LECTURE 11/11/2020 (1)

BIAS COMPENSATION

In bias stabilization circuits, the negative feedback improves the stability of the operating point but at the same time it reduces the gain of the amplifier. In certain applications, the loss in the gain becomes serious drawback and is intolerable.

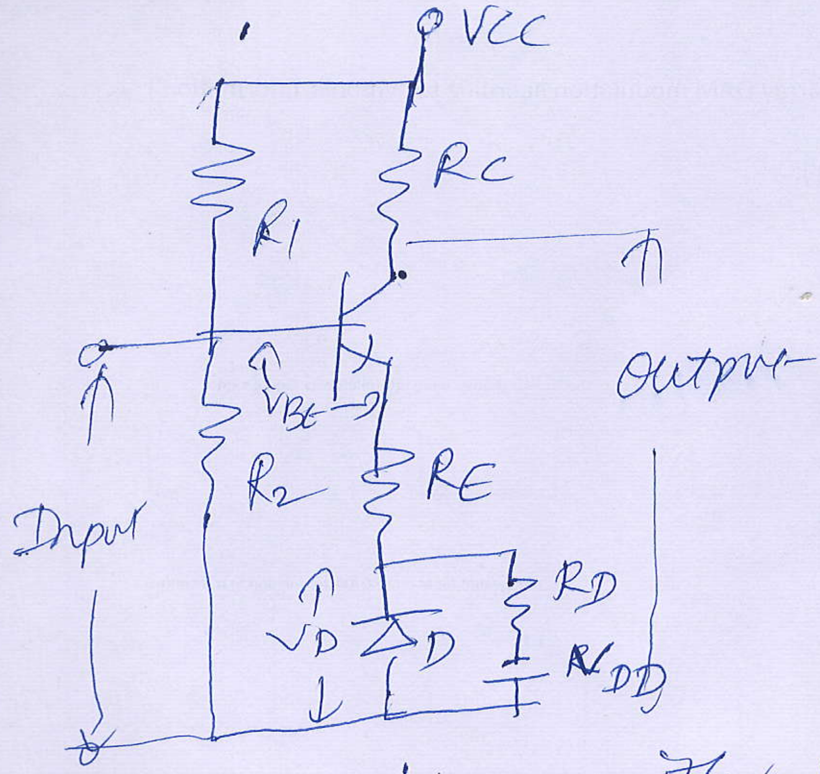
In such cases, compensation techniques are used to reduce the drift of the operating point. Sometimes for excellent bias and thermal stabilization both stabilization as well as compensation techniques are used.

Stabilization techniques refer to the use of resistive biasing whereas compensation techniques refer to the use of temperature sensitive devices such as diodes, transistors, thermistors etc to compensate for variation in currents.

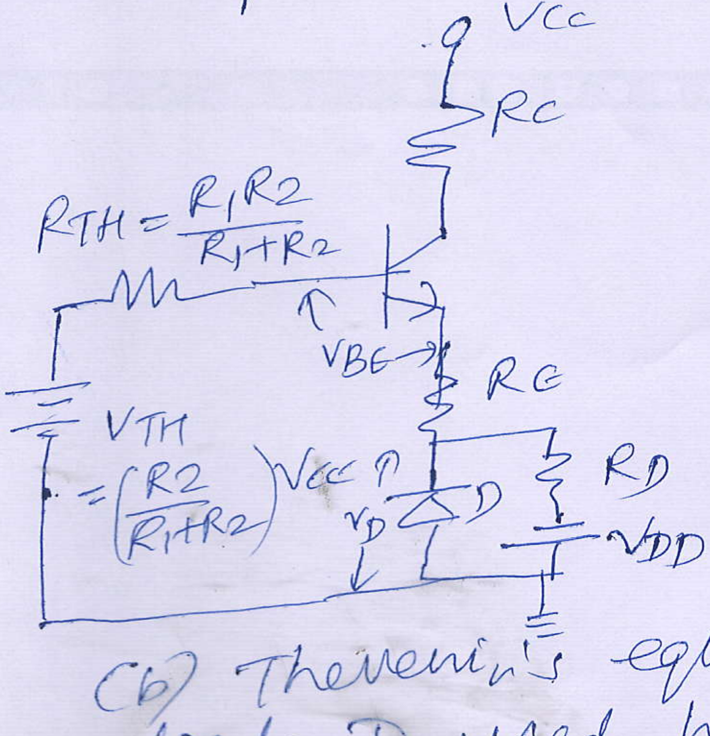
(1) Diode compensation for instability due to VBE variations:

Used for silicon transistors, where the changes of VBE with temp make changes significantly in I_C.

A diode may be used as compensation element.



