# Bipolar Junction Transistors: Characteristic Curves and Amplifying Signals

## I. Background (Elise Heim)

Bipolar junction transistors, or BJTs, may be been developed more than half a century ago, but they are still widely used today. They can be found in cellphones, televisions, computers, and so much more. BJTs are so commonly used because of their variety of applications, including as an amplifier, filter, rectifier, oscillator, or even a switch.

## II. Introduction (Elise Heim)

BJTs are three terminal devices wherein the emitter to collector current is controlled by base current. Unlike unipolar transistors, which are comprised of only one type of semiconductor, BJTs include both positive (P) and negative (N) semiconductors. The three terminals of a BJT are referred to as the base, collector, and emitter. For an NPN BJT, if a positive voltage is placed across the collector and emitter ($V_{CE}$), and some current $I_B$ is passed from the base to the emitter $I_{BE}$, current is able to flow from the collector to emitter $I_{CE}$. The greater the base current, the greater the current out the emitter.

## III. Characteristic Curves (Aidan Sharpe)

The characteristic curve of a BJT is a family of curves that describe the relationship between the input base current ($I_B$) and the input voltage between the collector and the emitter ($V_{CE}$) with the output collector current ($I_C$). Importantly, there are two input variables, that being $I_B$ and $V_{CE}$. An ideal characteristic curve for a BJT is seen in *Fig.* 1.

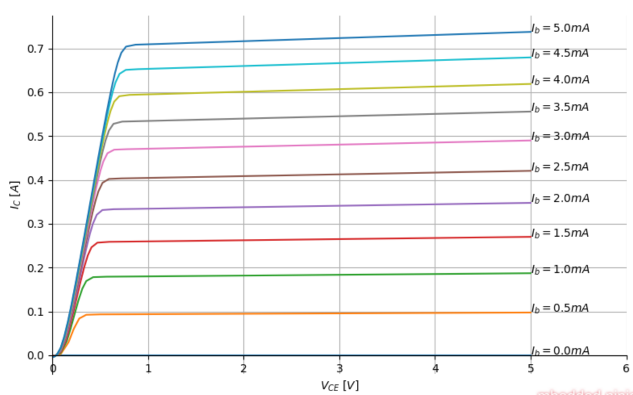


Fig. 1. Ideal Characteristic Curve

Each color represents a different input base current, in this case, values range between 0mA and 5mA. Additionally, sweeping along the horizontal axis, is the input voltage between the collector and emitter ($V_{CE}$). There are three types of behavior or regions to focus on here. First is the cut-off region. In this region, $I_B$ is 0mA, and no matter what $V_{CE}$ is applied, $I_C$ remains 0mA. The second is the saturation region. In this region, $I_B$ is positive, and a small change to $V_{CE}$ results in a large change to $I_C$. Looking at *Fig.* 1, the saturation region has a steep positive slope. The third and final region is the active region. The active region is the area where $I_B$ is positive, but changing $V_{CE}$ has little effect on the current $I_C$. Looking again at *Fig. 1*, the active region looks like a collection of nearly horizonatal lines.

The characteristic curves of a BJT were tested in the lab using a breadboard setup to attain small base input currents and larger collector currents. Sweeping about 30 input datapoints, parametrically varying $I_B$ and $V_C E$ the albeit rather uninspiring curves seen in *Fig. 2*.

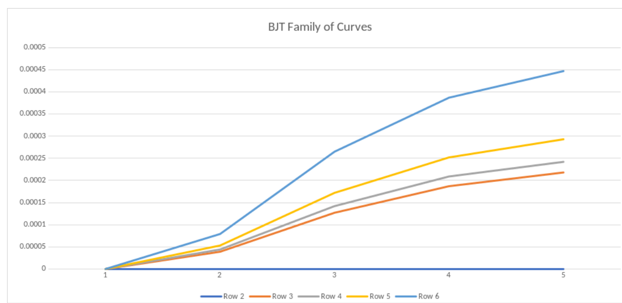


Fig. 2. Experimental Results

Since the experimental curves only slightly resemble the characteristic curves of a BJT, there was obviously some form of error here. Possible sources for error could range from too small of resistor values, to inaccurate readings from the digital multimeter due to high precision requirements, to a misconfiguration of the experiment. After brief discussion with the professor, the most likely culprit is that the resistor regulating $I_B$ was too small and our input currents were throwing off our results.

## IV. BJT Amplifiers (Aidan Sharpe)

Apart from making cool looking curves, BJTs can serve a practical purpose by acting as amplifiers and electrically controlled switches. Here, we will take a closer look at using BJTs as an amplifier. Take a look back at *Fig. 1*. Notice the scale of $I_B$ compared to the scale of $I_C$; it is roughly 2 orders of magnitude more. This scale from base input current to collector current is usually referred to as $\beta$ or $h_{FE}$ on data sheets, and for most BJTs it is usually in the ballpark of 100 to 200.

Setting up a BJT amplifier is quite easy. For this example we will use a standard NPN BJT in a common emitter arrangement seen in *Fig. 3*. We want to amplify voltage, not current, so we need to bias the circuit with some preset DC values. To do so, we take into account the rail voltages, in this case, the top rail is 12v and the emitter rail is set to 4v. To get the most out of the amplifier and avoid clipping the signal it is smart to pick an output bias voltage somewhere close to halfway between the rails, in this case, 8v.

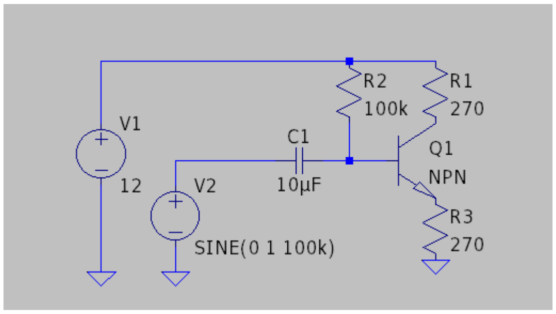


Fig. 3. Common Emitter Amplifier Schematic

To set up the bias voltage, we have to consider $I_C = \beta I_B$. Therefore, to determine $I_C$, we will start by defining $I_B$. Arbitrarily choosing $R_2$ as $100k\Omega$, knowing that we want the emitter voltage to be 4v and there will be a 0.7v drop from base to emitter, the base current will be $\frac{12-(4+0.7)}{100k}$, or 73uA. Approximating $\beta$ at 200, $I_C$ will be about 15mA. Knowing this, a desired voltage drop across the $R_1$ is 4v to bias the collector voltage at 8v, meaning $R_1$ must be $\frac{4v}{15mA}$, or about $270\Omega$. Additionally, since the emitter current is very close to the collector current, we can use another $270\Omega$ resistor for $R_3$ to set the emitter voltage to 4v.

Now that that's out of the way, we can apply a voltage to the base and see it amplified at the collector.

## V. Conclusion (Elise Heim)

So now we have seen what a BJT can do. The active region of the family of curves allows for amplification, as demonstrated. It is as simple as hopping from one line in the family to the next, using a greater current.

An even more common application of BJTs was not included in this lab. This utilizes the cutoff and saturation regions of operation. This allows for the BJT to be used as a switch. There are countless applications for switches, especially ones that are controlled by current. By investigating the family of curves of a BJT, one can recognize which regimes are best suited for different jobs.