BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ENEE2103

Circuits and Electronics Lab

Experiment No.7

BJT Transistor As An Amplifier, CE, CC, CB Connection

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May 27, 2023

Abstract

The aim of the experiment is to see the behavioral and the characteristics to a Transistor with a 3-terminal device called bipolar junction transistor (BJT). This is used as an amplifier in different configurations: common emitter (CE), common collector (CC), and common base (CB) connections.in addition to measuring and calculating the AC parameters such as voltage gain, current gain, and input and output impedance. In addition, to find the properties of the transistor amplifier in common emitter, common collector, and common base connection and compare their parameters such as voltage gain together

The objective of this experiment is to check the effect of applying sinusoidal signal to a transistor that will be connected in common emitter. In addition to examine the properties of the transistor amplifier in the three different configurations.

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Theory

1. Bipolar Junction Transistor (BJT)

A bipolar junction transistor is a three-terminal semiconductor device that consists of two p-n junctions which are able to amplify or magnify a signal. It is a current controlled device. The three terminals of the BJT are the base, the collector, and the emitter. A signal of a small amplitude applied to the base is available in the amplified form at the collector of the transistor. This is the amplification provided by the BJT. [1]

- ♣ Base: This is used to activate the transistor.
- ♣ Collector: It is the positive lead of the transistor.
- ♣ Emitter: It is the negative lead of the transistor.

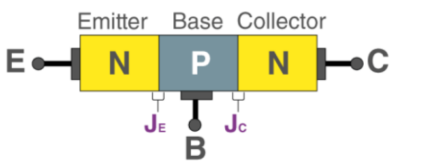


Figure 1:Bipolar Junction Transistor(1)

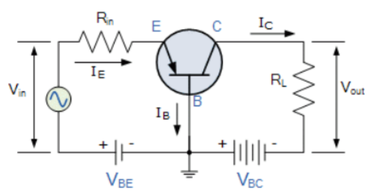


Figure 2: Bipolar Junction Transistor (2)

BJT is a semiconductor device that is constructed with 3 doped semiconductor Regions i.e. Base, Collector & Emitter separated by 2 p-n Junctions. [5]

Bipolar transistors are manufactured in two types, **PNP** and **NPN**, and are available as separate components, usually in large quantities. The prime use or function of this type of transistor is to amplify current. This makes them useful as switches or amplifiers. They have a wide application in electronic devices like mobile phones, televisions, radio transmitters, and industrial control.

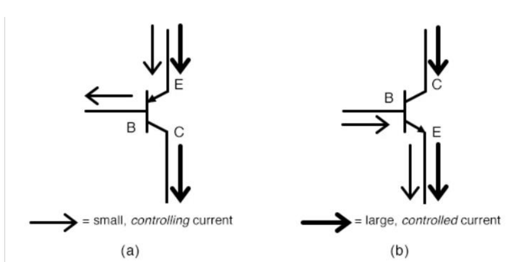


Figure 3: The direction of the small, controlling current and the large controlled current for (a) a PNP and (b) an NPN transistor.

Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

- **Active Region** : the transistor operates as an amplifier and Ic = β*Ib
- **Saturation**: the transistor is "Fully-ON" operating as a switch and Ic = I(saturation)
- **Cut-off**: the transistor is "Fully-OFF" operating as a switch and $I_C = I_E = I_B = 0$

Where I_C = collector current, I_E = emitter current, and I_B = base current.

Table 1: Transistor modes of operation.

EMITTER JUNCTION	COLLECTOR JUNCTION	REGION OF OPERATION
Forward biased	Forward biased	Saturation region
Forward biased	Reverse biased	Active region
Reverse biased	Forward biased	Inverse active region
Reverse biased	Reverse biased	Cutoff region

These regions can be represented in the following graph:

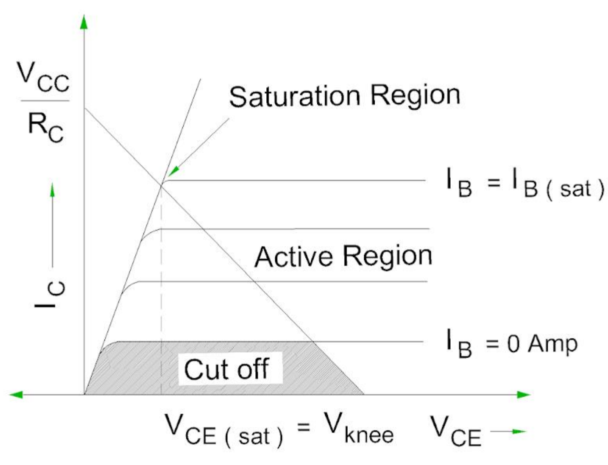


Figure 4: The three region of transistor.

