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THE NEW AUDIO CYCLOPEDIA

Glen Ballou
Editor

JANESVILLE
JANESVILLE, W

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An *attenuator* or pad is an arrangement of noninductive resistors in an electrical circuit used to reduce the level of an audio or radio-frequency signal without introducing appreciable distortion. Attenuators may be fixed or variable and are often designed to reduce the signal in a logarithmic manner.

Attenuator networks have been in use since the inception of the telephone for controlling sound levels and the matching of impedances. Many of the present-day configurations are the work of Otto J. Zobel, W. H. Bode, R. L. Diezold, Sallie Pero Mead, and T. E. Shay, all of the Bell Telephone Laboratories. Also, tables of constants developed by P. K. McElroy (also of Bell Telephone Laboratories) for various values of expression and substitution in equations have long been a time-saver for the design engineer.

Attenuators and pads may be unbalanced or balanced. In an unbalanced attenuator, the resistive elements are on one side of the line only (Fig. 16-1) while in the balanced configuration, the resistive elements are located on both sides of the line (Fig. 16-2).

An unbalanced pad should be grounded to prevent leakage at the higher frequencies. The line without the resistor elements, called the *common*, is the only line that should be grounded.

A balanced attenuator should be grounded at a center point created by a balancing shunt resistance.

Balanced and unbalanced configurations cannot be directly connected; however, they may be connected by the use of an isolation transformer (Fig. 16-3). If the networks are not separated electrically, severe instability and leakage at the high frequencies can result, as illustrated in Fig. 16-4. If the networks are connected without the transformer, half of the balanced circuit will be shorted to the ground, as indicated by the broken line. The transformer will permit the transfer of the audio signal inductively while separating the grounds of the two networks. Even if the balanced network is not grounded, it should be isolated by a transformer. Transformers are usually designed for a 1:1 impedance ratio; however, they may have taps for other impedance ratios.

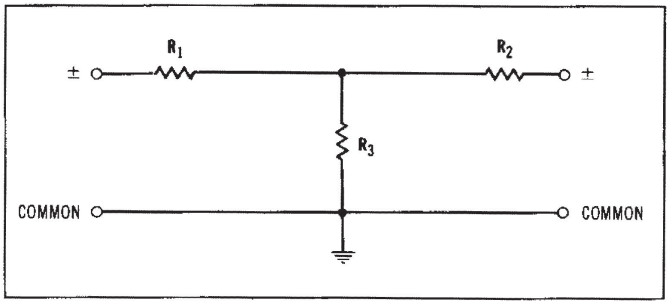


Figure 16-1 An unbalanced T-type attenuator.

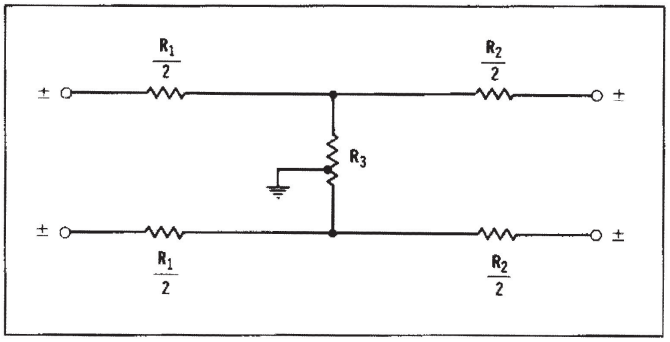


Figure 16-2 A balanced-T-type attenuator.

The term *loss* is constantly used in attenuator and pad design. Loss is a decrease in the power, voltage, or current at the output of a device compared to the power, voltage, or current at the input of the device. The loss in decibels may be calculated by means of one of the following equations:

$$dB_{loss} = 10 \log P_1/P_2 \quad (16\text{-}1)$$

or,

$$dB_{loss} = 20 \log V_1/V_2 \quad (16\text{-}2)$$

or,

$$dB_{loss} = 20 \log I_1/I_2 \quad (16\text{-}3)$$

where,

P_1 is the power at the input,
P_2 is the power at the output,
V_1 is the voltage at the input,
V_2 is the voltage at the output,
I_1 is the current at the input,
I_2 is the current at the output.

The *insertion loss* is created by the insertion of a device in an electrical circuit. The resulting loss is generally expressed in decibels.

A *minimum-loss pad* is designed to match circuits of unequal impedance with a minimum loss in the matching network. This minimum loss is dependent on the ratio of the terminating impedances.

The minimum loss for attenuators of unequal impedance may be read from the graph of Fig. 16-5.

The graph is entered at the bottom at the desired impedance ratio, then followed vertically until it intersects the diagonal line. The minimum loss in decibels is then read at the left margin. As an example, assume an impedance of 600 Ω is to be matched to an impedance of 150 Ω; this is an impedance ratio of four. For this ratio, the graph indicates a minimum loss of 11.5 dB. This is the lowest value for which a passive attenuator can be designed. In actual practice the network would be designed for a loss of 12 to 15 dB.

