Engineer's Mini-Notebook
Basic Semiconductor Circuits

Forrest M. Mims III
INTRODUCTION

RESISTORS

CAPACITORS

R-C CIRCUITS

DIODES AND RECTIFIERS

ZENER DIODES

BIPOLAR TRANSISTORS

This book includes standard application circuits and circuits designed by the author. Each circuit was assembled and tested by the author as the book was developed. After the book was completed, the author reassembled each circuit to check for errors. While reasonable care was exercised in the preparation of this book, variations in component tolerances and construction methods may cause the results you obtain to differ from those given here. Therefore, the author and Radio Shack assume no responsibility for the suitability of this book’s contents for any application, since we have no control over the use to which the information in this book is put. We assume no liability for any damages resulting from its use. Of course, it is your responsibility to determine if commercial use, sale or manufacture of any device that incorporates information in this book infringes any patents, copyrights or other rights.

Due to the many inquiries received by Radio Shack and the author, it is not possible to provide personal responses to requests for additional information (custom circuit design, technical advice, troubleshooting advice, etc.). If you wish to learn more about electronics, see other books in this series and Radio Shack’s “Getting Started in Electronics.” Also, read magazines like Modern Electronics and Radio-Electronics. The author writes a monthly column, “Electronics Notebook,” for Modern Electronics.
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**INTRODUCTION**

In this era of integrated circuit microchips, the simplicity and economy of circuits made from individual components are often overlooked. These circuits that follow illustrate more than 75 applications for such basic components as diodes, transistors, SCRs, and triacs. These circuits are preceded by sections on resistors and capacitors since these components are an essential ingredient in nearly all semiconductor circuits.

For more information about the components used in the circuits that follow, see "Getting Started in Electronics" (Radio Shack, 1983). This book covers basic electronics and includes 100 tested circuits. Also, see other titles in the "Engineer's Mini-Notebook" series.

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**CIRCUIT ASSEMBLY TIPS**

Test versions of the circuits in this book were assembled on Radio Shack modular breadboard sockets. After assembling and testing a circuit on a breadboard, you can assemble a permanent version on a circuit board and install it in an enclosure. Though each circuit includes specific component values, substitutions are usually okay if voltage, current, and power ratings are observed. For instance, a 12K resistor can usually be substituted for a 1K unit. A 10K potentiometer can be used in place of a 10K unit.

For more, see "Getting Started in Electronics."
RESISTORS

RESISTORS resist the flow of an electrical current. The unit of resistance is the ohm (Ω). A potential difference of one volt will force a current of one ampere through a resistance of one ohm.

OHM'S LAW

Voltage (V) is the potential difference across a resistor. Current (I) is the flow of electrons through a resistor. Given any two values of resistance, voltage, or current, the third value can be calculated from Ohm's law:

\[ V = I \times R \quad I = \frac{V}{R} \quad R = \frac{V}{I} \]

The power dissipated in a resistor can also be calculated:

\[ P = V \times I \quad P = I^2 R \]

The unit of power is the watt. It is important to be sure that all values are expressed properly when using Ohm's law. For example, 65 milli-volts should be expressed as 0.065 volts. 470 milli-watts should be expressed as 0.47 watts. A 47K resistor has a resistance of 47 x 1,000 or 47,000 ohms. A 2.2M resistor has a resistance of 2.2 x 1,000,000 or 2,200,000 ohms.

Usually you may use a resistor with a value within 10-20% of the required value. Always use resistors having the proper power rating.

---

RESISTORS IN SERIES

\[ R_1 \quad R_2 \quad \Rightarrow \]

\[ \text{Total Resistance } (R_T) = R_1 + R_2 \]

\[ R_1 \quad R_2 \quad R_3 \quad \Rightarrow \]

\[ \text{Total Resistance } (R_T) = R_1 + R_2 + R_3 \]

RESISTORS IN PARALLEL

\[ \begin{array}{c}
R_1 \quad R_2 \quad \Rightarrow \\
R_T = \frac{R_1 \times R_2}{R_1 + R_2}
\end{array} \]

\[ \begin{array}{c}
R_1 \quad R_2 \quad R_3 \quad \Rightarrow \\
R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}
\end{array} \]

If \( R_1 = R_2 = R_3 \), then \( R_T = R_1 / 3 \).

RESISTORS IN SERIES/PARALLEL

\[ \begin{array}{c}
R_1 \quad R_2 \quad \Rightarrow \\
R_T = \frac{R_1 \times R_2}{R_1 + R_2} + R_3
\end{array} \]
**HOW TO USE RESISTORS**

**CURRENT LIMITING**

A resistor can be placed in series with a lamp, LED, speaker, transistor, or other component to reduce the flow of current through the device. For example:

![Resistor Circuit Diagram]

Ohm's Law can be used to calculate the current through the LED for a range of standard resistance values. The formula for current is \( I = \frac{V}{R} \). An LED does not begin to conduct until the forward voltage is about 1.7 volts (red LED). Therefore, the formula for current is \( I = \frac{V - 1.7}{R} \).

