Experiment 8

Determination of Q-Point of a BJT

OBJECTIVE:

To determine the quiescent operating condition of the fixed, voltage divider bias, common collector and common emitter BJT configuration

Introduction:

In the previous introduction to the amplifier tutorial, we saw that a family of curves known commonly as the **Output Characteristic Curves**, relate the transistors Collector Current (Ic), to its Collector Voltage (Vce) for different values of the transistors Base Current (Ib). All types of transistor amplifiers operate using AC signal inputs which alternate between a positive value and a negative value so some way of "presetting" the amplifier circuit to operate between these two maximum or peak values is required. This is achieved using a process known as **Biasing**. Biasing is very important in amplifier design as it establishes the correct operating point of the transistor amplifier ready to receive signals, thereby reducing any distortion to the output signal.

We also saw that a static or DC load line can be drawn onto these output characteristics curves to show all the possible operating points of the transistor from fully "ON" to fully "OFF", and to which the quiescent operating point or **Q-point** of the amplifier can be found.

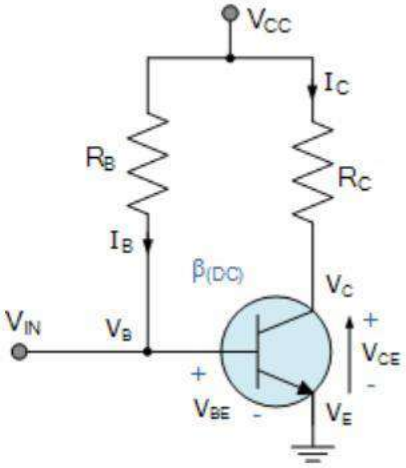
The aim of any small signal amplifier is to amplify all of the input signal with the minimum amount of distortion possible to the output signal, in other words, the output signal must be an exact reproduction of the input signal but only bigger (amplified).

To obtain low distortion when used as an amplifier the operating quiescent point needs to be correctly selected. This is in fact the DC operating point of the amplifier and its position may be established at any point along the load line by a suitable biasing arrangement.

Fixed Bias Configuration:

The steady state operation of a bipolar transistor depends a great deal on its base current, collector voltage, and collector current values. Therefore, if the transistor is to operate correctly

as a linear amplifier, it must be properly biased around its operating point as improper transistor biasing will result in a distorted output.



$V_C = V_{CC} - (I_C R_C)$
$V_{CE} = V_C - V_E$
$V_E = 0v$
$V_B = V_{BE}$
$I_B = \frac{V_{CC} - V_{BE}}{R_B}$
$I_C = \beta_{(DC)} I_B$
$I_E = (I_C + I_B) \cong I_C$

The circuit shown is called as a "fixed base bias circuit", because the transistors base current, IB remains constant for given values of Vcc, and therefore the transistors operating point must also remain fixed. This two resistor biasing network is used to establish the initial operating region of the transistor using a fixed current bias. This type of transistor biasing arrangement is also beta dependent biasing as the steady-state condition of operation is a function of the transistors beta β value, so the biasing point will vary over a wide range for transistors of the same type as the characteristics of the transistors will not be exactly the same. The emitter diode of the transistor is forward biased by applying the required positive base bias voltage via the current limiting resistor RB. Assuming a standard bipolar transistor, the forward base-emitter voltage drop would be 0.7V. Then the value of RB is simply: (VCC – VBE)/IB where IB is defined as IC/β. **Voltage Divider configuration**

The single stage common emitter amplifier circuit shown above uses what is commonly called "Voltage Divider Biasing". This type of biasing arrangement uses two resistors as a potential divider network across the supply with their center point supplying the required Base bias voltage to the transistor. Voltage divider biasing is commonly used in the design of bipolar transistor amplifier circuits.

