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ALLIED ELECTRONICS DATA HANDBOOK

Written and Compiled by the
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ALLIED RADIO CORPORATION
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FOREWORD

Allied Radio Corporation has long recognized the need for a comprehensive and condensed handbook of formulas and data most commonly used in the field of radio and electronics. It was felt also that such a book should serve entirely as a convenient source of information and reference and that all attempts to teach or explain the basic principles involved should be left to classroom instruction and to the many already existing publications written for this distinct purpose.

The *Electronics Data Handbook*, therefore, consists of formulas, tables, charts and data. Every effort has been made to present this information clearly and to arrange it in a convenient manner for instant reference. All material was carefully selected and prepared by *Allied's* technical staff to serve the requirements of many specific groups in the radio and electronics field. It is hoped that our objectives have been successfully attained and that this *Handbook* will serve as: (1) A valuable adjunct to classroom study and laboratory work for the student and instructor; (2) A dependable source of information for the beginner, experimenter and set builder; (3) A reliable guide for the service engineer and maintenance man in his everyday work; (4) A time-saving and practical reference for the radio amateur, technician and engineer, both in the laboratory and in the field of operations.

The publishers are indebted to the McGraw-Hill Book Company, Inc., for their permission to use material selected from "*Basic Mathematics for Electronics*" by Nelson M. Cooke. *Allied* also takes this opportunity to thank those manufacturers who so generously permitted our use of current data prepared by their engineering personnel. Special recognition and our sincere appreciation are extended to Commander Cooke for his helpful suggestions and generous contribution of his time and specialized knowledge in editing the material contained in this book.

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Mathematical Symbols

$\times$ or $\cdot$	Multiplied by
$\div$ or $:$	Divided by
$+$	Positive. Plus. Add
$-$	Negative. Minus. Subtract
$\pm$	Positive or negative. Plus or minus
$\mp$	Negative or positive. Minus or plus
$=$ or $::$	Equals
$\equiv$	Identity
$\cong$	Is approximately equal to
$\neq$	Does not equal
$>$	Is greater than
$\gg$	Is much greater than
$<$	Is less than
$\ll$	Is much less than
$\geqq$	Greater than or equal to
$\leqq$	Less than or equal to
$\therefore$	Therefore
$\angle$	Angle
Δ	Increment or Decrement
$\perp$	Perpendicular to
$\parallel$	Parallel to
$\lvert n \rvert$	Absolute value of n

Mathematical Constants

$\pi = 3.14$

$2\pi = 6.28$

$(2\pi)^2 = 39.5$

$4\pi = 12.6$

$\pi^2 = 9.87$

$\frac{\pi}{2} = 1.57$

$\frac{1}{\pi} = 0.318$

$\frac{1}{2\pi} = 0.159$

$\frac{1}{\pi^2} = 0.101$

$\frac{1}{\sqrt{\pi}} = 0.564$

$\sqrt{\pi} = 1.77$

$\sqrt{\frac{\pi}{2}} = 1.25$

$\sqrt{2} = 1.41$

$\sqrt{3} = 1.73$

$\frac{1}{\sqrt{2}} = 0.707$

$\frac{1}{\sqrt{3}} = 0.577$

$\log \pi = 0.497$

$\log \frac{\pi}{2} = 0.196$

$\log \pi^2 = 0.994$

$\log \sqrt{\pi} = 0.248$

Decimal Inches

Inches $\times$ 2.540 = Centimeters
Inches $\times$ 1.578×10^{-5} = Miles
Inches $\times$ 10^3 = Mils

Inches			Decimal Equivalent	Millimeter Equivalent
1/64			.0156	0.397
	1/32		.0313	0.794
3/64			.0469	1.191
		1/16	.0625	1.588
5/64			.0781	1.985
	3/32		.0938	2.381
7/64			.1094	2.778
		1/8	.1250	3.175
9/64			.1406	3.572
	5/32		.1563	3.969
11/64			.1719	4.366
		3/16	.1875	4.762
13/64			.2031	5.159
	7/32		.2188	5.556
15/64			.2344	5.953
		1/4	.2500	6.350
17/64			.2656	6.747
	9/32		.2813	7.144
19/64			.2969	7.541
		5/16	.3125	7.937
21/64			.3281	8.334
	11/32		.3438	8.731
23/64			.3594	9.128
		3/8	.3750	9.525
25/64			.3906	9.922
	13/32		.4063	10.319
27/64			.4219	10.716
		7/16	.4375	11.112
29/64			.4531	11.509
	15/32		.4688	11.906
31/64			.4844	12.303
		1/2	.5000	12.700
33/64			.5156	13.097
	17/32		.5313	13.494
35/64			.5469	13.891
		9/16	.5625	14.287
37/64			.5781	14.684
	19/32		.5938	15.081
39/64			.6094	15.478
		5/8	.6250	15.875
41/64			.6406	16.272
	21/32		.6563	16.669
43/64			.6719	17.067
		11/16	.6875	17.463
45/64			.7031	17.860
	23/32		.7188	18.238
47/64			.7344	18.635
		3/4	.7500	19.049
49/64			.7656	19.446
	25/32		.7813	19.842
51/64			.7969	20.239
		13/16	.8125	20.636
53/64			.8281	21.033
	27/32		.8438	21.430
55/64			.8594	21.827
		7/8	.8750	22.224
57/64			.8906	22.621
	29/32		.9063	23.018
59/64			.9219	23.415
		15/16	.9375	23.812
61/64			.9531	24.209
	31/32		.9688	24.606
63/64			.9844	25.004
		1.0	1.0000	25.400

Algebra

Exponents and Radicals

$$a^x \times a^y = a^{(x+y)}. \qquad \frac{a^x}{a^y} = a^{(x-y)}.$$

$$(ab)^x = a^x b^x. \qquad \left(\frac{a}{b}\right)^x = \frac{a^x}{b^x}.$$

$$\sqrt[x]{\frac{a}{b}} = \frac{\sqrt[x]{a}}{\sqrt[x]{b}}. \qquad a^{-x} = \frac{1}{a^x}.$$

$$(a^x)^y = a^{xy}. \qquad \sqrt[x]{\sqrt[y]{a}} = \sqrt[xy]{a}.$$

$$\sqrt[x]{ab} = \sqrt[x]{a}\sqrt[x]{b}. \qquad a^{\frac{x}{y}} = \sqrt[y]{a^x}.$$

$$a^{\frac{1}{x}} = \sqrt[x]{a}. \qquad a^0 = 1.$$

Solution of a Quadratic

Quadratic equations in the form

$$ax^2 + bx + c = 0$$

may be solved by the following:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

Transposition of Terms

If $A = \frac{B}{C}$, then $B = AC$, $C = \frac{B}{A}$.

If $\frac{A}{B} = \frac{C}{D}$, then $A = \frac{BC}{D}$,

$B = \frac{AD}{C}$, $C = \frac{AD}{B}$, $D = \frac{BC}{A}$

If $A = \frac{1}{D\sqrt{BC}}$, then $A^2 = \frac{1}{D^2BC}$,

$B = \frac{1}{D^2A^2C}$, $C = \frac{1}{D^2A^2B}$, $D = \frac{1}{A\sqrt{BC}}$.

If $A = \sqrt{B^2 + C^2}$, then $A^2 = B^2 + C^2$,

$B = \sqrt{A^2 - C^2}$, $C = \sqrt{A^2 - B^2}$.

Decibels

The number of db by which two power outputs P_1 and P_2 (in watts) may differ, is expressed by

$$10 \log \frac{P_1}{P_2};$$

or in terms of volts,

$$20 \log \frac{E_1}{E_2};$$

or in current,

$$20 \log \frac{I_1}{I_2}.$$

While power ratios are independent of source and load impedance values, voltage and current ratios in these formulas hold true only when the source and load impedances Z_1 and Z_2 are equal. In circuits where these impedances differ, voltage and current ratios are expressed by,

$$db = 20 \log \frac{E_1\sqrt{Z_2}}{E_2\sqrt{Z_1}} \quad \text{or,} \quad 20 \log \frac{I_1\sqrt{Z_1}}{I_2\sqrt{Z_2}}$$

DB Expressed in Watts & Volts

DB*	Above Zero Level		Below Zero Level	
	Watts	Volts	Watts	Volts
0	0.0010	0.775	1.00×10^{-3}	0.7746
1	0.0013	0.869	7.94×10^{-4}	0.6904
2	0.0016	0.975	6.31×10^{-4}	0.6153
3	0.0020	1.094	5.01×10^{-4}	0.5483
4	0.0025	1.227	3.98×10^{-4}	0.4888
5	0.0032	1.377	3.16×10^{-4}	0.4356
6	0.0040	1.545	2.51×10^{-4}	0.3883
7	0.0050	1.734	2.00×10^{-4}	0.3460
8	0.0063	1.946	1.59×10^{-4}	0.3084
9	0.0079	2.183	1.26×10^{-4}	0.2748
10	0.0100	2.449	1.00×10^{-4}	0.2449
11	0.0126	2.748	7.94×10^{-5}	0.2183
12	0.0159	3.084	6.31×10^{-5}	0.1946
13	0.0200	3.460	5.01×10^{-5}	0.1734
14	0.0251	3.882	3.98×10^{-5}	0.1545
15	0.0316	4.356	3.16×10^{-5}	0.1377
16	0.0398	4.888	2.51×10^{-5}	0.1228
17	0.0501	5.483	2.00×10^{-5}	0.1095
18	0.0631	6.153	1.59×10^{-5}	0.0975
19	0.0794	6.904	1.26×10^{-5}	0.0869
20	0.1	7.746	10^{-5}	7.75×10^{-2}
30	1.0	24.493	10^{-6}	2.45×10^{-2}
40	10.0	77.460	10^{-7}	7.75×10^{-3}
50	10^2	244.93	10^{-8}	2.45×10^{-3}
60	10^3	774.60	10^{-9}	7.75×10^{-4}
70	10^4	2,449.0	10^{-10}	2.45×10^{-4}
80	10^5	7,746.0	10^{-11}	7.75×10^{-5}
90	10^6	24,493.0	10^{-12}	2.45×10^{-5}
100	10^7	77,460.0	10^{-13}	7.75×10^{-6}

*Zero db = 1 milliwatt into a 600 ohm load. Power ratios hold for any impedance, but voltages must be referred to an impedance load of 600 ohms.

