Engineer's Mini-Notebook
Formulas, Tables and Basic Circuits

Forrest M. Mims III
ENGINEER'S
MINI-NOTEBOOK
FORMULAS, TABLES
AND BASIC CIRCUITS

BY
FORREST M. MIMS, III

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A SILICONCEPTS™ BOOK

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1. ELECTRONIC FORMULAS

DIRECT CURRENT

A DIRECT CURRENT (DC) FLOWS IN ONE DIRECTION, EITHER STEADILY OR IN PULSES.

CURRENT (I) — THE QUANTITY OF ELECTRONS PASSING A GIVEN POINT. (UNIT: AMPERE)

VOLTAGE (V) — ELECTRICAL PRESSURE OR FORCE. (UNIT: VOLT)

RESISTANCE (R) — RESISTANCE TO THE FLOW OF A CURRENT. (UNIT: OHM)

POWER (P) — THE WORK PERFORMED BY A CURRENT. (UNIT: WATT)

POTENTIAL DIFFERENCE — THE DIFFERENCE IN VOLTAGE BETWEEN THE TWO ENDS OF A CONDUCTOR THROUGH WHICH A CURRENT FLOWS. ALSO KNOWN AS VOLTAGE DROP.

OHM'S LAW

A POTENTIAL DIFFERENCE OF 1 VOLT WILL FORCE A CURRENT OF 1 AMPERE THROUGH A RESISTANCE OF 1 OHM, OR:

\[ V = I \times R \]

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

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

\[ P = I \times V \text{ (or) } I^2 \times R \]

V, I AND R.

OHM'S LAW HELPER

THIS DIAGRAM SHOWS THE RELATIONSHIP OF
RESISTOR NETWORKS

SERIES

\[ R_T = \text{TOTAL RESISTANCE} \]
\[ R_T = R_1 + R_2 + R_3 \]

PARALLEL (2)

\[ R_T = \frac{R_1 \times R_2}{R_1 + R_2} \]

PARALLEL (2 OR MORE)

\[ R_T = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_N} \]

VOLTAGEDivider

\[ V_{\text{OUT}} = V_{\text{IN}} \times \left( \frac{R_2}{R_1 + R_2} \right) \]

\( R_1 \) AND \( R_2 \) CAN BE A POTENTIOMETER.
ALTERNATING CURRENT

An alternating current (AC) flows in both directions through a conductor.

PEAK VOLTAGE - maximum positive and negative excursions of an alternating current.

RMS VOLTAGE - (root-mean-square voltage) that AC voltage that equals a DC voltage that does the same work. For a sine wave, 0.707 times the peak voltage.

IMPEDANCE (Z) - the opposition to an alternating current presented by a circuit. (Unit: Ohm)

Average AC voltage = 0.637 x peak
= 0.9 x RMS

RMS AC voltage = 0.707 x peak
= 1.11 x average

Peak AC voltage = 1.414 x RMS
= 1.57 x average

See the definitions of I, V, R and P on page 4.

7
**OHM'S LAW**

\[ V = I \times Z \]

\[ I = \frac{E}{Z} \]

\[ Z = \frac{E}{I} \]

\( \theta \) is phase angle, the difference in degrees between current and voltage. Current leads voltage in a capacitive circuit and lags voltage in a reactive circuit. In a resistive circuit, \( \theta \) is 0°. The cosine of 0° is 1. Thus, in a resistive circuit, \( P = E \times I \).

**CAPACITOR NETWORKS**

**SERIES**

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

**SERIES**

\[ C_T = \frac{C_1 \times C_2}{C_1 + C_2} \]

**PARALLEL (2 OR MORE)**

\[ C_T = C_1 + C_2 + C_N \]
2. MATHEMATICS

SYMBOLS

\[ + \quad \text{PLUS, POSITIVE OR ADD} \]
\[ - \quad \text{MINUS, NEGATIVE OR SUBTRACT} \]
\[ \times \quad \text{MULTIPLY} \]
\[ \div \quad \text{DIVIDE} \]
\[ = \quad \text{EQUAL(S)} \]
\[ \neq \quad \text{DOES NOT EQUAL} \]
\[ \approx \quad \text{APPROXIMATELY EQUAL} \]
\[ > \quad \text{GREATER THAN} \]
\[ \geq \quad \text{EQUAL TO OR GREATER THAN} \]
\[ < \quad \text{LESS THAN} \]
\[ \leq \quad \text{LESS THAN OR EQUAL TO} \]
\[ \pm \quad \text{PLUS OR MINUS; CHANGE SIGN} \]
\[ \frac{1}{n} \quad \text{RECIPIROCAL \,(1/2 = 0.5)} \]
\[ \sqrt[n]{n} \quad \text{SQUARE ROOT OF} \ n \]
\[ \sqrt[3]{n} \quad \text{CUBE ROOT OF} \ n \]

POWERS OF TEN

\[ 10^{-9} = 0.000000001 \quad \text{1 BILLIONTH (NANO)} \]
\[ 10^{-8} = 0.0000001 \]
\[ 10^{-7} = 0.000001 \]
\[ 10^{-6} = 0.00001 \quad \text{1 MILLIONTH (MICRO)} \]
\[ 10^{-5} = 0.001 \]
\[ 10^{-4} = 0.01 \]
\[ 10^{-3} = 0.1 \]
\[ 10^{-2} = 1 \]
\[ 10^{-1} = 10 \]
\[ 10^{1} = 100 \]
\[ 10^{2} = 1000 \]
\[ 10^{3} = 10000 \quad \text{THOUSAND (KILO)} \]
\[ 10^{4} = 100000 \]
\[ 10^{5} = 1000000 \]
\[ 10^{6} = 10000000 \quad \text{MILLION (MEGA)} \]
\[ 10^{7} = 100000000 \]
\[ 10^{8} = 1000000000 \]
\[ 10^{9} = 1,000,000,000 \quad \text{BILLION (GIGA)} \]
ALGEBRAIC TRANSPOSITION

If \( A + B = C \), then:

\[
A = C - B \\
B = C - A \\
A + B - C = 0
\]

If \( \frac{A}{B} = \frac{C}{D} \), then:

\[
A = \frac{C \cdot D}{B} \\
D = \frac{B \cdot C}{A}
\]

LAW OF EXPONENTS

\[
\left( \frac{a}{b} \right)^x = \frac{a^x}{b^x} \\
(a^x)(a^y) = a^{x+y} \\
\frac{a^x}{a^y} = a^{x-y} \\
(a^x)^y = a^{x \cdot y} \\
a^{-x} = \frac{1}{a^x} \\
a^{\frac{x}{y}} = \sqrt[y]{a^x}
\]

COMMON LOGARITHMS

THE COMMON LOGARITHM (\( \log_{10} \) OR \( \log \)) OF A NUMBER IS THE POWER OF 10 THAT EQUALS THE NUMBER. SINCE \( 10^2 = 100 \), 2 IS THE LOG OF 100. THE ANTILOGARITHM (ANTILOG) IS THE NUMBER THAT EQUALS A LOGARITHM. THEREFORE THE ANTILOG OF 2 IS 100. THE LOG OF NUMBERS GREATER THAN 1 IS POSITIVE; THE LOG OF NUMBERS LESS THAN 1 IS NEGATIVE. THEREFORE THE LOG OF 10^{-2} OR 0.01 IS -2. \( A \times B = \text{ANTILOG} (\log A + \log B) \); \( A \div B = \text{ANTILOG} (\log A - \log B) \). SCIENTIFIC CALCULATORS HAVE LOG AND ANTILOG KEYS.
THE DECIBEL

THE DECIBEL (dB) IS A UNIT OF MEASURE THAT PERMITS TWO DIFFERENT SIGNALS TO BE COMPARED ON A LOGARITHMIC SCALE. THE SENSITIVITY OF RECEIVERS AND THE GAIN OF AMPLIFIERS ARE OFTEN GIVEN IN DECIBELS. THE DIFFERENCE IN dB BETWEEN THE POWER OF A SIGNAL AT THE INPUT OF AN AMPLIFIER (P1) AND THE POWER OF THE AMPLIFIER’S OUTPUT (P2) IS:

\[ dB = 10 \log \left( \frac{P2}{P1} \right) \]

THE DIFFERENCE IN dB BETWEEN THE VOLTAGE (V) AND CURRENT (I) AT THE INPUT (V1 AND I1) AND OUTPUT (V2 AND I2) OF AN AMPLIFIER IS:

\[ dB = 20 \log \left( \frac{V2}{V1} \right) \]
\[ dB = 20 \log \left( \frac{I2}{I1} \right) \]

NOTE THAT DECIBELS DEFINE THE RATIO BETWEEN TWO SIGNAL LEVELS, NOT THEIR ABSOLUTE VALUE.

