

# Laboratory 6 (drawn from lab text by Alciatore)

## *Transistor and Photoelectric Circuits*

---

### Required Components:

- 1x 330 $\Omega$  resistor
- 2x 1 k $\Omega$  resistors
- 1x 10k $\Omega$  resistor
- 1x 2N3904 small signal transistor
- 1x TIP31C power transistor
- 1x 1N4004 small-signal diode
- 1 Radio Shack 1.5-3V DC motor (RS part number: 273-223)
- 1x LED
- 1x photodiode/phototransistor pair (Newark part# 95B4823) or infrared diode/detector pair


### 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.


### 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 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.



October 2014

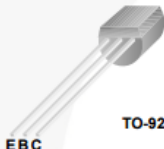


## 2N3904 / MMBT3904 / PZT3904 NPN General-Purpose Amplifier

**Description**

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.

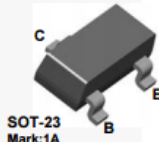
**2N3904**



TO-92

EBC

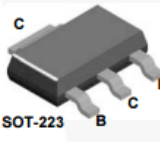
**MMBT3904**



SOT-23  
Mark:1A

C B E

**PZT3904**



SOT-223

C B E

2N3904 / MMBT3904 / PZT3904 — NPN General-Purpose Amplifier

**Absolute Maximum Ratings**<sup>(1), (2)</sup>

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at  $T_A = 25^\circ\text{C}$  unless otherwise noted.

Symbol	Parameter	Value	Unit
$V_{CEO}$	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	$^\circ\text{C}$

**Notes:**

- These ratings are based on a maximum junction temperature of  $150^\circ\text{C}$ .
- These are steady-state limits. Fairchild Semiconductor should be consulted on applications involving pulsed or low-duty cycle operations.

**Thermal Characteristics**

Values are at  $T_A = 25^\circ\text{C}$  unless otherwise noted.

Symbol	Parameter	Maximum			Unit
		2N3904	MMBT3904 <sup>(3)</sup>	PZT3904 <sup>(4)</sup>	
$P_D$	Total Device Dissipation	625	350	1,000	mW
	Derate Above $25^\circ\text{C}$	5.0	2.8	8.0	mW/ $^\circ\text{C}$
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			$^\circ\text{C}/\text{W}$
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	$^\circ\text{C}/\text{W}$

**Notes:**

- Device is mounted on FR-4 PCB 1.6 inch X 1.6 inch X 0.06 inch.
- Device is mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm, mounting pad for the collector lead minimum  $6\text{ cm}^2$ .

2N3904 / MMBT3904 / PZT3904 — NPN General-Purpose Amplifier

### Electrical Characteristics

Values are at  $T_A = 25^\circ\text{C}$  unless otherwise noted.

Symbol	Parameter	Conditions	Min.	Max.	Unit
<b>OFF CHARACTERISTICS</b>					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	$I_C = 1.0\text{ mA}, I_B = 0$	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	$I_C = 10\text{ }\mu\text{A}, I_E = 0$	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 10\text{ }\mu\text{A}, I_C = 0$	6.0		V
$I_{BL}$	Base Cut-Off Current	$V_{CE} = 30\text{ V}, V_{EB} = 3\text{ V}$		50	nA
$I_{CEX}$	Collector Cut-Off Current	$V_{CE} = 30\text{ V}, V_{EB} = 3\text{ V}$		50	nA
<b>ON CHARACTERISTICS<sup>(5)</sup></b>					
$h_{FE}$	DC Current Gain	$I_C = 0.1\text{ mA}, V_{CE} = 1.0\text{ V}$	40		
		$I_C = 1.0\text{ mA}, V_{CE} = 1.0\text{ V}$	70		
		$I_C = 10\text{ mA}, V_{CE} = 1.0\text{ V}$	100	300	
		$I_C = 50\text{ mA}, V_{CE} = 1.0\text{ V}$	60		
		$I_C = 100\text{ mA}, V_{CE} = 1.0\text{ V}$	30		
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	$I_C = 10\text{ mA}, I_B = 1.0\text{ mA}$		0.2	V
		$I_C = 50\text{ mA}, I_B = 5.0\text{ mA}$		0.3	
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	$I_C = 10\text{ mA}, I_B = 1.0\text{ mA}$	0.65	0.85	V
		$I_C = 50\text{ mA}, I_B = 5.0\text{ mA}$		0.95	
<b>SMALL SIGNAL CHARACTERISTICS</b>					
$f_T$	Current Gain - Bandwidth Product	$I_C = 10\text{ mA}, V_{CE} = 20\text{ V},$ $f = 100\text{ MHz}$	300		MHz
$C_{obo}$	Output Capacitance	$V_{CB} = 5.0\text{ V}, I_E = 0,$ $f = 100\text{ kHz}$		4.0	pF
$C_{ibo}$	Input Capacitance	$V_{EB} = 0.5\text{ V}, I_C = 0,$ $f = 100\text{ kHz}$		8.0	pF
NF	Noise Figure	$I_C = 100\text{ }\mu\text{A}, V_{CE} = 5.0\text{ V},$ $R_S = 1.0\text{ k}\Omega,$ $f = 10\text{ Hz to }15.7\text{ kHz}$		5.0	dB
<b>SWITCHING CHARACTERISTICS</b>					
$t_d$	Delay Time	$V_{CC} = 3.0\text{ V}, V_{BE} = 0.5\text{ V}$ $I_C = 10\text{ mA}, I_{B1} = 1.0\text{ mA}$		35	ns
$t_r$	Rise Time			35	ns
$t_s$	Storage Time	$V_{CC} = 3.0\text{ V}, I_C = 10\text{ mA},$ $I_{B1} = I_{B2} = 1.0\text{ mA}$		200	ns
$t_f$	Fall Time			50	ns

