Creating a Fully Automated Data Acquisition System for Transistor Characteristics in LabVIEW

Austin Doll-Hennis
Advisor: Dr. Raouf Selim
April 21, 2016

Abstract:

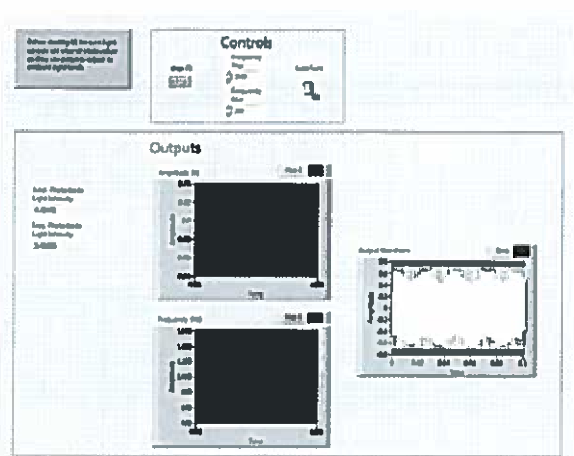
This research focused on designing a fully autonomous data acquisition system for transistor characteristics in LabVIEW. The final program I created autonomously tests for the output characteristic, generating a graph of collector-emitter voltage vs collector current at multiple base currents. This characteristic was used to determine the transistor gain and output resistance, as well as demonstrate how the collector current is controlled by the smaller base current, rather than the collector-emitter voltage. The program can test for the output characteristic of both PNP and NPN transistors through a user interface allowing the input of the appropriate initial and final currents/voltages.

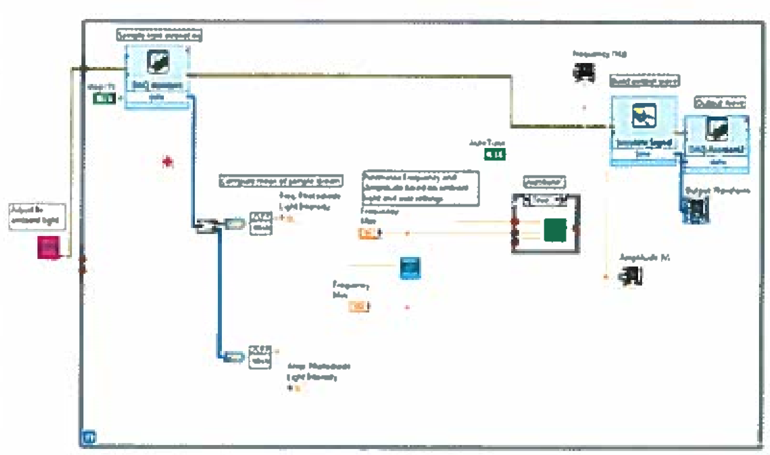
List of components:

- (4) General Purpose Interface Bus (GPIB)(IEEE-488)
- National Instruments LabVIEW 2013 software
- Keysight 34401A Digital Multimeter
- Keithley 2001 Multimeter
- Agilent E3631A Triple Output DC Power Supply
- HP 3245A Universal Source
- Wires
- Resistors
- Diodes
- Transistors

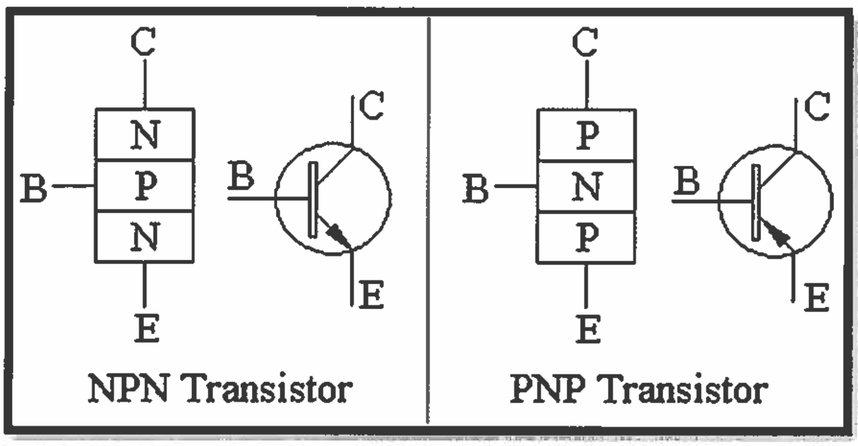
Background/Theory:

The purpose of this experiment was to design a fully autonomous data acquisition system for transistor characteristics in LabVIEW. National Instruments LabVIEW software specializes in data acquisition and is used in a variety of physics and engineering research. The programming environment separates itself from text based programming languages such as java and C++ by using a graphical, or "G", programming language. The G programming language allows the user to focus on the data and operations taking place in the program rather than the syntax of the code. Along with the programming environment, LabVIEW also has a development environment that excels at creating custom applications which are able to interact with real world data. Below is an example of the LabVIEW front panel and programming environment.





