Technical Training

Precision Measuring Equipment Specialist

METROLOGY HANDBOOK

January 1984

3400TH TECHNICAL TRAINING WING
3450th Technical Training Group
Lowry Air Force Base, Colorado

Designed For ATC Course Use
DO NOT USE ON THE JOB
Study guides (SGs), workbooks (WBs), study guide and workbooks (SWs), programmed texts (PTs), student texts (STs), and handouts (H0s) are authorized by ATC for students' use in ATC courses. They are designed to guide you through your study assignment in the most logical sequence for easy understanding. Answer the self-evaluation questions and complete each problem or work assignment in the sequence given, and it will aid you in understanding and retaining the key points covered in material you have studied.

### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Information</td>
<td>1</td>
</tr>
<tr>
<td>Formulas</td>
<td>35</td>
</tr>
<tr>
<td>Alphabetical Index</td>
<td>165</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAME</th>
<th>UC</th>
<th>COMMONLY DESIGNATES</th>
<th>LC</th>
<th>COMMONLY DESIGNATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>A</td>
<td></td>
<td>a</td>
<td>Angles, area, absorption factor, attenuation constant, I gain CB config.</td>
</tr>
<tr>
<td>Beta</td>
<td>B</td>
<td>Complex propagation constant</td>
<td>b</td>
<td>Angles, coefficients, phase constant, flux density, I gain CE config.</td>
</tr>
<tr>
<td>Gamma</td>
<td>G</td>
<td>Increment, determinant, permittivity, variation</td>
<td>y</td>
<td>Angles, specific gravity, electrical conductivity, propagation constant</td>
</tr>
<tr>
<td>Delta</td>
<td>D</td>
<td></td>
<td>y</td>
<td>Angles, density, increment</td>
</tr>
<tr>
<td>Epsilon</td>
<td>E</td>
<td>Impedance</td>
<td>e</td>
<td>Base of natural logs, dielectric constant, electrical intensity</td>
</tr>
<tr>
<td>Zeta</td>
<td>Z</td>
<td></td>
<td>z</td>
<td>Coordinates, coefficients</td>
</tr>
<tr>
<td>Eta</td>
<td>H</td>
<td>Hysteresis, coordinates, efficiency intrinsic impedance</td>
<td>h</td>
<td>Angular phase displacement, time constant, reluctance</td>
</tr>
<tr>
<td>Theta</td>
<td>TH</td>
<td>Current</td>
<td>t</td>
<td>Unit vector</td>
</tr>
<tr>
<td>Iota</td>
<td>I</td>
<td>Permeance</td>
<td>i</td>
<td>Coupling coefficient, susceptibility, dielectric constant</td>
</tr>
<tr>
<td>Kappa</td>
<td>K</td>
<td>Wavelength, attenuation constant</td>
<td>k</td>
<td>Wavelength, attenuation constant</td>
</tr>
<tr>
<td>Lambda</td>
<td>LM</td>
<td>Prefix micro, amplification factor, permeability</td>
<td>l</td>
<td>Prefix micro, amplification factor, permeability</td>
</tr>
<tr>
<td>Mu</td>
<td>M</td>
<td>Frequency, reluctivity</td>
<td>m</td>
<td>Frequency, reluctivity</td>
</tr>
<tr>
<td>Nit</td>
<td>N</td>
<td>Coordinates, output coefficients</td>
<td>n</td>
<td>Coordinates, output coefficients</td>
</tr>
<tr>
<td>Xi</td>
<td>X</td>
<td>Reference point</td>
<td>x</td>
<td>Reference point</td>
</tr>
<tr>
<td>Omicron</td>
<td>O</td>
<td>3.1416</td>
<td>o</td>
<td>3.1416</td>
</tr>
<tr>
<td>Pi</td>
<td>P</td>
<td>Resistivity, volume charge density, coordinates</td>
<td>p</td>
<td>Resistivity, volume charge density, coordinates</td>
</tr>
<tr>
<td>Rho</td>
<td>R</td>
<td>Electrical conductivity, leakage coefficient, complex propagation constant</td>
<td>r</td>
<td>Electrical conductivity, leakage coefficient, complex propagation constant</td>
</tr>
<tr>
<td>Sigma</td>
<td>S</td>
<td>Summation</td>
<td>s</td>
<td>Time constant, time phase displacement, transmission factor, torque</td>
</tr>
<tr>
<td>Tau</td>
<td>T</td>
<td></td>
<td>t</td>
<td>Phase angle</td>
</tr>
<tr>
<td>Upsilon</td>
<td>U</td>
<td>Scalar potential, magnetic flux, radiant flux</td>
<td>u</td>
<td>Phases, electrical susceptibility</td>
</tr>
<tr>
<td>Phi</td>
<td>P</td>
<td>Angles, coordinates, dielectric flux, phase difference</td>
<td>p</td>
<td>Angles, coordinates, dielectric flux, phase difference</td>
</tr>
<tr>
<td>Chi</td>
<td>X</td>
<td>Resistance in ohms</td>
<td>x</td>
<td>Angular velocity (2πf)</td>
</tr>
<tr>
<td>Psi</td>
<td>P</td>
<td></td>
<td>p</td>
<td></td>
</tr>
<tr>
<td>Omega</td>
<td>O</td>
<td></td>
<td>o</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+</td>
<td>Positive. Plus. Add</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Negative. Minus. Subtract</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±</td>
<td>Positive or negative. Plus or minus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* or \cdot</td>
<td>Multiplied by</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\div \ or /</td>
<td>Divided by</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>= or ::</td>
<td>Equals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\equiv</td>
<td>Identical with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\ne</td>
<td>Not equal to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\approx</td>
<td>Approximately equal to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;</td>
<td>Is greater than</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;</td>
<td>Is less than</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\geq</td>
<td>Greater than or equal to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\leq</td>
<td>Less than or equal to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\propto</td>
<td>Is proportional to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>:</td>
<td>Ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\therefore</td>
<td>Therefore</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\infty</td>
<td>Infinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\Delta</td>
<td>Increment or small change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>\angle</td>
<td>Angle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\perp</td>
<td>Perpendicular to</td>
</tr>
<tr>
<td>\parallel</td>
<td>Parallel to</td>
</tr>
<tr>
<td>\pi</td>
<td>\pi, 3.1416</td>
</tr>
<tr>
<td>\varepsilon</td>
<td>Base of natural log, 2.718</td>
</tr>
<tr>
<td>\sqrt[n]{}</td>
<td>n\text{th} root</td>
</tr>
<tr>
<td></td>
<td>Cube root</td>
</tr>
<tr>
<td></td>
<td>Square root</td>
</tr>
<tr>
<td></td>
<td>Absolute value of n</td>
</tr>
<tr>
<td></td>
<td>n degrees</td>
</tr>
<tr>
<td></td>
<td>n minutes of a degree</td>
</tr>
<tr>
<td></td>
<td>n seconds of a degree</td>
</tr>
<tr>
<td></td>
<td>n inches or n second</td>
</tr>
<tr>
<td></td>
<td>Average value of n</td>
</tr>
<tr>
<td></td>
<td>Square root of minus one</td>
</tr>
<tr>
<td></td>
<td>Percentage</td>
</tr>
<tr>
<td></td>
<td>Subscript of n</td>
</tr>
<tr>
<td></td>
<td>Parentheses</td>
</tr>
<tr>
<td></td>
<td>Brackets</td>
</tr>
<tr>
<td></td>
<td>Braces</td>
</tr>
<tr>
<td>\overline{x}</td>
<td>Vinculum</td>
</tr>
</tbody>
</table>
**MATHEMATICAL CONSTANTS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Number</th>
<th>$\log_{10}$</th>
<th>Symbol</th>
<th>Number</th>
<th>$\log_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi$</td>
<td>3.1416</td>
<td>0.4971</td>
<td>$\frac{4}{\pi}$</td>
<td>1.2732</td>
<td>0.1049</td>
</tr>
<tr>
<td>$\pi^2$</td>
<td>9.8696</td>
<td>0.9943</td>
<td>$\frac{1}{2\pi}$</td>
<td>0.1592</td>
<td>9.2018-10</td>
</tr>
<tr>
<td>$2\pi$</td>
<td>6.2832</td>
<td>0.7982</td>
<td>$\frac{1}{4\pi}$</td>
<td>0.0796</td>
<td>8.9008-10</td>
</tr>
<tr>
<td>$2\pi^2$</td>
<td>19.7392</td>
<td>1.2953</td>
<td>$\frac{1}{6\pi}$</td>
<td>0.0531</td>
<td>8.7247-10</td>
</tr>
<tr>
<td>$3\pi$</td>
<td>9.4248</td>
<td>0.9742</td>
<td>$\frac{1}{8\pi}$</td>
<td>0.0398</td>
<td>8.5998-10</td>
</tr>
<tr>
<td>$4\pi$</td>
<td>12.5664</td>
<td>1.0992</td>
<td>$\frac{\pi}{180}$</td>
<td>0.0175</td>
<td>8.2419-10</td>
</tr>
<tr>
<td>$4\pi^2$</td>
<td>39.4784</td>
<td>1.5964</td>
<td>$\frac{180}{\pi}$</td>
<td>57.2958</td>
<td>1.7581</td>
</tr>
<tr>
<td>$8\pi$</td>
<td>25.1327</td>
<td>1.4002</td>
<td>$\frac{1}{\pi^2}$</td>
<td>0.1013</td>
<td>9.0057-10</td>
</tr>
<tr>
<td>$\frac{\pi}{2}$</td>
<td>1.5708</td>
<td>0.1961</td>
<td>$\frac{1}{2\pi^2}$</td>
<td>0.0507</td>
<td>8.7047-10</td>
</tr>
<tr>
<td>$\frac{\pi}{3}$</td>
<td>1.0472</td>
<td>0.0200</td>
<td>$\frac{1}{4\pi^2}$</td>
<td>0.0253</td>
<td>8.4036-10</td>
</tr>
<tr>
<td>$\frac{\pi}{4}$</td>
<td>0.7854</td>
<td>9.8951-10</td>
<td>$\sqrt{\pi}$</td>
<td>1.7725</td>
<td>0.2486</td>
</tr>
<tr>
<td>$\frac{\pi}{6}$</td>
<td>0.5236</td>
<td>9.7190-10</td>
<td>$\sqrt{\frac{\pi}{2}}$</td>
<td>0.8862</td>
<td>9.9475-10</td>
</tr>
<tr>
<td>$\frac{\pi}{8}$</td>
<td>0.3927</td>
<td>9.5941-10</td>
<td>$\sqrt{\frac{\pi}{4}}$</td>
<td>0.4431</td>
<td>9.6465-10</td>
</tr>
<tr>
<td>$2\frac{\pi}{3}$</td>
<td>2.0944</td>
<td>0.3210</td>
<td>$\sqrt{\frac{2}{\pi}}$</td>
<td>1.2533</td>
<td>0.0980</td>
</tr>
<tr>
<td>$4\frac{\pi}{3}$</td>
<td>4.1888</td>
<td>0.6221</td>
<td>$\sqrt{\frac{2}{\pi}}$</td>
<td>0.7979</td>
<td>9.9019-10</td>
</tr>
<tr>
<td>$\frac{1}{\pi}$</td>
<td>0.3183</td>
<td>9.5029-10</td>
<td>$\pi^3$</td>
<td>31.0063</td>
<td>1.4914</td>
</tr>
<tr>
<td>$\frac{2}{\pi}$</td>
<td>0.6366</td>
<td>9.8039-10</td>
<td>$\frac{1}{\pi^3}$</td>
<td>0.03225</td>
<td>8.5086-10</td>
</tr>
<tr>
<td>Multiple or Submultiple</td>
<td>Symbol</td>
<td>Prefix</td>
<td>Name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------</td>
<td>--------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{12}$ = 1,000,000,000,000</td>
<td>T</td>
<td>tera</td>
<td>Trillion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{9}$ = 1,000,000,000</td>
<td>G</td>
<td>giga</td>
<td>Billion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{8}$ = 100,000,000</td>
<td></td>
<td></td>
<td>Hundred million</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{7}$ = 10,000,000</td>
<td></td>
<td></td>
<td>Ten million</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{6}$ = 1,000,000</td>
<td>M</td>
<td>mega</td>
<td>Million</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{5}$ = 100,000</td>
<td></td>
<td></td>
<td>Hundred thousand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{4}$ = 10,000</td>
<td></td>
<td></td>
<td>Ten thousand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{3}$ = 1,000</td>
<td>k</td>
<td>kilo</td>
<td>Thousand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{2}$ = 100</td>
<td>h</td>
<td>hecto</td>
<td>Hundred</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{1}$ = 10</td>
<td>dk</td>
<td>deka</td>
<td>Ten</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{0}$ = 1</td>
<td>d</td>
<td>deci</td>
<td>One</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-1}$ = 0.1</td>
<td>c</td>
<td>centi</td>
<td>One tenth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-2}$ = 0.01</td>
<td>m</td>
<td>milli</td>
<td>One hundredth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-3}$ = 0.001</td>
<td></td>
<td></td>
<td>One thousandth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-4}$ = 0.000 1</td>
<td></td>
<td></td>
<td>One ten-thousandth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-5}$ = 0.000 01</td>
<td></td>
<td></td>
<td>One hundred-thousandth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-6}$ = 0.000 001</td>
<td></td>
<td>micro</td>
<td>One millionth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-7}$ = 0.000 000 1</td>
<td></td>
<td></td>
<td>One ten-millionth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-8}$ = 0.000 000 01</td>
<td></td>
<td></td>
<td>One hundred-millionth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-9}$ = 0.000 000 001</td>
<td></td>
<td>n</td>
<td>Nano</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-12}$ = 0.000 000 000 001</td>
<td>n</td>
<td>pico</td>
<td>One trillionth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-15}$ = 0.000 000 000 000 001</td>
<td>f</td>
<td>femto</td>
<td>One quadrillionth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-18}$ = 0.000 000 000 000 000 001</td>
<td>a</td>
<td>atto</td>
<td>One quintillionth</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
NUMERICAL CONSTANTS (extended)

\[ = 3.14159 \ 26535 \ 89793 \ 23846 \ 26433 \ 83279 \ 50288 \ 41971 \]
\[ = 2.71828 \ 18284 \ 59045 \ 23536 \ 02874 \ 71352 \ 66249 \ 77572 \]

SEQUENCE of MATHEMATICAL OPERATIONS

Remember

My Dear Aunt Sally

Multiply \((M)\)
Divide \((D)\)
Add \((A)\)
Subtract \((S)\)

POWERS of TWO CHART

<table>
<thead>
<tr>
<th>(2^n)</th>
<th>(n)</th>
<th>(2^{-n})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>0.125</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>0.0625</td>
</tr>
<tr>
<td>32</td>
<td>5</td>
<td>0.03125</td>
</tr>
<tr>
<td>64</td>
<td>6</td>
<td>0.015625</td>
</tr>
<tr>
<td>128</td>
<td>7</td>
<td>0.0078125</td>
</tr>
<tr>
<td>256</td>
<td>8</td>
<td>0.00390625</td>
</tr>
<tr>
<td>512</td>
<td>9</td>
<td>0.001953125</td>
</tr>
<tr>
<td>1024</td>
<td>10</td>
<td>0.0009765625</td>
</tr>
<tr>
<td>2048</td>
<td>11</td>
<td>0.00048828125</td>
</tr>
<tr>
<td>4096</td>
<td>12</td>
<td>0.000244140625</td>
</tr>
<tr>
<td>8192</td>
<td>13</td>
<td>0.0001220703125</td>
</tr>
<tr>
<td>16384</td>
<td>14</td>
<td>0.00006103515625</td>
</tr>
<tr>
<td>32768</td>
<td>15</td>
<td>0.000030517578125</td>
</tr>
<tr>
<td>65536</td>
<td>16</td>
<td>0.0000152587890625</td>
</tr>
<tr>
<td>131072</td>
<td>17</td>
<td>0.00000762939453125</td>
</tr>
<tr>
<td>262144</td>
<td>18</td>
<td>0.000003814696265625</td>
</tr>
<tr>
<td>524288</td>
<td>19</td>
<td>0.0000019073486328125</td>
</tr>
<tr>
<td>1048576</td>
<td>20</td>
<td>0.00000095364731640625</td>
</tr>
<tr>
<td>2097152</td>
<td>21</td>
<td>0.000000476837158203125</td>
</tr>
<tr>
<td>4194304</td>
<td>22</td>
<td>0.0000002384185791015625</td>
</tr>
<tr>
<td>8388608</td>
<td>23</td>
<td>0.0000001192092895507509375</td>
</tr>
<tr>
<td>16777216</td>
<td>24</td>
<td>0.000000059064644775390625</td>
</tr>
<tr>
<td>33554432</td>
<td>25</td>
<td>0.0000000298023223876953125</td>
</tr>
</tbody>
</table>
BINARY CONVERSION

Example:

<table>
<thead>
<tr>
<th>Binary Number</th>
<th>2⁹</th>
<th>2⁸</th>
<th>2⁷</th>
<th>2⁶</th>
<th>2⁵</th>
<th>2⁴</th>
<th>2³</th>
<th>2²</th>
<th>2¹</th>
<th>2⁰</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>512</td>
<td>256</td>
<td>128</td>
<td>64</td>
<td>32</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Example: 0 0 1 0 1 0 1 1 0 0 = 172

<table>
<thead>
<tr>
<th>Binary Number</th>
<th>Decimal Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>101</td>
<td>5</td>
</tr>
<tr>
<td>110</td>
<td>6</td>
</tr>
<tr>
<td>111</td>
<td>7</td>
</tr>
<tr>
<td>1000</td>
<td>8</td>
</tr>
<tr>
<td>1001</td>
<td>9</td>
</tr>
<tr>
<td>1010</td>
<td>10</td>
</tr>
<tr>
<td>110010</td>
<td>50</td>
</tr>
<tr>
<td>1100100</td>
<td>100</td>
</tr>
</tbody>
</table>

EXONENTS

Zero exponent $a^0 = 1$

Negative exponent $a^{-x} = \frac{1}{a^x}$

Multiplication $a^x \cdot a^y = a^{x+y}$

Division $a^x \div a^y = \frac{a^x}{a^y} = a^{x-y}$

Power of a product $(ab)^x = a^x b^x$

Power of a power $(a^x)^y = a^{xy}$

Root of a power $\sqrt[y]{a^x} = a^{x\frac{1}{y}}$

Fractional exponents $\frac{1}{a^4} = 4\sqrt{a}$ $a^\frac{x}{y} = \sqrt[y]{a^x}$

Radicals $\frac{\sqrt{a}}{\sqrt{b}} = \frac{\sqrt{a}}{\sqrt{b}}$ $\sqrt{ab} = \sqrt{a} \cdot \sqrt{b}$
LOGARITHMS

The exponent of that power of a fixed number, called the base, which equals a given number.

\[ 10^2 = 100, \text{ therefore } 2 = \log_{10} 100 \text{ to the base } 10. \]

**Exponential Form** | **Logarithmic Form**
---|---
\[ 2^4 = 16 \] | \[ 4 = \log_2 16 \]
\[ 10^2 = 100 \] | \[ 2 = \log_{10} 100 \]
\[ 10^3 = 1000 \] | \[ 3 = \log_{10} 1000 \]
\[ a^b = c \] | \[ b = \log_a c \]

**Multiplication**

\[ \log (6.4) - \log 6 + \log 4 \]

**Division**

\[ \log 3 = \log 3 - \log 4 \frac{3}{4} \]

**Raising to a power**

\[ \log N^3 = 3 \log N \]

**Extracting roots**

\[ \log \sqrt[3]{N} = \frac{\log N}{3} \]

**Common to natural**

\[ \log_{10} N = 2.3026 \log e N \]

**Natural to common**

\[ \log e N = 0.4343 \log_{10} N \]

**SCIENTIFIC NOTATION**

A whole number between 1 and 10 times the proper power of ten, also called standard form.

Example: \( 4.30 \times 10^4 \)

**SIGNIFICANT FIGURES**

Figures arrived at by counting are often exact. On the other hand, figure arrived at by measuring are approximate. Significant figures express the accuracy of the measurement.

When counting significant figures, all digits (including zero) are counted EXCEPT those zeros that are to the left of the number.

Example: 4.3 contains 2 significant figures

0.0234 contains 3 significant figures

0.1100 contains 4 significant figures
ROUNDING OFF NUMBERS

If the last digit is a 5 and the number immediately prior to that is an EVEN number, DROP the five.

Example: 2.065 becomes 2.06
.205 becomes .20

If the last digit is a 5 and the number immediately prior to that is an UNEVEN number, drop the 5 and ADD 1 to the last figure retained.

Example: 2.055 becomes 2.06
.215 becomes .22

If the remaining sequence of numbers is larger than 5, add 1 to the last figure retained. Never round off one digit at a time. Consider all digits to the right of the point that you wish to round off as a single quantity when judging whether is more or less than 5.

Example: 3.45678 becomes 3.5

Remember

Oscar  O = S  Sick
Had    H  = T    Tomorrow
A      A = C  Call
Heap   H
Of
Apples A

PYTHAGOREAN THEOREM

In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides.

\[ c^2 = a^2 + b^2 \]
TRIGONOMETRIC RELATIONS

In a right triangle,

\[ H = \text{hypotenuse} \]
\[ A = \text{adjacent side} \]
\[ O = \text{opposite side} \]
\[ \theta = \text{angle between hypotenuse and adjacent side (base)} \]
\[ \phi = \text{angle between hypotenuse and the opposite side} \]

\[
\begin{align*}
\sin \theta &= \frac{O}{H} \\
\csc \theta &= \frac{H}{O} \\
\cos \theta &= \frac{A}{H} \\
\sec \theta &= \frac{H}{A} \\
\tan \theta &= \frac{O}{A} \\
\cot \theta &= \frac{A}{O}
\end{align*}
\]

\[
\begin{align*}
\sin \theta &= \cos \phi \\
\csc \theta &= \sec \phi \\
\cos \theta &= \sin \phi \\
\sec \theta &= \csc \phi \\
\tan \theta &= \cot \phi \\
\cot \theta &= \tan \phi
\end{align*}
\]

LENGTH of SIDES for RIGHT-ANGLE TRIANGLES

Length of Hypotenuse =
- Side opposite \( \times \) Cosecant
- Side opposite \( \div \) Sine
- Side adjacent \( \times \) Secant
- Side adjacent \( \div \) Cosine

Length of side Opposite =
- Hypotenuse \( \times \) Sine
- Hypotenuse \( \div \) Cosecant
- Side adjacent \( \times \) Tangent
- Side adjacent \( \div \) Cotangent

Length of side Adjacent =
- Hypotenuse \( \times \) Cosine
- Hypotenuse \( \div \) Secant
- Side opposite \( \times \) Cotangent
- Side opposite \( \div \) Tangent
The circular system of angular measurement is called radian measure.

A radian is an angle that intercepts an arc equal in length to the radius of a circle as illustrated below.

Length of arc $\theta C = \text{radius of circle}$
- 6.28 radians = $360^\circ$
- $2 \pi$ radians = $360^\circ$
- $\pi$ radians = $180^\circ$
- 1 radians = 57.2958°
- 1 degree = 0.01745 radian
QUADRATIC EQUATIONS

A quadratic equation that contains only terms of the second degree of the unknown is called a pure quadratic equation.

Example: \( a^2 = 9 \)
\( 2x^2 + 5y^2 = 20 \)

A quadratic equation that contains terms of both the first and second degree of the unknown is called a complete quadratic equation.

Example: \( x^2 + x + 3 = 15 \)
\( ax^2 + bx + c = 0 \)

The quadratic formula:
\[
x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

Where: 
\( a = \) coefficient of the first term
\( b = \) coefficient of the second term
\( c = \) constant or third term

**j OPERATOR**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Mathematical Equivalent</th>
<th>Direction of Rotation</th>
<th>Degree of Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( j )</td>
<td>( \sqrt{-1} )</td>
<td>ccw</td>
<td>90</td>
</tr>
<tr>
<td>( j^2 )</td>
<td>-1</td>
<td>ccw</td>
<td>180</td>
</tr>
<tr>
<td>( j^3 )</td>
<td>( -\sqrt{-1} )</td>
<td>ccw</td>
<td>270</td>
</tr>
<tr>
<td>( j^4 )</td>
<td>1</td>
<td>ccw</td>
<td>360</td>
</tr>
<tr>
<td>-( j )</td>
<td>( -\sqrt{-1} )</td>
<td>cw</td>
<td>-90</td>
</tr>
<tr>
<td>(-j)^2</td>
<td>-1</td>
<td>cw</td>
<td>-180</td>
</tr>
<tr>
<td>(-j)^3</td>
<td>( \sqrt{-1} )</td>
<td>cw</td>
<td>-270</td>
</tr>
<tr>
<td>(-j)^4</td>
<td>1</td>
<td>cw</td>
<td>-360</td>
</tr>
</tbody>
</table>

ACCELERATION due to GRAVITY

Acceleration due to gravity at sea level, 40 degrees latitude, is:

32.1578 feet/sec/sec
DECIBELS and POWER RATIO

The ratio between any two amounts of electrical power is usually expressed in units on a logarithmic scale. The decibel is a logarithmic unit for expressing a power ratio.

\[ PR(\text{dB}) = 10 \log \frac{P_2}{P_1} \]

Where:  
- \( PR \) = power ratio in db
- \( P_1 \) = power in (small)
- \( P_2 \) = power out (large)

When the output of a circuit is larger than the input, the device is an amplifier and there is a gain. When the output of a circuit is less than the input, the device is an attenuator and there is a loss. In the last example, use the same formula as above and place the larger power over the smaller power and put a minus sign in front of \( PR \) to indicate a power loss or attenuation.

Basically, the decibel is a measure of the ratio of two powers. Since voltage and current are related to power by impedance, the decibel can be used to express voltage and current ratios provided the input and output impedances are taken into account.

