University of Utah
Electrical & Computer Engineering Department
ECE 2100
Experiment No. 7

Transistor Introduction (BJT)

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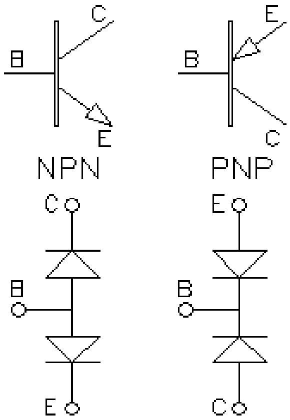
rev,2/23/03

Minimum required points = 38   Grade base, 100% = 57 points
Recommend parts = 57 points (100%, ALL parts are recommended this time)

Objectives

1.) Try a simple transistor test, involving only a multimeter.
2.) Measure and plot β as a function of collector current.
3.) Observe the I_C vs V_{CE} family of curves on the curve tracer.



Check out from stockroom:

- Wire kit
- 2nd Multimeter, if available

Parts to be supplied by the student:

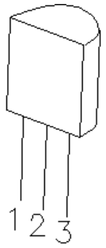
These items may be bought from stockroom.

- 10, 100, 1 k, & 10 kΩ, resistors
- 27, 18, 75, 270, 750 Ω, & 22 kΩ, resistors
- 2N3904 transistor

Meter Diode Setting
Recall from an earlier lab that most multimeters don't use enough voltage in the regular ohmmeter setting to forward bias a diode, so they give you a special setting to test diodes. If you don't use the special setting then the meter may show little or no conduction for either diode direction. Look for a diode symbol on your meter and set the meter to that position (It's a blue shift setting on the HP meter).

Experiment 1, Transistor diode test

(13 pts, Recommended) At its heart a bipolar junction (BJT) transistor consists of two pn junctions which can each individually act as diodes. These diodes can be tested just like any other diode, in particular, they can be tested with most multimeters. If both diodes test OK, and you measure no conductivity between the collector and emitter, then the transistor is almost always OK as well. This is a Q&D (quick-and-dirty) way to test a transistor and a good way to determine some important info about an unknown bipolar junction transistor.

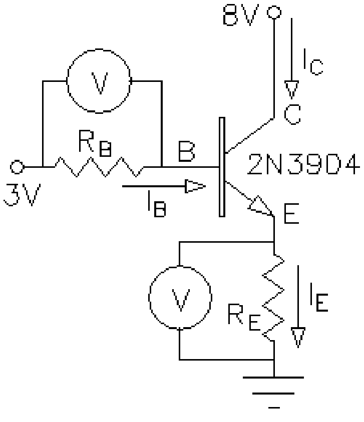


Multimeter transistor test: Set your multimeter or ohmmeter to its diode test setting. Make a sketch of the transistor showing the leads as 1, 2, & 3, and a little table like the one shown. Measure the conductivity all six ways and record the meter readings in your table. The meter should only indicate significant conductivity in two of the six cases. The common lead to those two cases is the base. Determine which lead is the base. Determine from your data if the transistor is an NPN (base is + lead in both cases) or a PNP (base is - lead in both cases). Also, your lowest meter reading will often indicate the base-collector junction, and thus which lead is the collector.

RED +	BLK −	Meter Shows Conduction?
1	2	
1	3	
2	3	
2	1	
3	1	
3	2	

Look at the data sheet for this transistor and see if you were right. (See the last page of this handout.) Comment in your notebook about the usefulness of this procedure.

Experiment 2, β vs I_C (27 pts, Recommended)



On the last page of this lab you'll find typical curves of ß verses I_C for the 2N3904 transistor. (The h_{FE} shown is the same as ß.) In this experiment you'll take data to plot a similar curve, in fact you'll plot your curve right on top of theirs.

Calculate R_E Values: Consider the circuit shown. V_{CC} is an 8 V supply and V_{BB} is a 3 V supply. Assume that I_B and thus the voltage drop across R_B are negligible so $V_B = 3$ V. Assume also that $V_{BE} = 0.7$ V, so $V_E \simeq 2.3$ V. Now, for each of the following emitter current values calculate values of R_E required to set the current at that value ($2.3\text{V}/I_E$).

a) $I_E = 0.1$ mA b) $I_E = 3$ mA c) $I_E = 8$ mA
d) $I_E = 30$ mA e) $I_E = 80$ mA

If you look at the resistors in the parts list, you'll find values close to the ones that you calculated. Calculate the power that will be dissipated by R_E in the last case and determine if one ¼ watt resistor will be alright. If it's just a little high, go ahead and use the ¼ watt resistor, but be aware that it will get hot.