Decibel—Voltage, Current and Power Ratio Table

− Voltage or Current Ratio	− Power Ratio	DB	+ Voltage or Current Ratio	+ Power Ratio	− Voltage or Current Ratio	− Power Ratio	DB	+ Voltage or Current Ratio	+ Power Ratio
1.0000	1.0000	**0**	1.000	1.000	.4898	.2399	**6.2**	2.042	4.169
.9886	.9772	**.1**	1.012	1.023	.4842	.2344	**6.3**	2.065	4.266
.9772	.9550	**.2**	1.023	1.047	.4786	.2291	**6.4**	2.089	4.365
.9661	.9333	**.3**	1.035	1.072	.4732	.2239	**6.5**	2.113	4.467
.9550	.9120	**.4**	1.047	1.096	.4677	.2188	**6.6**	2.138	4.571
.9441	.8913	**.5**	1.059	1.122	.4624	.2138	**6.7**	2.163	4.677
.9333	.8710	**.6**	1.072	1.148	.4571	.2089	**6.8**	2.188	4.786
.9226	.8511	**.7**	1.084	1.175	.4519	.2042	**6.9**	2.213	4.898
.9120	.8318	**.8**	1.096	1.202	.4467	.1995	**7.0**	2.239	5.012
.9016	.8128	**.9**	1.109	1.230	.4416	.1950	**7.1**	2.265	5.129
.8913	.7943	**1.0**	1.122	1.259	.4365	.1905	**7.2**	2.291	5.248
.8810	.7762	**1.1**	1.135	1.288	.4315	.1862	**7.3**	2.317	5.370
.8710	.7586	**1.2**	1.148	1.318	.4266	.1820	**7.4**	2.344	5.495
.8610	.7413	**1.3**	1.161	1.349	.4217	.1778	**7.5**	2.371	5.623
.8511	.7244	**1.4**	1.175	1.380	.4169	.1738	**7.6**	2.399	5,754
.8414	.7079	**1.5**	1.189	1.413	.4121	.1698	**7.7**	2.427	5.888
.8318	.6918	**1.6**	1.202	1.445	.4074	.1660	**7.8**	2.455	6.026
.8222	.6761	**1.7**	1.216	1.479	.4027	.1622	**7.9**	2.483	6.166
.8128	.6607	**1.8**	1.230	1.514	.3981	.1585	**8.0**	2.512	6.310
.8035	.6457	**1.9**	1.245	1.549	.3936	.1549	**8.1**	2.541	6.457
.7943	.6310	**2.0**	1.259	1.585	.3890	.1514	**8.2**	2.570	6.607
.7852	.6166	**2.1**	1.274	1.622	.3846	.1479	**8.3**	2.600	6.761
.7762	.6026	**2.2**	1.288	1.660	.3802	.1445	**8.4**	2.630	6.918
.7674	.5888	**2.3**	1.303	1.698	.3758	.1413	**8.5**	2.661	7.079
.7586	.5754	**2.4**	1.318	1.738	.3715	.1380	**8.6**	2.692	7.244
.7499	.5623	**2.5**	1.334	1.778	.3673	.1349	**8.7**	2.723	7.413
.7413	.5495	**2.6**	1.349	1.820	.3631	.1318	**8.8**	2.754	7.586
.7328	.5370	**2.7**	1.365	1.862	.3589	.1288	**8.9**	2.786	7.762
.7244	.5248	**2.8**	1.380	1.905	.3548	.1259	**9.0**	2.818	7.943
.7161	.5129	**2.9**	1.396	1.950	.3508	.1230	**9.1**	2.851	8.128
.7079	.5012	**3.0**	1.413	1.995	.3467	.1202	**9.2**	2.884	8.318
.6998	.4898	**3.1**	1.429	2.042	.3428	.1175	**9.3**	2.917	8.511
.6918	.4786	**3.2**	1.445	2.089	.3388	.1148	**9.4**	2.951	8.710
.6839	.4677	**3.3**	1.462	2.138	.3350	.1122	**9.5**	2.985	8.913
.6761	.4571	**3.4**	1.479	2.188	.3311	.1096	**9.6**	3.020	9.120
.6683	.4467	**3.5**	1.496	2.239	.3273	.1072	**9.7**	3.055	9.333
.6607	.4365	**3.6**	1.514	2.291	.3236	.1047	**9.8**	3.090	9.550
.6531	.4266	**3.7**	1.531	2.344	.3199	.1023	**9.9**	3.126	9.772
.6457	.4169	**3.8**	1.549	2.399	.3162	.1000	**10.0**	3.162	10.000
.6383	.4074	**3.9**	1.567	2.455	.2985	.08913	**10.5**	3.350	11.22
.6310	.3981	**4.0**	1.585	2.512	.2818	.07943	**11.0**	3.548	12.59
.6237	.3890	**4.1**	1.603	2.570	.2661	.07079	**11.5**	3.758	14.13
.6166	.3802	**4.2**	1.622	2.630	.2512	.06310	**12.0**	3.981	15.85
.6095	.3715	**4.3**	1.641	2.692	.2371	.05623	**12.5**	4.217	17.78
.6026	.3631	**4.4**	1.660	2.754	.2239	.05012	**13.0**	4.467	19.95
.5957	.3548	**4.5**	1.679	2.818	.2113	.04467	**13.5**	4.732	22.39
.5888	.3467	**4.6**	1.698	2.884	.1995	.03981	**14.0**	5.012	25.12
.5821	.3388	**4.7**	1.718	2.951	.1884	.03548	**14.5**	5.309	28.18
.5754	.3311	**4.8**	1.738	3.020	.1778	.03162	**15.0**	5.623	31.62
.5689	.3236	**4.9**	1.758	3.090	.1585	.02512	**16.0**	6.310	39.81
.5623	.3162	**5.0**	1.778	3.162	.1413	.01995	**17.0**	7.079	50.12
.5559	.3090	**5.1**	1.799	3.236	.1259	.01585	**18.0**	7.943	63.10
.5495	.3020	**5.2**	1.820	3.311	.1122	.01259	**19.0**	8.913	79.43
.5433	.2951	**5.3**	1.841	3.388	.1000	.01000	**20.0**	10.000	100.00
.5370	.2884	**5.4**	1.862	3.467	.03162	.00100	**30.0**	31.620	1,000.00
.5309	.2818	**5.5**	1.884	3.548	.01	.00010	**40.0**	100.00	10,000.00
.5248	.2754	**5.6**	1.905	3.631	.003162	.00001	**50.0**	316.20	10^5
.5188	.2692	**5.7**	1.928	3.715	.001	10^{-6}	**60.0**	1,000.00	10^6
.5129	.2630	**5.8**	1.950	3.802	.0003162	10^{-7}	**70.0**	3,162.00	10^7
.5070	.2570	**5.9**	1.972	3.890	.0001	10^{-8}	**80.0**	10,000.00	10^8
.5012	.2512	**6.0**	1.995	3.931	.00003162	10^{-9}	**90.0**	31,620.00	10^9
.4955	.2455	**6.1**	2.018	4.074	10^{-5}	10^{-10}	**100.0**	10^5	10^{10}

