



Introduction to the Transistor

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Purpose:

Demonstrate the current-controlled current source nature of the transistor, and investigate its three operating regions — cutoff, active and saturated.

Equipment Required:

- 1 - HP 34401A Digital Multimeter
- 1 - HP E3631A Power Supply
- 1 - Protoboard
- 1 - Transistor Curve Tracer (optional, shared)
- 1 - 2N3904 NPN Transistor
- 1 - 10-k Ω Resistor
- 1 - 820-k Ω Resistor
- 1 - 10-k Ω Potentiometer

Prelab:

Read Sections 4-1 to 4-3 in the textbook* on dependent sources and transistors. Assume the transistor you will be using has a nominal β of 200. The transistor will enter the active region when V_{in} reaches the turn-on voltage V_T . For the circuit of Fig. 1, calculate the value of V_{in} that will cause the transistor to enter saturation.

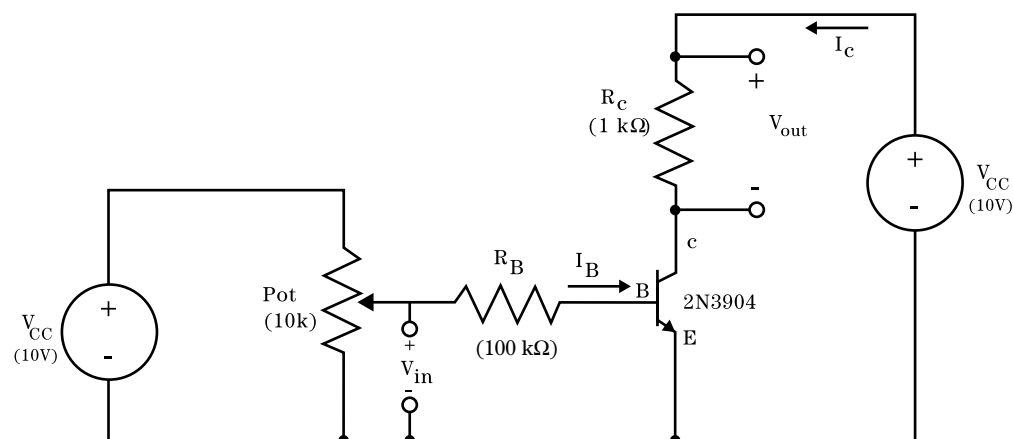


Figure 1

Procedure:

1. Build the circuit
 - a. Adjust the power supply V_{CC} so that it produces +10 V. Turn off the power supply.
 - b. Measure and record the actual value of the 10-k Ω and 820-k Ω resistors that will be used in your circuit.



Caution

The transistor, like any semiconductor device, can be destroyed by over-current, over-voltage or static discharge. Over-current conditions are usually due to a wiring error. Over-voltage occurs when the power supply voltage exceeds the voltage rating for the device. These conditions can be avoided by ensuring you are using the proper device, and double-checking the circuit layout to catch — and correct — wiring errors. In the laboratory, damage from static discharge is often controlled by the use of grounded anti-static mats on the floor and the work surface. Manufacturers of static-sensitive devices recommend the use of a grounded wrist strap when working on sensitive electronics. You can help avoid damage from static discharge by touching an earth ground before picking up a semiconductor device. Earth grounds are available throughout a modern circuits lab, in the form of any metal case on a grounded instrument. Some power supplies provide a ground lug (or jack) separate from the negative side of the supply. The ground lug provides a good quality connection to earth ground through the third wire (round pin) on the AC power cord. Touching the metal portion of this ground lug will discharge any static electricity you have accumulated, and significantly reduce the likelihood of damaging static-sensitive components.

- c. On a protoboard, build the circuit of Fig. 1. Turn on the power supply and adjust the potentiometer so that V_{out} is 5 V.

Table 1

Operating Mode	Value of V_{CE}
Cut off	$V_{CE} = V_{CC}$
Active	$0 < V_{CE} < V_{CC}$
Saturated	$V_{CE} = 0$