<table>
<thead>
<tr>
<th>R1 (Ohms)</th>
<th>LED Current (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.043</td>
</tr>
<tr>
<td>150</td>
<td>0.029</td>
</tr>
<tr>
<td>220</td>
<td>0.020</td>
</tr>
<tr>
<td>270</td>
<td>0.016</td>
</tr>
<tr>
<td>330</td>
<td>0.013</td>
</tr>
</tbody>
</table>

**VOLTAGE DIVISION**

\[ V_{out} = V_{in} \left( \frac{R_2}{R_1 + R_2} \right) \]

**WHEATSTONE BRIDGE**

The Wheatstone Bridge permits very accurate measurements of resistance. Here is the basic circuit:

![Wheatstone Bridge Diagram]

The bridge shown here permits the accurate measurement of an unknown resistance \( R_3 \). \( R_1 \) and \( R_2 \) should be precision (5% resistors). \( R_4 \) is a potentiometer with a calibrated dial. \( R_s \) is used to regulate the current from the power supply. \( R_6 \) and \( S_1 \) form a shunt that protects \( M_1 \). Adjust \( R_4 \) until \( M_1 = 0 \). Press \( S_1 \) and repeat. \( R_3 = R_4 \). If \( R_1 \neq R_2 \), then \( R_3 = \frac{(R_1 \times R_4)}{R_2} \).
CAPACITORS

CAPACITORS STORE AN ELECTRICAL CHARGE. THE UNIT OF CAPACITANCE IS THE FARAD. A 1-FARAD CAPACITOR CONNECTED TO A 1-VOLT SUPPLY WILL STORE A CHARGE OF 1.2B X 10^-18 ELECTRONS. MOST CAPACITORS HAVE CONSIDERABLY LESS CAPACITY, VALUES COMMONLY RANGE FROM A FEW PICOFARADS (10^-12 FARAD) TO A FEW THOUSAND MICROFARADS (10^-6 FARAD).

1 FARAD = 1 F
1 MICROFARAD = 1 μF = 10^-6 F
1 NANOFARAD = 1 nF = 10^-9 F
1 PICOFARAD = 1 pF = 10^-12 F

A CAPACITOR CAN BE CHARGED ALMOST INSTANTLY BY CONNECTING ITS LEADS DIRECTLY ACROSS A POWER SUPPLY. THE CHARGING TIME CAN BE INCREASED BY INSERTING A RESISTOR BETWEEN THE SUPPLY AND THE CAPACITOR.

A CHARGED CAPACITOR WILL GRADUALLY loose ITS CHARGE THROUGH LEAKAGE. THE DISCHARGE TIME CAN BE REDUCED BY CONNECTING A RESISTOR ACROSS THE CAPACITOR'S TWO LEADS.

WARNING!

MOST CAPACITORS CAN RETAIN A CHARGE FOR A CONSIDERABLE TIME AFTER THE CHARGING SUPPLY HAS BEEN SWITCHED OFF. THEREFORE USE CAUTION WHEN WORKING WITH CAPACITORS. A LARGE ELECTROLYTIC CAPACITOR CHARGED TO ONLY 5 TO 10 VOLTS CAN MELT THE TIP OF A SCREWDRIVER SHORTED ACROSS ITS LEADS! HIGH-VOLTAGE CAPACITORS IN TV SETS AND PHOTOFLASH UNITS CAN STORE A LETHAL CHARGE!
**HOW TO USE CAPACITORS**

**SIGNAL FILTERING**

A single capacitor can divert an unwanted signal to ground:

![Diagram of signal filtering](image)

A single capacitor can remove an unwanted dc component from a fluctuating signal:

![Diagram of signal filtering](image)

**POWER SUPPLY FILTERING**

A large capacitor will smooth the pulsating voltage from a power supply into steady direct current:

![Diagram of power supply filtering](image)

**SPIKE AND NOISE SUPPRESSION**

A 0.1 μF capacitor across the power supply pins of a logic chip will help suppress false triggering caused by brief power supply noise spikes.

---

**RESISTOR-CAPACITOR CIRCUITS**

Among the most important of all circuits are the basic resistor-capacitor (RC) circuits:

**INTEGRATOR**

The integrator is an RC circuit that transforms an incoming square wave into a triangle wave:

![Diagram of integrator circuit](image)

R & C is the time constant of the circuit. RC must be at least 10 times the period of the input signal. If not, the amplitude of the output signal will be reduced. The circuit will then be a low-pass filter that blocks high frequencies.