2. BJT transistors as Amplifiers

Transistor amplifiers amplify an AC input signals that alternates between some positive value and a corresponding negative value. Then some way of "presetting" a common emitter amplifier circuit configuration is required so that the transistor can operate between these two maximum or peak values. This can be achieved using a process known as **Biasing**.

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). [2]

2.1 Common Emitter Transistor Amplifier

The common emitter amplifier is a three basic single-stage bipolar junction transistor and is used as a voltage amplifier. The input of this amplifier is taken from the base terminal, the output is collected from the collector terminal and the emitter terminal is common for both the terminals. The basic symbol of the common emitter amplifier is shown below.

The single stage common emitter amplifier circuit shown below 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. [2]

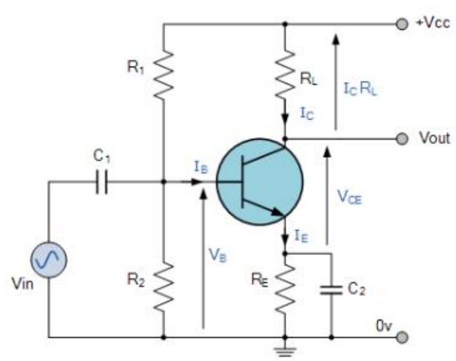


Figure 5: The Common Emitter Amplifier Circuit

The common emitter amplifier is also used as a configuration in electronic circuit design, serving as a voltage amplifier. It involves taking the input signal from the base terminal, collecting the output signal from the collector terminal, and having the emitter terminal common to both. This configuration is compatible with both PNP and NPN transistors, although NPN transistors are more commonly used. [3]

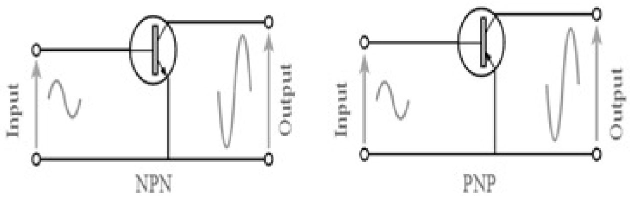
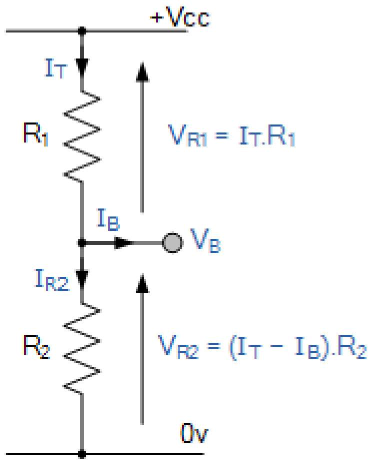


Figure 6: CE Amplifier Configurations.



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. [3]

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.

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:

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

As 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

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

This configuration will give a current gain but no voltage gain.

2.2 Common Collector Transistor Amplifier

The Common Collector Amplifier is another type of bipolar junction transistor, (BJT) configuration where the input signal is applied to the base terminal and the output signal taken from the emitter terminal. Thus the collector terminal is common to both the input and output circuits. This type of configuration is called Common Collector, (CC) because the collector terminal is effectively “grounded” or “earthed” through the power supply. [3]

the common collector (CC) configuration is the opposite of the common emitter (CE) configuration, as the connected load resistor is moved from the usual collector terminal, labelled R_C, to the emitter terminal where it is labelled R_E. [3]

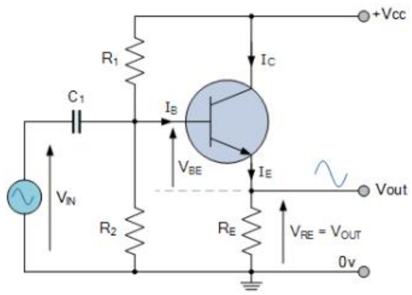


Figure 7: Common Collector Amplifier.