Data acquisition (DAQ) is the process of measuring electrical or physical forces such as voltage, current, temperature, pressure, or sound with a computer. DAQ systems are created from sensors, DAQ measurement hardware, and a computer with programmable software. Sensors measure physical phenomena and return the data as a measurable electrical signal. The electrical signal is sent through the connecting hardware to the computer where the software then performs the necessary tests and modifications while collecting the data. For this specific DAQ system, LabVIEW contains the programmable software, the digital multimeters are the sensors, and the DAQ hardware is the GPIBs being used to send information between the computer and power supplies/multimeters. This specific system was set up and designed to test for the output characteristic of a BJT, or bipolar junction transistor, detailed below. A BJT is a semiconductor device created with three semiconductor regions (base, emitter, and collector) separated by two p-n junctions. There are two types of bipolar junction transistors, PNP and NPN, where N and P refer to different semiconductor materials.



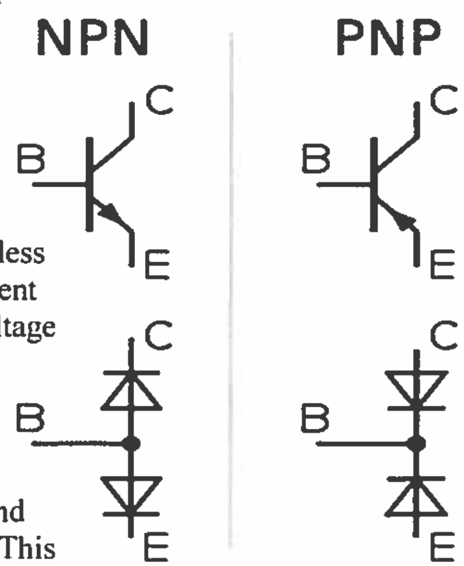
NPN transistors have a positive base (B), with negative emitter (E) and collector (C) currents, while PNP transistors have a negative base, with positive emitter and collector currents. Bipolar junction transistors are current operated, meaning that the current flowing between the emitter and collector of the transistor is much greater than the current flowing between the base and the emitter. The input current, or base current (I_B) added to the output, or collector current (I_C) gives the emitter current (I_E). An important property of the BJT is that a small base current can control a much larger collector current. We will be modeling this property with the output characteristic. It is expected that as the base current rises, the collector current will rise as well. The relationships among the multiple currents is given in the equations below, with α representing the current gain of the transistor from the collector terminal to the emitter terminal, and β representing the overall DC current gain.