**DIFFERENTIATOR**

The differentiator is an RC circuit that transforms an incoming square wave into a pulsed or spiked waveform:

![Diagram of differentiator circuit](image)

The RC time constant should be 1/10 (or less) of the duration of the incoming pulses. Differentiators are often used to create trigger pulses.
DIODES AND RECTIFIERS

Diodes and rectifiers are semiconductor devices that conduct electricity in only one direction. It is important to understand that a diode does not begin to conduct until the forward voltage reaches a threshold point. For silicon diodes, this voltage is about 0.6 volt. For germanium diodes, it is about 0.3 volt. This graph sums up diode operation:

\[ V_f = 0.6 \text{ volt (silicon)} \]
\[ I_f = \text{forward current} \]
\[ V_r = \text{reverse voltage} \]
\[ I_r = \text{reverse current} \]

VOLTAGE DROPPER

\[ V = V_0 - V \]
\[ D_1 \]
\[ V = V_0 - 0.4 \]
\[ D_2 \]
\[ V = V_0 - 1.2 \]
\[ D_n \]
\[ V = V_0 - (n \times 0.4) \]
\[ \text{Typical application: IN} \]
\[ \text{Load (R)} \]
\[ D_1, D_2, D_3 = 1N914 \]

This circuit will reduce voltage from a power supply by 0.4 volt per diode.

LOAD (R)

\[ D_1, D_2, D_3 = 1N914 \]

Allows 0-volts to power TTL chip.

VOLTAGE REGULATOR

\[ V_{in} \]
\[ V_{out} = (V_{in} - V_{out}) / I \]
\[ R_1 \]
\[ D_1 \]
\[ D_2 \]
\[ D_n \]

This circuit will supply a steady output voltage equal to the sum of the turn-on (threshold) voltage of diodes. \[ D_1 = D_n \] therefore:
\[ V_{out} = 0.64 \times (D_1 + D_2 + D_n) \]
\[ R_1 = (V_{in} - V_{out}) / I \]

CAUTION: \[ D_1 \] AND \[ R_1 \] MUST HAVE PROPER POWER RATING. (USE OHM’S LAW)

TRIANGLE-TO-SINE WAVE

\[ 2.5\text{-VOLT} \]
\[ \text{TRIANGLE WAVE} \]
\[ D_1, D_2 = 1N914 \]
\[ 3.5\text{-VOLT} \]
\[ \text{SINE WAVE} \]

PEAK-READING VOLTOMETER

\[ \text{PEAK} \]
\[ D_1 \]
\[ 1N914 \]
\[ R_1 \]
\[ 1K \]
\[ 6V \]
\[ 0.1mA \]
\[ 3.3\mu F \]

For best results, use digital multimeter for M1. Set to read voltage.

Frequency of incoming signal must be high enough to keep C1 charged.
REVERSE POLARITY PROTECTOR

DIODE PROTECTS CIRCUIT IF BATTERY IS INSTALLED WITH REVERSED POLARITY.

TRANSIENT PROTECTOR

WHEN THE CURRENT FLOWING THROUGH AN INDUCTOR IS SUDDENLY SWITCHED OFF, THE COLLAPSING MAGNETIC FIELD WILL GENERATE A HIGH VOLTAGE IN THE INDUCTOR’S COILS. THIS VOLTAGE SPIKE MAY HAVE AN AMPLITUDE OF HUNDREDS OR EVEN THOUSANDS OF VOLTS. A DIODE CAN PROTECT THE CIRCUIT TO WHICH THE INDUCTOR IS CONNECTED BY PROVIDING A SHORT CIRCUIT FOR THE HIGH VOLTAGE SPIKE. FOR EXAMPLE:

DRIVE CIRCUIT

RELAY

NOTE:
D1 INEFFECTIVE DURING T/R TURN-ON TIME.

METER PROTECTOR

CONNECT A DIODE ACROSS THE TERMINALS OF A METER TO PROVIDE REVERSE CURRENT PROTECTION.

ADJUSTABLE WAVEFORM CLIPPER

ADJUST R2 TO CONTROL CLIPPING AMPLITUDE. +V SHOULD BE A VOLT OR SO HIGHER THAN PEAK INPUT VOLTAGE.

ADJUSTABLE ATTENUATOR

THIS IS A BIPOLARITY (+/-) VERSION OF THE ADJUSTABLE CLIPPER.

AUDIO LIMITER

USE TO LIMIT NOISE, POPS, AND STATIC.
HALF-WAVE RECTIFIER

D1 is any diode rated for the input voltage. This circuit is used to transform an AC wave into pulsating DC and to detect modulated radio signals.

