Lab 4

Junction Transistor, Part I

REFERENCE: Horowitz and Hill — Section 2.01 - 2.12
Appendix G
Appendix K data sheet for 2N4400

INTRODUCTION

66 Junction transistors are either NPN or PNP, with the symbols in Figure 4-1.

Small signal-type transistors come in various pin configurations. An NPN in a TO-92 package is shown in Figure 4-2.

In the junction transistor, a small base current ($\approx$ few μA) controls a much larger Emitter-Collector current ($\approx$ 1.0 mA).

You will demonstrate the transistor in three common applications:

- Emitter Follower (Common Collector Amplifier)
- Transistor Switch
- Current Source (Better performing than the one in Lab 1)

This experiment will also improve your skills at wiring circuits and using test & measurement instruments.

EQUIPMENT

Prototyping board	
Digital Oscilloscope	
Function Generator	
Pulse Generator	
Digital Multimeter	
NPN Silicon Transistor	2N4400 for switching – you may substitute 2N2222 2N3904 for amplification
Light bulb	(typically # 47, 0.15 A @ 6.3 V, with wires)
Resistors	1 kΩ, 3.3 kΩ, 10kΩ, 22 kΩ, 33 kΩ, 1 MΩ
Decade Box	
Capacitors	0.1 μF

Amplifier Transistors
NPN Silicon

P2N2222A

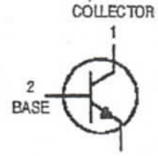
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector–Emitter Voltage	V_{CEO}	40	Vdc
Collector–Base Voltage	V_{CBO}	75	Vdc
Emitter–Base Voltage	V_{EBO}	6.0	Vdc
Collector Current — Continuous	I_C	600	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

CASE 29–11, STYLE 17
TO–92 (TO–226AA)



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

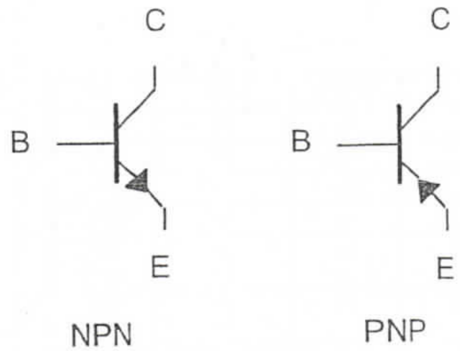
Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector–Emitter Breakdown Voltage ($I_C = 10$ mAdc, $I_B = 0$)	$V_{(BR)CEO}$	40	—	Vdc
Collector–Base Breakdown Voltage ($I_C = 10$ μAdc, $I_E = 0$)	$V_{(BR)CBO}$	75	—	Vdc
Emitter–Base Breakdown Voltage ($I_E = 10$ μAdc, $I_C = 0$)	$V_{(BR)EBO}$	6.0	—	Vdc
Collector Cutoff Current ($V_{CE} = 60$ Vdc, $V_{EB(off)} = 3.0$ Vdc)	I_{CEX}	—	10	nAdc
Collector Cutoff Current ($V_{CB} = 60$ Vdc, $I_E = 0$) ($V_{CB} = 60$ Vdc, $I_E = 0$, $T_A = 150°C$)	I_{CBO}	 — —	 0.01 10	μAdc
Emitter Cutoff Current ($V_{EB} = 3.0$ Vdc, $I_C = 0$)	I_{EBO}	—	10	nAdc
Collector Cutoff Current ($V_{CE} = 10$ V)	I_{CEO}	—	10	nAdc
Base Cutoff Current ($V_{CE} = 60$ Vdc, $V_{EB(off)} = 3.0$ Vdc)	I_{BEX}	—	20	nAdc

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

Characteristic	Symbol	Min	Max	Unit
ON CHARACTERISTICS				
DC Current Gain ($I_C = 0.1$ mAdc, $V_{CE} = 10$ Vdc) ($I_C = 1.0$ mAdc, $V_{CE} = 10$ Vdc) ($I_C = 10$ mAdc, $V_{CE} = 10$ Vdc) ($I_C = 10$ mAdc, $V_{CE} = 10$ Vdc, $T_A = -55°C$) ($I_C = 150$ mAdc, $V_{CE} = 10$ Vdc)(1) ($I_C = 150$ mAdc, $V_{CE} = 1.0$ Vdc)(1) ($I_C = 500$ mAdc, $V_{CE} = 10$ Vdc)(1)	h_{FE}	 35 50 75 35 100 50 40	 — — — — 300 — —	—
Collector–Emitter Saturation Voltage(1) ($I_C = 150$ mAdc, $I_B = 15$ mAdc) ($I_C = 500$ mAdc, $I_B = 50$ mAdc)	$V_{CE(sat)}$	 — —	 0.3 1.0	Vdc
Base–Emitter Saturation Voltage(1) ($I_C = 150$ mAdc, $I_B = 15$ mAdc) ($I_C = 500$ mAdc, $I_B = 50$ mAdc)	$V_{BE(sat)}$	 0.6 —	 1.2 2.0	Vdc

