Lab 2: Introduction to BJTs

Student name: Stanley Yang Student ID: 30142934 6

Student name: Cen Yun Zhao Student ID: 30140 1735

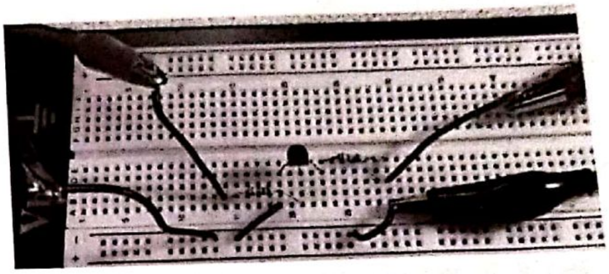
Pre-lab assignment completed? YES NO TA's signature: ____________

Required active components: 1×2N3904 npn BJT, 1×2N2222 npn BJT

Introduction

In this lab, you will study the basic operating principles of bipolar junction transistors (BJT) and look at some basic applications of BJTs. We will also investigate the effects of device parameter variations on circuit performance.

When building the circuits on your breadboard, use the minimum number of the shortest pieces of wire possible. Plan your circuit assembly before wiring and utilize the connections on the breadboard to minimize the needed wiring (see figure to the right).



Show your circuit to the TAs at the end of each section before dismantling your circuit.

1 BJT characteristics in active region

1.1 Prelab assignment

Refer to the datasheets for 2N3904 and 2N2222 npn BJTs and answer the following questions. Notice that many datasheets refer to β as the current gain or h_{FE} of the transistor.

2N3904:

$\beta(I_C = 5mA) =$ 70

$V_{BE,on}(I_C = 5mA) =$ 0.85 V

Maximum $I_C =$ 200 mA

Maximum $P_D =$ 625 mW

2N2222:

$\beta(I_C = 5mA) =$ 50

$V_{BE,on}(I_C = 5mA) =$ 1.2 V

Maximum $I_C =$ 1000 mA

Maximum $P_D =$ 625 mW

Question: Consider the circuit shown in Figure 1. Write down expressions for calculating I_B and I_C based on measurements of V_B and V_C as a function of other circuit parameters.

$I_C = \dfrac{V_{CC} - V_C}{R_C}$ $I_B = \dfrac{V_{in} - V_B}{R_B}$

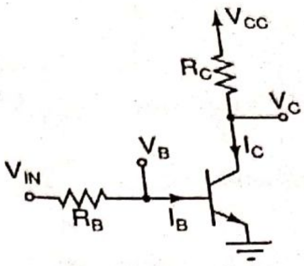


Figure 1: Basic BJT circuit.

1.2 Experiments

Build the circuit shown in Figure 1 on your breadboard using a 2N2222 transistor. Apply a fixed $+5V$ from the DC power supply for V_{CC}. Use the second output of the DC power supply to apply V_{IN} to the input of the circuit. Use $R_C = 560\Omega$ and $R_B = 330k\Omega$. Choose 7 different values for $1 < V_{IN} < 10V$ and use the multimeter to measure V_B and V_C at each step. Fill the table below.

V_{IN} (V)	1						10
V_B (V)							
V_C (V)							
I_B (μA)							
I_C (mA)							

NOTE: To calculate the current flowing in a branch, measure the voltage drop across a resistor in that branch and divide it by the resistor value. *DO NOT MEASURE THE CURRENT DIRECTLY.*

Plot the $I_C - V_{BE}$ characteristic curve of the transistor on the grid below.

Question: Compare your estimate for β for $I_C{\sim}5mA$ against the value reported in the datasheet.