**Equal Impedances:**

\[ dB = 20 \log \frac{E_2}{E_1} \]

Where:
- \( E_1 \) = input voltage
- \( E_2 \) = output voltage

\[ dB = 20 \log \frac{I_2}{I_1} \]

Where:
- \( I_1 \) = input current
- \( I_2 \) = output current

**Unequal Impedances:**

\[ dB = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}} \]

\[ dB = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}} \]

Where:
- \( R_1 \) = impedance of the input in ohms
- \( R_2 \) = impedance of the output in ohms
- \( E_1 \) = voltage of the input in volts
- \( E_2 \) = voltage of the output in volts
- \( I_1 \) = current of the input in amperes
- \( I_2 \) = current of the output in amperes

The NEPER

The neper, based on natural logarithms to the base \( e \), is a unit used to measure difference in power level in the same manner as the dB is used in the system of common logarithms.

\[ 1 \text{ dB} = 0.115 \text{ neper} \]
\[ 1 \text{ neper} = 8.686 \text{ dB} \]
<table>
<thead>
<tr>
<th>DECAY (−) VOLTAGE AND CURRENT RATIO</th>
<th>DECAY (−) POWER RATIO</th>
<th>NUMBER OF DBs</th>
<th>INCREASE (+) VOLTAGE AND CURRENT RATIO</th>
<th>INCREASE (+) POWER RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000</td>
<td>1.0000</td>
<td>0</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>.9886</td>
<td>.9772</td>
<td>.1</td>
<td>1.0120</td>
<td>1.0230</td>
</tr>
<tr>
<td>.9772</td>
<td>.9550</td>
<td>.2</td>
<td>1.0230</td>
<td>1.0470</td>
</tr>
<tr>
<td>.9661</td>
<td>.9330</td>
<td>.3</td>
<td>1.0350</td>
<td>1.0720</td>
</tr>
<tr>
<td>.9550</td>
<td>.9120</td>
<td>.4</td>
<td>1.0470</td>
<td>1.0960</td>
</tr>
<tr>
<td>.9441</td>
<td>.8913</td>
<td>.5</td>
<td>1.0590</td>
<td>1.1220</td>
</tr>
<tr>
<td>.9333</td>
<td>.8710</td>
<td>.6</td>
<td>1.0720</td>
<td>1.1480</td>
</tr>
<tr>
<td>.9226</td>
<td>.8511</td>
<td>.7</td>
<td>1.0840</td>
<td>1.1750</td>
</tr>
<tr>
<td>.9120</td>
<td>.8318</td>
<td>.8</td>
<td>1.0960</td>
<td>1.2020</td>
</tr>
<tr>
<td>.9016</td>
<td>.8128</td>
<td>.9</td>
<td>1.1060</td>
<td>1.2300</td>
</tr>
<tr>
<td>.8913</td>
<td>.7943</td>
<td>1.0</td>
<td>1.0960</td>
<td>1.2590</td>
</tr>
<tr>
<td>.7943</td>
<td>.6310</td>
<td>2.0</td>
<td>1.2590</td>
<td>1.5850</td>
</tr>
<tr>
<td>.7079</td>
<td>.5012</td>
<td>3.0</td>
<td>1.4130</td>
<td>1.9950</td>
</tr>
<tr>
<td>.6310</td>
<td>.3981</td>
<td>4.0</td>
<td>1.5850</td>
<td>2.5120</td>
</tr>
<tr>
<td>.5623</td>
<td>.3162</td>
<td>5.0</td>
<td>1.7780</td>
<td>3.1620</td>
</tr>
<tr>
<td>.5012</td>
<td>.2512</td>
<td>6.0</td>
<td>1.9950</td>
<td>3.9810</td>
</tr>
<tr>
<td>.4487</td>
<td>.1995</td>
<td>7.0</td>
<td>2.2390</td>
<td>5.0120</td>
</tr>
<tr>
<td>.3981</td>
<td>.1585</td>
<td>8.0</td>
<td>2.5120</td>
<td>6.3100</td>
</tr>
<tr>
<td>.3548</td>
<td>.1259</td>
<td>9.0</td>
<td>2.8180</td>
<td>7.9430</td>
</tr>
<tr>
<td>.3162</td>
<td>.1000</td>
<td>10.0</td>
<td>3.1620</td>
<td>10.0000</td>
</tr>
<tr>
<td>.1000</td>
<td>.0100</td>
<td>20.0</td>
<td>10.000</td>
<td>100.0000</td>
</tr>
<tr>
<td>.03162</td>
<td>.0010</td>
<td>30.0</td>
<td>31.6200</td>
<td>1,000.0000</td>
</tr>
<tr>
<td>.0100</td>
<td>.0001</td>
<td>40.0</td>
<td>100.0000</td>
<td>10,000.0000</td>
</tr>
<tr>
<td>.00316</td>
<td>.00001</td>
<td>50.0</td>
<td>316.2000</td>
<td>1 x 10^4</td>
</tr>
<tr>
<td>.0010</td>
<td>1 x 10^-6</td>
<td>60.0</td>
<td>1,000.0000</td>
<td>1 x 10^6</td>
</tr>
<tr>
<td>.000316</td>
<td>1 x 10^-7</td>
<td>70.0</td>
<td>3,162.0000</td>
<td>1 x 10^7</td>
</tr>
</tbody>
</table>

Table Showing the Relationship Between DBs and the Power, Voltage and Current Ratios
The decibel does not represent actual power, but only a measure of power ratios. It is desirable to have a logarithmic expression that represents actual power. The dBm is such an expression and it represents power levels above and below one milliwatt.

The dBm indicates an arbitrary power level with a base of one milliwatt and is found by taking 10 times the log of the ratio of actual power to the reference power of one milliwatt.

\[
P(dBm) = 10 \log \frac{P}{1 \text{ mw}}
\]

Where:

- \( P(dBm) \) = power in dBm
- \( P \) = actual power
- \( 1 \text{ mw} \) = reference power

GUARDING ILLUSTRATED

![Un-guarded Circuit](image1)

![Guarded Circuit](image2)

H0 G3ABR32430 002-1
### SINE WAVE VOLTAGE CONVERSION CHART

<table>
<thead>
<tr>
<th></th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective (RMS)</td>
<td>0.900</td>
</tr>
<tr>
<td>Average</td>
<td>1.110</td>
</tr>
<tr>
<td>Peak</td>
<td>0.707</td>
</tr>
<tr>
<td>Pk-to-Pk</td>
<td>0.354</td>
</tr>
<tr>
<td></td>
<td>Effective</td>
</tr>
<tr>
<td></td>
<td>1.414</td>
</tr>
<tr>
<td></td>
<td>1.571</td>
</tr>
<tr>
<td></td>
<td>0.637</td>
</tr>
<tr>
<td></td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td>Pk-to-Pk</td>
</tr>
<tr>
<td></td>
<td>2.828</td>
</tr>
<tr>
<td></td>
<td>3.142</td>
</tr>
<tr>
<td></td>
<td>2.000</td>
</tr>
<tr>
<td></td>
<td>0.500</td>
</tr>
</tbody>
</table>

### SINE WAVE ILLUSTRATED

![Sine Wave Illustration](image)

- Effective Voltage: $E_{	ext{rms}} = E_{	ext{eff}}$
- Average Voltage: $E_{	ext{ave}}$
- Peak Voltage
- Pk-to-Pk

---

**Ho G3ABR32430 002-1**

15
FREQUENCY CLASSIFICATION

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Classification</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-30</td>
<td>Very low frequencies</td>
<td>VLF</td>
</tr>
<tr>
<td>30-300</td>
<td>Low frequencies</td>
<td>LF</td>
</tr>
<tr>
<td>300-3,000</td>
<td>Medium frequencies</td>
<td>MF</td>
</tr>
<tr>
<td>3-30 MHz</td>
<td>High frequencies</td>
<td>HF</td>
</tr>
<tr>
<td>30-300 MHz</td>
<td>Very high frequencies</td>
<td>VHF</td>
</tr>
<tr>
<td>300-3,000 MHz</td>
<td>Ultra-high frequencies</td>
<td>UHF</td>
</tr>
<tr>
<td>3,000-30,000 MHz</td>
<td>Super-high frequencies</td>
<td>SHF</td>
</tr>
<tr>
<td>30,000-300,000 MHz</td>
<td>Extremely high frequencies</td>
<td>EHF</td>
</tr>
</tbody>
</table>

DIVIDER NETWORKS

The division of voltage and current in a circuit can be determined in the following manner.

Voltage Divider

\[ E_{\text{Ra}} = \frac{R_a}{R_a + R_b} \cdot E_a \]

Current Divider

\[ I_{\text{Ra}} = \frac{R_b}{R_a + R_b} \cdot I_t \]

Where:
- \( E_a \) = applied voltage in volts
- \( I_t \) = total current in amperes
- \( R_a \) = resistance in ohms
- \( R_b \) = resistance in ohms
- \( E_{\text{Ra}} \) = voltage across \( R_a \) in volts
- \( I_{\text{Ra}} \) = current through \( R_a \) in amperes
NETWORK CONVERSIONS

A simple method for remembering the $\Delta$ to $Y$ and $Y$ to $\Delta$ conversions is given using the illustration.

$\Delta$ to $Y$

The value of each $Y$ resistor is equal to the product of the two adjacent $\Delta$ resistors divided by the total $\Delta$ resistance.

$Y$ to $\Delta$

The value of each $\Delta$ resistor is found by dividing the sum of all the $Y$ resistances by the value of the opposite $Y$ resistance.

\[ R_y = \frac{R_1 R_3}{\Sigma R_\Delta} \quad R_\Delta = \frac{\Sigma R_Y}{R_c} \]

Delta circuit consists of:

\[ R_1, R_2, \text{ and } R_3 \]

$\Sigma = \text{the sum of the resistors in the network specified.}$

Wye circuit consists of:

\[ R_a, R_b, \text{ and } R_c \]
COLOR-CODE MARKING FOR RESISTORS

COMPOSITION-TYPE RESISTORS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
</table>

FIRST
SIGNIFICANT
FIGURE
SECOND
SIGNIFICANT
FIGURE

TERMINAL
TOLERANCE
MULTIPLIER

FAILURE-RATE LEVEL
(ESTABLISHED RELIABILITY
TYPES ONLY)

RAND A - The first significant figure of the resistance value.
(Rands A thru D are of equal width)

RAND B - The second significant figure of the resistance value.

RAND C - The multiplier is the factor by which the two significant
figures are multiplied to yield the nominal resistance
value.

RAND D - The resistance tolerance.

RAND E - When used on composition resistors, band E indicates the
established reliability failure-rate level. On film
resistors, this band is approximately 1 1/2 times the width
of the other hands, and indicates type of terminal.

RAND A

RAND B

RAND C

RAND D

RAND E

TERMINAL

TOLERANCE

MULTIPLIER

26069

HO G3ABR32430 002-1
## COLOR-CODE CHART

<table>
<thead>
<tr>
<th>Band A</th>
<th>Band B</th>
<th>Band C</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>First Figure</td>
<td>Color</td>
<td>Second Figure</td>
</tr>
<tr>
<td>Black</td>
<td>0</td>
<td>Black</td>
<td>0</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>Brown</td>
<td>1</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>Red</td>
<td>2</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>Orange</td>
<td>3</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>Yellow</td>
<td>4</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>Green</td>
<td>5</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>Blue</td>
<td>6</td>
</tr>
<tr>
<td>Purple (violet)</td>
<td>7</td>
<td>Purple (violet)</td>
<td>7</td>
</tr>
<tr>
<td>Grey</td>
<td>8</td>
<td>Gray</td>
<td>8</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>White</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band D</th>
<th>Band E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Tolerance (percent)</td>
</tr>
<tr>
<td>Silver</td>
<td>±10 Composition type only</td>
</tr>
<tr>
<td></td>
<td>±5</td>
</tr>
<tr>
<td>Red</td>
<td>±2</td>
</tr>
<tr>
<td></td>
<td>not applicable to established reliability</td>
</tr>
<tr>
<td>No Color</td>
<td>±20</td>
</tr>
</tbody>
</table>

*This is the percentage of failure per 1000 hours of use.*
COLOR CODE – CAPACITORS

ONLY A FEW OF THE MANY TYPES AND FORMS OF CAPACITORS ARE PRESENTED.

TYPE

VOLTAGE RATING

1ST DIGIT

2ND DIGIT

MULTIPLIER

TOLERANCE

CHARACTERISTIC OR CLASS

1ST DIGIT

2ND DIGIT

MULTIPLIER

VOLTAGE RATING

1ST DIGIT

2ND DIGIT

MULTIPLIER

TOLERANCE

NO COLOR

CAPACITANCE

1ST DIGIT

2ND DIGIT

MULTIPLIER

TOLERANCE

VOLTAGE
### 6-DOT RIVIA-JAIV-AWS STANDARD CAPACITOR COLOR CODE

<table>
<thead>
<tr>
<th>COLOR</th>
<th>TYPE</th>
<th>1ST DIGIT</th>
<th>2ND DIGIT</th>
<th>MULTIPLIER</th>
<th>TOLERANCE (PERCENT)</th>
<th>CHARACTERISTIC OR CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK</td>
<td>JAN, MICA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>APPLIES TO TEMPERATURE COEFFICIENTS OR METHODS OF TESTING</td>
</tr>
<tr>
<td>BROWN</td>
<td></td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>RED</td>
<td></td>
<td>2</td>
<td>2</td>
<td>100</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ORANGE</td>
<td></td>
<td>3</td>
<td>3</td>
<td>1,000</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>YELLOW</td>
<td></td>
<td>4</td>
<td>4</td>
<td>10,000</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GREEN</td>
<td></td>
<td>5</td>
<td>5</td>
<td>100,000</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>BLUE</td>
<td></td>
<td>6</td>
<td>6</td>
<td>1,000,000</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>PURPLE</td>
<td></td>
<td>7</td>
<td>7</td>
<td>10,000,000</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>GRAY</td>
<td>RMA, MICA</td>
<td>8</td>
<td>8</td>
<td>100,000,000</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>WHITE</td>
<td></td>
<td>9</td>
<td>9</td>
<td>1,000,000,000</td>
<td>.1</td>
<td></td>
</tr>
<tr>
<td>SILVER</td>
<td>AWS, PAPER</td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>BODY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

### 5-COLOR CAPACITOR COLOR CODE

<table>
<thead>
<tr>
<th>COLOR</th>
<th>1ST DIGIT</th>
<th>2ND DIGIT</th>
<th>MULTIPLIER</th>
<th>TOLERANCE (PERCENT)</th>
<th>VOLTAGE RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>BROWN</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>RED</td>
<td>2</td>
<td>2</td>
<td>100</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>ORANGE</td>
<td>3</td>
<td>3</td>
<td>1,000</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>YELLOW</td>
<td>4</td>
<td>4</td>
<td>10,000</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>GREEN</td>
<td>5</td>
<td>5</td>
<td>100,000</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>BLUE</td>
<td>6</td>
<td>6</td>
<td>1,000,000</td>
<td>1</td>
<td>700</td>
</tr>
<tr>
<td>PURPLE</td>
<td>7</td>
<td>7</td>
<td>10,000,000</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>GRAY</td>
<td>8</td>
<td>8</td>
<td>100,000,000</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>WHITE</td>
<td>9</td>
<td>9</td>
<td>1,000,000,000</td>
<td>.1</td>
<td>1000</td>
</tr>
<tr>
<td>SILVER</td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
<td>2000</td>
</tr>
<tr>
<td>BODY</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

### CERAMIC CAPACITOR COLOR CODE

<table>
<thead>
<tr>
<th>COLOR</th>
<th>1ST DIGIT</th>
<th>2ND DIGIT</th>
<th>MULTIPLIER</th>
<th>TOLERANCE OVER 10pf</th>
<th>LESS THAN 10pf</th>
<th>TEMPERATURE COEFFICIENT (PPM/DEG. C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>+20%</td>
<td>2.0 pf</td>
<td>0</td>
</tr>
<tr>
<td>BROWN</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>+1 %</td>
<td></td>
<td>-30</td>
</tr>
<tr>
<td>RED</td>
<td>2</td>
<td>2</td>
<td>100</td>
<td>+2 %</td>
<td></td>
<td>-80</td>
</tr>
<tr>
<td>ORANGE</td>
<td>3</td>
<td>3</td>
<td>1,000</td>
<td>+5 %</td>
<td>0.5 pf</td>
<td>-150</td>
</tr>
<tr>
<td>YELLOW</td>
<td>4</td>
<td>4</td>
<td>10,000</td>
<td></td>
<td></td>
<td>-220</td>
</tr>
<tr>
<td>GREEN</td>
<td>5</td>
<td>5</td>
<td>100,000</td>
<td></td>
<td></td>
<td>-330</td>
</tr>
<tr>
<td>BLUE</td>
<td>6</td>
<td>6</td>
<td>1,000,000</td>
<td></td>
<td></td>
<td>-470</td>
</tr>
<tr>
<td>PURPLE</td>
<td>7</td>
<td>7</td>
<td>.01</td>
<td>+10%</td>
<td>1.0 ppf</td>
<td>-750</td>
</tr>
<tr>
<td>GRAY</td>
<td>8</td>
<td>8</td>
<td>.1</td>
<td></td>
<td></td>
<td>+30</td>
</tr>
<tr>
<td>WHITE</td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>+500 TO -330</td>
</tr>
<tr>
<td>GOLD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+100</td>
</tr>
</tbody>
</table>

HO G3ARR32430 002-1

330603521-27
26066
DIFFERENT MARKING SCHEMES ARE USED MAINLY BECAUSE OF THE VARYING NEEDS
FULFILLED BY DIFFERENT CAPACITOR TYPES. TEMPERATURE COEFFICIENT IS OF MINOR
IMPORTANCE IN AN ELECTROLYTIC FILTER CAPACITOR, BUT IT IS VERY IMPORTANT IN
CERAMIC TRIMMERS FOR ATTENUATOR USE. YOU NEVER FIND TEMPERATURE COEFFICIENT
ON AN ELECTROLYTIC LABEL, BUT IT IS ALWAYS PRESENT ON CERAMIC TRIMMERS.

CERAMIC DISC CAPACITORS. INFORMATION IS USUALLY PRINTED. CAPACITANCE IS
IN PF. CAPACITANCE TOLERANCE IS SHOWN IN PERCENT OR BY LETTER. TEMPERATURE
COEFFICIENT IS INDICATED BY P200 WHICH MEANS +200 P/M/°C, OR M100 FOR -100
P/M/°C, ETC.

M = ± 20%
K = ± 10%
J = ± 5%
G = ± 2%
F = ± 1%

CERAMIC TUBULAR CAPACITORS. THESE CAPACITORS ARE USUALLY WHITE ENAMEL
COATED WITH PARALLEL RADIAL LEADS AND LOOK LIKE "DOG BONES." THE CODE
CONSISTS OF COLOR DOTS WHICH INDICATE TEMPERATURE COEFFICIENT, CAPACITANCE,
AND TOLERANCE.

BUTTON MICA CAPACITORS. THE MOST DIFFICULT PART OF READING THE CODE ON
 THESE CAPACITORS IS TO REMEMBER TO READ THE DOTS MOVING IN A CLOCKWISE
DIRECTION. THE DOTS ARE USUALLY PRINTED MORE TO ONE SIDE THAN THEY ARE TO
THE OTHER.

MOLDED MICA CAPACITORS. THIS WAS ONCE A VERY POPULAR TYPE, RECTANGULAR
WITH DOTS AND ARROW OR SIMILAR DIRECTIONAL INDICATOR. STANDARD COLOR CODE
APPLIES. THE CHARACTERISTIC IN MICA CAPACITORS REFERS TO THE TEMPERATURE
COEFFICIENT AND CAPACITANCE DRIFT.

DIPPED MICA CAPACITORS. THIS TYPE OF CAPACITOR HAS A PRINTED LABEL LIKE
THAT APPEARING ON CERAMIC DISC CAPACITORS.

PAPER AND FILM CAPACITORS. ALUMINUM AND TANTALUM ELECTROLYTIC
CAPACITORS, IN NEARLY ALL CASES, HAVE PRINTED OR STAMPED LABELS INDICATING
CAPACITANCE, TOLERANCE, AND VOLTAGE RATINGS. OTHER CHARACTERISTICS ARE
USUALLY UNIMPORTANT.

