**Group No:**

# Experiment-05

Study of I-V Characteristics of BJT and Implementation of CE Amplifier Using BJT

CSE251 - Electronic Devices and Circuits Lab

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## Objective

1. To measure the collector current and collector to emitter voltage and plot the output characteristics curves of a BJT.
2. To design a common emitter amplifier using BJT and observe the amplified current.

## Equipments

1. BJT (C828) $\times 1$
2. Resistance $(1k\Omega, 2.2k\Omega, 10k\Omega, 33k\Omega, 100k\Omega)$
3. Capacitor $(10\mu F, 47\mu F)$
4. DC power supply
5. Trainer Board
6. Digital Multimeter
7. Breadboard
8. Chords and Wire

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## Background Theory

### Introduction

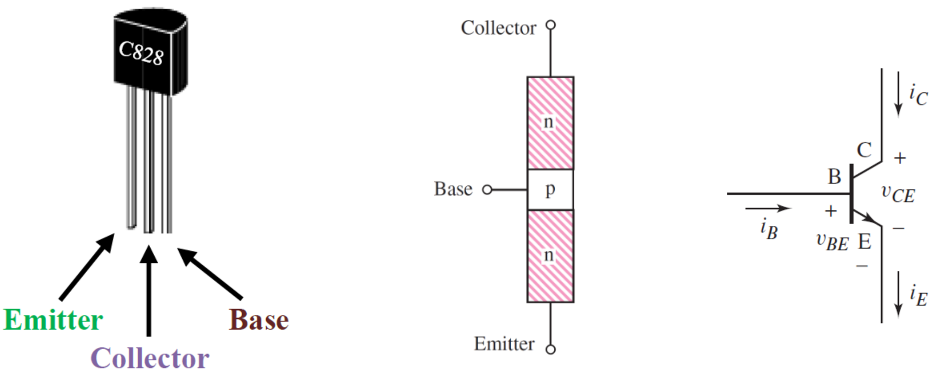


Figure 1: IC, Simple Geometry and Circuit Symbol of an npn BJT

The bipolar junction transistor (BJT) is a type of transistor that is used for electrical amplification and in very-high frequency applications such as radio frequency (RF) circuits for wireless systems and high-speed switching emitter-coupled logic (ECL) gates. BJT is primarily a three terminal device consisting of the following terminals: Base (B), Emitter (E), Collector (C). There are two types of BJTs: (i) npn BJT and (ii) pnp BJT. Our discussion and experiment will be confined to npn BJT. Figure 1 shows the IC, circuit symbol and simple geometry of an npn BJT. The arrowhead in the circuit symbol is always placed on the emitter terminal, and it indicates the direction of the emitter current. For an npn BJT, this direction is out of the emitter. The npn BJT contains a thin p-region between two n-regions. So the transistor consists of two pn junctions, the emitter–base junction (EBJ) and the collector–base junction (CBJ). Depending on the bias condition (forward or reverse) of each of these junctions, different modes of operation of the BJT are obtained. The operating modes are: Cut-off, Active and Saturation. Table 1 summarizes the modes of operation. The active mode is the one used if the transistor is to operate as an amplifier. Switching applications (e.g. logic circuits) utilize both the cutoff mode and the saturation mode. There can be a fourth mode of a BJT called the reverse-active mode which occurs when the EBJ is reversed biased and the CBJ junction is forward biased (not shown in the table).

**Table 1: BJT Modes of Operation**

| Mode | EBJ | CBJ |
|---|---|---|
| Cutoff | Reverse | Reverse |
| Active | Forward | Reverse |
| Saturation | Forward | Forward |

Of the three modes of operation of BJT, the active mode is the most important one because BJT can be used as an amplifier only in this mode. BJT will be in active mode when EBJ is in Forward Bias and CBJ is in Reverse Bias. BJT operates in saturation mode when its collector current is not dependent on the base current and has reached a maximum. This happens when both the EBJ and the CBJ are in Forward Bias. In saturation mode, huge amount of current flows through BJT and it acts like a closed switch. Cut-off mode is the opposite of saturation mode. In cut-off mode, both junctions of BJT remain reverse biased. That is why no current flows through the device (actually, very negligible amount of current flows) and the BJT acts like an open switch.

## Input and Output I-V Characteristics of BJT

The I-V characteristics of a BJT depends on the circuit configuration. There are three basic configurations for connecting the BJT: the common base (CB) configuration, the common emitter (CE) configuration, and the common collector (CC) configuration. Though each configuration has their own applications, the CE is the most widely used configuration and by far the most popular for amplifiers.
In CE configuration, the emitter is the common terminal. Hence, the input is between the base and the emitter while the output is between the collector and the emitter. So, the input I-V characteristics is the variation of the base current $I_B$ with the base-emitter voltage $V_{BE}$, and the output I-V characteristics is the variation of the collector current $I_C$ with the collector-emitter voltage $V_{CE}$.
The following figure shows the input I-V characteristics of an npn BJT for the CE circuit configuration which illustrates the variation in $I_B$ with respect to $V_{BE}$ when $V_{CE}$ is kept constant. In the graph, $I_B$ changes exponentially as $V_{BE}$ changes. This is obvious since the BJT's base-emitter junction is similar to a pn junction diode. So it's current voltage relationship should also be like a pn junction diode.