PROCEDURE

Figure 4-1



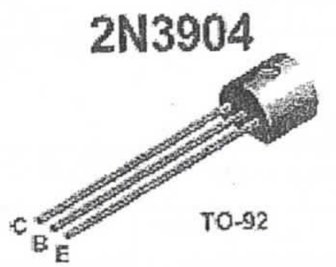


Figure 4-2.

" The 2N3904 and 2N4400 are similar, except that:

- 2N4400 withstands a higher collector current, and is therefore better suited for switching circuits (you may you may substitute 2N2222 for 2N4400).
- 2N3904 is better suited for signal amplifier circuits.

1. Multimeter Check of Transistor

This test is similar to the one you did in Lab 3 with the diode. If you are unsure of how to do this test, first go back to Lab 3 and repeat the diode test.

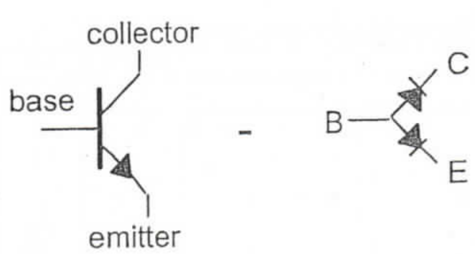


Figure 4-3

(a) Diode equivalent

☛ ✍ Use your multimeter's diode-check feature. It will display the forward bias voltage. Verify that the transistor looks like two diodes, as shown in Figure 4-3.

(b) Beta measurement

☛ ✍ If your multimeter has special connectors labeled C B E, then it has a transistor check function. For some multimeters, this will display the beta, or h_{FE}. Try it. For the 2N3904, beta is typically $h_{FE} \approx 210$.

2. Emitter Follower

(a) Emitter-Follower Operation

☛ Using the ± 12 Volt power supply that is built into your prototyping board, wire up an NPN transistor as an emitter follower, as shown in Figure 4-4.

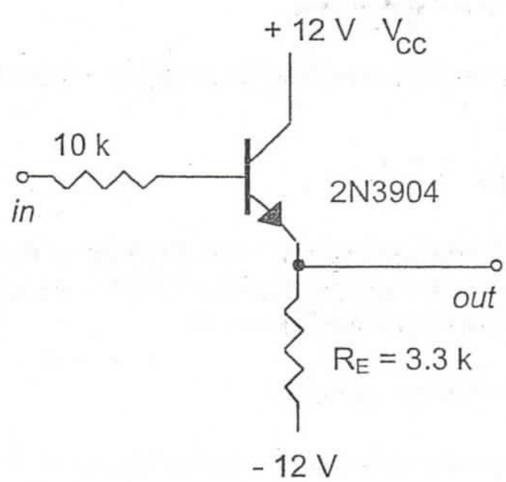


Figure 4-4

☛ Hint: On your prototyping board, use wires to connect the outputs of the ± 12 V power supply and ground (three wires in all) as shown in the left of Figure 4-5 to a couple of strips that look like those shown on the right of Figure 4-5:

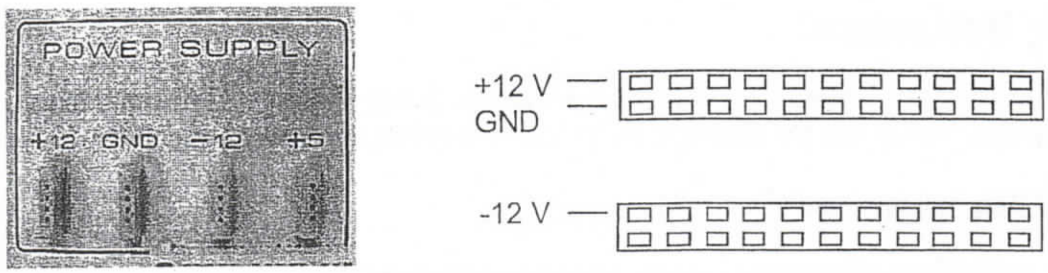


Figure 4-5. Power supply on prototyping board (left). Connect these using wires to the strips sketched on the right for convenient use.