The common collector or grounded collector configuration is generally used where a high impedance input source needs to be connected to a low impedance output load requiring a high current gain. The voltage gain of the CC amplifier is almost 1, while the current gain is as the following:

$$A_I = \frac{I_{emitter}}{I_{base}}$$

$$A_I = \frac{I_{collector} + I_{base}}{I_{base}}$$

$$A_I = \frac{I_{collector}}{I_{base}} + 1$$

$$A_I = \beta + 1$$

Figure 8: Current gain of CC amplifier.

2.3 Common Base Transistor Amplifier

The Common Base Amplifier is another type of bipolar junction transistor, (BJT) configuration where the base terminal of the transistor is a common terminal to both the input and output signals, hence its name common base (CB). The common base configuration is less common as an amplifier than compared to the more popular common emitter, (CE) or common collector, (CC) configurations but is still used due to its unique input/output characteristics. [4]

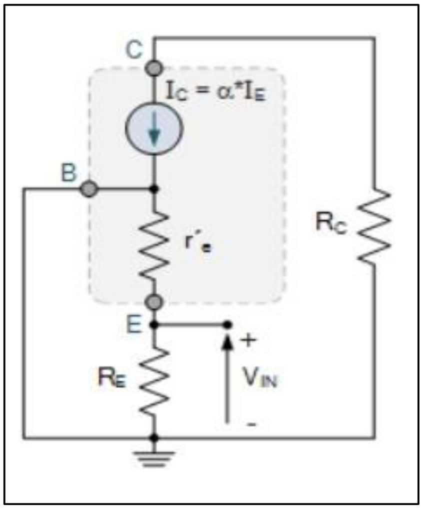


Figure 9:Common Base amplifier.

For the common base configuration to operate as an amplifier, the input signal is applied to the emitter terminal and the output is taken from the collector terminal. Thus the emitter current is also the input current, and the collector current is also the output current, but as the transistor is a three layer, two pn-junction device, it must be correctly biased for it to work as a common base amplifier. That is the base-emitter junction is forward-biased. [4]

- The common base current gain for this type is as the following:

$$A_i = \frac{i_{OUT}}{i_{IN}} = \frac{\beta}{\beta + 1} \cong 1$$

- While the voltage gain is:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{V_C}{V_E} \cong \frac{I_C \times R_C}{I_E \times R_E}$$

3. Beta (β) and alpha (α)

Beta (β) and alpha (α) are two key parameters used to describe the behavior of bipolar junction transistors (BJTs). Beta represents the current gain, indicating the ratio of the collector current (IC) to the base current (IB). Higher beta values indicate greater current amplification. Alpha, on the other hand, represents the current transfer ratio between the collector current (IC) and the emitter current (IE). It shows the proportion of the base current that is collected by the collector. Alpha is related to beta through the equation α = β / (β + 1). Both parameters are important for understanding transistor characteristics and optimizing circuit design, considering their variations with temperature, biasing conditions, and transistor aging.

$$\text{using } \beta = \frac{I_C}{I_B}, \quad \alpha = \frac{I_C}{I_E}$$

$$\textit{and} \qquad I_E = I_C + I_B$$

$$\frac{I_C}{\alpha} = I_C + \frac{I_C}{\beta} \quad \rightarrow \quad \frac{1}{\alpha} = 1$$

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

$$\boxed{\alpha = \frac{\beta}{\beta + 1}} \qquad \boxed{\beta = \frac{\alpha}{\alpha - 1}}$$

Figure 10: Relation between amplification factors alpha and beta.

Procedure and Data Analysis

1. Common Emitter Transistor Amplifier:

In this part, the first step was done is by connecting the following circuit in the board, and the power supply was switched and the function generator was set with 1 kHz sine wave and zero amplitude, and finally the base bias potentiometer was adjusted for a DC collector voltage (Vc) of 8 Volts.