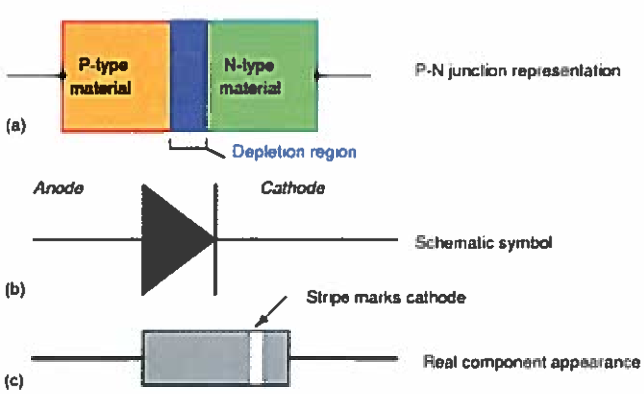
$$\alpha = \frac{I_C}{I_E}$$

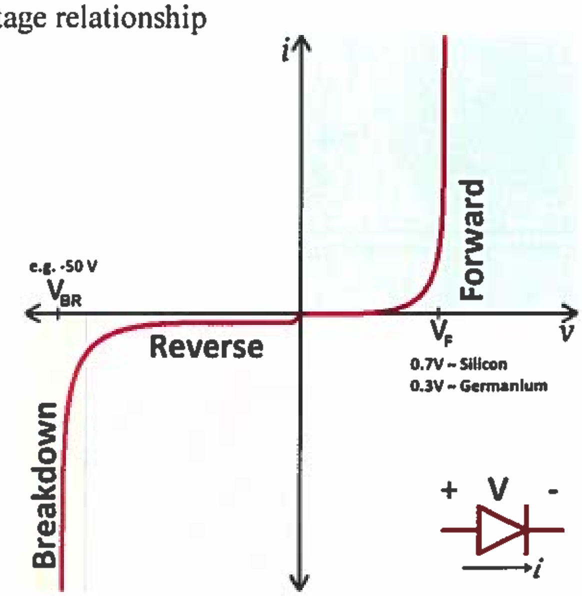
$$\beta = \frac{I_C}{I_B} = \frac{I_C}{I_E(1-\alpha)} = \frac{\alpha}{(1-\alpha)}$$

The four characteristics of a bipolar junction transistor are the transfer characteristic, input characteristic, output characteristic, and mutual characteristic. Graphs illustrating these characteristics are located in figure 1 (attached on page 10). The transfer characteristic is the total DC current gain and details the relationship between the collector current and the base current. Graphs of this characteristic can be used to detail the performance of a particular device, or as an aid in the design of amplifiers. The input characteristic refers the relationship between the base current and the base-emitter voltage. This relationship can help define the input conductance as well as input resistance. The mutual characteristic, collector current vs base-emitter voltage, helps to illustrate the mutual conductance as well as the change in collector current which takes place for a given change in base-emitter voltage. Finally, the output characteristic, collector current vs base-emitter voltage, shows the output conductance as the slope and gives a better idea of the output resistance. It also exemplifies how the collector current is controlled by a much smaller base current, rather than the collector-emitter voltage. This program models the output characteristic specifically, allowing us to use the graph to determine the gain through calculating β.

A simplified way to think of a BJT is to look at it as a circuit composed of two diodes, seen to the right. Diodes are electrical devices consisting of a single p-n junction which, ideally, allows current to flow through in the forward direction with no resistance, while not allowing any current to flow through in the reverse direction. Depending on the voltage applied across the diode, it will operate in one of three regions: forward bias, reverse bias, or breakdown. The forward bias region refers to when the voltage across the diode is positive. In this state the diode is considered "on" and current can flow through. It is important to note that unless the input voltage exceeds the forward voltage (V_F), the current will not be significant. The forward voltage refers to the voltage required to simply "turn on" the diode. The reverse bias region refers to the "off" mode of the diode, when the applied voltage is less than V_F, but greater than the breakdown voltage. The breakdown voltage denotes the massive negative voltage at which the diode breaks down and allows all current to flow through in the negative direction. This diode schematic and graph detailing the current-voltage relationship should help clarify any of the above information. Examining diodes allows for a much more concrete understanding of transistors. Diode testing will be used as a bench mark to ensure progress.







Before testing with diodes can begin, I will first start with resistors. Resistors, unlike diodes and transistors, have a linear voltage/current relationship:

$$V = IR$$

This equation demonstrates that you can apply a current by pushing a voltage through a resistor. For example, if you only have a voltage source but want to push a specific current, it is as simple as finding a resistor and pushing the appropriate voltage to create the desired current.

Methods:

DAQ System

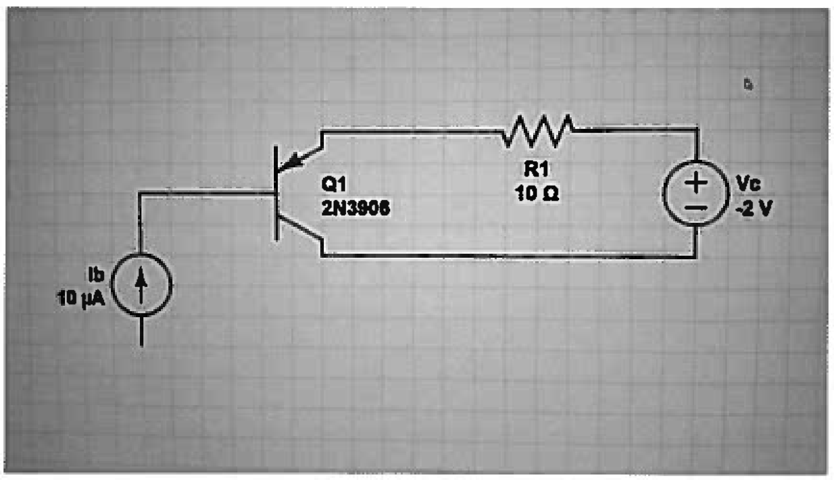
In this experiment, the data acquisition system was assembled from multiple GPIBs, a voltage source, current source, computer with LabVIEW software, and two digital multimeters. GPIBs, or general purpose interface buses, are responsible for connecting the computer to the digital multimeters (DMMs) and power supplies. Each device on the bus has a unique 5 bit primary address, between 0-31. The GPIBs communicate by sending specific symbols, unique to each machine, that determine what that machine does next. When first setting up the DAQ system, the most common test signal was *IDN which told the machine to identify itself. Later tests involved using symbols to increase/decrease the output of the power supplies or to indicate to the DMM that a measurement needed to be taken. The specific symbols associated with each machine were found in their accompanying programming manual in the section focused on IEEE-488. These programming manuals were invaluable when I needed to find specific communication commands.

Resistors/ Diodes

After communication with the four machines was perfected, a basic test circuit was constructed involving a simple 10Ω resistor. The initial goal was to write a code in LabVIEW capable of pushing 10mV through the 10Ω resistor, while recording the measured current. Once completed, the next step involved pushing 10mV through 50mV while recording all values in an array. It was at this point that I augmented the code so that the user could determine the initial and final voltage values, as well as the increment size. The final step of this phase was taking the data generated from recording the multiple voltages and currents, and using it to generate a graph detailing the voltage-current relationship in the 10Ω resistor. With a few tweaks, the same code that was used to calculate the voltage-current relationship in the resistor was used to observe the operating regions of a diode. At its core, the code allows the user to increment the voltage through any desired range while recording each voltage as well as the current created each time.

Transistors

The code created to observe diode and resistor characteristics is at the heart of the final code developed to test for transistor characteristics. Unlike diodes and resistors, transistors have three separate legs, leading to a lot more confusion and trouble when connecting the digital multimeters and power supplies. Before anything was connected, a circuit was designed using a 10Ω resistor, a voltage source, current source, and two DMMs. This circuit is specifically designed to test for the output characteristic, and is the result of quite a bit of trial and error. The HP is the current source and applies a negative base current to the base pin. The Agilent is the voltage source and is connected to the 10Ω resistor on the positive lead, and to the emitter pin on the negative lead. The Keithley, measuring for the collector current, is placed in series in the circuit and goes from the 10Ω resistor to the collector pin. Finally, the Keysight measures for the collector-emitter voltage, and is connected to the collector and emitter pins. A diagram detailing this circuit can be seen below.

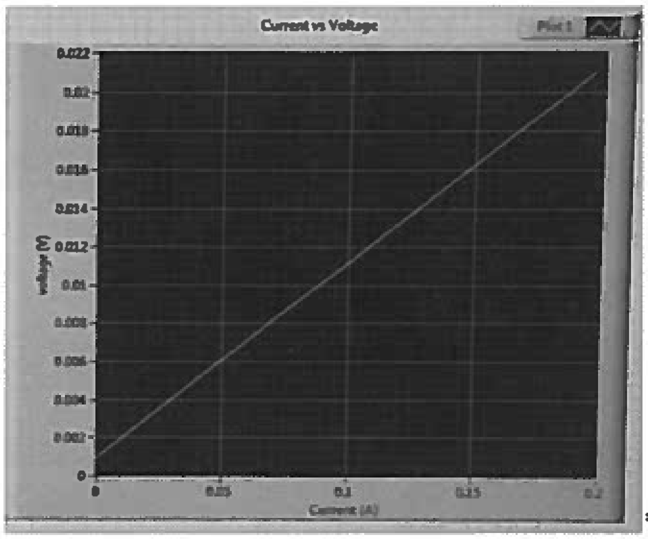


The LabVIEW code created to test for the diode and resistor characteristics allowed me to loop through multiple voltages while reading the current and recording both in separate arrays, but the third pin on transistors meant that I had to change the code to account for this. A second loop was added outside the first, where the base current can be determined and conditions can be applied. Though it sounds simple, implementing this second loop while trying to record all the data and implement communication with a fourth machine made this portion of the project take the longest. I overcame the problems I had in the code through trial and error as well as with the help of Dr. Selim. The outer loop, determining the base current, allows the code to run in the proper order, where the collector-current can be applied, while recording the collector-emitter voltage, all at multiple base currents. To record all of this data, a myriad of arrays were created that ultimately were funneled into producing a graph of the output characteristic. The program was also changed to allow the user to determine initial and final base currents as well as collector currents (through the collector voltage), along with their increment sizes. Once the graph is produced and the program has finished running, the user has the option of saving the graph. To determine whether or not the graph had usable data, I compared the known typical gain of the specific transistor I was using to the gain I calculated from the collector and base currents.