☞ Set up the function generator to produce a sine wave that is symmetric about zero volts (turn off the "offset"). Initially, adjust it for f ≈ 1 kHz and P-P amplitude ≈ 2 V.

☞ Set up the oscilloscope to show a dual-trace, using DC input coupling, with one channel showing *in*, and the other showing *out*.

☞ Be sure the grounds of the oscilloscope, function generator, and prototyping board are connected.

(i) input and output waveforms

☞ ✍ Print the oscilloscope display, and number your printout so that you can identify it in your report. Repeat for an input amplitude that is much larger and much smaller. Comment on any significant differences.

(ii) operation with non-symmetric power supply

☞ ✍ Now connect the emitter return (the resistor on the bottom of the figure) to ground instead of - 12 V. Observe the display for several amplitudes of input. Explain how the circuit functions more poorly.

(iii) breakdown

☞ ✍ Look for bumps appearing at reverse bias. This is called breakdown. Measure the breakdown voltage, i.e., the voltage at which breakdown first occurs. Compare your result to the specification in a data sheet for the transistor. [Note, the breakdown voltage specifications for the 2N3904 and the 2N4400 are identical, so for this purpose you may use either data sheet.]

(iv) voltage gain

☞ Connect the emitter return back to -12 V. Add a blocking capacitor to the output as shown in Figure 4-6.

❝ Why don't we use a blocking capacitor on the input? It's not necessary. When the function generator feeds the base directly, the DC bias of the base is held to that of the function generator, which is near the middle of the transistor's operating region. That's where we want it.

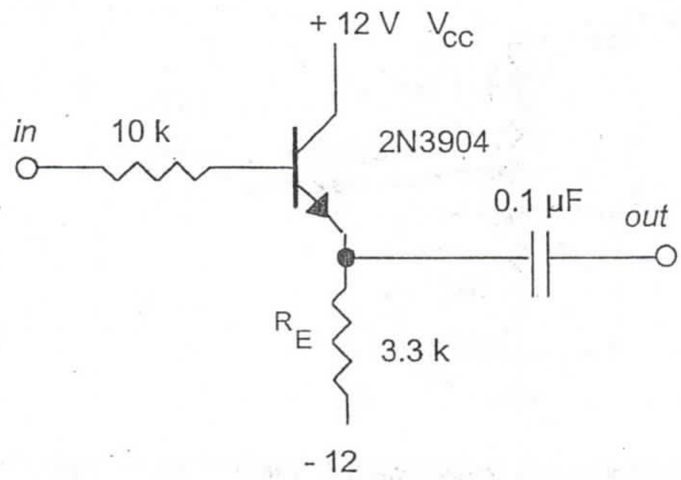


Figure 4-6

☞ ✍ Adjust the input amplitude of the sine wave from the function generator so that the output looks like a good sine wave. Measure the ac voltage gain.

(v) blocking capacitor test

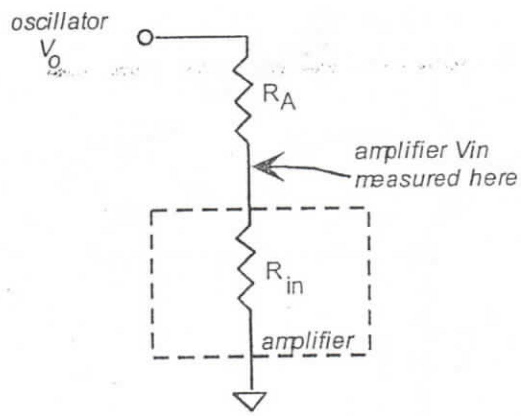
☞ ✍ Use your oscilloscope with dc coupling to measure the dc bias of the output on each side of the output capacitor. Confirm that the output capacitor is blocking a dc bias.

> ❝ *Note: the following procedures for measuring input and output impedances will be used again in later experiments.*

(b) Input Impedance

❝ You will measure the input impedance Z_{in}. Because there is no significant capacitance or inductance at the input of this circuit, we can write that $Z_{in} = R_{in}$.

You will connect a large input resistor R_A in series with the input impedance. Use the idea that the two in combination look like a voltage divider, as shown below. If the oscillator produces a voltage V_{osc}, and the voltage at the input of the amplifier is V_{in}, then $V_{in} / V_{osc} = R_{in} / (R_{in} + R_A)$. This can be re-arranged to read $R_{in} = R_A / [V_{osc} / V_{in} - 1]$. If your amplifier has a gain of unity, then you can use the output voltage in place of V_{in}.



Equivalent circuit for input impedance measurement. The dashed box represents the entire amplifier circuit, which to the oscillator looks like an impedance R_{in}.