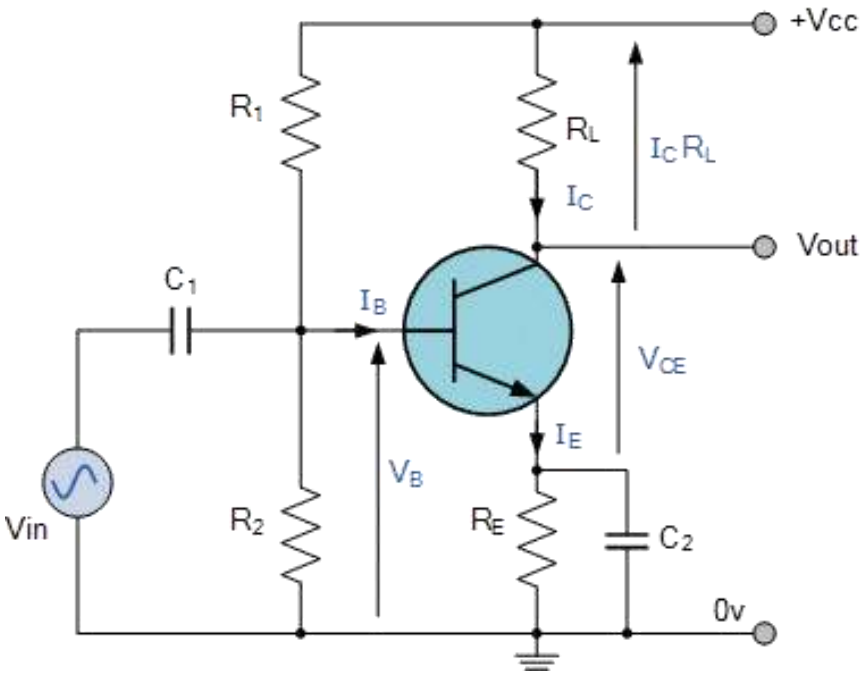
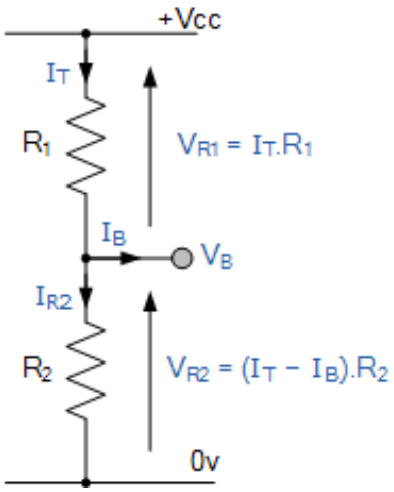


Figure 9.1: Voltage divider Bias

This method of biasing the transistor greatly reduces the effects of varying Beta, (β) by holding the Base bias at a constant steady voltage level allowing for best stability. The quiescent Base voltage (Vb) is determined by the potential divider network formed by the two resistors, R1, R2 and the power supply voltage Vcc as shown with the current flowing through both resistors.



Then the total resistance R_T will be equal to R1 + R2 giving the current as i = Vcc/R_T. The voltage level generated at the junction of resistors R1 and R2 holds the Base voltage (Vb) constant at a value below the supply voltage.

Then the potential divider network used in the common emitter amplifier circuit divides the supply voltage in proportion to the resistance. This bias reference voltage can be easily calculated using the simple voltage divider formula below:

Transistor Bias Voltage

$$V_B = \frac{V_{CC} R_2}{R_1 + R_2}$$

The same supply voltage, (Vcc) also determines the maximum Collector current, Ic when the transistor is switched fully "ON" (saturation), Vce = 0. The Base current Ib for the transistor is found from the Collector current, Ic and the DC current gain Beta, β of the transistor.

Beta Value

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Beta is sometimes referred to as h_{FE} which is the transistors forward current gain in the common emitter configuration. Beta has no units as it is a fixed ratio of the two currents, Ic and Ib so a small change in the Base current will cause a large change in the Collector current.

One final point about Beta. Transistors of the same type and part number will have large variations in their Beta value. For example, the *BC107 NPN Bipolar transistor* has a DC current gain Beta value of between 110 and 450 (data sheet value). So, one BC107 may have a Beta value of 110, while another one may have a Beta value of 450, but they are both BC107 npn transistors. This is because Beta is a characteristic of the transistor's construction and not of its operation.