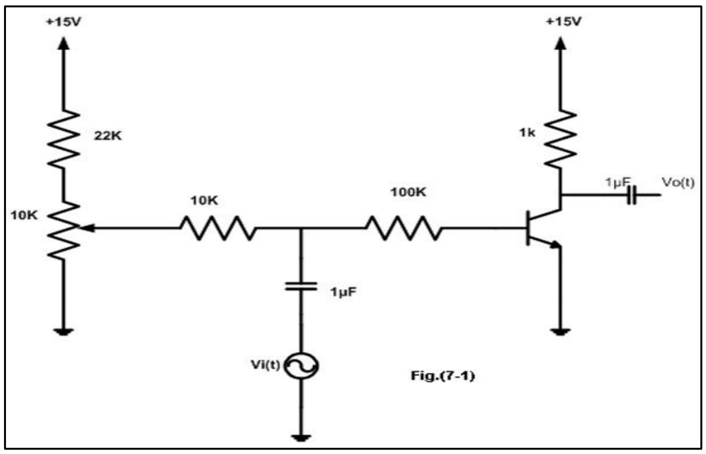


Figure 11: Common Emitter

Then, the following values were collected as the following values:

Table 2: Results for CE circuit

I_C	6.99 mA
I_B	31.79uA
V_{CE}	7.922 v
V_{BE}	0.67 v
V_{BC}	9.22 v

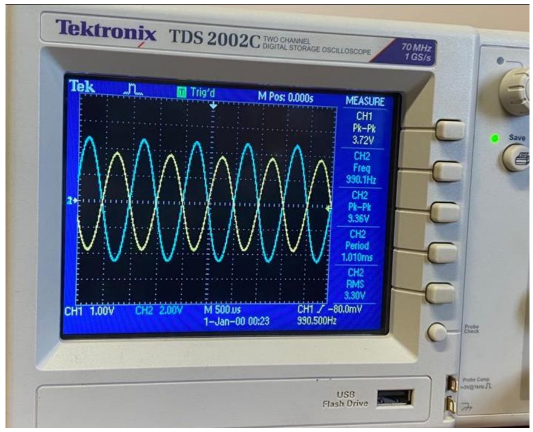


Figure 12: The input and output voltage signals.

Then, the oscilloscope was switched and connected to the base and the output of the previous circuit, and the function generator was turned up until the AC output of the circuit is 8 V peak-to peak. In addition, the input signal **Vi(t)**, output signal **Vo(t)** the base voltage **Vb(t)** were recorded. From the previous figure, it is shown that the input voltage with, the base voltage, and the output voltage as the following:

Vi(t) = 3.12 V. **Vo(t) = 8.16V**

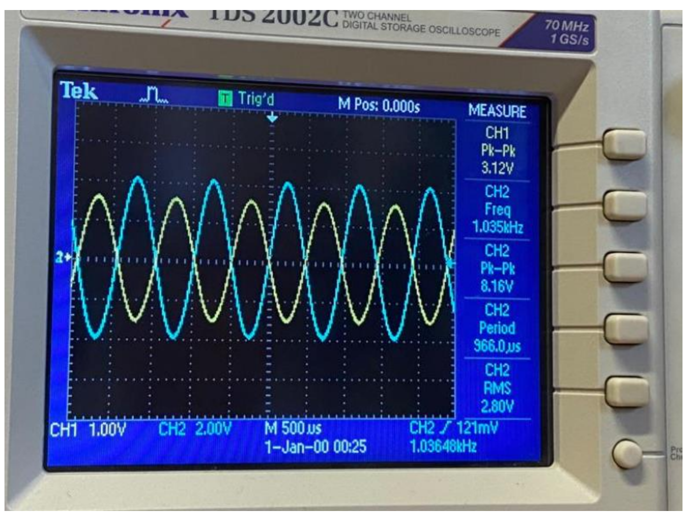


Figure 13: The input and output signals with 8 PK-PK

And then the base voltage Vb(t) signal was measured **Vb(t)= 45.6 mV**

Now, all the required values to find both the voltage gain Av and Av1 were found:

The value of voltage gain:

- **Av** = $\frac{Vo}{Vi} = \frac{8.16}{3.12} = 2.615\ Volts$

The value of voltage gain:

- **Av1** = $\frac{Vo}{VB} = \frac{8.16}{45.6\ m} = 178.947\ Volts$

Using DMM, the AC current for both the base (Ib) and the collector (Ic) of the transistor was measured as the following:

- AC current for the base (Ib) = 32.63 uA.
- AC current for the collector (Ic) = 6.697 mA.