☞ Insert a large-value resistor R_A (typically 1 MΩ) in series with the function generator on the input of the amplifier, as shown in Figure 4-7.

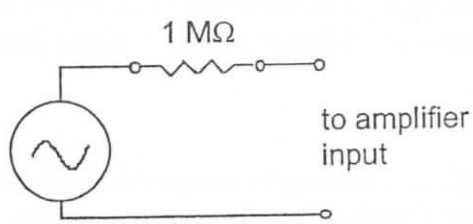


Figure 4-7

☞ ✍ Use the oscilloscope with AC input coupling to measure the output signal with and without the large input resistor R_A.

✍ Calculate the input impedance R_{in}. If you measured h_{fe} earlier, compare your result for R_{in} to the formula given in the **text**, p. 66: $R_{in} = (h_{fe} + 1)R_E$.

(c) <u>Output Impedance</u>

❝ To measure an amplifier's output impedance, you will connect a load resistor across the output. Recall that when two resistances R_1 R_2 are connected in parallel, the parallel resistance is $R_{eff} = R_1 R_2 / (R_1 + R_2)$. When the two resistances are identical, $R_1 = R_2 = R$, then $R_{eff} = R/2$. Now consider that a load resistance connected across the output of an amplifier is effectively a resistance in parallel with the output impedance of the amplifier. If a *fixed* current i passes through the effective resistance, the voltage drop across it as given by $v = i R$ will be reduced by half, if R is reduced by half.

☛ Set the decade box resistance (R_L) to the largest possible value. Then connect the decade box across the output of the amplifier, to serve as a load resistance, as shown in Figure 4-8.

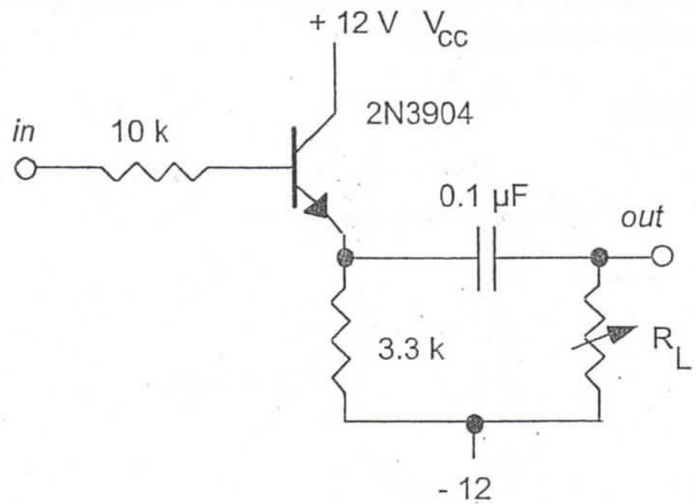


Figure 4-8

☛ ✍ Adjust the input signal to obtain a good sine wave on the output. Then reduce R_L until the peak-to-peak output signal falls by ½. Then, R_L equals the output impedance of the circuit.

(d) Comparison

✍ Compare the measured input and output impedances by calculating their ratio R_{out} / R_{in}. Usually it is desirable for an amplifier to have a *high input impedance* and a *low output impedance.* To what extent is that true here?

3. Transistor switch

❝ Transistors are used often as switches. One application is "cold switching", where a remotely located mechanical switch, which carries little current, controls a larger current someplace else.

❝ A transistor switch operates in the *saturated* mode when the switch is "on", and in the *cutoff* mode when the switch is "off". It should not be operated in the *normal or linear* mode, where $I_C = h_{fe} I_B$. See Appendix G in the **text** for more on saturation.

☞ Use a wire on your prototyping board instead of a mechanical switch.

☞ Using the + 5 Volt power supply that is built into your prototyping board, wire up an NPN transistor as a "cold switch", as shown in Figure 4-9. The lamp is the "load" here. (The 10 k resistor is not essential-- it makes sure that the base is near ground potential when the switch is open.)

(a) Cold switching

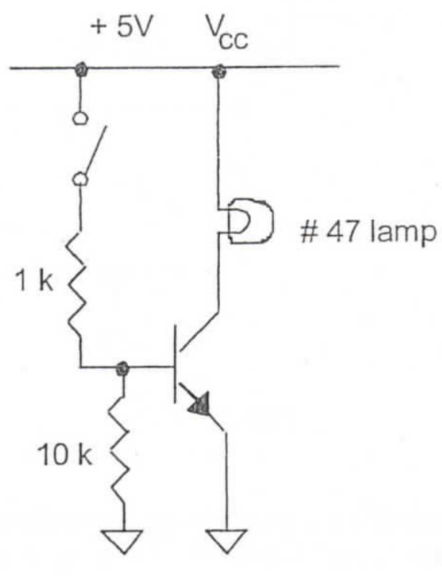


Figure 4-9. Cold switching

☞ ✍ Verify that the lamp is turned on as you close the mechanical switch and off as you open it.

