BME 3512 Bioelectronics
Laboratory Four - Bipolar Junction Transistor (BJT)

Learning Objectives:

Know how to differentiate between PNP & NPN BJT transistors using a multimeter.
Be familiar with the operation of a common emitter amplifier.
Be familiar with the use of a BJT transistor as a switching device.

Laboratory Equipment:

Agilent Oscilloscope Model 54622A
Agilent Function Generator Model HP33120A
Agilent Power Supply Model E3631A
Multimeter

Supplies and Components:

Breadboard
RC Decade Box
100 Ω Resistor
1 KΩ Resistor
3 KΩ Resistor
10 KΩ Resistor
33 KΩ Resistor
1 μF Capacitor
10 μF Capacitor (two each)
100 μF Capacitor
Transistors (2N3904 and 2N3906 one each)
LED

Pre-Lab Questions

1. Name the three terminal leads of a BJT transistor.
2. List the difference between PNP and NPN BJTs.
3. What is meant by the $B$ (hfe) of a BJT transistor?
4. What is meant by the term saturation; by the term cut-off?

Post-Lab Questions

1. Briefly explain the concept of a bipolar junction transistor.
2. Briefly explain the operation of a common emitter amplifier.
3. Briefly explain how a BJT transistor can function as a switch.
Laboratory Four - Bipolar Junction Transistor (BJT)

Laboratory Procedures

There are basically two types of BJT: NPN and PNP. 2N3904 is a popular NPN transistor and 2N3906 is a popular PNP. The maximum $V_{CE}$ and $I_C$ of these two kinds of transistor are 40V and 100 mA, respectively (another popular NPN transistor, 2N2222, can provide an $I_C$ up to 500 mA).

1) Use a multimeter to identify the type of transistor (NPN or PNP) and the three terminals: B (base), E (emitter), and C (collector).

Sometimes, the letters E, B, C are shown on the transistor. For many transistors however, E, B, and C are not shown. The following procedure lets you identify the three terminals as well as determine the type of transistor.

For an NPN transistor, from B to C is a forward-biased diode and from B to E is another forward-biased diode, as shown in Figure 1. For a PNP transistor, from C to B and from E to B are two forward-biased diodes, as shown in the figure. Based on this principle, we can find $\beta$ as well as to determine the type (NPN or PNP).

![Figure 1. Transistors of type NPN and type PNP](image)

a) Step 1. Name the three terminals of each transistor as 1, 2, and 3. (Usually the middle terminal (2) is the B, but you have to verify it). Set the multimeter selector to <diode> (a symbol —>). Place the meter leads on the transistor terminals as shown in Table 1 and record the reading of the meter.
Table 1

<table>
<thead>
<tr>
<th>Multimeter leads to Transistor Terminals</th>
<th>Meter Reading</th>
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<tr>
<td>Positive (red)</td>
<td>Negative (black)</td>
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<tr>
<td>2</td>
<td>1</td>
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<td>2</td>
<td>3</td>
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<td>1</td>
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<tr>
<td>3</td>
<td>1</td>
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A low reading (< 1.00) indicates a forward-biased diode. Therefore, if the first two rows show low reading, terminal 2 is B (base) and the transistor is type NPN. If rows 3 and 4 show low reading, 2 is B and the transistor is type PNP.

b) Step 2. After identifying the type of transistor and terminal B, you need to further identify terminals E and C. This can be done by measuring the β value of the transistor. On the lower-left corner of the meter, there is a blue circle with 8 holes. The left 4 holes are for NPN transistors and the right 4 holes are for PNP transistors. Switch the meter selector to <hfe> (which has a symbol of transistor) and plug in the transistor. Because you already know the type of transducer and the terminal B, there are only two ways to insert the transducer. For example, if the transducer is NPN and the terminal 2 is B, the terminal 2 should be inserted into the hole named B on the left side. Next, you may first insert terminal 1 into C and terminal 3 into E. If your guess is correct, the meter reading will be high (a normal β value is greater than 100), indicating the terminal 1 is indeed the collector (C) and terminal 3 is indeed the emitter (E). If the meter reading is very low (< 10), then reverse your insertion (put terminal 1 into E and terminal 3 into C). You should get a high reading now.

2) Using 2N3904 to build a common-emitter amplifier

1) A simplest amplifier for small signal

Figure 2 shows an amplifier that uses the minimum number of resistors and capacitors. An NPN transistor 2N3904 is used to build the amplifier. \( R_B \) is a variable resistor (using an R-substitution box) that is to be adjusted to achieve an \( I_C = 1 \text{ mA} \).

