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Experiment-05

Study of I-V Characteristics of BJT and Implementation of Logic Functions

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To observe and understand the I-V characteristics of BJT.
2. To implement a NAND gate and a Logic Function using BJTs and verify the truth tables.

Equipments

1. BJT (C828) - (×3)
2. Resistances: 4.7 kΩ (×1), 100 kΩ (×4)
3. DC power supply
4. Oscilloscope
5. Trainer Board
6. Breadboard
7. Chords and Wire

Background Theory

Introduction to BJT

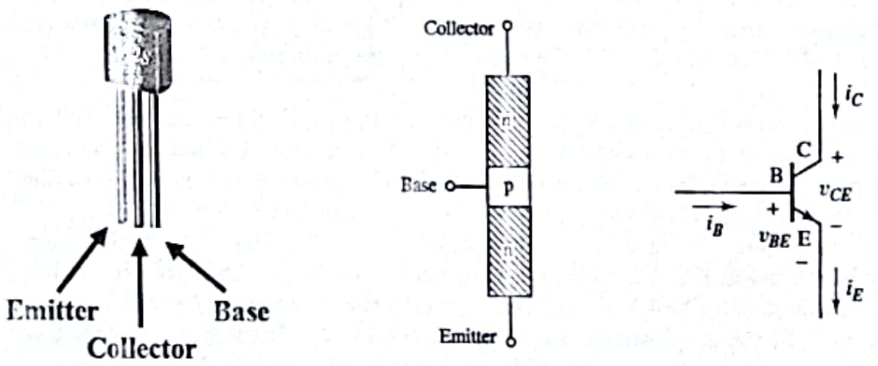


Figure 1: *IC (C828), Simple Geometry and Circuit Symbol of an npn BJT*

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.

The figure above 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. The following table summarizes the modes of operation.

The active mode is the one used if the transistor is to operate as an amplifier. Switching applications (e.B. 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 following table).

BJT Modes of Operation		
Modes ↓	Emitter-Base Junction	Collector-Base Junction
Cutoff	Reverse Bias	Reverse Bias
Active	Forward Bias	Reverse Bias
Saturation	Forward Bias	Forward Bias

The active mode is the most important mode of the 3 modes of operation of BJT. 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, large 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.
The output I-V characteristic of a BJT in CE configuration is also referred to as the collector characteristic. We are mainly interested in this one. 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 a rapid increase in collector current at the beginning. 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 increases rapidly)
3. Cut-off Region (where the current is zero/almost zero)

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 β is a constant. Typically, $\beta = 50$ to 200.

