**Educational Objective:**

The objective of this lab is to gain a better understanding of the transistor characteristic using a microprocessor to automate the measurements. Important concepts introduced in this lab include: 1) transistor characteristics, 2) microprocessor scripting, 3) Excel and graphing and 4) scope skills.

**Pre-Laboratory:**

1. Review section 3.5 of ***Boylestad “Electronic Devices and Circuit Theory”***
2. Read and completely understand the entire procedure portion of this laboratory.
3. This lab will be submitted prior to taking the lab practical and you will not have your report back. Keep a separate notebook to keep notes about the lab for the lab practical.
4. *The Transistor*:

Sketch the BJT device characteristics in Figure 1. Label the saturation, linear and cutoff regions.

|  |
| --- |
|  |
| BJT Device Characteristic |

Figure

**Overview:**

The lab will have you:

1. Build a Transistor Circuit in Section 1,
2. Verify the Automated Measurement Circuit in Section 2,
3. Setup and use the curve tracer in Section 3.

Two Automated Measurement Circuits were built earlier in the semester. Both circuits utilize the Arduino Uno microprocessor.

Do not remove the Automated Measurement Circuits from your breadboard after this lab. These circuits will be used again later in the semester.

Search EBay and you will find a large number of Curve Tracers that are neither new nor cheap. Curve Tracers are a specialized piece of lab equipment used to measure the device characteristics of discrete (single) diodes, BJTs, FETs, etc. Curve Tracers used to be widely used in industry to help repair circuit boards and in schools to understand transistor operation. However, curve tracers are hard to find in schools or industry today. Why? Modern circuits only use a few discrete transistors while they used to have hundreds. When discrete transistors are used today they are either large power transistors or small surface mount devices and neither of them is easily removed from a board or plugged into a Curve Tracer. So the need to remove and test dozens of discrete small transistors no longer exists in industry. Curve Tracers are very useful for understanding the operation of a transistor which is still important today. Why? A few reasons transistor knowledge is still required is so you can: 1) connect one IC to another IC (integrated circuit) in high speed circuits, 2) a single transistor with an IC to boost the current or voltage output, 3) read technical literature that describes IC functionality using transistor diagrams.

In this lab we will use a simple microcontroller, the lab equipment and Excel to make a curve tracer. Each of the skills presented in this lab can be used to automatically test numerous electronic devices and circuits. Building automated test equipment is a common job function of an engineer. This lab tries to strike a balance between automated measurement and simple manual measurements. Automation reduces repetition engineers hate but adds complexity. The student who loves microcontrollers can add additional circuitry and code to fully automatic the system.

**Procedure:**

1. Complete the quiz handed out in lab. The quiz will only be available for the first ten (10) minutes of your laboratory session. The content of this quiz is based on the knowledge you should have gained while completing the pre-lab section of this laboratory activity. You may use your pre-lab as a reference while taking the quiz.

Section 1: The Transistor Circuit – Print this page

|  |
| --- |
| 2N3904 BJT picture smily |
| BJT Circuit |

Figure 2

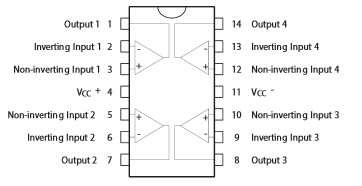
1. *BJT Characteristic – manual measurement*:
   1. Construct the BJT circuit (Figure **2**).
   2. Set V2 to 3V.
   3. Adjust V1 until 10A follows through R1.2.58”V
   4. Use the multi-meter to measure VCE and IC.
   5. Calculate  and verify it is between 100 and 300.
   6. Record these values on Figure **2**.

**NOTE: These values will be used to verify the automatic measurements taken later in the lab. Disconnect V2 only. Leave V1 and the circuit on your breadboard for use later in the lab.**

* 1. Obtain a sign-off.