And the next step, the current gain which is the ration of the input current and the output current was calculated, the **output current** considered as the **sum of the Ib and Ic**, while the input current considered as the current of the base **Ib**:

- **Current gain**=$\frac{Ioutput}{Iinput} = \frac{6.70963\ mA}{32.63\ uA} = 205.62\ A$.
- Vi (rms) = $\frac{Vi\ (p-p)}{2.\sqrt{2}}$
- **Input impedance**=$\frac{Vinput}{Iinput} = \frac{4.16}{32.63\ uA} = 127.49\ Kohm$.

Note: Unfortunately, we have forgotten to measure the output current and the input current using DMM, so I have used the relation of **(Ie= Ib+Ic)** to calculate the output current, while the input current considered as the same value of the current base **(Ib).**

Finally, to find the effect of the 100 Kohm resistor, it has been shorted and the following figure is the result of it, it is noticed that the voltage gain will be increased.

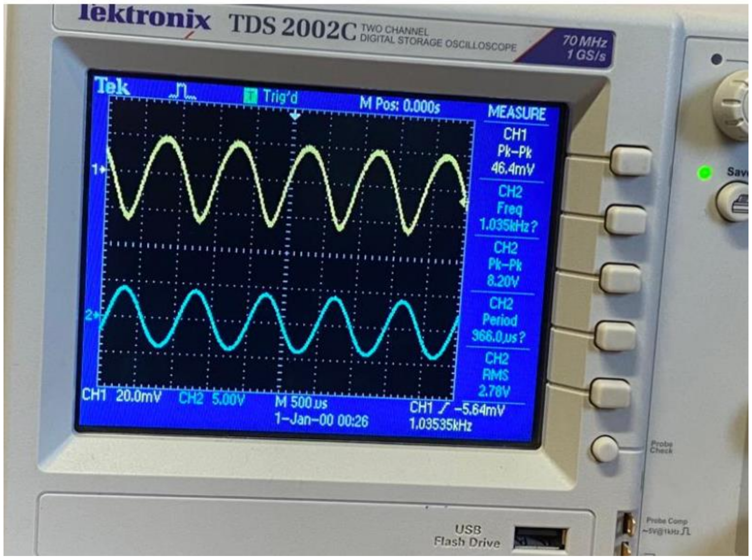


Figure 14: The effect of 100 Kohm resistor.

2. Common Collector Transistor Amplifier:

The first step in this part is that the following circuit with its elements was connected in the board, and the power supply was switched to 10 Volt. In addition, the generator was used to generate a frequency with 1 kHz, ,but either disconnecting its output ,or turn its output amplitude to zero, so there is no signal input to the circuit.

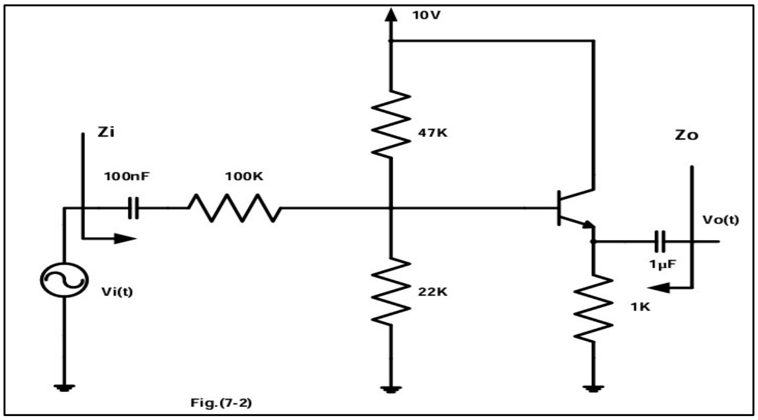


Figure 15:Common Collector Circuit

Then, the quiescent bias voltages of the circuit VE and VB was measured using the DVM, and the results were as the following:

- **VB** = 3.007 V.
- **VE** = 2.786 V.

The output amplitude of the sine wave generator was increased until an output amplitude from the amplifier VO(t) is about 2volts peak-to-peak. Then, the ac input voltage needed to achieve this output was measured. Figure 18 below shows the results, whereas, channel 1 represent the input voltage and channel 2 represent the output voltage.