An *impedance-matching network* is a noninductive, resistive network designed for insertion between two or more circuits of equal or unequal impedance. When prop-

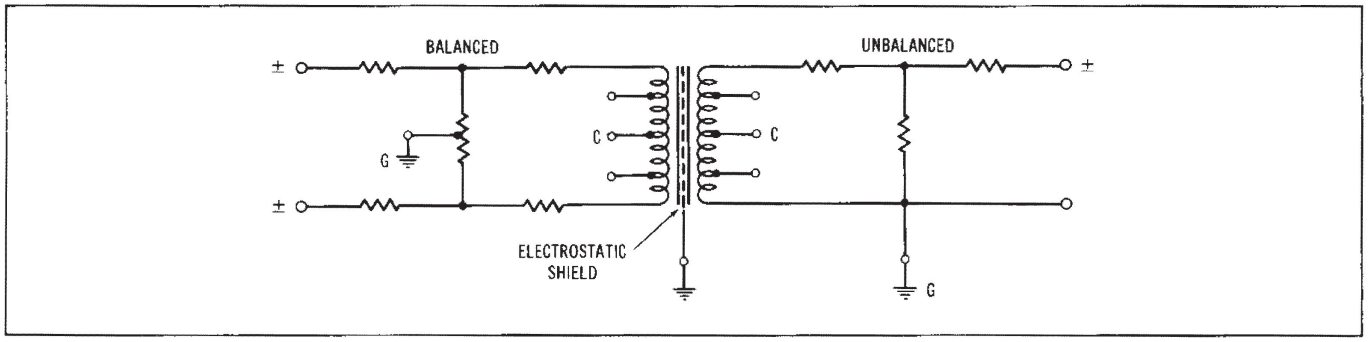


Figure 16-3 Method of connecting balanced and unbalanced networks through a transformer.

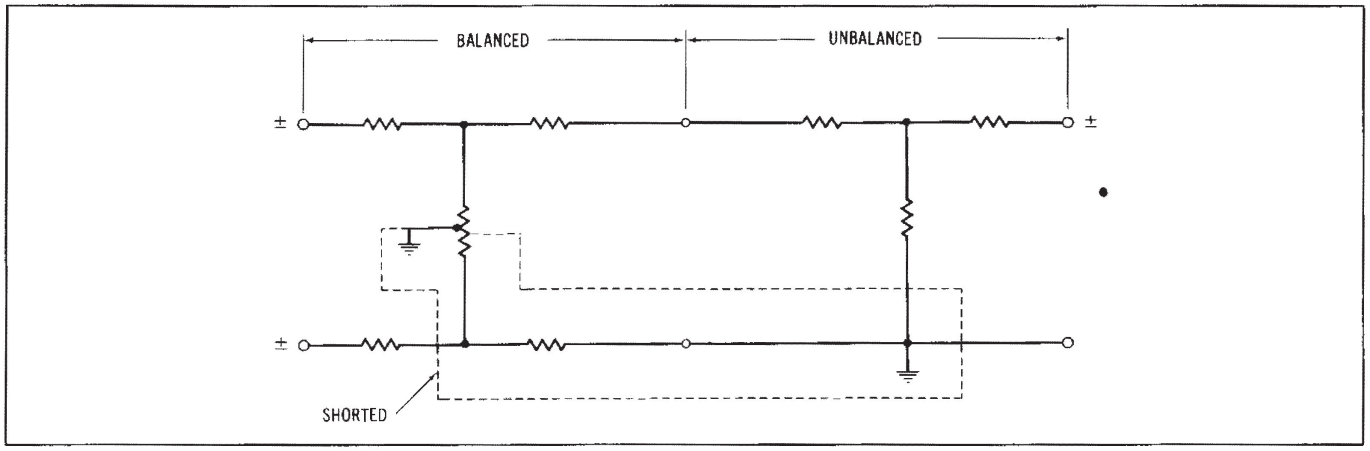


Figure 16-4 Two networks, one balanced and one unbalanced, connected incorrectly.