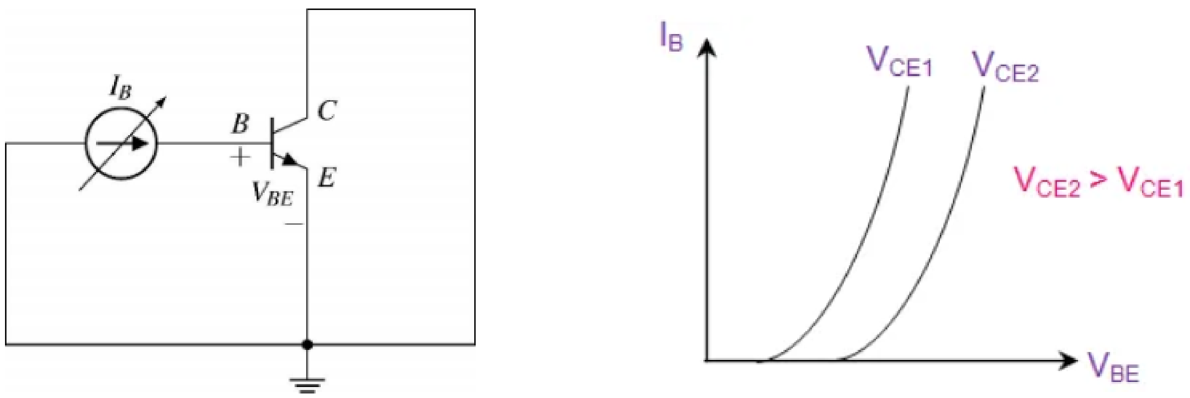


Figure 2: BJT input IV characteristics Circuit and Graph in CE configuration

The output I-V characteristics of a BJT in CE configuration are also referred to as collector characteristics. The following circuit and graph shows the output I-V characteristics of a BJT in CE configuration. The I-V characteristics shows the variation in $I_C$ with the changes in $V_{CE}$ when $I_B$ is held constant. In the graph we can see that there is a rapid increase of collector current at the beginning and then the collector current becomes almost constant. This graph can be divided into 3 regions:

1. Active Region (where output current becomes almost constant)
2. Saturation Region (where $I_C$ is increasing rapidly)
3. Cut-off Region (where the current is zero/almost zero)

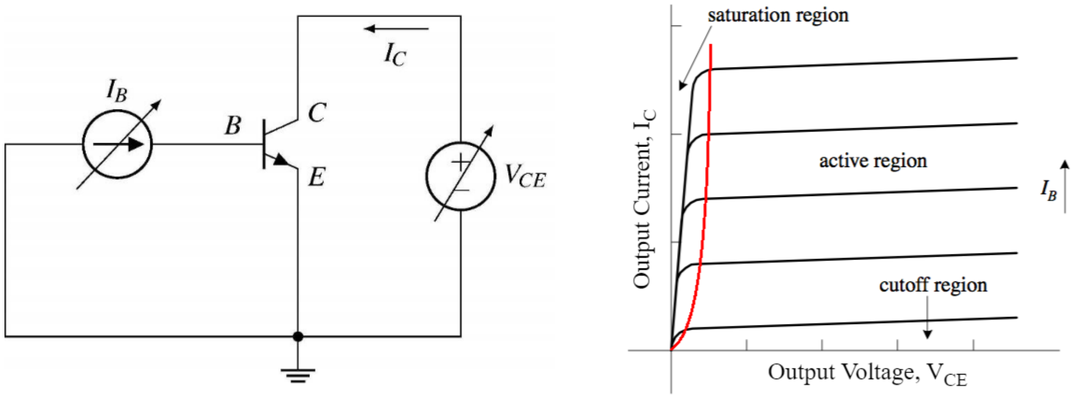


Figure 3: BJT output IV characteristics Circuit and Graph in CE configuration

From the output I-V characteristics we see that, in the active region, if we keep $V_{CE}$ constant, $I_C$ increases with the increase of $I_B$. This relationship between $I_C$ and $I_B$ in active mode is actually linear in nature which can be represented by the following equation: $I_C = \beta I_B$, where $\beta$ is a constant. Typically, $\beta$ = [50 to 200].

## Linear Amplifier and Its Circuit Realization

An amplifier is a device that can increase the power of a signal (a time-varying voltage or current) by increasing the amplitude of the signal applied to it. Amplification means increasing the amplitude (voltage or current) of a time-varying signal by a given factor.

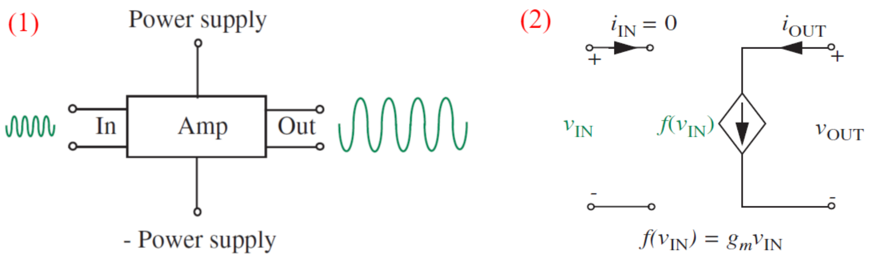


Figure 4: (1) Basic Representation of Amplifier (2) Transconductance Amplifier Realization

A linear amplifier amplifies the signal in the following manner: $Output = k \times Input$
here, $k$ = Gain of the Amplifier and Output/Input can be voltage/current
Linear amplifier circuits can be realized/made using dependent sources. For example, a transconductance amplifier (Input = Voltage, Output = Current) can be made using a voltage controlled current source which is shown in the figure above.

## BJT Common Emitter Amplifier

In Active mode, BJT acts like a current controlled current source because $I_C = \beta I_B$ and $\beta$ is constant. So, $I_C$ will change linearly with the change of $I_B$ and we can make linear amplifiers with BJT.

