LAB REPORT 4

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PART 1
AIM

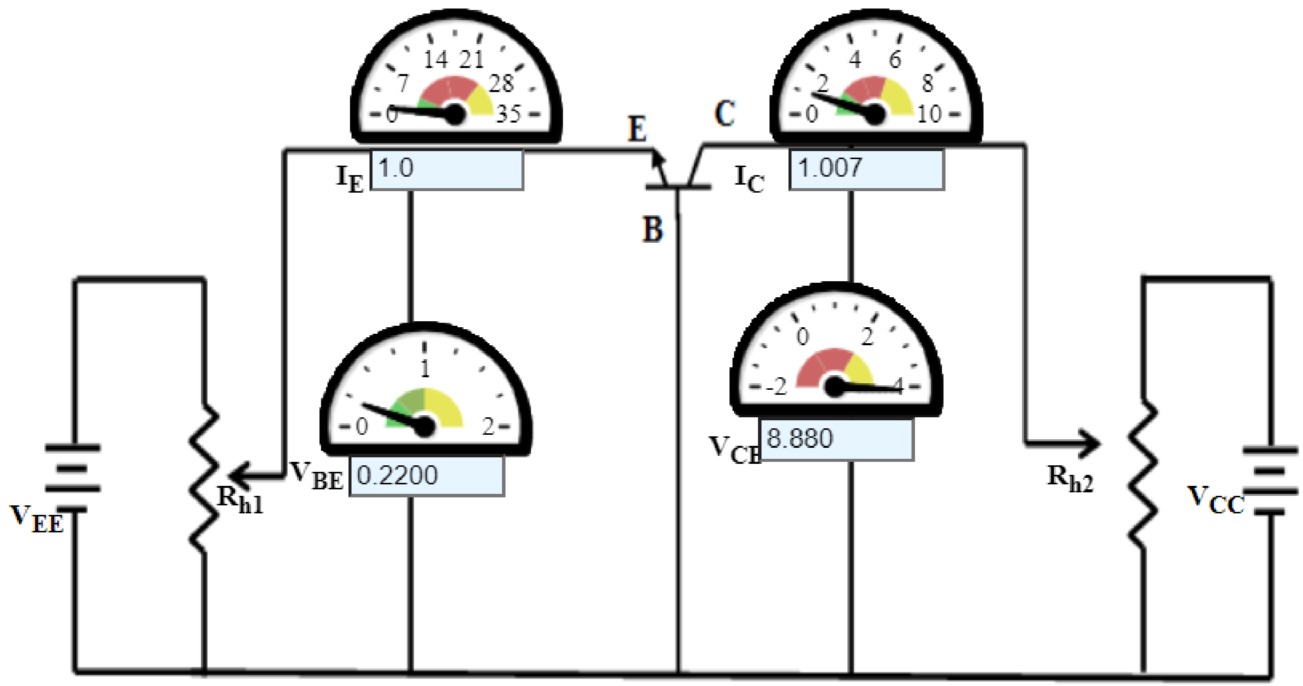
After this experiment, we will learn,

1.Structure of Bipolar Junction Transistor

2.Operation of Bipolar Junction Transistor

3.Working of Common Base configuration of Bipolar Junction Transistor

Circuit diagram

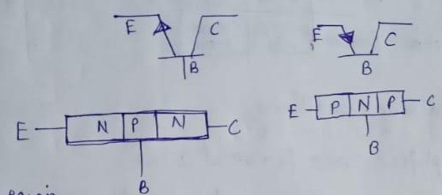


Theory with equations

Bipolar Junction Transistor

Structure

It is a single piece of silicon with two back-to-back P-N junctions. BJT can be made either as PNP or as NPN.



Base(B): middle region where either two p-type layers or n-type layers are sandwhiched. The majority carriers from the emittor region are injected into this region. This region is thin and very lightly doped.

Emitter(E): heavily doped region which supplies free charge carriers. electrons in n-p-n or holes in p-n-p transistors. These majority carriers are injected to the middle region electrons in p region of n-p-n or holes in n-region of p-n-p

Collector (C): It is intermediately doped and charge carriers are collected. The area of this region is largest. ~~the doping level~~

Application — 1. as switch in digital electronics
2. mostly N-P-N transistors used as switch
3. used as amplifier too.

Operation of BJT

		BE junction: Reverse	BE junction: Forward
BC junction	Reverse	Cut-off	Forward active
	Forward	Reverse active	Saturation

4 operating conditions,

For amplifier use - forward active

As switches - cut-off and saturation

Cut-off region

Both junctions are reverse biased → Base-emitter ($V_{BE}<0$) and Base-collector ($V_{CB}>0$). All currents are zero. There are some leakage currents associated with reverse biased junctions, but these currents are small and can therefor be neglected.

Forward Active region

Base-emitter — forward biased ($V_{BE}>0$)

Base-Collector — reverse biased ($V_{CB}>0$)

$$I_C = -\alpha_F \times I_E + I_{CO}$$

I_C: collector current

I_E: emitter current

α_F: forward current transfer ration

I_{CO}: collector reverse saturation current

injection of both holes and electrons take place across the BE junction

Hole current by appropriate doping levels. (n-p-n transistor)

Saturation Region

Both junction are forward biased, base-emitter junction is forward biased. ($V_{BE}>0$) and also collector-base junction is forward biased ($V_{CB}<0$). Maximum currents flows through the transistor with only a small voltage drop across the collector junction. It also ~~dep~~ respond to any change in I_E or $\cancel{I_B}$ V_{BE}.

It is used as a closed switch.

Reverse-Active region

Base-emitter - reverse biased ($V_{BE}<0$)

Base-collector - forward biased ($V_{CB}<0$)

current gain - smaller than forward active mode - unsuitable for amplification in general.

Application: In digital circuits and analog switching circuits

$$I_E = -\alpha_R * I_C + I_{E0}$$

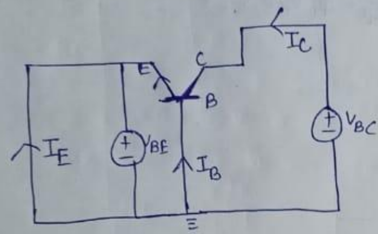
α_R = reverse current transfer ratio

I_{E0} = Emitter reverse saturation current

Most transistors are doped so as $|\alpha_F| \approx 1$ so $|\alpha_R| <<$ automatically (very low)

Bipolar Junction Transistor

Common base Characteristics

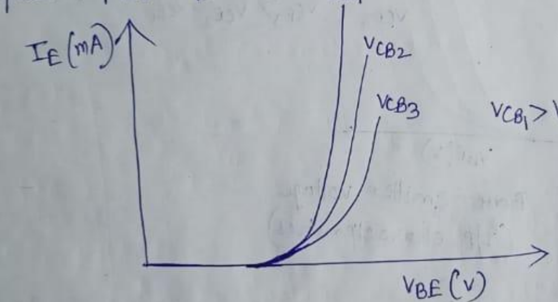


Input characteristics

I_E vs V_{BE}

$$I_E = \phi(V_{BE}, V_{CB})$$ function of V_{BE} and V_{CB}.

expected plot I_E vs V_{BE}



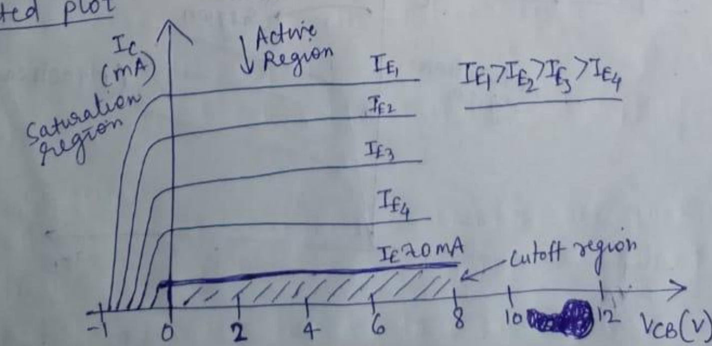
$V_{CB1} > V_{CB2} > V_{CB3}$

Output Characteristics

$$I_C = \phi(V_{CB}, I_E)$$

I_C vs V_{CB}

expected plot



$I_{E1} > I_{E2} > I_{E3} > I_{E4}$

Equations for BJT – CB amplifier

These equations are for n-p-n transistor.