Note: The next few sections will use circuits already built in lab that use a quad op-amp. The op-amp is similar to other ICs with four circuits that you already saw in Digital Fundamentals like a quad NAND gate. The function of an op-amp is obviously different than a NAND but similar in other ways. Both ICs: come in 14 pin dips, require power and ground and have four identical circuits. Unlike the NAND gate we will apply 12V and ground to the center pins 4 and 11. The pin-out of the op-amp is provided below (

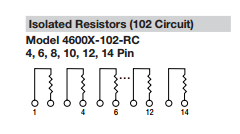
Figure 3).



Figure

The circuits also use the 8 pin SIP (serial in-line package) like the one shown in

Figure 4. Basically the SIP pack provides identical resistors for additional precision.



Figure

Section 2: The Automated Measurement Circuit – Print this page

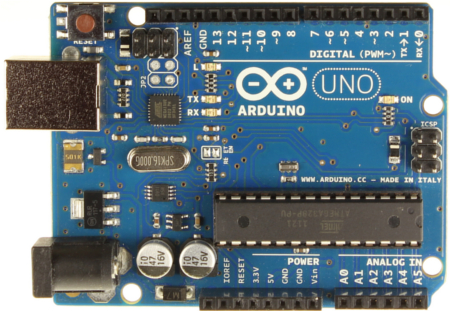
The automated measurement circuits in Figure 5 were built during the first week of lab. The circuits use a simple voltage divider to reduce the measured voltage by ½ and a buffer (gain = 1) to isolate the divider from the Arduino microprocessor.

|  |
| --- |
|  |
| Voltage Divider with Buffer - “Automated Measurement Circuit” |

Figure

1. *Automated Measurement Circuit setup.*
   1. Use the bench power supply to power your Voltage Divider with Buffer circuits (Figure 5) using V3 = 3V and V4 = 12V.
   2. Verify the correct operation of Figure 5 by completing the measurements in the table below. You will need to determine and fill in some of the expected values.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Vin0+ | Vin1+ | AnalogInA0 | AnalogInA1 | Vcc | Gnd |
| Located | U1A pin 3 | U1D pin 12 | U1A pin 1 | U1A pin 14 | U1A pin 4 | U1D pin 11 |
| Expected | 1.4 - 1.6V |  | 1.4 - 1.6V |  |  | 0 - 0.4V |
| Actual |  |  |  |  |  |  |



|  |
| --- |
|  |
| Voltage Divider with Buffer - “Automated Measurement Circuit” |

Figure 6

* 1. Connect AnalogInA0 to Arduino A0 and AnalogInA1 to Arduino A1.
  2. Connect the Arduino ground to the breadboard ground.
  3. Use the program below (Figure 7) to read the input voltages.

|  |
| --- |
| void setup()// routine used to setup the system, only runs once  { Serial.begin( 9600); // initialize serial communication:  delay(100); // wait for 100 ms, so output can stabilize  }  void loop() {  Serial.print("AnalogInA0 voltage = ");  delay(100);  unsigned int vin0=analogRead(0);  delay(100);  Serial.println(vin0);  delay(200);  Serial.print("AnalogInA1 voltage = ");  delay(100);  unsigned int vin1=analogRead(1);  delay(100);  Serial.println(vin1);  delay(200);  exit(1);  } |
| PWM out and Measure Code |

Figure

Note: The Arduino command analogRead(0) will report a digital value: 1023 for a value of 5V and 0 for 0V. By multiplying the digital value by 5/1023 the voltage at A0 can be determined.

* 1. Complete the table below. You need to complete the expected values.

|  |  |  |
| --- | --- | --- |
|  | AnalogIn0 | AnalogInA1 |
| Located | Serial Monitor | Serial Monitor |
| Expected |  |  |
| Actual |  |  |

**NOTE: Disconnect V3 only. Leave V4 and the circuit on your breadboard for use later in the lab.**

* 1. Obtain a sign-off.

Section 3: The Curve Tracer.

