Engineer’s Mini-Notebook
Basic Semiconductor Circuits

Forrest M. Mims III
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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. THE 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.

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 OK IF VOLTAGE, CURRENT, AND POWER RATINGS ARE OBSERVED. FOR INSTANCE, A 12K RESISTOR CAN USUALLY BE SUBSTITUTED FOR A 1K UNIT. A 100K POTENTIOMETER CAN BE USED IN PLACE OF A 5K UNIT AND MANY NPN TRANSISTORS CAN BE USED FOR THE POPULAR 2N2222. FOR MORE, SEE "GETTING STARTED IN ELECTRONICS."
RESISTORS

RESISTORS resist the flow of an electrical current. The unit of resistance is the ohm ($\Omega$). 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:

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

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, 0.045 volts, 470 milliamps, 0.047 watts. A 47k resistor has a resistance of 47,000 ohms. A 22M ohm resistor has a resistance of 22,000,000 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

\[ R_1 + R_2 + \cdots + R_n = R_{total} \]

Total Resistance ($R_{total}$) = $R_1 + R_2$

\[ R_1 \quad R_2 \quad R_3 \]

Total Resistance ($R_{total}$) = $R_1 + R_2 + R_3$

RESISTORS IN PARALLEL

\[ \frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

If $R_1 = R_2 = R_3$, then $R_{total} = R_1 / 3$.

RESISTORS IN SERIES/PARALLEL

\[ R_{total} = \frac{R_1 \times R_2 \times R_3}{R_1 + R_2 + R_3} \]
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:

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

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 \( I = \frac{V}{1.7} \).

<table>
<thead>
<tr>
<th>R (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

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

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

R1 = R2 and R3 = R4 form two voltage dividers. When the voltage at R equals the voltage at B, the meter indicates no voltage and the bridge is said to be balanced. When this occurs, then:

\[ \frac{R_1}{R_3} = \frac{R_2}{R_4} \]

The bridge shown here permits the accurate measurement of an unknown resistance (R3). R1 and R2 should be precision (1% or less) resistors. R4 is a potentiometer with a calibrated dial. R5 is used to regulate the current from the power supply. R6 and R7 form a shunt that protects M1. Adjust R4 until M1 = 0. Press S1 and repeat. R3 = R4.

If R1 ≠ R2, then R3 = (R1 x R4) / R2.
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 4.28 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 F = 1 FARAD
1 UF = 1 MICROFARAD = 10^-6 FARAD
1 NF = 1 NANOFARAD = 10^-9 FARAD
1 PF = 1 PICOFARAD = 10^-12 FARAD

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.

DIRECT CHARGE

RESISTIVE CHARGE

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

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CAPACITORS IN SERIES

\[ C_1 \quad C_2 \quad \frac{1}{C_1 + C_2} \]

TOTAL CAPACITANCE \( C_T \) = \( \frac{C_1 \times C_2}{C_1 + C_2} \)

CAPACITORS IN PARALLEL

\[ C_1 \quad C_2 \quad C_3 \quad \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \]

TOTAL CAPACITANCE \( C_T \) = \( \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \)

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:

A SINGLE CAPACITOR CAN REMOVE AN UNWANTED DC COMPONENT FROM A FLUCTUATING SIGNAL:

POWER SUPPLY FILTERING

A LARGE CAPACITOR WILL SMOOTH THE PULSATING VOLTAGE FROM A POWER SUPPLY INTO STEADY DIRECT CURRENT:

SPRIKE 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:


DIFFERENTIATOR

THE DIFFERENTIATOR IS AN RC CIRCUIT THAT TRANSFORMS AN INCOMING SQUARE WAVE INTO A PULSED OR SPIKED WAVEFORM:

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 0.4 volt. For germanium diodes, it is about 0.3 volt. This graph sums up diode operation:

\[ V_R \leftarrow \text{Avoid excess } I_f \]
\[ I_f = \text{Forward current} \]
\[ V_f = \text{Forward voltage} \]
\[ I_r = \text{Reverse current} \]
\[ V_r = \text{Reverse voltage} \]

VOLTAGE DROPPER

\[ +V \]
\[ D_1 \]
\[ V = V - 0.4 \]
\[ D_2 \]
\[ V = V - 1.2 \]
\[ D_n \]
\[ V = V - (n \times 0.4) \]
\[ \text{Load} (R_L) \]