$I_E = I_B + I_C$

V_{BE} – input
I_E – input current
I_C – output current
V_{CB} – output

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

$I_C = \alpha I_E = \beta I_B$

$\alpha = \beta/\beta+1$ or $\beta = \frac{\alpha}{1-\alpha}$

Common base amplifier Current Gain/Voltage gain

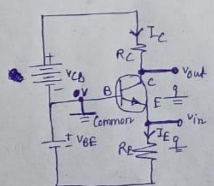
$$\boxed{A_i = \frac{i_{out}}{i_{in}} = \frac{\beta}{\beta+1} \simeq 1}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{V_C}{V_E} \simeq \frac{I_C R_C}{I_E R_E} \text{ or } A_V = \alpha \frac{R_C}{R_E} = A_i\left[\frac{R_C}{R_E}\right]$$

$$A_V = \alpha \frac{R_C}{r'_e} = A_i\left[\frac{R_C}{r'_e}\right]$$

$I_C \approx I_E$ so $A_i \simeq 1$

$$\boxed{A_V = \frac{R_C}{r'_e}}$$



Resistance gain

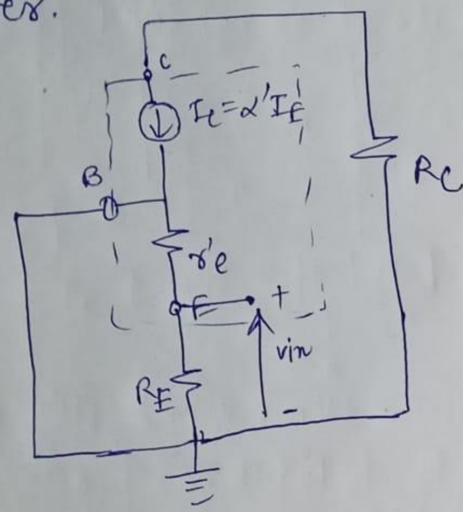
$A_R = \frac{Z_{in}}{Z_{out}}$ $Z_{in} = R_E \| r'_e$

$R_E >> r'_e$, $Z_{in} = r'_e$

$Z_{out} = R_C \| R_L \approx R_C$

$R_L >> R_C$

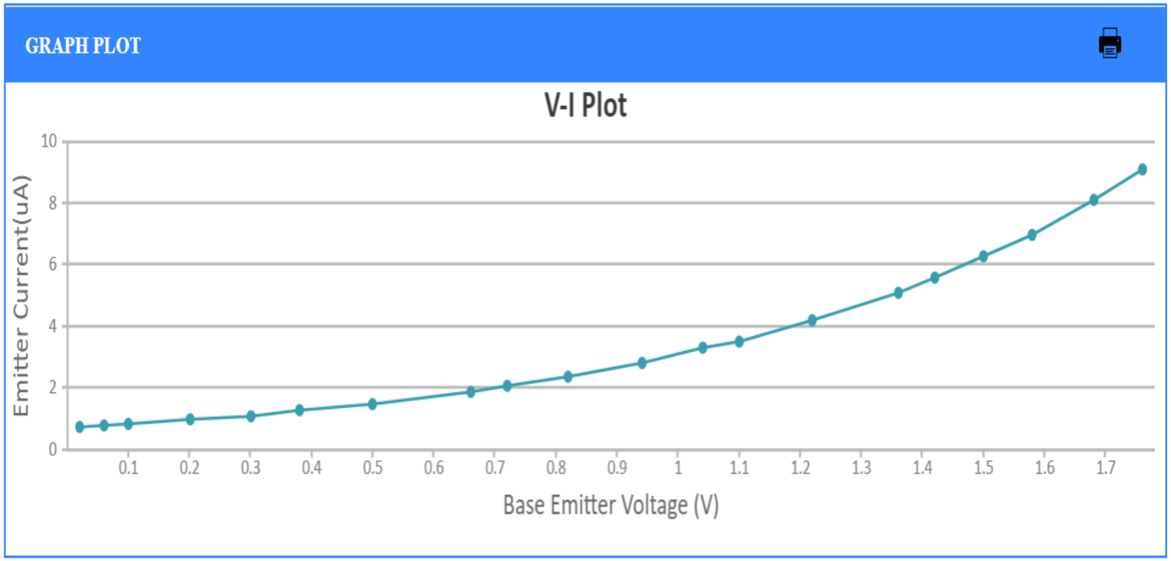
As output impedance of the amplifier looking back into the collector terminal can potentially be very large, the CB circuit operates almost like an ideal current source taking the input current from low input impedance side and sending the current to high output impedance side. Thus the CB configuration is also referred to as a current buffer or current follower configuration, and opposite of the common-collector (CC) configuration which is referred to as a voltage follower.



Observation table with graphs
Input Characteristics

EXPERIMENTAL TABLE

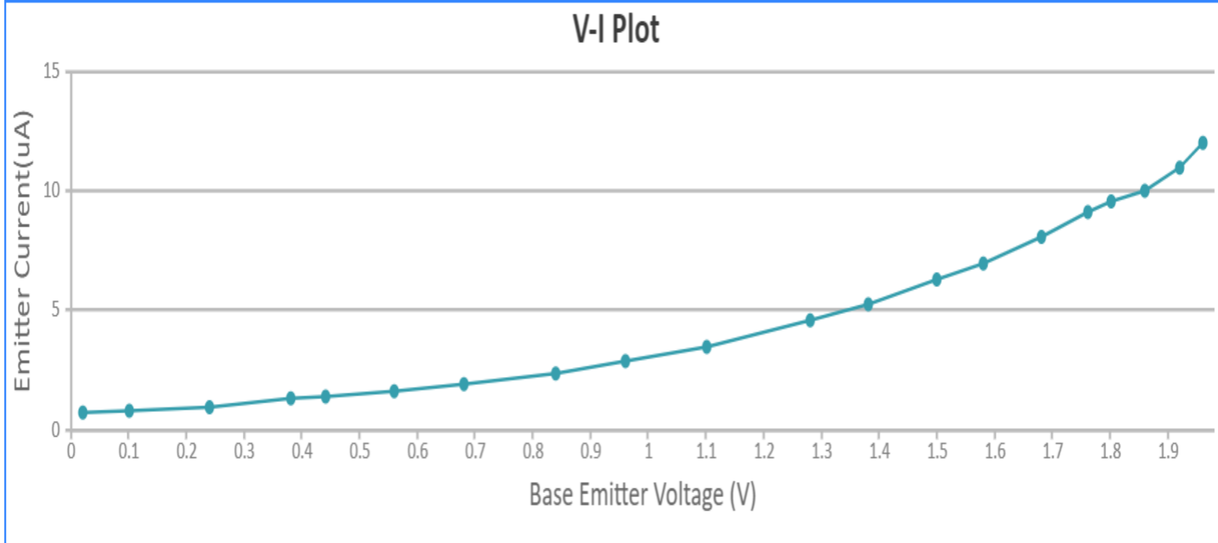
Serial No.	Base-Collector Voltage 1.000 V	
	Base-Emitter Voltage V	Emitter Current mA
1	0.02000	0.76
2	0.06000	0.80
3	0.1000	0.85
4	0.2000	0.98
5	0.3000	1.1
6	0.3800	1.3
7	0.5000	1.5
8	0.6600	1.9
9	0.7200	2.1
10	0.8200	2.4
11	0.9400	2.8
12	1.040	3.3
13	1.100	3.5