Measurements for β: Make a table like the one below in your notebook. Fill in the R_E column with the resistor values that you have for each of the cases, a) through e).

	R_B	V_{RB}(mV)	I_B(µA)	R_E	V_E(mV)	I_E(mA)	I_C(mA)	ß
a)	10kΩ							
b)	1kΩ							
c)	1kΩ							
d)	100Ω							
e)	10Ω							

Make the circuit shown above, using two power supplies and two voltmeters if you have them. Use R_B and R_E from the first row in your table. Disconnect the R_B - base connection (or turn off the 3 V supply) to stop the base current. What happens to the emitter and collector currents? Reconnect and try varying 3 V a little. Does the base current control the emitter and collector currents?

Return your base supply to 3 V and record your voltmeter readings. The voltmeter across R_B shows V_{RB} and the voltmeter across R_E shows V_E. Repeat this procedure for each row in your table.

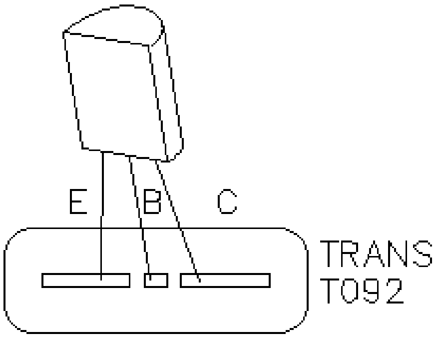
β calculations: Make the calculations necessary to fill in the rest of your table. ($I_C = I_E - I_B$) Find the typical curves of ß (h_{FE}) verses I_C on the last page of this lab (may be upside-down) and plot your β values onto the same graph. For our purposes you can assume that the β values are normalized to 200, as I've shown on the right side of the graph. Notice that the curves are drawn on a log-log scale to accommodate the large range of values. Cut and paste this graph in your notebook. Compare your curve shape to those published by Motorola. Don't panic if it's not all that close. One thing you should learn about transistors is that they vary widely from part to part.

Very often you will assume that $I_C \approx I_E$ when making transistor calculations. Look back at your table and comment about whether that assumption would have been reasonable in this case.

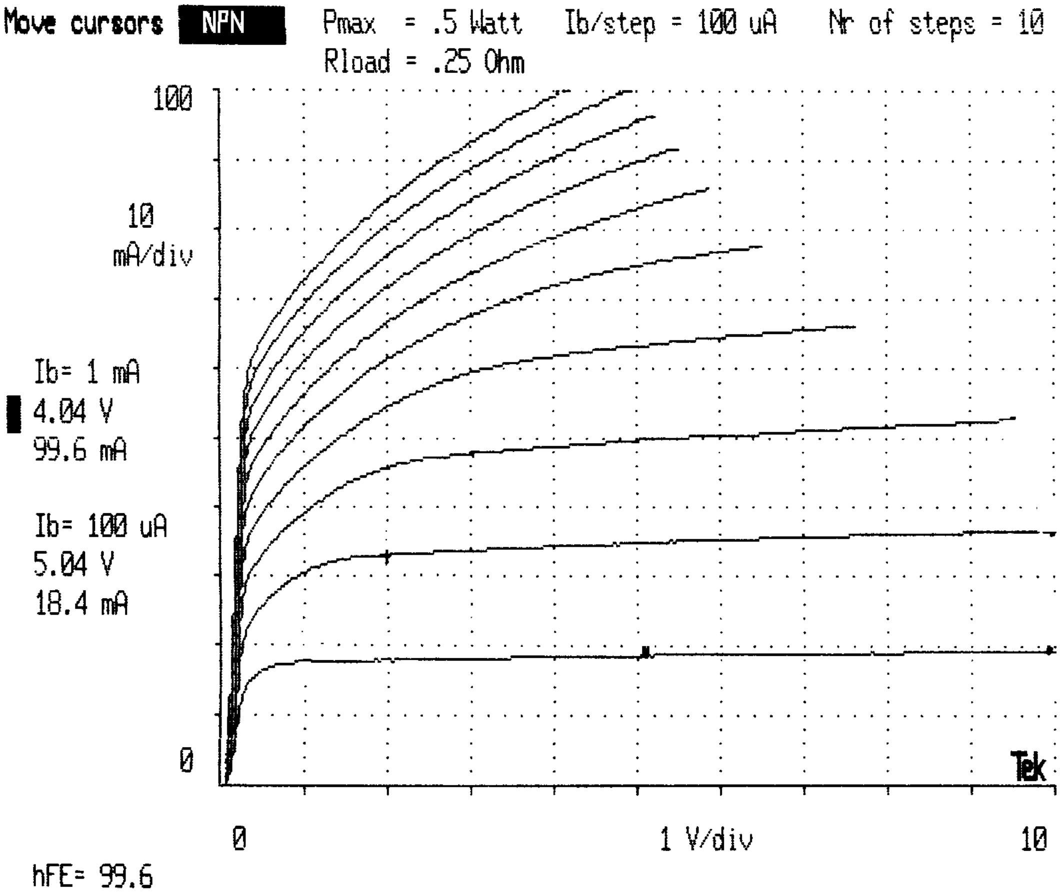
Experiment 3, Curve tracer (17 pts, Recommended)

