Engineer's Mini-Notebook
Basic Semiconductor Circuits

Forrest M. Mims III
CIRCUIT SYMBOLS

FIXED RESISTOR VARIABLE RESISTOR FIXED CAPACITOR POLARIZED CAPACITOR

RECTIFIER/ DIODE ZENER DIODE PNP TRANSISTOR NPN TRANSISTOR

LED SOLAR CELL PHOTO-RESISTOR PHOTO-TRANSISTOR

CONNECTED WIRES UNCONNECTED WIRES POSITIVE SUPPLY GROUND

SPST SWITCH SPDT SWITCH NORMALLY OPEN NORMALLY CLOSED PUSHBUTTON PUSHBUTTON

RELAY TRANSFORMER SPEAKER PIEZO-SPEAKER

METER LAMP BATTERY OP-AMP

ENGINEER'S MINI-NOTEBOOK

BASIC SEMICONDUCTOR CIRCUITS

BY

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THE AUTHOR WRITES A MONTHLY COLUMN, "ELECTRONICS NOTEBOOK," FOR MODERN ELECTRONICS.
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. 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 1K RESISTOR CAN USUALLY BE SUBSTITUTED FOR A 1K UNIT. A 10K POTentiometer CAN BE USED IN PLACE OF A 10K UNIT, AND MANY NPN TRANSISTORS CAN BE USED FOR THE POPULAR 2N3292. 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 x R
I = V / R
R = V / I

THE POWER DISSIPATED IN A RESISTOR CAN ALSO BE CALCULATED:

P = V x I
P = I² 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, 66 MILLIWATTS SHOULD BE EXPRESSED AS 0.066 VOLTS. 470 MILLIWATTS SHOULD BE EXPRESSED AS 0.47 WATTS. A 47K RESISTOR HAS A RESISTANCE OF 47 x 1,000 OR 47,000 OHMS. A 22M RESISTOR HAS A RESISTANCE OF 22 x 1,000,000 OR 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.
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:

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 \( I = \frac{4-1.7}{R} \).

<table>
<thead>
<tr>
<th>R1 (Ohms)</th>
<th>LED Current (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.43</td>
</tr>
<tr>
<td>150</td>
<td>0.29</td>
</tr>
<tr>
<td>220</td>
<td>0.20</td>
</tr>
<tr>
<td>270</td>
<td>0.16</td>
</tr>
<tr>
<td>330</td>
<td>0.13</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:

The bridge shown here permits the accurate measurement of an unknown resistance. \( R_3 \). \( R_1 \) and \( R_2 \) should be precision (0.1%) resistors. \( R_4 \) is a potentiometer with a calibrated dial. \( R_5 \) 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 \(4.2 \times 10^{18}\) 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 \(\mu\)F = 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.

![Diagram of charge and discharge]

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.

CAPACITORS IN SERIES

\[
\begin{align*}
C_1 & \quad C_2 \\
\frac{1}{C_T} &= \frac{1}{C_1} + \frac{1}{C_2} \\
C_T &= \frac{C_1 \times C_2}{C_1 + C_2}
\end{align*}
\]

Total capacitance (\(C_T\)) = \(\frac{C_1 \times C_2}{C_1 + C_2}\)

CAPACITORS IN PARALLEL

\[
\begin{align*}
\frac{1}{C_T} &= \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \\
C_T &= C_1 + C_2 + C_3
\end{align*}
\]

Warning!

Most capacitors can retain a charge for a considerable time after the charging supply has been switched off. Therefore, exercise 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.

10
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:

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:

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 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 = Vf + VR
Vf =forward voltage
VR = reverse voltage

VOLTAGE REGULATOR

The circuit will supply a steady output voltage equal to the sum of the turn-on (threshold) voltage of diodes D1 - Dn. Therefore,

Vout = 0.64(D1 + D2 + ... + Dn).

R1 = (Vin - Vout) / I

CAUTION: D1 AND R1 MUST HAVE PROPER POWER RATING (USE OHM'S LAW)

TRIANGLE-TO-SINE WAVE

This circuit will reduce voltage from a power supply by 0.6 volt per diode.