DUAL HALF-WAVE RECTIFIER

This circuit transforms both halves of an AC wave into pulsating DC.

FULL-WAVE RECTIFIER

Also called a bridge rectifier, used to transform both halves of an AC wave to DC.

CASCADE VOLTAGE DOUBLER

Components should be rated at 2 x Vin. Use large value capacitors to reduce ripple.

BRIDGE VOLTAGE DOUBLER

Components should be rated at 2 x Vin. Do not use bridge module for D1, D2, D3, and D4.

VOLTAGE QUADRUPLER

Components should be rated at 2 x Vin. Use large value capacitors to reduce ripple.

Caution: Voltage multiplication circuits can produce high voltages. Use care!
**DIODE LOGIC GATES**

These simple logic circuits can be used to teach basics of digital logic and in practical applications.

**OR GATE**

\[ \text{O = Ground} \]
\[ \text{I = +5V} \]

**NOR GATE**

\[ \text{A} \]
\[ \text{B} \]
\[ +5V \]
\[ 1k \]
\[ \text{LED} \]

**AND GATE**

\[ \text{A} \]
\[ \text{B} \]
\[ +5V \]
\[ 1k \]
\[ \text{LED} \]

**NAND GATE**

\[ \text{A} \]
\[ \text{B} \]
\[ +5V \]
\[ 1k \]
\[ \text{LED} \]

**NOTE:** Use 1N914 (or similar) for unmarked input diodes.

---

**DECIMAL-TO-BINARY ENCODER**

This circuit is a programmable read-only memory (PROM). Use 1N914 diodes.

**Truth Table**

<table>
<thead>
<tr>
<th>D</th>
<th>C</th>
<th>B</th>
<th>A</th>
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<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1011</td>
</tr>
</tbody>
</table>

**LEDS:**

- **OFF:** 0
- **ON:** 1

**READOUT**

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ZENER DIODES

NORMALLY A CURRENT DOES NOT FLOW THROUGH A DIODE CONNECTED IN THE REVERSE DIRECTION. THE ZENER DIODE IS DESIGNED SPECIFICALLY TO BEGIN CONDUCTING IN THE REVERSE DIRECTION WHEN THE REVERSE VOLTAGE EXCEEDS A THRESHOLD VALUE (THE BREAKDOWN VOLTAGE). THEREFORE THE ZENER DIODE IS A VOLTAGE-SENSITIVE SWITCH. THIS GRAPH SUMS UP ZENER DIODE OPERATION:

\[ V_{BE} < V_T \]

COMMERCIAL ZENER DIODES HAVE BREAKDOWN VOLTAGES FROM 2 TO 200 VOLTS.

VOLTAGE REGULATOR MODEL

\[ Vin = V_T \]
\[ I_T = I_V \]
\[ R_L = \frac{Vin - V_T}{I_V} \]

SAMPLE REGULATOR:

\[ I_L = \text{MAXIMUM LOAD CURRENT} \]
\[ I_T = \text{MAXIMUM ZENER CURRENT} \]
\[ R_L = \text{R1 CURRENT} \]
\[ V_T = \text{ZENER VOLTAGE} \]
\[ I_T = \text{ZENER CURRENT} \]

VOLTAGE INDICATOR

LEDs GLOW IN SEQUENCE AS INPUT VOLTAGE RISES. ON TO USE DIFFERENT ZENERS SO LONG AS SERIES RESISTOR LIMITS CURRENT THROUGH LED TO SAFE VALUE.

VOLTAGE SHIFTER

EXAMPLE (D1=6.2V):

\[ \begin{array}{ccc}
Vin & V_{out} \\
5 & 9 \quad 3.17 \\
6 & 15 \quad 6.37 \\
18 & 9.27 \\
\end{array} \]

WAVEFORM CLIPPERS

USE TO REDUCE LEVEL CLIPS BOTH HALVES OF INCOMING SIGNAL OR WAVE (EQUALLY). ALSO CONVERTS SINUSINE WAVE TO NEAR SQUARE WAVE. AS POP FILTER FOR SPEAKERS AND PHONES.
BIPOLAR TRANSISTORS

A bipolar transistor is a 3-terminal semiconductor device in which a small current at one terminal can control a much larger current flowing between the second and third terminal. This means transistors can function as both amplifiers and switches. Bipolar transistors are classified as NPN or PNP according to the doping contained in their three regions.

BASIC TRANSISTOR SWITCHES

BASIC TRANSISTOR AMPLIFIER

ADJUST R1 TO GIVE BEST RESULTS. Q1 R1 10k 5k Q1 2N2222

TEST CIRCUIT GAVE GAIN (Vout/Vin) = 50.

