Experiment No. 8
Transistor Biasing and Bias Stability

**Aim of experiment:**
To study the Transistor biasing types and bias stability.

**Theory**
Notice from the previous load line experiment (Experiment No.6)
1. The instantaneous operating point moves with instantaneous signal voltage. Linearity is best when operating point stays within the active regions.
2. The quiescent point is the dc (zero signal) operating point. It lies near the “middle” of the range of instantaneous operating points. This dc operating point is required if linear amplification is to be achieved!!!
3. The dc operating point (the quiescent point, the Q point, the bias point) obviously requires that dc sources be in the circuit.
4. The process of establishing an appropriate bias point is called biasing the transistor.
5. Given a specific type of transistor, biasing should result in the same or nearly the same bias point in every transistor of that type... this is called bias stability. Bias stability can also mean stability with temperature, with aging, etc.

**Transistor Biasing**

1. **The Fixed Bias Circuit**
   Fig.(1) shows the fixed biasing transistor circuit. The resistor $R_B$ is supplied from $V_{cc}$ directly then the $I_B$ (D.C base current) is fixed at certain value. Therefore;
   
   $$I_B = \frac{V_{cc} - V_{be}}{R_BE}$$

   The following example explains the fixed biasing circuit stability.

**Example**
We let $V_{cc} = 15$ V, $R_B = 200$ kΩ, and $RC = 1$ kΩ and $\beta$ varies from 100 to 300. To perform the analysis, we assume that operation is in the active region, and that $V_{BE} = 0.7$ V.
For $\beta = 100$:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{15 \text{ V} - 0.7 \text{ V}}{200 \text{ k}\Omega} = 7.15 \mu\text{A}$$

$$I_C = \beta I_B = 7.15 \text{ mA} \quad \Rightarrow \quad V_{CE} = V_{CC} - I_C R_C = 7.85 \text{ V}$$

Q. Active region???

$V_{CE} > 0.7 \text{ V}$ and $I_B > 0$ \hspace{1cm} Yes!!!

For $\beta = 300$:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{15 \text{ V} - 0.7 \text{ V}}{200 \text{ k}\Omega} = 7.15 \mu\text{A}$$

$$I_C = \beta I_B = 215 \text{ mA} \quad \Rightarrow \quad V_{CE} = V_{CC} - I_C R_C = -6.45 \text{ V}$$

Q. Active region???

$V_{CE} < 0.7 \text{ V}$ \hspace{1cm} No!!! \hspace{1cm} Saturation!!!

Thus our calculations for $\beta = 300$ are incorrect, but more importantly. We conclude that fixed bias provides extremely poor bias stability!!!
For $\beta = 100$:

$$I_E = \frac{V_{BB} - V_{BE}}{R_E} = 2.15 \text{ mA} \quad \Rightarrow \quad I_c = \frac{\beta}{\beta + 1} I_E = 2.13 \text{ mA}$$

$$V_{CE} = V_{CC} - I_c R_C - I_E R_E = 6.44 \text{ V}$$

For $\beta = 300$:

$$I_E = \frac{V_{BB} - V_{BE}}{R_E} = 2.15 \text{ mA} \quad \Rightarrow \quad I_c = \frac{\beta}{\beta + 1} I_E = 2.14 \text{ mA}$$

$$V_{CE} = V_{CC} - I_c R_C - I_E R_E = 6.41 \text{ V}$$

Thus we conclude that constant base bias provides excellent bias stability!!

Unfortunately, we can’t easily couple a signal into this circuit, so it is not as useful as it may first appear.

3. The Four-Resistor Bias Circuit (Self–Biasing Circuit)

A circuit which is used to establish a stable operating point is the self-biasing confirmation of Fig.(3-a). The current in the resistance $R_E$ in the emitter lead causes a voltage drop which is in the direction to reverse-bias the emitter junction. Since this junction must be forward-biased, the base voltage is obtained from the supply through the $R_1$ & $R_2$ network.

Now, if $I_C$ tends to increase, say, because $I_{CO}$ has rise as a result of an elevated temperature, the current in $R_E$ increases. Hence $I_C$ will increase less than it would have, had there been no self-biasing resistor $R_E$.