**Note:**

5. Pulse test: pulse width  $\leq 300\text{ }\mu\text{s}$ , duty cycle  $\leq 2.0\%$ .

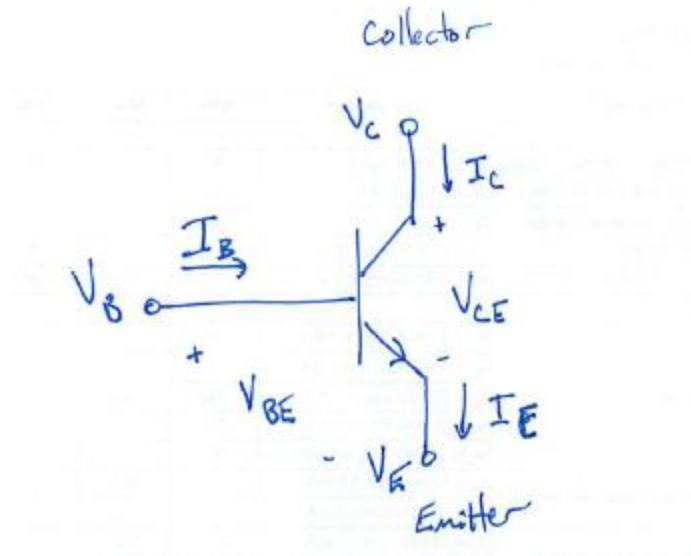


Figure 1: 1 npn bipolar transistor symbol and nomenclature.

Here are some general relationships between the variables shown in Figure 1:

$$V_{BE} = V_B - V_E \quad (1)$$

$$V_{CE} = V_C - V_E \quad (2)$$

$$I_E = I_B + I_C \quad (3)$$

Also, generally,

$$V_C > V_E \quad (4)$$

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

$$V_{BE} \approx 0.6V \text{ to } 0.7V, \quad V_{CE} \approx 0.2V, \text{ and } I_C \gg I_B \quad (5)$$

and when the transistor is in its cutoff state,

$$V_{BE} < 0.6V \text{ and } I_C = I_B = I_E = 0 \quad (6)$$

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

## Laboratory Procedure / Summary Sheet

Names: \_\_\_\_\_

1. Build the simple LED indicator circuit shown below (without the 2nd resistor). See Section 3.3.3 in textbook 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.

$V_{in} =$  \_\_\_\_\_

$V_D =$  \_\_\_\_\_

$I_D =$  \_\_\_\_\_

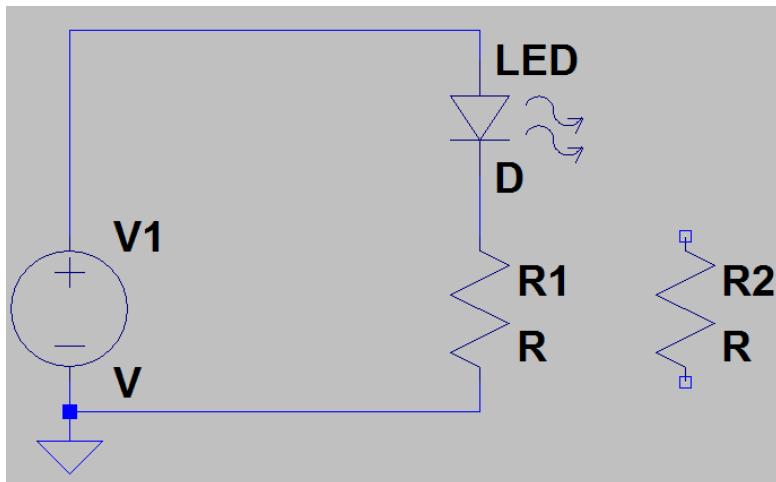


Figure 2 LED circuit.