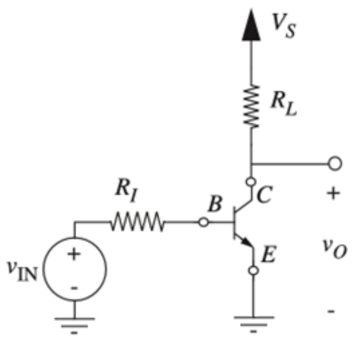


Figure 5: BJT Common Emitter Amplifier Basic Circuit

The figure above shows a basic BJT Common Emitter Amplifier which is by far the most popular BJT amplifier configuration. The CE configuration is the one best suited for realizing the bulk of the gain required in an amplifier. Depending on the magnitude of the gain required, either a single stage or a cascade of two or three stages can be used. The following figure shows a modified implementation of BJT CE Amplifier that takes some practical issues into consideration.

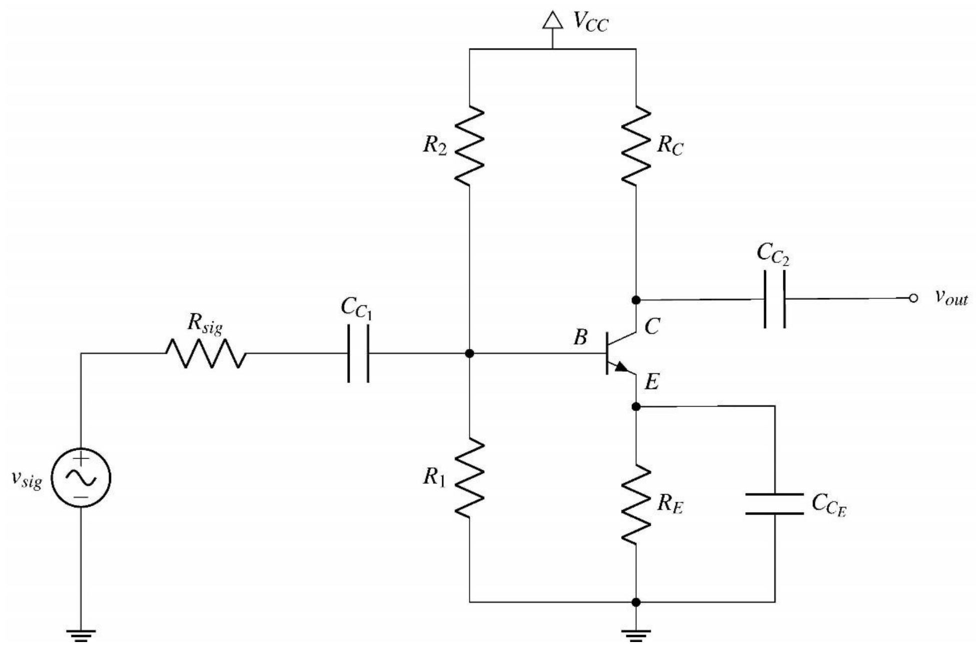


Figure 6: BJT Common Emitter Amplifier

To establish a signal ground (or an ac ground, as it is sometimes called) at the emitter, a large capacitor $C_{CE}$, usually in the range of microfarads or tens of microfarads is connected between emitter and ground. This capacitor is required to provide a very low impedance to ground (ideally, zero impedance, i.e., in effect, a short circuit) at all signal frequencies of interest. In this way, the emitter signal current passes through $C_{CE}$ to ground and thus bypasses the output resistance of the current source I (and any other circuit component that might be connected to the emitter); hence $C_{CE}$ is called a bypass capacitor. Obviously, the lower the signal frequency, the less effective the bypass capacitor becomes. For our purposes here we shall assume that $C_{CE}$ is acting as a perfect short circuit and thus is establishing a zero-signal voltage at the emitter.
In order not to disturb the dc bias currents and voltages, the signal to be amplified, shown as a voltage source $v_{sig}$ with an internal resistance $R_{sig}$, is connected to the base through a large capacitor $C_{C1}$. Capacitor $C_{C1}$, known as a coupling capacitor, is required to act as a perfect short circuit at all signal frequencies of interest while blocking dc. Here again we shall assume this to be the case and defer discussion of imperfect signal coupling, arising as a result of the rise of the impedance of $C_{C1}$ at low frequencies. At this juncture, we should point out that in situations where the signal source can provide a dc path for the dc base current $I_B$ without significantly changing the bias point, we may connect the source directly to the base, thus dispensing with $C_{C1}$ as well as $R_B$. Eliminating $R_B$ has the added beneficial effect of raising the input resistance of the amplifier.
Inclusion of an emitter resistance $R_E$ leads to significant improvements in the amplifier characteristics. $R_E$ increases the input resistance of a BJT substantially. With $R_E$, the gain of the amplifier is less sensitive to the value of $\beta$, which is desirable. Another important consequence of including the resistance in the emitter is that it enables the amplifier to handle larger input signals without incurring nonlinear distortion. This is because only a fraction of the input signal at the base appears between the base and the emitter.
The voltage signal resulting at the collector, $v_c$, is coupled to the load resistance $R_L$ via another coupling capacitor $C_{C2}$. We shall assume that $C_{C2}$ also acts as a perfect short circuit at all signal frequencies of interest; thus, the output voltage $v_o = v_c$. Note that $R_L$ can be an actual load resistor to which the amplifier is required to provide its output voltage signal, or it can be the input resistance of a subsequent amplifier stage in cases where more than one stage of amplification is needed.