Let us first to estimate the approximate value of \( R_B \). Assuming \( \beta = 100 \), then \( I_B = I_C/\beta = 1 \text{ mA}/100 = 10 \mu\text{A} \). Since the voltage between B and E is approximately 0.65 V (\( V_B = 0.65V \)), the value of \( R_B \) can then be determined by the following equation.

\[
R_B = \frac{V_{CC} - V_B}{I_B} = \frac{10V - 0.65V}{10\mu\text{A}} = 935 \text{ KΩ}
\]
Figure 2. A simplest amplifier for small signal

a) Step 1. Based on the above calculation, set the initial value of $R_B = 1000 \, \text{K}$ (use an RC-box) and build the above circuit.

b) Step 2. Adjust $R_B$ to achieve $I_C = 1 \, \text{mA}$ (the value of $I_C$ can be indirectly determined by measuring $V_C$ using a multimeter).

c) Step 3. Use the Function Generator to produce a 1000 Hz sine wave with the smallest amplitude. You may have to use a resistor inserted between $V_{in}$ and $C$ to further decrease the magnitude of input signal so that $V_{out}$ does not show saturation. Using the oscilloscope to display $V_{in}$ and $V_{out}$ at the same time by connecting $V_{in}$ to CH1 (displayed in the bottom half of the screen) and connecting $V_{out}$ to CH2 (displayed in the upper half of the screen).

d) Step 4. Observe the waveform of $V_{out}$, measure its peak-to-peak amplitude, and calculate the gain of the amplifier:

$$G = \frac{V_{out}}{V_{in}}$$

e) Step 5. Gradually increase the magnitude of $V_{in}$ and observe the waveform of $V_{out}$. At what value of $V_{in}$ does $V_{out}$ start to show waveform distortion?
2) A more typical common-emitter amplifier for larger input signal

The emitter of the transistor in circuit shown in Figure 2 is directly grounded. That makes the voltage \( V_B \) to be about 0.65 V. As a result, the input signal \( V_{in} \) can't be more negative than \(-0.65\) V. In addition, for the circuit shown in Figure 2, \( R_B \) needs to be adjusted for each transistor depending on the value of \( \beta \). To simplify the adjustment of the circuit and allow a larger input signal, the following circuit can be used.

![Figure 3. A more general common-emitter amplifier](image)

In the circuit shown in Figure 3, \( V_B \) is relatively stable for different transistors, and can be determined approximately by the following equation:

\[
V_B \cong V_{CC} \frac{R_2}{R_1 + R_2}
\]

Then, \( V_E, I_C \) are also relatively stable for different transistors which can be determined approximately by the following equations:

\[
V_E \cong V_B - 0.65\ V \quad I_C \cong \frac{V_E}{R_E}
\]

Finally, the DC value of \( V_C \) is: \( V_C = V_{CC} - I_C R_C \).

a) Step 1. Build the circuit according to Figure 3.

b) Step 2. Based on the actual values of \( R_1, R_2, \) and \( R_E \) used in your circuit, calculate the expected values of \( V_E \) and \( V_C \). (Measure the actual R values by removing them from the circuit and using the multimeter.)

c) Step 3. Measure the actual values of \( V_E \) and \( V_C \) using a multimeter, and compare them with the calculated values.
d) Step 4. Use the Function Generator to produce a 1000 Hz sine wave with 0.5 V peak-to-peak amplitude. Using the oscilloscope to display $V_{in}$ and $V_{out}$ at the same time by connecting $V_{in}$ to CH1 (displayed in the bottom half of the screen) and connecting $V_{out}$ to CH2 (displayed in the upper half of the screen).

e) Step 5. Observe the waveform of $V_{out}$, measure its peak-to-peak amplitude, and calculate the gain of the amplifier:

$$G = \frac{V_{out}}{V_{in}}$$

f) Step 6. Gradually increase the magnitude of $V_{in}$ and observe the waveform of $V_{out}$. At what value of $V_{in}$ does $V_{out}$ start to show waveform distortion?

3) Using 2N3904 to build a non-linear driver circuit in digital logic applications

The circuits shown in Figure 2 and Figure 3 are called linear amplifiers because one of the most important requirements for the circuit is that the output signal keeps exactly the same waveform of the input signal (no waveform distortion). In digital application, the output of the circuit has only two levels: zero level (logic 0, or logic No) and full-voltage level (logic 1, or logic Yes). For example, depending on the input, the circuit may turn on/off an LED, activate/de-activate a solenoid which opens or closes a valve, energize/de-energize a relay which in turn turns on/off a motor, light, or alarm. In design such a circuit, one mainly needs to consider the current required for driving the output device. For example, if the solenoid needs 150 mA to be activated, one has to use 2N2222 instead of 2N3904. The following two circuits show two examples. Build the circuit shown in Figure 4. The LED normally is off. When the switch S is closed, it should be turned on. In Figure 5, a diode is connected in parallel with the coil of the relay. Notice the direction of the diode. The function of this diode is to provide a pathway for the current generated by the coil when the transistor is turned off. Without this diode, the operation of the relay will be erratic. Remember this diode in your future senior design.