EXAMPLE: DETERMINE THE VOLTAGE GAIN IN dB OF THIS OPERATIONAL AMPLIFIER.

\[ R1 = 1,000 \Omega \]
\[ R2 = 1,000,000 \Omega \]
\[ V_{\text{Gain}} = \frac{R2}{R1} \]
\[ dB = 20 \log \left( \frac{V2}{V1} \right) \]
\[ dB = 20 \log \left( \frac{1,000}{1} \right) = 20 \log 1000 \]

\[ \log 1000 = 3 \text{ (FROM TABLE OR CALCULATOR)} \]
\[ \text{GAIN} = 20 \times 3 = 60 \text{ dB} \]

\[ V_{\text{out}} \]
### DECIBEL (dB) TABLE

<table>
<thead>
<tr>
<th>VOLTAGE OR CURRENT RATIO</th>
<th>POWER RATIO</th>
<th>dB</th>
<th>VOLTAGE OR CURRENT RATIO</th>
<th>POWER RATIO</th>
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<td>1.0000</td>
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<td>1.0000</td>
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<td>1</td>
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<td>100</td>
<td>100000.00</td>
<td>$10^{10}$</td>
</tr>
</tbody>
</table>

### POWER - dBm EQUIVALENTS

RECEIVER SENSITIVITY IS OFTEN GIVEN IN dB WITH RESPECT TO 1 MILLIWATT.

<table>
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<tr>
<th>dBm</th>
<th>POWER (mW)</th>
<th>UNITS</th>
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<td>10</td>
<td>10,000,000</td>
<td>10 MILLIWATTS</td>
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<td>100 NANOIWATT</td>
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<tr>
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<td>10</td>
<td>100 NANOIWATT</td>
</tr>
<tr>
<td>-60</td>
<td>1</td>
<td>1 NANOIWATT</td>
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</table>
NUMBER SYSTEMS

A NUMBER SYSTEM CAN BE BASED ON ANY NUMBER OF DIGITS. THE COMMON DECIMAL SYSTEM HAS 10 DIGITS. THE BINARY SYSTEM HAS 2 DIGITS; THE HEXADECIMAL SYSTEM HAS 16 DIGITS. NUMBERS ARE WRITTEN AS SUCCESSIVE POWERS OF THE BASE OF THE NUMBER SYSTEM. THUS:

\[
\begin{align*}
4327_{10} &\rightarrow 7 \times 10^0 = 7 \\
 &\quad \rightarrow 2 \times 10^1 = 20 \\
 &\quad \rightarrow 3 \times 10^2 = 300 \\
 &\quad \rightarrow 4 \times 10^3 = 4000
\end{align*}
\]

\[\boxed{72000} \]

BINARY NUMBERS

IN ELECTRONIC CIRCUITS DECIMAL NUMBERS ARE USUALLY REPRESENTED BY BINARY NUMBERS. BINARY NUMBERS ALSO SERVE AS CODES THAT REPRESENT LETTERS OF THE ALPHABET, VOLTAGES, COMPUTER INSTRUCTIONS, ETC. A BINARY 0 OR 1 IS A BIT. A PATTERN OF 4 BITS IS A NIBBLE. A PATTERN OF 4 BITS IS A BYTE OR WORD.

BINARY TO DECIMAL

\[
\begin{align*}
10.011 &\rightarrow 1 \times 2^0 = 1 \\
 &\quad \rightarrow 1 \times 2^1 = 2 \\
 &\quad \rightarrow 0 \times 2^2 = 0 \\
 &\quad \rightarrow 1 \times 2^3 = 8 \\
 &\quad \rightarrow 1 \times 2^4 = 16 \\
\end{align*}
\]

\[19 = 10011_2\]

DECIMAL TO BINARY

\[
\begin{align*}
19 \div 2 & = 9 + 1 \\
9 \div 2 & = 4 + 1 \\
4 \div 2 & = 2 + 0 \\
2 \div 2 & = 1 + 0 \\
1 \div 2 & = 0 + 1 *
\end{align*}
\]

*FINAL QUOTIENT IS FINAL REMAINDER

BINARY CODED DECIMAL (BCD); A SYSTEM IN WHICH EACH DECIMAL DIGIT IS ASSIGNED ITS BINARY EQUIVALENT. 19 = 0001 1001;
<table>
<thead>
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<th>BIN</th>
<th>BCD</th>
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</table>
3. CONSTANTS AND STANDARDS

U.S. WEIGHTS AND MEASURES

LINEAR

1,000 MILES = 1 INCH (IN)  3 FT = 1 YARD (YD)
12 INCHES = 1 FOOT (FT)  5,280 FT = 1 MILE (MI)

AREA

1 FOOT² = 144 IN²  1 ACRE = 43,560 FT²
1 YARD² = 9 FT²  1 MILE² = 640 ACRES

VOLUME

1 FOOT³ = 1,728 IN³  1 YARD³ = 27 FEET³

MASS

16 OUNCES (OZ) = 1 POUND (LB)

METRIC WEIGHTS AND MEASURES

LINEAR

1,000 MICROMETERS (µm) = 1 MILLIMETER (mm)
10 mm = 1 CENTIMETER (cm)  100 cm = 1 METER (m)
1,000 METERS = 1 KILOMETER (km)

AREA

100 mm² = 1 cm²  10,000 cm² = 1 m²

VOLUME

1 cm³ = 1 MILLICLITER (ml)  1,000 ml = 1 LITER (L)

MASS

1,000 MILLIGRAMS (mg) = 1 gram (g)
### U.S. - Metric Conversion

<table>
<thead>
<tr>
<th>To Convert</th>
<th>Into</th>
<th>Multiply By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micrometers</td>
<td>Mils</td>
<td>3.937 × 10^{-2}</td>
</tr>
<tr>
<td>Mils</td>
<td>Micrometers</td>
<td>2.54</td>
</tr>
<tr>
<td>Millimeters</td>
<td>Mils</td>
<td>3.937</td>
</tr>
<tr>
<td>Mils</td>
<td>Millimeters</td>
<td>2.54 × 10^{-2}</td>
</tr>
<tr>
<td>Millimeters</td>
<td>Inches</td>
<td>3.937 × 10^{-2}</td>
</tr>
<tr>
<td>Inches</td>
<td>Millimeters</td>
<td>2.54</td>
</tr>
<tr>
<td>Centimeters</td>
<td>Inches</td>
<td>0.3937</td>
</tr>
<tr>
<td>Inches</td>
<td>Centimeters</td>
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</tr>
<tr>
<td>Inches</td>
<td>Meters</td>
<td>2.54 × 10^{-2}</td>
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<td>Inches</td>
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</tr>
<tr>
<td>Feet</td>
<td>Meters</td>
<td>30.48 × 10^{-2}</td>
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<td>Feet</td>
<td>3.281</td>
</tr>
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<td>Yards</td>
<td>1.094</td>
</tr>
<tr>
<td>Yards</td>
<td>Meters</td>
<td>0.9144</td>
</tr>
<tr>
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<td>Feet</td>
<td>3.281</td>
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<tr>
<td>Feet</td>
<td>Kilometers</td>
<td>3.408 × 10^{-4}</td>
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<td>Miles</td>
<td>1.609</td>
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<td>Miles</td>
<td>Kilometers</td>
<td>1.609</td>
</tr>
<tr>
<td>Grams</td>
<td>Ounces</td>
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<td>Grams</td>
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<td>Pounds</td>
<td>2.205</td>
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<tr>
<td>Pounds</td>
<td>Kilograms</td>
<td>0.4536</td>
</tr>
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</table>