## Task-01: I-V Characteristics of a BJT

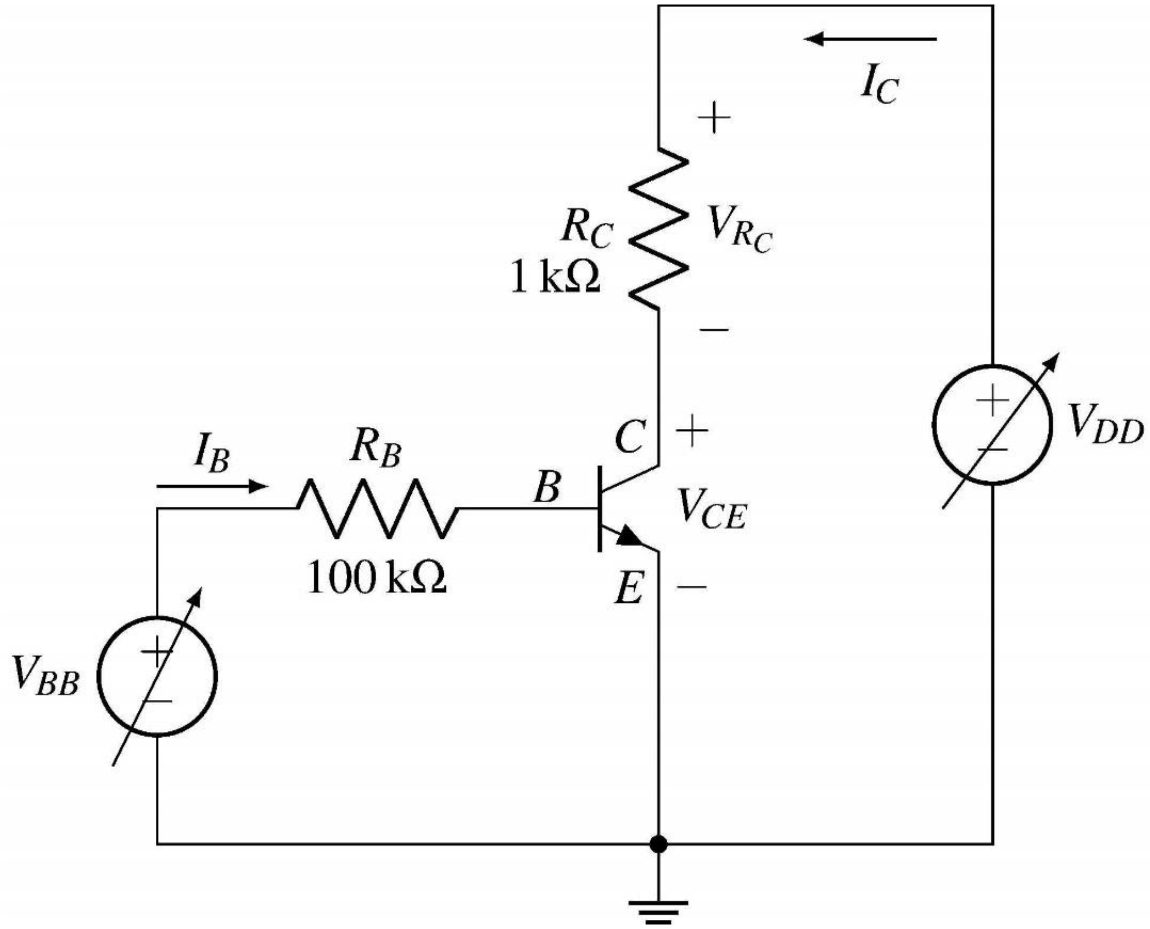


Figure 7: Circuit for determining the IV characteristics ($I_C$ vs $V_{CE}$) of BJT

### Procedure

1. Construct Circuit given above. Set $R_B = 100k\Omega$ and $R_C = 1k\Omega$.
2. Set and keep $V_{BB}$ constant at 2 V, increase $V_{DD}$ by 0.1 V increment from 0 to 1 V, then by 1 V increment from 1 V to 8 V (or 10 V) and measure the corresponding voltage $V_{RC}$ across the resistor $R_C$. Calculate the collector current for each value of $V_{DD}$ by using the formula $I_C = V_{RC}/R_C$. In addition to this, measure the collector-emitter voltage $V_{CE}$.
3. Repeat Step-2 for $V_{BB} = 2.5$ V and $V_{BB} = 3$ V.

## Data Table 1: Output IV Characteristics

Use Multimeter to get, actual value of $R_B =$ and $R_C =$

(1) $V_{BB} = 2$ V

| $V_{DD}$ (V) | $I_B = \frac{V_{BB}-0.7}{R_B[k\Omega]} \times 10^3$ ($\mu$A) | $V_{CE}$ (V) | $V_{RC}$ (V) | $I_C = \frac{V_{RC}}{R_C[k\Omega]} \times 10^3$ ($\mu$A) | $\beta = \frac{I_C}{I_B}$ |
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(2) $V_{BB} = 2.5$ V

| $V_{DD}$ (V) | $I_B = \frac{V_{BB}-0.7}{R_B[k\Omega]} \times 10^3$ ($\mu$A) | $V_{CE}$ (V) | $V_{RC}$ (V) | $I_C = \frac{V_{RC}}{R_C[k\Omega]} \times 10^3$ ($\mu$A) | $\beta = \frac{I_C}{I_B}$ |
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(2) $V_{BB} = 3$ V

| $V_{DD}$ **(V)** | $I_B = \frac{V_{BB}-0.7}{R_B[k\Omega]} \times 10^3$ **($\mu$A)** | $V_{CE}$ **(V)** | $V_{RC}$ **(V)** | $I_C = \frac{V_{RC}}{R_C[k\Omega]} \times 10^3$ **($\mu$A)** | $\beta = \frac{I_C}{I_B}$ |
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## Task-02: BJT Common Emitter (CE) Amplifier

