EXPERIMENT NUMBER 5
Characterization and Use of Bipolar Junction Transistors

Preface:

- **Preliminary** exercises are to be done and submitted individually and turned in **at the beginning of class**
- Laboratory hardware exercises are to be done in groups
- The **Lab Report** is the **Lab Notebook**, and it can be written by any one member of the group
- The student-group MUST have the data and answers acquired during the lab and entered in the **Lab Notebook** verified by the TA before they leave the class
- Failure to show the **Lab Notebook** to the TA, will result in no score for **Lab Report** for the entire group
- **Tech Memo** to be done in Word Doc according to the format uploaded on CANVAS and submitted by individual students at the **beginning of the next class**
- Review the guidelines for plagiarism to be aware of acceptable laboratory and classroom practices.

Bipolar junction transistors (BJTs) are common in many digital and analog applications. The following laboratory explores BJTs characteristic and their use in digital switching applications.

Objectives:

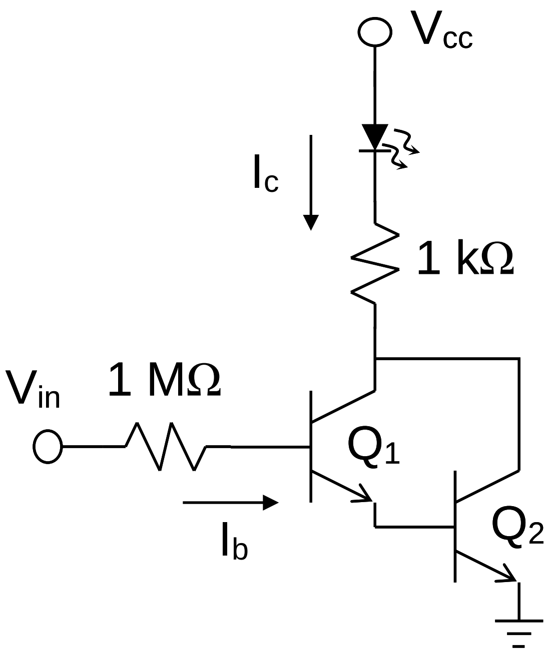
- Observe the I-V characteristics of both types of BJTs
- Learn how to use a BJT as a switch
- Demonstrate the significance of the Darlington Pair configuration

References:

- EE 121 Handouts
- EE 151 and EE 153 text: Cunningham and Stuller, *Circuit Analysis*, 2nd Ed. (Houghton Mifflin Company, Boston, 1995).
- Neamen, Donald A., Electronic Circuit Analysis and Design, 2nd ed., (McGraw-Hill, New York, New York, 2001), Chap 4.

Background:

Switches are needed in electronics to turn-on a voltage or current of sufficient power to operate a circuit. Many digital and analog applications use transistor circuits for amplifying the output current of a microcontroller. The outputs from microcontrollers often can sink current well but cannot source current. One of the most common circuits to handle this application is a Darlington pair shown in Figure 1. (The LED is included to provide an indication of I_C.) While a single transistor has a gain of β, a Darlington pair has a gain of approximately β^2, which means a small base current can control a larger collector current than with a single transistor.



Current Gain	
One transistor	$I_c = I_b \beta$
Two transistors	$I_c = I_b\beta(1+(\beta+1)) \cong I_b\beta^2$

Figure 1 – Dual-Transistor Darlington Circuit

To illustrate this concept, say a 1 MΩ resistor is placed in series with the base, and V_{in} is set to 5 V. If the ground connection was moved to the first transistor, Q_1 so that only a single transistor is used in the circuit, the current into the base should approximately be $\frac{5\ V - 0.7\ V}{1\ M\Omega} = 4.3\ \mu A$. Assuming β to be 100, the collector current should be about $100 \times 4.3\ \mu A = 430\ \mu\text{A}$. This current is not enough to turn on the LED. If the ground were connected at the emitter of Q_2, implementing the Darlington pair, the gain is approximately $100^2 = 10^4$, the base current is about $\frac{5\ V - 0.7\ V - 0.7\ V}{1\ M\Omega} = 3.6\ \mu A$, and the collector current is about $10^4 \times 3.6\ \mu A = 36\ \text{mA}$.

Light Emitting Diodes (LEDs)

A light emitting diode (LED) is a diode that emits light for forward bias conditions. The light emission increases as the diode current increases. Practically, a minimum current is required to clearly see the light. LEDs are often used as indicators, e,g, the light appears when a current threshold is reached.

Preliminary:

(Work on separate paper and turn in at the beginning of the laboratory session.)

- Print the data sheets for Fairchild 2N3904 (npn) and 2N3906 (pnp) transistors. Using these data sheets, find the DC current gain, collector saturation voltage, the maximum voltage rating, and the maximum current ratings. Put the results in a table.
- Consider a common-emitter, single-transistor npn-BJT circuit with R_b = 1 MΩ, R_c = 1 kΩ, and R_e = 0. Assume the base-emitter turn-on voltage is 0.7 V and the gain is 100. Calculate the value of V_{CC} for which the operating point at V_{BB} = 5 V is at the edge of the saturation region (about V_{CE} = 0.2 V). Calculate the corresponding collector current value. The circuit design is of a transistor switch that turns an LED "on" when the input is 5V and turns the LED "off" when the input is 0V.