As the Base/Emitter junction is forward-biased, the Emitter voltage, Ve will be one junction voltage drop different to the Base voltage. If the voltage across the Emitter resistor is known then the Emitter current, Ie can be easily calculated using Ohm's Law. The Collector current, Ic can be approximated, since it is almost the same value as the Emitter current.

Common Emitter Amplifier Example

A common emitter amplifier circuit has a load resistance, R_L of 1.2kΩ and a supply voltage of 12v. Calculate the maximum Collector current (Ic) flowing through the load resistor when the transistor is switched fully "ON" (saturation), assume Vce = 0. Also find the value of the Emitter resistor, R_E if it has a voltage drop of 1v across it. Calculate the values of all the other circuit resistors assuming a standard NPN silicon transistor.

$$I_{C(MAX)} = \frac{V_{CC} - V_{RE}}{R_L} = \frac{12 - 1}{1200} = 9.2mA$$

$$V_{CE} = 0 \ (Saturation)$$

This then establishes point "A" on the Collector current vertical axis of the characteristics curves and occurs when Vce = 0. When the transistor is switched fully "OFF", their is no voltage drop across either resistor R_E or R_L as no current is flowing through them. Then the voltage drop across the transistor, Vce is equal to the supply voltage, Vcc. This establishes point "B" on the horizontal axis of the characteristic's curves.

Generally, the quiescent Q-point of the amplifier is with zero input signal applied to the Base, so the Collector sits about half-way along the load line between zero volts and the supply voltage, (Vcc/2). Therefore, the Collector current at the Q-point of the amplifier will be given as:

$$Ic_{(Q)} = \frac{\frac{12-1}{2}}{1200} = \frac{5.5}{1200} = 4.58mA$$

This static DC load line produces a straight line equation whose slope is given as: $-1/(R_L + R_E)$ and that it crosses the vertical Ic axis at a point equal to $Vcc/(R_L + R_E)$. The actual position of the Q-point on the DC load line is determined by the mean value of Ib.

As the Collector current, Ic of the transistor is also equal to the DC gain of the transistor (Beta), times the Base current (β*Ib), if we assume a Beta (β) value for the transistor of say 100, (one

hundred is a reasonable average value for low power signal transistors) the Base current Ib flowing into the transistor will be given as:

$$\beta = \frac{I_C}{I_B}$$

$$\therefore I_B = \frac{I_C}{\beta} = \frac{4.58mA}{100} = 45.8\mu A$$

Instead of using a separate Base bias supply, it is usual to provide the Base Bias Voltage from the main supply rail (Vcc) through a dropping resistor, R1. Resistors, R1 and R2 can now be chosen to give a suitable quiescent Base current of 45.8µA or 46µA rounded off to the nearest integer. The current flowing through the potential divider circuit has to be large compared to the actual Base current, Ib, so that the voltage divider network is not loaded by the Base current flow.

A general rule of thumb is a value of at least 10 times Ib flowing through the resistor R2. Transistor Base/Emitter voltage, Vbe is fixed at 0.7V (silicon transistor) then this gives the value of R2 as:

$$R_2 = \frac{V_{(RE)} + V_{(BE)}}{10 \times I_B} = \frac{1 + 0.7}{458 \times 10^{-6}} = 3.71k\Omega$$

If the current flowing through resistor R2 is 10 times the value of the Base current, then the current flowing through resistor R1 in the divider network must be 11 times the value of the Base current. That is: I_{R2} + Ib.