(a) Voltage divider bias with stabilization and compensation



(b) Thevenin's equivalent circuit

The diode D used here is of the same material and type as the transistor. Hence the voltage V_D across the diode has same temperature coefficient as V_{BE} of the transistor. The diode is forward biased by the source V_{DD} and resistor R_D

(3)

So when V_{BE} changes by ΔV_{BE} with change in temperature V_D Changes by ΔV_D. The change tend to Cancel each other.

. Applying KVL to base circuit.

$$V_{TH} - V_{BE} + V_D = I_B R_{TH} + R_E (I_B + I_C) \quad \ldots (1)$$

But $I_C = \beta I_B + (1+\beta) I_{CO} \quad \ldots (2)$

$$\therefore I_B = \frac{I_C - (1+\beta) I_{CO}}{\beta}$$

$$V_{TH} - V_{BE} + V_D = R_E I_C + (R_{TH} + R_E) I_B$$

Substitute the value of I_B in equation (1)

$$V_{TH} - V_{BE} + V_D = R_E I_C + (R_{TH} + R_E) \left[\frac{I_C - (1+\beta) I_{CO}}{\beta} \right]$$

$$\therefore \beta [V_{TH} - V_{BE} + V_D] = \beta R_E I_C + (R_{TH} + R_E) I_C - (1+\beta) I_{CO} (R_{TH} + R_E)$$

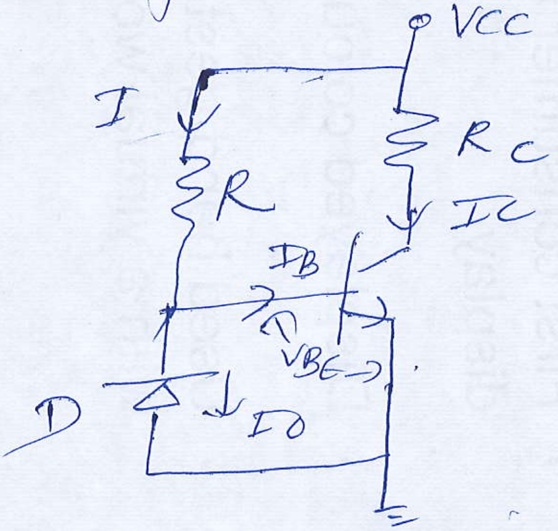
$$\therefore I_C [\beta R_E + R_{TH} + R_E) = \beta [V_{TH} - (V_{BE} - V_D)] + (1+\beta) I_{CO} (R_{TH} + R_E)$$

$$\therefore I_C = \frac{\beta [V_{TH} - (V_{BE} - V_D)] + (1+\beta) I_{CO} (R_{TH} + R_E)}{R_{TH} + (1+\beta) R_E} \quad (3)$$

Since variation in V_{BE} with temperature is the same as the variation in V_D with temperature, hence the quantity $(V_{BE} - V_D)$ remains constant in equation (3)

So I_C remains constant ~~inspite~~ (4)
inspete of variations in V_{BE}. Although diode compensation for V_{BE} variation is not perfect yet it is effective in cancelling most of the operating point drift.

(2) Diode compensation for instability due to I_{CO} variation: ~~in~~
Used for Germanium transistors.



The diode D and the transistor are of the same type and same material. 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}.

$$I = \frac{V_{CC} - V_{BE}}{R} \simeq \frac{V_{CC}}{R} = \text{constant} \quad (1)$$

The diode is reverse biased by V_{BE}

$$I_B = I - I_O \quad \ldots (2).$$

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

In the above equation substitute value of I_B given by equation (2) (5)

$$\therefore I_C = \beta(I - I_0) + (1+\beta) I_{C0}$$

$\beta >> 1$

$$\therefore I_C = \beta I - \beta I_0 + \beta I_{C0}$$

$$I_C = \beta I - \beta(I_0 - I_{C0}) \quad \ldots (3)$$

In expression (3) I is almost constant and if I_0 of diode D and I_{C0} of transistor track each other over operating temperature range, then I_C remains constant.

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(3) Bias compensation using thermistors

(i)