Table of Values for Attenuator Network Formulas

db	Voltage or Current Ratio	B	C	D	E	db	Voltage or Current Ratio	B	C	D	E
.1	.98855	.011447	86.360	.005756	86.857	**27.0**	.044668	.95533	.046757	.91448	.089515
.2	.97724	.022763	42.931	.011512	43.426	**27.5**	.042170	.95783	.044026	.91907	.084490
.25	.97163	.028372	34.247	.014390	34.739	**28.0**	.039811	.96019	.041461	.92343	.079748
.3	.96605	.034046	28.456	.017268	28.947	**30.0**	.031623	.96838	.032655	.93869	.063309
.4	.95499	.045008	21.219	.023022	21.707	**32.0**	.025119	.97488	.025766	.95099	.050269
.5	.94406	.055939	16.876	.028774	17.362	**32.5**	.023714	.97629	.024290	.95367	.047454
.6	.93325	.066745	13.982	.034525	14.428	**33.0**	.022387	.97761	.022900	.95621	.044797
.7	.92257	.077429	11.915	.040274	12.395	**34.0**	.019953	.98005	.020359	.96088	.039921
.75	.91728	.082724	11.088	.043147	11.567	**35.0**	.017783	.98222	.018105	.96506	.035577
.8	.91201	.087989	10.365	.046019	10.842	**36.0**	.015849	.98415	.016104	.96880	.031706
.9	.90157	.098429	9.1596	.051762	9.6337	**37.5**	.013335	.98666	.013515	.97368	.026675
1.0	.89125	.10875	8.1955	.057501	8.6667	**38.0**	.012589	.98741	.012750	.97513	.025183
1.5	.84140	.15860	5.3050	.086133	5.7619	**39.0**	.011220	.98878	.011348	.97781	.022443
2.0	.79433	.20567	3.8621	.11462	4.3048	**40.0**	.010000	.99000	.010101	.98020	.020002
2.5	.74989	.25011	2.9983	.14293	3.4268	**42.0**	.0079433	.99206	.0080069	.98424	.015888
3.0	.70795	.29205	2.4240	.17100	2.8385	**42.5**	.0074989	.99250	.0075556	.98511	.014999
3.5	.66834	.33166	2.0152	.19879	2.4158	**44.0**	.0063096	.99369	.0063496	.98746	.012620
4.0	.63096	.36904	1.7097	.22627	2.0966	**45.0**	.0056234	.99438	.0056552	.98882	.011247
4.5	.59566	.40434	1.4732	.25340	1.8465	**47.5**	.0042170	.99578	.0042348	.99160	.0084341
5.0	.56234	.43766	1.2849	.28013	1.6448	**48.0**	.0039811	.99602	.0039970	.99207	.0079623
6.0	.50119	.49881	1.0048	.33228	1.3386	**50.0**	.0031623	.99684	.0031723	.99370	.0063246
7.0	.44668	.55332	.80728	.38247	1.1160	**51.0**	.0028184	.99718	.0028264	.99438	.0056368
7.5	.42170	.57830	.72920	.40677	1.0258	**52.0**	.0025119	.99749	.0025182	.99499	.0050238
8.0	.39811	.60189	.66143	.43051	.94617	**54.0**	.0019953	.99800	.0019993	.99602	.0039905
9.0	.35481	.64519	.54994	.47622	.81183	**55.0**	.0017783	.99822	.0017815	.99645	.0035566
10.0	.31623	.68377	.46248	.51949	.70273	**56.0**	.0015849	.99842	.0015874	.99684	.0031698
11.0	.28184	.71816	.39244	.56026	.61231	**57.0**	.0014125	.99859	.0014145	.99718	.0028251
12.0	.25119	.74881	.33545	.59848	.53621	**60.0**	.0010000	.99900	.00100100	.99800	.0020000
12.5	.23714	.76286	.31085	.61664	.50253	**64.0**	.00063096	.99937	.00063136	.99874	.0012619
13.0	.22387	.77613	.28845	.63416	.47137	**65.0**	.00056234	.99944	.00056266	.99888	.0011247
14.0	.19953	.80047	.24926	.66732	.41560	**66.0**	.00050119	.99950	.00050144	.99900	.0010024
15.0	.17783	.82217	.21629	.69804	.36727	**68.0**	.00039811	.99960	.00039827	.99920	.0007962
16.0	.15849	.84151	.18834	.72639	.32515	**70.0**	.00031623	.99968	.00031633	.99937	.0006325
17.0	.14125	.85875	.16449	.75246	.28826	**72.0**	.00025119	.99975	.00025125	.99950	.0005024
17.5	.13335	.86665	.15387	.76468	.27153	**75.0**	.00017783	.99982	.00017786	.99964	.0003557
18.0	.12589	.87411	.14402	.77637	.25584	**76.0**	.00015849	.99984	.00015851	.99968	.0003170
19.0	.11220	.88780	.12638	.79823	.22726	**78.0**	.00012589	.99987	.00012591	.99975	.0002518
20.0	.100000	.90000	.111111	.81818	.20202	**80.0**	.00010000	.99990	.00010000	.99980	.0002000
21.0	.089125	.91087	.097846	.83634	.17968	**84.0**	.00006310	.99994	.00006310	.99987	.0001262
22.0	.079433	.92057	.086287	.85282	.15987	**85.0**	.00005623	.99994	.00005624	.99989	.0001125
22.5	.074989	.92501	.081069	.86048	.15083	**90.0**	.00003162	.99997	.00003162	.99994	.00006325
24.0	.063096	.93690	.067345	.88130	.12670	**95.0**	.00001778	.99998	.00001778	.99996	.00003557
25.0	.056234	.94377	.059585	.89352	.11283	**96.0**	.00001585	.99998	.00001585	.99997	.00003170
26.0	.050119	.94988	.052763	.90455	.10049	**100.0**	.00001000	.99999	.00001000	.99998	.00002000

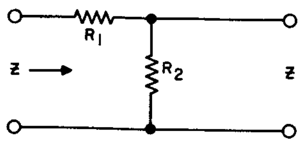
Attenuator Networks

For Insertion Between Equal Impedances

For data covering networks between unequal impedances, see Minimum Loss Pads on page 10. See also Decibel—Voltage Current and Power Ratio Table on page 6.

See table on page 7 for values of A, B, C, D, E used in the following attenuator network formulas.

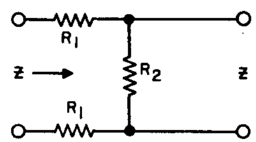
In the case of L and U networks where only the input or output can be matched, as required, the matched side is indicated by an arrow pointing toward the pad. On all other networks, both the input and output circuits are matched.



$R_1 = ZB$

$R_2 = ZC$

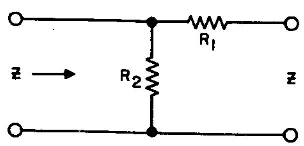
L



$R_1 = \frac{ZB}{2}$

$R_2 = ZC$

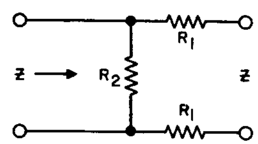
U



$R_1 = \frac{Z}{C}$

$R_2 = \frac{Z}{B}$

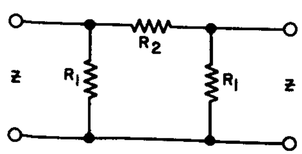
L



$R_1 = \frac{Z}{2C}$

$R_2 = \frac{Z}{B}$

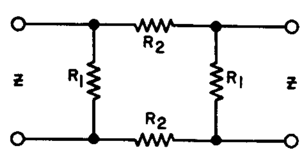
U



$R_1 = \frac{Z}{D}$

$R_2 = \frac{Z}{E}$

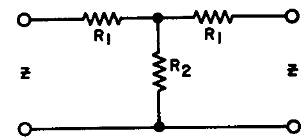
π



$R_1 = \frac{Z}{D}$

$R_2 = \frac{Z}{2E}$

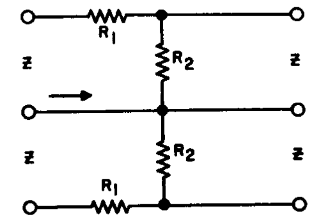
O



$R_1 = ZD$

$R_2 = ZE$

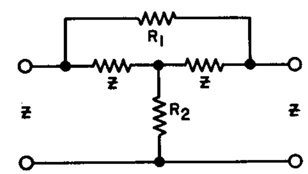
T



$R_1 = \frac{ZB}{2}$

$R_2 = \frac{ZC}{2}$

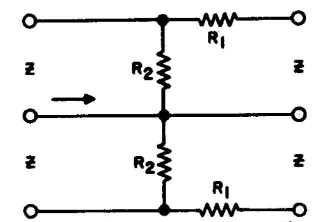
Balanced U



$R_1 = \frac{Z}{C}$

$R_2 = ZC$

Bridged T



$R_1 = \frac{Z}{2C}$

$R_2 = \frac{Z}{2B}$

Balanced U

Constant Impedance Attenuators in Parallel

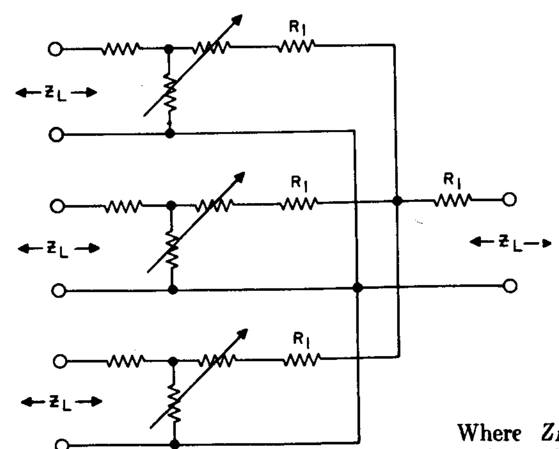


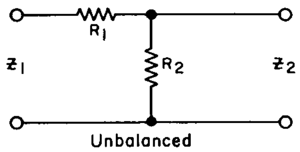
Table of R_1 Values in Ohms

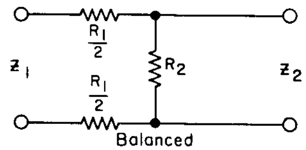
Z	Number of Channels 2	3	4	5	6
30	10	15	18	20	21.5
50	16.6	25	30	33.3	35.7
150	50	75	90	100	107
200	66.6	100	120	133	143
250	83.3	125	150	166	179
500	166	250	300	333	357
600	200	300	360	400	428
Network db Loss	6	9.5	12	14	15.5

$R_1 = Z_L\left(\frac{N-1}{N+1}\right)$ | Insertion loss in db $= 20 \log_{10} N$

Where $Z_L =$ identical line and load impedances;
and $N =$ number of channels in parallel.

Minimum Loss Pads





For Matching Two Impedances where $Z_1 > Z_2$

$$R_1 = \sqrt{Z_1 (Z_1 - Z_2)}$$

$$R_2 = \frac{Z_1 Z_2}{R_1}$$

$$db \text{ loss} = 20 \log_{10} \left(\sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1} \right)$$

Where Only One Impedance is to be Matched

If the larger impedance only is to be matched, use a resistor R_L in series with the smaller impedance such that

$$R_L = Z_1 - Z_2$$

$$db \text{ loss} = 20 \log_{10} \sqrt{\frac{Z_1}{Z_2}}$$

If the smaller impedance only is to be matched, use a resistor R_S in shunt across the larger impedance such that

$$R_S = \frac{Z_1 Z_2}{Z_1 - Z_2}$$

Here also db loss $= 20 \log_{10} \sqrt{\frac{Z_1}{Z_2}}$

Tables of R_1 and R_2 Values

When Z_1 is 600 ohms and Z_2 is less than 600 ohms.