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

TRIANGLE-TO-SINE WAVE

\[ +2.5 \text{V} \]
\[ \text{R}_1 \]
\[ D_1 \]
\[ \text{D}_2 \]
\[ \text{D}_3 \]

\[ +3.5 \text{V} \]

\[ \text{TYPICAL APPLICATION:} \]
\[ \text{IN} \]

PEAK-READING VOLTOMETER

\[ \text{PEAK} \]
\[ \text{D}_1 \]
\[ \text{D}_2 \]
\[ \text{D}_3 \]

\[ \text{M} \]
\[ 0.1 \text{mA} \]
\[ 1 \text{M} \]
\[ 1 \text{uF} \]

\[ \text{FOR BEST RESULTS, USE DIGITAL MULTIMETER FOR M}. \]
\[ \text{SET TO READ VOLTAGE.} \]

\[ \text{FREQUENCY OF INCOMING SIGNAL MUST BE HIGH ENOUGH TO KEEP C} \text{I CHARGED.} \]
REVERSE-POLEARITY PROTECTOR

+ 81 D1 TO CIRCUIT
3 TO 12 1N914 (RADIO, TAPE RECORDER, ETC.)

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 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 BIPOLAR (+/-) 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. Don't 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

\[ O = \text{ground} \quad 1 = +5\text{V} \]

\begin{align*}
A & \quad 0 & \quad 0 & \quad \text{OFF} \\
0 & \quad 1 & \quad \text{ON} \\
1 & \quad 0 & \quad \text{ON} \\
1 & \quad 1 & \quad \text{ON} \\
B & \quad \ldots & \quad \ldots & \quad \ldots \\
\end{align*}

NOR GATE

\begin{align*}
A & \quad 0 & \quad 0 & \quad \text{ON} \\
0 & \quad 1 & \quad \text{OFF} \\
1 & \quad 0 & \quad \text{OFF} \\
1 & \quad 1 & \quad \text{OFF} \\
B & \quad \ldots & \quad \ldots & \quad \ldots \\
\end{align*}

AND GATE

\begin{align*}
A & \quad 0 & \quad 0 & \quad \text{OFF} \\
0 & \quad 1 & \quad \text{OFF} \\
1 & \quad 0 & \quad \text{OFF} \\
1 & \quad 1 & \quad \text{ON} \\
B & \quad \ldots & \quad \ldots & \quad \ldots \\
\end{align*}

NAND GATE

\begin{align*}
A & \quad 0 & \quad 0 & \quad \text{ON} \\
0 & \quad 1 & \quad \text{OFF} \\
1 & \quad 0 & \quad \text{OFF} \\
1 & \quad 1 & \quad \text{OFF} \\
B & \quad \ldots & \quad \ldots & \quad \ldots \\
\end{align*}

Note: Use IN914 (or similar) for unmarked input diodes.

DEcimal-TO-BINARY ENCODER

This circuit is a programmable read-only memory (PROM), use IN914 diodes.

\begin{align*}
+5\text{V} & \quad 1k & \quad 1k & \quad 1k & \quad 1k \\
\text{DECIMAL-TO-BINARY ENCODER} & \quad \text{TABLE} & \quad \text{D C B A} \\
\text{INPUT SWITCHES} & \quad \text{DECIMAL} & \quad \text{BINARY} \\
0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
1 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
2 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
3 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
4 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
5 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
6 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
7 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
8 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
9 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 & \quad 0 \\
\end{align*}
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:

- **Breakdown Voltage (Vb)**: The voltage at which the diode begins to conduct.
- **Zener Voltage (Vz)**: The voltage at which the diode reaches its stable operating point.

**Commercial Zener Diodes Have Breakdown Voltages from 2 V to 200 Vols.**

VOLTAGE REGULATOR MODEL

\[
V_{in} = V_z + I_z R_1
\]

- **P1** = Internal Power
- **P2** = External Power
- **I_z** = Zener Current
- **R1** = Series Resistor

**Sample Regulator:**

- **I_L** = Maximum Load Current
- **I_z** = Maximum Zener Current
- **I_z** = Maximum Zener Current
- **V_z** = Zener Voltage
- **P2** = Zener Current

VOLTAGE INDICATOR

- **LEDs** glow in sequence as input voltage rises. Or to use different zeners so long as series resistor limits current through LED to safe value.