### Familiar Examples

#### Dimensions

- **Dime**: ≈ 1 mm × 1.8 cm
- **Nickel**: ≈ 2 mm × 2.1 cm
- **Quarter**: ≈ 2 mm × 2.4 cm
- **1-Mil Plastic Film**: = 25.4 μm

#### Mass

- **Plastic TO-92 Transistor**: ≈ 0.25 g
- **8-Pin Mini-DIP IC**: ≈ 0.5 g
- **16-Pin DIP IC**: ≈ 1.05 g
- **Nickel**: ≈ 5 g
TEMPERATURE

°F = (°C × 9/5) + 32
°C = 5/9 × (°F - 32)

LEAD MELTS → 328°F 622.4°C
WATER BOILS → 100°C 212°F

TYPICAL SEMICONDUCTOR OPERATING TEMPERATURE RANGE:

COMMERCIAL: 0°C to 70°C
INDUSTRIAL: -65°C to 150°C

HUMAN BODY (37°C; 98.6°F)
ROOM TEMPERATURE (22°C)
WATER FREEZES → 0°C 32°F

SOLDER

THE MOST COMMON ELECTRONIC SOLDER IS 60/40 (60% TIN AND 40% LEAD). ITS MELTING POINT IS 183°C TO 190°C (361°F TO 374°F).
## Copper Wire

<table>
<thead>
<tr>
<th>AWG</th>
<th>Dia</th>
<th>Ohms per 1000 ft</th>
<th>FT per Pound</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.19</td>
<td>0.99</td>
<td>31.62</td>
</tr>
<tr>
<td>12</td>
<td>8.08</td>
<td>1.58</td>
<td>50.59</td>
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<tr>
<td>14</td>
<td>6.41</td>
<td>2.52</td>
<td>80.49</td>
</tr>
<tr>
<td>16</td>
<td>5.08</td>
<td>4.01</td>
<td>127.9</td>
</tr>
<tr>
<td>18</td>
<td>4.03</td>
<td>6.39</td>
<td>203.4</td>
</tr>
<tr>
<td>20</td>
<td>3.20</td>
<td>10.15</td>
<td>323.4</td>
</tr>
<tr>
<td>22</td>
<td>2.54</td>
<td>16.14</td>
<td>514.2</td>
</tr>
<tr>
<td>24</td>
<td>2.01</td>
<td>25.67</td>
<td>817.7</td>
</tr>
<tr>
<td>26</td>
<td>1.59</td>
<td>40.81</td>
<td>1300.0</td>
</tr>
<tr>
<td>28</td>
<td>1.26</td>
<td>64.90</td>
<td>2067.0</td>
</tr>
<tr>
<td>30</td>
<td>1.00</td>
<td>103.2</td>
<td>3287.0</td>
</tr>
<tr>
<td>32</td>
<td>0.79</td>
<td>164.1</td>
<td>5227.0</td>
</tr>
<tr>
<td>34</td>
<td>0.63</td>
<td>260.9</td>
<td>8310.0</td>
</tr>
<tr>
<td>36</td>
<td>0.50</td>
<td>414.8</td>
<td>13210.0</td>
</tr>
<tr>
<td>38</td>
<td>0.40</td>
<td>659.6</td>
<td>21010.0</td>
</tr>
<tr>
<td>40</td>
<td>0.31</td>
<td>1049.0</td>
<td>33410.0</td>
</tr>
</tbody>
</table>

**AWG** - American Wire Gauge  
**Dia** - Diameter in Mil  
**Ohms per 1000 ft** - 20°C (68°F)

## Relative Resistances

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistance</th>
<th>Relative To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>0.936</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>1.000</td>
<td>Copper, 1 foot of</td>
</tr>
<tr>
<td>Gold</td>
<td>1.403</td>
<td>Circular Copper</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.530</td>
<td>Wire, 1 mil in</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.549</td>
<td>Diameter has a</td>
</tr>
<tr>
<td>Tungsten</td>
<td>3.203</td>
<td>Resistance of</td>
</tr>
<tr>
<td>Brass</td>
<td>4.822</td>
<td>10.37 Ohms,</td>
</tr>
<tr>
<td>Phosphor-Bronze</td>
<td>5.533</td>
<td>Alternatively,</td>
</tr>
<tr>
<td>Nickel</td>
<td>5.786</td>
<td>Copper Wire has</td>
</tr>
<tr>
<td>Iron</td>
<td>5.799</td>
<td>A Resistance</td>
</tr>
<tr>
<td>Tin</td>
<td>6.702</td>
<td>Of 10.37 Ohms</td>
</tr>
<tr>
<td>Steel</td>
<td>9.932</td>
<td>Per Circular</td>
</tr>
<tr>
<td>Lead</td>
<td>12.922</td>
<td>Stainless Steel</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>52.941</td>
<td>Nichrome</td>
</tr>
<tr>
<td>Nichrome</td>
<td>65.092</td>
<td></td>
</tr>
</tbody>
</table>
MECHANICAL VIBRATION IN SOLIDS, FLUIDS AND GASES PRODUCES WHAT THE BRAIN PERCEIVES AS SOUND.

SPEED OF SOUND IN AIR (27°C): 1,139.67 FT/SEC

RANGE OF HUMAN HEARING:
### Sound Intensity Levels

<table>
<thead>
<tr>
<th>Sound Source (Distance from Observer)</th>
<th>Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of Pain</td>
<td>120+</td>
</tr>
<tr>
<td>Aircraft engine (20')</td>
<td>120+</td>
</tr>
<tr>
<td>Amplified rock music</td>
<td>110</td>
</tr>
<tr>
<td>Thunder</td>
<td>110</td>
</tr>
<tr>
<td>Piezoelectric buzzer (12&quot;)</td>
<td>108</td>
</tr>
<tr>
<td>Air Force T-38 (2,500' overhead)</td>
<td>90</td>
</tr>
<tr>
<td>CO₂ pellet gun (12&quot;)</td>
<td>90</td>
</tr>
<tr>
<td>Digital alarm clock (12&quot;)</td>
<td>85</td>
</tr>
<tr>
<td>Electric typewriter (18&quot;)</td>
<td>80</td>
</tr>
<tr>
<td>Air Force T-38 (1 mile)</td>
<td>70</td>
</tr>
<tr>
<td>Typical conversation</td>
<td>65</td>
</tr>
<tr>
<td>Paper clip dropped on desk (12&quot;)</td>
<td>62</td>
</tr>
<tr>
<td>Telephone dial tone (1&quot;)</td>
<td>56</td>
</tr>
<tr>
<td>Pencil eraser tapped on desk (12&quot;)</td>
<td>54</td>
</tr>
<tr>
<td>Computer keyboard (18&quot;)</td>
<td>61</td>
</tr>
<tr>
<td>Average residence</td>
<td>45</td>
</tr>
<tr>
<td>Soft background music</td>
<td>30</td>
</tr>
<tr>
<td>Quiet whisper</td>
<td>20</td>
</tr>
<tr>
<td>Threshold of hearing</td>
<td>0</td>
</tr>
<tr>
<td>Frequency (m)</td>
<td>Electromagnetic Radiation</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>20</td>
<td>Radio Waves</td>
</tr>
<tr>
<td>100</td>
<td>Infrared</td>
</tr>
<tr>
<td>1000</td>
<td>Ultraviolet</td>
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<tr>
<td>10000</td>
<td>Visible Light</td>
</tr>
<tr>
<td>100000</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>1000000</td>
<td>X-Rays</td>
</tr>
<tr>
<td>10000000</td>
<td>Gamma Rays</td>
</tr>
</tbody>
</table>