$\beta_{est} = \frac{I_C}{I_B} =$ ______________

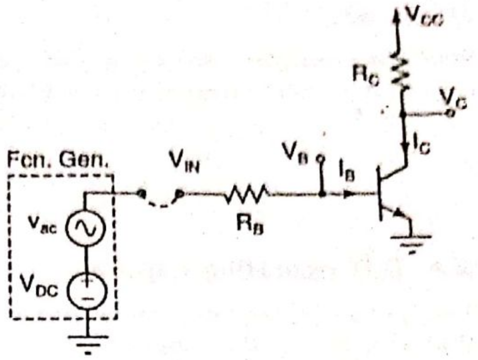


Figure 2. BJT circuit with AC input.

Question: Switch the Collector and Emitter pins of the transistor (i.e., put the transistor in *reverse active* region) and replace the base resistor with $R_B = 10k\Omega$. Estimate β_{ra} for the transistor when $I_C \sim 1mA$ (note that instead of I_C you are measuring the current that is going into the Emitter terminal, I_E). Compare your measurements with the results in the above and datasheet.

$\beta_{rev} = \frac{I_E}{I_B} =$ ______________

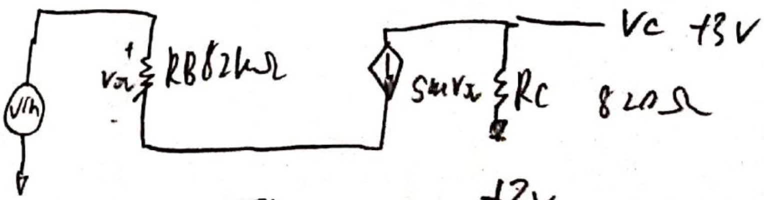
2 Operating regions of BJTs

A BJT may operate in active, saturation, or cut-off operating regions depending on the circuit around it. These operating regions are investigated in this section.

2.1 Prelab assignment

Consider the circuit in Figure 1 where $R_C = 820\Omega$, $R_B = 82k\Omega$, and $V_{CC} = +3V$. Draw the large signal model for the circuit and calculate I_C and V_C if the transistor is a 2N3904 npn BJT and $V_{IN} = 1.5V$ DC.

$I_C =$ 1.03 mA $\qquad$ $V_C =$ 1.0687 V



$I_c = \beta I_b$

$I_c = \frac{V_{cc} - V_c}{R_c}$

2.2 Experiments

Build the circuit shown in Figure 2 on your breadboard using a 2N3904 transistor. Use the DC power supply to provide V_{CC}. Use the *offset* value from the function generator to modify V_{DC}. The v_{ac} source parameters such as amplitude and frequency can also be set on the function generator. Use a multimeter to accurately measure the

DC voltages.

Note: The actual signal amplitude is what you measure on the oscilloscope, which may be different from what you set on the function generator. Can you explain why?

2.2.a BJT operating regions

Set v_{ac} to a 1kHz sine wave with the smallest possible amplitude. Measure the DC *voltage drop* across the base resistor (i.e., the $82k\Omega$ resistor) using the multimeter and modify V_{DC} until you calculate the base current to be about $I_B = 10\mu A$. Find out the DC collector current for your transistor.

$V_{BE} =$ ______ V $V_{BC} =$ ______ V $V_{CE} =$ ______ V

$I_C =$ ____________ mA Operating region: ____________

Change V_{DC} at the input to 0.5V and repeat the above steps.

$V_{BE} =$ ______ V $V_{BC} =$ ______ V $V_{CE} =$ ______ V

$I_C =$ ____________ mA Operating region: ____________

Change V_{DC} to $3V$ and repeat the above steps.

V_{BE} = ______ V V_{BC} = ______ V V_{CE} = ______ V

I_C = ______________ mA Operating region: ______________

2.2.b Input-output characteristic transfer function

Monitor V_{IN} and V_C on Channels 1 and 2 of the oscilloscope, respectively. Apply a $100Hz$ $3V$ peak-to-peak sine wave to the input of the circuit. Adjust V_{DC} (i.e., the *offset* on the function generator) such that the input signal changes between 0 and $3V$ (i.e., it has exactly $1.5V$ DC). Ensure both channels are DC coupled and centre the waveforms on the oscilloscope screen. Switch to *XY* plotting mode.