Results/Discussion:

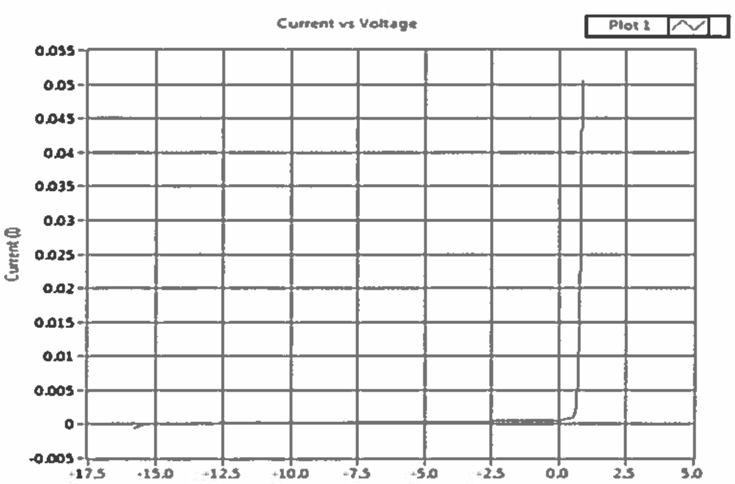
Diodes/Resistors

The LabVIEW programs developed for modeling diode and resistor characteristics on the way toward the final code produced some quality results in themselves that allow us to see how both of these devices operate. Resistors have a linear relationship between voltage and current demonstrated by V=IR. This is highly evident in the graph located below that was taken from an early resistor test in LabVIEW*. This relationship becomes extremely important to understand once the transistor circuit is constructed and the collector current is determined by the applied voltage divided by the resistance.