On a table along the north wall of the lab there are two Tektronix 571 curve tracers. You may have used these before for diode curves. They can also be used to view and print the characteristic curves of transistors similar to Fig. 4.15, p.240 in your textbook.

First take a set of low-current curves. To use the curve tracers:



1. Turn on the curve tracer and the printer.
2. Work down through the menu;
   a) Function: Acquisition
   b) Type: NPN
   c) V_{CEmax}: 2 V
   d) I_{Cmax}: 1 mA
   e) I_b/step 0.5 µA
   f) Steps 10
   g) R_{load}: 10 Ω
   h) Pmax: 0.5 Watt
3. Place your transistor in the holder marked "TRANS T092" matching E, B, & C.
4. Hit **Start**.
5. When you have a set of curves, hit **Cursor**, you'll see a couple of small squares on the screen that you can move around with the arrow keys. The left side of the screen shows the I_B, V_{CE}, & I_C at each cursor location. (To switch between cursors, hit **Cursor** a second time.)
6. Using the cursor data, find β for the lowest curve and for the highest curve. (The curve tracer will calculate β for you and display it on the screen as h_{FE}.) Record the I_C values at each point where you find β so you'll be able to add these points to the graph you made earlier.
7. Hit **Menu** to change some of the curve parameters to;
   a) V_{CEmax}: 10 V
   b) I_{Cmax}: 100 mA
   c) I_b/step 100 µA
   d) R_{load}: 0.25 Ω
   Note: You may change these values as needed to get a good set of curves (see next page).
8. Hit **Start**, wait for the curves, hit **Cursor**, and find β for the lowest curve.
9. Move the cursor to a curve where $I_C \approx 30$ mA and find β. Repeat for $I_C \approx 80$ mA.
10. When the printer is free, switch the Data Transfer Switch to your curve tracer (A is left, B is right). Hit **Copy** to print and paste a set of curves in your lab notebook.



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Move cursors  NPN   Pmax  = .5 Watt   Ib/step = 100 uA   Nr of steps = 10
                    Rload = .25 Ohm