The next step was to increase the amplitude of the sine wave generator until an output amplitude from the amplifier Vo(t) is about **2 Volts peak-to-peak** , as shown in the following figure. And from it is noticed that the amplitude of the amplitude of the input voltage which required to have a **2 Volts peak-to-peak output voltage** is:

Vi(t)= 16.0 V.

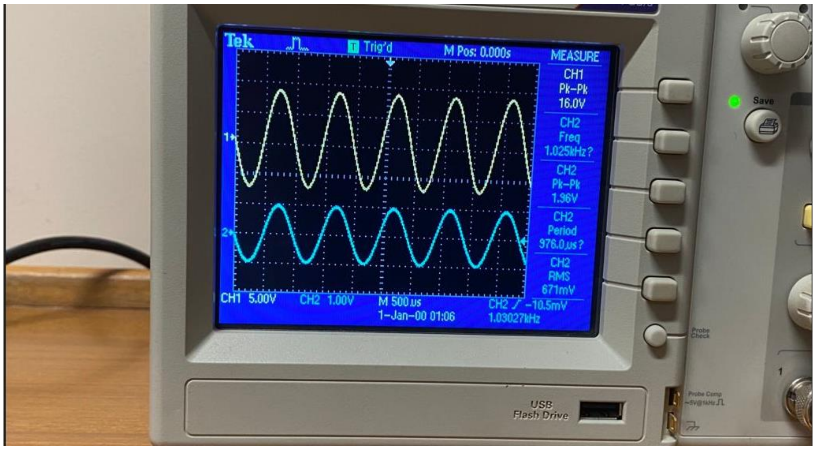


Figure 16:2 Volts peak-to-peak in CC amplifier

Now, all the required values to calculate the voltage gain Av was found:

$$\mathbf{Av} = \frac{V\ output}{V\ input} = \frac{1.96\ V}{16.0V} = 0.1225 \text{ Volts}$$

Vi (rms) = $\frac{Vi\ (p-p)}{2.\sqrt{2}} = \frac{16.0}{2.\sqrt{2}} = 5.656$ V

Vo (rms) = $\frac{Vo\ (p-p)}{2.\sqrt{2}} = \frac{2}{2.\sqrt{2}} = 0.70$ V

The ac voltage and the ac current across the 100 kΩ input resistor were measured.
V (r=100k) = 4.7 V rms

Ii (r=100k) = $\frac{4.88}{100K}$ = 0.047 mA

From the output voltage and the load resistor value the ac output current was calculated.

Io = 0.67 mA
Current gain:

$$Ai = \frac{Io}{Ii} = \frac{0.67m}{0.047m} = 14.25$$

Input impedance:

$$Zi = \frac{Vi}{Ii} = \frac{5.3}{0.047m} = 114.255\ K\Omega$$

To find the output impedance of the amplifier, the input sine wave generator was off and it replaced with a short circuit, then, the generator was connected to the output (emitter) via a capacitor, and its output voltage and current was measured.
Vt = 5 volt, It = 11 mA

$$Zo = \frac{Vt}{It} = \frac{5}{11mA} = 454.54\Omega$$

The following table summarizes the measured and calculated results: Table 2 The measured and calculated results in Common Base circuit

Table 3: final results of CC circuit

Quantity **Measured Values**

As rms V_{in}	5.656 V
As rms V_{out}	0.70 v
v_{100k_RMS}	4.7 v
i_{out}	0.67 mA
	Calculated values
$A_V=V_{out}/V_{in}$	0. 1225
$i_{in} = v_{100k\_RMS} /100k$	0. 0488 mA
$A_i=i_{out}/i_{in}$	13.729
$Z_{in}=V_{in}/i_{in}$	116.803KΩ
$Z_{out}=V_T/i_T$	230.946 Ω

Note: To compare the parameters in the CC circuit with CE circuit, it is noticed that the voltage gain in the CC is less than 1, while in the CE is greater than 1.

3. Common Base Transistor Amplifier:

As previous steps, the first step in this part is to connect the following circuit in the board. In addition, the power supply was switched, and the variable dc voltage was set to 10 Volts, and the sine wave generator was set to a frequency of 1 Kohm.