AIR TRIMMERS. THE SAME INFORMATION APPLIES AS WITH PAPER AND FILM
CAPACITORS. OFTEN ONLY THE CAPACITANCE RANGE IS INDICATED.
<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Symbol</th>
<th>Name</th>
<th>Atomic Weight</th>
<th>Electron Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>Hydrogen</td>
<td>1.0080</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>He</td>
<td>Helium</td>
<td>4.0026</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Li</td>
<td>Lithium</td>
<td>6.93</td>
<td>2 1</td>
</tr>
<tr>
<td>4</td>
<td>Be</td>
<td>Beryllium</td>
<td>9.0122</td>
<td>2 2</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>Boron</td>
<td>10.811</td>
<td>2 3</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>Carbon</td>
<td>12.011</td>
<td>2 4</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>Nitrogen</td>
<td>14.007</td>
<td>2 5</td>
</tr>
<tr>
<td>8</td>
<td>O</td>
<td>Oxygen</td>
<td>15.999</td>
<td>2 6</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>Fluorine</td>
<td>18.998</td>
<td>2 7</td>
</tr>
<tr>
<td>10</td>
<td>Ne</td>
<td>Neon</td>
<td>20.183</td>
<td>2 8</td>
</tr>
<tr>
<td>11</td>
<td>Na</td>
<td>Sodium</td>
<td>22.990</td>
<td>2 8 1</td>
</tr>
<tr>
<td>12</td>
<td>Mg</td>
<td>Magnesium</td>
<td>24.312</td>
<td>2 8 2</td>
</tr>
<tr>
<td>13</td>
<td>Al</td>
<td>Aluminum</td>
<td>26.982</td>
<td>2 8 3</td>
</tr>
<tr>
<td>14</td>
<td>Si</td>
<td>Silicon</td>
<td>28.086</td>
<td>2 8 4</td>
</tr>
<tr>
<td>15</td>
<td>P</td>
<td>Phosphorus</td>
<td>30.974</td>
<td>2 8 5</td>
</tr>
<tr>
<td>16</td>
<td>S</td>
<td>Sulfur</td>
<td>32.064</td>
<td>2 8 6</td>
</tr>
<tr>
<td>17</td>
<td>Cl</td>
<td>Chlorine</td>
<td>35.453</td>
<td>2 8 7</td>
</tr>
<tr>
<td>18</td>
<td>Ar</td>
<td>Aragon</td>
<td>39.948</td>
<td>2 8 8</td>
</tr>
<tr>
<td>19</td>
<td>K</td>
<td>Potassium</td>
<td>39.102</td>
<td>2 8 8 1</td>
</tr>
<tr>
<td>20</td>
<td>Ca</td>
<td>Calcium</td>
<td>40.08</td>
<td>2 8 8 2</td>
</tr>
<tr>
<td>21</td>
<td>Sc</td>
<td>Scandium</td>
<td>44.956</td>
<td>2 8 9 2</td>
</tr>
<tr>
<td>22</td>
<td>Ti</td>
<td>Titanium</td>
<td>47.90</td>
<td>2 8 10 2</td>
</tr>
<tr>
<td>23</td>
<td>V</td>
<td>Vanadium</td>
<td>50.942</td>
<td>2 8 11 2</td>
</tr>
<tr>
<td>24</td>
<td>Cr</td>
<td>Chromium</td>
<td>51.996</td>
<td>2 8 13 1</td>
</tr>
<tr>
<td>25</td>
<td>Mn</td>
<td>Manganese</td>
<td>54.938</td>
<td>2 8 13 2</td>
</tr>
<tr>
<td>26</td>
<td>Fe</td>
<td>Iron</td>
<td>55.847</td>
<td>2 8 14 2</td>
</tr>
<tr>
<td>27</td>
<td>Co</td>
<td>Cobalt</td>
<td>58.933</td>
<td>2 8 15 2</td>
</tr>
<tr>
<td>28</td>
<td>Ni</td>
<td>Nickle</td>
<td>58.71</td>
<td>2 8 16 2</td>
</tr>
<tr>
<td>29</td>
<td>Cu</td>
<td>Copper</td>
<td>63.54</td>
<td>2 8 18 1</td>
</tr>
<tr>
<td>30</td>
<td>Zn</td>
<td>Zinc</td>
<td>65.37</td>
<td>2 8 18 2</td>
</tr>
<tr>
<td>31</td>
<td>Ga</td>
<td>Gallium</td>
<td>69.72</td>
<td>2 8 18 3</td>
</tr>
<tr>
<td>32</td>
<td>Ge</td>
<td>Germanium</td>
<td>72.59</td>
<td>2 8 18 4</td>
</tr>
<tr>
<td>33</td>
<td>As</td>
<td>Arsenic</td>
<td>74.922</td>
<td>2 8 18 5</td>
</tr>
<tr>
<td>34</td>
<td>Se</td>
<td>Selenium</td>
<td>78.96</td>
<td>2 8 18 6</td>
</tr>
<tr>
<td>35</td>
<td>Br</td>
<td>Bromine</td>
<td>79.909</td>
<td>2 8 18 7</td>
</tr>
<tr>
<td>36</td>
<td>Kr</td>
<td>Krypton</td>
<td>83.80</td>
<td>2 8 18 8</td>
</tr>
<tr>
<td>37</td>
<td>Rb</td>
<td>Rubidium</td>
<td>85.47</td>
<td>2 8 18 8 1</td>
</tr>
<tr>
<td>38</td>
<td>Sr</td>
<td>Strontium</td>
<td>87.62</td>
<td>2 8 18 8 2</td>
</tr>
<tr>
<td>39</td>
<td>Y</td>
<td>Yttrium</td>
<td>88.905</td>
<td>2 8 18 9 2</td>
</tr>
<tr>
<td>40</td>
<td>Zr</td>
<td>Zirconium</td>
<td>91.22</td>
<td>2 8 18 10 2</td>
</tr>
<tr>
<td>41</td>
<td>Nb</td>
<td>Niobium</td>
<td>92.906</td>
<td>2 8 18 12 1</td>
</tr>
<tr>
<td>42</td>
<td>Mo</td>
<td>Molybdenum</td>
<td>95.94</td>
<td>2 8 18 13 1</td>
</tr>
<tr>
<td>43</td>
<td>Tc</td>
<td>Technetium</td>
<td>(99)</td>
<td>2 8 18 13 2</td>
</tr>
<tr>
<td>44</td>
<td>Ru</td>
<td>Ruthenium</td>
<td>101.07</td>
<td>2 8 18 15 1</td>
</tr>
<tr>
<td>45</td>
<td>Rh</td>
<td>Rhodium</td>
<td>102.91</td>
<td>2 8 18 16 1</td>
</tr>
<tr>
<td>46</td>
<td>Pd</td>
<td>Palladium</td>
<td>106.1</td>
<td>2 8 18 18</td>
</tr>
<tr>
<td>47</td>
<td>Ag</td>
<td>Silver</td>
<td>107.87</td>
<td>2 8 18 18 1</td>
</tr>
<tr>
<td>48</td>
<td>Cd</td>
<td>Cadmium</td>
<td>112.40</td>
<td>2 8 18 18 2</td>
</tr>
<tr>
<td>49</td>
<td>In</td>
<td>Indium</td>
<td>114.82</td>
<td>2 8 18 18 3</td>
</tr>
<tr>
<td>50</td>
<td>Sn</td>
<td>Tin</td>
<td>118.69</td>
<td>2 8 18 18 4</td>
</tr>
<tr>
<td>51</td>
<td>Sb</td>
<td>Antimony</td>
<td>121.75</td>
<td>2 8 18 18 5</td>
</tr>
<tr>
<td>52</td>
<td>Te</td>
<td>Tellurium</td>
<td>127.62</td>
<td>2 8 18 18 6</td>
</tr>
<tr>
<td>53</td>
<td>I</td>
<td>Iodine</td>
<td>126.90</td>
<td>2 8 18 18 7</td>
</tr>
<tr>
<td>54</td>
<td>Xe</td>
<td>Xenon</td>
<td>131.30</td>
<td>2 8 18 18 8</td>
</tr>
<tr>
<td>Element</td>
<td>Symbol</td>
<td>Atomic Weight</td>
<td>Protons</td>
<td>Neutrons</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>---------------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>Cs</td>
<td>Cs</td>
<td>132.91</td>
<td>55</td>
<td>77</td>
</tr>
<tr>
<td>Ba</td>
<td>Ba</td>
<td>137.34</td>
<td>56</td>
<td>81</td>
</tr>
<tr>
<td>La</td>
<td>La</td>
<td>138.91</td>
<td>57</td>
<td>83</td>
</tr>
<tr>
<td>Ce</td>
<td>Ce</td>
<td>140.12</td>
<td>58</td>
<td>86</td>
</tr>
<tr>
<td>Pr</td>
<td>Pr</td>
<td>140.91</td>
<td>59</td>
<td>89</td>
</tr>
<tr>
<td>Nd</td>
<td>Nd</td>
<td>144.24</td>
<td>60</td>
<td>92</td>
</tr>
<tr>
<td>Pm</td>
<td>Pm</td>
<td>(147)</td>
<td>61</td>
<td>95</td>
</tr>
<tr>
<td>Sm</td>
<td>Sm</td>
<td>150.35</td>
<td>62</td>
<td>97</td>
</tr>
<tr>
<td>Eu</td>
<td>Eu</td>
<td>151.96</td>
<td>63</td>
<td>98</td>
</tr>
<tr>
<td>Gd</td>
<td>Gd</td>
<td>157.25</td>
<td>64</td>
<td>99</td>
</tr>
<tr>
<td>Tb</td>
<td>Tb</td>
<td>158.92</td>
<td>65</td>
<td>101</td>
</tr>
<tr>
<td>Dy</td>
<td>Dy</td>
<td>162.50</td>
<td>66</td>
<td>103</td>
</tr>
<tr>
<td>Ho</td>
<td>Ho</td>
<td>164.93</td>
<td>67</td>
<td>105</td>
</tr>
<tr>
<td>Er</td>
<td>Er</td>
<td>167.26</td>
<td>68</td>
<td>107</td>
</tr>
<tr>
<td>Tm</td>
<td>Tm</td>
<td>168.93</td>
<td>69</td>
<td>109</td>
</tr>
<tr>
<td>Yb</td>
<td>Yb</td>
<td>173.04</td>
<td>70</td>
<td>111</td>
</tr>
<tr>
<td>Lu</td>
<td>Lu</td>
<td>174.97</td>
<td>71</td>
<td>113</td>
</tr>
<tr>
<td>Hf</td>
<td>Hf</td>
<td>178.49</td>
<td>72</td>
<td>117</td>
</tr>
<tr>
<td>Ta</td>
<td>Ta</td>
<td>180.95</td>
<td>73</td>
<td>119</td>
</tr>
<tr>
<td>W</td>
<td>W</td>
<td>183.85</td>
<td>74</td>
<td>127</td>
</tr>
<tr>
<td>Re</td>
<td>Re</td>
<td>186.2</td>
<td>75</td>
<td>128</td>
</tr>
<tr>
<td>Os</td>
<td>Os</td>
<td>190.2</td>
<td>76</td>
<td>156</td>
</tr>
<tr>
<td>Ir</td>
<td>Ir</td>
<td>192.2</td>
<td>77</td>
<td>157</td>
</tr>
<tr>
<td>Pt</td>
<td>Pt</td>
<td>195.09</td>
<td>78</td>
<td>158</td>
</tr>
<tr>
<td>Au</td>
<td>Au</td>
<td>196.97</td>
<td>79</td>
<td>197</td>
</tr>
<tr>
<td>Hg</td>
<td>Hg</td>
<td>200.59</td>
<td>80</td>
<td>208</td>
</tr>
<tr>
<td>Tl</td>
<td>Tl</td>
<td>204.37</td>
<td>81</td>
<td>205</td>
</tr>
<tr>
<td>Pb</td>
<td>Pb</td>
<td>207.19</td>
<td>82</td>
<td>207</td>
</tr>
<tr>
<td>Bi</td>
<td>Bi</td>
<td>208.98</td>
<td>83</td>
<td>209</td>
</tr>
<tr>
<td>Po</td>
<td>Po</td>
<td>(210)</td>
<td>84</td>
<td>209</td>
</tr>
<tr>
<td>At</td>
<td>At</td>
<td>(210)</td>
<td>85</td>
<td>209</td>
</tr>
<tr>
<td>Rn</td>
<td>Rn</td>
<td>(222)</td>
<td>86</td>
<td>222</td>
</tr>
<tr>
<td>Fr</td>
<td>Fr</td>
<td>(223)</td>
<td>87</td>
<td>223</td>
</tr>
<tr>
<td>Ra</td>
<td>Ra</td>
<td>(226)</td>
<td>88</td>
<td>226</td>
</tr>
<tr>
<td>Ac</td>
<td>Ac</td>
<td>(227)</td>
<td>89</td>
<td>227</td>
</tr>
<tr>
<td>Th</td>
<td>Th</td>
<td>232.04</td>
<td>90</td>
<td>232</td>
</tr>
<tr>
<td>Pa</td>
<td>Pa</td>
<td>(231)</td>
<td>91</td>
<td>231</td>
</tr>
<tr>
<td>U</td>
<td>U</td>
<td>238.03</td>
<td>92</td>
<td>238</td>
</tr>
<tr>
<td>Np</td>
<td>Np</td>
<td>(237)</td>
<td>93</td>
<td>237</td>
</tr>
<tr>
<td>Pu</td>
<td>Pu</td>
<td>(242)</td>
<td>94</td>
<td>242</td>
</tr>
<tr>
<td>Am</td>
<td>Am</td>
<td>(243)</td>
<td>95</td>
<td>243</td>
</tr>
<tr>
<td>Cm</td>
<td>Cm</td>
<td>(247)</td>
<td>96</td>
<td>247</td>
</tr>
<tr>
<td>Bk</td>
<td>Bk</td>
<td>(247)</td>
<td>97</td>
<td>247</td>
</tr>
<tr>
<td>Cf</td>
<td>Cf</td>
<td>(249)</td>
<td>98</td>
<td>249</td>
</tr>
<tr>
<td>Es</td>
<td>Es</td>
<td>(254)</td>
<td>99</td>
<td>254</td>
</tr>
<tr>
<td>Fm</td>
<td>Fm</td>
<td>(253)</td>
<td>100</td>
<td>253</td>
</tr>
<tr>
<td>Md</td>
<td>Md</td>
<td>(256)</td>
<td>101</td>
<td>256</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>(254)</td>
<td>102</td>
<td>254</td>
</tr>
<tr>
<td>Lw</td>
<td>Lw</td>
<td>(257)</td>
<td>103</td>
<td>257</td>
</tr>
</tbody>
</table>

HO G3ARR32430 002-1

27
### MASS and WEIGHT CONVERSION TABLE

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 gram</td>
<td>0.035 ounce</td>
</tr>
<tr>
<td>1 centigram</td>
<td>0.154 gram</td>
</tr>
<tr>
<td>1 kilogram</td>
<td>2.2046 pounds</td>
</tr>
<tr>
<td>1 pound</td>
<td>0.4536 kilogram = 7000 grains = 454 grams</td>
</tr>
<tr>
<td>1 ounce</td>
<td>28.349 grams = 437.5 grains</td>
</tr>
<tr>
<td>1 grain</td>
<td>0.0648 grams = 0.002285 ounce</td>
</tr>
</tbody>
</table>

### LENGTH CONVERSION TABLE

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>2.540 centimeters = 0.083 feet = 0.027 yards</td>
</tr>
<tr>
<td></td>
<td>= 25.4 millimeters = 25,400 microns</td>
</tr>
<tr>
<td>1 foot</td>
<td>30.480 centimeters = 12 inches = 0.333 yards</td>
</tr>
<tr>
<td>1 yard</td>
<td>0.914 meters = 3 feet = 36 inches</td>
</tr>
<tr>
<td>1 meter</td>
<td>39.37 inches = 1.094 yards</td>
</tr>
<tr>
<td>1 kilometer</td>
<td>0.6214 statute miles</td>
</tr>
<tr>
<td>1 centimeter</td>
<td>0.3937 inch</td>
</tr>
<tr>
<td>1 micron</td>
<td>0.0001 centimeter = 10^{-6} meter</td>
</tr>
<tr>
<td>1 angstrom</td>
<td>0.0000001 centimeter = 10^{-10} meter</td>
</tr>
<tr>
<td>1 statute mile</td>
<td>1.609 kilometers = 5280 feet = 1760 yards</td>
</tr>
<tr>
<td>1 nautical mile</td>
<td>6076.115 feet = 1852.0 meters</td>
</tr>
</tbody>
</table>

### VOLUME and PRESSURE CONVERSION TABLE

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cubic inch</td>
<td>16.387 cubic centimeters</td>
</tr>
<tr>
<td>1 cubic foot</td>
<td>0.028 cubic meters = 1728 cubic inches</td>
</tr>
<tr>
<td>1 cubic yard</td>
<td>0.765 cubic meters = 27 cubic feet</td>
</tr>
<tr>
<td>1 cubic centimeter</td>
<td>0.061 cubic inch</td>
</tr>
<tr>
<td>1 quart</td>
<td>946 cubic centimeters = 57.75 cubic inches</td>
</tr>
<tr>
<td>1 liter</td>
<td>1000 cubic centimeters = 1.057 quart</td>
</tr>
<tr>
<td>1 atmosphere</td>
<td>14.7 psi = 760 mm of Hg at 0°C at sea level</td>
</tr>
<tr>
<td>1 psi</td>
<td>51.7 mm of mercury</td>
</tr>
<tr>
<td>1 inch of mercury at 0°C</td>
<td>0.491 pounds per square inch</td>
</tr>
<tr>
<td>1 cm of mercury at 0°C</td>
<td>13.6 grams per square centimeter</td>
</tr>
<tr>
<td>1 foot of water</td>
<td>0.433 psi</td>
</tr>
<tr>
<td>1 cubic centimeter of water</td>
<td>1 gram</td>
</tr>
<tr>
<td>1 cubic foot of water</td>
<td>62.416 pounds</td>
</tr>
<tr>
<td>1 g</td>
<td>386 inches/sec^2</td>
</tr>
<tr>
<td>1 gallon</td>
<td>231 cubic inches</td>
</tr>
<tr>
<td>1 gallon water @ 4°C</td>
<td>8.3454 lbs</td>
</tr>
<tr>
<td>1 millibar</td>
<td>0.02953 in Hg = 0.750062 mm Hg</td>
</tr>
<tr>
<td>1 Torr</td>
<td>1/760 atmosphere = 1 millimeter</td>
</tr>
</tbody>
</table>

### POWER, WORK, and HEAT CONVERSION TABLE

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Btu</td>
<td>252 calories = 778 foot-pounds</td>
</tr>
<tr>
<td>1 watt</td>
<td>44.28 foot-pounds per minute</td>
</tr>
<tr>
<td>1 kilowatt</td>
<td>1000 watts = 1.34 horsepower</td>
</tr>
<tr>
<td>1 horsepower</td>
<td>746 watts = 550 ft/lbs/sec = 33,000 ft/lbs/min</td>
</tr>
<tr>
<td>1 erg</td>
<td>1 dyne centimeter</td>
</tr>
<tr>
<td>1 joule</td>
<td>10^7 erg = 0.239 calorie</td>
</tr>
<tr>
<td>1 calorie</td>
<td>4.18 joules</td>
</tr>
<tr>
<td>1 watt</td>
<td>1 joule per second = 3.4 Btu per hour</td>
</tr>
</tbody>
</table>
### Temperature Conversion Chart

<table>
<thead>
<tr>
<th>FROM</th>
<th>TO</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CÉLSIUS</td>
<td>KELVIN</td>
<td>$K = C + 273.15$</td>
</tr>
<tr>
<td>FAHRENHEIT</td>
<td>KELVIN</td>
<td>$K = \frac{5}{9} (F + 459.67)$</td>
</tr>
<tr>
<td>RANKINE</td>
<td>KELVIN</td>
<td>$K = \frac{5}{9} R$</td>
</tr>
<tr>
<td>FAHRENHEIT</td>
<td>CELSIUS</td>
<td>$C = \frac{(F - 32)}{1.8}$</td>
</tr>
<tr>
<td>KELVIN</td>
<td>CELSIUS</td>
<td>$C = K - 273.15$</td>
</tr>
<tr>
<td>CELSIUS</td>
<td>FAHRENHEIT</td>
<td>$F = 1.8C + 32$</td>
</tr>
<tr>
<td>FAHRENHEIT</td>
<td>RANKINE</td>
<td>$R = F + 459.69$</td>
</tr>
</tbody>
</table>

### Basic Temperature Scales Comparison Chart

<table>
<thead>
<tr>
<th></th>
<th>FAHRENHEIT</th>
<th>RANKINE</th>
<th>KELVIN</th>
<th>CELSIUS (CENTRIGRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOILING POINT WATER</td>
<td>212°F</td>
<td>671.67°R</td>
<td>373.15°K</td>
<td>100°C</td>
</tr>
<tr>
<td>FREEZING POINT WATER</td>
<td>32°F</td>
<td>491.67°R</td>
<td>273.15°K</td>
<td>0°C</td>
</tr>
<tr>
<td>ABSOLUTE ZERO</td>
<td>-459.67°F</td>
<td>0°R</td>
<td>0°K</td>
<td>-273.15°C</td>
</tr>
<tr>
<td>Celsius Scale</td>
<td>Fahrenheit Scale</td>
<td>Temperature Event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>------------------</td>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1410</td>
<td>2570</td>
<td>Silicon Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1083.4</td>
<td>1982.12</td>
<td>Copper Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1964.43</td>
<td>1947.974</td>
<td>Freezing Point of Gold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>937.4</td>
<td>1719.32</td>
<td>Germanium Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>961.93</td>
<td>1763.474</td>
<td>Freezing Point of Silver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>660.37</td>
<td>1220.666</td>
<td>Aluminum Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>630.74</td>
<td>1167.332</td>
<td>Silver Solder Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>630.74</td>
<td>1167.332</td>
<td>Antimony Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>444.674</td>
<td>832.4132</td>
<td>Boiling Point of Silver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>216</td>
<td>420</td>
<td>50/50 Lead/Tin Solder Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>156.61</td>
<td>313.898</td>
<td>Indium Melts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>212</td>
<td>Steam Point at Sea Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>57.8</td>
<td>136.04</td>
<td>Highest Recorded World Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>98.6</td>
<td>Human Body Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>39.2</td>
<td>Maximum Density of Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.010</td>
<td>32.018</td>
<td>Triple Point of Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>32</td>
<td>Ice Point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-38.87</td>
<td>-37.966</td>
<td>Mercury Freezes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-78.5</td>
<td>-109.3</td>
<td>Sublimation Point of CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-88.3</td>
<td>-126.94</td>
<td>Lowest Recorded World Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-182.962</td>
<td>-297.3316</td>
<td>Oxygen Boils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-273.15</td>
<td>-459.67</td>
<td>Absolute Zero</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### DECIMAL EQUIVALENTS OF COMMON FRACTIONS

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Decimal Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64</td>
<td>0.015625</td>
</tr>
<tr>
<td>1/32</td>
<td>0.03125</td>
</tr>
<tr>
<td>1/16</td>
<td>0.0625</td>
</tr>
<tr>
<td>5/64</td>
<td>0.09375</td>
</tr>
<tr>
<td>7/64</td>
<td>0.109375</td>
</tr>
<tr>
<td>1/8</td>
<td>0.125</td>
</tr>
<tr>
<td>9/64</td>
<td>0.140625</td>
</tr>
<tr>
<td>5/32</td>
<td>0.15625</td>
</tr>
<tr>
<td>11/64</td>
<td>0.171875</td>
</tr>
<tr>
<td>3/16</td>
<td>0.1875</td>
</tr>
<tr>
<td>13/64</td>
<td>0.203125</td>
</tr>
<tr>
<td>7/32</td>
<td>0.21875</td>
</tr>
<tr>
<td>15/64</td>
<td>0.234375</td>
</tr>
<tr>
<td>1/4</td>
<td>0.25</td>
</tr>
<tr>
<td>17/64</td>
<td>0.265625</td>
</tr>
<tr>
<td>9/32</td>
<td>0.28125</td>
</tr>
<tr>
<td>19/64</td>
<td>0.296875</td>
</tr>
<tr>
<td>5/16</td>
<td>0.3125</td>
</tr>
<tr>
<td>21/64</td>
<td>0.328125</td>
</tr>
</tbody>
</table>

### LENGTH EQUIVALENT CONVERSION CHART

<table>
<thead>
<tr>
<th>FROM</th>
<th>FEET</th>
<th>METERS</th>
<th>YARDS</th>
<th>CENTIMETERS</th>
<th>INCHES</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEET</td>
<td>1.0</td>
<td>0.3048</td>
<td>0.3333</td>
<td>30.48</td>
<td>12.0</td>
<td>304.8</td>
</tr>
<tr>
<td>METERS</td>
<td>3.281</td>
<td>1.0</td>
<td>1.0936</td>
<td>100.0</td>
<td>39.37</td>
<td>1000.0</td>
</tr>
<tr>
<td>YARDS</td>
<td>3.0</td>
<td>0.9144</td>
<td>1.0</td>
<td>91.44</td>
<td>36.0</td>
<td>914.4</td>
</tr>
<tr>
<td>CENTIMETERS</td>
<td>0.03281</td>
<td>0.01</td>
<td>0.01094</td>
<td>1.0</td>
<td>0.3937</td>
<td>10.0</td>
</tr>
<tr>
<td>INCHES</td>
<td>0.08333</td>
<td>0.0264</td>
<td>0.02778</td>
<td>2.540</td>
<td>1.0</td>
<td>25.40</td>
</tr>
<tr>
<td>MILLIMETERS</td>
<td>0.003281</td>
<td>0.001</td>
<td>0.001094</td>
<td>0.1</td>
<td>0.03937</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### ZEKE's REVERSIBLE FORMULA (C° - F° / -C°)

For converting degrees Celsius to degrees Fahrenheit and visa versa.

1. Add 40
2. Multiply by either (5/9 F to C) or (9/5 C to F)
3. Subtract 40
### SPECIFIC GRAVITY OF SOLIDS

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>2.7</td>
</tr>
<tr>
<td>Brass</td>
<td>8.2-8.7</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.9-3.5</td>
</tr>
<tr>
<td>Copper</td>
<td>8.9</td>
</tr>
<tr>
<td>Gold</td>
<td>19.3</td>
</tr>
<tr>
<td>Human body</td>
<td>1.07</td>
</tr>
<tr>
<td>Ice</td>
<td>0.917</td>
</tr>
<tr>
<td>Iron, steel</td>
<td>7.6-7.8</td>
</tr>
<tr>
<td>Lead</td>
<td>11.3</td>
</tr>
<tr>
<td>Oak</td>
<td>0.60-0.98</td>
</tr>
<tr>
<td>Pine</td>
<td>0.37-0.64</td>
</tr>
<tr>
<td>Silver</td>
<td>10.5</td>
</tr>
</tbody>
</table>

### SPECIFIC GRAVITY OF LIQUIDS

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, Distilled @ 4°C</td>
<td>1.000</td>
</tr>
<tr>
<td>Alcohol, Ethyl</td>
<td>0.789</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>1.60</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.66-0.69</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.82</td>
</tr>
<tr>
<td>Mercury @ 0°C</td>
<td>13.5951</td>
</tr>
<tr>
<td>Milk</td>
<td>1.029</td>
</tr>
<tr>
<td>Oil, Linseed</td>
<td>0.942</td>
</tr>
<tr>
<td>Water, Sea</td>
<td>1.025</td>
</tr>
</tbody>
</table>

### SPECIFIC GRAVITY OF GASES (air = 1.000)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>0.596</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>1.529</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.060</td>
</tr>
<tr>
<td>Neon</td>
<td>0.696</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.967</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.105</td>
</tr>
</tbody>
</table>

### TORQUE INDICATING HANDLES

Tolerances for torque indicating handles IAW Federal spec GGG-W-686.

<table>
<thead>
<tr>
<th>Range</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 19.9% of full scale</td>
<td>± 7% of indicated value</td>
</tr>
<tr>
<td>20 - 79.9% of full scale</td>
<td>± 4% of indicated value</td>
</tr>
<tr>
<td>80 - 100% of full scale</td>
<td>± 5% of indicated value</td>
</tr>
</tbody>
</table>

### SPEED OF LIGHT IN AIR

The speed of light is stated differently in various reference sources. In this handbook we will accept the speed of light as being:

Approximately 186,000 miles per second or 2.9979 x 10^8 meters per second.
VOLUMETERIC EXPANSION COEFFICIENTS

<table>
<thead>
<tr>
<th>Substance</th>
<th>n x 10^-4 °C</th>
<th>n x 10^-4 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol, Ethyl</td>
<td>11.0</td>
<td>6.10</td>
</tr>
<tr>
<td>Benzene</td>
<td>13.9</td>
<td>7.70</td>
</tr>
<tr>
<td>Petroleum (Pennsylvania)</td>
<td>9.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Mercury</td>
<td>1.82</td>
<td>1.01</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>5.56</td>
<td>3.10</td>
</tr>
<tr>
<td>Turpentine</td>
<td>9.70</td>
<td>5.40</td>
</tr>
<tr>
<td>Water</td>
<td>2.07</td>
<td>1.15</td>
</tr>
</tbody>
</table>

LINER COEFFICIENTS OF EXPANSION

<table>
<thead>
<tr>
<th>Material</th>
<th>n x 10^-6 °C</th>
<th>n x 10^-6 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>24.5</td>
<td>13.6</td>
</tr>
<tr>
<td>Copper</td>
<td>16.2</td>
<td>9.0</td>
</tr>
<tr>
<td>Iron (Cast)</td>
<td>11.7</td>
<td>6.5</td>
</tr>
<tr>
<td>Nickel</td>
<td>12.6</td>
<td>7.0</td>
</tr>
<tr>
<td>Platinum</td>
<td>9.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Steel (Carbon)</td>
<td>11.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Tungsten</td>
<td>4.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Zinc</td>
<td>30.6</td>
<td>17.0</td>
</tr>
<tr>
<td>PRESSURE UNITS</td>
<td>1 Psi</td>
<td>1 INCH H₂O (4°C)</td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>in H₂O</td>
<td>1.00</td>
<td>0.03713</td>
</tr>
<tr>
<td>ft H₂O</td>
<td>2.307</td>
<td>0.08333</td>
</tr>
<tr>
<td>cm H₂O</td>
<td>70.31</td>
<td>0.7356</td>
</tr>
<tr>
<td>KG/cm²</td>
<td>0.07031</td>
<td>0.00458</td>
</tr>
<tr>
<td>G/cm²</td>
<td>70.31</td>
<td>0.02850</td>
</tr>
<tr>
<td>mm Hg</td>
<td>0.748</td>
<td>0.009678</td>
</tr>
<tr>
<td>in H₂O</td>
<td>27.68</td>
<td>0.08333</td>
</tr>
<tr>
<td>ft H₂O</td>
<td>2.307</td>
<td>0.08333</td>
</tr>
<tr>
<td>cm H₂O</td>
<td>70.31</td>
<td>0.7356</td>
</tr>
<tr>
<td>KG/cm²</td>
<td>0.07031</td>
<td>0.00458</td>
</tr>
<tr>
<td>G/cm²</td>
<td>70.31</td>
<td>0.02850</td>
</tr>
<tr>
<td>mm Hg</td>
<td>0.748</td>
<td>0.009678</td>
</tr>
</tbody>
</table>
VARIOUS MEASUREMENTS

Plane figures bounded by straight lines.

Area of a triangle whose base is (b) and altitude (h).

\[ \text{area} = \frac{bh}{2} \]

Area of a rectangle with sides (a) and (b).

\[ \text{area} = ah \]

Area of a parallelogram with side (b) and perpendicular distance to the parallel side (h).

\[ \text{area} = bh \]

Plane figures bounded by curve lines.