*current and voltage should switch axis

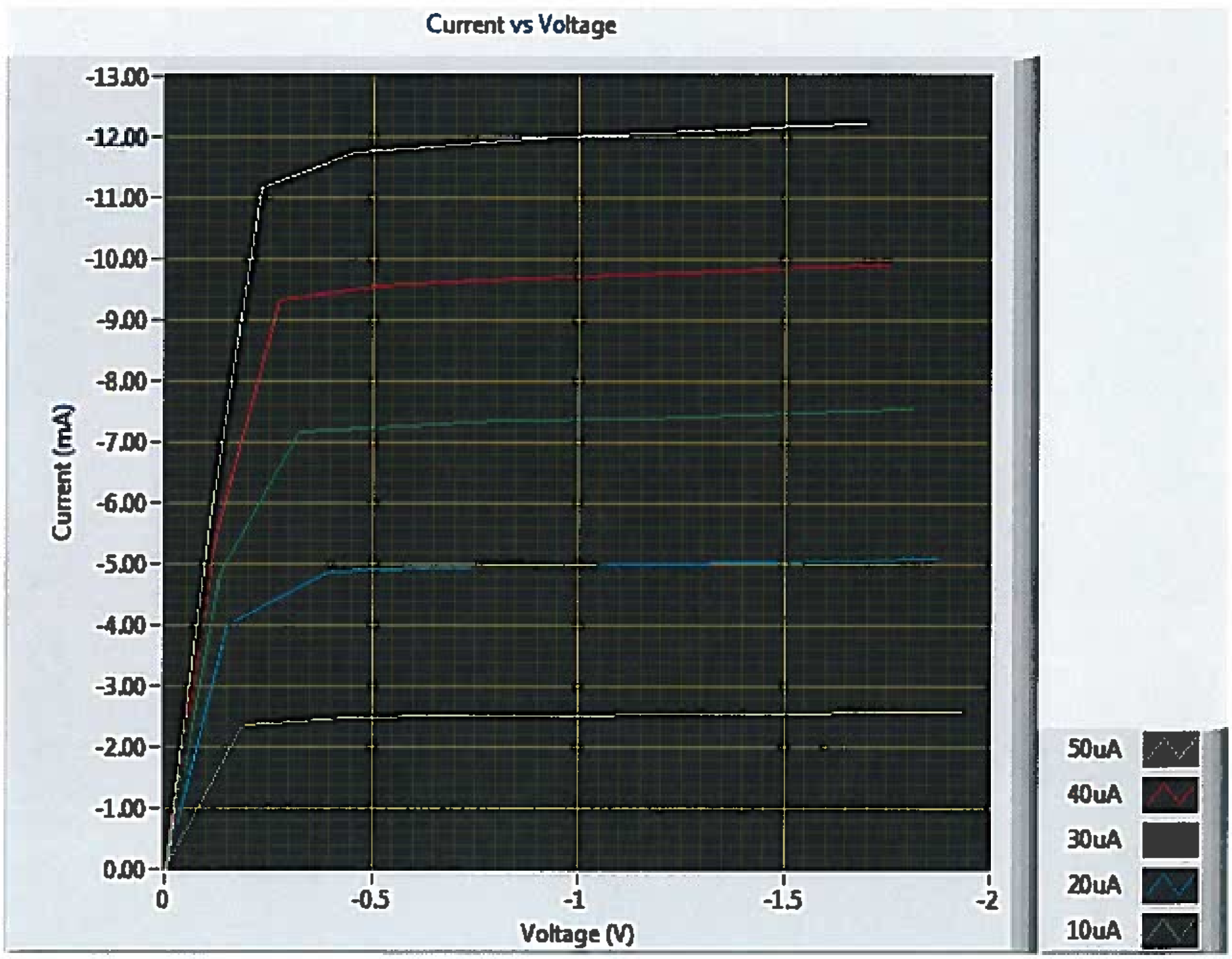
Diodes do not behave in the same manner as resistors, as they do not have a linear IV relationship. The graphs created from diode testing detail this relationship by showing the different ways in which the diode operates. In the graph pictured below, you can see that as long as a negative voltage is applied, the diode remains off and no current is detected, but once the forward-operating voltage is reached, the diode turns on and the current begins to increase with very little increase in voltage.



Transistors

The final LabVIEW program is capable of autonomously generating the output characteristic for a bipolar junction transistor by graphing the collector-emitter voltage vs collector current at multiple base currents. For the majority of my research I focused on using PNP transistors, so I was applying negative voltages and currents. To achieve the best results I decided I would graph V_{CE} vs I_C at base currents -10uA, -20uA, -30uA, -40uA, and-50uA. This graph can be seen below.

(This data is located in Table 1)



This graph demonstrates exactly what I expected to see in the output characteristic. Notice that both the x-axis and y-axis are inverted. This is due to the PNP transistor. If an NPN transistor was tested, the initial and final conditions applied would have to be positive, and the measured values would also be positive. This graph lets us get an idea of how this bipolar junction transistor is operating. Most importantly it demonstrates that the collector current is not being controlled by the collector-emitter voltage, but rather the base current. As the collector-emitter voltage rises, the collector current reaches a plateau, but as you can see, once the base current is increased, the collector current increases. This detail illustrates the fact that a very small base current is controlling a much larger collector current. The collector current being measured in this experiment is in mA, while the base current controlling it is only between 10-50uA. This output characteristic also allows us to compare the measured current gain to the given typical current gain. To calculate the current gain, the collector current, estimated at the beginning of the plateau, is divided by the base current being pushed at the time. Doing this I calculated the measured current gain for the PNP transistor that generated the graph above and got β values ranging from 212 to 225. The given typical gain for the 2N3906 PNP transistor I was using was 200, indicating to me that the data collected and graphed was reliable.

Conclusion:

An autonomous data acquisition system was designed with LabVIEW at its core to test for the output characteristic in a bipolar junction transistor. The program created outputs a graph detailing the relationship between the collector-emitter voltage, collector current, and base current. This graph demonstrates that the collector current isn't being controlled by the collector-emitter voltage, but is actually being controlled by the much smaller base current. The graph also gives enough information to calculate the gain of the transistor and then compare that to the known typical value. My results look much better than I expected and the similarity between the calculated β and given typical β makes me believe that my results are reliable.