- d. The voltage across the collector-emitter junction V_{CE} of the transistor is a good indicator of the present operating mode. Table 1 summarizes how to use the V_{CE} to determine the mode. In your journal, use the measured values of V_{CC} and V_{out} to write a KVL loop equation around the collector emitter side of your circuit. Solve for V_{CE} . Use the equations in Table 1 to determine the operating mode. Measure V_{CE} and compute the percent error between the computed and measured values of V_{CE} .
2. Measure the β of the transistor
- a. With V_{out} still at 5V, measure the voltage across R_B . Use Ohm's Law and the measured resistance values for R_B and R_C to compute I_B and I_C . Compute the forward current gain, β , from the dependent source equation for the transistor, $I_C = \beta I_B$. Record the measured β value in your lab journal.
- b. The β value is difficult to precisely control during the manufacturing process. Furthermore, β is subject to drift with time and temperature. The following procedure will demonstrate the dependence of β on the temperature of the transistor. Adjust V_{in} so the transistor is operating in the active region. While observing V_{out} , warm the transistor by pinching the package between your thumb and forefinger. If V_{out} does not change, ask someone with warm hands to help you. How is β related to the temperature of the transistor?



- c. Prepare a four-column table in your lab journal to record about thirty data points, labeling the columns V_{in} , V_{out} , V_{BE} and V_{CE} . For V_{in} from 0 to 1.5 volts, take data at intervals of 0.25 volts (0 V, 0.25 V, 0.5 V, etc.). For V_{in} from 1.5 V to 10 V, take data at 0.5 V intervals.

3. Plot the transfer characteristics

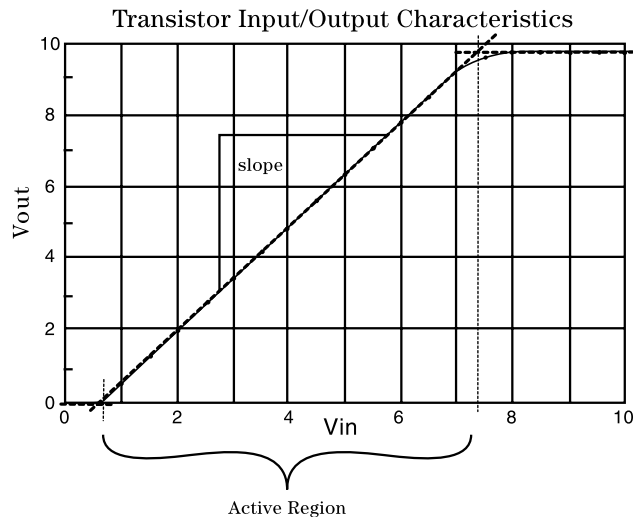


Figure 2

- a. Graph the data you collected on a full page in your journal. Place V_{in} on the x axis, and plot three curves, V_{out} , V_{BE} and V_{CE} as functions of V_{in} . Your graph should be similar to the one shown in Fig. 2, but should also show V_{BE} and V_{CE} . If enough data points were collected, the plot will show that the transitions between cutoff and active, and between active and saturated are somewhat rounded. Use a different color ink to fit straight lines to each of the three operating modes for the V_{out} data. The two intersections of these three straight lines represent the best approximation of the transition from cutoff mode to active mode, and from active mode to saturated mode. Draw a vertical line extending from the top to the bottom of your graph, at each of these two intersections. Label the mode of operation for each of the three regions.
- b. If there is a transistor curve tracer available in your laboratory, use it to measure the β of your transistor. Assume the β displayed by the transistor curve tracer is the actual β value. Compute the percent error between the β displayed by the transistor curve tracer and the β computed in Procedure 2a.

Conclusion:

The straight line drawn in the active region on the transistor input/output characteristics plot can be represented by an equation in the point-slope form, $y = mx + b$ (where x equals V_{in} and y equals V_{out}). Provide a mathematical proof (hint: use $I_c = \beta I_b$, and Ohm's law) that shows β is related to the slope of the line in the active region by the equation:

$$\beta = \frac{mR_B}{R_C} \quad (1)$$

- a. Measure the slope of the line in the active region of the transistor input/output characteristics plot for your particular transistor. Using the measured slope and Eq. (1), calculate the average β . Does this β agree with the β measured in Procedure 2a of this lab?



- b. Draw three schematic diagrams for the circuit of Fig. 1, one for each operating mode, however substitute the large-signal transistor model for the transistor element in each circuit. For all three circuits write two KVL loop equations, one for the base-emitter side (which will include the voltage across R_b) and one for the collector-emitter side of the circuit (which includes the voltage across R_c).
- c. The y-intercept (b in the point-slope form) offsets the line from the origin. Write an equation for b in terms of the variables used in this circuit. Project the line drawn in the active region until it crosses the y-axis. Use this value of b and the equation for b to determine an average V_{BE} for this transistor.

* Roland E. Thomas and Albert J. Rosa, The Analysis and Design of Linear Circuits, Prentice Hall, (New Jersey, 1994)