Circumference of a circle whose radius is (r) and diameter (d)

\[ \text{circumference} = 2\pi r = \pi d \]

Area of a circle

\[ \text{area} = \pi r^2 = \frac{1}{4} \pi d^2 = .7854d^2 \]

Length of an arc of a circle for an arc of \( \theta \) degrees

\[ \text{length of arc} = \frac{\pi r \theta}{180} \]
FORMULAS

ELECTROSTATICS

1. The force between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between the charges.

\[ F = \frac{Q_1 Q_2}{kd^2} \]

Where \( F \) = force in dynes
\( Q_1 \) = strength of charge one in electrostatic units (e.s.u.)
\( Q_2 \) = strength of charge two in electrostatic units.
\( d \) = distance separating charges in cm.
\( K \) = dielectric constant of the medium through which the force is exerted.

2. The following equation is used to show the work performed on an electrostatic field where a charge has been transferred.

\[ W = K \frac{Q_1 Q_2}{d} \]

Where \( W \) = work in joules
\( Q_1 \) = strength of charge one in electrostatic units.
\( Q_2 \) = strength of charge two in electrostatic units.
\( d \) = distance separating charge in cm.
\( K \) = dielectric constant of the medium through which the force is exerted.

3. The formula for electrical potential difference is as follows:

\[ E = \frac{W}{Q} \]

Where \( E \) = the potential in volts
\( W \) = work in joules
\( Q \) = charge in coulombs
4. The following formulas are used to determine the deflection factor or deflection sensitivity of a CRT:

**deflection factor**

\[ df = \frac{1}{ds} \]

**deflection sensitivity**

\[ ds = \frac{1}{df} \]

**MAGNETISM AND ELECTROMAGNETICS**

1. The force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.

\[ F = \frac{m_1 m_2}{\mu d^2} \]

Where \( F \) = force between the poles in dynes

\( m_1 \) = magnetic strength of the first pole in unit poles

\( m_2 \) = magnetic strength of the second pole in unit poles

\( d \) = distance between the poles in cm

\( \mu \) = permeability of the medium through which the force acts

2. The number of flux lines per unit area is known as flux density.

\[ \beta = \frac{\Phi}{A} \]

Where \( \beta \) = flux density

\( \Phi \) = total lines of flux

\( A \) = cross sectional area in cm²
3. The density of a magnetic field is directly related to the magnetic force exerted by the field. The formula for field intensity \( H \) is as follows:

\[
H = \frac{f}{m}
\]

Where \( H \) = field intensity in oersteds

\( f \) = force acting upon a magnetic pole in dynes

\( m \) = strength of magnetic pole in unit poles

4. The formula for magnetomotive force in a coil is as follows:

\[
\text{mmf} = \frac{4 \pi NI}{10}
\]

Where \( \text{mmf} \) = magnetomotive force in gilberts

\( N \) = number of turns

\( I \) = current in amperes

5. The formula for reluctance in a coil is as follows:

\[
R = \frac{L}{\mu A}
\]

Where \( R \) = reluctance in rels

\( \mu \) = permeability of the medium

\( L \) = length of winding in cm

\( A \) = area in square cm
6. The formula for permeability is as follows:

$$\psi = \frac{\beta}{H}$$

Where \( \psi \) = permeability of medium
\( \beta \) = flux density in gaussies
\( H \) = magnetic intensity in oersteds

7. Amplitude of induced EMF is affected by the rate at which lines of force are cut. This can be expressed mathematically by the following formula:

$$E_{ave} = \frac{N\Phi}{\ln Bt}$$

Where \( E_{ave} \) = average value of induced voltage
\( N \) = number of turns
\( t \) = time in seconds taken to cut all flux lines
\( \Phi \) = the number of lines of force
RESISTANCE

1. The resistance of a resistor is determined by the type of material used, its cross sectional area and its length. The resistance value is directly proportional to the length, and inversely proportional to its cross sectional area.

\[ R = \rho \frac{l}{d^2} = \rho \frac{l}{A} \]

Where \( R \) = resistance in ohms
\( \rho \) = resistance in ohms per circular mil foot of the material (specific resistance)
\( l \) = length of the conductor
\( d \) = diameter of material in mils
\( A \) = cross sectional area in circular mils

2. Resistance as a function of temperature (approximation).

\[ R_t = R_0 (1 + \alpha t) \]

Where \( R_t \) = resistance at a given temperature
\( R_0 \) = resistance at a reference temperature
\( \alpha \) = temperature coefficient of resistance at the reference temperature
\( t \) = elevation of the second temperature above the reference temperature in degrees Celsius
CONDUCTANCE

1. Conductance is the ability of a material to pass electrons. It can be found by using the following formula:

\[ G = \frac{A}{\rho l} \]

Where \( G \) = conductance measured in mhos
\( A \) = cross sectional area in circular mils
\( l \) = length measured in feet
\( \rho \) = specific resistance

2. The conductance is the reciprocal of resistance.

\[ G = \frac{1}{R} \]

Where \( G \) = conductance in mhos
\( R \) = resistance in ohms

METERS

1. The sensitivity of a meter movement is often stated in terms of ohms per volt. This relationship is shown in the following formula:

\[ \frac{\Delta I}{\Delta V} = R_m = \frac{1}{E_m I_m} \]

Where \( \frac{\Delta I}{\Delta V} \) = ohms per volt
\( R_m \) = resistance of the meter movement
\( E_m \) = full scale reading in volts
\( I_m \) = full scale current in amperes

NOTE: The input of a VTVM is constant over its entire range for any given frequency input.
2. The value of multiplier resistance needed to extend the range of a voltmeter can be determined using the following formula:

\[ R_{mul} = E(\Omega/V) - R_m \]

Where \( R_{mul} \) = resistance of the multiplier
\( E \) = extended range of the voltmeter
\( \Omega/V \) = ohms per volt
\( R_m \) = resistance of the meter movement

3. To extend the range of an ammeter the appropriate shunt resistor is determined using the following formula:

\[ R_s = \frac{I_m R_m}{I_t - I_m} \]

Where \( R_s \) = shunt value required
\( I_m \) = full scale deflection current of the meter movement
\( R_m \) = resistance of the meter movement
\( I_t \) = total current of desired range
4. To extend the range of a milliammeter using a ring (universal) type shunt the following formula will be used. Some of the resistors may be in series with the meter movement and some in parallel depending on the range used.

\[ R_s = \frac{R_t I_m}{I_t} \]

Where

- \( R_s \) = shunt value required
- \( R_t \) = sum of all resistance in the meter circuit, including the meter resistance
- \( I_m \) = full scale deflection current of the meter
- \( I_t \) = total current of the desired range

![Diagram of Ring Shunt Ammeter]
OHM'S LAW FOR DC CIRCUITS

When any two values are known, the other two circuit parameters may be determined. There are shown on the following formulaw chart:

<table>
<thead>
<tr>
<th>I = current in amperes</th>
<th>R = resistance in ohms</th>
<th>E = voltage in volts</th>
<th>P = power in watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>known</td>
<td>known</td>
<td>E = IR</td>
<td>P = I^2R</td>
</tr>
<tr>
<td>known</td>
<td>R = E/I</td>
<td>known</td>
<td>P = EI</td>
</tr>
<tr>
<td>known</td>
<td>R = P/I^2</td>
<td>E = P/I</td>
<td>known</td>
</tr>
<tr>
<td>I = E/R</td>
<td>known</td>
<td>known</td>
<td>P = E^2/R</td>
</tr>
<tr>
<td>I = P/E</td>
<td>R = E^2/P</td>
<td>known</td>
<td>known</td>
</tr>
<tr>
<td>I = \sqrt{P/R}</td>
<td>known</td>
<td>E = \sqrt{PR}</td>
<td>known</td>
</tr>
</tbody>
</table>

OHM'S LAW FOR AC CIRCUITS

When any two circuit values are known, the other two circuit parameters may be determined. These are shown in the following chart:

<table>
<thead>
<tr>
<th>I = current in amperes</th>
<th>Z = impedance in ohms</th>
<th>E = voltage in volts</th>
<th>P = power in watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>known</td>
<td>known</td>
<td>E = IZ</td>
<td>P = I^2Z cos θ</td>
</tr>
<tr>
<td>known</td>
<td>Z = E/I</td>
<td>known</td>
<td>P = IE cos θ</td>
</tr>
<tr>
<td>I = E/Z</td>
<td>known</td>
<td>known</td>
<td>P = E^2 cos θ /Z</td>
</tr>
<tr>
<td>known</td>
<td>Z = P / I^2 cos θ</td>
<td>E = P / I cos θ</td>
<td>known</td>
</tr>
<tr>
<td>I = P / Z cos θ</td>
<td>known</td>
<td>E = PZ / cos θ</td>
<td>known</td>
</tr>
<tr>
<td>I = P / E cos θ</td>
<td>Z = E^2 cos θ / P</td>
<td>known</td>
<td>known</td>
</tr>
</tbody>
</table>
SERIES DC CIRCUIT COMPUTATION

The following formulas assume that the source of power has negligible resistance.

1. Total resistance ($R_t$). The total resistance is the sum of the individual resistances.

$$R_t = R_1 + R_2 + R_3 + \ldots$$

2. Total voltage ($E_t$). The total voltage in a series circuit is the sum of the individual voltage drops, and is equal to the voltage of the source.

$$E_t = E_1 + E_2 + E_3 + \ldots$$

3. Total current ($I_t$). The total current is determined by the total resistance of the circuit and the applied voltage and will be of the same value at any point in the circuit.

$$I_t = I_1 = I_2 = I_3 = \ldots$$

4. Total power ($P_t$). The total power dissipated in a series circuit is the sum of all power losses in the circuit.

$$P_t = P_1 + P_2 + P_3 + \ldots$$

5. Total conductance ($G_t$).

$$G_t = \frac{1}{G_1 + \frac{1}{G_2} + \frac{1}{G_3}}$$

PARALLEL DC CIRCUIT COMPUTATION

The following formulas assume that the source of power has negligible resistance.
1. Total resistance ($R_t$). The total resistance is the reciprocal of the sum of the reciprocals. It will always be less than the resistance of the smallest parallel resistor.

$$R_t = \frac{1}{1 + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots}$$

For resistors of like value:

$$R_t = \frac{\text{value of one resistor}}{\text{number of resistors}}$$

For two parallel resistors:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

2. Total voltage ($E_t$). The total voltage is applied to each branch of the parallel circuit.

$$E_t = E_1 = E_2 = E_3 = \ldots$$

3. Total current ($I_t$). The total current is the sum of the currents in the individual branches. The current flow in each branch is inversely proportional to the resistance of that branch.

$$I_t = I_1 + I_2 + I_3 + \ldots$$

4. Total power ($P_t$). The total power dissipated in a parallel circuit is the sum of all power losses in the circuit.

$$P_t = P_1 + P_2 + P_3 + \ldots$$

5. Total conductance ($G_t$).

$$G_t = G_1 + G_2 + G_3 + \ldots$$
CAPACITANCE

1. The quantity of electricity stored within a capacitor is determined by the potential impressed across the capacitor and the capacitance of the capacitor.

\[ Q = CE \]

Where: 
- \( Q \) = the quantity stored in coulombs
- \( E \) = the potential impressed across the capacitor in volts
- \( C \) = capacitance in farads

2. The capacitance of a capacitor is determined by the dielectric constant of the dielectric used, plate area, and distance between the plates.

\[ C = 0.0885 \epsilon S(N - 1) \]

Where: 
- \( C \) = capacitance in picofarads
- \( \epsilon \) = dielectric constant (see table below)
- \( S \) = area of one plate in square centimeters
- \( N \) = number of plates
- \( d \) = thickness of the dielectric in centimeters (same as the distance between the plates)

*When \( S \) and \( d \) are given in inches, change constant 0.0885 to 0.224. The answer will still be in picofarads.

<table>
<thead>
<tr>
<th>Dielectric</th>
<th>( \epsilon ) Value*</th>
<th>Dielectric</th>
<th>( \epsilon ) Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.0</td>
<td>Mica</td>
<td>6.0</td>
</tr>
<tr>
<td>Bakelite</td>
<td>5.0</td>
<td>Paper (paraffin)</td>
<td>3.5</td>
</tr>
<tr>
<td>Beeswax</td>
<td>3.0</td>
<td>Porcelain</td>
<td>6.0</td>
</tr>
<tr>
<td>Cambric</td>
<td>4.0</td>
<td>Pyrex</td>
<td>4.5</td>
</tr>
<tr>
<td>Fibre</td>
<td>5.0</td>
<td>Quartz</td>
<td>5.0</td>
</tr>
<tr>
<td>Glass</td>
<td>8.0</td>
<td>Rubber</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*True value depends upon quality of material

3. The total capacitance (\( C_t \)) of capacitors in series is the reciprocal of the sum of the reciprocals. The total capacitance will be less than the value of the smallest capacitor.

\[ C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots} \]
For series capacitors of like value:
\[ C_t = \frac{\text{value of capacitors}}{\text{number of capacitors}} \]

For two series capacitors:
\[ C_t = \frac{C_1 C_2}{C_1 + C_2} \]

4. The total capacitance \( C_t \) of capacitors in parallel is the sum of the individual capacitors.
\[ C_t = C_1 + C_2 + C_3 \ldots \]

**SELF INDUCTANCE**

A number of factors determine the inductance of a coil, such as the number of turns, ratio of the diameter to length, type of core material used and the method of winding.

1. One common formula for self inductance is as follows:
\[ L = \frac{e}{\frac{\Delta i}{\Delta t}} = \frac{\Delta te}{\Delta t} \]

Where \( L \) = self inductance in henrys
\( e \) = induced voltage in volts (CEMF)
\( \Delta i \) = change in current in amps
\( \Delta t \) = change in time in seconds
2. The formula for the CEMF produced in an inductor is as follows:

\[ V = 0.4 \pi n^2 \lambda A \frac{\Delta i}{\Delta t} = -L \frac{\Delta i}{\Delta t} \]

Where:
- \( V \) = counter emf in volts
- 0.4 = a constant factor which will cause the answer to be in volts
- \( n \) = number of turns of the coil
- \( \lambda \) = permeability
- \( A \) = area of the cross section of the coil in cm²
- \( \Delta i \) = change in current
- \( \Delta t \) = change in time
- \( l \) = length of the coil
- \( L \) = inductance in henrys

3. The total inductance \( L_t \) of inductors in series is the sum of individual inductances. (Assume zero coupling between inductors).

\[ L_t = L_1 + L_2 + L_3 + \ldots \]

4. The total inductance of inductors in parallel is the reciprocal of the sum of the reciprocals. The total inductance will always be less than the value of the smallest inductor. (Assume zero coupling between inductors.)

\[ L_t = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}} \]
For inductors of like value:

\[ L_t = \frac{\text{value of one inductor}}{\text{number of inductors}} \]

For two inductors in parallel:

\[ L_t = \frac{L_1 L_2}{L_1 + L_2} \]

**COUPLED INDUCTANCE**

When the magnetic field of an inductor interacts with the field of another inductor in the circuit the inductance will be changed as indicated by the following formulas.

1. Inductors in series with aiding fields:

\[ L_a = L_1 + L_2 + 2M \]

Where \( L_a \) = total inductance with aiding fields

\( M \) = mutual inductance

2. Inductors in series with opposing fields:

\[ L_o = L_1 + L_2 - 2M \]

Where \( L_o \) = total inductance with opposing fields

\( M \) = mutual inductance
3. Inductors in parallel with fields aiding:

\[ L_a = \frac{1}{\frac{1}{L_1 + M} + \frac{1}{L_2 + M}} \]

Where \( L_a \) = total inductance with fields aiding
\( M \) = mutual inductance

4. Inductors in parallel with fields opposing:

\[ L_0 = \frac{1}{\frac{1}{L_1 - M} + \frac{1}{L_2 - M}} \]

Where \( L_0 \) = total inductance with fields opposing
\( M \) = mutual inductance

**MUTUAL INDUCTANCE**

The amount of mutual inductance present in a circuit depends on the amount of inductance in each coil and the coupling between them.

\[ M = K \sqrt{L_1 \times L_2} \]

Where \( M \) = mutual inductance in henrys.
\( K \) = coefficient of coupling expressed as a decimal factor.
\( L_1 \) = inductance of the primary in henrys.
\( L_2 \) = inductance of the secondary in henrys.
ALTERNATING CURRENT GENERATION

1. The voltage generated in a generator winding may be found by using the following formula:

\[ E_{ave} = \frac{N\phi}{t} \times 10^{-8} \]

Where \( E_{ave} \) = average induced voltage
\( N \) = number of turns in the coil
\( \phi \) = change of flux in maxwells
\( t \) = change of time increments in seconds

2. The instantaneous induced voltage during the generation of a sine wave is determined by the following formula:

\[ e = E_{max} \sin(\theta) \]

Where \( e \) = The instantaneous value of the induced voltage
\( E_{max} \) = the maximum induced voltage
\( \theta \) = the instantaneous angular displacement of the rotating vector

3. The maximum generated current is directly proportional to the generated voltage and inversely proportional to the load resistance.

\[ I_{max} = \frac{E_{max}}{R} \]
Where $I_{\text{max}}$ = maximum generated current

$E_{\text{max}}$ = maximum generated voltage

$R$ = load resistance

4. The instantaneous currents can be calculated using the following formula:

$$i = I_{\text{max}} (\sin \theta)$$

Where $i$ = the instantaneous value of the current

$I_{\text{max}}$ = maximum generated current

$\theta$ = the instantaneous angular displacement of the rotating vector

5. The frequency of an alternator output can be determined by the following formula:

$$f = \frac{PS}{120}$$

Where $f$ = frequency in Hertz

$P$ = the number of generator poles

$S$ = the speed in RPM

6. The period of a sine wave is the reciprocal of its frequency.

$$T = \frac{1}{f}$$

Where $T$ = period in seconds

$f$ = frequency in Hertz
7. To determine phase angle, the following equation is used:

\[ \frac{\theta}{360^\circ} = \frac{t}{T} \quad \text{OR} \quad \theta = 360^\circ tf \]

Where \( \theta \) = angle in degrees
\( t \) = given amount of time in seconds
\( f \) = frequency in Hertz
\( T \) = period of the wave in seconds

8. Circular velocity such as that of an armature of an alternator is called angular velocity and is symbolized by the Greek letter omega. It is determined by the following formula

\[ \omega = 2 \pi f \]

Where \( \omega \) = angular velocity in radians per second
\( f \) = frequency in Hertz

2 \( \pi \) = 6.28 radians, which equals 360°

**REACTANCE**

1. The inductive reactance of an inductor is determined by the following formula:

\[ X_L = 2 \pi fL \]

Where \( X_L \) = inductive reactance in ohms
\( f \) = frequency in Hertz
\( L \) = inductance in henrys

2. The capacitive reactance of a capacitor is determined by the following formula. Note that an increase in frequency or capacitance will result in a lower \( X_C \).

\[ X_C = \frac{1}{2 \pi fC} = 0.159 \]

\[ \frac{1}{fC} \]
Where $X_C$ = capacitive reactance in ohms

$f$ = frequency in Hertz

$C$ = capacitance in farads

**RESONANCE**

1. To determine the resonant frequency of a given inductance and capacitance combination the following formula is used:

$$f_r = \frac{1}{2 \pi \sqrt{LC}} = 0.159 \sqrt{LC}$$

Where $f_r$ = resonant frequency in Hertz

$L$ = inductance in henrys

$C$ = capacitance in farads

2. To determine the value of an inductor needed to produce a known resonant frequency with a given capacitor, the following formula is used:

$$L = \frac{1}{4 \pi^2 f_r^2 C}$$

Where $L$ = inductance in henrys

$f_r$ = resonant frequency desired in Hertz

$C$ = capacitance in farads

3. To determine the value of a capacitor needed to provide a known resonant frequency with a given inductor, the following formula is used:

$$C = \frac{1}{4 \pi^2 f_r^2 L}$$

Where $C$ = capacitance in farads

$f_r$ = resonant frequency desired in Hertz

$L$ = inductance in henrys
AC CIRCUIT COMPUTATION

Impedance is the total opposition in an AC circuit. In an AC circuit that is purely resistive, the Z is equal to the total resistance. This is also true when the AC circuit is resonant. However, when an AC circuit is either inductive or capacitive, the computation is more involved.

1. The impedance of a series AC inductive circuit can be determined by the following formula:

\[ Z = \sqrt{X_L^2 + R_t^2} \]

Where \( Z \) = impedance in ohms
\( X_L \) = inductive reactance in ohms
\( R_t \) = total circuit resistance in ohms

2. Impedance of a series capacitive circuit can be determined by the following formula:

\[ Z = \sqrt{X_C^2 + R_t^2} \]

Where \( Z \) = impedance in ohms
\( X_C \) = capacitive reactance in ohms
\( R_t \) = total circuit resistance in ohms

3. Impedance of a series circuit containing resistance, inductance and capacitance can be determined by the following formula:

\[ Z = \sqrt{R_t^2 + (X_C - X_L)^2} \]
Where $Z = \text{impedance in ohms}$

$X_L = \text{inductive reactance in ohms}$

$X_C = \text{capacitive reactance in ohms}$

4. The voltage drop across any component in a series AC circuit is the product of the current and resistance, or reactance, of that component.

$$E_R = IR$$

$$E_C = IXC$$

$$E_L = IX_L$$

Where $E_R = \text{voltage drop across a resistor}$

$E_C = \text{voltage drop across a capacitor}$

$E_L = \text{voltage drop across an inductor}$

5. The applied voltage of a series AC circuit may be computed in the same manner as the impedance.

$$E_a = \sqrt{E_R^2 + (E_C - E_L)^2}$$

Where $E_a = \text{applied voltage}$

$E_R = \text{voltage drop across the resistor}$

$E_L = \text{voltage drop across the inductor}$

$E_C = \text{voltage drop across the capacitor}$
6. The current of a series AC circuit is the same at all points in the series circuit.

\[ I_t = I_R = I_L = I_C \]

Where \( I_t \) = total current in amps

\( I_R \) = current through resistor in amps

\( I_L \) = current through inductor in amps

\( I_C \) = current through capacitor in amps

7. The current of a series AC circuit can be determined by using Ohm's law for AC circuits.

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

Where \( I \) = current flow in amps

\( E_a \) = applied voltage in volts

\( Z \) = impedance of the series AC circuit in ohms

8. The voltage of a parallel AC circuit is the same across each branch and is equal to the applied voltage.

\[ E_a = E_R = E_L = E_C \]

Where \( E_a \) = applied voltage

\( E_R \) = voltage across the resistor

\( E_L \) = voltage across the inductor

\( E_C \) = voltage across the capacitor
9. The current flow in each branch of a parallel AC circuit is proportional to the \( R, X_L \) or \( X_C \) of that branch.

\[
I_R = \frac{E}{R} \\
I_L = \frac{E}{X_L} \\
I_C = \frac{E}{X_C}
\]

Where \( I_R \) = current in resistive branch in amps  \\
\( I_L \) = current in inductive branch in amps  \\
\( I_C \) = current in capacitive branch in amps  \\
\( E \) = voltage across the parallel branch

10. The total current of a parallel AC circuit can be found using the Pythagorean theorem as indicated below.

\[
I_t = \sqrt{I_R^2 + (I_C - I_L)^2}
\]

Where \( I_t \) = total current in amps  \\
\( I_R \) = current through the resistor in amps  \\
\( I_C \) = current of capacitor in amps  \\
\( I_L \) = current through inductor in amps

11. The impedance of a parallel AC circuit can be found by using Ohm's law for an AC circuit.

\[
Z = \frac{E_a}{I_t}
\]

Where \( Z \) = impedance in ohms  \\
\( E_a \) = applied voltage in volts  \\
\( I_t \) = total current in amps
12. The plane angle is the angle, expressed in degrees, by which the current lags the voltage in an inductive circuit, or leads the voltage in a capacitive circuit. In a purely theoretical circuit, current leads or lags by 90°.