This combines features of fixed bias and constant base bias, but it takes a circuit-analysis “trick” to see that in Fig.(3-b):

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**Fig.(3)**

(a): Four resistor bias circuit.
(b): Equivalent after "trick" with supply voltage.
(c): Final equivalent Thevenin's
**Circuit Analysis**

Analysis begins with KVL around B-E loop:

\[ V_{BB} = I_B R_B + V_{BE} + I_E R_E \]

But in the active region \( I_E = (\beta + 1)I_B \):

\[ V_{BB} = I_B R_B + V_{BE} + (\beta + 1)I_B R_E \]

Now we solve for \( I_B \):

\[ I_B = \frac{V_{BB} - V_{BE}}{R_B + (\beta + 1)R_E} \]

And multiply both sides by \( \beta \):

\[ \beta I_B = I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B + (\beta + 1)R_E} \]

We complete the analysis with KVL around C-E loop:

\[ V_{CE} = V_{CC} - I_C R_C - I_E R_E \]

**Bias Stability**

Bias stability can be illustrated with equation below:

\[ \beta I_B = I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B + (\beta + 1)R_E} \]

Notice that if \( R_E = 0 \), we have *fixed bias*. While if \( R_B = 0 \), we have *constant base bias*.

**To maximize bias stability:**

1. We minimize variations in \( I_C \) with changes in \( \beta \).
   By letting \((\beta + 1)R_E >> R_B \), then \( \beta \) and \((\beta + 1) \) nearly cancel in above equation
   
   \[ \text{Rule of Thumb:} \quad \text{let} \ (\beta + 1)R_E = 10R_B \]
   
   \[ \text{Equivalent Rule:} \quad \text{let} \ I_{R_z} = 10I_{\ell_{max}} \]

2. We also minimize variations in \( I_C \) with changes in \( V_{BE} \).
   By letting \( V_{BB} >> V_{BE} \)
   
   \[ \text{Rule of Thumb:} \quad \text{let} \ V_{R_z} \approx V_{CE} \approx V_{Re} \approx \frac{1}{3}V_{CC} \]

   Because \( V_{Re} = V_{BB} \) if \( V_{BE} \) and \( I_B \) are small.
Example
For the circuit shown below, determine the stability of the circuit when vary from 100 to 300.

For $\beta = 100$ (and $V_{BE} = 0.7 \, V$):

\[ I_B = \frac{V_{BB} - V_{BE}}{R_E + (\beta + 1)R_E} = 41.2 \, \mu A \quad \Rightarrow \quad I_C = \beta I_B = 4.12 \, mA \]

\[ I_E = \frac{I_C}{\alpha} = 4.16 \, mA \quad \Rightarrow \quad V_{CE} = V_{CC} - I_C R_C - I_E R_E = 6.72 \, V \]

For $\beta = 300$:

\[ I_B = \frac{V_{BB} - V_{BE}}{R_E + (\beta + 1)R_E} = 14.1 \, \mu A \quad \Rightarrow \quad I_C = \beta I_B = 4.24 \, mA \]

\[ I_E = \frac{I_C}{\alpha} = 4.25 \, mA \quad \Rightarrow \quad V_{CE} = V_{CC} - I_C R_C - I_E R_E = 6.50 \, V \]

Thus we have achieved a reasonable degree of bias stability.

Procedure
1. Connect the circuit shown in Fig.(4).
2. Change values of "$R_B$" until $I_C = 5 \, mA$, then record the value of $R_B$.
3. Connect the source which gives $I_{CO}$. Then change the voltage source until $I_{CO} = 15 \mu A$. Record the value of collector current $I_C$.
4. Repeat step (3) for $I_C = (20, 25, 30) \mu A$.
5. Connect the circuit shown in Fig.(5)
6. Record the value of collector current without $I_{CO}$.
7. Repeat steps (3, 4) for $R_1 = \, k\Omega$ & $R_2 = \, k\Omega$.
8. Repeat steps (6, 7) for $R_1 = \, k\Omega$ & $R_2 = \, k\Omega$. 
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Calculations:
1. Plot the relationship between \( I_C \) & \( I_{CO} \) for two circuits.
2. Find the stability factor for each case.

Discussion
1. What the factors effects on the selection operating point (Q-point).
2. What the effect of decrease the values of \( R_1 \) and \( R_2 \) on the stability factors.
   What the disadvantage of using small values of \( R_1 \) and \( R_2 \).
3. Why we need stable operating point.
4. By using load line and Q-point, explain how the change in \( I_{CO} \) effect on the amplifier output.

Fig.(4): Fixed Biasing Circuit with \( I_{CO} \) source for test

Fig.(5): Self-bias circuit with \( I_{CO} \) source for test