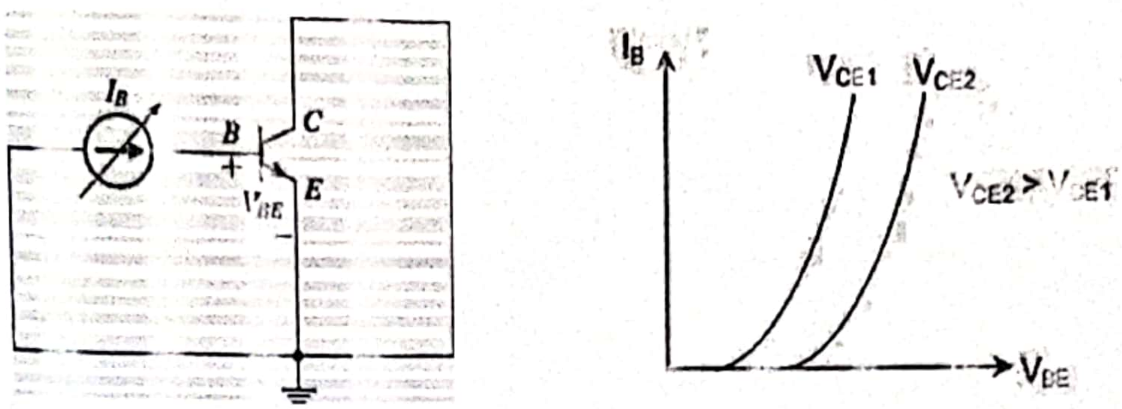


Figure 2: BJT input I-V characteristics Circuit and Graph in CE configuration

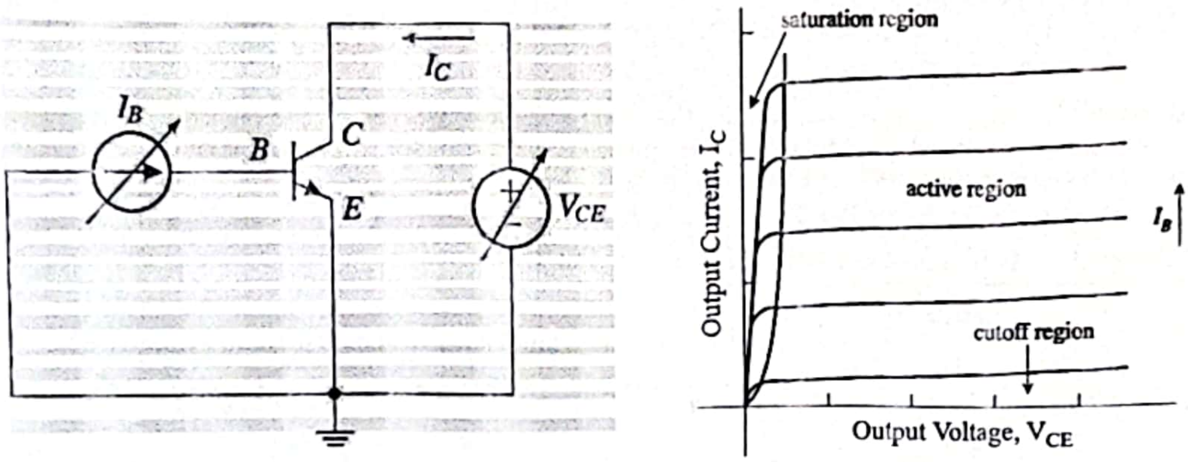


Figure 3: BJT output I-V characteristics Circuit and Graph in CE configuration

BJT as a Switch

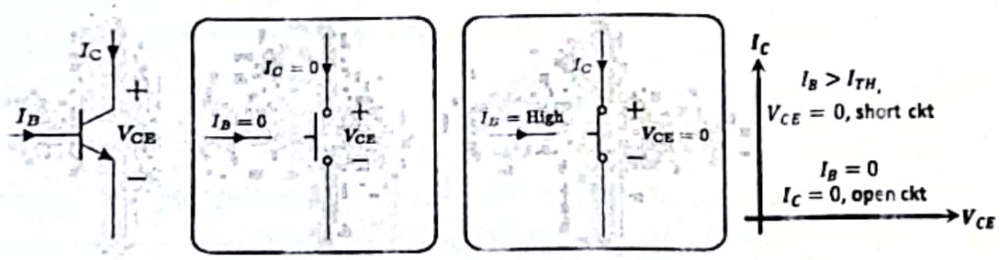


Figure 4: The S-model representation of a BJT acting as a current-controlled switch

BJT can act as a switch depending on the applied current in the input terminal. A simple circuit model known as 'Switch Model' or 'S-Model' is used to model this behavior. As seen in figure 4, when $I_B = 0$, $I_C = 0$, BJT acts like an open switch. When $I_B = high$, $V_{CE} = 0$, BJT acts like a closed switch.

Logic Gate Implementation using BJTs

BJTs can be used to construct logic gates just like MOSFETs. Unlike MOSFETs, they are current-controlled, their state is controlled by I_B.