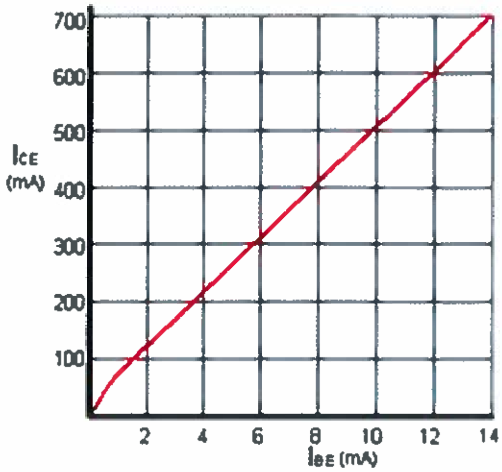
If I had more time to work on this project I would modify it so that it could potentially test for multiple transistor characteristics at once. While the final program was specifically designed to test for the output characteristic, some slight modifications could very easily be made to alter this program to test for the other characteristics of the same transistor.

Table 1: Output Characteristic

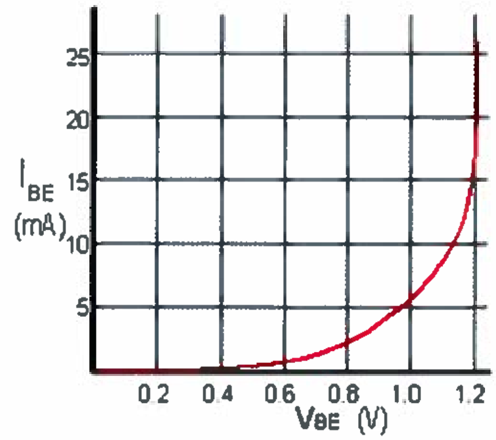
Voltage (V) I_b = -50uA	Current (mA) -50uA	Voltage (V) - 40uA	Current (mA) - 40uA	Voltage (V) - 30uA	Current (mA) - 30uA	Voltage (V) - 20uA	Current (mA) - 20uA	Voltage (V) - 10uA	Current (mA) - 10uA
-1.697215	-12.22	-1.76015	-9.91	-1.817931	-7.53	-1.87744	-5.09	-1.934051	-2.59
-1.567877	-12.16	-1.588963	-9.86	-1.634345	-7.49	-1.670177	-5.06	-1.762364	-2.57
-1.314682	-12.08	-1.335812	-9.79	-1.379132	-7.44	-1.468288	-5.03	-1.507164	-2.56
-0.953126	-11.98	-1.069325	-9.72	-1.164671	-7.39	-1.21406	-5	-1.251494	-2.54
-0.705817	-11.86	-0.760513	-9.63	-0.816928	-7.33	-0.875093	-4.96	-0.93518	-2.53
-0.476118	-11.76	-0.514739	-9.53	-0.570256	-7.26	-0.628424	-4.92	-0.695685	-2.51
-0.231553	-11.14	-0.276296	-9.33	-0.33879	-7.21	-0.377563	-4.87	-0.437609	-2.48
-0.108102	-5.69	-0.117396	-5.35	-0.130552	-4.84	-0.154228	-3.99	-0.189758	-2.36