**Beyond 10 pm:**
- Cosmic Rays
- Ultraviolet
- Visible Light
- Infrared
- Microwaves
- Radio Waves

* The eye's sensitivity to violet and red varies with the observer and the background illumination.

\[ f = \frac{c}{\lambda} \]

- Frequency (f)
- Wavelength (\lambda)
- Speed of light (c) = 3 \times 10^8 m/sec (see next page)
# Radio Frequency Spectrum

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 - 30 kHz</td>
<td>Very Low Frequencies (VLF)</td>
</tr>
<tr>
<td>30 - 300 kHz</td>
<td>Low Frequencies (LF)</td>
</tr>
<tr>
<td>300 - 3000 kHz</td>
<td>Medium Frequencies (MF)</td>
</tr>
<tr>
<td>3 - 30 MHz</td>
<td>High Frequencies (HF)</td>
</tr>
<tr>
<td>30 - 300 MHz</td>
<td>Very High Frequencies (VHF)</td>
</tr>
<tr>
<td>300 - 3000 MHz</td>
<td>Ultra High Frequencies (UHF)</td>
</tr>
<tr>
<td>3 - 30 GHz</td>
<td>Super High Frequencies (SHF)</td>
</tr>
<tr>
<td>30 - 300 GHz</td>
<td>Extremely High Frequencies (EHF)</td>
</tr>
<tr>
<td>300 - 3000 GHz</td>
<td>Microwave Frequencies</td>
</tr>
</tbody>
</table>

## Frequency vs. Wavelength

\[
\lambda = \frac{c}{f} \quad f = \frac{c}{\lambda}
\]

- \(\lambda\) = Wavelength (Meters)
- \(c\) = Speed of light \((3 \times 10^8 \text{ Meters/Sec})\)
- \(f\) = Frequency (Hertz)

**Example:** The wavelength of a 108 MHz signal is \(3 \times 10^8 / 1.08 \times 10^6\) or 2.76 meters.
IMPORTANT FREQUENCIES (MHz)

15.54: NAVIGATION BEACONS
1.5: INTERNATIONAL DISTRESS
1.64: AM BROADCAST BAND
1.67: AIRPORT INFORMATION
1.8 - 2.0: 160 METER AMATEUR BAND
2.3 - 2.498: 120 METER INT. BROADCAST
2.5: WWV TIME SIGNAL
3.5 - 4.0: 80 METER AMATEUR BAND
5.0: WWV TIME SIGNAL
5.95 - 6.2: 49 METER INT. BROADCAST
6.2 - 6.525: MARITIME COMMUNICATIONS
7.0 - 7.3: 40 METER AMATEUR
7.0 - 7.3: 40 METER INT. BROADCAST
9.5 - 9.9: 31 METER INT. BROADCAST
10.0: WWV TIME SIGNAL
10.1 - 10.15: 30 METER AMATEUR BAND
10.15 - 11.75: INT. BROADCAST
11.7 - 11.975: 25 METER INT. BROADCAST
14.0 - 14.35: 20 METER AMATEUR BAND
15.0: WWV TIME SIGNAL
20.0: WWV TIME SIGNAL
21.0 - 21.45: 15 METER AMATEUR BAND
21.45 - 21.85: 13 METER INT. BROADCAST
24.89 - 24.99: 12 METER AMATEUR BAND
25.67 - 26.1: 11 METER INT. BROADCAST
26.9 - 27.4: CITIZENS BAND
28.0 - 29.7: 10 METER AMATEUR BAND
49.82 - 49.9: LOW POWER COMMUNICATIONS
50.0 - 54.0: 6 METER AMATEUR BAND
54.0 - 88.0: TELEVISION (CH. 2-6)
72.03 - 72.9: RADIO CONTROL (AIRCRAFT ONLY)
75.43 - 75.87: RADIO CONTROL
88.0 - 108.0: FM BROADCAST BAND
88.0 - 108.0: WIRELESS MICROPHONES
108.0 - 118.0: AIR NAVIGATION BEACONS
118.0 - 136.0: AIRCRAFT
153 - 155: POLICE, FIRE, MUNICIPAL
156.8 - 159: POLICE, FIRE, MUNICIPAL
162.4 - 162.55: NOAA WEATHER
174 - 216: TELEVISION (CH. 7-13)
470 - 890: TELEVISION (CH. 14-83)
<table>
<thead>
<tr>
<th>UTC</th>
<th>PST</th>
<th>MST</th>
<th>CST</th>
<th>EST</th>
<th>AST</th>
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<tbody>
<tr>
<td>0000</td>
<td>4 PM</td>
<td>5 PM</td>
<td>6 PM</td>
<td>7 PM</td>
<td>8 PM</td>
</tr>
<tr>
<td>0100</td>
<td>5 PM</td>
<td>6 PM</td>
<td>7 PM</td>
<td>8 PM</td>
<td>9 PM</td>
</tr>
<tr>
<td>0200</td>
<td>6 PM</td>
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</tr>
<tr>
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<td>11 PM</td>
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<td>1 AM</td>
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<td>11 PM</td>
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<td>2 AM</td>
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<td>2 AM</td>
<td>3 AM</td>
<td>4 AM</td>
</tr>
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<td>0800</td>
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<td>4 AM</td>
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<td>3 AM</td>
<td>4 AM</td>
<td>5 AM</td>
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<td>5 AM</td>
<td>6 AM</td>
<td>7 AM</td>
<td>8 AM</td>
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<td>6 AM</td>
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<td>8 AM</td>
<td>9 AM</td>
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<td>7 AM</td>
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<tr>
<td>1500</td>
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<td>8 AM</td>
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<td>10 AM</td>
<td>11 AM</td>
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<td>12 AM</td>
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<td>1 AM</td>
<td>2 AM</td>
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<td>1900</td>
<td>11 AM</td>
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<td>2 AM</td>
<td>3 AM</td>
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<td>2000</td>
<td>12 AM</td>
<td>1 AM</td>
<td>2 AM</td>
<td>3 AM</td>
<td>4 AM</td>
</tr>
<tr>
<td>2100</td>
<td>1 PM</td>
<td>2 PM</td>
<td>3 PM</td>
<td>4 PM</td>
<td>5 PM</td>
</tr>
<tr>
<td>2200</td>
<td>2 PM</td>
<td>3 PM</td>
<td>4 PM</td>
<td>5 PM</td>
<td>6 PM</td>
</tr>
<tr>
<td>2300</td>
<td>3 PM</td>
<td>4 PM</td>
<td>5 PM</td>
<td>6 PM</td>
<td>7 PM</td>
</tr>
</tbody>
</table>