IN OUT

RELAY DRIVER

RELAY PULLS IN WHEN INPUT IS POSITIVE. APPLICATION:

RESISTIVE SENSOR OR MOISTURE-SENSING PROBES

RELAY CONTROLLER

RELAY SUPPLIES SEQUENCE OF DRIVE PULSES TO RELAY. R1 AND Q1 CONTROL PULSE RATE AND TIME. RELAY IS CLOSED PER PULSE. R, R3 CONTROLS PULSE RATE. USE TO TRIGGER LAMPS AND CONTROL MOTORS.

LED REGULATOR

SUPPLIES CONSTANT CURRENT TO LED AS SUPPLY VOLTAGE CHANGES.

LED CURRENT = 7-8 mA. LED:

C1 Q1 R3 10k 1/2W Q1 Q2 2N2907

1/2W
3-VOLT SPEAKER AMPLIFIER

Use to give low-power speaker to radios and tape players without speakers.

2-STAGE SPEAKER AMPLIFIER

This circuit requires no input transformer.

MICROPHONE PREAMPLIFIER

Use with tape recorders, public address systems and portable amplifiers.

AUDIO MIXER

OK to add more input networks (C1, R1, R3).

Use to combine signals from two (or more) amplifiers, microphones, etc.
**AUDIO OSCILLATOR**

With values shown, this circuit creates an audio tone of up to several thousand hertz. The frequency is controlled by R3. OK to use many different transistors for Q1 and Q2. For very slow frequencies, increase C1.

**ADJUSTABLE SIREN**

R1 22K
C1 22µF
R3 15K
R2 39K
R4 10K
C2 2222
Q2 2N2222
Q1 2N2222
C3 0.1µF

Closing S1 gives rising tone. Opening S1 gives falling tone. S2 and R4 control tone range.

**METRONOME**

This circuit is a variation of the circuit above. R2 controls the 'click' rate. OK to use various transistors for Q1 and Q2.

**LOGIC PROBE**

<table>
<thead>
<tr>
<th>Logic IN</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO</td>
<td>OFF</td>
</tr>
<tr>
<td>HI</td>
<td>ON</td>
</tr>
</tbody>
</table>

**AUDIO NOISE GENERATOR**

Use to create fuzz sound and other special effects or as noise source for testing room acoustics with sound meter.
1-TRANSISTOR OSCILLATOR

This is a simplified Hartley oscillator. Adjust R1 to change tone frequency. Consumes only 100-200 microamperes. Insulated 30 ga. wrapping wire.

Coil: Punch two small holes 1-1/8" apart in straw. Insert wire in first hole, wind 50 turns, insert wire loop in second hole, and wind back 25 turns. Punch hole through first winding and insert end of wire. Tap: Cut loop and twist exposed wires.

SWITCH DEBOUNCER

Supplies single trigger pulse to logic circuits. Switch alone will "bounce" when closed, causing false pulses. To lock out S1 for a second after a pulse, let C1=220 F.

MINIATURE RF TRANSMITTER

This circuit is patterned after a pill-sized biotelemetry transmitter first developed by Dr. R. Stewart Mackay and other medical researchers in the late 1950's. This transmitter remains one of the smallest ever developed.

Antenna (optional) 1-100 F

Signal at Q1's base:

12 K RF HARMONICS

Sends signal to am or sw radio a few feet away.

R1 and R2 controls signal frequency. OK to use 0.1 F or thermistor for R1/R2.

Coil: Use the coil shown on the facing page or make a much smaller version with a 1/2" length of soda straw and No. 30 magnet wire. Burn the varnish from the last 1/4" of the coil's leads (use a match). Then lightly buff the charred varnish with fine sand paper.

R1: Use a penlight cell or a mercury or silver oxide button cell. Warning: Never attempt to solder leads to miniature power cells. They will explode.

C1: 0.1 F gives audio tone; 10 F gives audible clicks. Insert ferrite core or steel nail in coil to alter the signal. Use miniature electrolytic capacitor.
FREQUENCY METER

1-VOLT SQUARE WAVE

IN = 1
R1 = 100
R2 = 50K
R3 = 1K
C1 = 1NF

BL - USE RECTIFIER BRIDGE MODULE OR FOUR 1N914 DIODES.

R4 = 150
R5 = 100

RECALIBRATE IF INPUT IS NOT A 1-V SQUARE WAVE.

THIS CIRCUIT IS SUITABLE FOR SPECIFIC ROLES RATHER THAN GENERAL FREQUENCY MEASUREMENTS. TO CALIBRATE FOR 0-1KHZ RANGE:

1. SET R2 AND R5 AT MID POINTS.
2. APPLY 1KHZ, 1VOLT SQUARE WAVE AT INPUT.
3. ADJUST R2 UNTIL M1 = 1MA.
4. REMOVE 1KHZ SIGNAL.
5. ADJUST R3 UNTIL M1 = 0.
6. REAPPLY 1KHZ SIGNAL.
7. ADJUST R2 UNTIL M1 = 1MA.