Figure 4. A circuit for drive an LED
Grading Rubric: Bipolar Junction Transistor (Lab 4)

Name:__________________________________________________

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<thead>
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<th>Points</th>
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Cover Page

I) Introduction

Discuss the following principles of a Bipolar Junction Transistor (BJT):
- Explain the “water faucet” analogy as it pertains to a transistor (Scherz, 2nd Ed.). Focus on the case for an NPN transistor (the case for a PNP transistor is essentially the exact opposite).
- In this analogy, what is the “control knob” in the transistor that controls current flow?
- How can we open/close the “control knob” to allow/prevent current flow?
- How can this be used to make a transistor behave like a switch?
- What property of the transistor makes it an ideal candidate to be used in amplifier circuits? Hint: What is $\beta$ (hfe)?

II) Circuit Diagrams (Circuit Maker Only)

1) Experiment 2 – Simple Common-Emitter Amplifier

Double-check to make sure you’ve used the correct transistor (NPN), and that it’s labeled with its correct part number (2N3904). Also, please differentiate between $V_{FG}$ (output from the function generator) and $V_{IN}$ (input to the amplifier), where the input resistor ($R_{IN}$) was necessary to reduce the peak-to-peak magnitude of the AC signal due to clipping.

II) Data and Results

1) Experiment 1- Identifying E, B and C for NPN/PNP Transistors

a. Table 1 (See Lab Manual) for NPN Transistor (2N3904)

b. Measured Value of $\beta$ (hfe) for NPN Transistor

c. Based on your analysis of the NPN transistor, identify the Base (B), Emitter (E) and Collector (C) using the pin notation (1, 2 and 3) shown in Figure 1 of the lab manual.

d. Table 1 (See Lab Manual) for PNP Transistor (2N3906)

e. Measured Value of $\beta$ (hfe) for PNP Transistor

f. Based on your analysis of the PNP transistor, identify the Base (B), Emitter (E) and Collector (C) using the pin notation (1, 2 and 3) shown in Figure 1 of the lab manual.

2) Experiment 2- Simple Common-Emitter Amplifier

a. Measured Values for Resistors and Capacitor

b. Equation for determining $I_C$ from $V_{CC}$, $V_C$ and $R_C$

c. Solve Equation for $V_C$ when $I_C = 1$ [mA] (Using Measured Values)

d. Final Value for $R_B$ when $I_C = 1$ [mA] (Based on Measuring $V_C$)

e. Graph of $V_{IN}$ and $V_{OUT}$ (Without Signal Distortion)

f. Measured Values of $|V_{IN}|$ and $|V_{OUT}|$ (Without Signal Distortion)

g. Equation and Calculation for Gain, $G$ (Based on $|V_{IN}|$ and $|V_{OUT}|$)

h. $|V_{IN}|$ when $V_{OUT}$ Starts to Show Distortion (Clipping)
3) Experiment 3– Typical Common-Emitter Amplifier

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<tbody>
<tr>
<td>a.</td>
<td>Measured Values for all Resistors and Capacitors</td>
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<tr>
<td>b.</td>
<td>Equation and Calculation of ( V_B ) Based on ( V_{CC} ), ( R_1 ) and ( R_2 ) (Measured)</td>
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<tr>
<td>c.</td>
<td>Equation and Calculation of ( V_E ) Based on ( V_B ) (Above)</td>
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<tr>
<td>d.</td>
<td>Equation and Calculation of ( I_C ) Based on ( V_E ) (Above) and ( R_E ) (Measured)</td>
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<tr>
<td>e.</td>
<td>Equation and Calculation of ( V_C ) Based on ( V_{CC} ), ( I_C ) and ( R_C )</td>
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<tr>
<td>f.</td>
<td>Measured Values of ( V_E ) and ( V_C )</td>
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<td>g.</td>
<td>Graph of ( V_{IN} ) and ( V_{OUT} ) (Without Signal Distortion)</td>
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III) Discussion

1) Experiment 2 vs. Experiment 1 – Compare Common Emitter Amplifiers

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<tbody>
<tr>
<td>a.</td>
<td>Based on your results from Experiment 2 and Experiment 3, compare the two common emitter amplifiers. Specifically, answer the following questions:</td>
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<tr>
<td>b.</td>
<td><strong>Which amplifier had the largest gain?</strong></td>
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<td>c.</td>
<td><strong>Which amplifier allowed the largest ( V_{IN} ) before clipping?</strong></td>
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<td>d.</td>
<td><strong>Which amplifier had a DC offset in ( V_{OUT} )?</strong></td>
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<td>e.</td>
<td><strong>Did either amplifier exhibit a phase shift?</strong> If so, estimate the phase shift angle between ( V_{IN} ) and ( V_{OUT} ) using the graphs you created from the waveforms you saved.</td>
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DC and AC Coupling

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<tr>
<td>a.</td>
<td>To understand one of the most prominent differences between then common emitter amplifiers in Experiments 2 and 3, look up the terms “DC Coupling” and “AC Coupling”. What does each term mean? Based on the definitions of these two terms, which common emitter configuration had an output that was AC coupled? Which common emitter configuration had an output that was DC coupled?</td>
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IV) Post-Lab Questions

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<td><strong>No Post-Lab Questions</strong></td>
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V) References

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