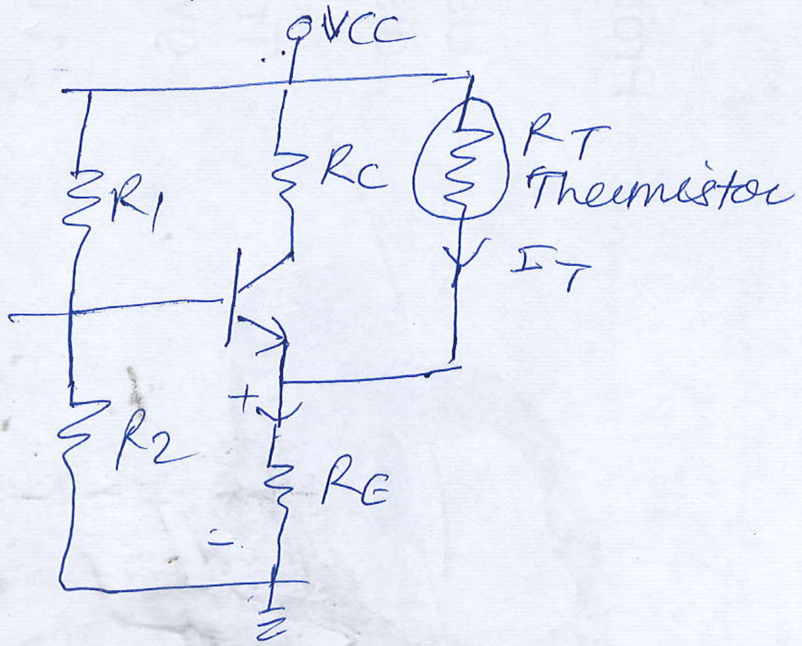
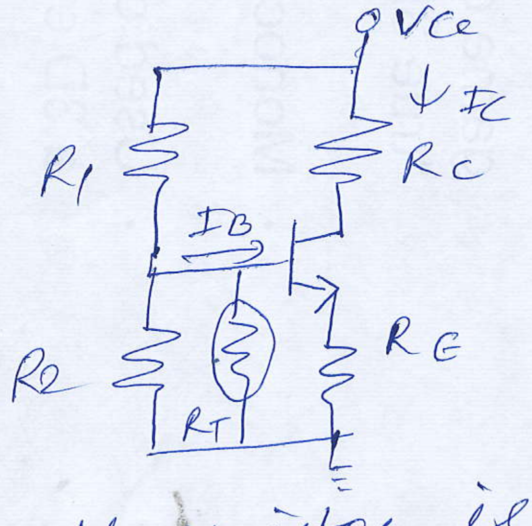


Figure shows the voltage divider bias CE amplifier with thermistor R_T. The thermistor has a negative temperature coefficient of resistance i.e. its resistance decreases exponentially with increasing temperature. The thermistor R_T is used to minimize the increase in I_C due to changes in I_{CO}, V_{BE} or β with temperature.

As the temperature increases resistance R_T of the thermistor decreases. Therefore current I_T increases which results in increase in current across R_E. So the voltage developed across R_E increases in magnitude. This voltage reverse biases the E junction, As a result I_C reduces. & I_C remains fairly constant

(ii)

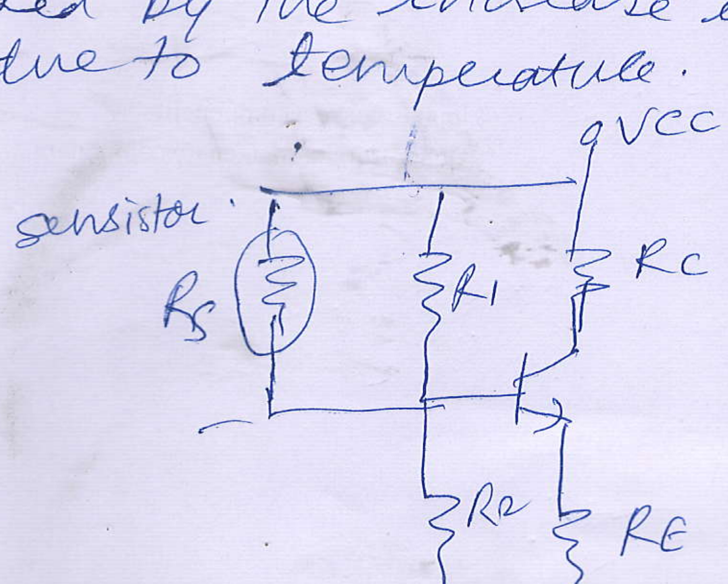


Here thermistor is placed in the B circuit across R_2. As the temperature increases, the drop across R_T decreases So the net forward bias of E decreases and consequently I_C decreases. This reduced I_C tends to compensate for the increased I_C caused by the rise in temperature.

(4) Sensistor compensation

Instead of a thermistor, a sensistor may be used for operating point stability. Sensistor is a temperature sensitive resistor having positive temperature coefficient of resistance. It is a heavily doped semiconductor. The sensistor may be used in parallel with R_1 or in parallel with (or in place of) R_E.

As the temperature increase the resistance of sensistor increases. Thus the resistance of parallel combination ($R_1 \parallel R_S$) increases. Now the voltage drop across R_2 decreases. Due to decrease of this voltage the net forward emitter bias decreases. As a result I_C decreases. This reduced I_C compensate for the increased I_C caused by the increase in I_{CO}, V_{BE} & β due to temperature.