Plot the result below and label the important points.

Question: Switch the input waveform to a pulse (0 to $3V$ at $100Hz$) and monitor the input and output signals on the oscilloscope in *YT* mode. If the input is considered a digital signal that is switching between logical 0 and 1, what is the logical operation that the circuit is performing on the input? Explain if a similar functionality would be possible with R-D (resistor-diode) circuits.

Question: What happens as you increase the frequency of the input signal to 10kHz? How about 100kHz? How about 1MHz? Can you explain the behaviour of the circuit at higher frequencies?

3 Simple biasing

In most analog circuits, we use a combination of resistors and sometimes voltage and current sources in order to bias a nonlinear device at a desired operating point so that we can use it for small-signal operations. Besides gain and node impedances, an important parameter in analog circuits is the "signal swing". Voltage swing at a node in a circuit is the difference between the maximum and minimum voltages that can appear at that node while the circuit remains in its desired operating region. For example, a BJT transistor in an amplifier circuit needs to stay within its active region during the circuit operation. If a terminal voltage changes so much that the transistor enters either the saturation or the cut-off regions, the circuit will no longer work as a linear amplifier, often leading to the clipping of the signal at either the high or low levels. A common design criterion, especially for the final stage of a multi-stage amplifier is to achieve maximum voltage swing.

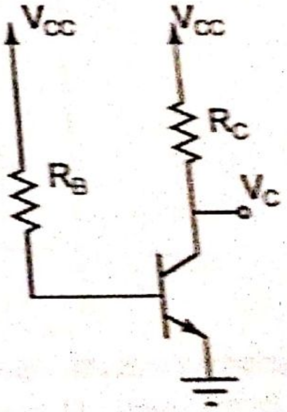
3.1 Prelab assignment

A BJT can be biased using two resistors in its base and collector circuits (to set I_C and V_{CE}). Build the circuit shown in Figure 3 with a 2N3904 transistor and $V_{CC} = +5V$ DC.

What is the required V_C in order to bias the transistor such that we will have the maximum voltage swing at the output? To do this, you need to set the DC voltage at the operating point to the middle of the minimum and maximum possible voltages at this node.

$V_C|_{max\ \ swing}$ = 2.45 V

$$\frac{V_{CC} - V_{CE,sat}}{2} = 2.45$$



Assuming $I_C = 5mA$ and V_{CE} as decided in the above, calculate the required value of R_C. Using the values of β and $V_{BE,on}$ from the datasheet, calculate R_B to bias the

Figure 3. Simple biasing

transistor at the selected operating point.

$R_C =$ 3.7 $k\Omega$ $R_B =$ 21.7 $k\Omega$

Derive an expression for I_C for the circuit in Figure 3 as a function of β, V_{BE}, V_{CC}, and resistor values.

$I_C(\beta, V_{CC}) = \beta \frac{V_{CC} - V_{BE}}{R_B}$

Calculate the sensitivity of the collector current to variations in β and V_{CC}. What are the values of the sensitivities based on the element values in your circuit?

$S_{V_{CC}}^{I_C} = \frac{\partial I_C}{\partial V_{CC}} = \frac{\beta}{R_b}$ = 2.4 mA/V

$S_{\beta}^{I_C} = \frac{\partial I_C}{\partial \beta} = \frac{V_{CC} - V_{BE}}{R_B}$ = 0.24 mA

3.2 Experiments

3.2.a Bias sensitivity to circuit parameters

Wire up the circuit on your breadboard using the closest standard E12 values for R_C and R_B (i.e., do NOT combine resistors). Measure the base and collector voltages of the transistor and calculate the following parameters.

$V_C =$ ________ V $V_B =$ ________ V $V_{BE} =$ ________ V

$I_C =$ ________ mA $I_B =$ ________ μA $\beta =$ ________

Question: What are the reasons for the deviation of the bias point from the designed one in the prelab?