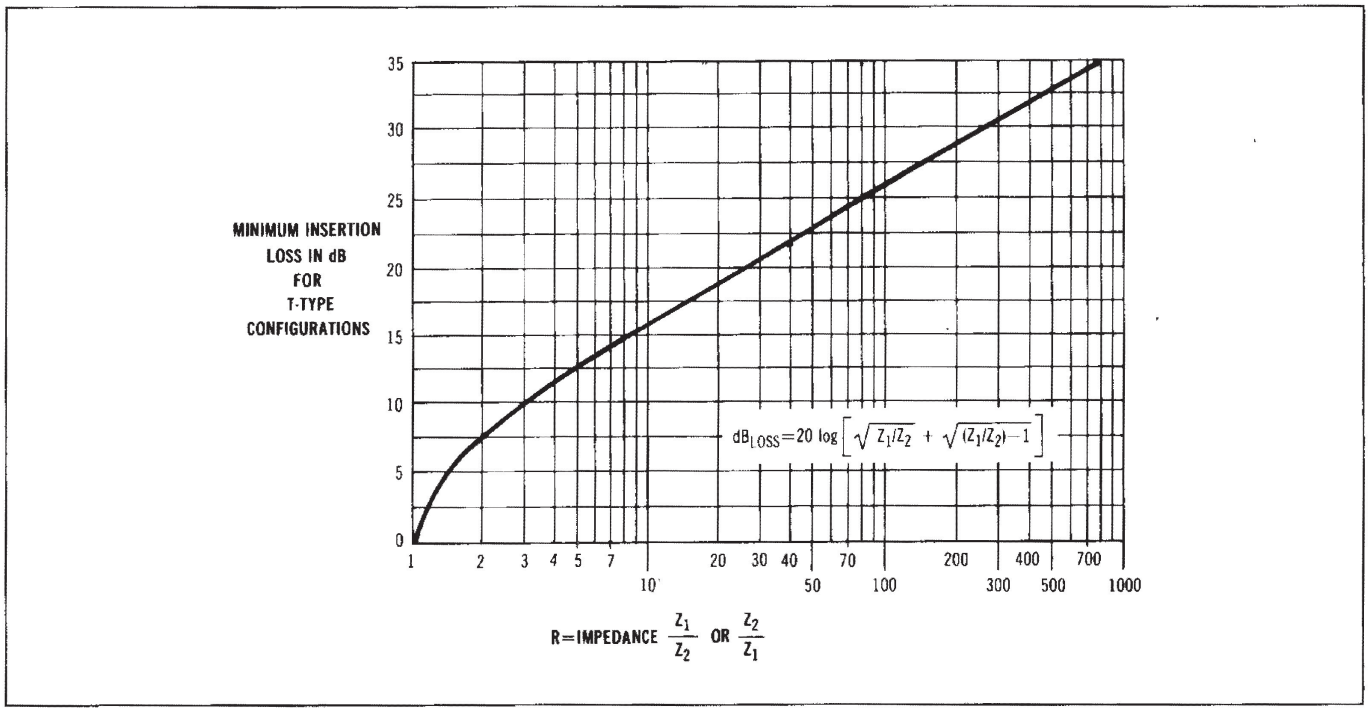


Figure 16-5 Minimum-loss graph for networks of unequal impedance.

erly designed, the network reflects the correct impedance to each branch of the circuit. A noninductive resistor is a resistor having little or no self-inductance.

If two resistive networks are mismatched, generally the frequency characteristics are not affected, only a loss in level occurs. If the impedance mismatch ratio is known, the loss in level may be directly read from the graph in Fig. 16-5 or with the formula

$$dB = 10\log[(Z_1 + Z_2)^2/(4Z_1Z_2)] \quad (16\text{-}4)$$

The equation used for designing a minimum-loss attenuator when only the larger impedance Z_1 is to be matched is

$$R_1 = Z_1 - Z_2 \quad (16\text{-}5)$$

Only a series resistor R is used, (Fig. 16-6).

If the smaller impedance is to be matched, the following formula is used:

$$R = Z_1 Z_2/(Z_1 - Z_2) \quad (16\text{-}6)$$

The resistor is shunted across the line as in Fig. 16-7.

To simplify the design of complex attenuators, a K value is used in the formula. K is the ratio of current, voltage, or power corresponding to a given value of attenuation expressed in decibels. The formula for K is

$$K = 10^{dB/20} \quad (16\text{-}7)$$

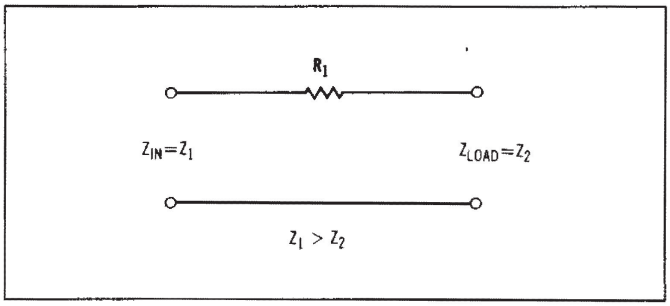


Figure 16-6 Impedance matching a low-impedance load to a high-impedance source.