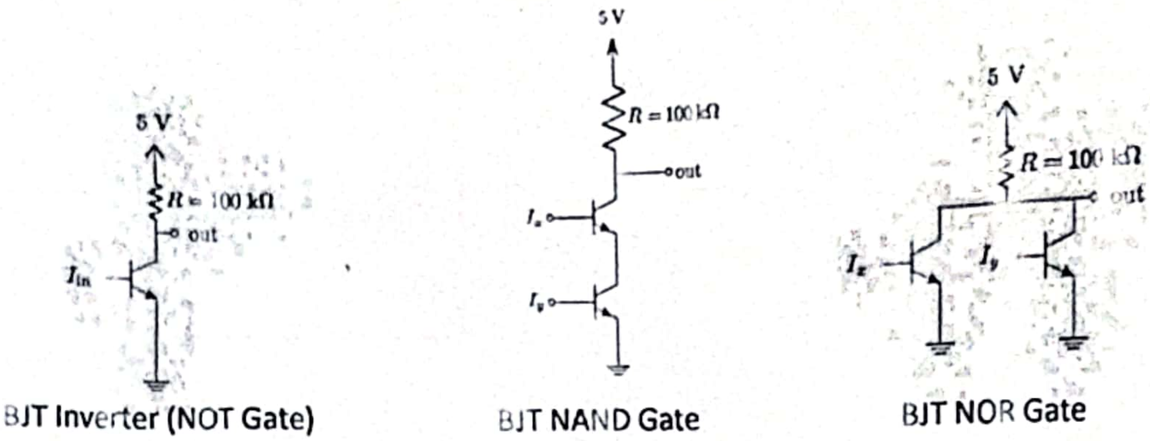
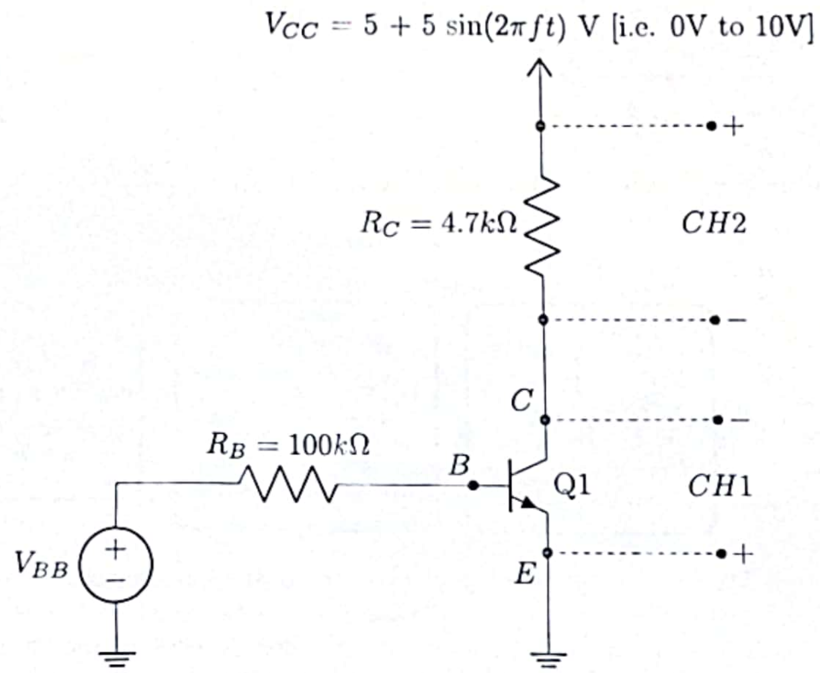


Figure 5: NOT, NAND & NOR gates using BJT

However, cascading these logic gates i.e, using the output of one logic gate as the input of another is not possible if the input is current and the output is voltage. Therefore, to translate the voltage output into a current input, we add resistors at the bases (input terminals) of the BJTs.