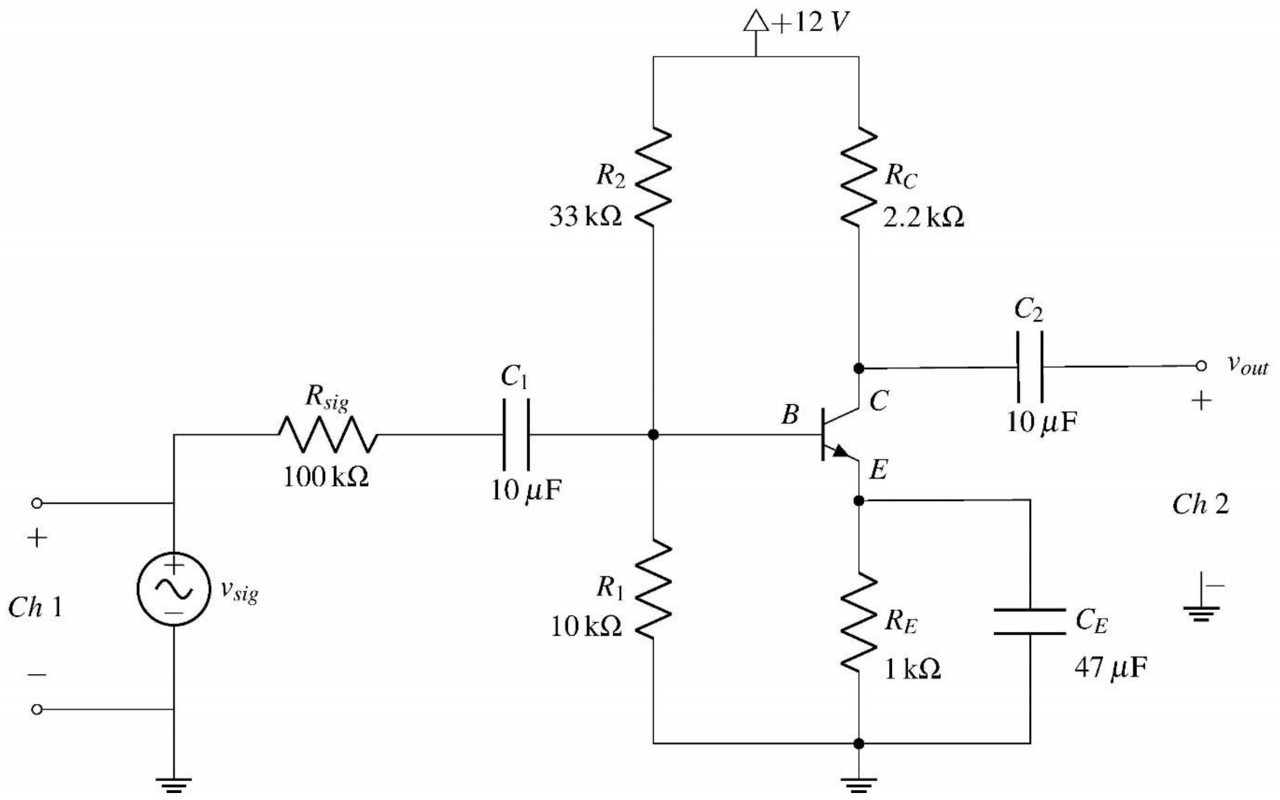



Figure 8: BJT CE Amplifier Circuit

### Procedure

1. Construct the circuit given above.
2. Apply a signal voltage of 150 mV (peak-to-peak) and frequency 1 kHz at the input terminals. Connect Ch.1 at the input between base and ground and Ch.2 at the output terminals. Measure peak-to-peak value of both $v_{sig} = v_{in}$ and $v_{out}$.
3. Observe Ch.1 and Ch.2 at the same time to observe the relationship between input and output voltage.

### Data Table 2: Common Emitter Amplifier

| Amplitude of the input signal, $v_{sig}$ (from signal generator) (mV) | Amplitude of the output signal, $v_{out}$ (from oscilloscope) (V) | Gain $= \frac{\lvert v_{sig}\rvert}{\lvert v_{out}\rvert}$ |
|---|---|---|
| | | |