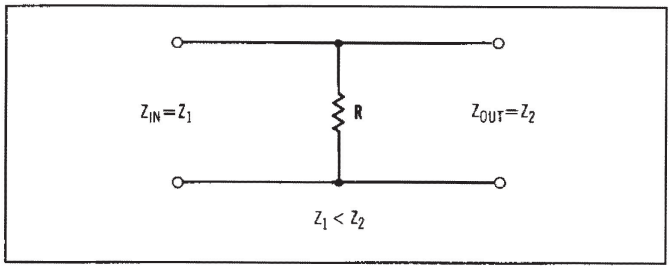


Figure 16-7 Impedance matching a high-impedance load to a low-impedance source.

To simplify the calculation of attenuator networks, the values of the most frequently used expressions as tabulated by P. K. McElroy are given in Table 16-1. The various values of the expressions are substituted in the equations, saving much time.

It is not good practice to build pads with over 40-dB loss, unless special precautions are taken to reduce the distributed capacity and leakage between the input and output sections. It is more practical to build two or more pads of lower loss and connect them in tandem. The total loss is the sum of the individual losses, assuming that all impedance matches are satisfied between sections.

When installing attenuators, the input and output circuits must be separated from each other and well shielded and grounded to prevent leakage at the higher frequencies. As an example, an attenuator of a 40-dB loss has a signal voltage reduction of 100:1 between the input and output terminals. Therefore, if coupling between the input and output circuits is permitted, serious leakage can occur at frequencies above 1000 Hz.

The resistance of an attenuator can be measured with an ohmmeter by terminating the output with a resistance equal to the terminating impedance and measuring the input resistance. The resistance as measured by the ohmmeter should equal the impedance of the pad. If the attenuator is variable, the dc resistance should be the same for all steps.

If the impedance of an attenuator is not known, its value can be determined by first measuring the resistance looking into one end with the far end open and then shorted. The impedance (Z) is the geometric mean of the two readings:

$$Z = \sqrt{Z_1 Z_2} \quad (16\text{-}8)$$

where,

Z_1 is the resistance measured with the far end open,

Z_2 is the resistance measured with the far end shorted.

This measurement will hold true only for pads designed to be operated between equal terminations. If the dc resistance of the two ends differs, the pad is designed to be operated between unequal impedances.

If an attenuator is to be converted to a different impedance, the new resistors can be calculated with the following formula:

$$R_x = K(R) \quad (16\text{-}9)$$

$$K = Z_x/Z \quad (16\text{-}10)$$

where,

Z_x is the new impedance,

Z is the known impedance,

K is the multiplying factor,

R is the known value of resistance,

R_x is the new value of resistance.

Any balanced or unbalanced attenuator may be directly

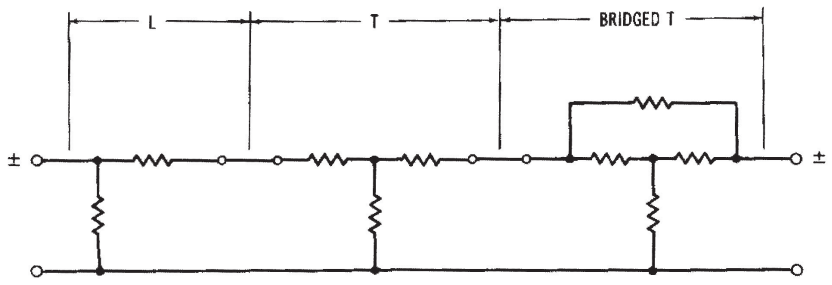
Table 16-1. "K" Factors for Calculating Attanuator Loss Values