Task-01: I-V Characteristics of a BJT

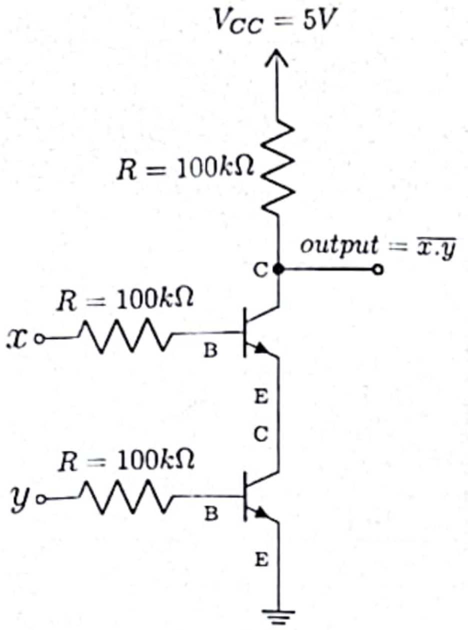


Procedure

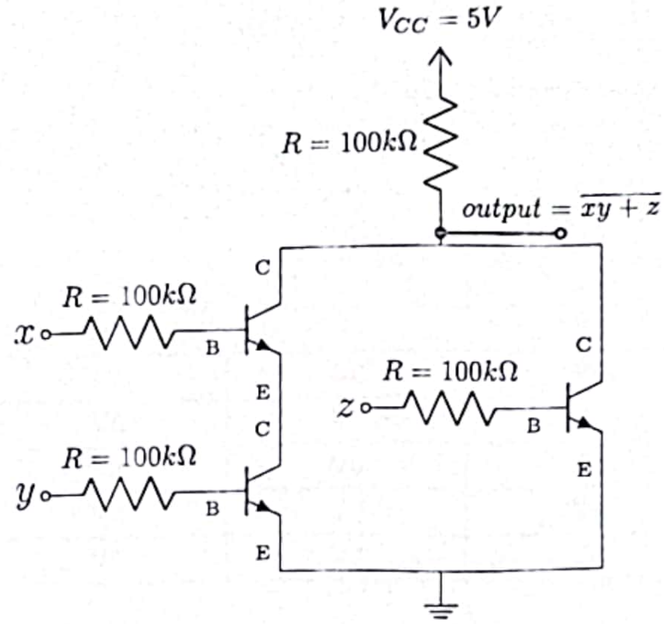
1. Construct the circuit shown above. Use the function generator for $V_{CC} = 5 + 5\sin(2\pi ft)$ V [i.e. an AC voltage that varies from 0V to 10V]. Set $f = 50$ Hz. Use the dc power supply for V_{BB}.
2. Invert the CH1. Set the oscilloscope in the X-Y mode.
3. Now, rotate the voltage knob of the dc power supply slowly from 0V to 5V to vary V_{BB}. You should observe the change in the I-V characteristics.
4. Use your mobile camera to capture the image of the I-V characteristics graphs for 3 different values of V_{BB}. Measure the values of V_{BB} of the captured images and write them below:

Values of V_{BB}	
1st Value	0.9
2nd Value	2.5
3rd Value	5

Task-02: Logic Gate and Logic Function Implementation



Circuit-1
NAND Gate using BJT



Circuit-2
Logic Function, $f = \overline{xy + z}$ using BJT

Procedure

1. On a trainer board, setup the Circuit 1.
2. Connect the gate terminals (input x and y) to data switches. Those switches provide 5V approximately.
3. Keeping V_{CC} constant at 5V, at first turn off the data switches connected to the gate terminal. This implies you are now applying V_x= 0V, V_y= 0V. Measure the corresponding output voltage, V_{out} which should be approximately 5V which corresponds to boolean 1.
4. The boolean outputs can also be determined by the state of an LED. Connect V_{out} to one of the LEDs and check it. When the LED is ON, the boolean output is 1. Similarly, when the LED is OFF, the boolean output is 0.
5. Next, use the input voltage combinations of Data Table 1 and observe the state of LED again.
6. Verify the truth table of the NAND gate.
7. Now we will implement a Logic Function, f = $\overline{xy + z}$ using BJT. Circuit 2 in the figure shown above represents the Logic Function f = $\overline{xy + z}$. Setup Circuit 2 in a similar way to the procedure followed for Circuit 1.
8. Keeping V_{DD} constant at 5V, observe the state of the LED for different combinations of the inputs x, y and z as shown in Data Table 1.
9. Verify the truth table of the Logic Function, f = $\overline{xy + z}$.

Data Table 1: Verification of the Truth Tables of Logic Gate and Logic Function

1. NAND Gate

Input Voltage, V_x (volt)	Input Voltage, V_y (volt)	State of LED (On/Off)	Boolean Output (0 or 1)
0V	0V	on	1
0V	5V	on	1
5V	0V	on	1
5V	5V	off	0

2. Logic Function, f = $\overline{xy + z}$

Input Voltage, V_x (volt)	Input Voltage, V_y (volt)	Input Voltage, V_z (volt)	State of LED (On/Off)	Boolean Output (0 or 1)
0V	0V	0V	on	1
0V	0V	5V	off	0
0V	5V	0V	on	1
0V	5V	5V	off	0
5V	0V	0V	on	1
5V	0V	5V	off	0
5V	5V	0V	off	0
5V	5V	5V	off	0

17.08.25

Signature of the lab faculty

Report Submission Guidelines

1. Attach the signed Data Sheet (if any)
2. Attach the captured images (if any)
3. Answer the questions in the "Test Your Understanding" section
4. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
   - What did you learn from this experiment?
   - What challenges did you face and how did you overcome the challenges? (if any)
   - What mistakes did you make and how did you correct the mistakes? (if any)
   - How will this experiment help you in future experiments of this course?