THERMAL RESISTANCE

Transistor is a temperature dependent device. In order to keep the temperature within the limits, the heat generated must be dissipated to the surroundings. Most of the heat within the transistor is produced at the C junction. If the temperature exceeds the permissible limit, this junction is destroyed and the transistor is rendered useless.

Consider a transistor operating in open air. Let T_A = ambient temp i.e. the temperature of surrounding air around transistor.

T_j = the temperature of C-B junction

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

$$\therefore T_j - T_A \propto P_D$$

$$T_j - T_A = \Theta P_D \quad \cdots (1)$$

where Θ is constant of proportionality and is called as thermal resistance or resistance to heat flow from the junction to surrounding air.

$$\Theta = \frac{T_j - T_A}{P_D}$$

Unit of Θ is °C/watt

Value of (H) depends on
(i) Size of transistor (ii) Convection or radiation to the surroundings (iii) forced air cooling (if used) (iv) thermal connection of the device to a metal chassis or heat sink.

Thermal Runaway:

The maximum power $P_{D_{max}}$ which a transistor can dissipate depends on the transistor construction & may lie in the range from few mW to 200 W.
Max. power is limited by the temp. that C-B junction can withstand.
For Si transistors 150 to 225°c & for Ge transistors 60 to 100°c.

Junction temp. may rise due to ambient temp. rise or self heating which results from the power dissipation at the C-B junction.

As a consequence of junction ~~temp.~~ power dissipation the junction temp. rises and this in turn increases the I_c with a subsequent increase in power dissipation. This phenomenon is referred as thermal runaway and if continued it may result in permanently damaging the transistor.

Condition for thermal stability

For a transistor, it is necessary to avoid thermal run away. The thermal stability of a transistor is defined as the ability of a transistor to avoid thermal runaway.

Therefore the required condition is that the rate at which heat is produced at the C-B junction must not exceed the rate at which heat can be dissipated

$$\therefore \frac{\partial P_C}{\partial T_j} < \frac{\partial P_D}{\partial T_j} \quad \ldots (1)$$

$$T_j - T_A = \Theta P_D$$

Differentiating above equation w.r.t. T_j

$$1 = \Theta \frac{\partial P_D}{T_j} \ldots$$

$$\frac{\partial P_D}{\partial T_j} = \frac{1}{\Theta} \quad \ldots (2)$$

From equation (1) & (2).

The condition to prevent thermal runaway is.

$$\boxed{\frac{\partial P_C}{\partial T_j} < \frac{1}{\Theta}}$$

$$\frac{\partial P_C}{\partial T_j} \times \frac{\partial I_C}{\partial I_C} < \frac{1}{\Theta}$$

$$\therefore \frac{\partial P_C}{\partial I_C} \times \frac{\partial I_C}{\partial T_j} < \frac{1}{\Theta} \quad \ldots (3)$$

Consider voltage divider bias, The value of P_C (~~heat produce~~ is given by. (11)

$$P_C = V_{CC} I_C - I_C^2 R_C - I_E^2 R_E.$$

or $P_C = V_{CC} I_C - I_C^2 (R_C + R_E)$ $(I_E \simeq I_C)$

$V_{CC} I_C$ is power taken from supply V_{CC}.

$$\therefore \frac{\partial P_C}{\partial I_C} = V_{CC} - 2 I_C (R_C + R_E) \quad \text{.. (4)}$$

Rewriting equation (3)

$$\frac{\partial P_C}{\partial I_C} \times \frac{\partial I_C}{\partial T_j} < \frac{1}{(H)} \quad \text{.. (3)}$$

In this equation (H), $\frac{\partial I_C}{\partial T_j}$ are positive, therefore the condition (3) is always satisfied if $\frac{\partial P_C}{\partial I_C}$ is negative

$$\frac{\partial P_C}{\partial I_C} = V_{CC} - 2 I_C (R_C + R_E)$$

$$\therefore V_{CC} < 2 I_C (R_C + R_E) \quad \text{.. (5)}$$

$$\therefore \frac{V_{CC}}{2} < I_C (R_C + R_E)$$

$$\therefore I_C > \frac{V_{CC}}{2 (R_C + R_E)}$$

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

$$\therefore I_C (R_C + R_E) = V_{CC} - V_{CE} \quad \text{.. (6)}$$

Substituting value of $I_C (R_C + R_E)$ in equation 5

12

$$\frac{V_{CC}}{2} < V_{CC} - V_{CE}$$

$$\therefore V_{CE} < V_{CC} - \frac{V_{CC}}{2}$$

$$V_{CE} < \frac{V_{CC}}{2} \quad (7)$$

Thus if $V_{CE} < \frac{V_{CC}}{2}$ stability is ensured