VOLTAGE SHIFTER

Example (D1=6.2V):

<table>
<thead>
<tr>
<th>Vin</th>
<th>Vout</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>.36</td>
</tr>
<tr>
<td>12</td>
<td>6.37</td>
</tr>
<tr>
<td>15</td>
<td>9.27</td>
</tr>
</tbody>
</table>

WAVEFORM CLIPPERS

Use to reduce level. Clips both halves of incoming signal or wave (equally) when D1 = D2. Use to convert sine wave to near square wave. 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

RELAY DRIVER

RELAY CONTROLLER

RELAY PULLS IN WHEN INPUT IS POSITIVE. APPLICATION: RESISTIVE SENSOR OR MOISTURE-SENSING PROBES

BASIC TRANSISTOR AMPLIFIER

TEST CIRCUIT GAVE GAIN \( \frac{V_{out}}{V_{in}} = 50 \). ADJUST R1 TO GIVE BEST RESULTS. C1 R1 1μF 5k Q1 2N2222

LED REGULATOR

LED CURRENT = 7-8 mA. LED SUPPLIES CONSTANT CURRENT TO LED AS SUPPLY VOLTAGE CHANGES.
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.

**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>TO</th>
<th>R1 10K</th>
<th>Q1 2N2222</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGIC CIRCUIT</td>
<td>R2 1K</td>
<td>LED</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOGIC LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
</tr>
</tbody>
</table>

USE TO CREATE BUZZ SOUND AND OTHER SPECIAL EFFECTS OR AS NOISE SOURCE FOR TESTING ROOM ACOUSTICS WITH SOUNDMETER.

**ADJUSTABLE SIREN**

R1 22K
C1 22 μF

R3 15K CLOSING S1 GIVES RISING TONE. OPENING S1 GIVES FALLING TONE.

R2 39K
C4 10μF

S2 AND R4 CONTROL TONE RANGE.

**AUDIO NOISE GENERATOR**

R1 100K
C1 1 μF

USE TO CREATE BUZZ SOUND AND OTHER SPECIAL EFFECTS OR AS NOISE SOURCE FOR TESTING ROOM ACOUSTICS WITH SOUNDMETER.
1-TRANSISTOR OSCILLATOR

This is a simplified Hartley oscillator. Adjust R1 to change tone frequency. Consumes only 100-200 microamperes.

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 DEBOUNCE

30

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)

Sends signal to AM or SW radio a few feet away. R1 and R2 control signal frequency. OK to use C1's cell or thermistor for R1/R2.

Coil: Use the coil shown on the facing page or make a much smaller version with 1/2" length of soda straw and no. 36 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 sandpaper.

B1: 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 uf gives audio tone; 10 uf gives audible clicks. Insert ferrite core or steel nail in coil to alter the signal. Use miniature electrolytic capacitor.

Q1

Q1

Q1

2N2222

2N2222

2N2222

2N2222

2N2222

10K

4.7K

4.7K

1K

4.7K

1K

4.7K

1K

4.7K
FREQUENCY METER

1. Volt
2. SQUARE WAVE
3. R1 100
4. IN
5. R2 50k
6. C1 1nF
7. R3 1K
8. R4 100
9. C2 1nF

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

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

THIS CIRCUIT IS SUITABLE FOR SPECIFIC RANGES RATHER THAN GENERAL FREQUENCY MEASUREMENTS. TO CALIBRATE FOR 0-1 KHz RANGES:

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

TYPICAL RESULTS:

<table>
<thead>
<tr>
<th>SIGNAL (Hz)</th>
<th>M1 (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>200</td>
<td>2.4</td>
</tr>
<tr>
<td>300</td>
<td>3.4</td>
</tr>
<tr>
<td>400</td>
<td>4.4</td>
</tr>
<tr>
<td>500</td>
<td>5.5</td>
</tr>
<tr>
<td>600</td>
<td>6.6</td>
</tr>
<tr>
<td>700</td>
<td>7.7</td>
</tr>
<tr>
<td>800</td>
<td>8.8</td>
</tr>
<tr>
<td>900</td>
<td>9.9</td>
</tr>
<tr>
<td>1000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

DC METER AMPLIFIER

TO CALIBRATE, FIRST CONNECT INPUT TO +6 V 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.