In a pure resistive circuit, \( \theta = 0° \)
In a pure reactive circuit, \( \theta = 90° \)
    (capacitive) \( \theta = -90° \)
    (inductive) \( \theta = +90° \)

In a resonant circuit, \( \theta = 0° \)

The phase angle is equal to the angle whose tangent is:
For series circuit, \( \theta = \text{arc tan} \frac{X}{R} \)
For parallel circuit, \( \theta = \text{arc tan} \frac{R}{X} \)

Where \( \theta \) = phase angle in degrees
\( X \) = reactance in ohms
\( R \) = resistance in ohms
\( \text{arc tan} \) = the angle whose tangent is

13. Voltage phase angle is the angle, expressed in degrees, that the output voltage of a circuit varies in phase with respect to the input voltage.

\[ E\theta = \frac{\phi_{\text{out}}}{\phi_{\text{tot}}} \]

Where \( E\theta \) = phase of the output voltage
\( \phi_{\text{out}} \) = phase angle across the output impedance
\( \phi_{\text{tot}} \) = phase angle across the total impedance of the circuit.
14. The apparent power in an AC circuit is obtained by multiplying the effective value of voltage and current in a reactive circuit, and is expressed in terms of volt-amperes.

\[ P_a = EI \]

Since \( E = IZ \) in an \( \text{PC or RL} \) circuit

\[ P_a = I^2Z \]

Where \( P_a = \) apparent power in volt-amperes
\( E = \) voltage in volts
\( I = \) current in amperes
\( Z = \) impedance in ohms

15. True power is the actual amount of power consumed by the resistive circuit elements in an AC circuit, and is expressed in terms of watts. The power expended in a circuit may be found by using any of the following formulas.

\[ P_t = I^2R \]
\[ P_t = ERI \]
\[ P_t = EI \text{pf} \]

Where \( P_t = \) true or active power in watts
\( I = \) current in amperes
\( R = \) resistance in ohms
\( ER = \) voltage across the resistance
\( E = \) voltage in volts
\( \text{pf} = \) power factor

16. The power factor is the ratio of true power to apparent power in a reactive resistive circuit. It is an expression of the lead or lag as represented by the cosine of the phase angle.

\[ \text{power factor} = \frac{\text{true power}}{\text{apparent power}} \]
\[ pf = \frac{P_t}{P_a} = \frac{I^2R}{I^2Z} = R = \cos \theta \]

Where:
- \( pf \) = power factor
- \( P_t \) = true power in watts
- \( P_a \) = apparent power in volt-amperes
- \( I \) = current in amperes
- \( R \) = resistance in ohms
- \( Z \) = impedance in ohms
- \( \cos \theta \) = cosine angle theta

17. The figure of merit, or quality factor \((Q)\) of a component is a measure of its energy storing ability. It is the ratio of reactance for a reactive component or a circuit containing a reactive component to resistance.

a. For an inductor and resistance in series the formula is:
\[ Q = \frac{X_L}{R_s} \]

Where:
- \( Q \) = quality factor
- \( X_L \) = inductive reactance in ohms
- \( R_s \) = series resistance in ohms

b. For a capacitor and resistance in series the formula is:
\[ Q = \frac{X_C}{R_s} \]

Where:
- \( Q \) = quality factor
- \( X_C \) = capacitive reactance in ohms
- \( R_s \) = series resistance in ohms
c. For an inductor and resistance in parallel the formula is:

\[ Q = \frac{R_p}{X_L} \]

Where \( Q \) = quality factor
\( X_L \) = inductive reactance in ohms
\( R_p \) = parallel resistance in ohms. This value is relatively high. Remember that any additional resistance in parallel will lower the \( Q \).

d. For a capacitor and resistance in parallel the formula is:

\[ Q = \frac{R_p}{X_C} \]

Where \( Q \) = quality factor
\( X_C \) = capacitive reactance in ohms
\( R_p \) = parallel resistance in ohms. This value is relatively high. Remember that any additional parallel resistance will lower the \( Q \).

e. For a series resonant circuit the \( Q \) of the circuit expressed at the resonant frequency is:

\[ Q = \frac{X_L \text{ or } X_C}{R_{ts}} \]

Where \( Q \) = quality factor
\( X_L \) = inductive reactance in ohms
\( X_C \) = capacitive reactance in ohms
\( R_{ts} \) = total effective series resistance in ohms

f. For a parallel resonant circuit the \( Q \) of the circuit expressed at the resonant frequency is:

\[ Q = \frac{R_{tp}}{X_L} \]
Where $Q$ = quality factor

$X_L$ = inductive reactance in ohms

$R_{tp}$ = total effective parallel resistance in ohms

18. The $Q$ of an inductor, or a capacitor, can be decreased by adding series resistance to the series resistance that the inductor or capacitor possesses by reason of its design. The total value of resistance needed can be found using the following formulas.

$$R_t = \frac{X_L}{Q_L}$$

$$R_t = \frac{X_C}{Q_C}$$

Where $R_t$ = total resistance needed to achieve desired $Q$

$X_L$ = inductive reactance in ohms

$X_C$ = capacitive reactance in ohms

$Q_L$ = desired $Q$ value of the inductor

$Q_C$ = desired $Q$ value of the capacitor

19. The $Q$ of an inductor, tank circuit, or capacitor can be lowered by adding parallel resistance. In order to ascertain the value of parallel resistance needed to obtain the desired new $Q$, three operations are performed as follows.

a. Find the total value of parallel resistance needed to lower the $Q$ to the desired value.

$$R_t = Q_LX_L$$

$$R_t = Q_CX_C$$

Where $R_t$ = total parallel resistance needed to produce the desired $Q$

$X_L$ = inductive reactance in ohms

$X_C$ = capacitive reactance in ohms

$Q_L$ = quality of the inductive circuit desired

$Q_C$ = quality of the capacitive circuit desired
h. Determine the value of parallel equivalent resistance.

\[ R_E = Q_L X_L \quad R_E = Q_C X_C \]

Where \( R_E \) = parallel equivalent resistance

\( X_L \) = inductive reactance in ohms

\( X_C \) = capacitive reactance in ohms

\( Q_L \) = quality of inductor that now exists

\( Q_C \) = quality of capacitor that now exists

c. Find the actual value of parallel resistance needed.

\[ R_p = \frac{1}{1 + \frac{1}{R_t R_E}} \]

Where \( R_p \) = actual parallel resistance needed

\( R_t \) = total resistance

\( R_E \) = Parallel equivalent resistance

20. The dissipation factor (D) of a capacitor or inductor can be determined by the following formulas:

\[ D = \frac{R}{X_C} = \frac{1}{Q} \]

\[ D_L = \frac{R}{X_L} = \frac{1}{Q} \]

Where \( D \) = dissipation factor of a capacitor

\( D_L \) = dissipation factor of an inductor

\( X_C \) = capacitive reactance in ohms

\( Q \) = quality factor of inductor or capacitor
21. For solution of complex RC or RL circuits, each branch can be treated as a separate circuit in order to calculate the \( Z \) for each. The total impedance can then be determined by the following formula.

**NOTE:** Total impedance must be in rectangular notation.

\[
Z_t = \frac{1}{Z_{R1}} + \frac{1}{Z_{R2}} + \frac{1}{Z_{R3}}
\]

\[
Z_t = \frac{Z_{R1} Z_{R2} Z_{R3}}{Z_{R1} (Z_{R2} + Z_{R3}) + Z_{R2} Z_{R3}}
\]

Where \( Z_t \) = total impedance in ohms

\( Z_{R1} \) = impedance of branch one

\( Z_{R2} \) = impedance of branch two

\( Z_{R3} \) = impedance of branch three

22. In order to compute the total current of a complex RC or RL circuit, the current of each branch is computed and the branch currents are then added.

\[
I_t = I_{R1} + I_{R2} + I_{R3}
\]

Where \( I_t \) = total current

\( I_{R1} \) = current of branch one

\( I_{R2} \) = current of branch two

\( I_{R3} \) = current of branch three
SERIES AC CIRCUIT VECTORS

1. SERIES RL CIRCUITS

\[ Z_T = \sqrt{R^2 + X_L^2} \]
\[ E_Z = \sqrt{E_R^2 + E_L^2} \]
\[ \theta = \text{INV (ARC) TAN} \]
\[ E_L = \text{INV (ARC) TAN} \frac{X_L}{R} \]

2. SERIES RC CIRCUITS

\[ Z_T = \sqrt{R^2 + X_C^2} \]
\[ E_A = \sqrt{E_R^2 + E_C^2} \]
\[ \theta = \text{INV (ARC) TAN} \]
\[ \frac{E_C}{E_R} = \text{INV (ARC) TAN} \frac{X_C}{R} \]
3. SERIES RCL CIRCUITS

\[ Z_T = \sqrt{R^2 + (X_L - X_C)^2} \]
\[ E_A = \sqrt{E_R^2 + (E_L - E_C)^2} \]
\[ \theta = \text{INV (ARC) TAN} \frac{E_L - E_C}{E_R} = \text{INV (ARC) TAN} \frac{X_L - X_C}{R} \]
PARALLEL AC CIRCUIT VECTORS

1. PARALLEL RL CIRCUITS

\[ Z_T = \frac{E_A}{I_T} \]

\[ I_T = \sqrt{I_R^2 + I_L^2} = \frac{I_R}{\cos \theta} = \frac{I_L}{\sin \theta} \]

\[ \theta = \text{INV (ARC) TAN} \quad \frac{I_L}{I_R} = \text{INV (ARC) TAN} \quad \frac{R}{X_L} \]

NOTE: THE PHASE ANGLE OF Z_T WILL ALWAYS BE THE SAME NUMERICAL VALUE AS I_T BUT OPPOSITE IN POLARITY.
2. Parallel RC Circuits

\[ Z_T = \frac{E_A}{I_T} \]

\[ I_T = I_R^2 + I_C^2 = \frac{I_R}{\cos \theta} = \frac{I_C}{\sin \theta} \]

\[ = \text{INV} (\text{ARC}) \tan \frac{I_C}{I_R} = \text{INV} (\text{ARC}) \tan \frac{R}{X_C} \]

NOTE: The Phase angle of \( Z_T \) will always be the same numerical value as \( I_T \) but opposite in polarity.
3. Parallel RCL Circuits

\[ Z_T = \frac{E_A}{I_T} \]

\[ I_T = \sqrt{I_R^2 + (I_C - I_L)^2} = \frac{I_R}{\cos \theta} = \frac{I_C - I_L}{\sin \theta} \]

\[ I_T = \text{INV (ARC) TAN} \frac{I_C - I_L}{I_R} \]

**NOTE:** The Phase Angle of \( Z_T \) will always be the same numerical value as \( I_T \) but opposite in polarity.
BANDWIDTH

1. The bandwidth \((\Delta f)\) of a circuit is largely dependent on the \(Q\) of that circuit. This is shown in the following formula:

\[
\Delta f = \frac{f_r}{Q}
\]

Where \(\Delta f\) = bandwidth in Hertz
\(f_r\) = resonant frequency of the circuit in Hertz
\(Q\) = quality factor of the circuit

2. The lowest frequency of the bandpass can be determined by the use of the following formula:

\[
f_1 = f_r - \frac{\Delta f}{2}
\]

Where \(f_1\) = lowest frequency of the bandpass
\(f_r\) = resonant frequency of the circuit in Hertz
\(\Delta f\) = bandwidth of the circuit in Hertz

3. The highest frequency of the bandpass can be determined using the following formula:

\[
f_2 = f_r + \frac{\Delta f}{2}
\]

Where \(f_2\) = highest frequency of the bandpass
\(f_r\) = resonant frequency of the circuit in Hertz
\(\Delta f\) = bandwidth of the circuit in Hertz

TRANSFORMERS

1. The relationship between voltage, current, and number of turns is shown in the following formulas:

\[
\frac{E_p}{E_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}
\]

Where \(E_p\) = voltage of the primary
\(E_s\) = voltage of the secondary
\(I_p\) = current of the primary

\(N_p\) = number of turns of the primary
\(N_s\) = number of turns of the secondary
\[ I_s = \text{current of the secondary} \]
\[ N_p = \text{number of turns of the primary} \]
\[ N_s = \text{number of turns of the secondary} \]

2. The power relationship between the primary and secondary circuit in an ideal transformer is shown as follows:
\[ P_p = P_s \quad \text{or} \quad E_p I_p = E_s I_s \]

Where \( P_p \) = power of the primary
\( P_s \) = power of the secondary
\( E_p \) = voltage of the primary
\( E_s \) = voltage of the secondary
\( I_p \) = current of the primary
\( I_s \) = current of the secondary

3. The relationship between impedance and the number of turns is shown by the following equation,
\[ \frac{Z_p}{Z_s} = \left( \frac{N_p}{N_s} \right)^2 \]

Where \( Z_p \) = impedance of the primary
\( Z_s \) = impedance of the secondary
\( N_p \) = number of turns of the primary
\( N_s \) = number of turns of the secondary
4. The relationship between the primary and secondary voltages, currents and impedances are shown in the following equation.

\[
\frac{Z_p}{Z_s} = \left( \frac{E_p}{E_s} \right)^2 = \left( \frac{I_s}{I_p} \right)^2
\]

Where:
- \(Z_p\) = impedance of the primary
- \(Z_s\) = impedance of the secondary
- \(E_p\) = voltage of the primary
- \(E_s\) = voltage of the secondary
- \(I_p\) = current of the primary
- \(I_s\) = current of the secondary

5. The impedance reflection from the secondary to the primary can be determined using the following formula.

\[
Z_r = \frac{-Z_m^2}{Z_2 + Z_s}
\]

Where:
- \(Z_r\) = reflection impedance
- \(Z_m\) = mutual impedance
- \(Z_2\) = impedance in series with the secondary
- \(Z_s\) = impedance of the secondary winding
6. The total impedance when looking into the primary of a transformer may be found using the following formula:

\[ Z_t = Z_1 + Z_p - \frac{Z_m^2}{Z_2 + Z_s} \]

Where:
- \( Z_t \) = total impedance when looking into the primary
- \( Z_1 \) = impedance in series with the primary winding
- \( Z_p \) = impedance of the primary winding
- \( Z_m \) = mutual impedance
- \( Z_2 \) = impedance in series with the secondary winding
- \( Z_s \) = impedance of the secondary winding

7. The voltage induced in a stator leg of a syncho from a rotor:

\[ E_{\text{ind}} = E_{\text{max}} \cos \theta \]

Where:
- \( E_{\text{ind}} \) = voltage induced in the stator leg
- \( E_{\text{max}} \) = maximum voltage that can be induced in the stator leg for that input
- \( \cos \theta \) = cosine of the angle between the rotor and stator
RC TIME CONSTANTS

1. The time of one time constant in an RC circuit is found by using the following formula:

\[ TC = RC \]

Where TC = time for one time constant

\[ R = \text{resistance in ohms} \]

\[ C = \text{capacitance in farads} \]

2. The number of time constants per any given time must often be known before we can ascertain what effect the RC circuit will have on an input waveform. If an RC circuit has a time constant at least ten times longer than the period of the input, it is said to have a long time constant. The number of time constants per a given time can be found by using the following formula:

\[ \text{Number of time constants} = \frac{t}{RC} \]

Where \( t \) = any given time in seconds

\[ R = \text{resistance in ohms} \]

\[ C = \text{capacitance in farads} \]
3. The voltage across a capacitor in an RC circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accurately by using the following equation.

\[ e_c = E_a \left( 1 - e^{\frac{-t}{RC}} \right) \]

Where \( e_c \) = instantaneous capacitor voltage
\( E_a \) = applied voltage
\( t \) = time in seconds
\( R \) = resistance of the RC circuit in ohms
\( C \) = capacitance in farads of the RC circuit
\( e \) = the base of natural logarithms, 2.718

4. The voltage across a resistor in an RC circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accurately by using the following formula.

\[ e_r = E_a \left( e^{\frac{-t}{RC}} \right) \]

Where \( e_r \) = instantaneous resistor voltage
\( E_a \) = applied voltage
\( t \) = time in seconds
\( R \) = resistance in ohms
\( C \) = capacitance in farads
\( e \) = the base of natural logarithms, 2.718
5. If $e_c$ or $e_r$, and the applied voltage of an RC circuit are known, the unknown parameter can be readily determined using the formulas:

$$e_c = E_a - e_r$$

$$e_r = E_a - e_c$$

Where $e_c$ = instantaneous capacitor voltage

$e_r$ = instantaneous resistor voltage

$E_a$ = applied voltage

6. The instantaneous charge current in an RC circuit can be found by the following formula:

$$i = \frac{E_a}{R} \left( e^{\frac{-t}{RC}} \right)$$

Where $i$ = instantaneous charge current in amps

$E_a$ = applied voltage in volts

$R$ = resistance in ohms

$t$ = time in seconds

$C$ = capacitance in farads

$e$ = the base of natural logarithms, 2.718
7. The discharge of a capacitor, through a resistor, follows the same exponential curve as the charge through a resistor. The following formula can be used to determine the instantaneous voltage across a resistor during discharge.

\[ e_r = E_C \left( e^{\frac{-t}{RC}} \right) \]

where \( e_r \) = instantaneous voltage across a resistor

\( E_C \) = voltage of the capacitor

\( t \) = time in seconds

\( R \) = resistance in ohms

\( C \) = capacitance in farads

\( \epsilon \) = the base of natural logarithms, 2.718

**RL Time Constants**

1. The time of one time constant in an RL circuit is found by using the following formula.

\[ T_C = \frac{L}{R} \]

Where \( T_C \) = time for one time constant

\( L \) = inductance in henrys

\( R \) = resistance in ohms
2. The number of time constants per any given time can be determined by using the following formula:

\[
\text{number of time constants} = \frac{-tR}{L}
\]

where 
- \( t \) = any given time in seconds
- \( L \) = inductance in henrys
- \( R \) = resistance in ohms

3. The voltage across the inductor in an LR circuit at a given time may be found by using the following formula:

\[
e_L = E_a \left( e\left(\frac{-Rt}{L}\right)\right)
\]

Where
- \( e_L \) = instantaneous inductor voltage
- \( E_a \) = applied voltage
- \( R \) = resistance in ohms
- \( t \) = time in seconds
- \( L \) = inductance in henrys
- \( e \) = the base of natural logarithms, 2.718

4. The voltage across a resistor in an LR circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accurately by using the following equation.

\[
e_r = E_a \left( 1 - e\left(\frac{-Rt}{L}\right)\right)
\]

Where
- \( e_r \) = instantaneous resistor voltage
- \( E_a \) = applied voltage
- \( R \) = resistance in ohms
- \( t \) = time in seconds
- \( L \) = inductance in henrys
- \( e \) = the base of natural logarithms, 2.718
5. If $e_L$ or $e_r$ and the applied voltage of a RL circuit is known, the unknown parameter can be determined by using the following formulas:

$$e_L = E_a - e_r$$
$$e_r = E_a - e_L$$

- $e_L$ = the instantaneous inductor voltage
- $e_r$ = the instantaneous resistor voltage
- $E_a$ = the applied voltage
6. The instantaneous charge current in an LR circuit can be found by the following formula:

\[ i = \frac{E_a}{R} \left( 1 - e^{(-\frac{tR}{L})} \right) \]

Where \( i \) = instantaneous charge current in amps
\( E_a \) = applied voltage
\( R \) = resistance in ohms
\( t \) = time in seconds
\( L \) = inductance in henrys
\( e \) = the base of natural logarithms, 2.718

**POWER SUPPLIES**

1. The percentage of ripple can be determined by the formula:

\[
\text{percentage of ripple} = \frac{E_{\text{rms}} \times 100}{E_o}
\]

Where \( E_{\text{rms}} \) = rms value of the ripple in volts
\( E_o \) = DC output of the power supply in volts

2. The percentage of regulation can be determined using the equation:

\[
E_{\text{req}} = \frac{E_{\text{NL}} - E_{\text{FL}}}{E_{\text{FL}}} \times 100
\]

\( E_{\text{req}} \) = percentage of regulation
\( E_{\text{NL}} \) = no load voltage
\( E_{\text{FL}} \) = full load voltage
ELECTRON TUBES

1. The following formula is used to compute the DC resistance of a diode.

\[ R_p = \frac{E_p}{I_p} \]

Where \( R_p \) = DC resistance in ohms

\( E_p \) = the potential between plate and cathode in volts

\( I_p \) = the plate current in amps

2. The AC plate resistance is the opposition offered to the flow of alternating current by an electron tube. It can be determined by using the following formula:

\[ r_p = \frac{\Delta e_p}{\Delta i_p} \quad (E_q \text{ constant}) \]

Where \( r_p \) = AC plate resistance in ohms

\( e_p \) = the change in instantaneous voltage at the plate

\( i_p \) = the change in instantaneous current through the tube

3. The amplification factor can be determined by using the following formula:

\[ \mu = \frac{\Delta e_p}{\Delta e_g} \quad (I_p \text{ constant}) \]

Where \( \mu \) = amplification factor

\( e_p \) = the potential between the plate and cathode in volts

\( e_g \) = grid voltage in volts

\( \Delta = \) a change of

4. Transconductance is a term used to express the ratio of the change in current in one electrode to the change in voltage of another electrode while other voltages are constant. It can be found using the following formula:

\[ q_m = \frac{\Delta i_p}{\Delta e_g} \quad (E_p \text{ constant}) \]
Where $q_m =$ transconductance in mhos

$i_p =$ plate current in amps

$e_q =$ grid voltage in volts

= a change of

5. The following formulas express the relationship between three dynamic characteristics of electron tubes.

$$q_m = \frac{\mu}{r_p}$$

$$r_p = \frac{\mu}{q_m}$$

Where $q_m =$ transconductance in mhos

$\mu =$ (mu) amplification factor

$r_p =$ AC plate resistance in ohms

AMPLIFIERS

1. The voltage gain of an amplifier can be defined as the ratio of output voltage to input voltage, as indicated in the following formula:

$$A = \frac{e_o}{e_i}$$

Where $A =$ voltage gain of the amplifier

$e_o =$ output voltage

$e_i =$ input voltage

$e_q =$ grid voltage

2. Since the voltage gain of an amplifier is the ratio of the output to the input, and the input was the grid voltage ($e_q$), the following formula can be used to determine gain.
A = \frac{\mu Z_L}{r_p + Z_L}

Where A = voltage gain of an amplifier
\mu = amplification factor
Z_L = impedance of the load
r_p = AC plate resistance

3. The voltage or current gain of an amplifier in decibels can be computed by using the following formulas. These formulas assume that the input resistance and the output resistance are the same.

\[ dB = 20 \log \frac{E_o}{E_{in}} \]

\[ dB = 20 \log \frac{I_o}{I_{in}} \]

Where dB = voltage or current gain in decibels
\log = logarithm to the base 10
E_o = output power
E_{in} = input power
I_o = output current
I_{in} = input current

4. The power gain of an amplifier in decibels may be determined by using the following formula. This formula assumes that the input resistance and the output resistance are the same.

\[ dB = 10 \log \frac{P_o}{P_{in}} \]

Where dB = power gain in decibels
\log = logarithm to the base 10
P_o = output power
P_{in} = input power
5. The power gain of an amplifier in decibels may be determined by using the following formula, even though, the input and output resistance are not the same.

\[
\frac{E_o^2}{R_o} = 10 \log \frac{E_{in}^2}{R_{in}}
\]

Where \( dB \) = power gain in decibels

\( \log \) = logarithm to the base 10

\( E_o \) = output voltage

\( R_o \) = output resistance

\( E_{in} \) = input voltage

\( R_{in} \) = input resistance

6. The total voltage gain of amplifier stages in cascade can be found by the following formula.

\[
A_t = A_1 A_2 A_3
\]

Where \( A_t \) = total gain of the stages

\( A_1 \) = first stage

\( A_2 \) = second stage

\( A_3 \) = third stage

7. The formula for the equivalent resistance of the constant current equivalent circuit at mid-frequencies is as follows:

\[
R_{eq} = \frac{1}{\frac{1}{r_p} + \frac{1}{R_L} + \frac{1}{R_g}}
\]

Where \( R_{eq} \) = the equivalent resistance of the constant current equivalent circuit at mid-frequencies

\( r_p \) = AC plate resistance in ohms for stage \( V_1 \)
**RL** = plate load resistor in ohms for stage $V_1$

**Rg** = grid resistance in ohms for stage $V_2$

**MID FREQUENCY EQUIVALENT CIRCUIT (CONSTANT CURRENT)**

8. The formula for gain at mid frequencies is as follows:

$$A_m = q_m R_{eq}$$

Where $A_m$ = mid frequency gain

$q_m$ = transconductance of $V_1$

$R_{eq}$ = equivalent resistance of the constant current equivalent circuit at mid frequencies

9. The formula for determining the Miller effect capacitance for high frequency consideration is as follows:

$$C_m = C_{qp} (A_m + 1)$$

Where $C_m$ = Miller capacitance

$A_m$ = mid frequency gain

$C_{qp}$ = capacitance between grid and plate of $V_1$

10. The input or looking in capacitance of $V_1$ can be determined by use of the formula shown below. This represents the shunt capacitance ($C_s$) of a single stage amplifier.

$$C_{in} = C_w + C_{qk} + C_{qp} (A_m + 1)$$

Where $C_{in}$ = input capacitance of $V_1$ or shunt capacitance ($C_s$)

$C_w$ = wiring capacitance

$C_{qk}$ = capacitance between grid and cathode of $V_1$

$C_{qp} (A_m + 1)$ = Miller capacitance of $V_1$
11. The total shunt capacitance of a two stage amplifier can be determined by the use of the following formula:

\[ C_s = C_{pk} + C_{qk} + C_{dp} (A_m + 1) + C_w \]

Where \( C_s \) = total shunt capacitance of a two stage amplifier

\( C_{pk} \) = plate to cathode capacitance of \( V_1 \)

\( C_{qk} \) = grid to cathode capacitance of \( V_2 \)

\( C_{dp} (A_m + 1) \) = Miller capacitance of \( V_2 \)

\( C_w \) = Wiring capacitance of the circuit. This can be dropped if not given.