2. Add the second resistor in parallel and repeat the same experiment looking for the  $V_{in}$  that makes the LED the same brightness as before.

$V_{in} =$  \_\_\_\_\_

$V_D =$  \_\_\_\_\_

$I_D =$  \_\_\_\_\_

Explain what happens and why.

- Build a simple transistor switch (See figure below) using a 2N3904 small signal transistor and a base resistor ( $R_B$ ) of  $1\text{ k}\Omega$ . Use one channel of the DC power supply with a voltage meter to supply  $V_{in}$ . Use another channel of the DC power supply for  $V_2 = 10\text{V}$ .

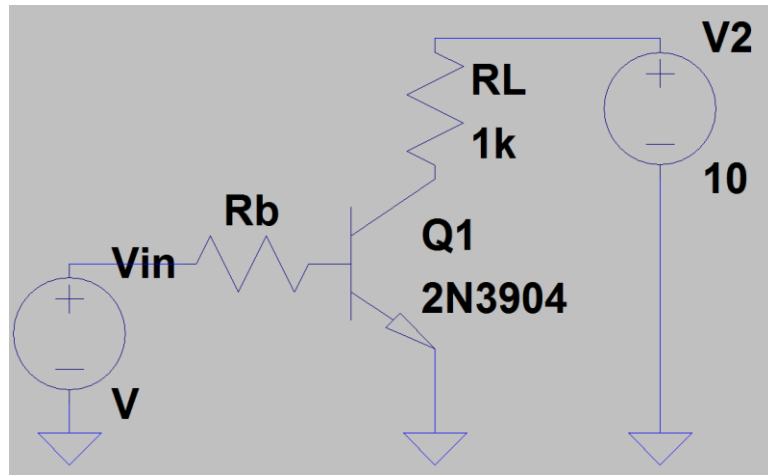


Figure 3 Transistor switch circuit.

Label the pins of the transistor in Fig. 3. Now use the 2N3904 datasheet provided to help you **draw and label the pins on Fig. 4** and to record the following values:

$I_{C(max)} =$  \_\_\_\_\_  $V_{CE(max)} =$  \_\_\_\_\_

$V_{BE(sat)} =$  \_\_\_\_\_

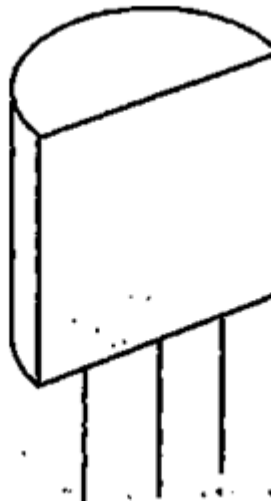


Figure 4 2N3904 pin-out.

\_\_\_\_\_

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

Laboratory 6, Transistors and Photoelectric Circuits

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

Graph your data and describe your conclusions about when saturation occurs for the transistor.

Change the base resistor ( $R_B$ ) to 10 k $\Omega$  and repeat the measurements.

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

Graph your data and explain what the effect of a larger base resistor is? Why is this so?

## Laboratory 6, Transistors and Photoelectric Circuits

- Build the circuit shown in Figure 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 1N4004 diode is well suited to this motor" since the motor current is well within the surge current capacity of the diode.

