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 β as well as to determine the type (NPN or PNP).

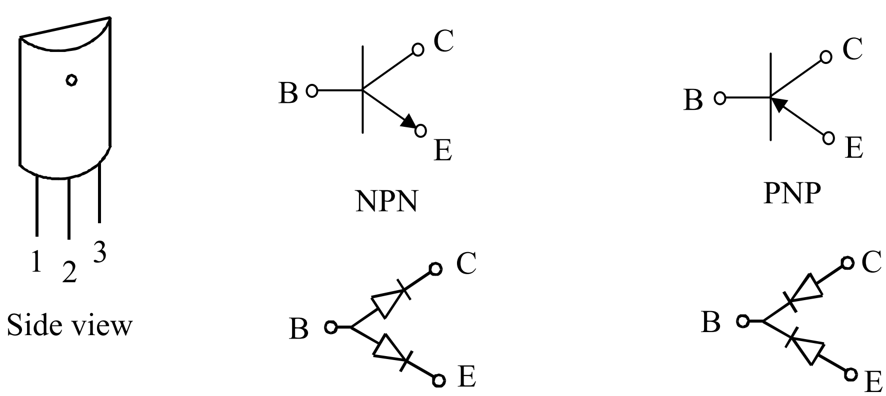

Figure 1. Transistors of type NPN and type PNP

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

Multimeter leads to Transistor Terminals		Meter Reading
Positive (red)	Negative (black)	
2	1	
2	3	
1	2	
3	2	
1	3	
3	1	

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 identified 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 built the amplifier. R_B is a variable resistor (using an R-substitution box) that is to be adjusted to achieve an I_C = 1 mA. Let us first to estimate the approximate value of R_B. Assuming $\beta = 100$, then $I_B = I_C/\beta$ = 1 mA/100 = 10 μA. 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.

$$R_B = \frac{V_{CC} - V_B}{I_B} = \frac{10V - 0.65V}{10\mu A} = 935\ K\Omega$$

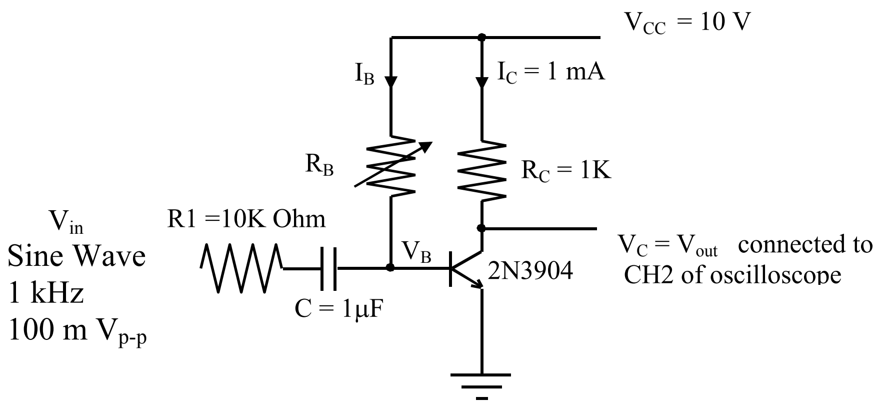

Figure 2. A simplest amplifier for small signal

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

b) Step 2. Adjust R_B to achieve I_C = 1 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 β. To simplify the adjustment of the circuit and allow a larger input signal, the following circuit can be used.

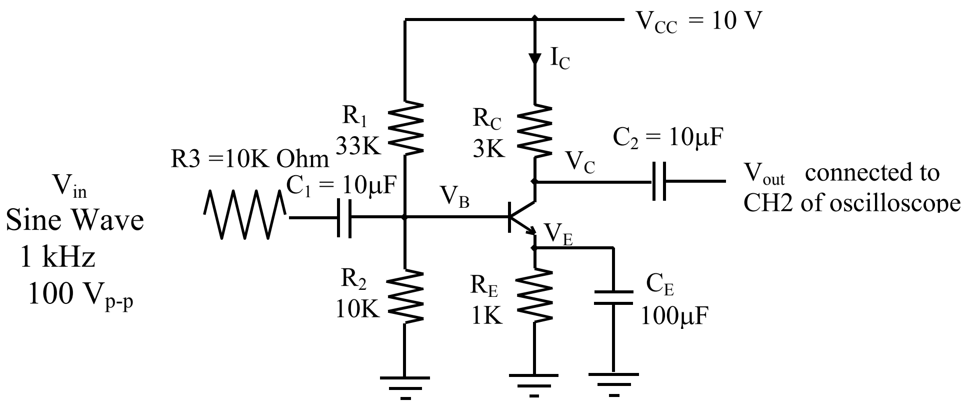

Figure 3. A more general common-emitter amplifier

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:

$$V_E \cong V_B - 0.65 \text{ V} \qquad\qquad I_C \cong \frac{V_E}{R_E}$$

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.