n(dB)	$r = \frac{1}{K}$	K	K^2	$\frac{K-1}{K+1}$	$\frac{K+1}{K-1}$	$\frac{K}{K^2-1}$	$\frac{K^2-1}{K} = \frac{}{K-r}$	$\frac{K^2+1}{K^2-1}$	$\frac{K-1}{K} = \frac{}{1-r}$	$\frac{K}{K-1} = \frac{}{\frac{1}{1-r}}$	$\frac{1}{K-1}$	n(dB)
0.05	0.994260	1.0057731	1.011579	0.0028783	347.43	86.8618	0.011513	173.73	0.0057395	174.22	173.22	0.05
0.1	0.98855	1.011579	1.023292	0.0057562	173.73	43.4303	0.023029	86.866	1.011448	87.363	86.363	0.1
0.2	0.97724	1.023292	1.047128	0.011512	86.866	21.713	0.046052	43.437	0.022762	33.933	32.933	0.2
0.3	0.96605	1.035143	1.071520	0.017268	57.911	14.473	0.069093	28.965	0.033949	19.455	18.455	0.3
0.4	0.95499	1.047128	1.096477	0.023022	43.437	10.854	0.092138	21.730	0.045007	22.219	21.219	0.4
0.5	0.94406	1.059254	1.12202	0.028774	34.754	8.6810	0.11519	17.391	0.055939	17.877	16.877	0.5
0.6	0.93325	1.071520	1.14815	0.034525	28.965	7.2327	0.13827	14.499	0.066746	14.982	13.982	0.6
0.7	0.92257	1.083928	1.17490	0.040274	24.830	6.1974	0.16136	12.435	0.077428	12.915	11.915	0.7
0.8	0.91201	1.096477	1.20227	0.046019	21.730	5.4209	0.18447	10.888	0.087988	11.365	10.365	0.8
0.9	0.90157	1.10917	1.23027	0.051763	19.319	4.8168	0.20760	9.6853	0.098429	10.160	9.1600	0.9
1.0	0.89125	1.12202	1.25893	0.057502	17.391	4.3335	0.23077	8.7237	0.10875	9.1954	8.1954	1.0
1.1	0.88105	1.13501	1.28825	0.063237	15.814	3.9376	0.25396	7.9384	0.11895	8.4069	7.4069	1.1
1.2	0.87096	1.14815	1.31826	0.068968	14.499	3.6076	0.27719	7.2842	0.12904	7.7499	6.7499	1.2
1.3	0.86099	1.16145	1.34896	0.074695	13.388	3.3283	0.30046	6.7313	0.13901	7.1939	6.1939	1.3
1.4	0.85114	1.17490	1.38038	0.080418	12.435	3.0888	0.32376	6.2579	0.14886	6.7176	5.7176	1.4
1.5	0.84139	1.18850	1.41254	0.086132	11.610	2.8809	0.34711	5.8480	0.15861	6.3050	5.3050	1.5
1.6	0.83176	1.20227	1.44544	0.091846	10.888	2.6991	0.37051	5.4899	0.16824	5.9439	4.9439	1.6
1.7	0.82224	1.21618	1.47911	0.097551	10.251	2.5384	0.39394	5.1744	0.17776	5.6258	4.6258	1.7
1.8	0.81283	1.23027	1.51356	0.103249	9.6853	2.3956	0.41744	4.8944	0.18717	5.3427	4.3427	1.8
1.9	0.80353	1.24452	1.54882	0.108939	9.1794	2.2676	0.44099	4.6442	0.19647	5.0897	4.0897	1.9
2.0	0.79433	1.25893	1.58489	0.11463	8.7241	2.1523	0.46460	4.4195	0.20567	4.8620	3.8620	2.0
2.2	0.77625	1.28825	1.65959	0.12597	7.9384	1.9531	0.51200	4.0322	0.22375	4.4692	3.4692	2.2
2.4	0.75858	1.31826	1.73780	0.13728	7.2842	1.7867	0.55968	3.7108	0.24142	4.1421	3.1421	2.4
2.5	0.74989	1.33352	1.77828	0.14293	6.9966	1.7133	0.58363	3.5698	0.25011	3.9983	2.9983	2.5
2.6	0.74131	1.34896	1.81970	0.14856	6.7313	1.6457	0.60765	3.4399	0.25829	3.8657	2.8657	2.6
2.8	0.72444	1.38038	1.90546	0.15980	6.2579	1.5245	0.65594	3.2088	0.27556	3.6289	2.6289	2.8
3.0	0.70795	1.41254	1.99526	0.17100	5.8480	1.4192	0.70459	3.0095	0.29205	3.4240	2.4240	3.0
3.2	0.69183	1.44544	2.08930	0.18215	5.4899	1.3269	0.75361	2.8360	0.30817	3.2450	2.2450	3.2
3.4	0.67608	1.47911	2.18776	0.19326	5.1744	1.2453	0.80302	2.6838	0.32392	3.0872	2.0872	3.4
3.5	0.66834	1.49623	2.2387	0.19879	5.0304	1.2079	0.82789	2.6147	0.33166	3.0152	2.0152	3.5
3.6	0.66069	1.51356	2.2909	0.20432	4.8944	1.1725	0.85289	2.5493	0.33931	2.9472	1.9472	3.6
3.8	0.64565	1.54882	2.3988	0.21532	4.6442	1.1072	0.90314	2.4298	0.35435	2.8221	1.8221	3.8
4.0	0.63096	1.58489	2.5119	0.22627	4.4194	1.0483	0.95393	2.3229	0.36904	2.7097	1.7097	4.0
4.5	0.59566	1.67880	2.8184	0.25340	3.9464	0.92323	1.08314	2.0999	0.40434	2.4732	1.4732	4.5
5.0	0.56234	1.77828	3.1623	0.28013	3.5698	0.82241	1.21594	1.9249	0.43766	2.2849	1.2849	5.0
5.5	0.53088	1.88365	3.5481	0.30643	3.2633	0.73922	1.35277	1.7849	0.46912	2.1317	1.1317	5.5
6.0	0.50119	1.99526	3.9811	0.33228	3.0095	0.66932	1.49407	1.6709	0.49881	2.0048	1.0048	6.0
6.5	0.47315	2.1135	4.4668	0.35764	2.7961	0.60964	1.6403	1.5769	0.52685	1.89807	0.89807	6.5
7.0	0.44668	2.2387	5.0119	0.38246	2.6146	0.55801	1.7920	1.4985	0.55332	1.80730	0.80730	7.0
7.5	0.42170	2.3714	5.6234	0.40677	2.4854	0.51291	1.9497	1.4326	0.57830	1.72918	0.72918	7.5