EXPERIMENTAL TABLE

Serial No.	Base-Collector Voltage 2.000 V	
	Base-Emitter Voltage V	Emitter Current mA
1	0.02000	0.76
2	0.1000	0.85
3	0.2400	1.0
4	0.3800	1.3
5	0.4400	1.4
6	0.5600	1.6
7	0.6800	1.9
8	0.8400	2.4
9	0.9600	2.9
10	1.100	3.5
11	1.280	4.6
12	1.380	5.3
13	1.500	6.3

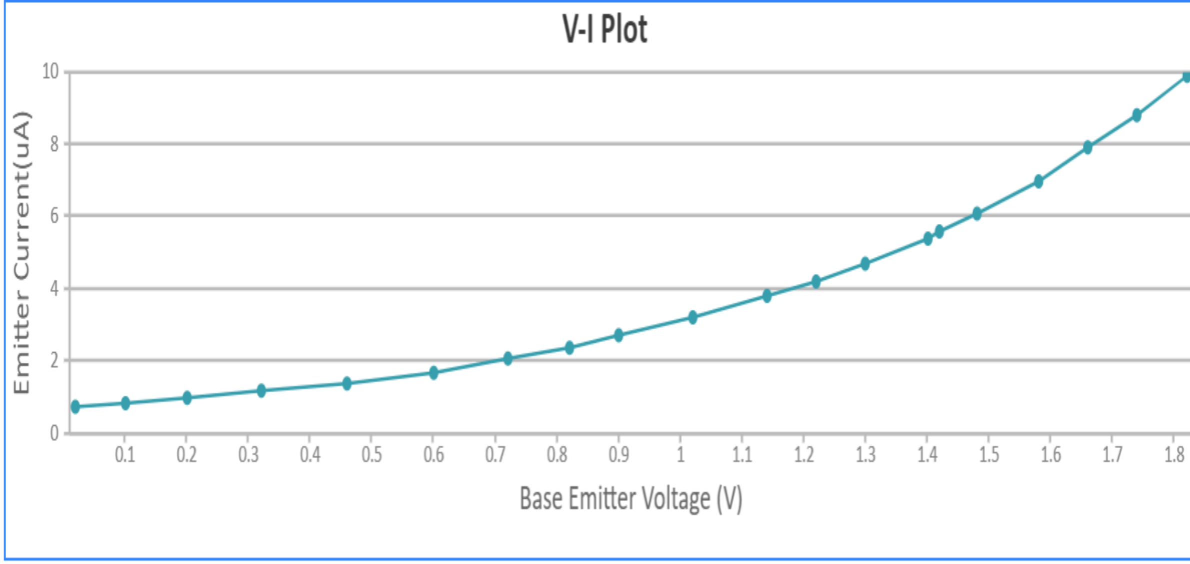
GRAPH PLOT



EXPERIMENTAL TABLE

Serial No.	Base-Collector Voltage 3.000 V	
	Base-Emitter Voltage V	Emitter Current mA
1	0.02000	0.76
2	0.1000	0.85
3	0.2000	0.98
4	0.3200	1.2
5	0.4600	1.4
6	0.6000	1.7
7	0.7200	2.1
8	0.8200	2.4
9	0.9000	2.7
10	1.020	3.2
11	1.140	3.8
12	1.220	4.2
13	1.300	4.7