PULSE GENERATOR

R3 CONTROLS PULSE RATE.

D1 1N914

R1 470

C1 0.01 TO 1.0 nF

R2 1M

C2 2N2222

R3 1M

R4 50

50

RISETIME = 100 nSEC
**LIGHT-ACTIVATED FLASHER**

+4.5V to +6V

LED

R1 1K
R2 2M
Q1 2N2907
Q3 2N2222
Q1 PHOTO TRANSISTOR

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

**HIGH-BRIGHTNESS FLASHER**

+6V

R1 100K
R2 1K
R3 5.6K
Q1 2N2907
Q4 2N2222
Q1 PHOTO TRANSISTOR

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

R1 - adjust with care.

**DARK-ACTIVATED FLASHER**

+4.5V to +6V

LED

R1 1K
R2 2K
Q1 2N2907
Q3 2N2222
Q1 PHOTO TRANSISTOR

This circuit can be used as a warning flasher that turns on at night. Q1 controls flash rate.

**LED TRANSMITTER/RECEIVER**

+4.5V

Q1 1N914
Q4 PHOTO TRANSISTOR 47K

Use high-output infrared LED.

R1 22K
R2 4.7K
Q1 0.1µF
Q2 2N2222
Q4 4.7K

R4 4.7K
R5 22K

Sends tone over LED beam; lenses will increase range.

PIEZO: ALARMER ELEMENT
RESISTOR-TRANSISTOR LOGIC

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

OR GATE

\[ V = 6V \]
\[ A \quad B \quad LED \]
\[ 0 \quad 0 \quad OFF \]
\[ 0 \quad 1 \quad ON \]
\[ 1 \quad 0 \quad ON \]
\[ 1 \quad 1 \quad ON \]

10k
Q1
Q2
R1
R2
R3
4.7k

NOR GATE

\[ V = 6V \]
\[ A \quad B \quad LED \]
\[ 0 \quad 0 \quad ON \]
\[ 0 \quad 1 \quad OFF \]
\[ 1 \quad 0 \quad OFF \]
\[ 1 \quad 1 \quad OFF \]

10k
Q1
Q2
R1
R2
R3
4.7k

AND GATE

\[ V = 6V \]
\[ A \quad B \quad LED \]
\[ 0 \quad 0 \quad OFF \]
\[ 0 \quad 1 \quad OFF \]
\[ 1 \quad 0 \quad ON \]
\[ 1 \quad 1 \quad ON \]

10k
Q1
Q2
R1
R2
R3
4.7k
R4
1k

NAND GATE

\[ V = 6V \]
\[ A \quad B \quad LED \]
\[ 0 \quad 0 \quad ON \]
\[ 0 \quad 1 \quad ON \]
\[ 1 \quad 0 \quad ON \]
\[ 1 \quad 1 \quad OFF \]

10k
Q1
Q2
R1
R2
R3
4.7k
R4
1k

INVERTER

\[ V = 6V \]
\[ A \quad LED \]
\[ 0 \quad ON \]
\[ 1 \quad OFF \]

10k
Q1
R1
R2
R3
4.7k
1k
LED

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JUNCTION FETS

A JUNCTION FIELD-EFFECT TRANSISTOR (FET) IS A 3-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 DOING OF THE CURRENT-CARRYING CHANNEL REGION.

BASIC FET SWITCHES (N-FET)

BASIC FET AMPLIFIER (N-FET)

HI-Z MICROPHONE PREAMPLIFIER

USE TO COUPLE HIGH-IMPEDANCE CRYSTAL-TYPE MICROPHONES TO AMPLIFIER. 2N3819

C1 1µF 100K

C3 1µF TO AMPLIFIER

R1 1K

R2 1K

R3 100

R4 470

R5 470

C3 1µF

C2 1µF

MIC

HI-Z AUDIO MIXER

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 S1 TO CHARGE C1. THE PIEZO-BUZZER EMITS TONE AFTER C1 SELDI CHARGES. LARGE VALUES FOR C1 INCREASE THE DELAY. PLACE A LARGE VALUE RESISTOR ACROSS C1 TO REDUCE DELAY. Q1-POWER MOSFET. Q2-2N3819.