**UTC** - COORDINATED UNIVERSAL TIME  
(GREENWICH MERIDIAN TIME, LONDON)  
**PST** - PACIFIC STANDARD TIME  
**MST** - MOUNTAIN STANDARD TIME  
**CST** - CENTRAL STANDARD TIME  
**EST** - EASTERN STANDARD TIME  
**AST** - ATLANTIC STANDARD TIME  
**DAYLIGHT SAVINGS TIME** - ADD 1 HOUR
THE SINE WAVE

The sine, or sinusoidal wave is the most common periodic wave in analog electronic circuits. If peak amplitudes are +1 and -1, then:

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Amplitude (Sin(θ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0</td>
</tr>
<tr>
<td>30°</td>
<td>0.500</td>
</tr>
<tr>
<td>45°</td>
<td>0.707</td>
</tr>
<tr>
<td>90°</td>
<td>1</td>
</tr>
<tr>
<td>135°</td>
<td>0.707</td>
</tr>
<tr>
<td>180°</td>
<td>0</td>
</tr>
<tr>
<td>225°</td>
<td>-0.707</td>
</tr>
<tr>
<td>270°</td>
<td>-1</td>
</tr>
<tr>
<td>315°</td>
<td>-0.707</td>
</tr>
<tr>
<td>360°</td>
<td>0</td>
</tr>
</tbody>
</table>

The phase of simultaneous sine waves may differ:

This wave lags 26°
This wave leads 24°

Frequency of a sine wave is the number of cycles per second. Hertz (Hz) is the unit of frequency. One hertz (1 Hz) is one cycle per second (1 CPS).

Period of a sine wave is the time for one complete cycle to occur.
PERIODIC WAVES

Many different periodic waveforms can be processed or generated by analog electronic circuits. They include:

**Square Wave**  **Rectangular Wave**

![Square Wave](image)

**Triangle Wave**  **Sawtooth Wave**

![Triangle Wave](image)

Periodic waves can be rectified by diodes and clipped by zener diodes:

![Rectifier and Clipper Diagram](image)

**Half-Wave Rectified Sine Wave**  **Full-Wave Rectified Sine Wave**

![Half-Wave Rectified Sine Wave](image)

**Clipped Sawtooth Trapezoidal Wave**

![Clipped Sawtooth Trapezoidal Wave](image)
PULSES

Single pulses or trains of periodic pulses are processed and generated by digital electronic circuits. They are also used to trigger (activate) many kinds of circuits.

The Ideal Pulse

A Real Pulse

Ringing (caused by inductance of wire leads, etc.)

Careful design will reduce ringing and both rise and fall time.

Pulse Train

The number of pulses per second is the pulse repetition rate.
SIGNS

Electronic signals range from audible tones to complex information carried by a fluctuating (analog) or pulsating (digital) wave, current, or voltage. Many modulation methods are used to impress a signal on a carrier.

MODULATION METHODS

ANALOG

UNMODULATED CARRIER WAVE

ANALOG SIGNAL

AMPLITUDE MODULATION

FREQUENCY MODULATION

PULSE

ANALOG SIGNAL

PULSE AMPLITUDE

PULSE DURATION

PULSE FREQUENCY

DIGITAL

BINARY BIT PATTERN

NON-RETURN TO ZERO (NRZ)

RETURN TO ZERO (RZ)

MANCHESTER

FREQUENCY SHIFT KEYING (FSK)
### Codes and Symbols

#### Alphabet, ASCII & Morse Code

<table>
<thead>
<tr>
<th>Alphabet</th>
<th>ASCII</th>
<th>Morse Code</th>
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<tbody>
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<td>-...-</td>
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<tr>
<td>B</td>
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<td>-...-</td>
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<tr>
<td>C</td>
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<tr>
<td>D</td>
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**ASCII**

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<th>ROW</th>
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<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**SP - SPACE**

**CONTROL CHARACTERS (NON PRINTING)**

**ASCII - AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE. ASCII IS THE PRINCIPLE COMPUTER KEYBOARD CODE. ASSEMBLY LANGUAGE PROGRAMMERS CONVERT BINARY ASCII (ABOVE) TO HEXADECIMAL. PRINCIPLE HEX EQUIVALENTS:**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>43</td>
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<td>46</td>
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<td>47</td>
<td>48</td>
<td>49</td>
<td>4A</td>
<td>4B</td>
<td>4C</td>
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<td>O</td>
<td>P</td>
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<td>5E</td>
<td>5F</td>
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<td>5B</td>
<td>5C</td>
</tr>
<tr>
<td>S</td>
<td>T</td>
<td>U</td>
<td>V</td>
<td>W</td>
<td>X</td>
</tr>
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<td>53</td>
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<td>57</td>
<td>58</td>
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<tr>
<td>Y</td>
<td>Z</td>
<td>Ø</td>
<td>Æ</td>
<td>Æ</td>
<td>DEL</td>
</tr>
<tr>
<td>59</td>
<td>5A</td>
<td>5B</td>
<td>5C</td>
<td>5D</td>
<td>5E</td>
</tr>
<tr>
<td>4 - 34</td>
<td>5 - 35</td>
<td>6 - 36</td>
<td>7 - 37</td>
<td>8 - 38</td>
<td>9 - 39</td>
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# Greek Alphabet

<table>
<thead>
<tr>
<th>Name</th>
<th>U</th>
<th>L</th>
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<tbody>
<tr>
<td>Alpha</td>
<td>α</td>
<td>α</td>
</tr>
<tr>
<td>Beta</td>
<td>β</td>
<td>β</td>
</tr>
<tr>
<td>Gamma</td>
<td>γ</td>
<td>γ</td>
</tr>
<tr>
<td>Delta</td>
<td>δ</td>
<td>δ</td>
</tr>
<tr>
<td>Epsilon</td>
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<td>ε</td>
</tr>
<tr>
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<td>ζ</td>
<td>ζ</td>
</tr>
<tr>
<td>Eta</td>
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<tr>
<td>Theta</td>
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</tr>
<tr>
<td>Iota</td>
<td>ι</td>
<td>ι</td>
</tr>
<tr>
<td>Kappa</td>
<td>κ</td>
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</tr>
<tr>
<td>Lambda</td>
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<td>λ</td>
</tr>
<tr>
<td>Mu</td>
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# Common Greek Symbols

<table>
<thead>
<tr>
<th>Letter</th>
<th>Symbolizes or Designates</th>
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<tbody>
<tr>
<td>Α</td>
<td>Angles, Acceleration, Area</td>
</tr>
<tr>
<td>Β</td>
<td>Angles, Conductivity, Specific Gravity</td>
</tr>
<tr>
<td>Γ</td>
<td>Increment, Decrement</td>
</tr>
<tr>
<td>Δ</td>
<td>Dielectric Constant</td>
</tr>
<tr>
<td>Ε</td>
<td>Energy</td>
</tr>
<tr>
<td>Ν</td>
<td>Impedance</td>
</tr>
<tr>
<td>Μ</td>
<td>FM Modulation Index</td>
</tr>
<tr>
<td>Ν</td>
<td>Angles, Time Constant, Temperature</td>
</tr>
<tr>
<td>Χ</td>
<td>Wavelength, Conductivity</td>
</tr>
<tr>
<td>Μ</td>
<td>Micro (Prefix), Amplification Factor</td>
</tr>
<tr>
<td>Υ</td>
<td>Frequency</td>
</tr>
<tr>
<td>Τ</td>
<td>Circumference ÷ Diameter (3.14159...)</td>
</tr>
<tr>
<td>Ρ</td>
<td>Resistivity, Reflectance</td>
</tr>
<tr>
<td>Σ</td>
<td>Summation, Sign</td>
</tr>
<tr>
<td>Τ</td>
<td>Time Constant, Transmittance</td>
</tr>
<tr>
<td>Φ</td>
<td>Angle, Radiant Power</td>
</tr>
<tr>
<td>Ω</td>
<td>Angle, Angular Frequency</td>
</tr>
<tr>
<td>Ω</td>
<td>Solid Angle, Resistance (Ohms)</td>
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</table>
**RESISTOR COLOR CODE**

