Laboratory 5

Transistor and Photoelectric Circuits

Required Components:

- 1 330Ω resistor
- 2 1 kΩ resistors
- 1 10kΩ resistor
- 1 2N3904 small signal transistor
- 1 TIP31C power transistor
- 1 1N4001 power diode
- 1 Radio Shack 1.5-3V DC motor (RS part number: 273-223)
- 1 LED
- 1 photodiode/phototransistor pair (Digikey part number: H21A1QT-ND)

5.1 Objectives

In this laboratory, you will study bipolar junction transistors (BJTs) and common photoelectric components. You will learn how to use light-emitting diodes (LEDs) as indicators, switch an inductive load with a power BJT, and use LED and phototransistor pairs as photo-interrupters. You will also learn how to bias a transistor and how to provide flyback protection with a diode.

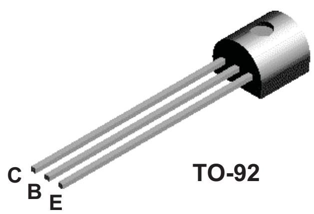
5.2 Introduction

The following two pages provide information from the 2N3904 transistor data sheet. Data sheets provide pin-out information, where each pin is labeled with a function name and, if appropriate, a number. A data sheet also provides detailed electrical specifications that can help you properly design a circuit using the component.

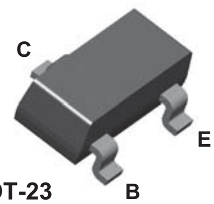
Figure 5.1 illustrates the nomenclature used to describe the behavior of an npn bipolar transistor. It is a three terminal device consisting of the base, collector, and emitter. The transistor acts like a current valve by using the voltage bias across the base and emitter (V_{BE}) to control the flow of current in the collector-emitter circuit (I_C). The circuit connected to the collector and emitter along with the bias voltage dictate how much current flows.

FAIRCHILD
SEMICONDUCTOR ™

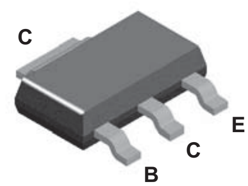
2N3904 MMBT3904 PZT3904



TO-92



SOT-23
Mark: 1A



SOT-223

NPN General Purpose Amplifier

This device is designed as a general purpose amplifier and switch. The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics

T_A = 25°C unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	***MMBT3904**	****PZT3904**	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

**Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

NPN General Purpose Amplifier
(continued)

Electrical Characteristics
T_A = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0 mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10 μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10 μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1 mA, V_{CE} = 1.0 V I_C = 1.0 mA, V_{CE} = 1.0 V I_C = 10 mA, V_{CE} = 1.0 V I_C = 50 mA, V_{CE} = 1.0 V I_C = 100 mA, V_{CE} = 1.0 V	40 70 100 60 30	 300 	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10 mA, V_{CE} = 20 V, f = 100 MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0 V, I_E = 0, f = 1.0 MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5 V, I_C = 0, f = 1.0 MHz		8.0	pF
NF	Noise Figure	I_C = 100 μA, V_{CE} = 5.0 V, R_S =1.0kΩ,f=10 Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0 V, V_{BE} = 0.5 V,		35	ns
t_r	Rise Time	I_C = 10 mA, I_{B1} = 1.0 mA		35	ns
t_s	Storage Time	V_{CC} = 3.0 V, I_C = 10mA		200	ns
t_f	Fall Time	I_{B1} = I_{B2} = 1.0 mA		50	ns

*Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%

Spice Model

NPN (Is=6.734f Xti=3 Eg=1.11 Vaf=74.03 Bf=416.4 Ne=1.259 Ise=6.734 Ikf=66.78m Xtb=1.5 Br=.7371 Nc=2 Isc=0 Ikr=0 Rc=1 Cjc=3.638p Mjc=.3085 Vjc=.75 Fc=.5 Cje=4.493p Mje=.2593 Vje=.75 Tr=239.5n Tf=301.2p Itf=.4 Vtf=4 Xtf=2 Rb=10)

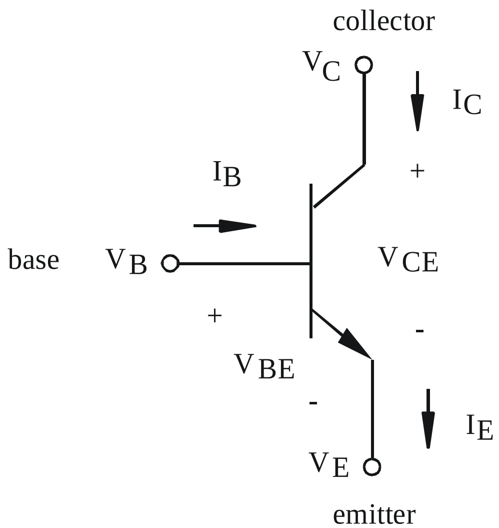


Figure 5.1 npn Bipolar Transistor Symbol and Nomenclature

Here are some general relationships between the variables shown in Figure 5.1:

$$V_{BE} = V_B - V_E \tag{5.1}$$

$$V_{CE} = V_C - V_E \tag{5.2}$$

$$I_E = I_B + I_C \tag{5.3}$$

Also, generally,

$$V_C > V_E \tag{5.4}$$

When the transistor is in saturation (i.e., fully ON),

$$V_{BE} \approx 0.6\text{V to } 0.7\text{V}, \quad V_{CE} \approx 0.2\text{V}, \quad \text{and} \quad I_C >> I_B \tag{5.5}$$

and when the transistor is in its cutoff state,

$$V_{BE} < 0.6\text{V} \quad \text{and} \quad I_B = I_C = I_E = 0 \tag{5.6}$$

In the cutoff state, the transistor does not conduct current.

5.3 Laboratory Procedure / Summary Sheet

Group: ____ Names: ______________________________ ______________________________

______________________________ ______________________________

(1) Build the simple LED indicator circuit shown below (without the 2nd resistor). See Figure 4.7 in Lab 4 to identify the LED polarity. Gradually increase V_{in} from 0 V to 5 V and record V_{in} and measure V_D when you consider the LED to be on. Also **calculate** (don't measure) the current I_D based on the recorded voltages.

Vin = __________

V_D = __________

I_D = __________

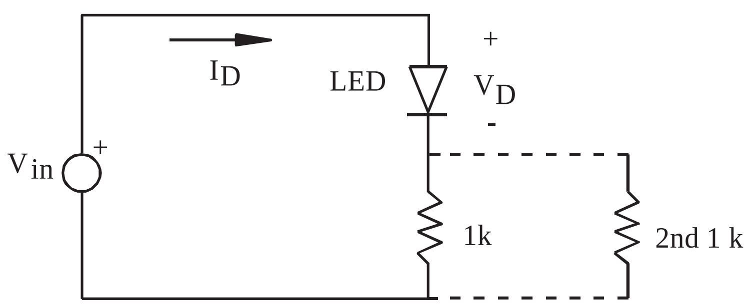


Figure 5.2 LED Circuit

(2) Add the second resistor in parallel and repeat the same experiment.

Vin = __________

V_D = __________

I_D = __________

Explain what happened and why.

(3) Build a simple transistor switch (see figure below) using a 2N3904 small signal transistor and a base resistor (R_B) of 1 kΩ. Use the function generator for V_{in} so it can be later adjusted in small increments. Use the DC power supply for the 10V source.

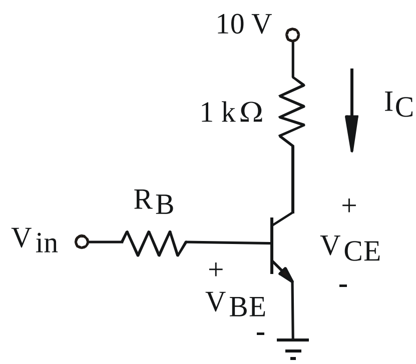


Figure 5.3 Transistor Switch

Use the 2N3904 datasheet provided in Section 5.2 to help you **draw and label the pins on the figure below** and to record the following values:

maximum allowed I_C = ___________ maximum allowed V_{CE} = ______________

minimum required V_{BE} for saturation = _____________

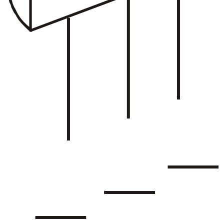


Figure 5.4 2N3904 Pin-out

Vary V_{in} as indicated in the table below and record the associated values for V_{BE} and V_{CE}. Use R_B = 1 kΩ for the base resistor.

V_{in}	V_{BE}	V_{CE}
0.0		
0.4		
0.5		
0.6		
0.7		
0.8		
0.9		
1.0		

Describe your conclusions about when saturation occurs for the transistor.

Change the base resistor (R_B) to 10 kΩ and repeat the measurements.

V_{in}	V_{BE}	V_{CE}
0.0		
0.4		
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		

What is the effect of a larger base resistor? Why?

(4) Build the circuit shown in Figure 5.5 with a TIP31C transistor (note the pinout shown in the right side of the diagram below) and a 1.5V-3V DC motor. The TIP31C transistor is required to provide adequate current to the motor. Be sure to use the flyback diode as shown. This diode provides protection to the transistor when control signal V_{in} is turned off. Flyback diodes are recommended when switching inductive loads such as motors and solenoids. The 1N4001 power diode is well suited to this motor since the motor current is well within the surge current capacity of the diode.