Figure 1: Transistor Characteristics

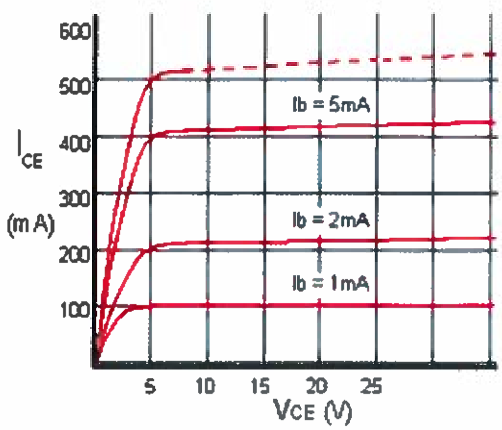
Transfer Characteristic



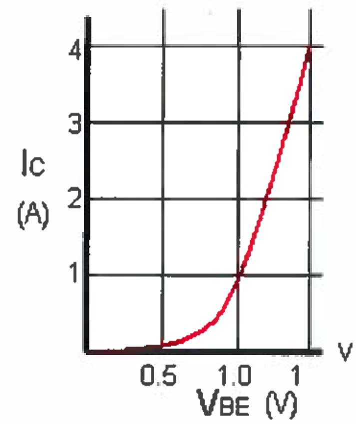
Input Characteristic



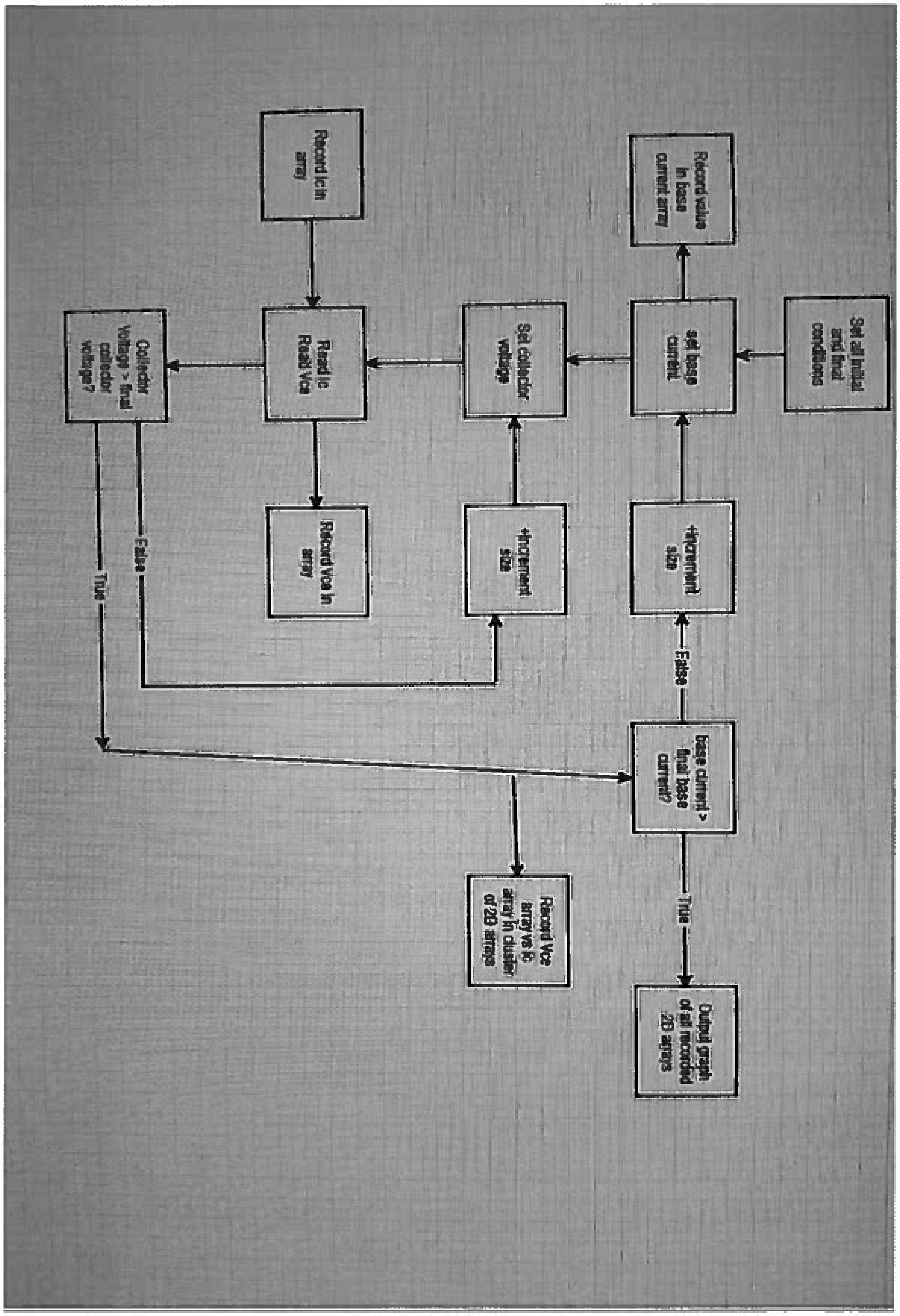
Output Characteristic



Mutual Characteristic



Flowchart


Set all initial and final conditions
set base current
Record value in base current array
+increment size
False
base current > final base current?
True
Output graph of all recorded 2D arrays
Set collector voltage
+increment size
Record Vce array vs Ic array in cluster of 2D arrays
Record Ic in array
Read Ic Read Vce
Record Vce in array
Collector Voltage > final collector voltage?
False
True