<table>
<thead>
<tr>
<th>COLOR</th>
<th>SIGNIFICANT DIGITS (1$2)</th>
<th>MULTIPLIER (3)</th>
<th>TOL. (4)</th>
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</thead>
<tbody>
<tr>
<td>BLACK</td>
<td>0</td>
<td>1</td>
<td>± 1%</td>
</tr>
<tr>
<td>BROWN</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>RED</td>
<td>2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>ORANGE</td>
<td>3</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>YELLOW</td>
<td>4</td>
<td>1,000,000</td>
<td>NO</td>
</tr>
<tr>
<td>GREEN</td>
<td>5</td>
<td>1,000,000,000</td>
<td>COLOR</td>
</tr>
<tr>
<td>BLUE</td>
<td>6</td>
<td>1,000,000,000</td>
<td>BAND:</td>
</tr>
<tr>
<td>VIOLET</td>
<td>7</td>
<td>100,000,000,000</td>
<td>± 20%</td>
</tr>
<tr>
<td>GRAY</td>
<td>8</td>
<td>100,000,000,000</td>
<td></td>
</tr>
<tr>
<td>WHITE</td>
<td>9</td>
<td>-</td>
<td>± 5%</td>
</tr>
<tr>
<td>GOLD</td>
<td>-</td>
<td>-</td>
<td>± 10%</td>
</tr>
<tr>
<td>SILVER</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**EXAMPLE:**

1 = BROWN = 1
2 = BLACK = 0
3 = YELLOW = × 10,000
4 = SILVER = ± 10% TOLERANCE

\[ 100,000 \, \Omega \pm 10\% \]

**TRANSFORMER COLOR CODE**

**AUDIO INTERSTAGE AND OUTPUT:**

- BLUE
- GRN
- RED
- BLK
- BRN
- YEL
- BLK
- GRN
- RED
- BNL
- GRN
- BLK
- GRN

**POWER:** UNTAPPED PRIMARY - BLACK; FILAMENT SECONDARY - GREEN (ADDITIONAL FILAMENT: YELLOW, BROWN AND SLATE); HIGH-VOLTAGE SECONDARY - RED. COLORS MAY VARY.

**NOTE:** THESE ARE EIA RECOMMENDED COLORS. SEE TRANSFORMER SPECIFICATIONS TO VERIFY CODE.
5. ELECTRONIC ABBREVIATIONS

AC - ALTERNATING CURRENT
AF - AUDIO FREQUENCY
AFC - AUTOMATIC FREQUENCY CONTROL
AGC - AUTOMATIC GAIN CONTROL
AM - AMPLITUDE MODULATION
AMP - AMPLIFIER
ANL - AUTOMATIC NOISE LIMITER
ANT - ANTENNA
AVC - AUTOMATIC VOLUME CONTROL
AWG - AMERICAN WIRE GAUGE
B - BASE OF TRANSISTOR
BC - BROADCAST
BFO - BEAT FREQUENCY OSCILLATOR
BP - BANDPASS
C - COLLECTOR OF TRANSISTOR
CAL - CALIBRATE
CAP - CAPACITOR
CB - CITIZENS BAND
CKT - CIRCUIT
CLK - CLOCK
CRT - CATHODE RAY TUBE
C/SEC - CYCLES PER SECOND (HERTZ; HZ)
CT - CENTER TAP
CW - CONTINUOUS WAVE
CY - CYCLE
°C - DEGREES CELSIUS
D - DRAIN OF FET
DB - DECIBEL
DBLR - DOUBLER
DC - DIRECT CURRENT
DEG - DEGREES
DEMOD - DEMODULATION
DF - DIRECTION FINDER
DPDT - DOUBLE POLE DOUBLE THROW
DPST - DOUBLE POLE SINGLE THROW
DSB - DOUBLE SIDEBAND
E - Emitter of Transistor; ENERGY
EM - ELECTROMAGNETIC
EMF - ELECTROMOTIVE FORCE
EMP - ELECTROMAGNETIC PULSE
ERP - EFFECTIVE RADIATED POWER
32
F - FREQUENCY
ºF - DEGREES FAHRENHEIT
FDBK - FEEDBACK
FET - FIELD EFFECT TRANSISTOR
FF - FLIP FLOP
FIL - FILAMENT
FM - FREQUENCY MODULATION
FREQ - FREQUENCY
FSC - FULL SCALE
FWHM - FULL WIDTH HALF MAXIMUM
G - GATE OF FET
GA - GAUGE
GND - GROUND
HF - HIGH FREQUENCY
HI FI - HIGH FIDELITY
HV - HIGH VOLTAGE
HZ - HERTZ
I - CURRENT
IC - INTEGRATED CIRCUIT
IMPD - IMPEDANCE
IR - INFRARED
JFET - JUNCTION FIELD EFFECT TRANSISTOR
KWH - KILOWATT HOUR
LED - LIGHT EMITTING DIODE
LP - LOW PASS
LSI - LARGE SCALE INTEGRATION
MA - MILLIAMPERES
MIC - MICROPHONE
MOS - METAL-OXIDE-SEMICONDUCTOR
MOSFET - MOS FIELD EFFECT TRANSISTOR
NC - NO CONTACT
NEG - NEGATIVE
NF - NOISE FIGURE
NO - NORMALLY OPEN
NOM - NOMINAL
NPN - NEGATIVE-POSITIVE-NEGATIVE
OP AMP - OPERATIONAL AMPLIFIER
OSC - OSCILLATOR
OUT - OUTPUT
PAM - PULSE AMPLITUDE MODULATION
PC - PRINTED CIRCUIT
PCM - PULSE CODE MODULATION
PDM - PULSE DURATION MODULATION
PF - PICOFARAD
PFM - PULSE FREQUENCY MODULATION
PK - PEAK
PLL - PHASE LOCKED LOOP
PNP - POSITIVE - NEGATIVE - POSITIVE
POS - POSITIVE
POT - POTENTIOMETER
PREAMP - PREAMPLIFIER
PRI - PRIMARY
PRV - PEAK REVERSE VOLTAGE
PVC - POLYVINYL CHLORIDE
PWR - POWER
PWR SUP - POWER SUPPLY
PZ - PIEZOELECTRIC
Q - QUALITY FACTOR
QTZ - QUARTZ
R - RESISTANCE
RAD - RADIAN
RC - RESISTANCE - CAPACITANCE
RCDR - RECORDER
RCVR - RECEIVE
RCVR - RECEIVER
RECHRG - RECHARGE
RECT - RECTIFIER
REF - REFERENCE
RF - RADIO FREQUENCY
RFC - RADIO FREQUENCY CHoke
RFI - RADIO FREQUENCY INTERFERENCE
RL - RESISTANCE - INDUCTANCE
RLC - RESISTANCE - INDUCTANCE - CAPACITANCE
RY - RELAY
RMS - ROOT MEAN SQUARE
RMT - REMOTE
ROT - ROTATE
RPM - REVOLUTIONS PER MINUTE
RPS - REVOLUTIONS PER SECOND
RTTY - RADIO TELETYPewriter
S - SOURCE OF FET
SB - SIDEBAND
SCR - SILICON CONTROLLED RECTIFIER
SEC - SECONDARY
SERVO - SERVOMECHANISM
SHEILD - SHIELD
SIG - SIGNAL
SNR - SIGNAL-TO-NOISE RATIO (ALSO S/N)
SPDT - SINGLE POLE DOUBLE THROW
SPKR - SPEAKER
SPST - SINGLE POLE SINGLE THROW
SQ - SQUARE
SSB - SINGLE SIDEBAND
SUBMIN - SUBMINIATURE
SW - SHORTWAVE
SWL - SHORTWAVE LISTENING
SWR - STANDING WAVE RATIO
SYM - SYMBOL
T - TIME
TACH - TACHOMETER
TEL - TELEPHONE
TELECOM - TELECOMMUNICATIONS
TEMP - TEMPERATURE
TERM - TERMINAL
TRF - TUNED RADIO FREQUENCY
TTL - TRANSISTOR-TRANSISTOR LOGIC
TVI - TELEVISION INTERFERENCE
UHF - ULTRA HIGH FREQUENCY
UNIT - UNIJUNCTION TRANSISTOR
UTC - COORDINATED UNIVERSAL TIME
V - VOLTAGE
VAC - VACUUM; AC VOLTAGE
VC - VOICE COIL
VCO - VOLTAGE CONTROLLED OSCILLATOR
VF - VARIABLE FREQUENCY
VHF - VERY HIGH FREQUENCY
VID - VIDEO
VLF - VERY LOW FREQUENCY
VOL - VOLUME
VOM - VOLT-OHM METER
VT - VACUUM TUBE
VOX - VOICE-OPERATED TRANSMITTER
W - WATT
WHM - WATT-HOUR METER
WV - WORKING VOLTAGE
X - REACTANCE
XMTR - TRANSMITTER
Z - IMPEDANCE
6. BASIC ELECTRONIC CIRCUITS