Equipment:

- I-V Curve Tracer
- DC Power Supply
- Breadboard
- Signal Generator
- Oscilloscope
- Fairchild 2N3904 (npn) Transistor
- LED
- Resistors

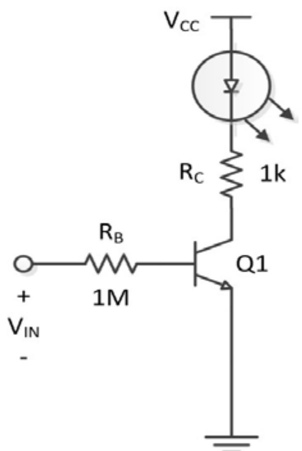


Figure 1- Single BJT Circuit

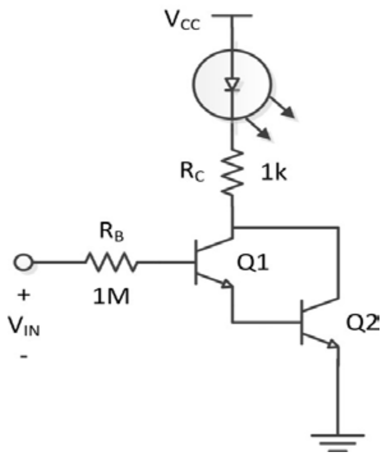


Figure 2- Darlington Pair w/ LED

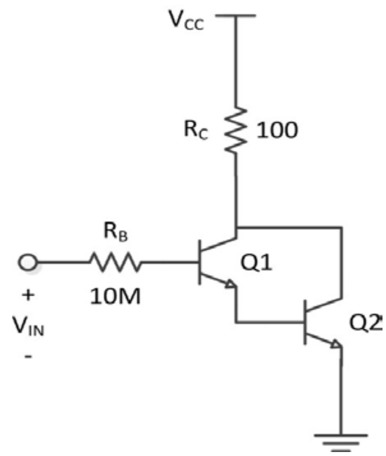


Figure 3- Darlington Pair w/o LED

Experimental Procedure:

(Record specifics in the Laboratory Notebook.)

1. TA to setup the Oscilloscope and Curve Tracer at one station. Each group then takes a turn. Use the curve tracer to determine the I-V curves of the Fairchild 2N3904 (npn) and 2N3906 (pnp) transistors. Plot or sketch the common-emitter I-V curves.

   King Instruments Curve Tracer (KI-3020A) and Oscilloscope settings for Diode Measurement:

   ***OSCILLOSCOPE**:*

   Save/Recall Button -> Default Setup

   Menu/Zoom Button -> XY

   ***KI-3020A**:*

   Horizontal -> X or Oscilloscope Channel 1

   Vertical -> Y or Oscilloscope Channel 2

   Polarity Knob -> PNP or NPN

   V Knob -> 20V

   Bias Knob -> 0.2V

   H Length Knob fully Clock Wise

   Connect Transistor following diagram on tracer panel

   Selector Switch to side using

   Current Limit Switch -> signal

   Transistor Type Switch -> Trans

   Power ON

Adjust Oscilloscope V/div, Time/div, and Horizontal Position accordingly XY Origin denoted on the oscilloscope display at the left and top

Q1: What are the approximate collector-emitter voltages at the transition between the saturation and active regions?

2. Build circuit shown in Figure 1. Set V_{CC} to 5 V using a DC voltage supply. For V_{IN}, use a function generator to create a low frequency (<10 Hz) square wave. Use a T-junction to attach the signal generator output to the oscilloscope before attaching it to your circuit. Using the measurement functions on your oscilloscope, view the maximum and minimum voltage of the signal from the function generator. By manipulating the amplitude and offset knobs of the function generator, create a square wave with a minimum voltage of ~0 V and a maximum voltage of 5 V. Note that you will have to pull the offset knob towards you to turn it. When you have the correct input voltage, connect the function generator to your circuit. The LED should be blinking at this point.

   Q2: Keeping V_{IN} the same, find the value of V_{CC} that the LED stops blinking.

   Q3: How does the experimental value of V_{CC} compare to the calculated value?

   Q4: Set V_{CC} back to 5 V, adjust the frequency so that the LED stops blinking? Why do you think this is?

3. Build the Darlington Pair circuit shown in Figure 2. Set the frequency of V_{IN} back to something less than 10 Hz, and make sure V_{CC} is still 5 V. Observe the change in brightness of the LED.

   Q5: How does the brightness of the LED in the Darlington Pair circuit compare to that of the LED in the previous circuit? Why are they different?

4. Alter the Darlington Pair circuit so that it matches the circuit shown in Figure 3. This will involve removing the LED, changing R_B to 10 MΩ, and R_C to 100 Ω. Set V_{CC} to 10 V. Disconnect the function generator and use a DC supply for V_{IN}. Set V_{IN} to 5 V.

5. Vary V_{IN} from 2 V to 6 V in increments of 0.5 V. Measure the voltage across R_C (V_O) at each point using the digital multi-meter at your station, **not the oscilloscope**.

   Q6: Put these values in a table, where V_{IN} is in one column and V_O is in the other.

Technical Memorandum:

(1) Describe, based on your observations, the I-V curves of the Fairchild 2N3904 npn transistor. At approximately what collector-emitter voltage (V_{CE}) does the transition from saturation to active region occur? (Q1) Does this match theoretical expectations?

(2) Describe the necessary conditions operation in the active region in terms of V_{BE} and V_{CE}. Why does the transistor not work correctly as a switch when V_{CE} is below a certain voltage? (Q2)

(3) Describe the differences in operation of the Darlington Pair circuit and the single transistor circuit. Specifically address why you would use a Darlington Pair instead of the single transistor circuit. (Q5) What is the expected theoretical gain of the single transistor circuit? What is the expected theoretical gain of the Darlington pair circuit?