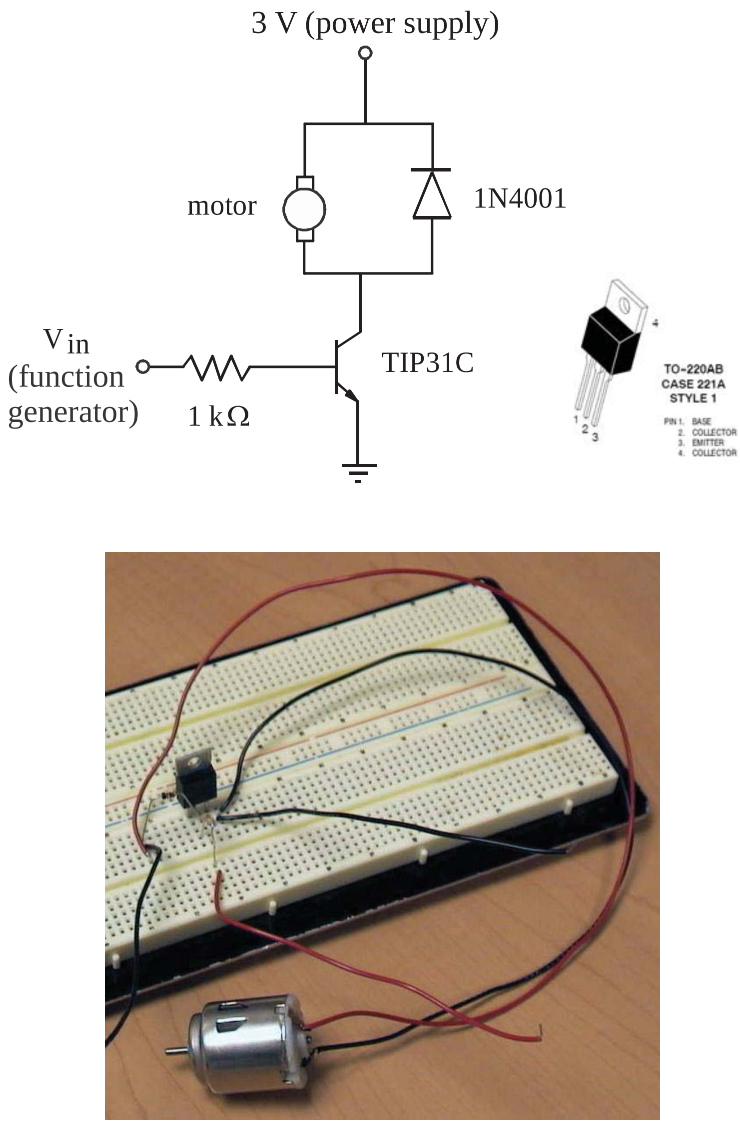


Figure 5.5 Motor and Flyback Diode

Gradually increase V_{in} from 0 V to 10 V and describe what happens.

Apply a 5Vpp, 2.5V dc offset (0 to 5V) square wave input to V_{in}. Start with a low frequency (e.g., 1 Hz) and then try some higher frequencies, increasing the frequency in 1 Hz increments up to 20 Hz and then 10 Hz increments up to 100 Hz. Describe what happens.

Explain how the flyback diode works.

(5) Examine the photo-interrupter and look at its specifications. Build the circuit shown in Figure 5.6, using the resistors indicated. Note that a single 5V source can be used to provide both voltage signals, and the ground for the input and output circuits must be connected to be common.

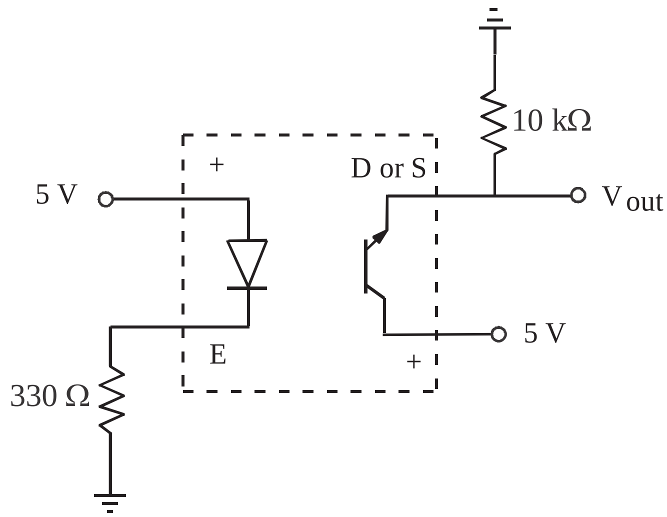


Figure 5.6 Photo-interrupter

Measure the output voltage (V_{out}) with and without the beam interrupted (e.g., with a thick sheet of paper or a plastic card). What conditions (interrupted or not) correspond to the high and low states of the output? Explain why each condition results in the respective state.

Why are the resistors required?