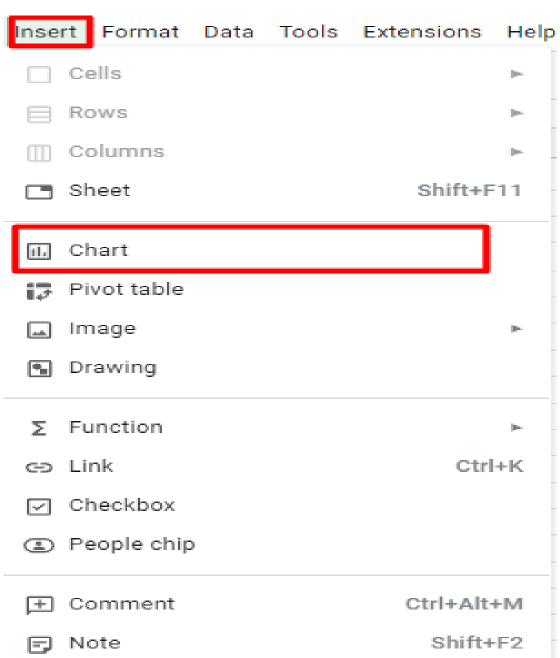
# Task-03

**PLOTTING GRAPHS ON SPREADSHEET (HOMETASK)**

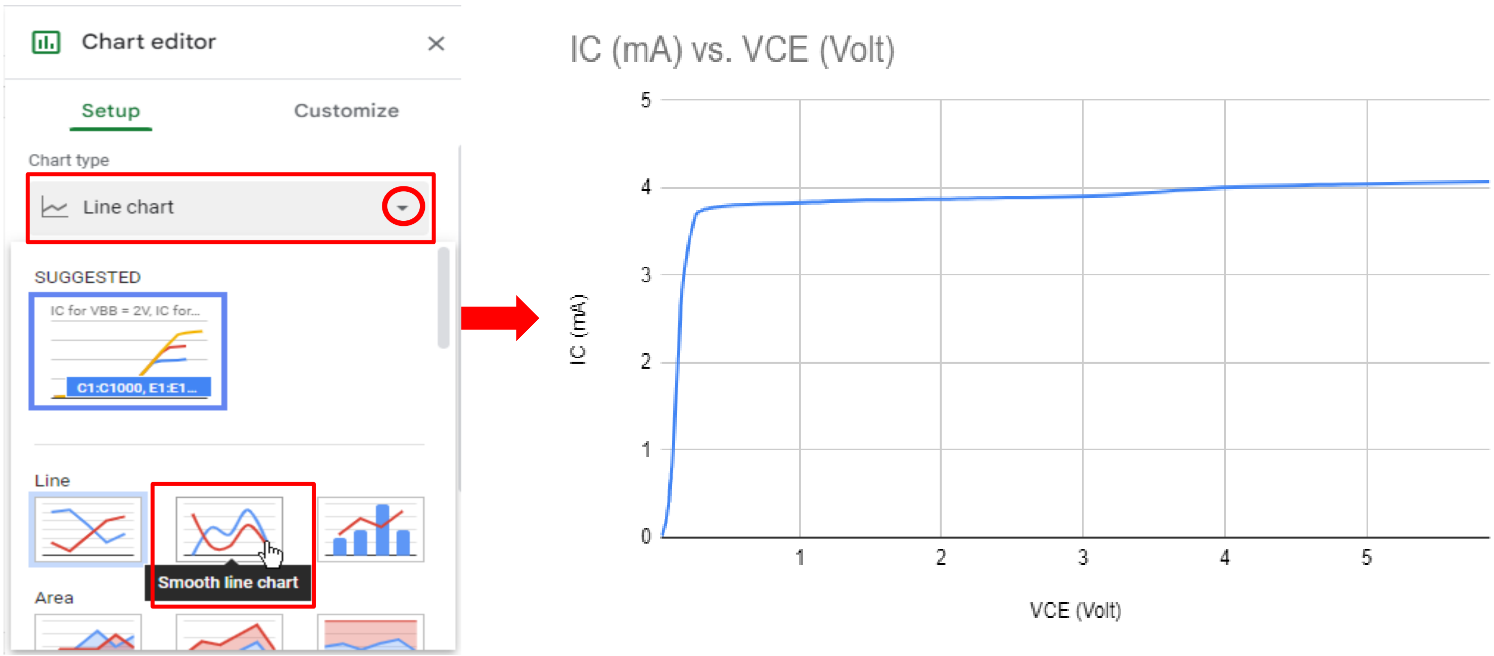
1. Create a Google spreadsheet by visiting https://docs.google.com/spreadsheets
2. Fill in the spreadsheet with the data of Table 1 for $V_{BB}$ = 2V (refer to your labsheet). Select both the columns of VCE and IC (to select a column, click on the column head, e.g., "B". Then hold CNTRL while clicking the second column, e.g., "D", to select both columns).

| A | B | C | D |
|---|---|---|---|
| VDD (Volt) | VCE (Volt) | VR (Volt) | IC (mA) |
| 0.1 | 0.023 | 0.023 | 0.023 |
| 0.2 | 0.035 | 0.06 | 0.06 |
| 0.3 | 0.057 | 0.182 | 0.182 |
| 0.4 | 0.066 | 0.266 | 0.266 |
| 0.5 | 0.074 | 0.364 | 0.364 |
| 0.6 | 0.081 | 0.462 | 0.462 |
| 0.7 | 0.087 | 0.599 | 0.599 |
| 0.8 | 0.093 | 0.684 | 0.684 |
| 0.9 | 0.096 | 0.756 | 0.756 |
| 1 | 0.099 | 0.808 | 0.808 |
| 2 | 0.134 | 1.83 | 1.83 |
| 3 | 0.169 | 2.828 | 2.828 |
| 4 | 0.266 | 3.688 | 3.688 |
| 5 | 1.134 | 3.839 | 3.839 |
| 6 | 2.122 | 3.876 | 3.876 |
| 7 | 3.071 | 3.908 | 3.908 |
| 8 | 3.975 | 4.001 | 4.001 |
| 9 | 4.9 | 4.04 | 4.04 |
| 10 | 5.87 | 4.07 | 4.07 |

3. Select Insert → Chart.

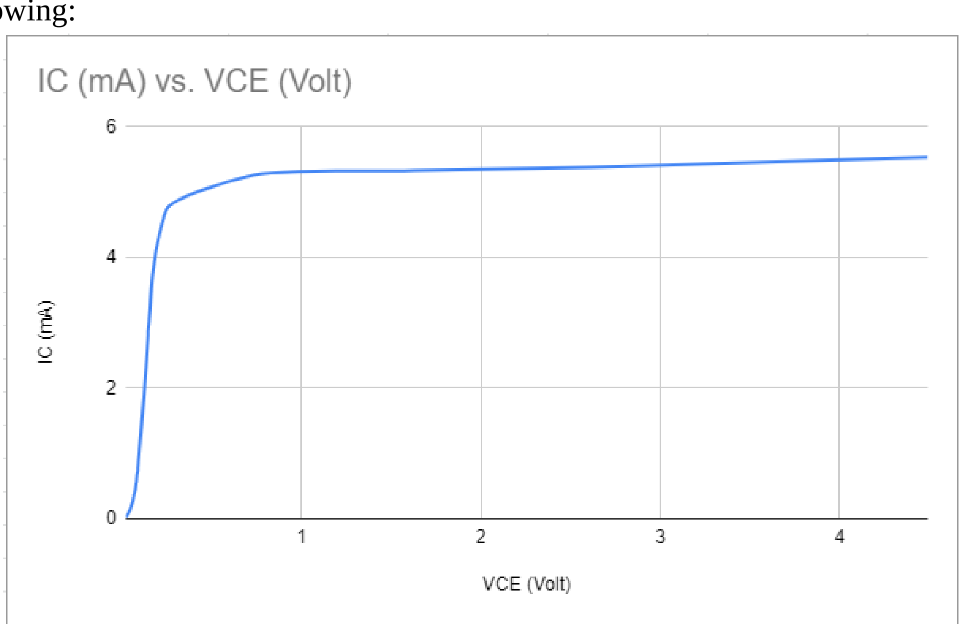


4. A Chart Editor section should pop up at the right side of your screen. If it doesn't show up, then double click on the graph. Go the setup section in the chart editor and change the "Chart type" to "Line Chart" if not set by default. Expand by clicking on the small triangle adjacent to "Line Chart". Select "Smooth line chart" as shown in the following figure.