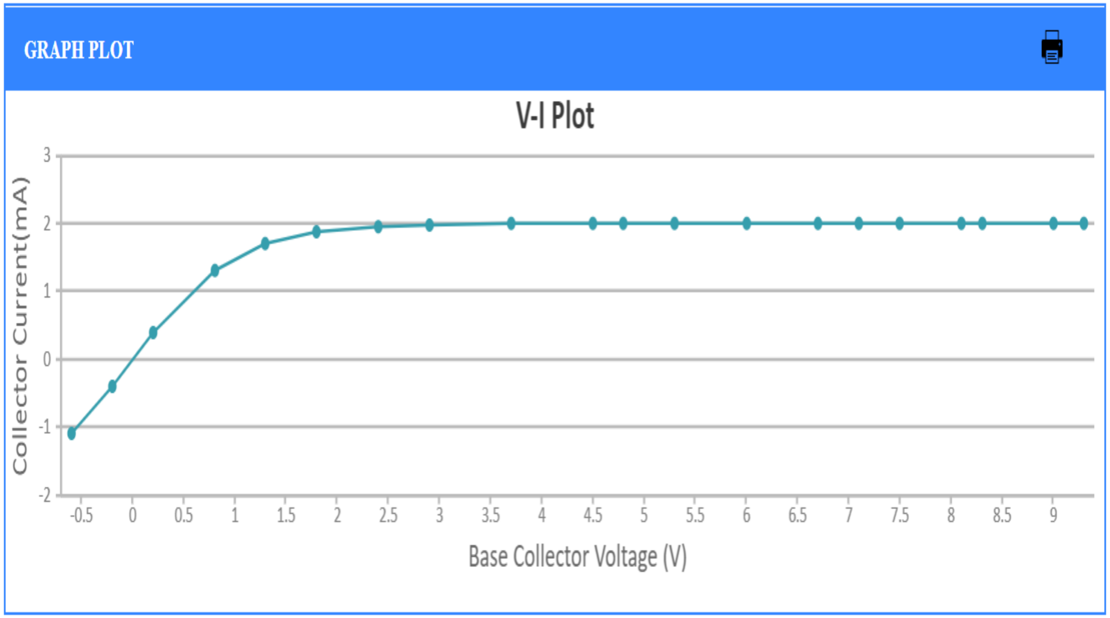
GRAPH PLOT



Output Characteristics

EXPERIMENTAL TABLE

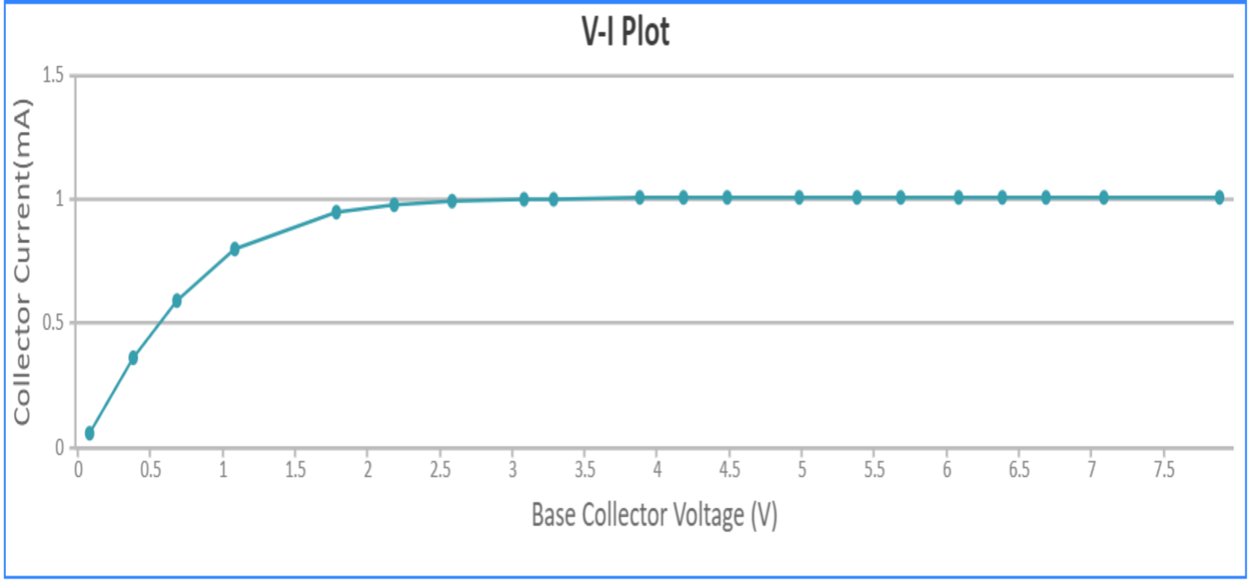
Serial No.	Emitter Current 2.0 mA	
	Base-Collector Voltage V	Collector Current mA
1	-0.6000	-1.074
2	-0.2000	-0.3948
3	0.2000	0.3948
4	0.8000	1.328
5	1.300	1.723
6	1.800	1.894
7	2.400	1.967
8	2.900	1.988
9	3.700	1.998
10	4.500	2.000
11	4.800	2.000
12	5.300	2.000
13	6.000	2.000



EXPERIMENTAL TABLE

Serial No.	Emitter Current 1.0 mA	
	Base-Collector Voltage V	Collector Current mA
1	0.08000	0.06043
2	0.3800	0.3654
3	0.6800	0.5959
4	1.080	0.7991
5	1.780	0.9517
6	2.180	0.9820
7	2.580	0.9959
8	3.080	1.003
9	3.280	1.005
10	3.880	1.007
11	4.180	1.007
12	4.480	1.007
13	4.980	1.007

GRAPH PLOT



Conclusion and Observations

1.The input characteristics follow an exponential curve.

2.The output characteristics remain linear with Vce but become constant after some time.

3.In the v-labs experiment page for output characteristic of CB, upon increasing Ie beyond 20 micro-amperes, the vlab page was able to give only 6 readings.

4.The different data-sets for different values of base collector voltage are same for all values of Vbc which is a glitch in Vlab, which is a glitch in vlab

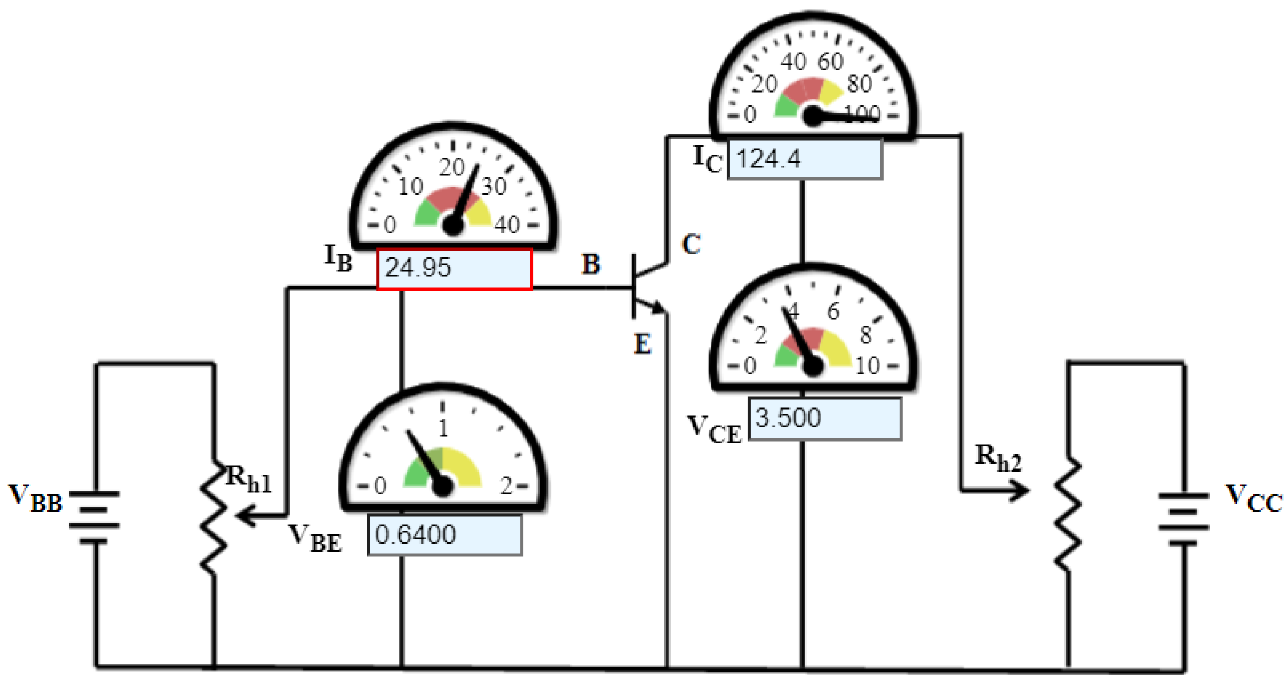
5.The part where Ic varies with Vbc in output characteristics is the saturation region.