12. The frequency at the upper half power point can be determined by the following formula:

\[ f_h = \frac{0.159}{(R_{eq})(C_s)} \]

Where \( f_h \) = frequency at upper half power point

\( R_{eq} \) = equivalent resistance of constant current equivalent circuit at mid frequency

\( C_s \) = total shunt capacitance of the amplifier used

13. The gain at the upper half power point can be determined by the following formula:

\[ A_h = (A_m) (0.707) \]

Where \( A_h \) = gain at the upper half power point

\( A_m \) = mid frequency gain
14. The formula used to determine the equivalent resistance of the constant voltage equivalent circuit at low frequency is as shown below.

\[ R_{eq}' = R_q + \frac{r_D R_L}{r_D + R_L} \]

Where \( R_{eq}' \) = equivalent resistance of the constant voltage equivalent circuit at low frequency

\( r_D \) = AC plate resistance in ohms for stage \( V_1 \)

\( R_L \) = plate load resistance in ohms for stage \( V_1 \)

\( R_q \) = grid resistor in ohms for stage \( V_2 \)

15. The frequency at the lower half power point can be determined by the following formula:

\[ f_L = \frac{0.159}{R_{eq}' C_C} \]

Where \( f_L \) = frequency at the lower half power point

\( R_{eq}' \) = equivalent resistance of the constant voltage equivalent circuit at low frequency

\( C_C \) = coupling capacitor between \( V_1 \) and \( V_2 \)

16. The gain at the lower half power point can be determined by the following formula:

\[ A_L = (A_m)(0.707) \]
Where $A_L$ = gain at lower half power point

$A_m =$ mid frequency gain

17. The bandwidth of an amplifier is determined by using the formula shown below.

$$BW = f_h - f_L$$

Where $BW =$ bandwidth of amplifier

$f_h =$ frequency at upper half power point

$f_L =$ frequency at lower half power point

---

**Amplifiers with Feedback**

1. The gain of an amplifier with feedback can be determined by the following formula:

$$A' = \frac{A}{1 - (± \beta A)}$$

Where $A'$ = gain with feedback

$A =$ gain without feedback

$\beta =$ amount of feedback

2. The percentage of feedback can be determined by the following formula:

$$|\beta| = \frac{R_2}{R_1 + R_2}$$

Where $|\beta|$ = the percentage of feedback

$R_1 =$ ohmic value of resistor $R_1$

$R_2 =$ ohmic value of resistor $R_2$
3. The voltage gain of a cathode follower is as follows:

\[ A = \frac{\mu R_k}{r_p + R_k (\mu + 1)} \text{ or } A = \frac{\mu}{\mu + 1} \]

Where \( A \) = voltage gain of the cathode follower
\( \mu \) = amplification factor (mu)
\( R_k \) = resistance of the cathode
\( r_p \) = AC plate resistance in ohms

4. The input capacitance of a cathode follower can be determined by the following formula:

\[ C_{in} = C_{gp} + C_{gk}(1 - A) \]

Where \( C_{in} \) = input capacitance of the cathode follower
\( C_{gp} \) = grid to plate capacitance
\( C_{gk}(1 - A) \) = anti-Miller effect

5. The input impedance of a conventional cathode follower is as follows:

\[ Z_{in} = R_g \]

Where \( Z_{in} \) = input impedance of the conventional cathode follower
\( R_g \) = grid resistor

6. The output impedance of a cathode follower can be determined by using the following formula:

\[ Z_o = \frac{R_k r_p}{r_p + R_k (\mu + 1)} \]

\[ Z_o = \frac{1}{\alpha m} \]

Where \( Z_o \) = output impedance in ohms
\( R_k \) = cathode resistor
\( r_p \) = AC plate resistance
\( \mu \) = amplification factor (mu)
7. The input impedance of a cathode follower with grid resistor returned to cathode circuit is as follows:

\[ Z_{in} = \frac{-R_g}{1-A} \frac{R_k - R_B}{R_k} \]

Where \( Z_{in} \) = input impedance of the long-tailed cathode follower
\( R_g \) = grid resistor
\( A \) = gain of the cathode follower
\( R_k \) = total cathode resistance
\( R_B \) = ton resistor of the two cathode resistors
OPERATIONAL AMPLIFIERS WITH FEEDBACK.

INVERTING AMPLIFIER

GAIN FORMULA \( A = \frac{Z_{fb}}{Z_{in}} \)

NON-INVERTING AMPLIFIER

GAIN FORMULA \( A = \frac{R_{fb}}{R_{1}} + 1 \)

SUMMING AMPLIFIER

\[
V_{out} = \frac{(-R_{fb})}{(R_{1})} V_{1} + \frac{(-R_{fb})}{(R_{2})} V_{2} + \frac{(-R_{fb})}{(R_{3})} V_{3} \ldots . . . .
\]

28056
TRANSISTORS

1. The direct current in a transistor can be related by using the following formula:

\[ I_e = I_b + I_c \]

Where \( I_e \) = emitter current
\( I_b \) = base current
\( I_c \) = collector current

2. The current amplification factor for a common base configuration (\( \alpha \)) can be determined using the following formula:

\[ \alpha = \frac{\Delta I_o}{\Delta I_e} \mid V_C \]

Where \( \alpha \) = current amplification factor in a common base configuration
\( I_o \) = collector current
\( I_e \) = emitter current
\( \Delta \) = a change of
\( V_C \) = collector voltage

3. The current amplification factor in a common emitter configuration can be determined by the following formula:

\[ \beta = \frac{\Delta I_c}{\Delta I_b} \mid V_C \]

Where \( \beta \) (beta) = current amplification factor in a common emitter configuration
\( I_c \) = collector current
\( I_b \) = base current
\( \Delta \) = a change of
\( V_C \) = collector voltage
4. The current amplification factor in a common collector configuration can be determined using the following formula:

\[ \gamma = \frac{\Delta I_e}{\Delta I_b} \mid V_c \]

Where \( \gamma \) (gamma) = current amplification factor in a common collector

\( I_e \) = emitter current

\( I_b \) = base current

\( \Delta \) = a change of

\( V_c \) = collector voltage

5. The percentage of change for a unijunction transistor sweep generator can be determined using the following formula:

\[ \% \ of \ change = \frac{V_p - V_d}{V_1 - V_d} \times 100 \]

Where \( V_p \) = Firing potential

\( V_d \) = Valley voltage

\( V_1 \) = Voltage that capacitor is charging toward

6. The percentage of change for a thyatron (soft tube) sweep generator can be determined using the following formula:

\[ \% \ of \ change = \frac{E_{\text{max}} - E_{\text{min}}}{E_{\text{app}} - E_{\text{min}}} \times 100 \]

7. The percent of discharge for pulse width calculation for multivibrators can be determined using the following formula:

\[ \% \ of \ discharge = \frac{\Delta e_p - C_0}{\Delta e_p} \times 100 \]

Where \( \Delta e_p = E_{\text{applied}} - E_{\text{min}} \)

\( C_0 = \) Bias necessary for the cutoff.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Common Base</th>
<th>Common Emitter</th>
<th>Common Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Amplification Factor</td>
<td>$\alpha = \frac{\Delta I_c}{\Delta I_e} \mid V_C$</td>
<td>$\beta = \frac{\Delta I_c}{\Delta I_b} \mid V_C$</td>
<td>$\gamma = \frac{\Delta I_e}{\Delta I_b} \mid V_C$</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Voltage Gain</td>
<td>$A_V = \frac{V_{out}}{V_{in}}$</td>
<td>$500 - 1500$</td>
<td>$300 - 1500$</td>
</tr>
<tr>
<td>Current Gain</td>
<td>$A_1 = \frac{I_{out}}{I_{in}}$</td>
<td>Low</td>
<td>Moderate - High</td>
</tr>
<tr>
<td>Power Gain</td>
<td>$A_p = \frac{P_{out}}{P_{in}}$</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Phase Relationship</td>
<td>Output and Input Voltage In Phase</td>
<td>Output and Input Voltage 180° Out-Of-Phase</td>
<td>Output and Input Voltage In Phase</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>50KHz - 1 MHz</td>
<td>5KHz - 50KHz</td>
<td>20KHz - 500KHz</td>
</tr>
<tr>
<td>Thermal Stability</td>
<td>Good</td>
<td>Poor</td>
<td>Fair</td>
</tr>
</tbody>
</table>

26073
Common-base amplifier

Current gain $A_1$: approximately 1

Voltage gain $A_V$: very high, 100-2500 typical

Power gain $A_p$: high; 100-2500 typical

Input impedance $Z_{ib}$: very low; 10⁻²⁻²₀₀ typical

Output impedance $Z_{ob}$: high; 10 k typical

Phase shift (input to output): 0°

**FORMULAS**

\[
A_v = \frac{v_{out}}{v_{in}}
\]

\[
A_i = \frac{i_{out}}{i_{in}}
\]

\[
A_p = \frac{p_{out}}{p_{in}} = A_v \times A_i
\]

\[
\alpha = \frac{I_C}{I_E} = \frac{i_C}{i_E}
\]

\[
h_{fb} = \alpha
\]

\[
h_{ib} = \frac{\Delta V_{BE}}{\Delta I_E} \approx \frac{0.025 \text{ V}}{I_E}
\]
DEFINITIONS

Input signal-variations in input voltage or current (AC portion of input).
Output signal-variations in output voltage or current (AC portion of output).
Reproduction-duplication of input signal by an amplifier.
Amplification-enlargement of input signal by an amplifier.
Voltage (current, power) gain-ratio of output signal voltage (current, power)
to input signal voltage (current, power).
Impedance-effective AC resistance.
Input (output) impedance-impedance seen looking into the input (output)
terminals of a circuit.

$h_{f}$-transistor's forward AC current gain between input and output, and
configuration.

$h_{i}$-transistor's AC input resistance, any configuration.

Q point-quiescent operating point; DC bias values of amplifier voltages and
currents.

(alpha)-AC current gain between emitter and collector.

$h_{fb}$-forward AC current gain in common-base configuration; same as
$h_{ib}$-AC input resistance in common-base configuration.

$Z_{in}$-total input impedance of Com.-B amplifier.

$Z_{ob}$-total output impedance of Com.-B amplifier.

$r_{ob}$-transistor's AC output resistance in Com-B configuration. Usually can be
neglected.

AC load line-load line passing through Q point and with slope determined by
$R_{C}$ $R_{L}$.

Clipping-distortion of output waveform when transistor is driven out of
active region.
COMMON-EMITTER AMPLIFIER: SUMMARY

The important characteristics of the Com.-E transistor amplifier are summarized:

Current gain $A_t$: $\beta$, much greater than 1
Voltage gain $A_v$: very high; 100-2500
Power gain $A_p$: extremely high; 20,000 is typical
Input impedance $Z_{ie}$: moderately high; 1 k is typical
Output impedance $Z_{oe}$: moderately high; 2 k is typical
Phase shift: $180^\circ$ in mid-frequency range

FORMULAS

$$\beta = h_{fe} = \frac{\Delta I_C}{\Delta I_R} = \frac{i_C}{i_B}$$

$$h_{ie} = \frac{V_{BE}}{I_R} \quad | \quad V_{CE} = \text{constant}$$

$$h_{oe} \approx h_{fe} h_{ib}$$

$$r_{oe} = \frac{1}{h_{oe}} = \frac{V_{CE}}{I_C} \quad | \quad I_B = \text{constant}$$

$$V_R \approx \frac{R_1}{R_1 + R_2} \quad V_{CC} \text{ when } R'_E \geq 20 R_{TH}$$

$$X_C \ll h_{ib} \text{ for effective bypassing}$$
DEFINITIONS

\( \beta (h_{fe}) \)-AC forward current gain in common-emitter configuration.

\( h_{ie} \)-transistor AC input resistance in common-emitter configuration.

\( Z_{ie} \)-Com.E amplifier input impedance.

\( Z_{oe} \)-Com.-E amplifier output impedance.

\( r_{oe} \)-transistor's AC output resistance in common-emitter configuration.

\( h_{oe} \)-transistor's AC output conductance in common-emitter configuration.

Q point stability-variation of Q point with changes in temperature and with transistor replacement.

Base-current bias-method of biasing a common-emitter amplifier with a constant base current.

Base-voltage bias-biasing a Com.-E amplifier with a constant base-to-ground voltage.

Emitter bypass capacitor-used in base voltage bias circuit to ground the emitter for AC.
OSCILLATORS

1. The frequency of an LC oscillator is determined by the values of L and C in the frequency determining tank or series resonant circuit.

\[ f_0 = \frac{1}{2 \pi \sqrt{LC}} = 0.159 \sqrt{\frac{L}{C}} \]

Where \( f_0 \) = frequency of the oscillator output in hertz
\( L \) = inductance in henrys
\( C \) = capacitance in farads

2. The output frequency of a phase shift oscillator may be determined by the following formula:

\[ f_0 = \frac{1}{2 \pi RC \sqrt{\beta}} \quad f_0 = \frac{1}{2 \pi RC \sqrt{10}} \]

(3 section only) (4 section only)

Where \( f_0 \) = frequency of the oscillator output in hertz
\( R \) = value of the phase shift resistor in ohms
\( C \) = capacitance of the phase shift capacitor in farads

3. The output frequency of a Wein bridge oscillator is determined by the RC values of the reactive side of the bridge. This is shown by the following formula:

\[ f_0 = \frac{1}{2 \pi \sqrt{R_1 C_1 R_2 C_2}} \]

Where \( f_0 \) = frequency of the oscillator output in hertz
\( R_1 \) = resistance of the series RC branch in ohms
\( C_1 \) = capacitance of the series branch in farads
\( R_2 \) = resistance of the parallel RC branch in ohms
\( C_2 \) = capacitance of the parallel RC branch in farads
4. When the value of $R_1 \ C_1$ is equal to $R_2 \ C_2$ in a Wein Bridge oscillator the following simplified formula may be used.

$$f_0 = \frac{1}{2 \pi \ R_1 \ C_1}$$

Where $f_0 = \text{frequency of the oscillator output.}$

$R_1 = \text{resistance in ohms of the series RC branch (equal to resistance of the parallel RC branch).}$

$C_1 = \text{capacitance in farads of the series RC branch (equal to capacitance of the parallel RC branch).}$
PULSES

1. The fundamental sine wave component of a pulse can be determined by using the following formula:

$$F_{fr} = \frac{1}{2 \text{PW}}$$

Where $f_{fr}$ = the fundamental frequency in hertz

$\text{PW}$ = pulse width in seconds

2. The highest harmonic content in a pulse, square wave or rectangular wave can be determined using the following formula:

$$f_h = \frac{1}{2 \text{R}_t}$$

Where $f_h$ = highest harmonic of the fundamental sinewave frequency

$\text{R}_t$ = rise time of the pulse, square wave or rectangular wave in seconds

3. The relationship between the parameters of a pulse are shown by the following equations:

$$\frac{\text{P}_{av}}{\text{P}_{pk}} = \frac{\text{PW}}{\text{PRT}}$$

Where $\text{P}_{av}$ = average power in watts

$\text{P}_{pk}$ = peak power in watts

$\text{PRT}$ = pulse recurrence time in seconds

$\text{PW}$ = pulse width in seconds
4. The pulse recurring frequency (PRF) can be determined if the pulse recurring time (PRT) is known, or conversely, the PRT can be determined if the PRF is known.

\[
PRF = \frac{1}{PRT}
\]

\[
PRT = \frac{1}{PRF}
\]

Where \( PRF \) = pulse recurring frequency in hertz

\( PRT \) = pulse recurring time in seconds

5. The duty cycle of a pulse is the ratio of the on time to total time for one pulse. It can be determined from the following formula:

\[
\text{Duty cycle} = \frac{PW}{PRT}
\]

Where \( PW \) = pulse width or "on" time in seconds

\( PRT \) = pulse recurring time in seconds
1. The arithmetic mean of a group of readings can be determined by using the following formula:

\[ a_m = \frac{\sum R_e}{N} \]

Where \( a_m \) = arithmetic mean
\( \sum R_e \) = the sum of all readings
\( N \) = number of readings

2. The standard deviations of a group of readings can be determined by using the following formula:

\[ SD = \sqrt{\frac{\sum \chi^2}{N}} \]

Where \( SD \) = standard deviation
\( \sum \) = the sum of
\( \chi^2 \) = square of the individual deviations from the arithmetic mean
\( N \) = number of readings

3. Small factors of correction or error are often stated in PPM (parts per million) as well as % (percentage). The mathematical relationships, as well as the conversion values, are shown below:

1 ppm (of one unit) = \( \frac{1}{1000000} \) or .000001 units.

1% (of one unit) = \( \frac{1}{100} \) or .01 units.

To change percentage to parts per million:

\[ \text{ppm} = \% \times (10,000) \].

To change parts per million to percentage:

\[ \% = \text{ppm} \times (.0001) \].
4. Correction, Correction Factors, and Error

a. Definitions:

Nominal: The value specified by the manufacturer; the units value an item should be.

Actual: The certified value; the value in units an item is.

Correction: The value in units that, when added algebraically to the nominal, will result in the actual \( N + C = A \).

Correction Factor: Correction expressed in either percentage or parts per million.

Error: The difference the Actual is from the Nominal \( E = N - A \). (The error will always carry the same numerical value and opposite polarity of its equivalent correction or correction factor.)

\[
C = A - N \quad E(\%) = \frac{N - A}{A} \times 100
\]

\[
CF(\%) = \frac{C}{N} \times 10^2 \quad CF_{ppm} = \frac{C}{N} \times 10^6
\]

Where:

\( A \) = Actual

\( N \) = Nominal

\( C \) = Correction (in units)

\( CF(\%) \) = Correction Factor expressed in percentage

\( CF_{ppm} \) = Correction Factor expressed in parts per million

\( E(\%) \) = Error in percentage

b. Remember these simple rules:

1. \( N + C = A \)
2. Correction and error are always equal in magnitude, but opposite in sign.
3. Correction factors must be converted to the same units as the nominal before they can be added.

5. \( e_r = \frac{M - T}{T} \)

Where:

\( e_r \) = relative error

\( M \) = measured value

\( T \) = True value
\[ e_r(\%) = \frac{M - T}{T} \times 100 \]

Where:  
- \( e_r(\%) \) = percent relative error  
- \( M \) = measured value  
- \( T \) = true value

a. The true value is usually replaced by the accepted or nominal value because the true value is never exactly known.

CLASSIFICATION OF MEASUREMENT ERRORS
TRANSFER RESISTANCE STANDARDS

Formulas for using the SR1010 resistance boxes as transfer standards:

\[ R_s = 10R \left( 1 + \frac{\Delta_{\text{ave}}}{10^6} \right) \]

\[ R_p = \frac{R}{10} \left( 1 + \frac{\Delta_{\text{ave}}}{10^6} \right) \]

\[ R_{sp} = R \left( 1 + \frac{\Delta_{sp}}{10^6} \right) \]

\[ \Delta_{\text{ave}} = \frac{\text{total deviation}}{\text{number of units}} \]

\[ \Delta d = R_{sp} - R_{10} \]

\[ \Delta_{sp} = \Delta_{\text{ave}} + \frac{\Delta d}{10} \]

- \( R_s \) = series resistance of 10 nominally equal resistances
- \( R_p \) = parallel resistance of 10 nominally equal resistances
- \( R_{sp} \) = series-parallel resistances of 9 nominally equal resistances
- \( R_{10} \) = resistance of the 10th resistor
- \( R \) = the nominal value of one resistor
- \( \Delta_{\text{ave}} \) = the average deviation from nominal of 10 nominally equal resistors in either series or parallel (expressed in ppm)
- \( \Delta d \) = the difference between \( R_{sp} \) and \( R_{10} \) (expressed in ppm)
- \( \Delta_{sp} \) = the deviation from nominal of 9 nominally equal resistors in series-parallel (in ppm)
Temperature Correction for Thomas 1-ohm Std:

\[ R_t = R_{25} \left[ 1 + \alpha(t - 25) + \beta(t - 25)^2 \right] \]

- \( R_t \) = true resistance at ambient temperature
- \( R_{25} \) = absolute resistance at 25°C
- \( \alpha \) = alpha (always positive) in units
- \( \beta \) = beta (always negative) in units
- \( t \) = ambient temperature (in degrees centigrade)

\[ C_t = C_{25} + \alpha(t - 25) + \beta(t - 25)^2 \]

- \( C_t \) = correction factor in ppm for true resistance
- \( C_{25} \) = correction factor in ppm at 25°C
- \( \alpha \) = alpha (+) in ppm
- \( \beta \) = beta (-) in ppm
- \( t \) = ambient temperature in degrees centigrade
OSCILLOSCOPES

1. The rise time of an oscilloscope can be determined if the rise time of the oscilloscope and the rise time of the preamplifier are known. This is shown by the formula:

\[ R_{ts} = \sqrt{R_{tra}^2 + R_{tpa}^2} \]

Where \( R_{ts} \) = combined rise time of the oscilloscope vertical amplifiers and preamplifier plug-in
\( R_{tra} \) = rise time of the vertical amplifier of the oscilloscope
\( R_{tpa} \) = rise time of the preamplifier plug-in

NOTE: The values of \( R_{tra} \) and \( R_{tpa} \) are indicated on their respective panels.

2. In most applications the measured rise is considered to be the true rise time. However, as the measured rise time begins to approximate the rise time of the oscilloscope \( (R_{ts}) \) the following formula is used.

\[ R_{tt} = \sqrt{R_{tm}^2 - R_{ts}^2} \]

Where \( R_{tt} \) = true rise time
\( R_{tm} \) = measured rise time
\( R_{ts} \) = combined rise time of the oscilloscope-preamplifier combination

NOTE: It is recommended that this formula be used in this course when the measured rise time is 0.1 micro seconds or less.
3. The upper 3dB limit of frequency response of an oscilloscope or amplifier can be determined by using the following formula:

\[ UFR = \frac{.35}{R_t} \]

Where \( UFR \) = upper end frequency response (3dB limit) in hertz
\( R_t \) = rise time in seconds

.35 = a constant value arrived at as a result of empirical discovery

4. The phase angle between two signals of the same frequency, can be determined by measuring the amplitude of the Lissajou pattern at two points on the Y axis and applying the following formula:

\[ \text{Sine } \theta = \frac{Y_1}{Y_2} \]

Where \( \text{Sine } \theta \) = phase angle between the two signals
\( Y_1 \) = Y axis intercept 1, taken at the very center of the pattern in centimeters
\( Y_2 \) = Y axis intercept 2, which represents the maximum amplitude of the pattern in centimeters

NOTE: Readings made by this method are ambiguous, that is, there are two possible answers for each pattern. The problem can be resolved if the frequencies compared, are low enough so that the direction of rotation of the pattern can be observed.

5. The percentage of amplitude modulation can be determined a number of ways by using an oscilloscope. These methods compare the maximum voltage amplitudes with the minimum voltage amplitudes. The following formula can be used to determine the percentage of amplitude modulation.
% of AM = \( \frac{H_1 - H_2}{H_1 + H_2} \times 100 \)

Where % of AM = percentage of amplitude modulation

\( H_1 \) = largest dimension in centimeters

\( H_2 \) = smallest dimension in centimeters

**DISTORTION**

The total distortion of a sine wave caused by a number of harmonics can be determined by the following formula:

\[
TD = \sqrt{H_2^2 + H_3^2 + H_4^2 + \ldots}
\]

Where TD = total distortion in percentage

\( H_2 \) = percentage of distortion caused by the second harmonic

\( H_3 \) = percentage of distortion caused by the third harmonic

\( H_4 \) = percentage of distortion caused by the fourth harmonic

**PHASE ANGLE READINGS**

1. The phase angle between two signals of the same frequency can be determined using the Phase Unit plug-in of the electronic counter. If the input signal frequency is not 400 Hz ± 4 Hz, the following formula is used to determine the phase angle.

\[
\Theta = \frac{P_{meas}}{P_{tot}} \times 360
\]

Where \( \Theta \) = phase angle in degrees

\( P_{meas} \) = time interval measured between the same point on two signals being compared

\( P_{tot} \) = total time required for a period of either signal (both are the same)

360 = a factor to convert the time ratio to degrees
LOGIC GATES
EQUIVALENT GATES.

A B C
+AND

A B C
-AND

`- N  A N D

A B C
+ N A N D

A B C
- N A N D

A B C
+ N O R

A B C
- N O R

A B
+ I N V E R T E R S

A B
- I N V E R T E R S

26059

HO G3ARR32430 902-1
115
| AND | OR |  
|-----|----|---
| A   | A  | H H H H  
| B   | B  | H H L L  
|     | X  | H L L L  
|     | X  | L H L L  
|     | X  | L L L L  
| A   | A  | H H L L  
| B   | B  | H L H H  
|     | X  | L H H L  
|     | X  | L L H H  
|     | X  | L L L L  
| A   | A  | H H L L  
| B   | B  | H L H L  
|     | X  | L H H L  
|     | X  | L L H L  
|     | X  | L L L L  
| A   | A  | H H L L  
| B   | B  | H L H H  
|     | X  | L H H L  
|     | X  | L L H L  
|     | X  | L L L L  
| A   | A  | H H H H  
| B   | B  | H L L L  
|     | X  | L H L L  
|     | X  | L L L L  
|     | X  | L L L L  
| A   | A  | H H H L  
| B   | B  | H L H L  
|     | X  | L H L L  
|     | X  | L L H L  
|     | X  | L L L L  

26060
MICROWAVE

1. Wavelength is the distance along the direction of propagation between two points which are in phase, on adjacent waves. It is symbolized by the Greek letter lambda (\(\lambda\)). It can be determined by the following formulas.

\[
\lambda (\text{meters}) = \frac{300 \times 10^6}{f (\text{hertz})}
\]

\[
\lambda (\text{cms}) = \frac{300 \times 10^8}{f (\text{hertz})}
\]

\[
\lambda (\text{cms}) = \frac{30}{f (\text{gigahertz})}
\]

\[
\lambda (\text{feet}) = \frac{982.08 \times 10^6}{f (\text{hertz})}
\]

\[
\lambda (\text{miles}) = \frac{186,000}{f (\text{hertz})}
\]

Where \(\lambda\) = wavelength in meters, centimeters, feet or miles

\(f\) = frequency in hertz

2. The velocity constant (K) is the ratio of the velocity of propagation, along the two wire or coaxial line, to velocity in free space, which is the same as the velocity of light.

\[
K = \frac{V_g}{V_o} = \frac{\lambda g}{\lambda o}
\]

Where \(K\) = velocity constant

\(V_g\) = velocity of propagation in meters per second

\(V_o\) = velocity of light in meters per second

\(\lambda o\) = wavelength in free space

\(\lambda g\) = wavelength on a transmission line
3. The wavelength on a two-wire transmission line or coaxial line can be determined if the velocity constant is indicated and the frequency is known.

\[ \lambda = \frac{K V_o}{f} \]

Where:
- \( \lambda \) = wavelength in meters in a transmission line
- \( V_o \) = velocity of light in meters
- \( f \) = frequency of operation in hertz
- \( K \) = velocity constant of the transmission line

4. The characteristic impedance in ohms of a lossless transmission line can be determined by using the following formula:

\[ Z_o = \sqrt{\frac{L}{C}} \]

Where:
- \( Z_o \) = characteristic impedance of a lossless line in ohms
- \( L \) = inductance per unit length in henrys
- \( C \) = capacitance per unit length in farads

5. The characteristic impedance of a coaxial transmission line may be found using the following formula:

\[ Z_o = \frac{138}{\sqrt{\epsilon'}} \log \frac{D}{d} \]

Where:
- \( Z_o \) = characteristic impedance in ohms
- \( D \) = inside diameter of the outer conductor
- \( d \) = outside diameter of the inner conductor
- \( \epsilon' \) = dielectric constant
- \( \log \) = logarithm of the base 10
- 138 = a constant for coaxial lines

6. The characteristic impedance in ohms of a two-wire transmission line may be found by using the following formula:

\[ Z_o = \frac{276}{\sqrt{\epsilon'}} \log \frac{2D}{d} \]
Where $Z_0$ = characteristic impedance in ohms

$D$ = center to center spacing between conductors

$d$ = diameter of the conductors

$\log$ = logarithm of the base 10

276 = a constant for a two-wire line

$\varepsilon' = $ dielectric constant

7. The voltage maximums and minimums of standing waves, as well as $E_i$ and $E_r$, can be determined by the following formulas.

$$E_{\text{max}} = E_i + E_r$$
$$E_{\text{min}} = E_i - E_r$$

$$E_i = \frac{E_{\text{max}} + E_{\text{min}}}{2}$$
$$E_r = \frac{E_{\text{max}} - E_{\text{min}}}{2}$$

Where $E_{\text{max}} = $ maximum voltage points (loops)

$E_{\text{min}} = $ minimum voltage point (node)

$E_i = $ incident voltage

$E_r = $ reflected voltage

8. The standing wave ratio can be determined by the following formula:

$$\text{SWR} = \frac{E_{\text{max}}}{E_{\text{min}}} = \frac{I_{\text{max}}}{I_{\text{min}}} = \frac{Z_{\text{max}}}{Z_{\text{min}}} = E_i + E_r = \sqrt{\frac{P_{\text{max}}}{P_{\text{min}}}} = \sqrt{\frac{P_i}{P_r}} + \sqrt{\frac{P_r}{P_i}}$$

$$E_{\text{max}} = E_i + E_r$$

$$E_{\text{min}} = E_i - E_r$$

$$P_{\text{max}} = \sqrt{P_i} + \sqrt{P_r}$$

$$P_{\text{min}} = \sqrt{P_i} - \sqrt{P_r}$$
Where SWR = standing wave ratio

\[ E_{\text{max}} = \text{maximum voltage (loop)} \]
\[ E_{\text{min}} = \text{minimum voltage (node)} \]
\[ I_{\text{max}} = \text{maximum current (loop)} \]
\[ I_{\text{min}} = \text{minimum current (node)} \]
\[ Z_{\text{max}} = \text{maximum impedance point on a line} \]
\[ Z_{\text{min}} = \text{minimum impedance point on a line} \]
\[ E_i = \text{incident voltage} \]
\[ E_r = \text{reflected voltage} \]
\[ P_{\text{max}} = \text{maximum power} \]
\[ P_{\text{min}} = \text{minimum power} \]
\[ P_i = \text{incident power} \]
\[ P_r = \text{reflected power} \]

9. The voltage standing wave ratio of small discontinuities may be found by sliding load method and using the following formula:

\[ VSWR_L \text{ or } VSWR_D = \sqrt{VSWR_{\text{max}}} (VSWR_{\text{min}}) \]

or

\[ \sqrt{\frac{VSWR_{\text{max}}}{VSWR_{\text{min}}}} \]

Where

\[ VSWR_L = \text{voltage standing wave ratio of the moving load} \]
\[ VSWR_D = \text{voltage standing wave ratio of the discontinuity} \]
\[ VSWR_{\text{max}} = \text{VSWR when the reflections add in phase} \]
\[ VSWR_{\text{min}} = \text{VSWR when the reflections are out of phase} \]

NOTE: If the reflection of the moving load is unknown the measurement must be repeated with another load.
10. A VSWR greater than 10:1 can be measured by the double minimum method and its value determined by the following formula:

\[
VSWR = \frac{\lambda g}{\pi (d_1 - d_2)}
\]

Where \( VSWR \) = voltage standing wave ratio

\( \lambda g \) = wavelength on the transmission line or waveguide

\( d_1 \) = first 3 dB point

\( d_2 \) = second 3 dB point

\( \pi \) = 3.14

11. The VSWR of a purely resistive load can be determined in terms of the line characteristic impedance (\( Z_0 \)) and load resistance.