TYPICAL RESULTS:

<table>
<thead>
<tr>
<th>SIGNAL (Hz)</th>
<th>M1 (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>800</td>
<td>8.5</td>
</tr>
<tr>
<td>900</td>
<td>9.5</td>
</tr>
<tr>
<td>1000</td>
<td>10.0</td>
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PULSE GENERATOR

C1 = 0.01 5 USEC
C2 = 0.01 22 USEC
C3 = 0.1 200 USEC

R3 CONTROLS PULSE RATE.

R1 = 470
R2 = 2N2222
R3 = 1M

AMPLITUDE IS ABOUT 10 VOLTS WHEN SUPPLY IS 12.5 VOLTS.

RISETIME = 100 NSEC

DC METER AMPLIFIER

Q1 = 2N3904
Q2 = 2N2222
Q3 = 1N914
R1 = 1K
R2 = 10K
R3 = 1M

TO CALIBRATE, FIRST CONNECT INPUT TO +6V THROUGH A 1M POT AND A DIGITAL MULTIMETER SET TO READ CURRENT IN MILLIAMPERES. THEN SET R2 AT ITS MID POINT, NEXT:

1. SET 1M POT FOR DESIRED CURRENT.
2. ADJUST R3 UNTIL M1 INDICATES 1 MA.
3. REPEAT STEPS 1 AND 2.
4. ADJUST R2 UNTIL M1 INDICATES 1 MA.
**Light-Activated Flasher**

- LED
- Q2 2N2907
- Q3 2N2222
- R1 1K
- R2 2M
- Q1 Phototransistor

The LED flashes when Q1 is illuminated by sunlight or artificial light. When Q1 is dark, the flasher is disabled. C1 controls the flash rate.

**Dark-Activated Flasher**

- LED
- Q2 2N2907
- Q3 2N2222
- R1 1K
- R2 1N
- Q1 Phototransistor

This circuit can be used as a warning flasher that turns on at night. C1 controls the flash rate.

**High-Brightness Flasher**

- Q1 2N2907
- R1 100K
- R2 1K
- R3 22K
- C1 22µF
- RS 10
- L1
- R1 = Adjust with care.

This circuit sends a high-current pulse to lamp L1 about once each second. R1 controls the flash rate. L1 is a 14 or 24 volt lamp. Do not allow L1 to stay on.

**LED Transmitter/Receiver**

- Q1 2N2907
- Q2 2N2222
- R1 22K
- R2 2M
- C1 0.1µF
- LED

Use high-output infrared LED. This circuit sends a tone over LED beam. C1 decreases. Will increase range.
RESISTOR-TRANSISTOR LOGIC

These logic circuits can be used to teach basics of digital logic and in practical applications.

OR GATE

\[ A \] \[ B \] \[ LED \]
\[ 0 \] \[ 0 \] \[ OFF \]
\[ 0 \] \[ 1 \] \[ ON \]
\[ 1 \] \[ 0 \] \[ ON \]
\[ 1 \] \[ 1 \] \[ ON \]

R1 10K
R2 10K
R3 4.7K
Q1 Q2 = 2N2222

AND GATE

\[ A \] \[ B \] \[ LED \]
\[ 0 \] \[ 0 \] \[ OFF \]
\[ 0 \] \[ 1 \] \[ OFF \]
\[ 1 \] \[ 0 \] \[ OFF \]
\[ 1 \] \[ 1 \] \[ ON \]

R1 10K
R2 10K
R3 4.7K
Q1 Q2 = 2N2222

NAND GATE

\[ A \] \[ B \] \[ LED \]
\[ 0 \] \[ 0 \] \[ ON \]
\[ 0 \] \[ 1 \] \[ ON \]
\[ 1 \] \[ 0 \] \[ ON \]
\[ 1 \] \[ 1 \] \[ OFF \]

R1 10K
R2 10K
R3 4.7K
Q1 Q2 = 2N2222

NOR GATE

\[ A \] \[ B \] \[ LED \]
\[ 0 \] \[ 0 \] \[ ON \]
\[ 0 \] \[ 1 \] \[ OFF \]
\[ 1 \] \[ 0 \] \[ OFF \]
\[ 1 \] \[ 1 \] \[ OFF \]

R1 10K
R2 10K
R3 4.7K
Q1 Q2 = 2N2222

INVERTER

\[ A \] \[ LED \]
\[ 0 \] \[ ON \]
\[ 1 \] \[ OFF \]

R1 10K
R2 4.7K
Q1 Q2 = 2N2222
JUNCTION FETS

A junction field-effect transistor (FET) is a three-terminal semiconductor device in which a small voltage at one terminal can control a current flowing between the second and third terminal. FETs can function as both amplifiers and switches. The principle advantage of the FET is its very high input (gate) impedance. FETs are classified as either N- or P-channel according to the doping of the current-carrying channel region.