PART 2
AIM

After this experiment, we will learn,

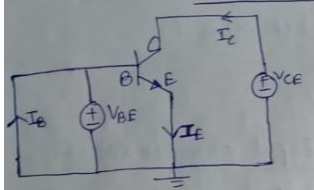
1.Working of Common Base configuration of Bipolar Junction Transistor and knowing the circuit equations

Circuit diagram



Theory with equations

Common Emitter Characteristics



Input characteristics

$I_B = \phi(V_{BE}, V_{CE})$

expected plot I_B vs V_{BE}

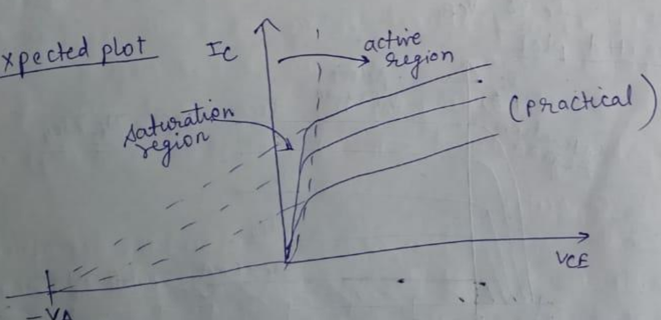
$V_{CE3} > V_{CE2} > V_{CE1}$

Base-emitter voltage
(I/P characteristics)

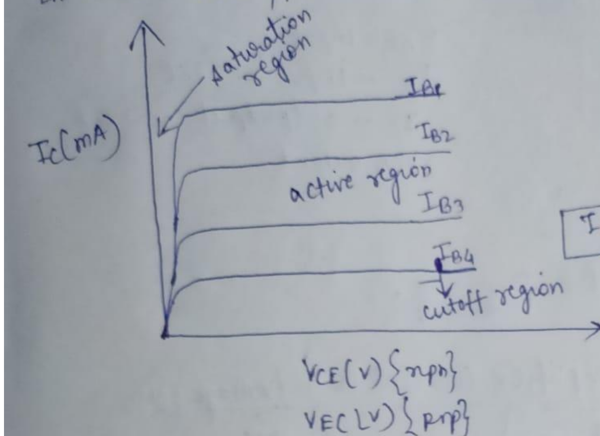
Output characteristics

I_C vs V_{CE} $I_C = \phi(V_{CE}, I_B)$

expected plot



In ideal case, plot looks like this



$\boxed{I_{B1} > I_{B2} > I_{B3} > I_{B4}}$

Equations for BJT – CE circuit

Behaviours:
It can be described by Ebers – Moll Model.

$$I_F = I_{ES}\left(\exp\left(\frac{V_{BE}}{V_T}\right)-1\right)$$
$$I_R = I_{CS}\left(\exp\left(\frac{V_{CB}}{V_T}\right)-1\right)$$

I_{ES} is base-emitter saturation currents
I_{CS} is base-collector saturation currents

$V_T = \frac{KT}{q}$ $\quad K = 1.381\times10^{-23}$ V C/K [Boltzmann's Constant]

$q = 1.6\times10^{-19}C$
T = temp in kelvin

$$\beta_F = \alpha_F/1-\alpha_F \;/\; \beta_R = \alpha_R/1-\alpha_R$$

Where β_F is large signal forward current gain of CE configuration / β_R is Large signal reverse current gain of the CE configuration

$$\alpha_F = \beta_F/1+\beta_F \;;\; \alpha_R = \beta_R/1+\beta_R$$

$$I_C = \alpha_F \times I_F - I_R$$
$$I_E = -I_F + \alpha_R \times I_R$$
$$I_B = (1-\alpha_F)I_F + (1-\alpha_R)I_R$$

$\alpha_R I_{CS} = \alpha_F I_{ES} = I_S$; I_S: BJT transport saturation current

α_R & α_F — depend on doping conc and junction depths

$I_S = J_S \times A$
J_S: transport saturation current density
A: area of emitter.

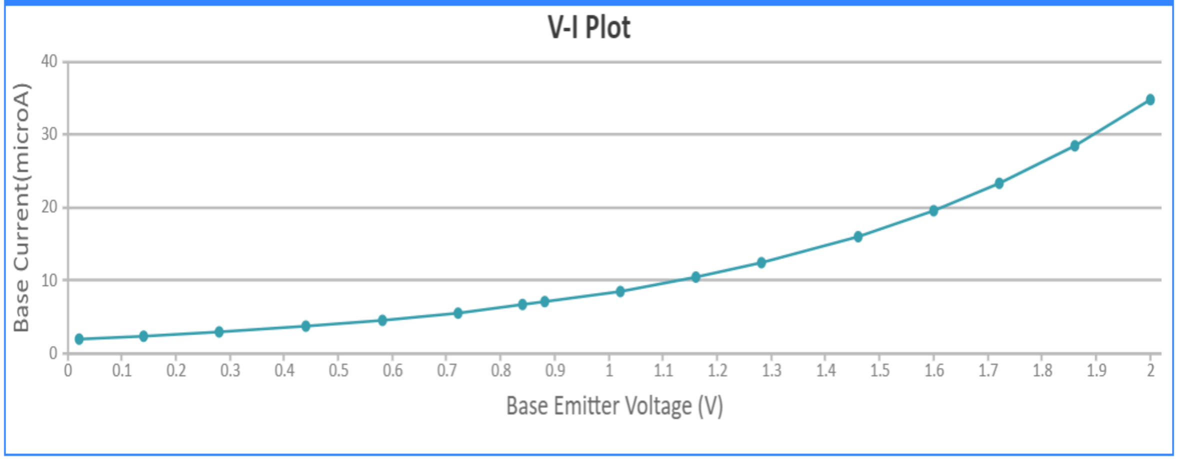
Observation table with graphs
Input characteristics

EXPERIMENTAL TABLE

Collector-Emitter Voltage 1.000 V

Serial No.	Base-Emitter Voltage V	Base Current(μA)
1	0.02000	2.058
2	0.1400	2.443
3	0.2800	2.984
4	0.4400	3.750
5	0.5800	4.580
6	0.7200	5.594
7	0.8400	6.640
8	0.8800	7.031
9	1.020	8.587
10	1.160	10.49
11	1.280	12.45
12	1.460	16.10
13	1.600	19.67
14	1.720	23.34

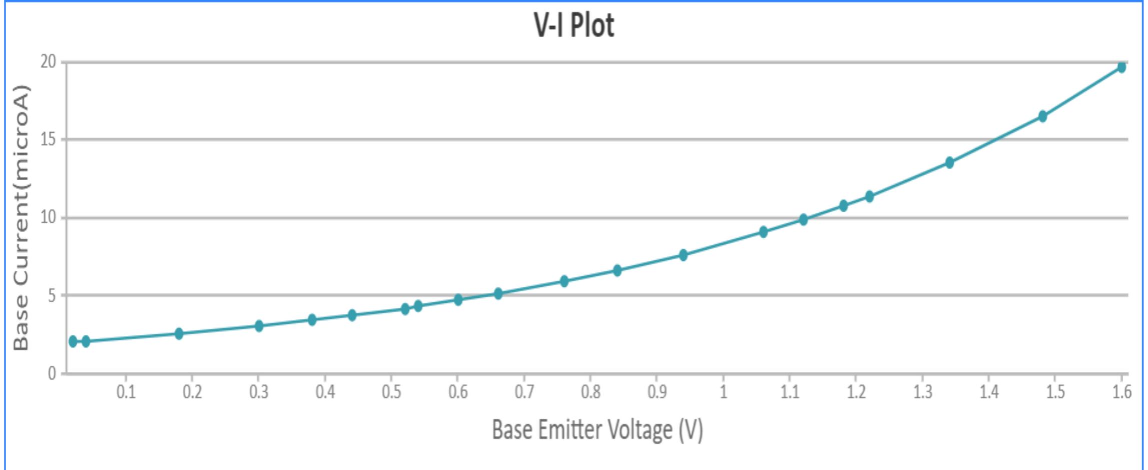
GRAPH PLOT



EXPERIMENTAL TABLE

Serial No.	Collector-Emitter Voltage 2.000 V	
	Base-Emitter Voltage V	Base Current(µA)
1	0.02000	2.058
2	0.04000	2.118
3	0.1800	2.586
4	0.3000	3.070
5	0.3800	3.442
6	0.4400	3.750
7	0.5200	4.204
8	0.5400	4.326
9	0.6000	4.713
10	0.6600	5.135
11	0.7600	5.923
12	0.8400	6.640
13	0.9400	7.660
14	1.060	9.092