Z_2	500	400	300	250	200	150	100	75	50	40	30	25
R_1	245	346	424	458	490	520	548	561	575	580	585	587
R_2	1,225	694	425	328	245	173	110	80.2	52.2	41.4	30.8	25.6
db Loss	3.8	5.7	7.6	8.7	10.0	11.4	13.4	14.8	16.6	17.6	18.9	19.7

When Z_2 is less than 25 ohms,

$$\text{let } R_1 = 600 - \frac{Z_1}{Z_2}$$
$$\text{and } R_2 = Z_2$$

Where Z_2 is 600 ohms, and Z_1 is greater than 600 ohms

Z_1	800	1,000	1,200	1,500	2,000	2,500	3,000	3,500	4,000	5,000	6,000	8,000	10,000
R_1	400	632	849	1,162	1,673	2,180	2,683	3,186	3,688	4,690	5,692	7,694	9,695
R_2	1,200	949	849	775	717	688	671	659	651	638	633	624	619
db Loss	4.8	6.5	7.6	9.0	10.5	11.6	12.5	13.3	13.9	15.0	15.8	17.1	18.1

When Z_1 is greater than 10,000 ohms,

$$\text{let } R_1 = Z_1 - 300$$
$$\text{and } R_2 = 600$$

70-Volt Loud-Speaker Matching Systems

The EIA 70.7 volt constant voltage system of power distribution provides the engineer and technician with a simple means of matching a number of loudspeakers to an amplifier. To use this method:

1. Determine the power required at each loudspeaker.
2. Add the powers required for the individual speakers and select an amplifier with a rated power output equal to or greater than this total.
3. Select 70.7-volt transformers having primary wattage taps as determined in step 1.*
4. Wire the selected primaries in parallel across the 70.7-volt line.
5. Connect each secondary to its speaker; selecting the tap which matches the voice coil impedance.

For transformers rated in impedance, the following formulas may be used to determine the proper taps in step 3.

$$\text{Primary Impedance} = \frac{(\text{Amplifier output voltage})^2}{\text{Desired speaker power}}$$

or

$$Z = \frac{E^2}{P} \qquad (1)$$

*These transformers have the primary taps marked in watts and the secondaries marked in ohms.

Since the voltage at rated amplifier power is 70.7, this reduces to:

$$Z = \frac{70.7^2}{P} = \frac{5000}{P} \qquad (2)$$

From formula (2) these relationships are:

1 watt requires 5000 ohm primary
2 watts requires 2500 ohm primary
5 watts requires 1000 ohm primary
10 watts requires 500 ohm primary

Once the primary taps have been determined, continue on through step 4 and 5 as outlined above. When selecting transformer primary taps, use the next highest available value above the computed value. A mismatch of 25% is generally considered permissible.

Example: Required

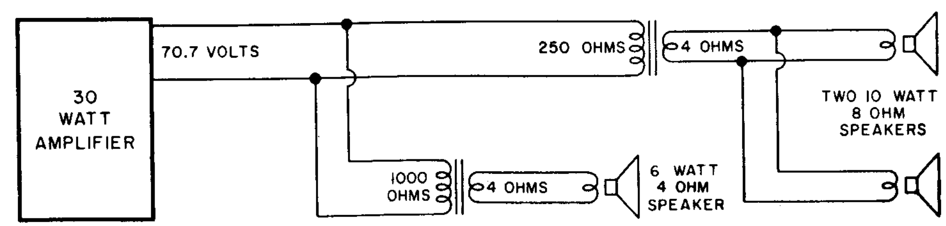
One 6 watt speaker with 4 ohm voice coil.
Two 10 watt speakers with 8 ohm voice coils (use one transformer at this location).

(1-2) Total power = 6 + 10 + 10 = 26 watts (use a 30-watt amplifier or other amplifier capable of handling at least 26 watts)

(3) $Z_{6 \text{ watts}} = \frac{5000}{6} = 833$ ohms (use 1000 ohm transformer)

$Z_{20 \text{ watts}} = \frac{5000}{20} = 250$ ohms

(4-5) See sketch below.



Most Used Formulas

Resistance Formulas

In series $R_t = R_1 + R_2 + R_3 \ldots$ etc.

In parallel $R_t = \dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} \ldots \text{etc.}}$

Two resistors in parallel $R_t = \dfrac{R_1 R_2}{R_1 + R_2}$

Capacitance

In parallel $C_t = C_1 + C_2 + C_3 \ldots$ etc.

In series $C_t = \dfrac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} \ldots \text{etc.}}$

Two capacitors in series $C_t = \dfrac{C_1 C_2}{C_1 + C_2}$

The Quantity of Electricity Stored Within a Capacitor is Given by

$$Q = CE$$

where Q = the quantity stored, in coulombs,
E = the potential impressed across the capacitor in volts,
C = capacitance in farads.

The Capacitance of a Parallel Plate Capacitor is Given by

$$C = 0.0885 \frac{KS\,(N-1)}{d}$$

where C = capacitance in mmfd.,
K = dielectric constant,
*S = area of one plate in square centimeters,
N = number of plates,
*d = thickness of the dielectric in centimeters (same as the distance between plates).

* When S and d are given in inches, change constant 0.0885 to 0.224. Answer will still be in micromicrofarads.

DIELECTRIC CONSTANTS

Kind of Dielectric	*Approximate* K Value*
Air (at atmospheric pressure)	1.0
Bakelite	5.0
Beeswax	3.0
Cambric (varnished)	4.0
Fibre (Red)	5.0
Glass (window or flint)	8.0
Gutta Percha	4.0
Mica	6.0
Paraffin (solid)	2.5
Paraffin Coated Paper	3.5
Porcelain	6.0
Pyrex	4.5
Quartz	5.0
Rubber	3.0
Slate	7.0
Wood (very dry)	5.0

* These values are approximate, since true values depend upon quality or grade of material used, as well as moisture content, temperature and frequency characteristics of each.

Self-Inductance

In series $L_t = L_1 + L_2 + L_3 \ldots$ etc.

In parallel $L_t = \dfrac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3} \ldots \text{etc.}}$

Two inductors in parallel $L_t = \dfrac{L_1 L_2}{L_1 + L_2}$

Coupled Inductance

In series with fields *aiding*

$$L_t = L_1 + L_2 + 2M$$

In series with fields *opposing*

$$L_t = L_1 + L_2 - 2M$$

In parallel with fields *aiding*

$$L_t = \frac{1}{\dfrac{1}{L_1 + M} + \dfrac{1}{L_2 + M}}$$

In parallel with fields *opposing*

$$L_t = \frac{1}{\dfrac{1}{L_1 - M} + \dfrac{1}{L_2 - M}}$$

where L_t = the total inductance,
M = the mutual inductance,
L_1 and L_2 = the self inductance of the individual coils.

Mutual Inductance

The mutual inductance of two r-f coils with fields interacting, is given by

$$M = \frac{L_A - L_O}{4}$$

where M = mutual inductance, expressed in same units as L_A and L_O,
L_A = Total inductance of coils L_1 and L_2 with fields *aiding*,
L_O = Total inductance of coils L_1 and L_2 with fields *opposing*.

Coupling Coefficient

When two r-f coils are inductively coupled so as to give transformer action, the coupling coefficient is expressed by

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

where K = the coupling coefficient; ($K \times 10^2$ = coupling coefficient in %),
M = the mutual inductance value,
L_1 and L_2 = the self-inductance of the two coils respectively, both being expressed in the same units.

Resonance

The resonant frequency, or frequency at which inductive reactance X_L equals capacitive reactance X_C, is expressed by

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

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

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

where f_r = resonant frequency in cycles per second,
L = inductance in henrys,
C = capacitance in farads,
$2\pi = 6.28$
$4\pi^2 = 39.5$

Reactance

of an inductance is expressed by

$$X_L = 2\pi f L$$

of a capacitance is expressed by

$$X_C = \frac{1}{2\pi f C}$$

where X_L = inductive reactance in ohms, (known as positive reactance),
X_C = capacitive rectance in ohms, (known as negative reactance),
f = frequency in cycles per second,
L = inductance in henrys,
C = capacitance in farads,
$2\pi = 6.28$

Frequency from Wavelength

$$f = \frac{3 \times 10^5}{\lambda} \text{ (kilocycles)}$$

where λ = wavelength in *meters*.

$$f = \frac{3 \times 10^4}{\lambda} \text{ (megacycles)}$$

where λ = wavelength in *centimeters*.

Wavelength from Frequency

$$\lambda = \frac{3 \times 10^5}{f} \text{ (meters)}$$

where f = frequency in *kilocycles*.

$$\lambda = \frac{3 \times 10^4}{f} \text{ (centimeters)}$$

where f = frequency in *megacycles*.

Q or Figure of Merit

of a simple reactor

$$Q = \frac{X_L}{R_L}$$

of a single capacitor

$$Q = \frac{X_C}{R_C}$$

where Q = a ratio expressing the figure of merit,

X_L = inductive reactance in ohms,

X_C = capacitive reactance in ohms,

R_L = resistance in ohms acting in series with inductance,

R_C = resistance in ohms acting in series with capacitance,

Impedance

In any a-c circuit where resistance and reactance values of the R, L and C components are given, the absolute or numerical magnitude of impedance and phase angle can be computed from the formulas which follow.

In general the basic formulas expressing total impedance are:

for series circuits,

$$Z_t = \sqrt{R_t^2 + X_t^2},$$

for parallel circuits,

$$Z_t = \frac{1}{\sqrt{G_t^2 + B_t^2}}.$$

See page 17 for formulas involving impedance, conductance, susceptance and admittance.

In series circuits where phase angle and any two of the Z, R and X components are known, the unknown component may be determined from the expressions:

$$Z = \frac{R}{\cos\theta} \qquad Z = \frac{X}{\sin\theta}$$

$$R = Z\cos\theta \qquad X = Z\sin\theta$$

where Z = magnitude of impedance in ohms,

R = resistance in ohms,

X = reactance (inductive or capacitive) in ohms.

Nomenclature

Z = absolute or numerical value of impedance magnitude in ohms

R = resistance in ohms,

X_L = inductive reactance in ohms,

X_C = capacitive reactance in ohms,

L = inductance in henrys,

C = capacitance in farads,

R_L = resistance in ohms acting in series with inductance,

R_C = resistance in ohms acting in series with capacitance,

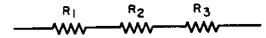
θ = phase angle in degrees by which current leads voltage in a capacitive circuit, or lags voltage in an inductive circuit. In a resonant circuit, where X_L equals X_C, θ equals 0°.