Thus the voltage across resistor R1 is equal to Vcc – 1.7v (V_{RE} + 0.7 for silicon transistor) which is equal to 10.3V, therefore R1 can be calculated as:

$$R_1 = \frac{V_{CC} - \left(V_{(RE)} + V_{(BE)}\right)}{11 \times I_B} = \frac{12 - 1.7}{504 \times 10^{-6}} = 20.45k\Omega$$

The value of the Emitter resistor, R_E can be easily calculated using Ohm's Law. The current flowing through R_E is a combination of the Base current, Ib and the Collector current Ic and is given as:

$$I_E = I_C + I_B = 4.58mA + 45.8\mu A = 4.63mA$$

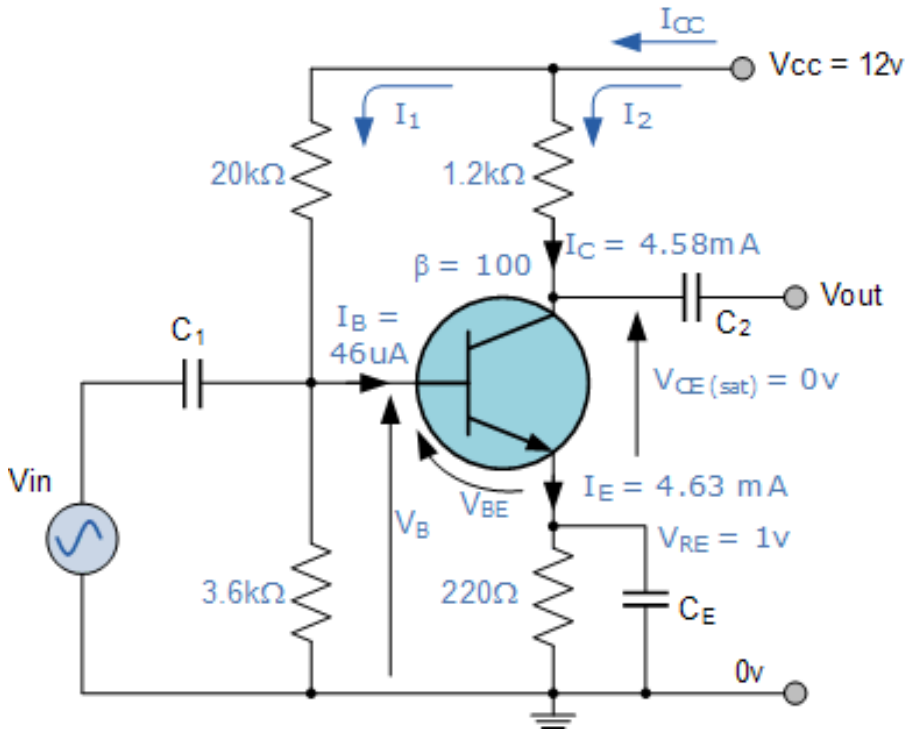
Resistor, R_E is connected between the transistors Emitter terminal and ground, and we said previously that there is a voltage drop of 1 volt across it. Thus the value of the Emitter resistor, R_E is calculated as:

$$R_E = \frac{V_{RE}}{I_E} = \frac{1v}{4.63mA} = 216\Omega$$

So, for our example above, the preferred values of the resistors chosen to give a tolerance of 5% (E24) are:

$$R_1 = 20k\Omega,\ R_2 = 3.6k\Omega,\ R_L = 1.2k\Omega,\ R_E = 220\Omega$$

Then, our original **Common Emitter Amplifier** circuit above can be rewritten to include the values of the components that we have just calculated above.



Amplifier Coupling Capacitors

In **Common Emitter Amplifier** circuits, capacitors C1 and C2 are used as **Coupling Capacitors** to separate the AC signals from the DC biasing voltage. This ensures that the bias condition set up for the circuit to operate correctly is not affected by any additional amplifier stages, as the capacitors will only pass AC signals and block any DC component. The output AC signal is then superimposed on the biasing of the following stages. Also a bypass capacitor, C_E is included in the Emitter leg circuit.

This capacitor is effectively an open circuit component for DC biasing conditions, which means that the biasing currents and voltages are not affected by the addition of the capacitor maintaining a good Q-point stability.

However, this parallel connected bypass capacitor effectively becomes a short circuit to the Emitter resistor at high frequency signals due to its reactance. Thus only R_L plus a very small internal resistance acts as the transistors load increasing voltage gain to its maximum. Generally, the value of the bypass capacitor, C_E is chosen to provide a reactance of at most, 1/10th the value of R_E at the lowest operating signal frequency.