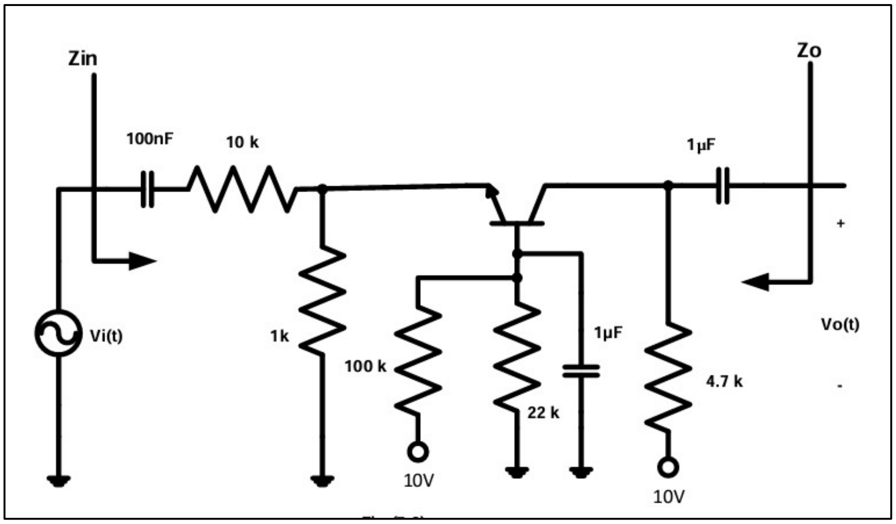


Figure 17 Common Base Circuit.

Using DMM, the values of the quiescent bias voltages and currents were recorded as the following:

Table 4: Quiescent bias for CB amplifier

IC	1.09 mA
IB	4.24uA
VCE	3.845V
VBE	1.85V
VBC	-8.2V

The next step was to increase the amplitude of the input sine wave until the output sine signal has a 2 V peak-to-peak as the following:

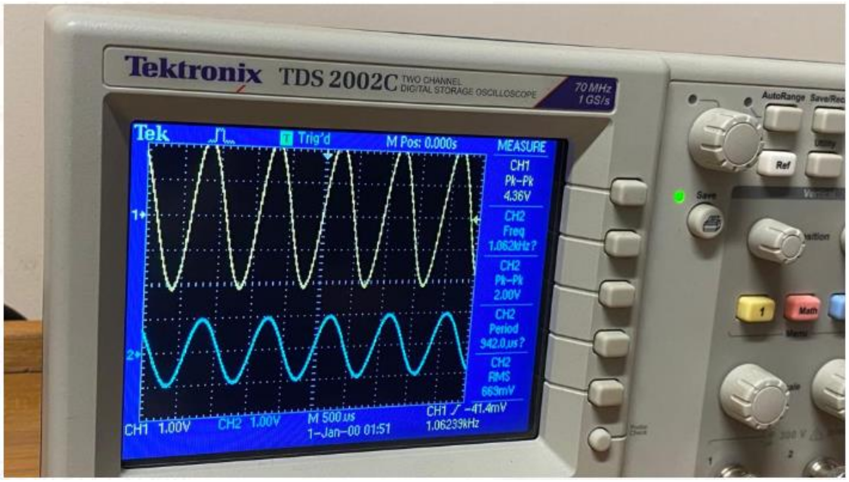


Figure 17: plots of Vi and Vo for circuit 3.

- ✓ **From the previous figure, it is noticed that to get an output voltage with 2 V peak-topeak, the input voltage with 4.36 V was required.**

Vi(t)= 4.36 V.

- ✓ **Now, all the required values to calculate the voltage gain Av was found:**

$$\boldsymbol{Av} = \frac{Voutput}{Vinput} = \frac{2.00}{4.36} = 0.4587\, Volt.$$

- ✓ **The AC voltage across the 10 Kohm was also measured, the result was:**

Vo(10k)= 1.5 .