Where \( R_L \) is greater than \( Z_0 \), \( VSWR = \frac{R_L}{Z_0} \)

Where \( Z_0 \) is greater than \( R_L \), \( VSWR = \frac{Z_0}{R_L} \)

Where \( VSWR \) = voltage standing wave ratio

\( Z_0 \) = characteristic impedance

\( R_L \) = Load resistance
12. The reflection coefficient magnitude is the ratio of the voltage of the reflected wave to the voltage of the incident wave. It is symbolized by the Greek lower case letter rho (\( \rho \)) or by the absolute value of gamma. The following formulas can be used to determine the reflection coefficient magnitude.

\[
\rho = \left| \Gamma \right| = \frac{E_r}{E_i} = \frac{I_r}{I_i} = \frac{P_r}{P_i}
\]

Where \( \left| \Gamma \right| = \text{reflection coefficient magnitude} = \rho \)

- \( E_r \) = reflected voltage
- \( E_i \) = incident voltage
- \( I_r \) = reflected current
- \( P_r \) = reflected power
- \( P_i \) = incident power

13. The reflection coefficient magnitude can be determined in terms of the line characteristic impedance and load resistance (for purely resistive loads).

\[
\rho = \left| \Gamma \right| = \frac{Z_o - R_L}{R_L + Z_o}
\]

Where \( R_L \) is greater than \( Z_o \)

\[
\rho = \left| \Gamma \right| = \frac{R_L - Z_o}{R_L + Z_o}
\]

Where \( \left| \Gamma \right| = \text{reflection coefficient magnitude} \)

- \( Z_o \) = characteristic impedance of the line
- \( R_L \) = load resistance

14. The VSWR can be determined if the reflection coefficient magnitude is known, and conversely, the reflection coefficient magnitude can be determined if the VSWR is known. This is shown in the following formula.
VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + \rho}{1 - \rho}

\rho = |\Gamma| = \frac{VSWR - 1}{VSWR + 1}

Where VSWR = voltage standing wave ratio
\rho = |\Gamma| = reflection coefficient magnitude

15. The percentage of reflected power (\%Pr) can be determined by using the following formulas.

\%Pr = 100 \left(\frac{VSWR - 1}{VSWR + 1}\right)^2 = |\Gamma|^2 (100) = 100 \left(\frac{E_r}{E_i}\right)^2

Where \%Pr = percentage of reflected power
VSWR = voltage standing wave ratio
|\Gamma| = reflection coefficient magnitude = \rho
E_r = reflected voltage
E_i = incident voltage

16. A helpful equation of ratio and proportion can be used to determine total power from a source, the power dissipated in the microwave line, or the percentage of the power dissipated.

\frac{100\%}{\%Pd} = \frac{P_i}{P_a}

Where P_i = total power of the source in watts
P_a = measured or computed power of the load
\%Pd = percentage of total power dissipated.
17. To determine the actual value of impedance from the normalized value the following formula is used:

\[ Z_A = Z_o \tan \theta \]

Where \( Z_A \) = actual impedance value at a given point in ohms  
\( Z_o \) = characteristic impedance  
\( \tan \theta \) = tangent of the phase angle which is the normalized value of impedance

NOTE: This formula can only be used where the load is an open, short or pure reactance.

18. To determine \( Z_o \) in ohms of a quarter wave matching transformer the following formula is used:

\[ Z_o = \sqrt{Z_{\text{in}} Z_{\text{out}}} \]

Where \( Z_o \) = characteristic impedance of a quarter wave matching transformer  
\( Z_{\text{in}} \) = characteristic impedance of the input transmission line  
\( Z_{\text{out}} \) = characteristic impedance of the output transmission line

19. To determine the effective efficiency of a working bolometer mount the following equation is used.

\[ \frac{\eta_e(\text{std})}{\eta_e(\text{ti})} = \frac{P_{\text{std}}}{P_{\text{ti}}} \]

Where: \( \eta_e(\text{std}) \) = known efficiency of the standard bolometer  
\( \eta_e(\text{ti}) \) = computed efficiency of the test bolometer (test instrument)  
\( P_{\text{std}} \) = absorbed power of the standard  
\( P_{\text{ti}} \) = absorbed power of the test instrument (bolometer)
20. To determine the calibration factor of a bolometer mount, the following formula is used.

\[ K_b = \eta e \left( 1 - |\Gamma_m|^2 \right) \]

Where \( K_b \) = calibration factor of a bolometer mount

\( |\Gamma_m| \) = reflection coefficient magnitude of the bolometer mount

21. The cutoff wavelength of a rectangular waveguide in its dominant mode may be determined by using the following formula.

\[ \lambda_{co} = 2a \]

Where \( \lambda_{co} \) = cutoff wavelength for a rectangular waveguide in centimeters

\( a \) = width of the inner wide dimension in centimeters

22. The cutoff (\( f_{co} \)) of a rectangular waveguide may be determined if the cutoff wavelength is known by using the following formula.

\[ f_{co} = \frac{V_0}{\lambda_{co}} \]

Where \( f_{co} \) = cutoff frequency of the rectangular waveguide in hertz

\( V_0 \) = velocity of light in centimeters per second

\( \lambda_{co} \) = cutoff wavelength in centimeters

23. Free space wavelength (\( \lambda_0 \)) can be computed if the cutoff wavelength of the waveguide and wavelength on the waveguide is known, by using the following formulas.

\[ \lambda_0 = \lambda_{co} \left[ \cos \left( \tan^{-1} \frac{\lambda_{co}}{\lambda_g} \right) \right] \]

\[ g = \frac{\lambda_0}{\sqrt{1 + \left( \frac{\lambda_g}{\lambda_{co}} \right)^2}} \]
Where $\lambda_0 =$ free space wavelength in centimeters

$\lambda_{co} =$ cutoff wavelength of the waveguide in centimeters

$\lambda_g =$ wavelength in centimeters (usually measured)

24. Waveguide wavelength can be computed if the free space, and cutoff wavelength are known. The following formulas can be used to compute waveguide wavelength.

$$\lambda_g = \frac{\lambda_{co}}{\tan(\cos^{-1}\frac{\lambda_0}{\lambda_{co}})}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_{co}}\right)^2}}$$

Where $\lambda_g =$ waveguide wavelength

$\lambda_0 =$ free space wavelength

$\lambda_{co} =$ cutoff wavelength

25. The phase velocity of a waveguide can be determined by using the following formula.

$$V_{ph} = \frac{V_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_{co}}\right)^2}}$$

Where $V_{ph} =$ phase velocity on a waveguide in meters per second

$V_0 =$ velocity of light in meters per second

$\lambda_0 =$ free space wavelength in meters

$\lambda_{co} =$ cutoff wavelength in meters
26. The group velocity on a waveguide can be determined by using the following formula.

\[ V_g = V_o \sqrt{1 - \frac{\lambda_0}{\lambda_{co}}^2} = \frac{V_o}{\sqrt{1 + \left( \frac{\lambda_0}{\lambda_{co}} \right)^2}} \]

Where
- \( V_o \) = group velocity in meters per second
- \( \lambda_0 \) = free space wavelength in meters
- \( \lambda_{co} \) = cutoff wavelength of the waveguide in meters
- \( \lambda_q \) = guide wavelength
- \( V_o \) = velocity of propagation in free space

27. The velocity of light can be expressed as a function of group and phase velocities as indicated below.

\[ V_o = \sqrt{V_g \times V_{ph}} \]

Where
- \( V_o \) = velocity of light in meters per second
- \( V_g \) = group velocity in meters per second
- \( V_{ph} \) = phase velocity in meters per second

28. The gain or attenuation of a device may be expressed in decibels using the following formula.

\[ dR = 10 \log_{10} \frac{P_L}{P_S} \]

Where
- \( dR \) = gain in decibels
- \( P_L \) = the larger of the two power levels
- \( P_S \) = the smaller of the two power levels
- \( \log_{10} \) = logarithms of the base 10

NOTE: If there was a gain in the device, \( P_L \) would represent the output. If there was an attenuation in the device, \( P_L \) would represent the input.
29. The attenuation in a "waveguide below cutoff" attenuator (circular TE_{11} mode) is as follows:

\[ \alpha = \frac{54.6}{\lambda c_0} \sqrt{1 - \left( \frac{\lambda c_0}{\lambda} \right)^2} \]

Where \( \alpha \) = attenuation per unit length in dBs
\( c_0 \) = cutoff wavelength
\( \lambda \) = free space wavelength

or if \( \lambda \) is much greater than \( \lambda c_0 \)

\[ \alpha = \frac{54.6}{\lambda c_0} \]

Where \( \alpha \) = attenuation per unit length in dBs
\( \lambda c_0 \) = cutoff wavelength (3.42 times the guide radius)

30. The coupling factor of a directional coupler can be computed if the input power to the main arm and the output power of the auxiliary arm are known.

\[ CF_{dB} = 10 \log \frac{P_i}{P_0} \]

Where \( CF_{dB} \) = coupling factor in dB
\( P_i \) = power applied to the input of the main arm
\( P_0 \) = power output at the auxiliary arm
\( \log \) = logarithm of the base 10

31. The attenuation of a rotary vane attenuator is a function of the angular position of the resistive card. This is shown by the following formula.

\[ dB = 40 \log \frac{1}{\cos \theta} \]

Where \( dB \) = attenuation in decibels
\( \cos \theta \) = cosine of the angular position of the resistive cards
\( \log \) = logarithm of the base 10
32. The ratio between the standing wave maximum and standing wave minimum may be used to express VSWR.

\[ VSWR_{dB} = 20 \log \frac{E_{\text{max}}}{E_{\text{min}}} = 20 \log \text{VSWR} \]

Where \( VSWR_{dB} \) = ratio of the standing wave maximum to standing wave minimum in decibels

\( E_{\text{max}} \) = maximum voltage

\( E_{\text{min}} \) = minimum voltage

\( \text{VSWR} \) = voltage standing wave ratio

\( \log \) = logarithm of the base 10

33. The mismatch loss in decibels can be determined by using the following formula.

\[ L_{\text{mm}} = 10 \log \left( \frac{1}{(1 - |\Gamma|)^2} \right) = 10 \log \frac{1}{1 - \rho^2} \]

Where \( L_{\text{mm}} \) = mismatch loss in decibels

\( |\Gamma| \) = absolute value of the reflection coefficient = \( \rho \)

\( \log \) = logarithm of the base 10

34. The return loss in decibels may be determined by using the following formula

\[ LR_{dB} = 10 \log \frac{P_i}{P_r} = 20 \log \frac{E_i}{E_r} = 20 \log \frac{1}{\rho} = 10 \log \frac{1}{\rho^2} \]

Where \( LR_{dB} \) = return loss in decibels

\( \log \) = logarithm of the base 10

\( P_i \) = incident power in watts

\( P_r \) = reflected power in watts

35. The uncertainty in decibels due to a mismatch between the source and load can be determined by the following formula.

\[ \text{dB} = 10 \log \left( 1 \pm \frac{1}{|\Gamma 1| |\Gamma 2|} \right)^2 \]
Where \( d\theta \) = uncertainty in decibels due to mismatch

\[ |\Gamma_1| = \text{reflection coefficient magnitude at the generator end.} \]

\[ |\Gamma_2| = \text{reflection coefficient magnitude at the load end.} \]

36. The frequency applied to the waveguide can be calculated once the free space wavelength has been found using the following formula.

\[ f = \frac{V_0}{\lambda_0} \]

Where \( f \) = frequency in hertz applied to the waveguide

\( V_0 \) = velocity of light in meters

\( \lambda_0 \) = free space wavelength in meters

37. The time delay caused by one section of an artificial transmission line, or the total delay caused by a number of sections, can be determined by using the following formulas.

\[ T_d = \sqrt{LC} \]

\[ T_{dt} = N \sqrt{LC} \]

Where \( T_d \) = time delay in seconds

\( T_{dt} \) = time delay total in seconds

\( L \) = inductance in henrys per section

\( C \) = capacitance in farads per section

\( N \) = number of sections

38. The following formulas are used for determining an unknown frequency applied to the transfer oscillator. The two adjacent harmonics are designated \( F_1 \) and \( F_2 \). The highest of the two is \( F_1 \).

\[ f = H_1 F_1, \quad f = H_2 F_2 \]

\[ H_1 = \frac{F_2}{F_1 - F_2}, \quad H_2 = \frac{F_1}{F_1 - F_2} \]
Where \( f \) = input frequency in hertz

\( H_1 \) = harmonic number \( F_1 \)

\( H_2 \) = harmonic number of \( F_2 \)

\( F_1 \) = the highest of the two adjacent beat frequencies in hertz

\( F_2 \) = the lower of the two adjacent beat frequencies in hertz

39. The width of the main lobe of a pulse modulated RF spectrum as viewed on the spectrum analyzer may be computed using the following formula.

\[
MLW = \frac{2}{PW}
\]

Where \( MLW \) = main lobe width in hertz

\( PW \) = pulse width in seconds, of the modulating signal

40. The general expression for power transfer between a source and a load of reflection coefficients \( |\Gamma_s| \) and \( |\Gamma_l| \) is:

\[
\frac{(1 - |\Gamma_s|^2) (1 - |\Gamma_l|^2)}{(1 \pm |\Gamma_s| |\Gamma_l|)^2}
\]
MICROWAVE NOISE EQUATIONS

1. The value of the "average noise voltage squared" may be determined using the following formula.

$$\frac{2}{n} = 4KTR$$

Where $$\frac{2}{n}$$ = average noise voltage squared

$$K =$$ Boltzmann's constant which relates temperature to energy. It is equal to 1.38 x 10^{-23} joules per degree Kelvin

$$T =$$ temperature of the network at room temperature

$$R =$$ resistance in ohms

$$B =$$ frequency bandwidth in hertz

2. The available noise power may be determined by the use of the following formulas.

$$P_n = \left| \frac{e_n}{4R} \right|^2$$

$$P_n = KTB$$

Where $$P_n$$ = noise power in watts

$$\left| \frac{2}{e_n} \right|$$ = the absolute value of the average voltage

$$R =$$ resistance in ohms

$$K =$$ Boltzmann's constant which relates temperature to energy. It is equal to 1.38 x 10^{-23} joules per degree Kelvin

$$T =$$ temperature of the network at room temperature

$$B =$$ frequency bandwidth in hertz
3. The noise output of a system, without the noise source turned on, can be determined by using the following formula.

\[ N_0 = K T_0 R G_s \]

Where \( N_0 \) = noise output in watts of the system under test, without the noise source turned on

\( K \) = Boltzmann's constant which relates temperature to energy. It is equal to \( 1.38 \times 10^{-23} \) joules per degree Kelvin.

\( T_0 \) = standard temperature of 290° Kelvin

\( R \) = frequency bandwidth in hertz

\( G_s \) = power gain in watts of the system under test

4. The noise figure rating of a device may be expressed as a ratio of signal to noise. This value may be determined by using the following formulas.

\[ F = \frac{N_0}{K T_0 R G_s} \]

\[ F = \frac{S_i/N_i}{S_o/N_0} \]

\[ F = \frac{N_0}{K T_0 R G_s} \]

Where

\( F \) = the noise figure rating of a device expressed as a ratio of signal to noise

\( N_0 \) = noise output in watts of the system under test without the noise source turned on

\( T_0 \) = standard temperature of 290° Kelvin

\( R \) = frequency bandwidth in hertz

\( S_i \) = signal at the input of the system under test

\( S_o \) = signal at the output of the system under test

\( N_i \) = noise input in watts to system under test

\( K \) = Boltzmann's constant which relates temperature to energy. It is equal to \( 1.38 \times 10^{-23} \) joules per degree Kelvin.

\( G_s \) = power gain of the system under test
5. The noise figure rating of a device may be expressed in dBs. This can be determined by using the following formula.

\[ F_{dB} = 10 \log \left( \frac{T_2 - T_0}{T_0} \right) - 10 \log \left( \frac{N_2}{N_0} - 1 \right) \]

Where
- \( F_{dB} \) = noise figure rating in dBs
- \( \log \) = logarithm to the base 10
- \( T_0 \) = standard temperature of 290° Kelvin
- \( T_2 \) = the equivalent noise temperature or the ambient temperature for the measurement system
- \( N_2 \) = noise output with the source generator turned on
- \( N_0 \) = noise output with source generator turned off

6. To determine the noise power of a noise source, the following formula is used.

\[ P_{ns} = K (T_2 - T_0) B \]

Where
- \( P_{ns} \) = noise power of the noise source
- \( K \) = Boltzmann's constant which relates temperature to energy
- \( T_2 \) = the equivalent noise temperature or the ambient temperature for the measurement system
- \( T_0 \) = standard temperature of 290° Kelvin
- \( B \) = frequency bandwidth in hertz

7. The amount of noise power contributed by a receiver to the measured total noise power output is given by \( N_r \).

\[ N_r = (f-1) \left( K T_0 B G_s \right) \]

Where
- \( N_r \) = noise power contributed by the receiver
- \( f \) = receiver noise figure
- \( K \) = Boltzmann's constant, \( 1.38 \times 10^{-23} \text{ joule/K} \)
- \( T_0 \) = reference temperature, 290°K
- \( B \) = receiver bandwidth
- \( G_s \) = power gain of receiver
MICROWAVE SIGNAL FLOWGRAPH ANALYSIS

1. The following definitions are directly related to microwave network analysis and are included here to better relate the rules, diagrams and formulas.

A. Signal Flowgraph. A direct picture of signal flow, in which the variables are represented by points and are interrelated by directed lines. Figure 1 shows an example of a signal flowgraph. The arrows indicate the direction of signal flow.

![Signal Flowgraph Diagram]

Figure 1. Signal Flowgraph

B. Branch. The direction of signal flow and those operations performed on the signal. In figure 1, "c" is a branch entering "E2" and "d" is a branch entering "E1."

C. Node. A node is a point representing an equation variable. In figure 1, "E1" is a node and depends on "E0" and "a." (E0 x a = E1). "E2" and "E3" are also nodes.

D. Source Node. A node with no input branch. In figure 1, "E0" is the source node.
E. **Sink Node.** A node with no output branch. In figure 1, "E₃" is the sink node.

F. **Intermediate Node.** A node with input and output branches. In figure 1, "E₁" and "E₂" are intermediate nodes.

G. **Open Path.** A path along which a node is encountered only once. In figure 1, "a" to "b" is an open path. "a" to "c" to "f" is also an open path but not "a" to "c" to "d" since "E₁" would be encountered twice.

H. **Forward Path.** A path between source and sink node, directed toward the sink node. In figure 1, there are five forward paths.

- Path #1: "a" to "b" to "E₃"
- Path #2: "a" to "c" to "f" to "E₃"
- Path #3: "a" to "c" to "d" to "b" to "E₃"
- Path #4: "a" to "c" to "e" to "f" to "E₃"
- Path #5: "a" to "c" to "e" to "d" to "b" to "E₃"

I. **Feedback loop.** A path which returns to the starting node while encountering no node twice. In figure 1, "e" and "cd" are both feedback loops.

J. **Self-loop.** A feedback loop consisting of only one branch. In figure 1, "e" is a self-loop.

K. **Branch gain or loss.** A linear quantity relating one node to another. In figure 1, "a" relates "E₁" to "E₀."

L. **Loop gain.** The product of the branch gains in the closed loops. In figure 1, the product "cd" represents a loop gain.
2. The following mathematical rules are illustrated and related to flowgraph analysis.

A. Multiplication: The product of all forward branches. In figure 2, the dependent variable "E₁" is the product of E₀ × a.

```
E₀ → E₁
```

Figure 2. "E₁" is the product of (E₀)(a)

In figure 3, the variable "E₁" is the product of (E₀)(\(Γ_L\)), or \(E₁ = (E₀)(Γ_L)\).

```
E₀ → Γ_L
   ↓
E₁
```

Figure 3. Multiplication and dependent variable

B. Division: Multiplication of a reciprocal quantity accomplishes division. In figure 4, the dependent variable "E₁" is the product of the independent variable "E₀" and \(\frac{1}{R}\) (note: \(\frac{1}{R} = G\)), \(E₁ = E₀G\).

```
E₀ → E₁
   ↓ \(\frac{1}{R}\) = G
```

Figure 4. Dependent variable E₁
C. Addition: The sum of all the forward paths. In figure 5, the dependent variable $E_3$ is the sum of the two forward paths ($E_3 = E_{1a} + E_{2b}$).

![Figure 5. The sum of two forward paths](image)

Figure 6 shows another way of representing addition

$$E_1 = E_{0a} + E_{0b} = E_0 (a+b).$$

![Figure 6. Alternate method of addition](image)

D. Subtraction. A minus sign is used to denote the difference of the forward paths. In figure 7, the dependent variable $E_3$ is the difference between the forward paths ($E_3 = E_{1a} - E_{2b}$).

![Figure 7. The difference between forward paths](image)
E. Distributed Signals. In figure 8, the independent variable $E_0$ is distributed through three other branches. The dependent variable $E_1$ is the product of "$E_0 a\]." The dependent variable $E_2 = E_1 b = h E_0 a$. The dependent variable $E_3 = CE_1 = CE_0 a$.

![Figure 8. Distribution of the independent variable $E_0$](image)

F. Self-loop Gain. In figure 9A, "C" is a self-loop. The signal in the self-loop follows an infinite geometric progression with a common ratio of less than one. (This will be true for our microwave applications.) A geometric progression is a sequence of numbers in which each term, after the first, can be obtained from the preceding by multiplying it by a fixed number called the common ratio. Example: The sequence of numbers, 0.1, 0.01, 0.001, form a geometric progression with the common ratio of 0.1. The self-loop of figure 9A can therefore be expanded as shown in figure 9B.

![Figure 9A. Self-loop (C)](image)
G. Rule for Self-loop Elimination. To reduce the flowgraph to simpler terms, self-loops are eliminated from the flowgraph and treated mathematically as a node. See figures 9C and 9D.