1. *Curve Tracer: Bring the three circuits together and verify the setup*
   1. Replace the DC supply for V2 in Figure **2** with a 0 to 8V peak triangle wave input at 1/10 Hz. Setup the function generator:
      * Press the CH1/2 button until the CH2 page is front.
      * Select Ramp. The top blue portion of the ribbon should be front and say Ramp CH2.
      * Press the top right screen button to select Period. The button allows you to toggle between Frequency and Period. Enter 10 and then press the top right screen button for “s” (seconds).
      * Press the second screen button to select HLevel (high level), enter 8 and then select V.
      * Press the third screen button to select LLevel (low level), enter 0 and then select V.
   2. Adjust the vertical and horizontal scales on the scope so you see a triangle wave scroll across the screen.
   3. Set V1 to the value recorded to make IB = 10A from section 1.
   4. Connect the top of R2 to the left side of R6 and the bottom of R2 to the left side of R8 as shown by the arrows.
   5. Connect the Arduino A0 to AnalogInA0, Arduino A1 to AnalogInA1 and all grounds as shown by the arrows.

|  |
| --- |
| http://arduino.cc/en/uploads/Main/ArduinoUno_R3_Front_450px.jpg |
| Curve Tracer |

Figure

* 1. Verify that all the connections in Figure 8 is made and then copy the code in Figure 9 into a sketch.
  2. Open the Serial Monitor to start the measures.

|  |
| --- |
| void setup() {  Serial.begin( 9600); // initialize serial communication:  delay(100);  }  void loop() {  for (int i = 0; i < 100; i++) {  delay(100);  int a0 = analogRead(0); // read vcc  float vcc = 2.0 \* a0 \* 5.0 / 1023.0; // calculate voltage at vcc  int a1 = analogRead(1); // read vce  float vce = 2.0 \* a1 \* 5.0 / 1023.0; // calculate voltage at vce  float ie = vcc - vce; // divided by 1K simply makes ie in mA  Serial.print("vcc = ");  Serial.print(vcc);  Serial.print(" vce = ");  Serial.print(vce);  Serial.print(" ie = ");  Serial.println(ie);  }  exit(1);  } |

Figure

*Curve Tracer: Plotting in Excel.*

* 1. Copy the displayed values into Excel. You may need to use Excel’s “Text to Column” function found in the data tab to separate the values into individual columns.
  2. Delete unneeded columns.
  3. Add a label to the top row describing the data as in Figure 10.
  4. Plot the Characteristic curves by selecting the Vce and Ic columns and then Scatter under the Insert ribbon.
     + Add a title, label the x and y axis

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  | | --- | --- | --- | | Vcc (V) | Vce (V) (Ib = 10uA) | Ic (mA) (Ib = 10uA) | | 0.06 | 0.04 | 0.02 | | 0.12 | 0.06 | 0.06 | |
| Sample data |

Figure

* 1. Increase V1 until the base current is 20A.
  2. Close and open the serial monitor so the program runs again.
  3. Copy the Vcc, Vce and Ic data into an available column. Delete the extra columns and add a heading. Verify Vcc has not changed then delete this column.
  4. Increase V1 until the base current is 30A.
  5. Collect the data again and clean it up.
  6. Add the two new curves to the plot by doing the following:
     + Select the plot
     + Click on Select Data in the Chart Tools Design ribbon.
     + Click on Add to add additional legend, X data and Y data.
     + Figure 11 shows the typical results.
  7. Label the saturation and linear regions.
  8. Determine  of each value if Ib when Vce = 3V. Write the value on the plot.

Figure

* 1. Obtain a sign-off for the above completed work:

**NOTE: Leave the circuit on your breadboard for use in labs later this semester.**

1. *Sign-offs Name*

Section 1: Transistor Circuit

|  |  |  |
| --- | --- | --- |
|  |  | / / |
| Signature |  | Date |

Section 2: Automated Measurement Circuit

|  |  |  |
| --- | --- | --- |
|  |  | / / |
| Signature |  | Date |

Section 3: Curve Tracer

|  |  |  |
| --- | --- | --- |
|  |  | / / |
| Signature |  | Date |

1. *Post Lab Work*:

Provide a summary, all sign-offs and the labeled characteristic curve.