V = V - 0.6

TYPICAL APPLICATION:

D1, D2, D3 = 1N914

PEAK-READING VOLTOMETER

For best results, use digital multimeter for mV range to read voltage.

Frequency of incoming signal must be high enough to keep C1 charged.
**Reverse-Polarity Protector**

![Diagram of 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:

![Diagram of transient protector]

When the drive circuit switches the relay off, a high-voltage spike is generated in the relay's coil. D1 short circuits this spike.

**Meter Protector**

Connect a diode across the terminals of a meter to provide reverse current protection.

![Diagram of meter protector]

**Adjustable Waveform Clipper**

Adjust R2 to control clipping amplitude. *V should be a volt or so higher than peak input voltage.

**Adjustable Attenuator**

![Diagram of adjustable attenuator]

This is a bipolarity (+/-) version of the adjustable clipper.

**Audio Limiter**

Use to limit noise, pops, and static.

![Diagram of audio limiter]
**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 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 QUADRUPLE**

Components should be rated at 4 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**

\[ \begin{align*}
  A & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{ON} & 1 & \rightarrow \text{ON} \\
  B & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{ON} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
\end{align*} \]

**NOR GATE**

\[ \begin{align*}
  A & \rightarrow +6V & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{ON} & 0 & \rightarrow \text{OFF} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
  B & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{ON} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
\end{align*} \]

**AND GATE**

\[ \begin{align*}
  A & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} & 1 & \rightarrow \text{OFF} \\
  B & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{ON} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
\end{align*} \]

**NAND GATE**

\[ \begin{align*}
  A & \rightarrow +6V & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{ON} & 0 & \rightarrow \text{OFF} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
  B & \rightarrow 1K & 0 & \rightarrow \text{LED} & 0 & \rightarrow \text{OFF} & 0 & \rightarrow \text{ON} & 1 & \rightarrow \text{OFF} & 1 & \rightarrow \text{ON} \\
\end{align*} \]

**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.

**Truth Table**

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Decimal Input Switches} & \text{DCBA} & \text{Binary} \\
\hline
0 & 0 & 0 & 0 & 0 & 0.0000 \\
1 & 0 & 0 & 0 & 1 & 0.0001 \\
2 & 0 & 0 & 1 & 0 & 0.0010 \\
3 & 0 & 0 & 1 & 1 & 0.0011 \\
4 & 0 & 1 & 0 & 0 & 0.0100 \\
5 & 0 & 1 & 0 & 1 & 0.0101 \\
6 & 0 & 1 & 1 & 0 & 0.0110 \\
7 & 0 & 1 & 1 & 1 & 0.0111 \\
8 & 1 & 0 & 0 & 0 & 1.0000 \\
9 & 1 & 0 & 0 & 1 & 1.0001 \\
\hline
\end{array}
\]

**Binary Readout LEDs**
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:

Commercial zener diodes have breakdown voltages from 2 to 200 volts.

VOLTAGE REGULATOR MODEL

\[ V_{in} = V_o + I_L \cdot R_L \]
\[ I_L = \frac{V_{in} - V_o}{R_L} \]

V_{in} must be at least 1 volt above \( V_o \). \( I_L \) can vary from zero to maximum planned value. \( D_1 \) and \( R_1 \) must have proper power rating (use ohm's law).

Sample regulator:

\[ I_L = \text{maximum load current} \]
\[ I_Z = \text{maximum zener current} \]
\[ I = R_1 \text{ current} \]
\[ V_Z = \text{zener voltage} \]
\[ I_Z = R_1 \text{ current} \]

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>( V_{in} )</th>
<th>( V_{out} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>.36</td>
</tr>
<tr>
<td>10</td>
<td>6.37</td>
</tr>
<tr>
<td>15</td>
<td>9.27</td>
</tr>
</tbody>
</table>

WAVEFORM CLIPPERS

Use to reduce level of incoming signal. Clips both halves of wave equally.