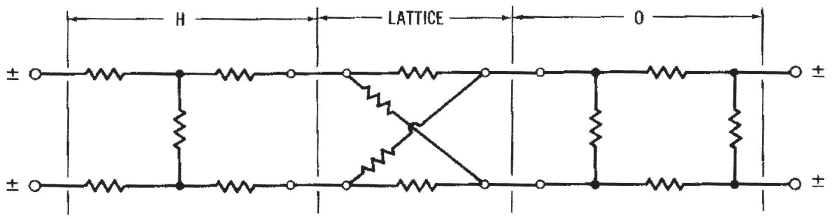
8.0	0.39811	2.5119	6.3096	0.43051	2.3228	0.47309	2.1138	1.3767	0.60180	1.66142	0.66142	8.0
8.5	0.37584	2.6607	7.0795	0.45366	2.2043	0.43765	2.2849	1.3290	0.62416	1.60216	0.60216	8.5
9.0	0.35481	2.8184	7.9433	0.47622	2.0999	0.40592	2.4636	1.2880	0.64519	1.54993	0.54993	9.0
9.5	0.33497	2.9854	8.9125	0.49817	2.0074	0.37730	2.6504	1.2528	0.66503	1.50368	0.50368	9.5
10.0	0.31623	3.1623	10.000	0.51950	1.9249	0.35137	2.8561	1.2222	0.68377	1.46247	0.46247	10.0
10.5	0.29854	3.3497	11.220	0.54020	1.8512	0.32775	3.0512	1.1957	0.70146	1.42559	0.42559	10.5
11.0	0.28184	3.5481	12.589	0.56026	1.7849	0.30616	3.2663	1.1726	0.71816	1.39245	0.39245	11.0
11.5	0.26607	3.7584	14.125	0.57969	1.7251	0.28635	3.4923	1.1524	0.73393	1.36253	0.36253	11.5
12.0	0.25119	3.9811	15.849	0.59848	1.6709	0.26811	3.7299	1.1347	0.74881	1.33545	0.33545	12.0
12.5	0.23714	4.2170	17.783	0.61664	1.6217	0.25127	3.9799	1.1192	0.76286	1.31085	0.31085	12.5
13.0	0.22387	4.4668	19.953	0.63416	1.5769	0.23568	4.2429	1.1055	0.77613	1.28845	0.28845	13.0
13.5	0.21135	4.7315	22.387	0.65105	1.5360	0.22123	4.5202	1.0935	0.78865	1.26799	0.26799	13.5
14.0	0.19953	5.0119	25.119	0.66733	1.4985	0.20780	4.8124	1.0829	0.80047	1.24926	0.24926	14.0
14.5	0.18836	5.3088	28.184	0.68298	1.4642	0.19529	5.1204	1.0736	0.81164	1.23208	0.23208	14.5
15.0	0.17783	5.6234	31.623	0.69804	1.4326	0.18363	5.4456	1.0653	0.82217	1.21629	0.21629	15.0
15.5	0.16788	5.9566	35.481	0.71250	1.4035	0.17275	5.7887	1.0580	0.83212	1.20175	0.20175	15.5
16.0	0.15849	6.3096	39.811	0.72639	1.3767	0.16257	6.1511	1.0515	0.84151	1.18834	0.18834	16.0
16.5	0.14962	6.6834	44.668	0.73970	1.3519	0.15305	6.5338	1.0458	0.85038	1.17595	0.17595	16.5
17.0	0.14125	7.0795	50.119	0.75246	1.3290	0.14413	6.9382	1.04071	0.85875	1.16449	0.16449	17.0
17.5	0.13335	7.4989	56.234	0.76468	1.3077	0.13577	7.3655	1.03621	0.86665	1.15387	0.15387	17.5
18.0	0.12589	7.9433	63.096	0.77637	1.2880	0.12792	7.8174	1.03220	0.87411	1.14402	0.14402	18.0
18.5	0.118850	8.4139	70.795	0.78755	1.2698	0.12055	8.2950	1.02866	0.88115	1.13488	0.13488	18.5
19.0	0.112202	8.9125	79.433	0.79823	1.2528	0.11363	8.8003	1.02550	0.88780	1.12638	0.12638	19.0