5. Create another table with the data of Table 2 for $V_{BB}$ = 2.5 V (refer to your labsheet). Select columns of VCE and IC (VCE = x-axis, IC = y-axis).

6. Repeat the same procedure and plot another line chart. Your graph must look like the following:



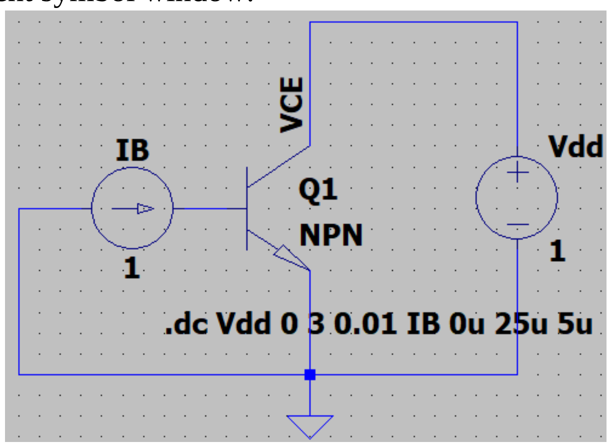

****Note: This is a sample data collected from a simulation. Your data may not match with this one**

# Task-04

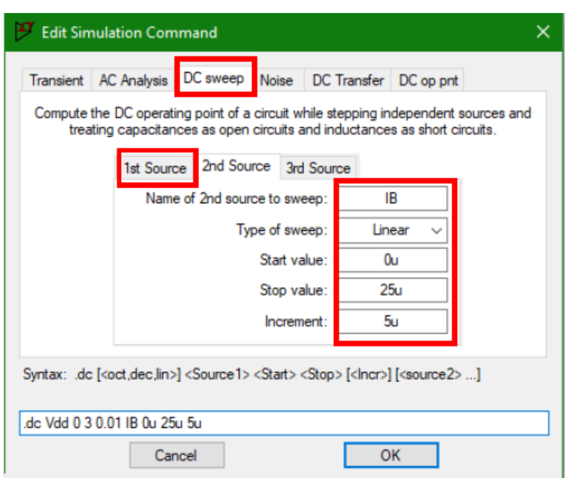
**SIMULATION (HOMETASK)**

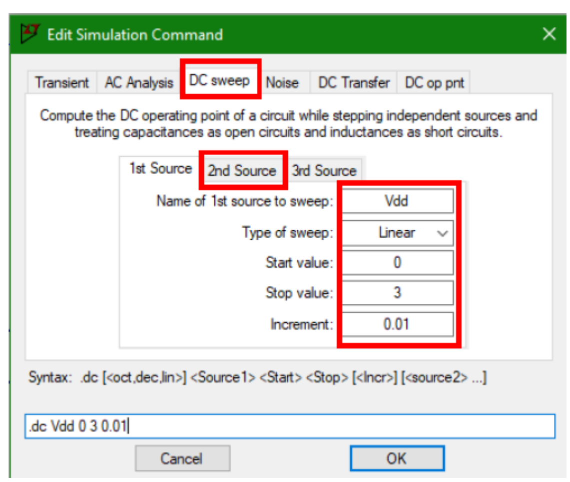
In this task, we will observe the I-V characteristics of BJT using LTspice simulation.

1. Open a new schematic and build the circuit. To insert an n-channel MOSFET, type 'nmos' in the select component symbol window.



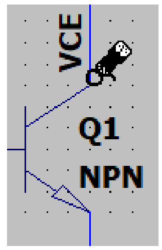

2. Rename (9) the components as shown in the figure above. Set the two voltages (VGS and Vdd) to any dc value for the time being. We will sweep the two sources in a while. Label the node ‘VCE’.
3. Go to the Edit Simulation Command window. In the ‘DC sweep’ tab, set the properties to sweep ‘VCE’ and ‘IB’ as shown in the figure below.