BASIC FET SWITCHES (N-FET)

+9V NOTE: +9V
LD = -9V
GL 2N3819
R1 1M
R2 1K
S1 LED
S ON
LD OFF
R1 2N3819
R2 1K
S1 LED
S ON
LD OFF

BASIC FET AMPLIFIER (N-FET)

+9V
2N3819
R1 1K
C1 1µF
IN
OUT

TEST CIRCUIT
LOW GAIN:
VERY HIGH INPUT IMPEDANCE.
GAVE GAIN (Vout/Vin) = 2.

HI-Z MICROPHONE PREAMPLIFIER

+9V
R2 IS GAIN CONTROL.
R4 470
C1 1µF
R1 100K
MIC 1M
R2 1M
C1 1µF
TO AMPLIFIER

KEEP LEADS TO MICROPHONE SHORT OR USE SHIELDED CABLE.

HI-Z AUDIO MIXER

A, B
R1 1M
R3 100K
R4 470
R5 470
MIC 1M
C1 1µF
TO AMPLIFIER

USE TO COMBINE SIGNALS FROM TWO OR MORE MICROPHONES, PREAMPLIFIERS, ETC.
POWER MOSFETS

A METAL-OXIDE-SEMICONDUCTOR FET (MOSFET) HAS A GATE WHICH IS INSULATED FROM THE CHANNEL BY A VERY THIN GLASSY OXIDE. THEREFORE THE INPUT IMPEDANCE OF THE MOSFET IS CONSIDERABLY HIGHER THAN THAT OF THE STANDARD FET. POWER MOSFETS HAVE A VERY LOW RESISTANCE CHANNEL, THEREFORE THEY CAN CONTROL MUCH MORE CURRENT THAN FETS.

ON-AFTER-DELAY TIMER

Press Sl to charge C1. The piezo buzzer emits tone after C1 self discharges. Large values for C1 increase the delay. Place large value resistor across C1 to reduce delay.

Q1 - Power MOSFET
Q2 - 2N3819

ON-DURING-DELAY TIMER

Press Sl to charge C1. The piezo buzzer emits tone until C1 self discharges. Increase C1 to increase delay. Resistor across C1 will reduce delay.

Q1, Q2 - Power MOSFETs

HI-Z SPEAKER AMPLIFIER

R3, R5 - 470 ohm
R1 - 1K
R2 - 10K
C2 - 1 uF
Q1, Q2 - Power MOSFET

Q3, Q4 - 2N3819
R4 - 1K
C3 - 47 uF
R7 - 100
C4 - 47 uF
R9 - 1M

R1 controls gain. Input can be high impedance microphone, radio, etc.

DUAL LED FLASHER

R1 - 10K
Q1 - Power MOSFET

R4, R8 - 1K
C2 - 22 uF
C1 - 10K
Q2, Q3 - Power MOSFETs

LEDs flash alternately. R3 controls flash rate. Quickly short R1 or C1 if circuit fails to flash.
UNIJUNCTION TRANSISTORS

The unijunction transistor (UJT) is a voltage-controlled switch and not a true transistor. The UJT is well suited for many oscillator applications.

BASIC UJT OSCILLATOR

INCREASE Rs TO REDUCE FREQUENCY.

LOW-VOLTAGE INDICATOR

SOUNDS WARNING TONE WHEN THE SUPPLY VOLTAGE FALLS BELOW D1'S TURN-ON VOLTAGE. SELECT D1 FOR DESIRED VOLTAGE. OK TO USE A SINGLE FIXED CAPACITOR FOR R1 AND R2 (4.7K GIVES 2.8 KHZ).

SOUND-EFFECTS GENERATOR

This circuit generates chirps having a frequency controlled by R4. R3 controls rate.

1-MINUTE TIMER

This circuit pulls in the relay at a repetitive cycle controlled by R1. Relay must be low-voltage type.
PIEZO-ELECTRIC BUZZERS

PIEZO BUZZERS DELIVER EAR-PIERCING TONE AT LOW DRIVE CURRENT AND VOLTAGE.

CAUTION: USE EAR PROTECTORS WHEN EXPERIMENTING WITH PIEZO BUZZERS AT CLOSE RANGE FOR MORE THAN BRIEF INTERVALS.