Degrees × 0.0175 = radians.
1 radian = 57.3°.

Numerical Magnitude of Impedance . . .

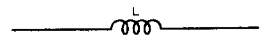
of resistance alone

$$Z = R$$
$$\theta = 0°$$



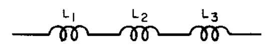
of resistance in series

$$Z = R_1 + R_2 + R_3 \ldots \text{etc.}$$
$$\theta = 0°$$



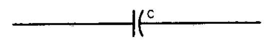
of inductance alone

$$Z = X_L$$
$$\theta = +90°$$



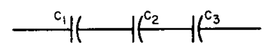
of inductance in series

$$Z = X_{L1} + X_{L2} + X_{L3} \ldots \text{etc.}$$
$$\theta = +90°$$



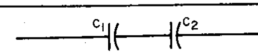
of capacitance alone

$$Z = X_C$$
$$\theta = -90°$$



of capacitance in series

$$Z = X_{C1} + X_{C2} + X_{C3} \ldots \text{etc.}$$
$$\theta = -90°$$



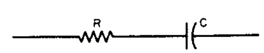
or where only 2 capacitances C_1 and C_2 are involved,

$$Z = \frac{1}{2\pi f}\left(\frac{C_1 + C_2}{C_1\,C_2}\right)$$
$$\theta = -90°$$

of resistance and inductance in series

$$Z = \sqrt{R^2 + X_L^2}$$

$$\theta = \arctan\frac{X_L}{R}$$



of resistance and capacitance in series

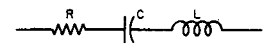
$$Z = \sqrt{R^2 + X_C^2}$$

$$\theta = \arctan\frac{X_C}{R}$$

of inductance and capacitance in series

$$Z = X_L - X_C$$

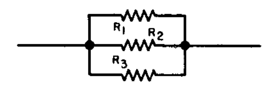
$$\theta = -90° \text{ when } X_L < X_C$$
$$= 0° \text{ when } X_L = X_C$$
$$= +90° \text{ when } X_L > X_C$$



of resistance, inductance and capacitance in series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

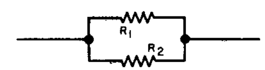
$$\theta = \arctan\frac{X_L - X_C}{R}$$



of resistance in parallel

$$Z = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots \text{etc.}}$$

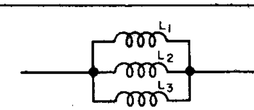
$$\theta = 0°$$



or where only 2 resistances R_1 and R_2 are involved,

$$Z = \frac{R_1\,R_2}{R_1 + R_2}$$

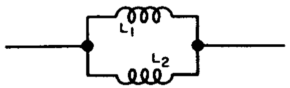
$$\theta = 0°$$



of inductance in parallel

$$Z = \frac{1}{\frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}} \ldots \text{etc.}}$$

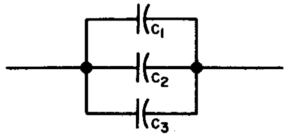
$$\theta = +90°$$



or where only 2 inductances L_1 and L_2 are involved,

$$Z = 2\pi f\left(\frac{L_1 L_2}{L_1 + L_2}\right)$$

$$\theta = +90^\circ$$



of capacitance in parallel

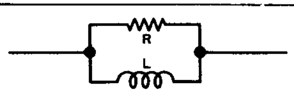
$$Z = \cfrac{1}{\cfrac{1}{X_{C1}} + \cfrac{1}{X_{C2}} + \cfrac{1}{X_{C3}} \ldots \text{etc.}}$$

$$\theta = -90^\circ$$

or where only 2 capacitances C_1 and C_2 are involved,

$$Z = \frac{1}{2\pi f\,(C_1 + C_2)}$$

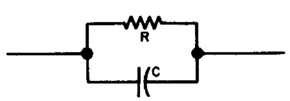
$$\theta = -90^\circ$$



of inductance and resistance in parallel,

$$Z = \frac{RX_L}{\sqrt{R^2 + X_L^2}}$$

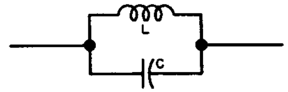
$$\theta = \text{arc tan}\,\frac{R}{X_L}$$



of capacitance and resistance in parallel,

$$Z = \frac{RX_C}{\sqrt{R^2 + X_C^2}}$$

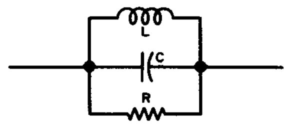
$$\theta = -\text{arc tan}\,\frac{R}{X_C}$$



of inductance and capacitance in parallel,

$$Z = \frac{X_L\,X_C}{X_L - X_C}$$

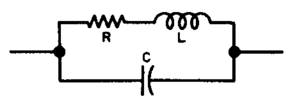
$$\theta = 0^\circ \text{ when } X_L = X_C$$



of inductance, resistance and capacitance in parallel

$$Z = \frac{RX_LX_C}{\sqrt{X_L^2X_C^2 + (RX_L - RX_C)^2}}$$

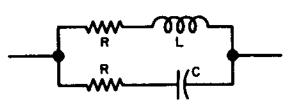
$$\theta = \text{arc tan}\,\frac{RX_C - RX_L}{X_L\,X_C}$$



of inductance and series resistance in parallel with capacitance

$$Z = X_C\sqrt{\frac{R^2 + X_L^2}{R^2 + (X_L - X_C)^2}}$$

$$\theta = \text{arc tan}\left(\frac{X_L\,X_C - X_L^2 - R^2}{RX_C}\right)$$



of capacitance and series resistance in parallel with inductance and series resistance

$$Z = \sqrt{\frac{(R_L^2 + X_L^2)\,(R_C^2 + X_C^2)}{(R_L + R_C)^2 + (X_L - X_C)^2}}$$

$$\theta = \text{arc tan}\,\frac{X_L(R_C^2+X_C^2) - X_C\,(R_L^2+X_L^2)}{R_L(R_C^2+X_C^2) + R_C(R_L^2+X_L^2)}$$

Conductance

In direct current circuits, conductance is expressed by

$$G = \frac{1}{R}$$

where G = conductance in mhos,
R = resistance in ohms.

In d-c circuits involving resistances R_1, R_2, R_3, etc., in parallel,

the total conductance is expressed by

$$G_{\text{total}} = G_1 + G_2 + G_3 \ldots \text{ etc.}$$

and the total current by

$$I_{\text{total}} = E\,G_{\text{total}}$$

and the amount of current in any single resistor, R_2 for example, in a parallel group, by

$$I_2 = \frac{I_{\text{total}}\,G_2}{G_1 + G_2 + G_3 \ldots \text{etc.}},$$

R, E and I in Ohm's law formulas for d-c circuits may be expressed in terms of conductance as follows:

$$R = \frac{1}{G}, \qquad E = \frac{I}{G}, \qquad I = EG,$$

where G = conductance in mhos,
R = resistance in ohms,
E = potential in volts,
I = current in amperes.

Susceptance

In an alternating current circuit, the susceptance of a series circuit is expressed by

$$B = \frac{X}{R^2 + X^2}$$

or, when the resistance is 0, susceptance becomes the reciprocal of reactance, or

$$B = \frac{1}{X}$$

where B = susceptance in mhos,
R = resistance in ohms,
X = reactance in ohms.

Admittance

In an alternating current circuit, the admittance of a series circuit is expressed by

$$Y = \frac{1}{\sqrt{R^2 + X^2}}$$

Admittance is also expressed as the reciprocal of impedance, or

$$Y = \frac{1}{Z}$$

where Y = admittance in mhos,
R = resistance in ohms,
X = reactance in ohms,
Z = impedance in ohms.

R and X in Terms of G and B

Resistance and reactance may be expressed in terms of conductance and susceptance as follows:

$$R = \frac{G}{G^2 + B^2}, \qquad X = \frac{B}{G^2 + B^2}.$$

G, B, Y and Z in Parallel Circuits

In any given a-c circuit containing a number of smaller parallel circuits only,

the effective conductance G_t is expressed by

$$G_t = G_1 + G_2 + G_3 \ldots \text{etc.},$$

and the effective susceptance B_t by

$$B_t = B_1 + B_2 + B_3 \ldots \text{etc.}$$

and the effective admittance Y_t by

$$Y_t = \sqrt{G_t^2 + B_t^2}$$

and the effective impedance Z_t by

$$Z_t = \frac{1}{\sqrt{G_t^2 + B_t^2}} \text{ or } \frac{1}{Y_t}$$

where R = resistance in ohms,
X = reactance (capacitive or inductive) in ohms,
G = conductance in mhos,
B = susceptance in mhos,
Y = admittance in mhos,
Z = impedance in ohms.

Transient *I* and *E* in *LCR* Circuits

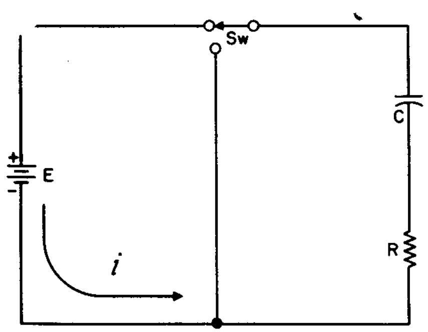
The formulas which follow may be used to closely approximate the growth and decay of current and voltage in circuits involving L, C and R:

where i = instantaneous current in amperes at any given time (t),
E = potential in volts as designated,
R = circuit resistance in ohms,
C = capacitance in farads,
L = inductance in henrys,
V = steady state potential in volts,
V_C = reactive volts across C,
V_L = reactive volts across L,
V_R = voltage across R

RC = time constant of RC circuit in seconds,
$\frac{L}{R}$ = time constant of RL circuit in seconds,
t = any given time in seconds after switch is thrown,
ϵ = a constant, 2.718 (base of the natural system of logarithms),
Sw = switch

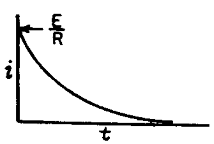
The time constant is defined as the time in seconds for current or voltage to fall to $\frac{1}{\epsilon}$ or 36.8% of its initial value or to rise to $\left(1-\frac{1}{\epsilon}\right)$ or approximately 63.2% of its final value.