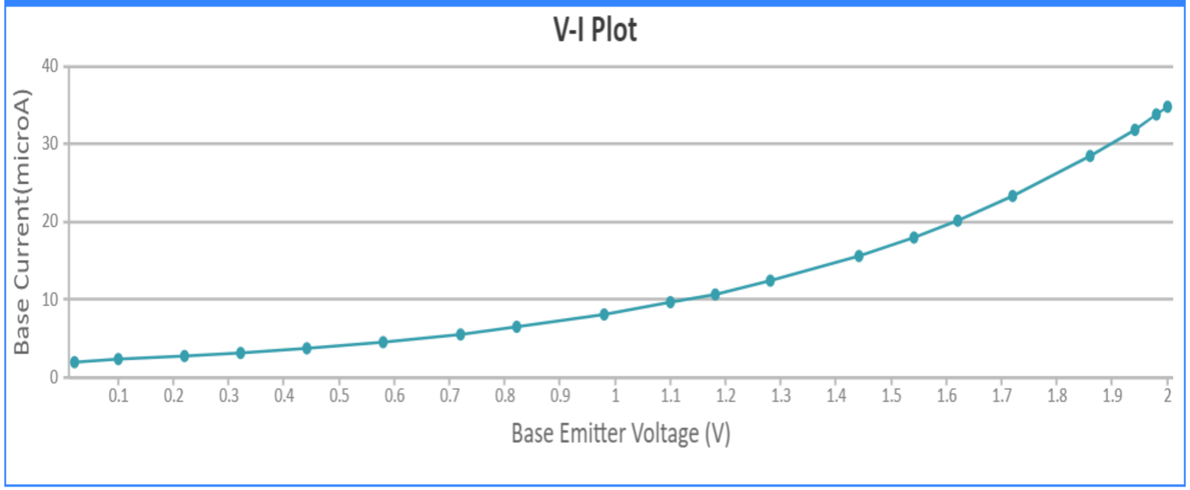
GRAPH PLOT



EXPERIMENTAL TABLE

Serial No.	Collector-Emitter Voltage 4.000 V	
	Base-Emitter Voltage V	Base Current(μA)
1	0.02000	2.058
2	0.1000	2.307
3	0.2200	2.739
4	0.3200	3.159
5	0.4400	3.750
6	0.5800	4.580
7	0.7200	5.594
8	0.8200	6.453
9	0.9800	8.110
10	1.100	9.627
11	1.180	10.79
12	1.280	12.45
13	1.440	15.65
14	1.540	18.05

GRAPH PLOT

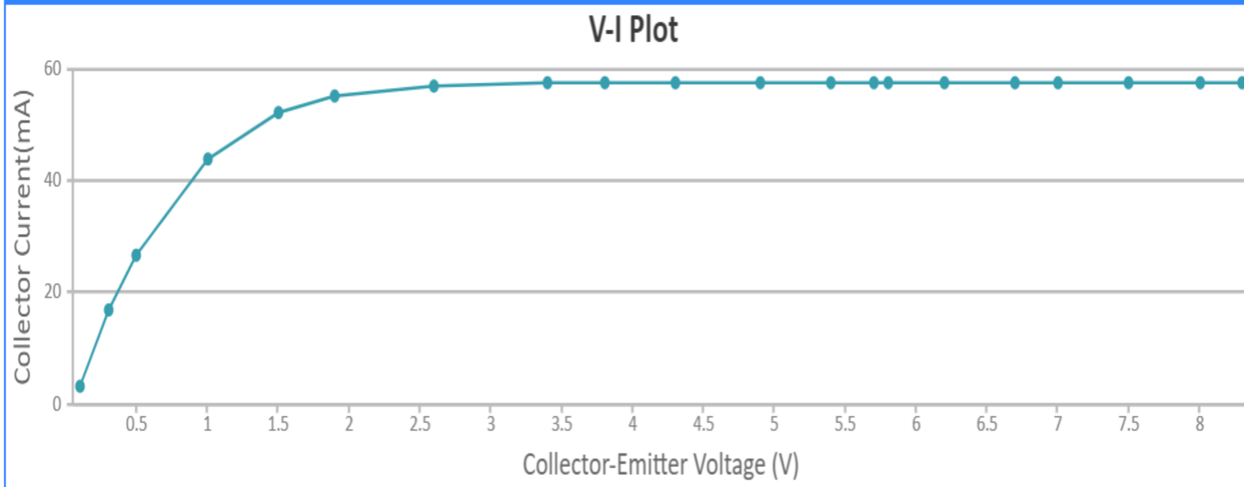


Output Characteristics

EXPERIMENTAL TABLE

Serial No.	Base-Current 14.92 µA	
	Collector-Emitter Voltage V	Collector Current mA
1	0.1000	3.290
2	0.3000	16.79
3	0.5000	26.63
4	1.000	43.88
5	1.500	52.16
6	1.900	55.10
7	2.600	56.99
8	3.400	57.49
9	3.800	57.56
10	4.300	57.60
11	4.900	57.61
12	5.400	57.62
13	5.700	57.62

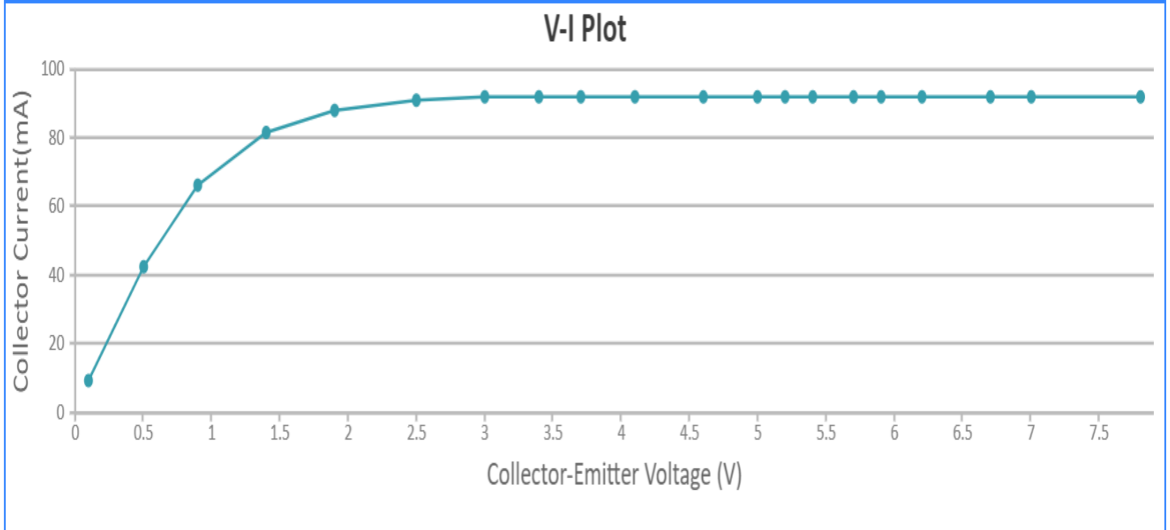
GRAPH PLOT



EXPERIMENTAL TABLE

Serial No.	Base-Current 20.43 μA	
	Collector-Emitter Voltage V	Collector Current mA
1	0.1000	9.202
2	0.5000	42.66
3	0.9000	66.13
4	1.400	81.74
5	1.900	88.28
6	2.500	91.09
7	3.000	91.87
8	3.400	92.12
9	3.700	92.21
10	4.100	92.27
11	4.600	92.31
12	5.000	92.32
13	5.200	92.32

GRAPH PLOT



Conclusion and Summary

1. Upon increasing the base current in the output characteristics, the number of readings was few beyond 2mA.
2. The Ib vs Vbe plot in input characteristics looks pretty much like the diode curve as the BE junction behaves as p-n junction without getting much affected by the other junction.
3. As Ib increases, collector current also increases in output characteristics.
4. In Ib vs Vbe plot in input characteristics, as cutoff point shifts right on increasing Vce.