"To eliminate a self-loop, divide all branches entering the node containing the self-loop by the value of 1 minus the value of the self-loop."

\[
E_2 = \frac{1}{1 - \Gamma_g \Gamma_L} \\
E_3 = E_0 \frac{1}{1 - \Gamma_g \Gamma_L}
\]

3. The "non-touching loop" rule is described in the following explanations and formulas.
When networks are cascaded, it is only necessary to cascade the flowgraphs, since the outgoing wave from one network is the incoming wave to the next. This is demonstrated in figure 10 where a network is placed between a generator and a load. The system now has only one independent variable, the generator amplitude $E$. The flowgraph contains paths and loops. A "path" is a series of directed lines followed in sequence and in the same direction in such a way that no node is touched more than once. The value of the path is the product of all coefficients encountered en route. There is one path from $E$ to $b_2$. It has a value $S_{21}$. 
Figure 10. Cascading of a network between load and generator

There are two paths from \( E \) to \( b_1 \), namely \( S_{11} \) and \( S_{21} \) \( L S_{12} \). A first order "loop" is a series of directed lines coming to a closure when followed in sequence and in the same direction with no node passed more than once. The value of the loop is the product of all coefficients encountered en route. A second-order loop is the product of any two first-order loops which do not touch at any point. A third-order loop is the product of any three first-order loops, namely, \( \Gamma_{S_{11}}, \Gamma_{S_{22}}, \Gamma_{L} \), and \( \Gamma_{\Gamma_{S_{21}}} \Gamma_{L}, \Gamma_{S_{12}} \) and there is one second-order loop \( \Gamma_{\Gamma_{S_{11}}} \Gamma_{S_{22}} \Gamma_{L} \).

The solution of a flow balance is accomplished by application of the non-touching loop rule, which written symbolically is

\[
T = \left\{ \begin{aligned}
 p_1 (1 - \Sigma L(1)) + \Sigma L(2) - \Sigma L(3) + \ldots \ldots \\
 p_2 (1 - \Sigma L(1)) + \Sigma L(2) - \Sigma L(3) + \ldots \ldots \\
 p_3 (1 - \Sigma L(1)) + \Sigma L(2) - \Sigma L(3) + \ldots \ldots \\
\end{aligned} \right. 
\]

Here \( \Sigma L(1) \) denotes the sum of all first-order loops. \( \Sigma L(2) \) denotes the sum of all second-order loops, and so on. \( p_1, p_2, p_3, \) etc., are the values of all the various paths which can be followed from the independent-variable node to the node whose value is desired. \( \Sigma L(1)(1) \) denotes the sum of all first-order loops which do not touch path \( P_1 \) at any point, and so on.
In other words, each path is multiplied by the factor in brackets which involves all the loops of all orders which the path does not touch. \( T \) is a general symbol representing the ratio between the dependent variable or interest and the independent variable. This process is repeated for each independent variable of the system, and the results are summed.

As examples of the application of the rule, the transmission \((b_2/E)\) and the reflection coefficient \((b_1/a_1)\) are written as follows:

\[
\frac{b_2}{E} = \frac{S_{21} S_{11}}{1 - T_0 S_{11} - S_{22} T_0 + S_{21} S_{11} S_{22} T_0}
\]

\[
\frac{b_1}{a_1} = \frac{S_{11} (1 - S_{22} T_0) + S_{21} S_{11} S_{12}}{1 - S_{22} T_0}
\]

Note that the generator flowgraph is unnecessary when solving for \( b_1/a_1 \) and the loops associated with it are deleted when writing this solution. It is worth mentioning at this point that second and higher-order loops can quite often be neglected while writing down the solution, if one has orders of magnitude for the various coefficient in minds.

4. Various flowgraph diagrams are shown in figures 11 through 17.
1. The present intensity of radiation can be determined by using the following formula.

\[ I_1 = I_0 \times df \]

Where \( I_1 \) = present intensity in milliroentgen per hour at one meter
\( I_0 \) = original intensity in mR/hr at one meter
\( df \) = decay factor

2. The distance that the test instrument must be placed from the source, in order to achieve a desired intensity, can be determined by using the following formulas.

\[ d = 39.37 \sqrt{\frac{I_1}{I_2}} \]

\[ d = \sqrt{\frac{1550 I_1}{I_2}} \]

Where \( d \) = distance in inches from the source
\( I_1 \) = present intensity of the source in milliroentgens per hour, at one meter
\( I_2 \) = desired intensity in milliroentgens per hour
39.37 = a factor to convert meters into inches
1550 = the square of 39.37
3. The intensity at a stated distance can be determined by using the following formula.

\[ I_d = \frac{1550 \times I_1}{d^2} \]

Where \( I_d \) = intensity at a given distance in milliroentgens per hour

\( I_1 \) = present intensity of the source in milliroentgens per hour at one meter

\( d \) = predetermined distance in inches

1550 = the square of 39.37 (inches in a meter)

NOTE: To physically relate the currie to the roentgen, a rule of thumb has been developed. A source of 1 currie will produce a radiation intensity of about 1 roentgen at a distance of 3 feet. This rule of thumb is often referred to as the 3 foot rule.
1. Acceleration is the change of velocity per unit time. This relationship is shown by the following formula.

\[ a = \frac{v_2 - v_1}{t} \]

Where:
- \( a \) = acceleration
- \( v_1 \) = initial velocity
- \( v_2 \) = velocity after acceleration
- \( t \) = time in seconds

2. Density is the mass per unit volume of a given substance. Density can be determined by one of the following formulas.

\[ \rho = \frac{M}{V} \]

Where:
- \( \rho \) = mass density
- \( V \) = volume
- \( M \) = mass

3. Force is the total push or pull. The basic relationship between force, mass and acceleration is shown in the following formula.

\[ F = ma \]

Where:
- \( F \) = force
- \( m \) = mass
- \( a \) = acceleration
4. True weight is its apparent weight, plus or minus its net buoyant force, when compared to a standard.

\[ W_t = W_a \pm \rho_{air} (V_x - V_s) \left( \frac{q}{q_0} \right) \]

Where 
- \( W_t \) = true weight
- \( W_a \) = apparent weight
- \( \rho_{air} \) = density of air
- \( V_x \) = volume of test weight
- \( V_s \) = volume of standard
- \( q \) = local gravity
- \( q_0 \) = standard gravity

5. Pressure is the amount of force on each unit area of the surface acted upon. The following formula may be used to express this relationship.

\[ p = \frac{F}{A} \]

Where
- \( p \) = pressure
- \( F \) = force
- \( A \) = area
6. The pressure of a liquid may be determined by the following formulas.

\[ P = hD \]

Where \( P \) = pressure of the liquid
\( h \) = height
\( D \) = density

7. Weight is the pull of gravity on a body. The relationship of weight, mass, and gravity is shown in the following formula.

\[ W = mg \]

Where \( W \) = weight
\( m \) = mass
\( g \) = acceleration of gravity

8. The total force due to liquid pressure may be determined by the following formula.

\[ F = PA \]
\[ F = Ah Dm \]
\[ F = Ah Dw \]

Where \( F \) = total force due to liquid pressure
\( A \) = area over which the force acts
\( h \) = height
\( Dm \) = mass density
\( P \) = pressure
\( Dw \) = weight density
9. The specific gravity of a solid or liquid substance is the ratio of the weight of a certain volume of that substance, to the weight of an equal volume of water at 4°C. This is shown by the following formulas.

\[
SG = \frac{D_x}{D_w} = \frac{\text{weight of the substance in air}}{\text{buoyant force of displaced water}} = \frac{W_a}{W_a - W_n} \quad \text{SOLIDS MORE DENSE THAN WATER}
\]

\[
SG = \frac{\text{buoyant force of liquid}}{\text{buoyant force of water}} = \frac{W_a - W_x}{W_a - W} \quad \text{Liquids}
\]

Where \( SG \) = specific gravity

\( D_x \) = density of the substance

\( D_w \) = density of water

NOTE: The buoyant force of water is equal to the weight of object in air minus the weight of object in water.

10. The relationship between volume and pressure as indicated by Boyle's Law are shown below. Remember that the law assumes the temperature to be constant.

\[
\frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{or} \quad V_1P_1 = V_2P_2
\]

Where \( V_1 \) = original volume

\( V_2 \) = new volume

\( P_1 \) = original pressure

\( P_2 \) = new pressure
11. The relationship between temperature and volume as indicated by Charles' Law is shown below. Remember the law assumes that the pressure remains constant.

\[ \frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2} \]

Where
- \( V_1 \) = original volume
- \( V_2 \) = new volume
- \( T_1 \) = original absolute temperature
- \( T_2 \) = new absolute temperature

12. The temperature, volume, and pressure relationship of a gas is shown by the general gas law formula shown below. Note this formula is only valid when absolute units of temperature and pressure are used.

\[ \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \]

Where
- \( P_1 \) = original pressure in PSIA
- \( P_2 \) = new pressure in PSIA
- \( V_1 \) = original volume
- \( V_2 \) = new volume
- \( T_1 \) = original temperature in degrees Kelvin or Rankin
- \( T_2 \) = new temperature in degrees Kelvin or Rankin

13. The absolute pressure is the sum of the gage pressure and atmospheric pressure as indicated below.

\[ P_{ab} = P_G + P_{at} \]

Where
- \( P_{ab} \) = absolute pressure
- \( P_G \) = pressure indicated on the gage
- \( P_{at} \) = atmospheric pressure
14. The local gravity can be calculated using the following formula.

\[ q_1 = 980.632 - 2.586 \cos 2\theta + .003 \cos 4\theta - .000094a \]

Where

- \( q_1 \) = local gravity
- \( \theta \) = latitude in degrees
- \( a \) = elevation in feet above sea level

15. The head pressure correction due to differences in height between the test gauge and the pressure tester can be determined by using the following formula.

\[ P_q = P_t \pm P_h (P_h = hD) \]

Where

- \( P_q \) = actual gauge pressure
- \( P_t \) = tester pressure
- \( P_h \) = difference in pressure between the gauge and the reference line on the pressure tester.
- \( h \) = difference in height between gauge and tester
- \( D \) = density of test liquid

16. To calculate true pressure from a pressure tester reading, the following formula can be used.

\[ P_t = \left( M \frac{q_1}{q_s} \right) \left( 1 - \frac{\rho_a}{\rho_{Rr}} \right) \]

\[ \frac{1}{A_0(1 + bP)(1 + \alpha \Delta T)} \]

Where

- \( P_t \) = true pressure
- \( M \) = actual mass of weights used, in pounds, as taken from the certification or calibration report plus the piston weight
- \( q_1 \) = local gravity
- \( q_s \) = standard gravity, 980.665 cm/sec²
\[ \rho_a = (\rho_{oa}) = \text{nominal air density, } 0.0012 \text{ gm/cm}^3 \]

\[ \rho_{Br} = (\rho_{oBr}) = \text{nominal brass density, } 8.4 \text{ gm/cm}^3 \]

\[ A_0 = \text{area of piston at zero pressure from cal report} \]

\[ b = \text{deformation coefficient from cal report} \]

\[ P = \text{nominal test pressure} \]

\[ \alpha = \text{coefficient of linear expansion from cal report} \]

\[ \Delta T = \text{change in temperature in degrees Celsius from } 25^\circ C \]

17. To determine the unknown candle power of a light source using the photometer method the following formula is used.

\[
\frac{I_x}{I_s} = \frac{d_x^2}{d_s^2}
\]

Where

- \( I_x \) = candle power of the unknown
- \( I_s \) = candle power of the standard
- \( d_x \) = distance of the unknown light source from the screen
- \( d_s \) = distance of the standard light source from the screen

18. The illumination may be determined by the following formula.

\[
E = \frac{F}{A}
\]

Where

- \( E \) = illumination
- \( F \) = luminous flux
- \( A \) = area
10. The illumination in foot candles can be determined by the following formula.

\[ E = \frac{I}{d^2} \]

Where
- \( E \) = illumination in foot candles
- \( I \) = candlepower of source
- \( d \) = distance from the source

20. The following equation shows the relationship between illumination and distance.

\[ \frac{E_1}{E_2} = \left( \frac{d_2}{d_1} \right)^2 \]

Where
- \( E_1 \) = illumination at \( d_1 \)
- \( E_2 \) = illumination at \( d_2 \)
- \( d_1 \) = distance from \( E_1 \)
- \( d_2 \) = distance from \( E_2 \)

21. The magnification factor can be expressed as the ratio of the size of an image to the size of the object, or the ratio of the image distance to the object distance.

\[ MF = \frac{I}{\alpha} = \frac{D_i}{D_0} = \frac{\alpha}{\alpha} \]

Where
- \( MF \) = magnification factor
- \( I \) = image size
- \( D_i \) or \( \alpha \) = image distance
- \( D_0 \) or \( \alpha \) = object distance
22. The relationship between the distance of the object and the focal length for any spherical mirror is shown in the following equation.

\[
\frac{1}{f} = \frac{1}{D_0} + \frac{1}{D_i}
\]

This equation is often shown as: \( \frac{1}{f} = \frac{1}{p} + \frac{1}{q} \)

Where  
- \( f \) = focal length  
- \( D_0 \) or \( p \) = object distance  
- \( D_i \) or \( q \) = image distance

23. The index of refraction is the ratio of velocity of light in a vacuum to the velocity of light in the media as indicated below:

\[
n = \frac{V_{LV}}{V_{Lm}}
\]

Where  
- \( n \) = index of refraction  
- \( V_{LV} \) = velocity of light in a vacuum  
- \( V_{Lm} \) = velocity of light in the media

24. The index of refraction as stated by Snell's Law is shown below:

\[
\mu = \frac{n^1 \sin \theta^1}{\sin \theta}
\]

Where  
- \( n \) = index of refractions of the first medium  
- \( \theta \) = incident angle  
- \( n^1 \) = index of refraction of the second media  
- \( \theta^1 \) = refraction angle

When the first medium is air, the formula is shown below:

\[
u = \frac{\sin i}{\sin r^1} = \frac{v^1}{v^2}
\]

Where  
- \( u \) = index of refraction  
- \( \sin i \) = sine of angle of incidence  
- \( \sin r^1 \) = sine of angle of refraction  
- \( v^1 \) = speed of light in air  
- \( v^2 \) = speed of light in other medium
25. The change of length due to a temperature change can be computed using the following formula.

\[ \Delta l = \alpha l (T - T_0) \]

Where
\[ \Delta l = \text{change in length} \]
\[ \alpha = \text{coefficient of linear expansion} \]
\[ l = \text{original length} \]
\[ T = \text{final temperature} \]
\[ T_0 = \text{original temperature} \]

NOTE: Algebraically add the total change of length to the total length to obtain the corrected total length.

26. The change of length due to temperature change linear expansion:

\[ L_f = L_o (1 + \alpha \Delta t) \]

Where
\[ \alpha = \text{linear coefficient of expansion} \]
\[ \Delta t = \text{change of temperature} \]
\[ L_o = \text{original length} \]
\[ L_f = \text{final length} \]

27. The relationship between relative humidity, absolute humidity, and capacity of the air is shown by the following formula.

\[ \%R_h = \frac{A_h}{C_{ap}} \times 100 \]

Where
\[ \%R_h = \text{relative humidity in percentage} \]
\[ A_h = \text{absolute humidity in grains per foot} \]
\[ C_{ap} = \text{capacity of air in grains per foot at that temperature} \]
28. The formula for determining the relative humidity is shown below.

\[ \%Rh = \frac{P_s (t_{dew})}{P_x (t_a)} \times 100 \]

Where
- \( \%Rh \) = relative humidity in percentage
- \( P_s \) = pressure of saturated vapor in inches of mercury
- \( t_{dew} \) = temperature at the dew point
- \( t_a \) = ambient temperature

29. Torque is a force which produces, or tends to produce, rotation or torsion. It is symbolized by the Greek letter Tau (\( \tau \)). The amount of torque can be determined by the following formula.

\[ \tau = FL \]

Where
- \( \tau \) = torque
- \( F \) = tangential force
- \( L \) = length of moment arm

30. The angular velocity can be determined by the following formula. Angular velocity is symbolized by the Greek letter omega (\( \omega \)).

\[ \omega = \frac{\theta}{T} \]

Where
- \( \omega \) = angular velocity in radians per second
- \( \theta \) = angular displacement
- \( T \) = time elapsed
31. The relationship between speed (velocity), distance and time is shown in the following formula.

\[ V_{av} = \frac{d}{T} \]

Where
- \( V_{av} \) = average speed or velocity
- \( T \) = time
- \( d \) = distance traveled

32. The frequency of vibration can be determined by the following formulas.

\[ f = \frac{1}{T} = \frac{V_{av}}{2DA} \]

Where
- \( f \) = frequency of vibration in hertz
- \( T \) = time in seconds
- \( V_{av} \) = average velocity
- \( DA \) = double amplitude

33. The computation of the acceleration level of a vibration at its maximum displacement can be accomplished by the following formula.

\[ q = 0.0512 f^2 DA \]

Where
- \( q \) = acceleration in "g" units
- \( f \) = frequency in hertz
- \( DA \) = double amplitude

34. The open circuit sensitivity of a velocity pickup can be determined from the following formula.

\[ E_1 = E_2 \left( \frac{R_1 + R_2}{R_2} \right) \]

Where
- \( E_1 \) = open circuit sensitivity
- \( E_2 \) = sensitivity of the pickup
- \( R_1 \) = impedance of the pickup
- \( R_2 \) = input impedance of the readout device

35. The corrected sensitivity of the pickup may be determined by the following formula.
\[ E_3 = E_1 \left( \frac{R_2}{R_1 + R_2} \right) \]

Where
- \( E_3 \) = corrected sensitivity
- \( E_1 \) = open circuit sensitivity
- \( R_2 \) = input \( Z \) of the device
- \( R_1 \) = \( Z \) of the pickup

36. If the open circuit sensitivity is known, a sensitivity can be corrected for any load by use of the following formula.

\[ \text{Sen}_{\text{corr}} = \text{Sen}_{\text{oc}} \left( \frac{R_2}{R_1 + R_2} \right) \]

Where
- \( \text{Sen}_{\text{corr}} \) = sensitivity corrected for loading effect
- \( \text{Sen}_{\text{oc}} \) = open circuit sensitivity
- \( R_1 \) = \( Z \) of the pickup
- \( R_2 \) = input \( Z \) of the device

37. The sensitivity of a velocity pickup can be determined by using the following formula.

\[ \text{Sen} = \frac{\sqrt{2}}{\pi f \text{ DA}} \text{ RMS}_{\text{mv}} \]

Where
- \( \text{Sen} \) = sensitivity in \( \text{mv/inch/sec} \)
- \( \text{RMS}_{\text{mv}} \) = the RMS reading in millivolts
- \( f \) = frequency in hertz
- \( \text{DA} \) = double amplitude
FORCE MEASUREMENTS

1. Strain: Change in length divided by original length.
   \[ \varepsilon = \frac{\Delta L}{L} \]
   Where
   \( \varepsilon \) = strain
   \( L \) = length
   \( \Delta L \) = change in length

2. Stress: Force per unit area.
   \[ \sigma = \frac{F}{A} \]
   Where
   \( \sigma \) = stress
   \( F \) = force
   \( A \) = area

3. Young's Modulus: Stress divided by strain.
   \[ Y = \frac{\sigma}{\varepsilon} = \frac{F/A}{L/L} = \text{PSI} \]

4. Poisson's Ratio: Transverse strain to axial strain.
   \[ \mu = \frac{\varepsilon_T}{\varepsilon_A} \]
   Where
   \( \mu \) = Poisson's Ratio
   \( \varepsilon_T \) = transverse strain (right angle to applied force)
   \( \varepsilon_A \) = axial strain (in line with applied force)
SOUND MEASUREMENT

Weber--Fechner Law: An approximate law which states that the magnitude of the sensation of loudness is proportional to the logarithm of the intensity, or:

\[ L_{(dB)} = 10 \log_{10} \frac{I}{I_0} \]

Where

- \( L \) = magnitude of the sensation of loudness
- \( I \) = intensity
- \( I_0 \) = intensity at the threshold of hearing (10^{-10} \text{ microwatts/cm}^2)

NOTE: \( I_0 \) is also given as 20 \text{ Newtons/M}^2, the threshold of hearing is 0 \text{ dBs}; and the threshold of pain of hearing is 120 \text{ dBs}.
<table>
<thead>
<tr>
<th>ALPHABETICAL INDEX</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Circuit Computation Formulas</td>
<td>56-71</td>
</tr>
<tr>
<td>Acceleration Due to Gravity</td>
<td>11</td>
</tr>
<tr>
<td>Alternating Current Generation Formulas</td>
<td>52-54</td>
</tr>
<tr>
<td>Amplifier Formulas</td>
<td>85-91</td>
</tr>
<tr>
<td>Amplifier with Feedback</td>
<td>91-93</td>
</tr>
<tr>
<td>Angle Functions</td>
<td>10</td>
</tr>
<tr>
<td>Area of Triangle, Rectangle, Parallelogram and Circle</td>
<td>35</td>
</tr>
<tr>
<td>Atomic Element List</td>
<td>26-27</td>
</tr>
<tr>
<td>Bandwidth Formula</td>
<td>72</td>
</tr>
<tr>
<td>Basic Temperature Scales Comparison Chart</td>
<td>29</td>
</tr>
<tr>
<td>Binary Conversion Tables</td>
<td>6</td>
</tr>
<tr>
<td>Cathode Followers</td>
<td>92-93</td>
</tr>
<tr>
<td>Capacitance Formulas</td>
<td>47-48</td>
</tr>
<tr>
<td>Celsius (Centigrade) Temperature Scale</td>
<td>29</td>
</tr>
<tr>
<td>Circumference of a Circle</td>
<td>35</td>
</tr>
<tr>
<td>Classification of Measurement Errors</td>
<td>108</td>
</tr>
<tr>
<td>Color Code for Capacitors</td>
<td>21-23</td>
</tr>
<tr>
<td>Color Code for Resistors</td>
<td>19-20</td>
</tr>
<tr>
<td>Conductance Formulas</td>
<td>41</td>
</tr>
<tr>
<td>Correction, Correction Factors, and Error</td>
<td>107</td>
</tr>
<tr>
<td>Coupled Inductance</td>
<td>50-51</td>
</tr>
<tr>
<td>Current Divider</td>
<td>17</td>
</tr>
</tbody>
</table>
Current Relationships to Voltage, Resistance, and Power

dB Relationship Chart

dBm

Decibels and Power Ratios

Decimal Equivalents

Deflection Factor and Deflection Sensitivity Formula

Delay Line Formula

Delta-Wye Conversion

Distortion Formula

Divider Networks

Electronic Tube Formulas

Electromagnetic Wave Spectrum

Electrostatic Formulas

Error

Exponents

Fahrenheit Temperature Scale

Force Measurements

Fractions and Decimal Equivalents

Frequency Classification

Glossary (Book 2)

Greek Alphabet

Guarding Illustrated

Harmonic Number Formula

Heat Conversion Table
Operator
Kelvin Temperature Scale
Length Conversion Table
Length Equivalent Conversion Chart
Length of an Arc
Length of the Sides of Right Angle Triangles
Linear Coefficients of Expansion
Logarithms
Logic Gates
Magnetism and Electromagnetism Formulas
Mass and Weight Conversion Table
Mathematical Constants
Mathematical Symbols
Meter Formulas
1. Sensitivity
2. Multipliers
3. Shunts
4. Shunt (Universal)
Metrology Formulas
Microwave Formulas
Microwave Noise Equations
Microwave Signal Flowgraph Analysis
Mutual Inductance Formula
Neper
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC/RL Time Constant Formulas</td>
<td>76-80</td>
</tr>
<tr>
<td>Resistance Formulas</td>
<td>40</td>
</tr>
<tr>
<td>Reactance Formulas</td>
<td>54-55</td>
</tr>
<tr>
<td>Resonance Formulas</td>
<td>55</td>
</tr>
<tr>
<td>Rounding Off Numbers</td>
<td>8</td>
</tr>
<tr>
<td>Scientific Notation</td>
<td>7</td>
</tr>
<tr>
<td>Self-Inductance Formulas</td>
<td>48-50</td>
</tr>
<tr>
<td>Sequence of Mathematical Operations</td>
<td>5</td>
</tr>
<tr>
<td>Series DC Circuit Computation</td>
<td>45</td>
</tr>
<tr>
<td>Significant Figures</td>
<td>7</td>
</tr>
<tr>
<td>Sine, Cosine, Tangent Relationships</td>
<td>8-9</td>
</tr>
<tr>
<td>Sine Wave Illustrated</td>
<td>15</td>
</tr>
<tr>
<td>Sine Wave Voltage Conversion Chart</td>
<td>15</td>
</tr>
<tr>
<td>Sound Measurement</td>
<td>161</td>
</tr>
<tr>
<td>Specific Gravity of Gases, Liquids, and Solids</td>
<td>32</td>
</tr>
<tr>
<td>Speed of Light in Air</td>
<td>32</td>
</tr>
<tr>
<td>Temperature Conversion Chart</td>
<td>29</td>
</tr>
<tr>
<td>Thermal Spectrum</td>
<td>30</td>
</tr>
<tr>
<td>Torque Indicating Handles</td>
<td>32</td>
</tr>
<tr>
<td>Transfer Resistance Standards</td>
<td>109-110</td>
</tr>
<tr>
<td>Transformer Formulas</td>
<td>72-75</td>
</tr>
<tr>
<td>Transistor Formulas</td>
<td>95-101</td>
</tr>
<tr>
<td>Trigonometric Relations</td>
<td>9</td>
</tr>
<tr>
<td>Universal Time Constant Chart</td>
<td>81-82</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Various Measurements</td>
<td>35</td>
</tr>
<tr>
<td>Voltage, Current, Power, and Resistance Relationship Chart</td>
<td>10</td>
</tr>
<tr>
<td>Voltage Divider</td>
<td>17</td>
</tr>
<tr>
<td>Volume and Pressure Conversion</td>
<td>28</td>
</tr>
<tr>
<td>Volumetric Expansion Coefficients</td>
<td>33</td>
</tr>
<tr>
<td>Weight and Mass Conversion</td>
<td>28</td>
</tr>
<tr>
<td>Wavelength Formulas</td>
<td>117-118</td>
</tr>
<tr>
<td></td>
<td>125-126</td>
</tr>
<tr>
<td>Zeke's Reversible Temperature Formula</td>
<td>31</td>
</tr>
</tbody>
</table>