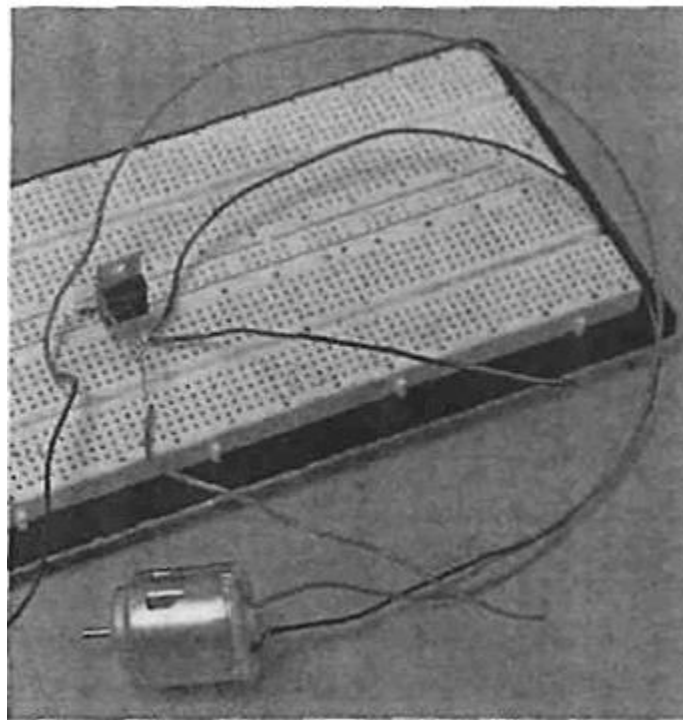
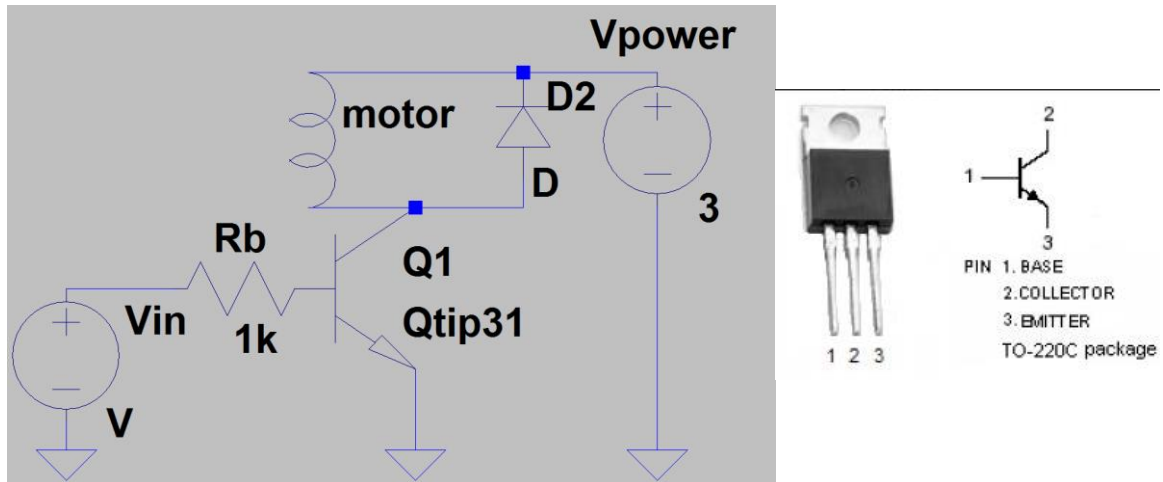


Figure 5 Motor and flyback diode.

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



## Laboratory 6, Transistors and Photoelectric Circuits

Apply a  $4V_{pp}$ , 8V DC offset (0 to 8V) 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 6, using the resistors indicated. Note that a single 5V source can be used to provide both voltage signals.

Laboratory 6, Transistors and Photoelectric Circuits

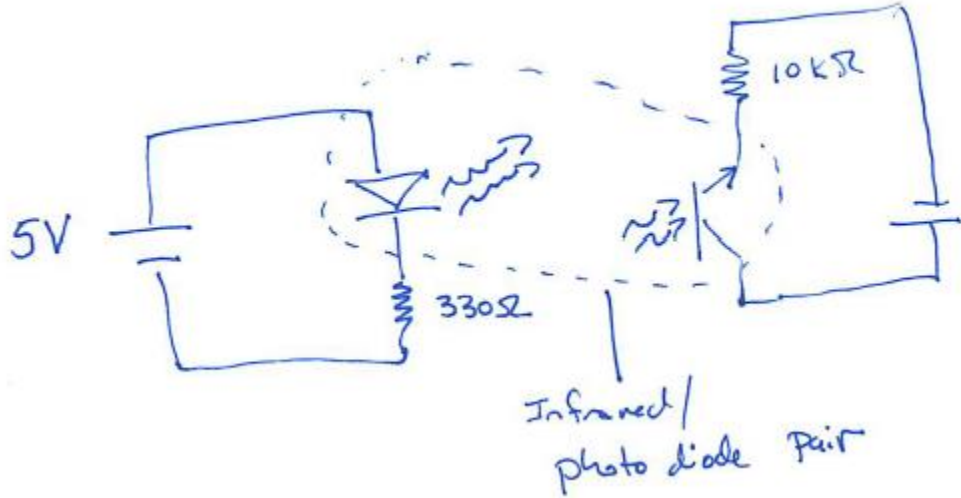
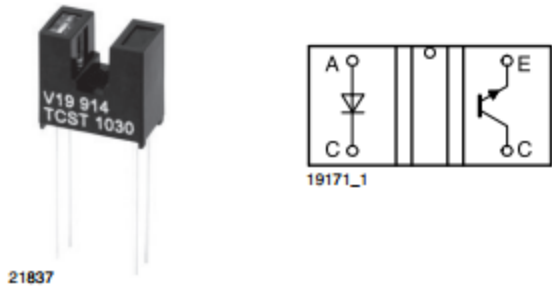


Figure 6 Photo-interrupter, use 5V for both DC voltage sources.  $V_{out}$  is the voltage across the 10kOhm resistor

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?