Test Your Understanding

Answer the following questions:

1. We can use the BJT as a switch. Which operating regions do we need for this purpose and why?
Answer:

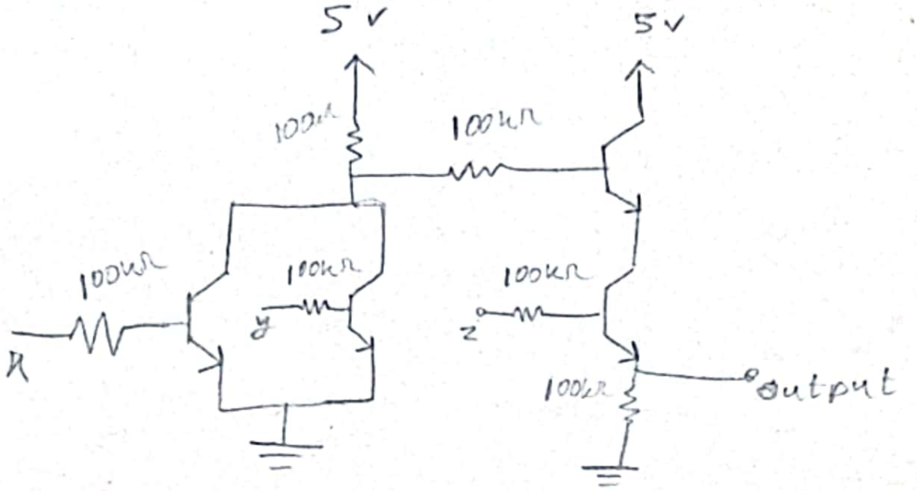
We can use the two regions called cut off region and saturation Region, for the function of a switch. In cut off region, transistor is off, hence no current flows, we can use it as off switch. In saturation region, transistor is on and current flows, which is used as on switch.

2. Suppose we want to cascade two BJT logic gates (use the output of the first logic gate as one of the inputs of the second one). Why do we need to add a resistor at the input of the second logic gate?
Answer:

As the output of the first logic gate is connected to the Base of the second one, connecting directly may overflow the Base line of the second logic gate as well as damaging it. Even for the conversation of logic for the gates, a resistor is necessary to overcome these problems.

3. Draw a circuit using BJTs that implements the following logic function, $f = (\overline{x + y}).z$

Answer:



4. Suppose, a BJT is operating in the active region where, $I_B = 0.01mA$. If $\beta = 100$, find the value of I_C and I_E.

Answer:

in active

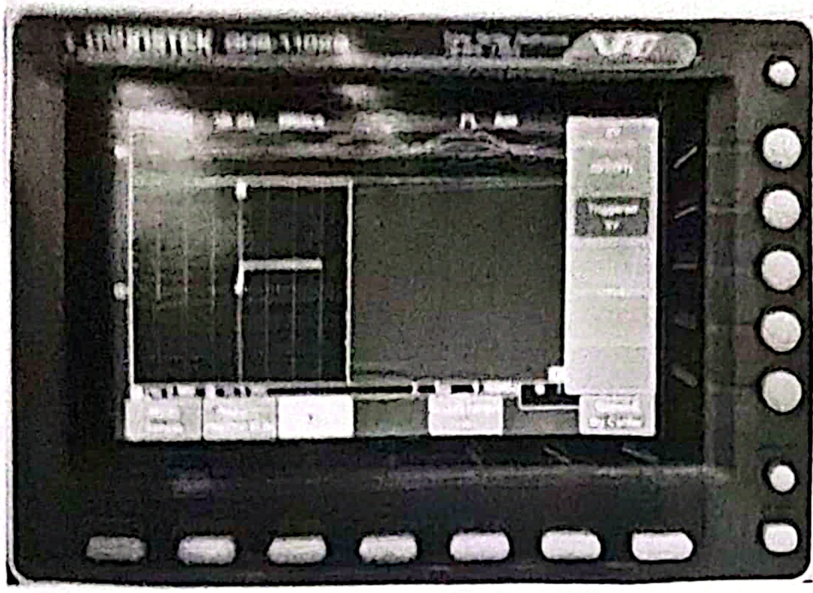
$$I_C = \beta I_B = 100 \times 0.01mA = 1mA$$