Also converts sine wave to near square wave. As pop filter for speakers and phones.
BIPOLAR TRANSISTORS

A bipolar transistor is a three-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 depending on the doping contained in their three regions.

BASIC TRANSISTOR SWITCHES

![Diagram of a basic transistor switch]

BASIC TRANSISTOR AMPLIFIER

Adjust R1 to give best results. G1, R1, 1μF 5V, R2, 1k, 2N2222.

TEST CIRCUIT GAVE GAIN $\frac{V_{out}}{V_{in}} = 50$.

RELAY DRIVER

RELAY PULLS IN WHEN INPUT IS POSITIVE. APPLICATION:

- Resistive sensor or moisture-sensing probes
- Supplies sequence of drive pulses to relay, R1 and Q1 control pulse rate and time.
- Relay is closed per pulse. R4 controls pulse rate. Use to flash lamps and control motors.

RELAY CONTROLLER

RELAY 275-004

S1 1k

Q1 1n914

R1 1k

IN

+5V

NO

LOOK

RELAY 275-004

S1 1k

Q1 1n914

R1 1k

IN

+5V

NO

LOOK

LED REGULATOR

LED CURRENT = 7.48 mA. LED 5V.

SUPPLIES CONSTANT CURRENT to LED as supply voltage changes.

+5 TO +12V

Q1 1/2W 1/2W 2N2907

R1 1/2W 1/2W 2N2907

R3, 100

R5, 100

1/2W

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 RECORDER, 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 R5. OK TO USE MANY DIFFERENT TRANSISTORS FOR Q1 AND Q2. FOR VERY LOW 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
TO LOGIC CIRCUIT R1 1OK Q1 2N2222
R2 1K LED
+SV

AUDIO NOISE GENERATOR
USE TO CREATE FUZZ SOUNDS AND OTHER SPECIAL EFFECTS OR AS NOISE SOURCE FOR TESTING ROOM ACOUSTICS WITH SOUNDMETER.

ADJUSTABLE SIREN
R1 22K
R2 15K
R3 5K
R4 10K
C1 22uF
C2 2N2222
C3 2N2907
C4 2N2222
+3 TO +9V

S1 AND S2 CONTROL TONE RANGE. C1 22uF
C2 100k
C3 10k
C4 2N2222
S1 GIVES RISING TONE. OPENING S2 GIVES FALLING TONE.
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 1-1/2" 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. Taper cut loop and twist exposed wires.

SWITCH DEBOUNCE

Q1 2N2222
R1 10k
R2 4.7k
C1 1uF
S1

Q1 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 = 220uF.

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 1950s. This transmitter remains one of the smallest ever developed.

1/4" antenna (optional)

Sends signal to AM or SW radio a few feet away. R1 (AND R2) controls signal frequency. OK to use C4's cell 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: 0.1uF gives audio tone; 10uF 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**
2. **IN**
3. **R1**: 1K
4. **R2**: 50K
5. **R3**: 1K
6. **C1**: 1µF
7. **Q1**: 2N2222
8. **Q2**: 2N2222
9. **R4**: 100
10. **R5**: 1K
11. **ML**: 0-1 mA

**Circuits:**
- Input is 1-volt square wave.
- Use rectifier bridge module or four 1N914 diodes.
- Recalibrate if input is not a 1-volt square wave.

**Typical Results:**

<table>
<thead>
<tr>
<th>Signal (Hz)</th>
<th>M1 (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.02</td>
</tr>
<tr>
<td>200</td>
<td>0.24</td>
</tr>
<tr>
<td>300</td>
<td>0.34</td>
</tr>
<tr>
<td>400</td>
<td>0.44</td>
</tr>
<tr>
<td>500</td>
<td>0.55</td>
</tr>
<tr>
<td>600</td>
<td>0.65</td>
</tr>
<tr>
<td>700</td>
<td>0.79</td>
</tr>
<tr>
<td>900</td>
<td>0.85</td>
</tr>
<tr>
<td>900</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**PULSE GENERATOR**

