Experiment-1

Bipolar Junction Transistor Characterization

Introduction

The objectives of this experiment are to observe the operating characteristics of bipolar junction transistors (BJTs). Methods for extracting device parameters for circuit design and simulation purposes are also presented.

Precautions

Bipolar junction transistors do not employ a fragile, thin gate oxide like MOSFETs do, and they are thus much more robust against electrostatic discharge (ESD) damage. Since all three leads of the BJT are interconnected by internal pn-junctions, small charges can bleed off through the leakage currents of these junctions, and static charges are soon dissipated internally. For these reasons, BJTs can usually be handled freely, and are rarely damaged by ESD. This makes them very pleasant to work with.

Procedure 1 BJT base lead and sex identification

Set-Up

Locate a type 2N3904 BJT from the parts kit. This should be a three lead device in a small plastic TO-92 package. Turn on a DMM and configure it to measure (two wire) resistance. Plug a black squeeze-hook test lead into the negative (–) banana jack of the meter and a red squeeze-hook test lead into the positive (+) banana jack of the meter. The objective of this procedure will be to determine which lead of the BJT is the base, and whether the BJT is an npn or pnp device using only the ohmmeter function of the DMM. Also locate a 1N4148 diode that will be used for reference.

Measurement-1

Measure the resistance of the 1N4148 diode with the DMM in both the forward and reverse bias directions. Note that the red lead from the (+) input of the DMM is the one which will have the more positive voltage for this type of test. Record these readings in your lab notebook, and note these readings as being "typical" for a forward and reverse biased pn-junction. You can then refer to these readings to determine the polarity of pn-junctions that exist within the BJT.

Recall that a BJT has pn-junctions between the base and both the emitter and collector terminals. Use the DMM in its ohmmeter setting to test pairs of leads on the BJT and therefore identify the base lead on the device. From the polarity which causes the base terminal to conduct, deduce whether the BJT is an npn or pnp device.

With the base lead identified, it stands to reason that the remaining leads must be the emitter and collector. A few measurements will next be made to examine if these two remaining leads can be distinguished by DMM measurements. First, use the DMM, again in its ohmmeter setting, to measure the resistance between emitter and collector with the base terminal open circuited. Try this with both polarities of the DMM leads. Next, use the DMM to measure the resistance between emitter and collector with the base now connected to the (–) lead of the DMM in addition to the other transistor lead that is already there. Again, try this in both polarity directions. Finally, use the DMM to measure the resistance between the emitter and collector with the base connected to the (+) lead of the DMM in addition to the other transistor lead that is already there. Again, try both polarity directions. You should end up with a total of six resistance measurements: 3 different base conditions (open, voltage low, voltage high) times 2 emitter/collector test voltage polarities.

Question-1 From your measurements above, summarize your findings about the given 2N3904 BJT in your notebook. Draw a picture of the device package and label the leads appropriately as E, B, C. (It is conventional to do this with a view of the device looking down on it with the leads pointing away from you, as if it were soldered into a printed circuit board. This is usually termed a component-side view, in reference to the component side of the circuit board.) Is it possible to distinguish the emitter lead from the collector lead using only an ohmmeter? Explain why or why not. Look up the data sheet for the the 2N3904 and compare your deductions with the manufacturer's specifications. The base terminal is normally thought of as the “control” terminal for the BJT, as it controls current flow from emitter to collector. With the base lead open circuited, is the BJT a “normally-on” or a “normally-off” device? Explain your answer in reference to the internal pn-junctions of the BJT and how they must be biased in order for conduction to occur.

Comment Many DMMs have a separate function for pn-junction testing. On some meters this is an option on the resistance measurements. In this mode, often termed “diode test,” the DMM outputs a constant current of about 1 mA and it measures the voltage between the two leads without computing a resistance. The measured voltage is the turn-on voltage of the pn-junction for a 1 mA current, if the diode is forward biased. If the diode is reverse biased, then the DMM cannot force 1 mA of current into the diode and the voltage across the diode rises up to the upper range limit of the DMM, usually about 1.5 to 2.0 Volts. Some meters give an over-range indication in this case. Using the diode function of a DMM is another way to perform the above tests, and it gives more understandable information about the typical junction voltages of the BJT.

Procedure 2 Measurement of BJT & Dependence of β_F on collector current level

Set-Up

To set up this front-end, use the following parts:

RB = 1.0 MΩ 5% 1/4W

RC = 10.0 kΩ 5% 1/4W

The measurements will be made with the emitter at a ground potential reference. Power supplies PPS1 and PPS2 are used for the collector and base voltage excitations, respectively. The current sensing resistors RC and RB and the BJT under test are then connected as shown in Figure E1.2a below.