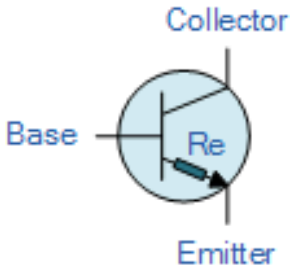
Common Emitter Voltage Gain

The **Voltage Gain** of the common emitter amplifier is equal to the ratio of the change in the input voltage to the change in the amplifiers output voltage.

Then ΔV_L is Vout and ΔV_B is Vin. But voltage gain is also equal to the ratio of the signal resistance in the Collector to the signal resistance in the Emitter and is given as:

$$\text{Voltage Gain} = \frac{\text{Vout}}{\text{Vin}} = \frac{\Delta V_L}{\Delta V_B} = -\frac{R_L}{R_E}$$

We mentioned earlier that as the signal frequency increases the bypass capacitor, C_E starts to short out the Emitter resistor due to its reactance. Then at high frequencies $R_E = 0$, making the gain infinite.



However, bipolar transistors have a small internal resistance built into their Emitter region called R_e. The transistors semiconductor material offers an internal resistance to the flow of current through it and is generally represented by a small resistor symbol shown inside the main transistor symbol.

Transistor data sheets tell us that for a small signal bipolar transistors this internal resistance is the product of 25mV ÷ Ie (25mV being the internal volt drop across the Emitter junction layer), then for our common Emitter amplifier circuit above this resistance value will be equal to:

$$R_e = \frac{25mV}{I_E} = \frac{25mV}{4.58mA} = 5.5\Omega$$

This internal Emitter leg resistance will be in series with the external Emitter resistor, R_E, then the equation for the transistors actual gain will be modified to include this internal resistance so will be:

$$\text{Voltage Gain} = -\frac{R_L}{(R_E + R_e)}$$

At low frequency signals the total resistance in the Emitter leg is equal to $R_E + R_e$. At high frequency, the bypass capacitor shorts out the Emitter resistor leaving only the internal resistance R_e in the Emitter leg resulting in a high gain. Then for our common emitter amplifier circuit above, the gain of the circuit at both low and high signal frequencies is given as:

Gain at Low Frequencies

$$\text{Gain} = -\frac{R_L}{(R_E + R_e)} = -\frac{1200}{220+5.5} = -5.32$$

Gain at High Frequencies

$$\text{Gain} = -\frac{R_L}{R_e} = -\frac{1200}{5.5} = -218$$

One final point, the voltage gain is dependent only on the values of the Collector resistor, R_L and the Emitter resistance, $(R_E + R_e)$ it is not affected by the current gain Beta, β (h_{FE}) of the transistor.

Common Emitter Amplifier Summary

The **Common Emitter Amplifier** circuit has a resistor in its Collector circuit. The current flowing through this resistor produces the voltage output of the amplifier. The value of this resistor is chosen so that at the amplifiers quiescent operating point, **Q-point** this output voltage lies half way along the transistors load line.

The Base of the transistor used in a common emitter amplifier is biased using two resistors as a potential divider network. This type of biasing arrangement is commonly used in the design of bipolar transistor amplifier circuits and greatly reduces the effects of varying Beta, (β) by holding the Base bias at a constant steady voltage. This type of biasing produces the greatest stability.

A resistor can be included in the emitter leg in which case the voltage gain becomes $-R_L/R_E$. If there is no external Emitter resistance, the voltage gain of the amplifier is not infinite as there is a very small internal resistance, R_e in the Emitter leg. The value of this internal resistance is equal to $25mV/I_E$

Activity:

Activity: 1

Using 2 NPN transistor (2N3904 and 2N4401) calculate the following for both configuration:

$$\%\Delta B = \frac{|B(4401) - B(3904)|}{|B(3904)|}$$

$$\%\Delta IC = \frac{|Ic(4401) - Ic(3904)|}{|Ic(3904)|}$$

$$\%\Delta Vce = \frac{|Vce(4401) - Vce(3904)|}{|Vce(3904)|}$$

$$\%\Delta IB = \frac{|IB(4401) - IB(3904)|}{|IB(3904)|}$$

- Fixed Bias Configuration:

  $\%\Delta B =$

  $\%\Delta IC =$

  $\%\Delta Vce =$

  $\%\Delta IB =$

- Voltage Divider Bias Configuration:

  $\%\Delta B =$

  $\%\Delta IC =$

  $\%\Delta Vce =$

  $\%\Delta IB =$

Collector Feedback Configuration:

This self-biasing collector feedback configuration is another beta dependent biasing method which requires two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β). The DC base bias voltage is derived from the collector voltage VC, thus providing good stability. In this circuit, the base bias resistor, RB is connected to the transistors collector C, instead of to the supply voltage rail, Vcc. Now if the collector current increases, the collector voltage drops, reducing the base drive and thereby automatically reducing the collector current to keep the transistors Q-point fixed. Therefore this method of collector feedback biasing produces negative feedback round the transistor as there is a direct feedback from the output terminal to the input terminal via resistor, RB. Since the biasing voltage is derived from the voltage drop across the load resistor, RL, if the load current increases there will be a larger voltage drop across RL, and a corresponding reduced collector voltage, VC. This effect will cause a corresponding drop in the base current, IB which in turn, brings IC back to normal. The opposite reaction will also occur when the transistors collector current reduces. Then this method of biasing is called self-biasing with the transistors stability using this type of feedback bias network being generally good for most amplifier designs.

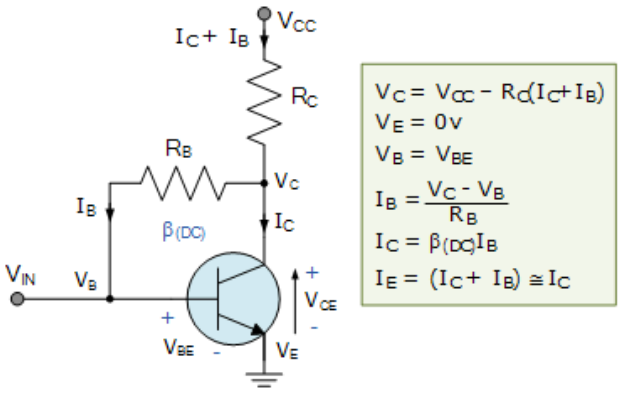


Figure 1 collector feedback circuit

Emitter Feedback Configuration:

This type of transistor biasing configuration, often called self-emitter biasing, uses both

emitter and base-collector feedback to stabilize the collector current even further. This is because resistors RB1 and RE as well as the base-emitter junction of the transistor are all effectively connected in series with the supply voltage, VCC. The downside of this emitter feedback configuration is that it reduces the output gain due to the base resistor connection. The collector voltage determines the current flowing through the feedback resistor, RB1 producing what is called “degenerative feedback”. The current flowing from the emitter, IE (which is a combination of IC + IB) causes a voltage drop to appear across RE in such a direction, that it reverse biases the base-emitter junction. So if the emitter current increases, due to an increase in collector current, voltage drop I*RE also increases. Since the polarity of this voltage reverse biases the base-emitter junction, IB automatically decrease. Therefore the emitter current increase less than it would have done had there been no self-biasing resistor. Generally, resistor values are set so that the voltage dropped across the emitter resistor RE is approximately 10% of VCC and the current flowing through resistor RB1 is 10% of the collector current IC. Thus this type of transistor biasing configuration works best at relatively low power supply voltages.