BELL VOLUME CONTROL

+ 5 TO +12V
+ 5 TO +12V

SL OK TO ALTER C1'S VALUE. R1 - 10K TO 50K POTentiOMETER

R1 220K

C1 47uF

PIEZO BUZZER

PRESS AND RELEASE SL. R1 CONTROLS VOLUME TO SIMULATE BELL.

LOGIC INTERFACES

G1 2N2222

R1 1K

IN

TONE

LO OFF

MI ON

G1 2N2222

R1 1K

IN

TONE

LO ON

HI OFF

PIEZO-ELEMENT DRIVERS

FIXED TONE

+ 3 TO +12V

CONNECT 6V C&nS. C&LL ACROSS R1 FOR DARK-ACTIVATED TONE OR HERE FOR LIGHT-ACTIVATED TONE.

Q1 2N2222

R3 220K

R2 10K

R4

BLUE

BLACK

ADJUSTABLE FREQUENCY

+ 1 TO +15V

+ 0.5 TO +15V

Q1 2N2222

R1 50K

R2 4.7K

R3 1M

R4 1K

Q1 2N2222

R1

BLUE

BLACK

1uF

T1

THIS CIRCUIT CAN BE EASILY MINIATURIZED. R1 CONTROLS FREQUENCY.
SILICON-CONTROLLED RECTIFIERS

THE SILICON-CONTROLLED RECTIFIER (SCR) IS A TRUE SOLID-STATE ON-OFF SWITCH. THE SCR IS SWITCHED ON BY A SMALL CURRENT AT ITS GATE TERMINAL. THE SCR WILL REMAIN ON UNTIL THE CURRENT FLOWING THROUGH IT FALLS BELOW A MINIMUM LEVEL (IN OR HOLDING CURRENT).

LATCHING PUSHBUTTON SWITCH

SL - PUSH TO ACTIVATE (NORMALLY OPEN)
S2 - PUSH TO RESET (NORMALLY CLOSED)
RL - LOAD (AMP, ETC.)
SCR - TERMINAL PINOUTS VARY, TYPICAL:

LIGHT-ACTIVATED RELAY

RELAY IS PULLED IN WHEN Q1 IS ILLUMINATED. RELAY REMAINS LATCHED UNTIL S1 IS PRESSED. WORKS WITH FLASHLIGHTS AND PHOTO STROBE UNITS.

Q1 - PHOTO-TRANSISTOR
S1 - PUSH TO ACTIVATE (NORMALLY CLOSED)

RELAXATION OSCILLATOR

CL IS CHARGED THROUGH R1 UNTIL ITS CHARGE IS HIGH ENOUGH TO SWITCH ON THE SCR THROUGH R2. CL THEN DISCHARGES THROUGH THE SCR AND THE SPEAKER. R1 CONTROLS THE REPEITION RATE.

DC MOTOR SPEED CONTROLLER

THIS CIRCUIT WILL VARY THE SPEED OF SELECTED DC MOTORS. R4 CONTROLS THE SPEED. AT SLOW PULSE RATES FROM THE 555 OSCILLATOR, THE MOTOR WILL ROTATE IN BURSTS. FOR BEST RESULTS, USE A SEPARATE POWER SUPPLY FOR THE MOTOR.

CHECK MOTOR WITH THIS CIRCUIT. IF LED FLASHES ON AND OFF WHEN SHAFT OF MOTOR IS ROTATED, IT WILL PROBABLY WORK.
TRIACS

The TRIAC is a solid-state on-off switch that can control alternating current. It is electronically equal to two SCRs connected in reverse-parallel.

WARNING: TRIACS are designed for AC operation. Use common sense safety precautions when working with circuits that use household line current. All connections must be well insulated. Never work on an AC line powered circuit when the power cord plug is inserted in a wall socket.

TRIAC SWITCH BUFFER

LAMP DIMMER

RESISTOR COLOR CODE

- Black: 0
- Brown: 1
- Red: 2
- Orange: 3
- Yellow: 4
- Green: 5
- Blue: 6
- Violet: 7
- Gray: 8
- White: 9

Fourth band indicates tolerance (accuracy): Gold = ± 5%, Silver = ± 10%, None = ± 20%

Ohm's Law:

\[ V = IR \]

\[ R = \frac{V}{I} \]

\[ P = VI = I^2R \]

ABBREVIATIONS

A = Amperes
R = Resistance
F = Farad
V (or E) = Volt
I = Current
W = Watt
P = Power
Ω = Ohm

M (Meg-) = \times 1,000,000
K (Kilo-) = \times 1,000
m (Milli-) = \times 0.001
μ (Micro-) = \times 0.000 001
n (Nano-) = \times 0.000 000 001
p (Pico-) = \times 0.000 000 000 001