- **R3** controls pulse rate.
- **D1**: 1N914
- **C1**: 1µF
- **R1**: 470
- **Q1**: 2N2222
- **R2**: 1M
- **Q2**: 1N914
- **R3**: 50

**Amplitude is about 10 volts when supply is 12.5 volts.**

**DC METER AMPLIFIER**

- **Q1**: 2N3904
- **R1**: 1K
- **R2**: 0-1 mA
- **R3**: 10K
- **D1**: 1N914

**To calibrate:**
1. Connect input to 1.5V.
2. Set to read current in milliamperes.
3. Set at mid point. Next:

**Notes:**
- Set pot for desired current.
- Adjust R3 until M1 indicates 1 mA.
- Repeat steps 1 and 2.
- Adjust R2 until M1 indicates 1 mA.
**Light Activated Flasher**

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.

**High-Brightness Flasher**

This circuit sends a high-current pulse to lamp L1 about once each second. R1 controls flash rate. C1 is a 1uF or 2uF lamp. Do not allow L1 to stay on.

**Dark Activated Flasher**

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

**LED Transmitter/Receiver**

Use high-output infrared LED. Sends tone over LED beam. C1 increases range.
RESISTOR-TRANSISTOR LOGIC

THESE LOGIC CIRCUITS CAN BE USED TO TEACH BASICS OF DIGITAL LOGIC AND IN PRACTICAL APPLICATIONS.

OR GATE

O = GROUND
1 = +6V

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

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

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

INVERTER

A LED
0 ON
1 OFF

R1 10K
R2 1K
Q1, Q2 = 2N2222
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 doping of the current-carrying channel region.

BASIC FET SWITCHES (N-FET)

HI-Z MICROPHONE PREAMPLIFIER

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

R2 IS GAIN CONTROL.

C1 1µF 470k 1µF TO AMPLIFIER

C2 R1 100k

R3 100

C3 1µF

KEEP LEADS TO MICROPHONE SHORT OR USE SHIELDED CABLE.

HI-Z AUDIO MIXER

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

R1 1µF

INPUTS: A, B

R2 100k

R4 100k

R5 470k

C1 1µF

C4 1µF TO AMPLIFIER

C2 1µF

IN

OUT

38
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 JFET. 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 PIEZOBUZZER EMITS TONE AFTER C1 SELFS DISCHARGES. LARGE VALUES FOR C1 INCREASE THE DELAY. PLACE LARGE VALUE RESISTOR ACROSS C1 TO REDUCE DELAY. Q1-POWER MOSFET. Q2-2N3922.

ON-DURING-DELAY TIMER

PRESS SL TO CHARGE C1. THE PIEZOBUZZER EMITS TONE UNTIL C1 SELFS DISCHARGES. INCREASE C1 TO INCREASE DELAY. RESISTOR ACROSS C1 WILL REDUCE DELAY.

HI-Z SPEAKER AMPLIFIER

R1 CONTROLS GAIN. INPUT CAN BE HIGH-IMPEDANCE MICROPHONE, RADIO, ETC.

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 R1 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

+5 TO +12V

SL

OK TO ALTER C1'S VALUE.

PIEZO BUZZER

PRESS AND RELEASE SL R1 CONTROLS VOLUME TO SIMULATE BELL.

LOGIC INTERFACES

+5 TO +12V

IN

TONI

LO

OFF

MI

ON

Q1 2N2222

R1 1K

R2 1K

Q1 2N2401

R1 1K

R2 1K

T1 IS PRIMARY OF CENTER-TAPPED AUDIO TRANSFORMER (RADION SHACK 273-1580).

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:
  - Typical:
  - RELAXATION OSCILLATOR

- +9V
- R1 100K
- SCR
- R2 10K
- C1
- B2
- SPKR
- NOTE: Some SCRs require careful adjustment of R2.

DC MOTOR SPEED CONTROLLER

- +9V
- +3 to +6V
- R1 100K
- R2 100
- R3 100
- Q1 2N4819
- C1 4.7µF
- M
- CHECK MOTOR WITH THIS CIRCUIT. IF LED FLASHER 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 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=±2.5%  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