Ib= 1 mA
4.04 V
99.6 mA

Ib= 100 uA
5.04 V
18.4 mA

hFE= 99.6
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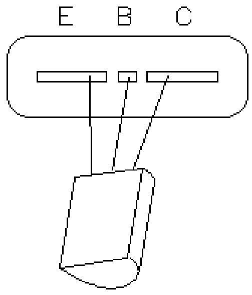
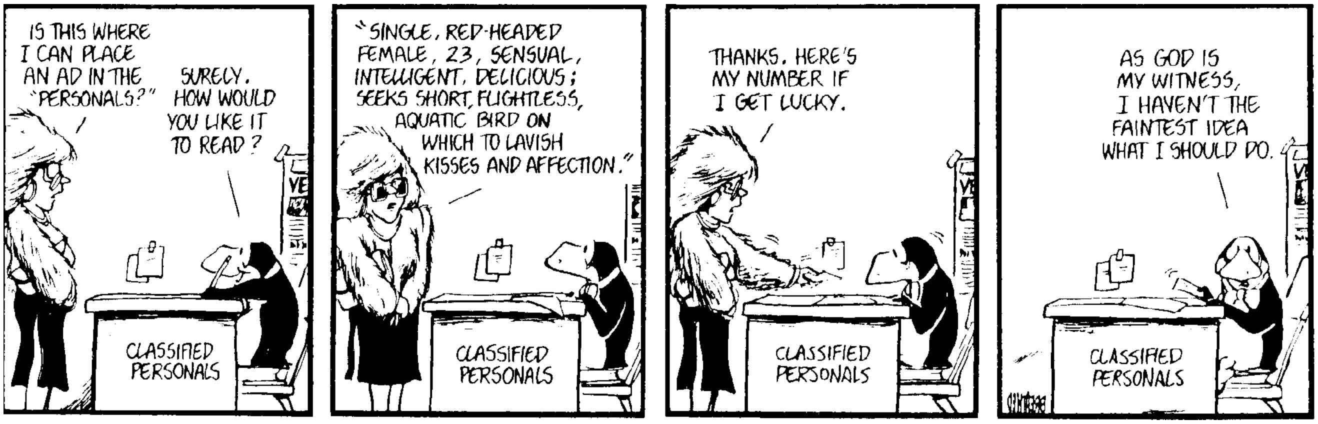
11. If you look at the very first figures in this lab you might get the impression that the transistor is symmetrical and that you could swap the emitter and collector leads and still have a useable transistor. Try this now in the curve tracer. Turn the transistor around and try to get some curves for this configuration. What is the β this way?

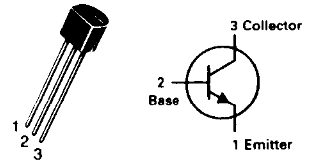


Plot the β values you found with the curve tracer onto the β vs I_C graph already in your notebook. Use different marks than you used before and make it clear where the different measurements come from. Comment on the results.



2N3903
2N3904★

CASE 29-04, STYLE 1
TO-92 (TO-226AA)



GENERAL PURPOSE TRANSISTORS

NPN SILICON

★This is a Motorola designated preferred device.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Vdc
Collector-Base Voltge	V_{CBO}	60	Vdc
Emitter-Base Voltage	V_{EBO}	6.0	Vdc
Collector Current — Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	625 5.0	mW mW/°C
*Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D	1.5 12	Watts mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +150	°C

*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W

*Indicates Data in addition to JEDEC Requirements.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Breakdown Voltage(1) (I_C = 1.0 mAdc, I_B = 0)		$V_{(BR)CEO}$	40	—	Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)		$V_{(BR)CBO}$	60	—	Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)		$V_{(BR)EBO}$	6.0	—	Vdc
Base Cutoff Current (V_{CE} = 30 Vdc, V_{EB} = 3.0 Vdc)		I_{BL}	—	50	nAdc
Collector Cutoff Current (V_{CE} = 30 Vdc, V_{EB} = 3.0 Vdc)		I_{CEX}	—	50	nAdc
ON CHARACTERISTICS					
DC Current Gain(1) (I_C = 0.1 mAdc, V_{CE} = 1.0 Vdc)	2N3903 2N3904	h_{FE}	20 40	— —	—
(I_C = 1.0 mAdc, V_{CE} = 1.0 Vdc)	2N3903 2N3904		35 70	— —	
(I_C = 10 mAdc, V_{CE} = 1.0 Vdc)	2N3903 2N3904		50 100	150 300	
(I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	2N3903 2N3904		30 60	— —	
(I_C = 100 mAdc, V_{CE} = 1.0 Vdc)	2N3903 2N3904		15 30	— —	
Collector-Emitter Saturation Voltage(1) (I_C = 10 mAdc, I_B = 1.0 mAdc) (I_C = 50 mAdc, I_B = 5.0 mAdc)		$V_{CE(sat)}$	— —	0.2 0.3	Vdc
Base-Emitter Saturation Voltage(1) (I_C = 10 mAdc, I_B = 1.0 mAdc) (I_C = 50 mAdc, I_B = 5.0 mAdc)		$V_{BE(sat)}$	0.65 —	0.85 0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS					
Current-Gain — Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	2N3903 2N3904	f_T	250 300	— —	MHz

TYPICAL STATIC CHARACTERISTICS

FIGURE 15 — DC CURRENT GAIN