19.5	0.105925	9.4406	89.125	0.80844	1.2369	0.10713	9.3347	1.02269	0.89407	1.11847	0.11847	19.5
20.0	0.100000	10.0000	100.000	0.81818	1.2222	0.10101	9.9000	1.02020	0.90000	1.11111	0.11111	20.0
20.5	0.094406	10.5925	112.202	0.82747	1.2085	0.095255	10.498	1.01799	0.90559	1.10425	0.10425	20.5
21.0	0.089125	11.2022	125.893	0.83634	1.1957	0.089841	11.131	1.01601	0.91087	1.09785	0.097815	21.0
21.5	0.084139	11.8850	141.254	0.84478	1.1837	0.084739	11.801	1.01426	0.91586	1.09187	0.091870	21.5
22.0	0.079433	12.589	158.49	0.85282	1.1726	0.079935	12.510	1.01270	0.92057	1.08629	0.086291	22.0
22.5	0.074989	13.335	177.83	0.86048	1.1621	0.075411	13.260	1.01126	0.92501	1.08107	0.081070	22.5
23.0	0.070795	14.125	199.53	0.86777	1.1524	0.071148	14.054	1.01007	0.92921	1.07619	0.076190	23.0
23.5	0.066834	14.962	223.87	0.87470	1.1432	0.067133	14.895	1.00897	0.93317	1.07162	0.071623	23.5
24.0	0.063096	15.849	251.19	0.88130	1.1347	0.063348	15.786	1.00799	0.93690	1.06734	0.067345	24.0
24.5	0.059566	16.788	281.84	0.88756	1.1267	0.059778	16.728	1.00712	0.94043	1.06334	0.063339	24.5
25.0	0.056234	17.783	316.23	0.89352	1.1192	0.056413	17.727	1.00634	0.94377	1.05985	0.059584	25.0
25.5	0.053088	18.836	354.81	0.89917	1.1121	0.053238	18.783	1.00565	0.94691	1.05607	0.056066	25.5
26.0	0.050119	19.953	398.11	0.90455	1.1055	0.050246	19.903	1.00504	0.94988	1.05276	0.052762	26.0
26.5	0.047315	21.135	446.68	0.90965	1.0993	0.047422	21.088	1.00449	0.95268	1.04966	0.049665	26.5
27.0	0.044668	22.387	501.19	0.91448	1.0935	0.044757	22.342	1.00400	0.95533	1.04676	0.046757	27.0
27.5	0.042170	23.714	562.34	0.91907	1.0881	0.042245	23.672	1.00356	0.95783	1.04403	0.044026	27.5
28.0	0.039811	25.119	630.96	0.92343	1.0829	0.039874	25.079	1.00317	0.96019	1.04146	0.041461	28.0
28.5	0.037584	26.607	707.95	0.92755	1.0781	0.037636	26.569	1.00283	0.96242	1.03905	0.039052	28.5
29.0	0.035481	28.184	794.33	0.93147	1.0736	0.035526	28.149	1.00252	0.96452	1.03679	0.036786	29.0
29.5	0.033497	29.854	891.25	0.93518	1.0693	0.033534	29.821	1.00225	0.96650	1.03466	0.034657	29.5
30.0	0.031623	31.623	1,000.0	0.93869	1.0653	0.031655	31.591	1.00200	0.96836	1.03266	0.032655	30.0
31.0	0.028184	35.481	1,258.9	0.94518	1.0580	0.028207	35.453	1.00159	0.97182	1.02900	0.029001	31.0