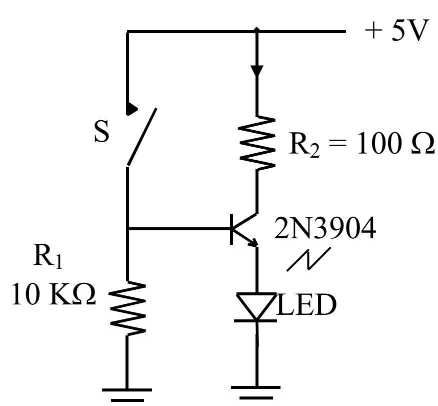

Figure 4. A circuit for drive an LED

Grading Rubric: Bipolar Junction Transistor (Lab 4)

Name:____

	Points
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 β (hfe)?**	**__ / 10**
I) Circuit Diagrams (Circuit Maker Only)	
1) Experiment 2 – Simple Common-Emitter Amplifier	**__ / 5**
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.	
2) Experiment 3 – Typical Common-Emitter Amplifier	**__ / 5**
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)	**__ / 3**
b. Measured Value of β (hfe) for NPN Transistor	**__ / 2**
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.	**__ / 3**
d. Table 1 (See Lab Manual) for PNP Transistor (2N3906)	**__ / 3**
e. Measured Value of β (hfe) for PNP Transistor	**__ / 2**
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.	**__ / 3**
2) Experiment 2- Simple Common-Emitter Amplifier	
a. Measured Values for Resistors and Capacitor	**__ / 3**
b. Equation for determining I_C from V_{CC}, V_C and R_C	**__ / 4**
c. Solve Equation for V_C when I_C = 1 [mA] **(Using Measured Values)**	**__ / 3**
d. Final Value for R_B when I_C = 1 [mA] **(Based on Measuring V_C)**	**__ / 2**
e. Graph of V_{IN} and V_{OUT} (Without Signal Distortion)	**__ / 5**
f. Measured Values of $\|V_{IN}\|$ and $\|V_{OUT}\|$ (Without Signal Distortion)	**__ / 2**
g. Equation and Calculation for Gain, G (Based on $\|V_{IN}\|$ and $\|V_{OUT}\|$)	**__ / 3**
h. $\|V_{IN}\|$ when V_{OUT} Starts to Show Distortion (Clipping)	**__ / 2**

3) Experiment 3- Typical Common-Emitter Amplifier	
a. Measured Values for all Resistors and Capacitors	**__ / 3**
b. Equation and Calculation of V_B Based on V_{CC}, R_1 and R_2 (Measured)	**__ / 4**
c. Equation and Calculation of V_E Based on V_B (Above)	**__ / 2**
d. Equation and Calculation of I_C Based on V_E (Above) and R_E (Measured)	**__ / 2**
e. Equation and Calculation of V_C Based on V_{CC}, I_C and R_C	**__ / 4**
f. Measured Values of V_E and V_C	**__ / 2**
g. Graph of V_{IN} and V_{OUT} (Without Signal Distortion)	**__ / 5**
h. Measured Values $\|V_{IN}\|$ and $\|V_{OUT}\|$ (Without Signal Distortion)	**__ / 2**
i. Equation and Calculation for Gain, G (Based on $\|V_{IN}\|$ and $\|V_{OUT}\|$)	**__ / 3**
j. $\|V_{IN}\|$ when V_{OUT} Starts to Show Distortion (Clipping)	**__ / 2**
III) Discussion	
1) Experiment 2 vs. Experiment 1 – Compare Common Emitter Amplifiers	
a. Based on your results from Experiment 2 and Experiment 3, compare the two common emitter amplifiers. Specifically, answer the following questions: b. **Which amplifier had the largest gain?** c. **Which amplifier allowed the largest V_{IN} before clipping?** d. **Which amplifier had a DC offset in V_{OUT}?** e. **Did either amplifier exhibit a phase shift? If so, <u>estimate</u> the phase shift angle between V_{IN} and V_{OUT} using the graphs you created from the waveforms you saved.**	**__ / 5**
DC and AC Coupling	
a. 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?	**__ / 5**
IV) Post-Lab Questions	
No Post-Lab Questions	
V) References	**__ / 1**