$$I_E = I_C + I_B = 1mA + 0.01mA = 1.01mA$$

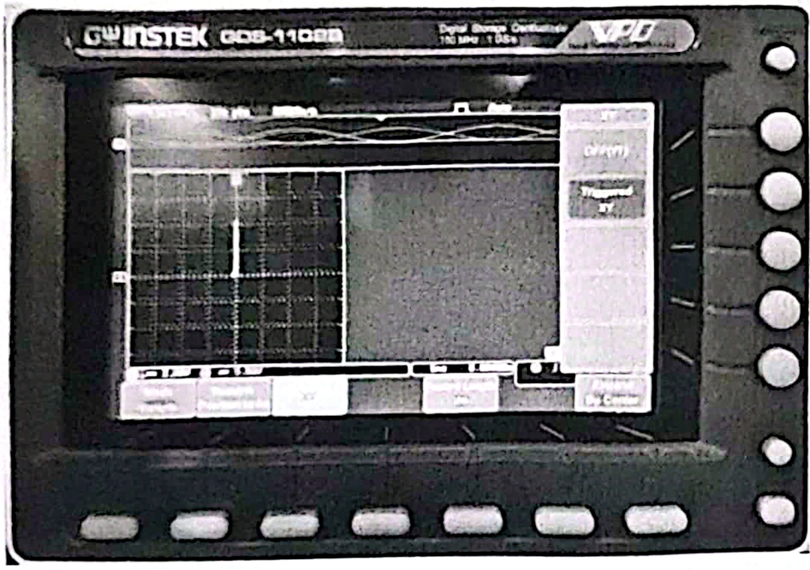
From this experiment, I learned about the usage of transistor; how they are optimised to produce Nand gate, or gate; How it is used as a switch by shifting voltage such as saturation, cut off. I Also learned how to create amplifiers by using the collector, base, emitter of a transistor.

The mistakes I made was the positioning of the transistor in the braidboard as well as the setting of voltage.

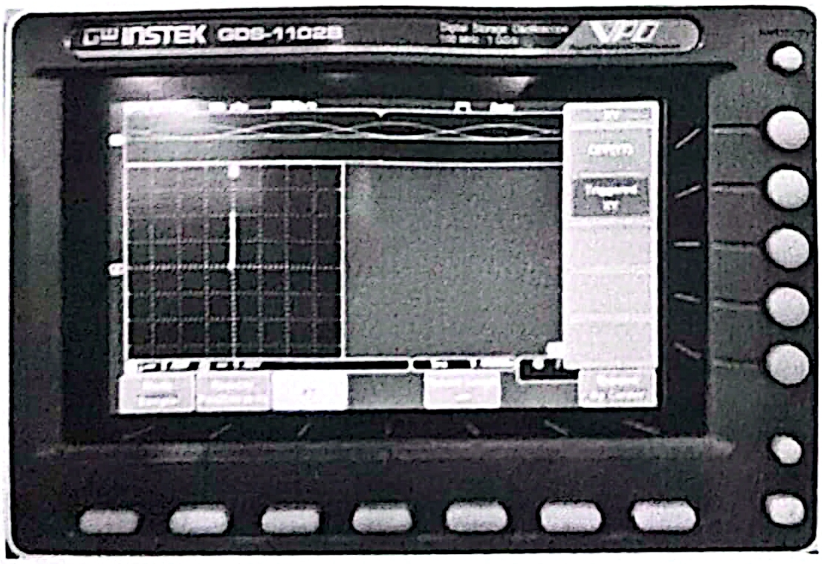
In the future to build logic, I can use the knowledge to implement it, to create a speaker, or starting a heavy machine through small power.



With 0.9V



With 2.5V



With 5 V