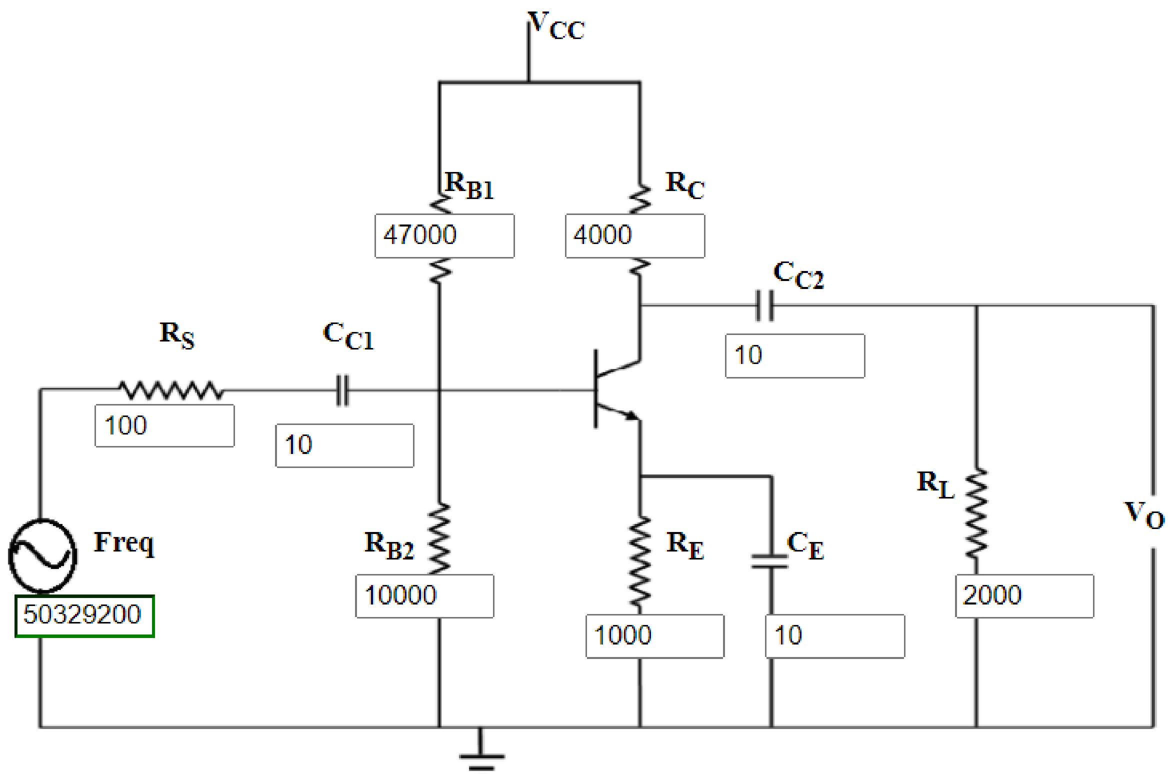
PART 3
AIM

After this experiment,we will have learnt,

1.Calculate gain factor for CE amplifier circuit at various frequencies and compare them

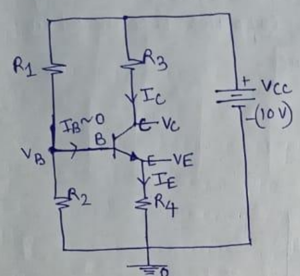
2.Frequency response of a CE amplifier circuit.

Circuit diagram



Theory with equations

Studies on BJT CE Amplifier



One can neglect base current in preliminary estimation of the bias point. Then:-

$$V_B \approx V_{CC}\left(\frac{R_1}{R_1+R_2}\right)$$

$$V_E \approx V_B - 0.7 \quad [\text{cutoff}, V_{BE}=0.7V]$$

$$I_E = \frac{V_E}{R_4} \approx I_C$$

$$V_C = V_{CC} - I_C R_3$$

⇒ The small signal parameters in terms of I_C are

$$g_m = \frac{I_{CQ}}{V_{Th}}, \quad r_\pi = \frac{\beta}{g_m}, \quad r_o = \frac{V_A}{I_C}$$

Operation

This configuration has both voltage and current amplification. R_1 and R_2 form a voltage divider across the base, which provides necessary bias condition to ensure that emitter-base is operating in active region. Q-point is so chosen such that load line is bisected. Therefore, in practical $V_{CE}=\frac{V_{CC}}{2}$. This will confirm that Q-point always swings in active region.

Max signal handling capacity - max input signal for which output is produced without distortion and clipping.

Bypass Capacitor

R_E (emitter resistance) is required to obtain the DC Q-point stability. However it decreases the amplification factor at higher frequencies. In order to avoid such a condition, it is bypassed by a capacitor so that it shorts R_E in the AC equivalent circuit while stabilising the DC Q-point. Hence capacitor is connected in parallel to emitter resistance.

$$X_{CE} << R_E$$

$$\frac{1}{2\pi f C_E} << R_E$$

$$\boxed{C_E >> \frac{1}{2\pi f R_E}}$$

Blocking (or Coupling) Capacitors (Input and Output)

To block all DC disturbances or impurity noise in the output AC signal, we use / insert a coupling capacitor in series with input and output terminals.

$$X_{CC} << \{R_i \times h_{ie}\} \to R_o$$

$$\frac{1}{2\pi f C_C} << \{R_i \times h_{ie}\} \to R_o$$

$$C_C >> \frac{1}{2\pi f \underbrace{(R_i \times h_{ie})}_{R_o}}$$

$$X_{CB} << R_i$$

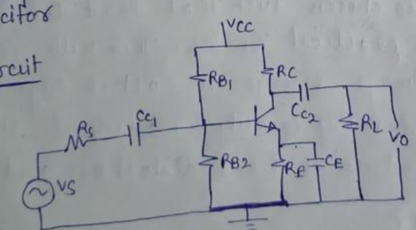
$$\frac{1}{2\pi f C_B} << R_i$$

$$C_B >> \frac{1}{2\pi f R_i}$$

$C_C \to$ Output coupling

$C_B \to$ Input Coupling Capacitor

The net circuit



Frequency response of CE Amplifier

Emitter bypass capacitors are used to short circuit the emitter resistor and thus increases the gain at high frequency. The coupling and bypass capacitors cause the fall of the signal in the low frequency response of the amplifier because impedance of the capacitors is large causing them to behave as open circuit. In the mid-frequency range, large capacitors are effectively short circuits and stray capacitors are open circuits, so that no capacitance appears in mid frequency range. Hence, the mid band frequency gain is maximum. At high frequencies, the bypass and coupling capacitors are replaced by short circuits. The stray capacitors and transistor then determine the response.