(b) Current through the switch

☞ ✍ Setting your multimeter to operate in its highest current range to begin with, use it to measure the current flowing through the lamp.

☞ ✍ Setting your multimeter to measure voltage, measure the voltage-drop across the two resistors. Compute the current flowing into the base.

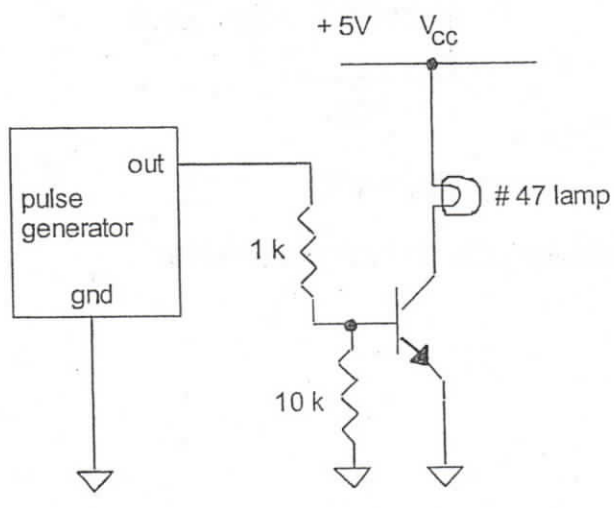
✍ Comparing these two currents, is it true that the "cold switch" allows you to switch a larger current through the load (lamp) than passes through the actual switch?

(c) Saturation mode

☞ ✍ With the switch closed, use your multimeter to measure the DC voltage drops V_{CE} and V_{BE}.

✍ Is $V_C < V_B$ as expected for saturation?

(c) Cold switching from a pulse generator's output



☞ Replace the manual switch with the pulse generator's output, as shown in the diagram, so that a high output from the pulse generator will cause the lamp to light. Adjust the pulse generator to produce its maximum output voltage and maximum period.

☞ ✍ Verify that the lamp is turned on and off periodically, and estimate the period.

4. Current Source

" A current source (Figure 4-10) will supply a constant current to a range of load resistances. The current that is "sourced" or "sinked" is determined by the emitter potential and the emitter resistor R_E.

A transistor current source is a far better current source than the crude voltage-resistor combination you tested in Lab1.

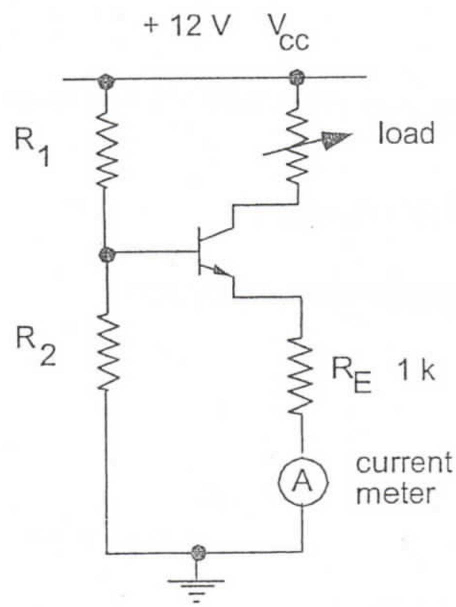


Figure 4-10

Use $R_1 = 22$ k and $R_2 = 33$ k for the biasing resistors.

(a) Calculation

☞ ✍ Measure the component values. Then calculate:
- the bias on the base.
- the potential at the emitter (assuming an 0.6 V B-E drop).

(b) Experiment

CAUTION:
In using the current measurement function of the multimeter, start at the highest possible range.

☞ Using the +12 V power supply built into your prototyping board, connect the circuit shown in Figure 4-10. For the load resistor, use a decade box, set to 2 kΩ to begin.

(i) comparison to calculated values

☞ ✍ Measure and compare to the values calculated above:
the bias on the gate.
the potential at the emitter.

(ii) current vs. load resistance

☞ Vary R_L from 100 Ω to 2 kΩ, in 100 Ω increments.

✍ Make a table of current vs. load resistance.

(iii) compliance

✍ Determine the range of load over which the current remains constant to 10%. Compare this result to your result in Lab 1 with the crude current source.