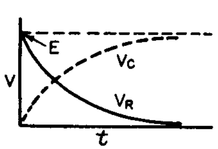
Charging a De-energized Capacitive Circuit



E = applied potential.

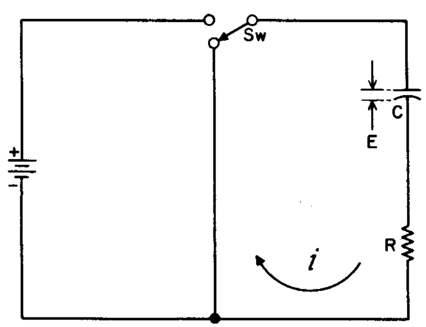
$$i = \frac{E}{R}\epsilon^{-\frac{t}{RC}}$$





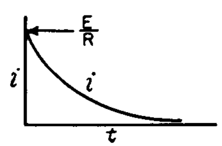
$$V_C = E\left(1-\epsilon^{-\frac{t}{RC}}\right) \qquad V_R = E\,\epsilon^{-\frac{t}{RC}}$$

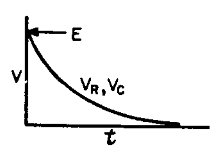
Discharging an Energized Capacitive Circuit



E = potential to which C is charged prior to closing Sw.

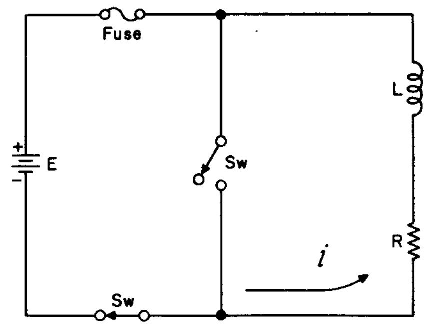
$$i = \frac{E}{R}\epsilon^{-\frac{t}{RC}}$$





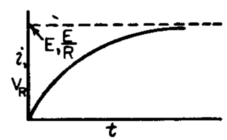
$$V_C = V_R = E\,\epsilon^{-\frac{t}{RC}}$$

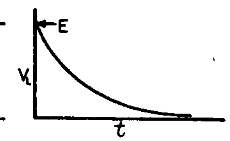
Voltage is Applied to a De-energized Inductive Circuit



E = applied potential

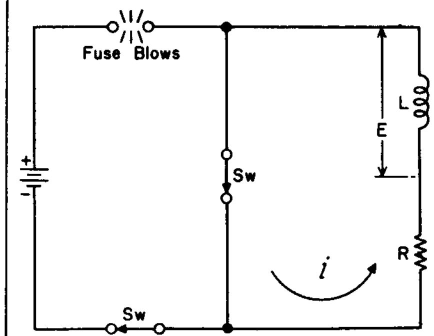
$$i = \frac{E}{R}\left(1-\epsilon^{-\frac{Rt}{L}}\right)$$





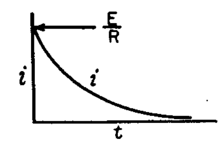
$$V_R = E\left(1-\epsilon^{-\frac{Rt}{L}}\right) \qquad V_L = E\epsilon^{-\frac{Rt}{L}}$$

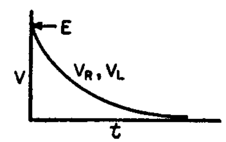
An Energized Inductive Circuit is Short Circuited



E = counter potential induced in coil when switch is closed.

$$i = \frac{E}{R}\epsilon^{-\frac{Rt}{L}}$$





$$V_L = V_R = E\epsilon^{-\frac{Rt}{L}}$$

Steady State Current Flow

In a Capacitive Circuit

In a capacitive circuit, where resistance loss components may be considered as negligible, the flow of current at a given alternating potential of constant frequency, is expressed by

$$I = \frac{E}{X_C} = \frac{E}{\left(\frac{1}{2\pi fC}\right)} = E\,(2\pi fC)$$

where I = current in amperes,
X_C = capacitive reactance of the circuit in ohms,
E = applied potential in volts.

In an Inductive Circuit

In an inductive circuit, where inherent resistance and capacitance components may be so low as to be negligible, the flow of current at a given alternating potential of a constant frequency, is expressed by

$$I = \frac{E}{X_L} = \frac{E}{2\pi fL}$$

where I = current in amperes,
X_L = inductive reactance of the circuit in ohms,
E = applied potential in volts.

Transmission Line Formulas

Concentric Transmission Lines

Characteristic impedance in ohms is given by

$$Z = 138 \log \frac{d_1}{d_2}$$

R-f resistance in ohms per foot of copper line, is given by

$$r = \sqrt{f}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)\times 10^{-3}$$

Attenuation in decibels per foot of line, is given by

$$a = \frac{4.6\sqrt{f}\,(d_1+d_2)}{d_1 d_2\left(\log \frac{d_1}{d_2}\right)}\times 10^{-6}$$

where Z = characteristic impedance in ohms,
r = radio frequency resistance in ohms per foot of *copper line,*
a = attenuation in decibels per foot of *line,*
d_1 = the *inside* diameter of the *outer conductor*, expressed in inches,
d_2 = the *outside* diameter of the *inner conductor*, expressed in inches,
f = frequency in megacycles.

Two-Wire Open Air Transmission Lines

Characteristic impedance in ohms is given by

$$Z = 276\left(\log \frac{2D}{d}\right)$$

Inductance in microhenrys per foot of *line* is given by

$$L = 0.281\left(\log \frac{2D}{d}\right)$$

Capacitance in micromicrofarads per foot of *line* is given by

$$C = \frac{3.68}{\log \frac{2D}{d}}$$

Attenuation in decibels per foot of *wire* is given by

$$db = \frac{0.0157\,R_f}{\log \frac{2D}{d}}$$

R-f resistance in Ohms per loop-foot of *wire*, is given by

$$R_f = \frac{2\times 10^{-3}\sqrt{f}}{d}$$

where Z = characteristic impedance in ohms,
D = spacing between wire centers in inches,
d = the diameter of the conductors in inches,
L = inductance in microhenrys per foot of *line,*
C = capacitance in micromicrofarads per foot of *line,*
db = attenuation in decibels per foot of *wire,*
R_f = *r-f* resistance in ohms per loop-foot of *wire,*
f = frequency in megacycles.

Vertical Antenna

The capacitance of a vertical antenna, shorter than one-quarter wave length at its operating frequency, is given by

$$C_a = \frac{17l}{\left[\left(\log_\epsilon \frac{24l}{d}\right)-1\right]\left[1-\left(\frac{fl}{246}\right)^2\right]}$$

where C_a = capacitance of the antenna in micromicrofarads,
l = height of antenna in feet,
d = diameter of antenna conductor in inches,
f = operating frequency in megacycles,
ϵ = 2.718 (the base of the natural system of logarithms).

Trigonometric Relationships

In any right triangle, if we let

θ = the acute angle formed by the hypotenuse and the base leg,
ϕ = the acute angle formed by the hypotenuse and the altitude leg,
H = the hypotenuse,
A = the side adjacent θ and opposite ϕ,
O = the side opposite θ and adjacent ϕ,

then

$$\text{sine of } \theta = \sin\theta = \frac{O}{H}$$

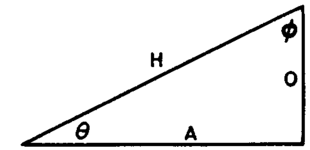
$$\text{cosine of } \theta = \cos\theta = \frac{A}{H}$$

$$\text{tangent of } \theta = \tan\theta = \frac{O}{A}$$

$$\text{cosecant of } \theta = \csc\theta = \frac{H}{O}$$

$$\text{secant of } \theta = \sec\theta = \frac{H}{A}$$

$$\text{cotangent of } \theta = \cot\theta = \frac{A}{O}$$



also

$\sin\theta = \cos\phi$ $\quad\csc\theta = \sec\phi$
$\cos\theta = \sin\phi$ $\quad\sec\theta = \csc\phi$
$\tan\theta = \cot\phi$ $\quad\cot\theta = \tan\phi$

and

$\frac{1}{\sin\theta} = \csc\theta$ $\quad\frac{1}{\csc\theta} = \sin\theta$

$\frac{1}{\cos\theta} = \sec\theta$ $\quad\frac{1}{\sec\theta} = \cos\theta$

$\frac{1}{\tan\theta} = \cot\theta$ $\quad\frac{1}{\cot\theta} = \tan\theta$

The expression "arc sin" indicates, "the angle whose sine is" . . .; likewise arc tan indicates, "the angle whose tangent is" . . . etc. See formulas in table below.