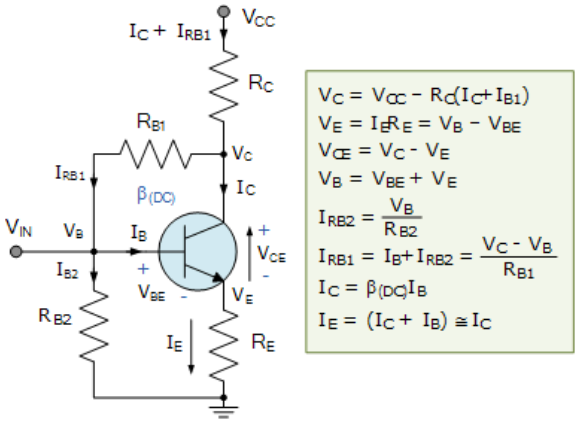
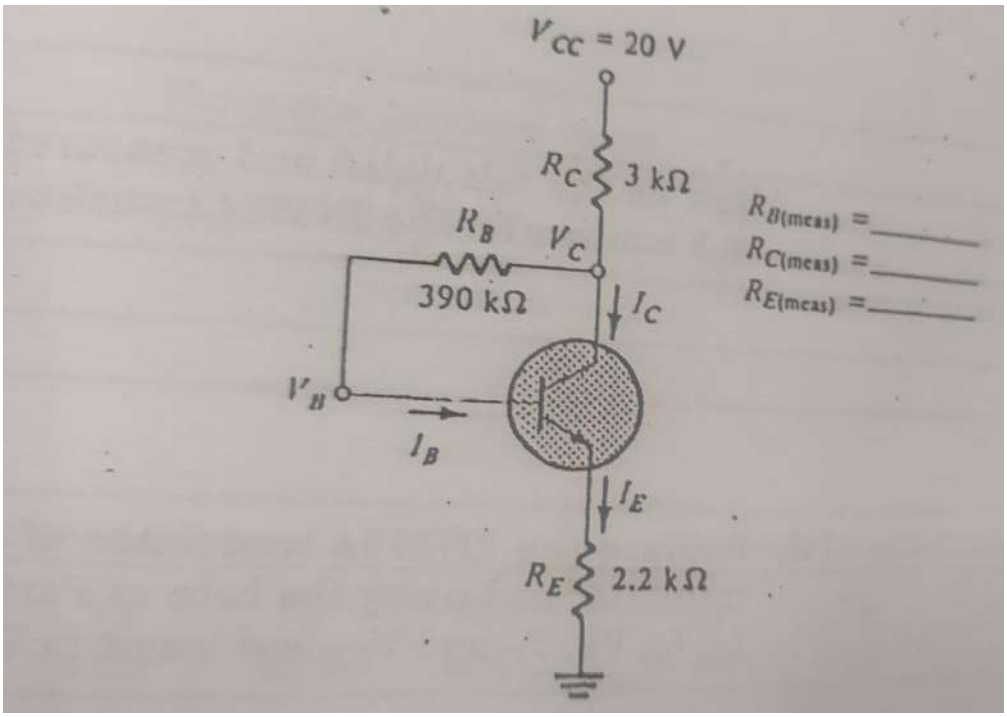


Figure 2 Emitter Feedback Configuration

Activities:

Task 1:

Construct the network of Figure shown below using the 2N3904 transistor. Insert the measured resistance value.



Task: 02

Calculate and Measure values of Ic, Ib and Vce and record the values below:

Ic =

Ib =

Vce =

Beta =

Task: 3

Replace the transistor 2N3904 with 2N4401 transistor and measure the values of Ib, Ic and Vce

and record the value given below:

Ic =

Ib =

Vce =

Beta =

Task: 4

Calculate the change in value for both transistor using following formulae:

$$\%\Delta B = \frac{|B(4401) - B(3904)|}{|B(3904)|} x\ 100$$

$$\%\Delta IC = \frac{|Ic(4401) - Ic(3904)|}{|Ic(3904)|}\ x\ 100$$

$$\%\Delta Vce = \frac{|Vce(4401) - Vce(3904)|}{|Vce(3904)|} x\ 100$$

$$\%\Delta IB = \frac{|IB(4401) - IB(3904)|}{|IB(3904)|} x\ 100$$

$\%\Delta B$ =

$\%\Delta IC$ =

$\%\Delta Vce$ =

$\%\Delta IB$ =

Lab Exercise and Summary

Summary should cover Introduction, Procedure, Data Analysis and Evaluation.