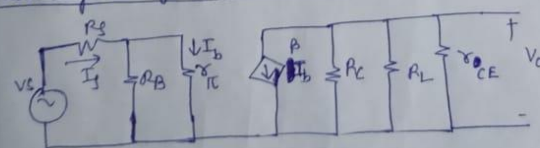
Rin is medium — independent of R_L

Ro is high — independent of R_S.

$$A_m = \frac{V_o}{V_S} = -\beta(r_{CE})(R_C||R_L)\left[\frac{R_B}{R_B+r_\pi}\right]\left[\frac{1}{R_S+(R_B||r_\pi)}\right]$$

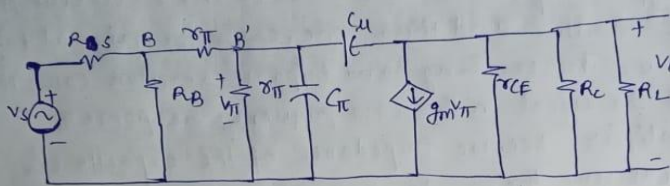
(mid band gain) → The circuit for deriving this equation is the figure below

small signal hybrid π model



model for calculating midband gain by short circuiting all external capacitors.

At high frequency, equivalent of CE amplifier is as shown,

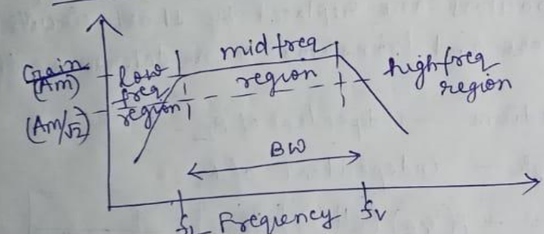


C_μ: collector base capacitance

C_π: emitter base capacitance

r_x: resistance of material of base region and an internal base terminal in B'

Expected of gain vs frequency



Observation table with graphs

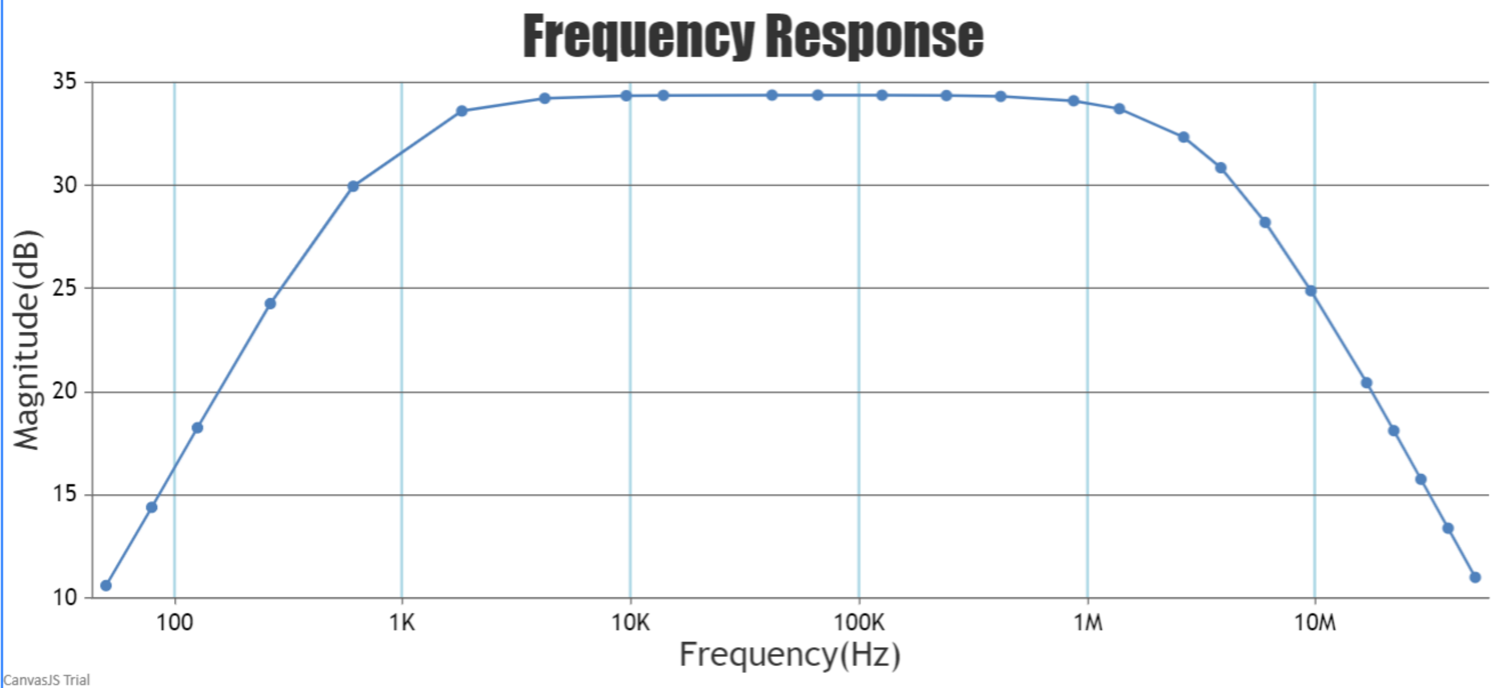
Serial No.	Frequency(Hz)	Magnitude(dB)
1	50	10.599
2	80	14.39246
3	126	18.25316
4	264	24.2756
5	605	29.9652
6	1827	33.6182
7	4186	34.2308
8	9590	34.358
9	13862	34.3738
10	41862	34.3864
11	66347	34.3864
12	126421	34.3824
13	240891	34.367
14	418620	34.3238
15	874621	34.1124
16	1386180	33.7256
17	2641310	32.3504
18	3817860	30.8644
19	6050900	28.2154
20	9590030	24.8974
21	16665600	20.437
22	21969500	18.11174
23	28961400	15.75542
24	38178600	13.38066
25	50329200	10.99534

GRAPH PLOT

Midband gain= -52.4119

Low frequency cut-off = 5058.95432374 Hz

High frequency cut-off= 2.14455e+7 Hz



Conclusion and Observation

1.The gain obtained at low frequencies is less as the capacitors offer a high impedance, at high frequencies, the gain is still less as all capacitors are short circuited and the effect of stray capacitors if observed. But at middle frequency maximum gain is obtained as there are no stray capacitor effects interfering much

2.The bypass capacitor is necessary to stabilize the DC Q point but it reduces the gain at high frequencies, therefore a bypass capacitor shorts it at high frequencies and the gain increases.

3.The coupling capacitors block the DC part of the impure AC signal so that a pure sinusoid/AC signal is obtained at the output.

4.The biasing is done wisely such that the Q point is obtained at a point across which the ac variations refine confined within the active region only.

5.In the Vlabs experiment page, the Draw circuit part of the experiment has a linear scale of frequency on x axis whereas the other page provides a graph where the x axis is a log scale of frequency.