Known Values	Formulas for Determining Unknown Values of . . .				
	A	O	H	θ	ϕ
A & O			$\sqrt{A^2+O^2}$	arc tan $\frac{O}{A}$	arc tan $\frac{A}{O}$
A & H		$\sqrt{H^2-A^2}$		arc cos $\frac{A}{H}$	arc sin $\frac{A}{H}$
A & θ		$A\tan\theta$	$\frac{A}{\cos\theta}$		$90^\circ-\theta$
A & ϕ		$\frac{A}{\tan\phi}$	$\frac{A}{\sin\phi}$	$90^\circ-\phi$	
O & H	$\sqrt{H^2-O^2}$			arc sin $\frac{O}{H}$	arc cos $\frac{O}{H}$
O & θ	$\frac{O}{\tan\theta}$		$\frac{O}{\sin\theta}$		$90^\circ-\theta$
O & ϕ	$O\tan\phi$		$\frac{O}{\cos\phi}$	$90^\circ-\phi$	
H & θ	$H\cos\theta$	$H\sin\theta$			$90^\circ-\theta$
H & ϕ	$H\sin\phi$	$H\cos\phi$		$90^\circ-\phi$	

Vacuum Tube Formulas and Symbols

Vacuum Tube Constants

Amplication factor (*Mu or* μ) is given by

$$\mu = \frac{\Delta E_p}{\Delta E_g} \text{ (with } I_p \text{ constant)}$$

Dynamic plate resistance in ohms, is given by

$$r_p = \frac{\Delta E_p}{\Delta I_p} \text{ (with } E_g \text{ constant)}$$

Mutual conductance in mhos, is given by

$$g_m = \frac{\Delta I_p}{\Delta E_g} \text{ (with } E_p \text{ constant)}$$

Vacuum Tube Formulas

Gain per stage is given by

$$\mu\left(\frac{R_L}{R_L + r_p}\right)$$

Voltage output appearing in R_L is given by

$$\mu\left(\frac{E_s R_L}{r_p + R_L}\right)$$

Power output in R_L, is given by

$$R_L\left(\frac{\mu E_s}{r_p + R_L}\right)^2$$

Maximum power output in R_L which results when $R_L = r_p$, is given by

$$\frac{(\mu E_s)^2}{4 r_p}$$

Maximum undistorted power output in R_L, which results when $R_L = 2r_p$, is given by

$$\frac{2(\mu E_s)^2}{9 r_p}$$

Required cathode biasing resistor in ohms, for a single tube is given by

$$\frac{E_g}{I_k}$$

Vacuum Tube Symbols

Mu or μ = Amplification factor,
r_p = Dynamic plate resistance in ohms,
g_m = Mutual conductance in mhos,
E_p = Plate voltage in volts,
E_g = Grid voltage in volts,
I_p = Plate current in amperes,
R_L = Plate load resistance in ohms,
I_k = Total cathode current in amperes,
E_s = Signal voltage in volts,
Δ = change or variation in value, which may be either an increment (increase), or a decrement (decrease).

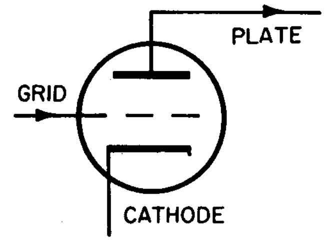
Peak, R.M.S., and Average A-C Values of *E* & *I*

Given Value	To get . . . Peak	R.M.S.	Av.
Peak		0.707 × Peak	0.637 × Peak
R.M.S.	1.41 × R.M.S.		0.9 × R.M.S.
Av.	1.57 × Av.	1.11 × Av.	

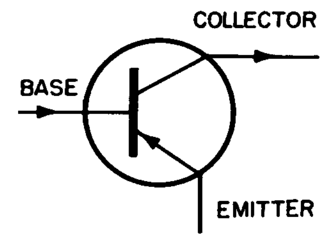
Transistor Formulas and Symbols

Common Emitter Configuration

Transistors can be made to amplify, detect, or to oscillate in much the same manner as vacuum tubes. Shown in the drawings below is a comparison between a triode vacuum-tube and a PNP transistor; where the transistor



Triode Vacuum Tube



PNP Transistor

base is comparable to the tube grid, the transistor emitter is comparable to the tube cathode, and the transistor collector is comparable to the tube plate.

Transistor Formulas

Input Resistance,

$$R_i = \frac{\Delta V_i}{\Delta I_i}$$

Current Gain,

$$A_i = \frac{\Delta I_c}{\Delta I_b} \text{ (with } V_c \text{ constant)}$$

Voltage Gain,

$$A_e = \frac{\Delta V_c}{\Delta V_b} \text{ (with } I_c \text{ constant)}$$

Output Resistance,

$$R_o = \frac{\Delta V_o}{\Delta I_o}$$

Power Gain,

$$A_p = \frac{\Delta P_o}{\Delta P_i}$$

The current gain of the common base configuration is alpha, where

$$\alpha = \frac{\Delta I_c}{\Delta I_e} \text{ (with } V_c \text{ constant)}$$

The current gain of the common emitter is beta, where

$$\beta = \frac{\Delta I_c}{\Delta I_b} \text{ (with } V_c \text{ constant).}$$

Transistor Symbols

α = Current gain common base
A_e (A_v) = Voltage gain
A_i = Current gain
A = Power gain
B = Current gain common emitter
I_b = Base current
I_c = Collector current
I_e = Emitter current
I_i = Input current
P_i = Input power
P_o = Output power
R_i = Input resistance
R_o = Output resistance
V_b = Base voltage
V_c = Collector voltage
V_i = Input voltage

A direct relationship exists between the alpha and beta of a transistor.

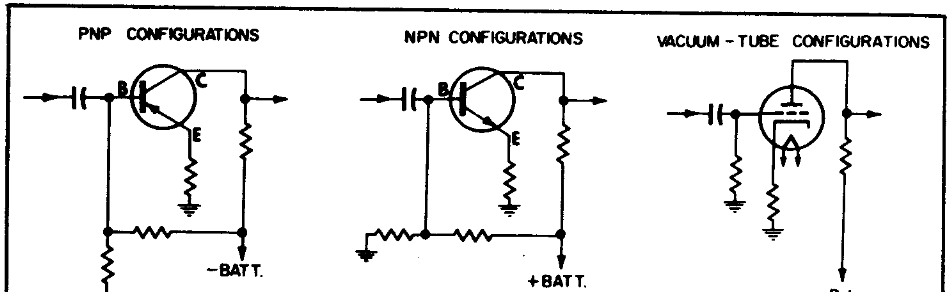
$$\alpha = \frac{B}{1 + B} \qquad B = \frac{\alpha}{1 - \alpha}$$

Courtesy Howard W. Sam's Photofact Publication: "ABC's of Transistors."

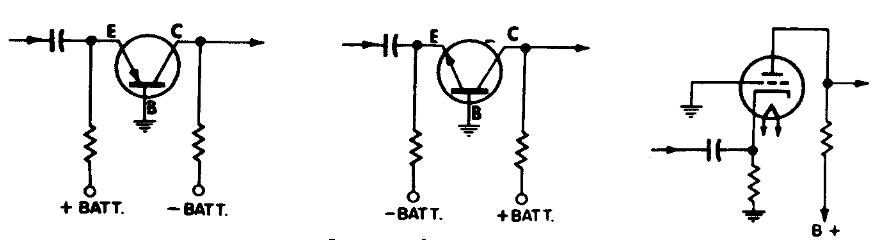
Transistor Amplifier Circuit Configurations

With Vacuum & Tube Counterparts

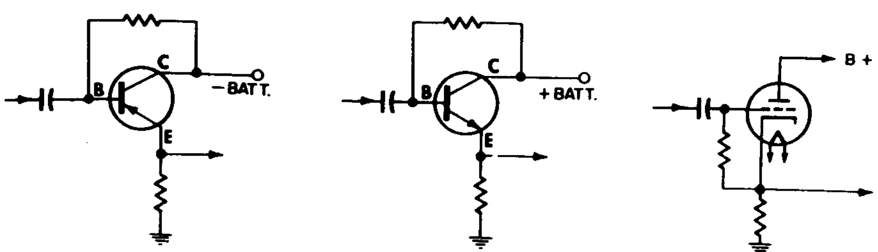
The transistors of primary interest to the radio engineer and service technician are the PNP and NPN junction types, whose transistor actions are identically alike, except that symbolically, the emitter arrow points towards the base in the PNP and away from the base in the NPN. The common-emitter circuits are used almost exclusively for most amplification purposes as are the common or grounded-cathode vacuum tube circuits. The common-base and common-grid as well as common-collector common-plate circuits are used more for special applications such as impedance matching to and from audio transmission lines, etc.



Common emitter—Common cathode.



Common base—Common grid.



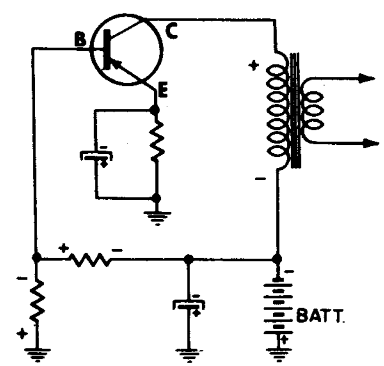
Common collector—Common plate.

Common-Emitter Amplifier Circuits

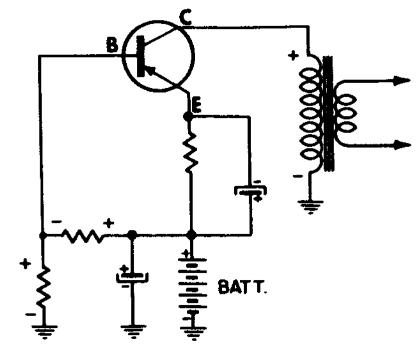
Using Transistors Only

In comparing the PNP and NPN circuits shown here, note that the current flow in the components of one is completely reversed in the other. With the vacuum tube, this complete interchange of current and voltage polarities does not exist. Because of this interchange in the transistor, circuits which have no parallel in vacuum-tube circuitry can be produced. Nevertheless, the circuits of transistorized equipment are still quite similar in many respects to those of equipment employing vacuum tubes.

