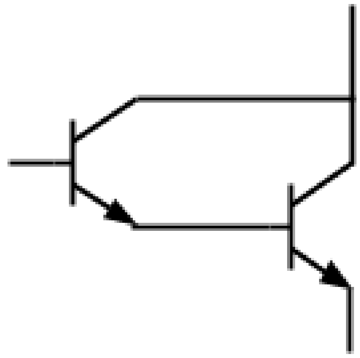

Figure 1: Two NPN BJTs connected to form a Darlington pair.

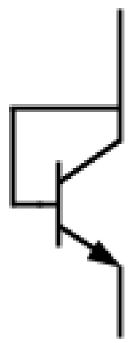

Figure 2: A diode connected NPN Device.

1 Warm-Up Problems

1. The configuration of transistors in Figure 1 is referred to as a Darlignton Pair or simply a Darlington.
   (a) What is the effective β of the Darlington Pair? i.e. the ratio of current injected into the left transistor to the combined collector current.
   (b) What is the effective $V_{BE,ON}$ of the Darlington Pair? i.e. the total voltage drop from the base of the left transistor to the emitter of the right one.
   (c) If V_{be} and V_{ce} of the Darlington are varied, what regions of operation do each of the transistors pass through?
2. The configuration of transistors in Figure 2 is referred to as a diode connection
   (a) What region of operation does a diode connected BJT operate in?
   (b) What is the large signal I-V relationship of a diode connected BJT?
   (c) Why is this called a diode connection?

2 Lab Introduction

In this lab we will be characterizing some of the device parameters of bipolar junction tranistors (BJTs). The learning goals are listed below:

1. Understand large signal models of NPN and PNP transistors, including regions of operation.
2. Relate large signal measurements of BJT behavior to small signal measurements.
3. Get practice biasing both NPN and PNP BJTs.

References: *Hays and Horowitz Lab Manual 94, 97*

3 Measurements of BJT Parameters

Please simulate the following measurements:

1. Measure the diode drop across the base-emitter and collector-base diodes of a 2N3904 transistor at a 1mA current level. You may use current sources for this measurement. Explain why the collector-base diode drop is slightly smaller than the base-emitter drop. Hays and Horowitz has a relevant explanation on page 94.
2. Measure the $\beta, g_m, V_{ce,sat}$ and r_π of a 2N3904 transistor. Vary the collector current over at least the three decades from 100µA to 100mA when measuring these quantities. Be careful not to saturate your transistor when you take these measurements because β, g_m and r_π are only defined in the forward active region; consider monitoring the collector voltage as you take your data. Check your results for self consistency: what's the relation between r_π and g_m? I_C and g_m? Also compare your results against datasheets. Note that h_{fe} is commonly used synonym for β.

   In this section we are going to simulate the limitations of lab equipment more carefully than the rest of the lab. Like last week, we will be putting some artificial restrictions on our measurement abilities to simulate the in-lab experience:

   (a) You may only directly measure voltages, and not currents.
   (b) You may not measure voltages or voltage changes smaller than 10mV.
   (c) All voltage measurements must be taken across a simulated multimeter or oscilloscope probe that has an input resistance of 10MΩ. Multimeter measurements must be DC measurements.
   (d) You may use a variable voltage source to provide stimulus to your circuit, but the source can't be controlled more precisely than 10mV steps.
   (e) You may not stack voltage sources, and function generators and scope probes must be grounded to earth ground. This means you need to use a common ground for your function generators, power supplies and oscilloscope probes. This constraint may require you to AC couple some of your test signals.
   (f) Assume all resistors have a maximum power handling capacity of 1/8 W.
   (g) All resistors must have standard values as listed here:
   `https://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf`
3. Generate an $I_C - V_{CE}$ curve for the 2N3904 transistor. Extract the Early Voltage, V_A from this data and compare it to the datasheet.
4. For extra credit you may repeat steps 2-3 with a 2N3906 transistor.

Required Data: Diode drop measurement and explanation. Curves of $\beta, g_m, V_{CE,SAT}$ and r_π vs. I_C with appropriate summaries of experimental setup and equivalent circuit models for each measurement. Curve tracer output and V_A estimate.