Decrease V_{CC} to $+4.5V$ in Figure 3. Calculate I_C again and find out the sensitivity of the collector current to variations in V_{CC}. Compare with your prelab calculations and explain possible discrepancies.

$I_C\ (V_{CC} = 4.5V) =$____________mA

$S_{V_{CC}}^{I_C} \approx \frac{\Delta I_C}{\Delta V_{CC}} =$ ____________________ = ______________ mA/V

Turn V_{CC} back to +5V DC. Switch the 2N3904 transistor in your circuit with a 2N2222 npn transistor (make sure to connect the pins properly). Measure and calculate parameters below.

$V_C =$ __________ V $V_B =$ __________ V $V_{BE} =$ __________ V

$I_C =$ __________ mA $I_B =$ __________ μA $\beta =$ __________

Assume that the main outcome of switching the transistors is a change in β of the transistor. Calculate the sensitivity of the collector current to variations in β. Compare the results with your prelab calculations and explain possible discrepancies.

$S_\beta^{I_C} \approx \frac{\Delta I_C}{\Delta \beta} =$ ____________________ = __________ mA

3.2.b Bias sensitivity to temperature

Build the circuit shown to the right on your breadboard using a 2N2222 transistor with $V_{CC} = +5V$, $R_C = 1k\Omega$, $R_{B1} = 20k\Omega$, and $R_{B2} = 10k\Omega$. Set the amplitude of a 10kHz sine wave from the function generator to the smallest possible value and adjust the offset on the function generator such that $V_C \approx +1.5V$. Measure the DC voltages at nodes V_{IN}, V_B, and V_C and fill the table below.

V_{IN} (V)	V_B (V)	V_C (V)	I_C (mA)	I_B (μA)	β

What is the ratio of the signal amplitudes at the output and the input of the circuit?

Hint: You can use the oscilloscope in AC coupled mode to measure the AC values at nods V_{IN} and V_C more accurately.

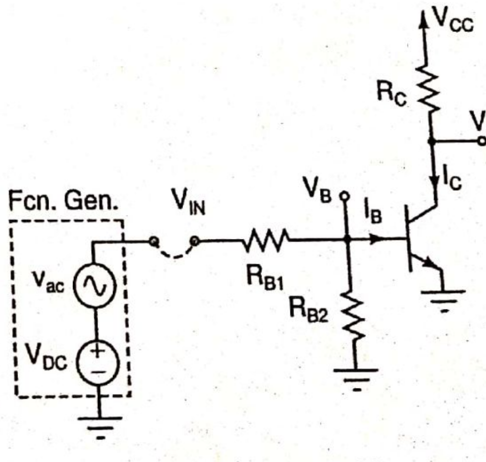


Figure 4: BJT amplifier

$\frac{v_C}{v_{ac}} =$ ________ V/V

Keep the offset value constant and monitor V_C on the oscilloscope. Gradually increase the AC signal amplitude until you notice significant distortion at node V_C (i.e., when the output is no longer a symmetric sine wave). What is the maximum symmetric swing (i.e., maximum peak-to-peak voltage without significant distortion) at V_C?

Maximum peak-to-peak swing: ________

What is the reason for distortion of the voltage at this node?

Reduce the AC signal amplitude to about 75% of the value that caused distortion at the output. Measure the DC voltage at V_C using a multimeter and monitor the AC signal at this node using the oscilloscope. Record your measurements.

$V_{C,DC} =$ ________ V $\quad v_{C,AC_{pk-pk}} =$ ________ V

Use a hair-dryer at a distance of 5-10cm from the circuit to heat up the transistor for a minute or two. Record the DC and AC voltages at V_C.

$V_{C,DC} =$ ________ V $\quad v_{C,AC_{pk-pk}} =$ ________ V

Referring to the datasheet for graphs for the dependence of device parameters on temperature, can you explai the effect of temperature rise on the performance of your circuit?