HALF-WAVE RECTIFIER

D1 MUST BE RATED FOR THE INPUT VOLTAGE.

FULL-WAVE RECTIFIER

D1-D4 MUST BE RATED FOR THE INPUT VOLTAGE. USE INDIVIDUAL DIODES OR RECTIFIER MODULE.

VOLTAGE DOUBLER

C1, C2 = 0.1 μF TO 100 μF

CAUTION: C1 AND C2 CAN HOLD CHARGE WITHOUT VIN.

D1-D4, C1 AND C2 MUST BE RATED FOR AT LEAST TWICE THE INPUT VOLTAGE.
BASIC LED DRIVER

\[ R_s = \frac{V_{IN} - V_{LED}}{I_{LED}} \]

\[ V_{IN} = \text{INPUT VOLTAGE} \]

\[ I_{LED} = \text{LED FORWARD CURRENT (DESIRED OR SPECIFIED)} \]

\[ V_{LED} = \text{LED VOLTAGE DROP} \]

**EXAMPLE:** Assume \( V_{IN} = 9 \text{ VOLTS} \) and \( V_{LED} = 1.7 \) Volts. Calculate value of \( R_s \) for \( I_{LED} = 20 \text{ mA} \).

\[ R_s = \frac{9 - 1.7}{.02} = 365 \text{ OHMS} \] (OK TO USE CLOSEST STANDARD VALUE)

LOGIC GATE LED DRIVERS

**NOTE:** CMOS will directly drive super bright LEDs if \( I_{LED} \) is kept below a few milliamperes.

This circuit will drive LED when supply voltage to logic gate and Q1-LED are different.
INVERTING AMPLIFIER

OK TO USE ANY OP AMP IN THIS BASIC CIRCUIT. PIN NUMBERS MAY VARY. (SEE DATA SHEET.)

\[ R_3 = \frac{(R_1 \times R_2)}{(R_1 + R_2)} \]

EXAMPLE: IF \( R_1 = 4,700 \) OHMS AND \( R_2 = 47,000 \) OHMS, THEN GAIN IS \( -\left(\frac{47,000}{4,700}\right) \) OR -10. \( R_3 = 4,273 \) OHMS (USE CLOSEST STANDARD VALUE).

NON-INVERTING AMPLIFIER

OK TO USE ANY OP AMP. (SEE ABOVE.)

NOTE: SOME OP AMPS REQUIRE COMPENSATION CAPACITOR.

\[ V = \pm 3 \text{ TO } \pm 15 \text{ V} \]

GAIN = \( 1 + \left(\frac{R_2}{R_1}\right) \)

EXAMPLE: IF \( R_1 = 4,700 \) OHMS AND \( R_2 = 47,000 \) OHMS, THEN GAIN IS \( 1 + \left(\frac{47,000}{4,700}\right) \) OR 11.
VOLTAGE-TO-CURRENT CONVERTER

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

\[ I_{\text{out}} = \frac{V_{\text{out}}}{(R_1 + R_2)} \]

\[ I_{\text{out}} = \frac{V_{\text{in}}}{R_2} \]

EXAMPLE: Assume R1 is a resistor and LED with combined resistance of 1,000 ohms and R2 is 470 ohms. When \( V_{\text{in}} = 5 \) volts, current (Iout) through LED is 10.6 mA.

CURRENT-TO-VOLTAGE CONVERTER

\[ V_{\text{out}} = \text{gain} \times I_{\text{in}} \]

\[ \text{gain} = \frac{V_{\text{out}}}{I_{\text{in}}} \]

\[ \text{gain} = -R_1 \]

EXAMPLE: Assume a solar cell connected to \( I_{\text{in}} \) delivers a current of 1 mA. If R1 is 1,000 ohms, then \( V_{\text{out}} = -(1,000 \times 0.001) = -1 \) volt.
INVERTING COMPARATOR

Vref 3 +V
VIN 2 741 4 OUT

WHEN VREF EXCEEDS VIN, OUTPUT SWINGS FROM HIGH TO LOW.

NON-INVERTING COMPARATOR

Vref 2 +V
VIN 3 741 4 OUT

WHEN VIN EXCEEDS VREF, OUTPUT SWINGS FROM LOW TO HIGH.

WINDOW COMPARATOR

Vref (H) 2 1/2 8 1/2 1458 1 1N914
VIN 3 1458

Vref (L) 5 1/2 1458 4

NOTE: OK TO USE 741, 339 OR OTHER OP AMPS.
**PULSE GENERATOR**

\[ t_1 = 0.693 \times (R_1 + R_2) \times C_1 \]

\[ t_2 = 0.693 \times R_2 \times C_1 \]

Frequency: \[ \frac{1.44}{(R_1 + 2R_2) \times C_1} \]
7. BASIC LOGIC CIRCUITS

AND GATE

\[
\begin{array}{ccc}
A & B & \text{OUT} \\
L & L & L \\
L & H & L \\
H & L & L \\
H & H & H \\
\end{array}
\]

NAND GATE

\[
\begin{array}{ccc}
A & B & \text{OUT} \\
L & L & H \\
L & H & H \\
H & L & H \\
H & H & L \\
\end{array}
\]

OR

\[
\begin{array}{ccc}
A & B & \text{OUT} \\
L & L & L \\
L & H & H \\
H & L & H \\
H & H & H \\
\end{array}
\]

NOR

\[
\begin{array}{ccc}
A & B & \text{OUT} \\
L & L & H \\
L & H & L \\
H & L & L \\
H & H & L \\
\end{array}
\]

EXCLUSIVE OR

\[
\begin{array}{ccc}
A & B & \text{OUT} \\
L & L & H \\
L & H & L \\
H & L & L \\
H & H & L \\
\end{array}
\]
EXCLUSIVE NOR

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
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<td>L</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

BUFFER (3-STATE BUFFER)

\[ \text{C} = \text{CONTROL} \]

\[ \begin{array}{ccc}
\text{A} & \rightarrow & \text{OUT} \\
\text{X} & = & \text{DON'T CARE} \\
\text{(H)} & & (X) (\text{HI-Z})
\end{array} \]

<table>
<thead>
<tr>
<th>C</th>
<th>A</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>(H)</td>
<td>(X)</td>
<td>(HI-Z)</td>
</tr>
</tbody>
</table>

INVERTER (3-STATE INVERTER)

\[ \text{C} = \text{CONTROL} \]

\[ \begin{array}{ccc}
\text{A} & \rightarrow & \text{OUT} \\
\text{X} & = & \text{DON'T CARE} \\
\text{(H)} & & (X) (\text{HI-Z})
\end{array} \]

<table>
<thead>
<tr>
<th>C</th>
<th>A</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>(H)</td>
<td>(X)</td>
<td>(HI-Z)</td>
</tr>
</tbody>
</table>

3-STATE BUS

COMPUTERS USUALLY HAVE A 3-STATE BUS.