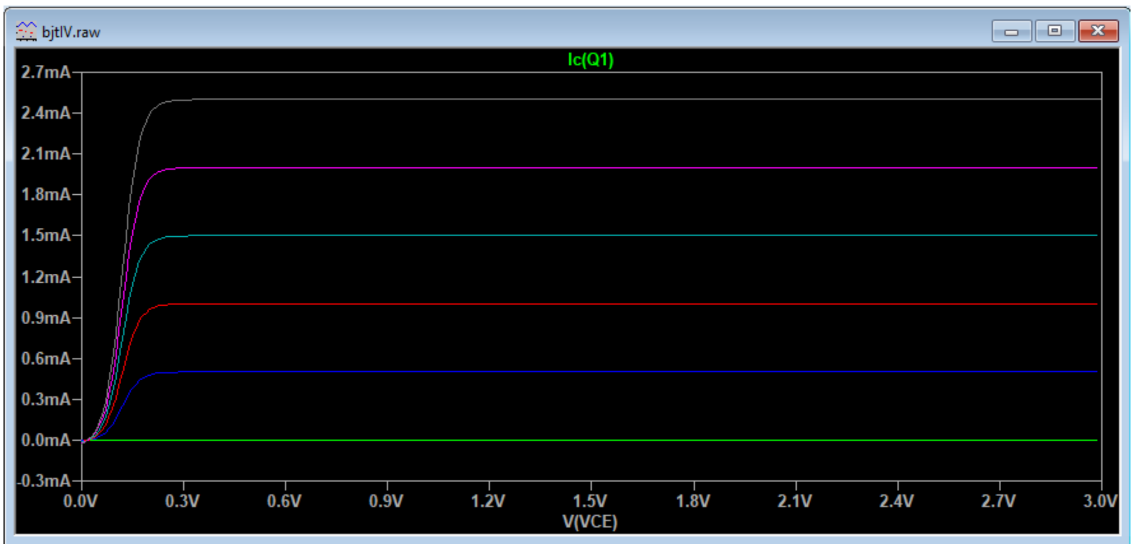




4. Run the simulation. Note that, ‘Vdd’ is plotted along the horizontal axis and for this circuit diagram, Vdd = VCE.

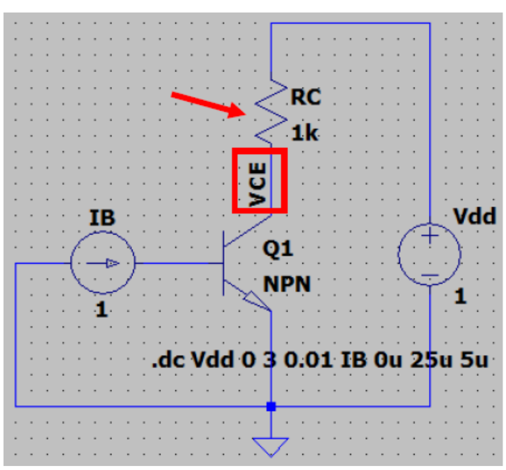
5. Plot the current through the collector to emitter of the BJT. To do so, hover the cursor close to the collector terminal. The cursor will change into something like the following figure.

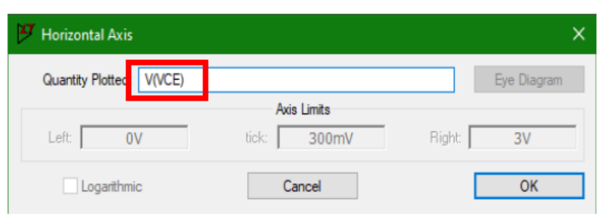



6. Now, if you click there, you should get a plot like this following one. Notice that, the plot looks like the one you have studied in theory.

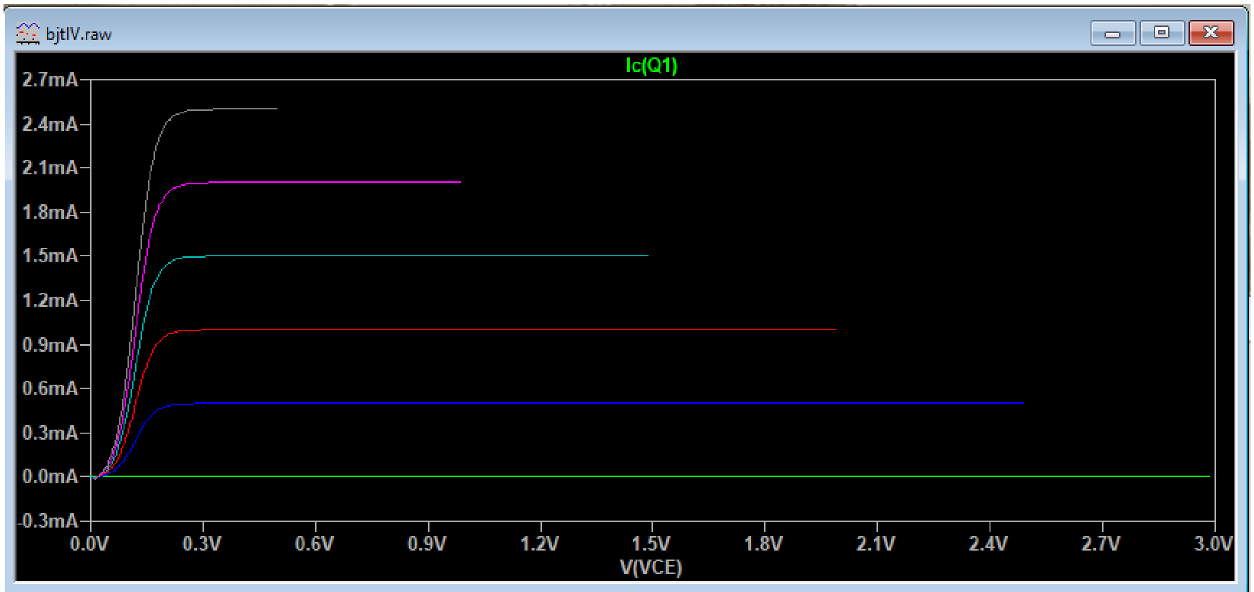



7. Now add a resistor of 1 kΩ in series with the collector terminal and simulate. Plot the collector to emitter current vs VCE. Don't forget to change the horizontal axis from 'Vdd' to 'VCE'.



8. A plot like the following one will be generated. Why does the collector current not reach the end of VCE? Think!




# Task-05

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**REPORT**

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Attach the Circuit Diagrams
3. Attach the signed data sheet and calculation
4. Attach the graphs of $I_C$ *vs* $V_{CE}$ for $V_{BB}$ = 2 V, 2.5 V, and 3 V using Google Sheets
5. Attach the circuit diagrams of the LTspice simulation
6. Attach the plots generated in the simulation
7. Discussion (It should contain the precautions you took and discrepancies you noticed)