We have to choose commercially available resistors, which are nearest to these values.