<table>
<thead>
<tr>
<th>CONTROL</th>
<th>GATE OUTPUT TO BUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>ALL</td>
<td>NONE</td>
</tr>
</tbody>
</table>
RS FLIP-FLOP (LATCH)

CLOCKED RS FLIP-FLOP

JK FLIP-FLOP

AFTER CLOCK PULSE ARRIVES:

SJ | Q | Q
---|---|---
L | | (DISALLOWED)
H | | H
H | L | H
H | | NO CHANGE
L | | NOT L

AFTER CLOCK PULSE ARRIVES:

JK | Q | Q
---|---|---
L | | NO CHANGE
H | | H
H | L | L
H | | (DISALLOWED)

*SEE FACING PAGE.
D (DATA OR DELAY) FLIP-FLOP

AFTER CLOCK PULSE ARRIVES:

\[
\begin{array}{c|c|c}
\text{D} & \text{Q} & \text{Q} \\
\hline
\text{L} & \text{L} & \text{H} \\
\text{H} & \text{H} & \text{L} \\
\end{array}
\]

DATA

T (TOGGLE) FLIP-FLOPS

THE Q (OR \( \bar{Q} \)) OUTPUT IS L (OR H) FOR EVERY OTHER INPUT PULSE. THEREFORE THE OUTPUT IS THE INPUT \( \div 2 \):

\[
\begin{array}{c|c|c}
\text{IN} & \text{T} & \text{OUT} \\
\hline
\text{T} & \text{Q} & \text{Q} \\
\text{Q} & \text{Q} & \text{Q} \\
\end{array}
\]

CHAINS OF T FLIP-FLOPS ARE USED TO MAKE BINARY COUNTERS. THE JK FLIP-FLOP (FACING PAGE) FUNCTIONS AS A T FLIP-FLOP WHEN BOTH THE T AND \( \bar{T} \) INPUTS ARE KEPT HIGH AND INPUT PULSES ARE APPLIED TO THE CLOCK INPUT. OTHER T FLIP-FLOPS:

D FLIP-FLOP

CLOCKED RS FLIP-FLOP
8. POWER SUPPLIES

BATTERIES

SYMBOLS

SINGLE CELL: $\begin{array}{c|c} + & - \\ \hline & \end{array}$

MULTIPLE CELL: $\begin{array}{c|c} + & - \\ \hline & \\ \hline & \end{array}$

CONNECTIONS

SERIES:

$\begin{array}{c|c} + & - \\ \hline & - \\ \hline & + \\ \hline & \end{array}$

TOTAL VOLTAGE IS SUM OF EACH CELL VOLTAGE.

PARALLEL:

$\begin{aligned}
&+ \\
&| \\
&| \\
&- \\
&+ \\
&| \\
&B1 \\ B2
\end{aligned}$

TOTAL CURRENT CAPACITY IS SUM OF EACH CELL CAPACITY. CELLS SHOULD HAVE EQUAL CAPACITY.

BIPOLAR:

$\begin{array}{c|c} + & - \\ \hline & - \\ \hline & + \\ \hline & - \\ \hline & \end{array}$

USE TO POWER OPERATIONAL AMPLIFIERS.

STORAGE BATTERIES

STORAGE BATTERIES CAN BE USED AND RECHARGED MANY TIMES. PRINCIPLE TYPES:

LEAD-ACID — 2.0 VOLTS PER CELL, HIGH CURRENT CAPACITY, GOOD AT LOW TEMPERATURE.

NICEL-CADMIUM (NICAD) — 1.2 VOLTS PER CELL, CAN BE STORED FOR EXTENDED TIME WHEN DISCHARGED. MANY DIFFERENT KINDS AVAILABLE, VERY ECONOMICAL POWER SOURCE.
PRIMARY BATTERIES

PRIMARY BATTERIES ARE NOT RECHARGEABLE. CHIEF AMONG THE MANY TYPES AVAILABLE:

CARBON-ZINC—1.5 VOLTS PER CELL. READILY AVAILABLE AND LOW COST.

ZINC-CHLORIDE—1.5 VOLTS PER CELL. TWICE THE ENERGY DENSITY OF CARBON-ZINC.

ALKALINE—1.5 VOLTS PER CELL. USE FOR HIGH CURRENT LOADS (MOTORS, LAMPS, ETC.).

MERCURY—1.35 AND 1.4 VOLTS PER CELL. UNIFORM VOLTAGE DURING DISCHARGE.

SILVER OXIDE—1.5 VOLTS PER CELL. NEARLY UNIFORM VOLTAGE DURING DISCHARGE.

LITHIUM MANGANESE—3.0 VOLTS PER CELL. EXCEPTIONALLY LONG STORAGE LIFE. VERY HIGH ENERGY DENSITY.

BATTERY PRECAUTIONS

1. DO NOT CHARGE PRIMARY CELLS.

2. BATTERIES MAY EXPLODE WHEN HEATED.

3. DO NOT SOLDER LEADS TO A BATTERY. USE A BATTERY CLIP OR HOLDER.

4. NEVER SHORT CIRCUIT A BATTERY'S TERMINALS.

5. MOST BATTERIES SHOULD BE REMOVED FROM EQUIPMENT IN STORAGE. EXCEPTIONS ARE STORAGE BATTERIES AND LITHIUM CELLS.

6. WHEN BATTERY LEADS EXCEED ∼ 6 INCHES, CONNECT 0.1μF CAPACITOR ACROSS LEADS AT CIRCUIT BOARD.
LINE-POWERED SUPPLY

CAUTION: ALL CONNECTIONS THAT CARRY LINE CURRENT MUST BE INSULATED OR ENCLOSED! DISCONNECT POWER WHEN SERVICING!

F1: FUSE
(SELECT TO MATCH CURRENT RATING OF T1.)

BLACK

S1
SPST POWER SWITCH

T1: POWER TRANSFORMER
(CURRENT RATING MUST EXCEED MAXIMUM OUTPUT.)

*COLORS MAY VARY. SOME TRANSFORMERS HAVE SOLDER LUGS INSTEAD OF WIRE LEADS.

C1, C2 = 1,000µF
35 VDC

B1: 1 TO 4 AMP.
BRIDGE RECTIFIER RATED FOR AT LEAST 2X SECONDARY VOLTAGE OF T1.

(FRONT)

7805 - 5V
7812 - 12V
7815 - 15V

ATTACH HEAT SINK TO METAL TAB IF NECESSARY.
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:  \[ V = IR \quad R = \frac{V}{I} \]
            \[ I = \frac{V}{R} \quad P = VI = I^2R \]

ABBREVIATIONS

A = AMPERE  \quad R = RESISTANCE
F = FARAD  \quad V (OR E) = VOLT
I = CURRENT  \quad W = WATT
P = POWER  \quad \Omega = OHM

M (MEG-) = \times 1,000,000
K (KILO-) = \times 1,000
\mu (MILLI-) = .001
\mu (MICRO-) = .000 001
\mu (NANO-) = .000 000 001
\mu (PICO-) = .000 000 000 001