- ✓ **We can calculate the input current across the input resistor as the following:**

$$Iin_{10k} = \frac{V}{R} = \frac{1.491}{10k} = 1.49 * \ 10^{-4}\ A$$

- ✓ **The output current can be calculated using the output voltage and the 4.7Kohm resistor as the following:**

$$Iout = \frac{V}{R} = \frac{2.00}{4.7k} = 4.2 * \ 10^{-4}\ A$$

- ✓ **Now, we have the input and output current, so the current gain can be calculated as the following:**

$$Ai = \frac{Ioutput}{Iinput} = \frac{4.2 * 10^{-4}}{1.49 * 10^{-4}} = 2.8187\ A$$

- ✓ **Calculating the input impedance Zin:**

$$Zin = \frac{Vin}{Iin} = \frac{4.36}{1.49 * 10^{-4}} = 29.26\ Kohm$$

- ✓ **To find the output impedance of the amplifier, the input sine wave generator was removed with short circuit, and the generator to the output (emitter) was connected via a capacitor:**

I=0.3117 mA and V=1.49 V.

Therefore:

$$Zin = \frac{Vin}{Iin} = \frac{1.49}{0.3117 * 10^{-3}} = 4.78\ Kohm$$

- ✓ **The following table summarizes the measured and calculated results:**

Table 2 The measured and calculated results in Common Base circuit.

Quantity	**Measured Values**
Vin	4.36 V
Vout	2.00 V
V10kohm	1.491 V
	Calculated Values
Av=Vout/Vin	0.4587 V
Iout=Vout/4.7k	$\mathbf{4.2 * 10^{-4}\ A}$
Iin=Vin/10k	$\mathbf{1.49 * 10^{-4}\ A}$
Ai=Iout/Iin	$\mathbf{2.8187\ A}$
Zin=Vin/Iin	$\mathbf{29.26\ Kohm}$

Conclusion

This experiment has covered many concepts and applications for the BJT transistor amplifier in common emitter, common collector, and common base connection circuits. And many AC parameters were measured and calculated such as input and output impedance, voltage gain, and the current gain. Most measured and calculated values were in the accepted range such as voltage gains and current gains.

As well as this experiment taught us how to build and measure BJT circuits practically. We learned how to connect different components and use oscillators and a Digital Multimeter to measure DC and AC quantities. We studied the characteristics of each circuit configuration, such as voltage gain, current gain, input impedance, output impedance, and phase shift. The results we obtained from the experiments were similar to the theoretical expectations, although there were some errors due to the limitations of the tools and components used, which are not very accurate. We also became more familiar with Pspice, a software used for circuit design and signal generation in the prelab stage. Throughout the experiment, we gained a better understanding of the significance of each element in the circuit and its impact on circuit behavior.

Questions

1. **In Common Collector Transistor Amplifier circuit**

- **How is the output quiescent voltage related to the input?**

The output quiescent voltage in a Common Collector Transistor Amplifier circuit is determined by the biasing of the circuit, which is directly related to the input voltage.

- **How do the parameters compare with those of the common emitter stage?**

the common collector stage in the following ways:

  - Voltage Gain: CC stage amplifies the voltage slightly, while CE stage amplifies it more.
  - Current Gain: CC stage does not amplify the input current significantly, while CE stage provides significant current amplification.
  - Input Impedance: CC stage has a high input impedance, suitable for high impedance signal sources. CE stage also has a relatively high input impedance.
  - Output Impedance: CC stage has a low output impedance, allowing it to drive low impedance loads effectively. CE stage has a higher output impedance.
  - Phase Shift: CC stage introduces a small phase shift between input and output signals, usually close to zero or slightly negative. CE stage introduces a phase shift of approximately 180 degrees.

2. **In a common base transistor amplifier**

- **How is the output quiescent voltage related to the input?**

the output quiescent is not directly affected by the input voltage. The input voltage mainly controls the current in the amplifier. The output quiescent voltage is determined by a separate part of the circuit called the biasing circuit. The input voltage mostly influences the signal part of the output voltage, while the biasing circuit determines the output quiescent voltage on its own.

- **How do the parameters compare with those of the common emitter stage?**

common emitter amplifier stage in the following ways:

- Voltage Gain: CB stage has lower voltage gain compared to CE stage.
- Current Gain: CB stage provides higher current gain than CE stage.
- Input Impedance: CB stage has lower input impedance, while CE stage has higher input impedance.
- Output Impedance: CB stage has higher output impedance compared to CE stage.
- Phase Shift: CB stage introduces a small phase shift, while CE stage introduces a phase shift of approximately 180 degrees.

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