LABORATORY SKILLS ASSESMENT (Psychomotor)

Total Marks: 100

Criteria (Max Marks)	Level 1 0% ≤ S < 50%	Level 2 50% ≤ S< 70%	Level 3 70% ≤ S< 90%	Level 4 90%≤ S ≤100%	Score (S)
Procedural Awareness (20)	Selects inappropriate skills and/or strategies required by the task	Selects and applies appropriate skills and/or strategies required by the task with some errors	Selects and applies the appropriate strategies and/or skills specific to the task without significant errors	Selects and applies appropriate strategies and/or skills specific to the task without any error	
Practical Implementation (30)	Makes several critical errors in applying procedural knowledge related to QPoint for fixed and voltage divider bias configuration of a BJT	Makes few critical errors in applying procedural knowledge related to Q-Point for fixed and voltage divider bias configuration of a BJT	Makes some non-critical errors in applying procedural knowledge related to Q-Point for fixed and voltage divider bias configuration of a BJT	Applies the procedural knowledge in perfect ways related to Q-Point for fixed and voltage divider bias configuration of a BJT	
Safety (10)	Requires constant reminders to follow safety procedures	Requires some reminders to follow safety procedures	Follows safety procedures with only minimal reminders	Routinely follows safety procedures	
Use of Tool/Equipment (20)	Uses tools, equipment and materials with limited competence	Uses tools, equipment and materials with some competence	Uses tools, equipment and materials with considerable competence	Uses tools, equipment and materials with a high degree of competence	
Participation to Achieve Group Goals (10)	Shows little commitment to group goals and fails to perform assigned roles	Demonstrates commitment to group goals, but has difficulty performing assigned roles	Demonstrates commitment to group goals and carries out assigned roles effectively	Actively helps to identify group goals and works effectively to meet them in all roles assumed	
Interpersonal Skills in Group Work (10)	Rarely interacts positively within a group, even with prompting	Interacts with other group members if prompted	Interacts with all group members spontaneously	Interacts positively with all group members and encourages such interaction in others	
				Marks Obtained	

Student's Signature: _____ **Date: _____**

LABORATORY SKILLS ASSESMENT (Affective) **Total Marks: 40**

Criteria (Max. Marks)	Level 1 0% ≤ S < 50%	Level 2 50% ≤ S < 70%	Level 3 70% ≤ S < 90%	Level 4 90% ≤ S ≤ 100%	Score (S)
Introduction (5)	Very little background information provided or information is incorrect	Introduction is brief with some minor mistakes	Introduction is nearly complete, missing some minor points	Introduction complete and well-written; provides all necessary background principles for the experiment	
Procedure (5)	Many stages of the procedure are not entered on the lab report.	Many stages of the procedure are entered on the lab report.	The procedure could be more efficiently designed but most stages of the procedure are entered on the lab report.	The procedure is well designed and all stages of the procedure are entered on the lab report.	
Data Record (10)	Data is brief and missing significant pieces of information.	Data provides some significant information and has few critical mistakes.	Data is almost complete but has some minor mistakes.	Data is complete and relevant. Tables with units are provided. Graphs are labeled. All questions are answered correctly.	
Data Analysis (10)	Data is presented in very unclear manner. Error analysis is not included.	Data is presented in ways (charts, tables, graphs) that are not clear enough. Error analysis is included.	Data is presented in ways (charts, tables, graphs) that can be understood and interpreted. Error analysis is included.	Data are presented in ways (charts, tables, graphs) that best facilitate understanding and interpretation. Error analysis is included.	
Report Quality (10)	Report contains many errors.	Report is somewhat organized with some spelling or grammatical errors.	Report is well organized and cohesive but contains some grammatical errors.	Report is well organized and cohesive and contains no grammatical errors. Presentation seems polished.	
				Marks Obtained	

LABORATORY SKILLS ASSESSMENT (Cognitive)

Total Marks: 10

(If any) **Marks Obtained**	

Instructor's Signature: _____ **Date: _____**