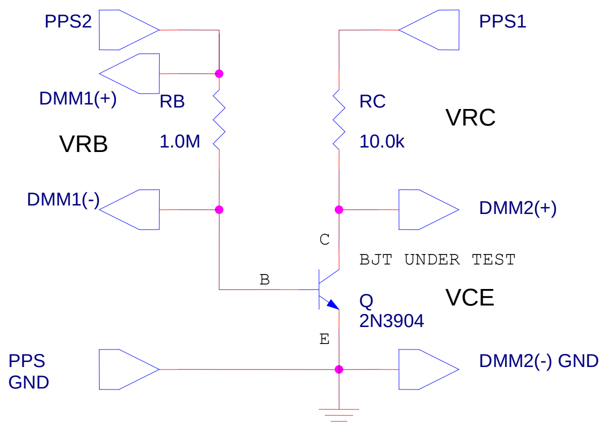

Figure E1.2a

The excitation voltage VCC is from PPS1 power supply. This voltage is applied across the series connection of a current limiting resistor RC = 10.0 kΩ, the collector-emitter leads of the device under test (DUT), and the collector current sensing resistor R = 10.0 kΩ. Thus, VCC = VCE + VRC.

The voltage of DMM1 is equivalent to the voltage VRB, while the voltage from DMM2 is the voltage VCE.

Measurement-2

Adjust the PPS2 to produce voltages +1.0 Volts. Then adjust PPS1 from 0.0 V to 5.0 V with increment 1.0 V. Measure the VRB and VCE with DMMs. If two DMMs are not available at your lab bench, you may have to switch back and forth between the two terminals at DMM1 and DMM2. Calculate IB=VRB/1.0 MΩ and IC=(PPS1-VCE)/10.0 kΩ. Record the IB, IC, and VCE in a table in your notebook.

Increase the PPS2 0.25 V and repeat till measuring at least six different (IC,VCE) pairs.

Using some graph paper, plot the I-V characteristics (IC vs VCE) of BJT.

Question-2 Compute the value of $\beta_F = I_C/I_B$ for each measurement point and observe the general trend of the data as a function of the collector current level. Create a plot of β_F versus I_C for those points corresponding to a forward-active operating point of V_{CE} = 3.0 Volts. Comment on the dependence of β_F on I_C, and from your plot, estimate the value of I_C which yields the maximum value of β_F.

Comment At low values of collector current, generation-recombination processes in the base-emitter juction produce additional base current which is not associated with a proportional collector current. Hence, at low current levels, the current gain falls. At high values of collector current, series resistance and high-level injection phenomenon become important both of which cause the current gain to fall off in this region. All BJTs have a designed “sweet spot” where they deliver maximum current gain. Usually, other operational parameters such as frequency response, power efficiency, and minimum noise production are also optimized around this region. It is certainly possible to use a BJT outside of this region of optimal current gain, but one must suffer degradation in all of these parameters when doing so. The manufacturer’s data sheets provide very detailed information about how all of these parameters vary with collector current level. A little effort expended in matching these performance curves to a given design will lead to much better circuit performance.

Procedure 3 Measurement of BJT output conductance

Comment

The characteristic output curves for a BJT are not exactly horizontal in the forward-active region of operation. The slight slope that the curves exhibit in this region is their output conductance. If the BJT behaved like an ideal current source, the output current would not be a function of V_{CE}, and the curves would be truly horizontal. This slight increase in I_C as a function of V_{CE} in the forward-active region can be represented by a small conductance in parallel with the ideal current source in the BJT model.

Set-Up

Start from the same set up as in Procedure 2 except using RB = 100 kΩ and RC = 1.0 kΩ.

Measurement-3

Next, insert a 10 kΩ resistor in parallel with the emitter and collector terminals of the 2N3904 BJT under test. This will simulate additional output conductance to emphasize what the effects are on the output I-V characteristics of the transistor. This resistor simulates the effect of increasing the output conductance of the BJT. Repeat previous procedure to produce (IC, VCE) plots.

Question-3

Plot the BJT characteristics *without* the additional 10 kΩ resistor connected, use Excel to compute the slope of the output curves in units of Ω^{-1} (or Mhos, Siemens, or S).

Unlike when the 10 kΩ resistor was connected, the value of the BJT output conductance will tend to increase in proportion to the collector current I_C. The output conductance is usually expressed as λI_{Csat}, where λ is a constant with units of V^{-1}. I_{Csat} is the saturated value of forward-active collector current, i.e. the current that would result in the absence of any output conductance, and which is usually measured close to the saturation knee of the output curve. Using Excel, find the best fit value of λ which allows the forward-active output curves to be well approximated by the relationship

$$I_C = I_{Csat} (1 + \lambda V_{CE}) .$$