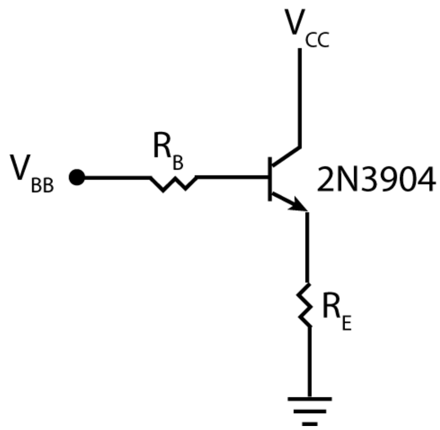
Experiment 8 – Transistor i-v Characteristic and Load-Line Analysis

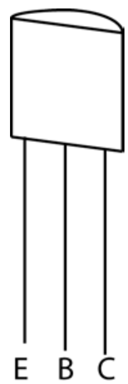
Physics 242 – Electronics

Introduction

The transistor is the fundamental building block in all integrated circuits, and is commonly used as a discrete component in many applications, especially switches and power amplifiers. In this experiment we will map out the characteristic curves $I_C\ vs.\ V_{CE}$ for a small-signal bipolar junction transistor, the 2N3904 npn transistor.

Procedure

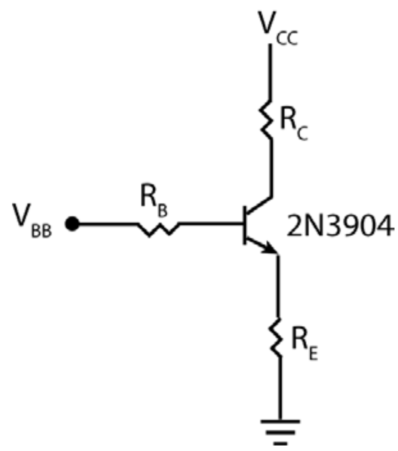




Important: All measurements in this experiment must be made using the same transistor. Different transistors, even with the same part number, can have significantly different *i*-*v* curves and values of β, the current gain factor.

1. Measure the values of your resistors, and then construct the circuit shown above. The pin diagram of the 2N3904 npn transistor is also shown above. Use R_E = 100 Ω and R_B = 200 kΩ. Use the fixed +5 V source as V_{BB}. Using your +15 V adjustable source as V_{CC}, vary its magnitude over its full range in steps of around 1.5 V or 2 V. For each value of V_{CC}, measure the voltage across R_E and the voltage difference V_{CE} between collector and emitter. Also measure the voltage across R_B when V_{CC} = 7.5 V (approximately).

2. Repeat your above measurements for R_B = 100 kΩ, then for R_B = 50 kΩ, and R_B = 20 kΩ.



3. Measure your resistor values, then build the circuit shown above, using R_C = 200 Ω, R_E = 100 Ω, R_B = 50 kΩ, V_{BB} = 5 V (fixed supply), and V_{CC} = 12.0 V (adjustable supply). Measure the voltage across R_C and the voltage difference V_{CE} between collector and emitter.

Analysis

Make a plot of I_C (y-axis) vs. V_{CE} (x-axis), showing your data for each different value of R_B. Draw a smooth curve (or line) through your data points for each different value of R_B, and label each curve with the value of base current I_B that corresponds to it. Then draw the load line for your circuit of Procedure 3 on the same plot. Calculate the operating point (V_{CE}, I_C) from the intersection of your load line with the appropriate transistor curve, and compare the values of V_{CE} and I_C that you obtain to those you measured directly from the circuit in Procedure 3 (i.e. find the percent difference). If you would like to use Mathematica to plot the i-v curves and load line, see the appended Mathematica code for a template of how to make the plots.

What is the value of β for your transistor? Does it depend on the transistor's operating point (that is, on the values of V_{CE} and I_C)?

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(* Example Mathematica code to analyze Lab9 - Phys 242 *)

(* Data in the form: {Vce (volts), Ic (mA)}  *)

demodata = {
   {1.0, 4.00},
   {3.1, 4.12},
   {4.9, 4.19},
   {6.8, 4.32},
   {9.2, 4.44},
   {11.3, 4.52},
   {13.1, 4.71}
  };

demoplot =
  ListPlot[demodata, PlotMarkers → {Automatic, 10}, PlotRange → {{0, 15}, {0, 25}} ];

fdemo = Fit[demodata, {1, x}, x];

(* This defines the fit line to the data as a function called demofunc. *)
demofunc[v_] := fdemo /. x → v;
demofuncplot = Plot[demofunc[v], {v, 0, 15}, PlotRange → {{0, 15}, {0, 25}}];

(* This defines and plots a load-line,
with Ic in mA on the y-axis and Vce in volts on the x-axis. *)
vcc = 12.0; rc = 200.0; re = 100.0;
loadline[x_] := (vcc/(rc + re) - x/(rc + re)) 1000;
plotloadline = Plot[loadline[v], {v, 0, 15}, PlotRange → {{0, 15}, {0, 25}}];

Show[demoplot, p1, plotloadline, AxesLabel → {"Vce (volts)", "Ic (mA)"},
 PlotLabel → "i-v characteristic of 2N3904 npn transistor"]

(* Calculate the voltage Vce predicted by the load-line plot.  The
  desired voltage is the intersection of the loadline and the curve passing through
  the data. You have to supply an initial guess for the intersection point. *)
FindRoot[loadline[v] == demofunc[v], {v, 8.0}]
(* Calculate the current Ic predicted at the above voltage Vce,
by reading off the fit curve. *)
demofunc[v] /. %
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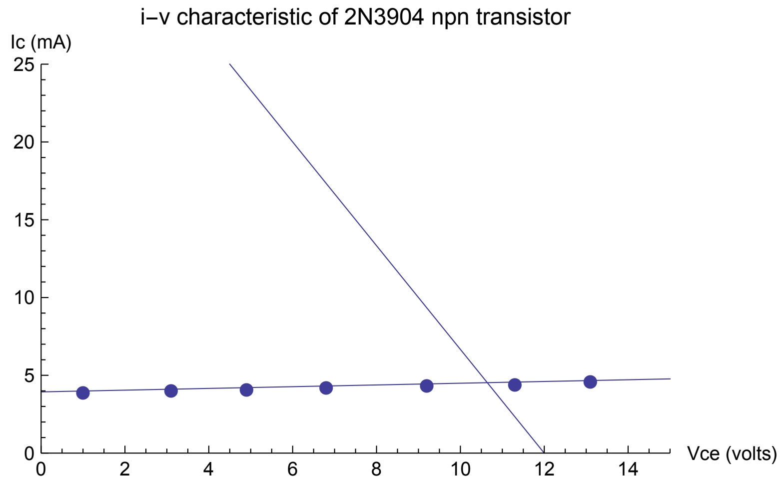


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{v → 10.6415}
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4.52827
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(* So the load line intersects the i-v characteristic of the
   transistor at Vce = 10.64 V and Ic = 4.53 mA. *)
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