Using PNP Transistors

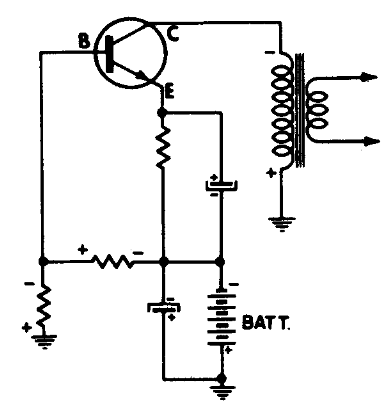


With Positive
Battery Terminal Grounded

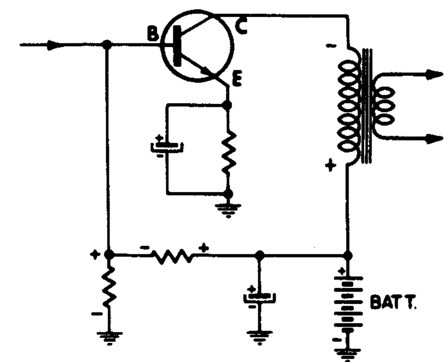


With Negative
Battery Terminal Grounded

Using NPN Transistors



With Positive
Battery Terminal Grounded

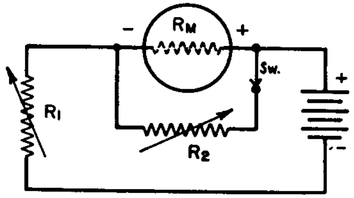


With Negative
Battery Terminal Grounded

D-C Meter Formulas

Meter Resistance

The d-c resistance of a milliammeter or voltmeter movement may be determined as follows:



1. Connect the meter in series with a suitable battery and variable resistance R_1 as shown in the diagram above.
2. Vary R_1 until a full scale reading is obtained.
3. Connect another variable resistor R_2 across the meter and vary its value until a half scale reading is obtained.
4. Disconnect R_2 from the circuit and measure its d-c resistance.

The meter resistance R_m is equal to the measured resistance of R_2.

Caution: Be sure that R_1 has sufficient resistance to prevent an off scale reading of the meter. The correct value depends upon the sensitivity of meter, and voltage of the battery. The following formula can be used if the full scale current of the meter is known:

$$R_1 = \frac{\text{voltage of the battery used}}{\text{full scale current of meter in amperes}}$$

For safe results, use twice the value computed. Also, never attempt to measure the resistance of a meter with an ohmmeter. To do so would in all probability result in a burned-out or severely damaged meter, since the current required for the operation of some ohmmeters and bridges is far in excess of the full scale current required by the movement of the average meter you may be checking.

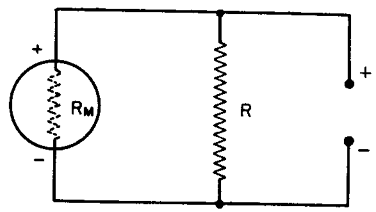
Ohms per Volt Rating of a Voltmeter

$$\Omega/V = \frac{1}{I_{fs}}$$

where Ω/V = ohms per volt,

I_{fs} = full scale current in amperes.

Fixed Current Shunts



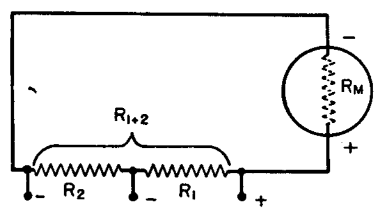
$$R = \frac{R_m}{N-1}$$

R = shunt value in ohms,

N = the new full scale reading divided by the original full scale reading, both being stated in the same units,

R_m = meter resistance in ohms.

Multi-Range Shunts



$$R_1 = \frac{R_{1+2} + R_m}{N}$$

R_1 = intermediate or tapped shunt value in ohms,

R_{1+2} = total resistance required for the lowest scale reading wanted,

R_m = meter resistance in ohms,

N = the new full scale reading divided by the original full scale reading, both being stated in the same units.

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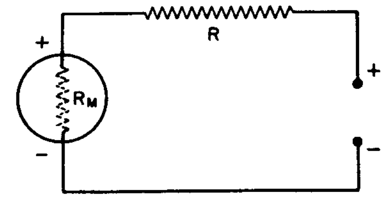
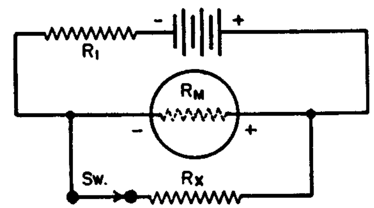
Voltage Multipliers



$$R = \frac{E_{fs}}{I_{fs}} - R_m$$

R = multiplier resistance in ohms,
E_{fs} = full scale reading required in volts,
I_{fs} = full scale current of meter in amperes,
R_m = meter resistance in ohms.

Measuring Resistance



with Milliammeter and Battery*

$$R_x = R_m \left(\frac{I_2}{I_1 - I_2}\right)$$

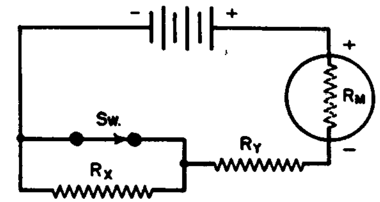
R_x = unknown resistance in ohms,
R_m = meter resistance in ohms, or effective meter resistance if a shunted range is used,
I_1 = current reading with switch open,
I_2 = current reading with switch closed,
R_1 = current limiting resistor of sufficient value to keep meter reading on scale when switch is open.

* Approximately true only when current limiting resistor is large as compared to meter resistance.

Shunt Values for 27-Ohm 0-1 Milliammeter

FULL SCALE CURRENT	SHUNT RESISTANCE
0-10 ma	3.0 ohms
0-50 ma	0.551 ohms
0-100 ma	0.272 ohms
0-500 ma	0.0541 ohms

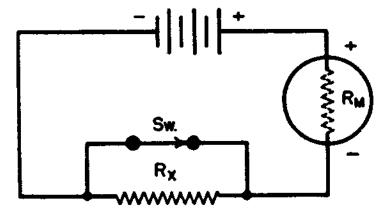
Measuring Resistance—(Continued)



with Milliammeter, Battery and Known Resistor

$$R_x = \left(R_y + R_m\right)\left(\frac{I_1 - I_2}{I_2}\right)$$

R_x = unknown resistance in ohms,
R_y = known resistance in ohms,
R_m = meter resistance in ohms,
I_1 = current reading with switch closed,
I_2 = current reading with switch open.



with Voltmeter and Battery

$$R_x = R_m \left(\frac{E_1}{E_2} - 1\right)$$

R_x = unknown resistance in ohms,
R_m = meter resistance in ohms, including multiplier resistance if a multiplied range is used,
E_1 = voltmeter reading with switch closed,
E_2 = voltmeter reading with switch open.

Multiplier Values for 27-Ohm 0-1 Milliammeter

FULL SCALE VOLTAGE	MULTIPLIER RESISTANCE
0-10 volts	10,000 ohms
0-50 volts	50,000 ohms
0-100 volts	100,000 ohms
0-250 volts	250,000 ohms
0-500 volts	500,000 ohms
0-1,000 volts	1,000,000 ohms

Ohm's Law for A-C Circuits

The fundamental Ohm's law formulas for a-c circuits are given by

$$I = \frac{E}{Z}, \qquad Z = \frac{E}{I},$$

$$E = IZ, \qquad P = EI \cos\theta$$

where I = current in amperes,
Z = impedance in Ohms,
E = volts across Z,
P = power in watts,
θ = phase angle in degrees.

Phase Angle

The phase angle is defined as the difference in degrees by which current leads voltage in a capacitive circuit, or lags voltage in an inductive circuit, and in series circuits is equal to the angle whose tangent is given by the

ratio $\frac{X}{R}$ and is expressed by

$$\text{arc tan} \frac{X}{R}$$

where X = the inductive or capacitive reactance in ohms,
R = the non-reactive resistance in ohms,
of the combined resistive and reactive components of the circuit under consideration.

Therefore
in a purely resistive circuit, $\theta = 0°$
in a purely reactive circuit, $\theta = 90°$
and in a resonant circuit, $\theta = 0°$

also when

$\theta = 0°$, $\cos\theta = 1$ and $P = EI$,
$\theta = 90°$, $\cos\theta = 0$ and $P = 0$.

Degrees $\times$ 0.0175 = radians.
1 radian = 57.3°.

Power Factor

The power-factor of any a-c circuit is equal to the true power in watts divided by the apparent power in volt-amperes which is equal to the cosine of the phase angle, and is expressed by

$$p.f. = \frac{EI \cos\theta}{EI} = \cos\theta$$

where

$p.f.$ = the circuit load power factor,
$EI \cos\theta$ = the true power in watts,
EI = the apparent power in volt-amperes,
E = the applied potential in volts
I = load current in amperes.

Therefore

in a purely resistive circuit.

$\theta = 0°$ and $p.f. = 1$

and in a reactive circuit,

$\theta = 90°$ and $p.f. = 0$

and in a resonant circuit,

$\theta = 0°$ and $p.f. = 1$

Ohm's Law for D-C Circuits

The fundamental Ohm's law formulas for d-c circuits are given by,

$$I = \frac{E}{R}, \qquad R = \frac{E}{I},$$

$$E = IR, \qquad P = EI.$$

where I = current in amperes,
R = resistance in ohms,
E = potential across R in volts,
P = power in watts.

Ohm's Law Formulas for D-C Circuits

Known Values	Formulas for Determining Unknown Values of . . .			
	I	R	E	P
I & R			IR	I^2R
I & E		$\frac{E}{I}$		EI
I & P		$\frac{P}{I^2}$	$\frac{P}{I}$	
R & E	$\frac{E}{R}$			$\frac{E^2}{R}$
R & P	$\sqrt{\frac{P}{R}}$		$\sqrt{PR}$	
E & P	$\frac{P}{E}$	$\frac{E^2}{P}$		

Ohm's Law Formulas for A-C Circuits

Known Values	Formulas for Determining Unknown Values of . . .			
	I	Z	E	P
I & Z			IZ	$I^2Z \cos\theta$
I & E		$\frac{E}{I}$		$IE \cos\theta$
I & P		$\frac{P}{I^2 \cos\theta}$	$\frac{P}{I \cos\theta}$	
Z & E	$\frac{E}{Z}$			$\frac{E^2 \cos\theta}{Z}$
Z & P	$\sqrt{\frac{P}{Z \cos\theta}}$		$\sqrt{\frac{PZ}{\cos\theta}}$	
E & P	$\frac{P}{E \cos\theta}$	$\frac{E^2 \cos\theta}{P}$		