ON-DURING-DELAY TIMER

PRESS S1 TO CHARGE C1. THE PIEZO-BUZZER EMITS TONE UNTIL C1 SELDI CHARGES. INCREASE C1 TO INCREASE DELAY. A RESISTOR ACROSS C1 WILL REDUCE DELAY.

HI-Z SPEAKER AMPLIFIER

DUAL LED FLASHER

LEDS Flash alternately. R3 CONTROLS FLASH RATE. QUICKLY SHORT C1 or C2 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 R5 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.

<table>
<thead>
<tr>
<th>R1 + R2 (OHMS)</th>
<th>DELAY (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10K</td>
<td>7</td>
</tr>
<tr>
<td>15K</td>
<td>10</td>
</tr>
<tr>
<td>22K</td>
<td>12</td>
</tr>
<tr>
<td>47K</td>
<td>27</td>
</tr>
<tr>
<td>100K</td>
<td>68</td>
</tr>
</tbody>
</table>
PIEZOELECTRIC 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

+3 TO +12V
SL

OK TO ALTER C1'S VALUE.

R1 - 10K TO 50K POTENTIOMETER

C1

47uF

PIEZO BUZZER

PRESS AND RELEASE SL R1 CONTROLS VOLUME TO SIMULATE BELL.

LOGIC INTERFACES

+3 TO +12V

Q1

RL 2N2222

1K

IN

INJ TONE

LO OFF

MI ON

+3 TO +12V

Q1

RL 2N2222

1K

IN

INJ TONE

LO OFF

MI ON

R2 1M

R3 220K

PIEZO - ELEMENT DRIVERS

FIXED TONE

+3 TO +12V

R1 220K

BLUE

R2 10K

BLACK

R3 1/4W

Q1 2N2222

CONNECT C&D CELL ACROSS R1 FOR DARK-ACTIVATED TONE OR HERE FOR LIGHT-ACTIVATED TONE.

ADJUSTABLE FREQUENCY

+1 TO +15V

Q1

2N2907

R1 1K

R2 1K

Q2 2N2222

R3 4.7K

Q1

1/4W

R1 220K

Q1

2N2222

T1 IS PRIMARY OF CENTER-TAPPED AUDIO TRANSFORMER (RADIO SHACK 273-1380) 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 (holding current).

**Latching Pushbutton Switch**

- **S1**: Push to actuate (normally open)
- **S2**: Push to reset (normally closed)
- **R1**: Load (lamp, etc.)
- **SCR**: Terminal pinouts vary, typical:

**Light-Activated Relay**

- **R1**: Pull in when Q1 is illuminated
- **R2**: Remain latched until S1 is pressed
- **Q1**: 2N4481
- **Q2**: Photo-transistor
- **S1**: Push to reset (normally closed)

**Relaxation Oscillator**

- **C1**: Charged through R2 until its charge is high enough to switch on the SCR through R1. C1 then discharges through the SCR and the speaker. R2 controls the repetition rate.

**DC Motor Speed Controller**

- **C1**: Charged through R2 until its charge is high enough to switch on the SCR through R1. C1 then discharges through the SCR and the speaker. R2 controls the repetition rate.

**Note**: Some SCRs require careful adjustment of R2.

**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

[Diagram of TRIAC Switch Buffer]

LAMP DIMMER

[Diagram of Lamp Dimmer]

RESISTOR COLOR CODE

BLACK 0 0 x 1
BROWN 1 1 x 10
RED 2 2 x 100
ORANGE 3 3 x 1,000
YELLOW 4 4 x 10,000
GREEN 5 5 x 100,000
BLUE 6 6 x 1,000,000
VIOLET 7 7 x 10,000,000
GRAY 8 8 x 100,000,000
WHITE 9 9

FOURTH BAND INDICATES TOLERANCE (ACCURACY):
GOLD=± 5%  SILVER=±10%  NONE=±20%

OHM'S LAW:
V=IR  R=V/I  I=V/R  P=VI=I^2R

ABBREVIATIONS

A = AMPERE  R = RESISTANCE
F = FARAD  V (or E) = VOLT
I = CURRENT  W = WATT
P = POWER  Ω = OHM

M (MEG-) = x 1,000,000
K (KILO-) = x 1,000
m (MILLI-) = .001
μ (MICRO-) = .000 001
n (NANO-) = .000 000 001
p (PICO-) = .000 000 000 001