Table 16-1—cont. "K" Factors for Calculating Attenuator Loss Values

n(dB)	$r = \frac{1}{K}$	K	K^2	$\frac{K-1}{K+1}$	$\frac{K+1}{K-1}$	$\frac{K}{K^2-1}$	$\frac{K^2-1}{K} = \frac{}{K-r}$	$\frac{K^2+1}{K^2-1}$	$\frac{K-1}{K} = \frac{}{1-r}$	$\frac{K}{K-1} = \frac{}{\frac{1}{1-r}}$	$\frac{1}{K-1}$	n(dB)
31.5	0.026607	37.584	1,412.5	0.94817	1.0547	0.026627	37.558	1.00142	0.97339	1.02733	0.027334	31.5
32.0	0.025119	39.811	1,584.9	0.95099	1.0515	0.025135	39.786	1.00126	0.97488	1.02577	0.025766	32.0
33.0	0.022387	44.668	1,995.3	0.95621	1.0458	0.022398	44.646	1.00100	0.97761	1.02290	0.022900	33.0
34.0	0.019953	50.119	2,511.9	0.96088	1.04072	0.019961	50.099	1.00080	0.98005	1.02036	0.020359	34.0
34.5	0.018836	53.088	2,818.4	0.96302	1.03840	0.018843	53.069	1.00071	0.98116	1.01920	0.019198	34.5
35.0	0.017783	56.234	3,162.3	0.96506	1.03621	0.017788	56.216	1.00063	0.98222	1.01810	0.018105	35.0
36.0	0.015849	63.096	3,981.1	0.96880	1.03221	0.015853	63.080	1.00050	0.98415	1.01610	0.016104	36.0
37.0	0.014125	70.795	5,011.9	0.97214	1.02866	0.014128	70.781	1.00040	0.98588	1.01433	0.014328	37.0
37.5	0.013335	74.989	5,623.4	0.97368	1.02703	0.013338	74.976	1.00036	0.98666	1.01352	0.013516	37.5
38.0	0.012589	79.433	6,309.6	0.97513	1.02550	0.012591	79.420	1.00032	0.98741	1.01275	0.012750	38.0
39.0	0.0112202	89.125	7,943.3	0.97781	1.02270	0.0112216	89.114	1.00025	0.98878	1.01135	0.011348	39.0
40.0	0.0100000	100.000	10,000.	0.98020	1.02020	0.0100010	99.990	1.00020	0.99000	1.01010	0.010101	40.0
40.5	0.0094406	105.925	11,220.	0.98130	1.01906	0.0094414	105.916	1.00018	0.99056	1.00953	0.0095306	40.5
41.0	0.0089125	112.202	12,589.	0.98233	0.01799	0.0089134	112.193	1.00016	0.99109	1.00899	0.0089926	41.0
42.0	0.0079433	125.89	15,849.	0.98424	1.01601	0.0079436	125.88	1.00013	0.99206	1.00801	0.0080070	42.0
43.0	0.0070795	141.25	19,953.	0.98594	1.01426	0.0070795	141.24	1.00010	0.99292	1.00713	0.0071301	43.0
43.5	0.0066834	149.62	22,387.	0.98672	1.01346	0.0066834	149.61	1.00009	0.99332	1.00673	0.0067286	43.5
44.0	0.0063096	158.49	25,119.	0.98746	1.01270	0.0063096	158.49	1.00008	0.99369	1.00635	0.0063496	44.0
45.0	0.0056234	177.83	31,623.	0.98887	1.01131	0.0056234	177.83	1.00006	0.99438	1.00566	0.0056551	45.0
46.0	0.0050119	199.53	39,811.	0.99003	1.01007	0.0050119	199.53	1.00005	0.99499	1.00504	0.0050370	46.0
46.5	0.0047315	211.35	44,668.	0.99058	1.00951	0.0047315	211.35	1.000045	0.99527	1.00475	0.0047540	46.5
47.0	0.0044668	223.87	50,119.	0.99111	1.00897	0.0044668	223.87	1.000040	0.99553	1.00449	0.0044869	47.0
48.0	0.0039811	251.19	63,096.	0.99207	1.00799	0.0039811	251.19	1.000032	0.99602	1.00400	0.0039970	48.0
49.0	0.0035481	281.84	79,433.	0.99293	1.00712	0.0035481	281.84	1.000025	0.99645	1.00356	0.0035607	49.0
50.0	0.0031623	316.23	100,000.	0.99370	1.00634	0.0031623	316.23	1.000020	0.99684	1.00317	0.0031723	50.0
51.0	0.0028184	354.81	125,890.	0.99438	1.00565	0.0028184	354.81	1.000016	0.99718	1.00283	0.0028264	51.0
52.0	0.0025119	398.11	158,490.	0.99499	1.00504	0.0025119	398.11	1.000013	0.99749	1.00252	0.0025182	52.0
54.0	0.0019953	501.19	251,190.	0.99602	1.00400	0.0019953	501.19	1.000008	0.99801	1.00200	0.0019992	54.0
55.0	0.0017783	564.34	316,230.	0.99645	1.00356	0.0017783	562.34	1.000006	0.99822	1.00178	0.0017815	55.0
56.0	0.0015849	630.96	398,110.	0.99684	1.00317	0.0015849	630.96	1.000005	0.99842	1.00159	0.0015874	56.0
57.0	0.0014125	707.95	501,190.	0.99718	1.00283	0.0014125	707.95	1.000004	0.99859	1.00141	0.0014145	57.0
58.0	0.0012589	794.33	630,960.	0.99749	1.00252	0.0012589	794.33	1.000003	0.99874	1.00126	0.0012605	58.0
60.0	0.0010000	1,000.0	10^6	0.99800	1.00200	0.0010000	1,000.0	1.000002	0.99900	1.00100	0.0010010	60.0
65.0	0.00056234	1,778.3	3.1623×10^6	0.99888	1.00112	0.00056234	1,778.3	1.000001	0.99944	1.00056	0.00056265	65.0
70.0	0.00031623	3,162.3	10^7	0.99937	1.00063	0.00031623	3,162.3	1.000000	0.99968	1.00032	0.00031633	70.0
75.0	0.00017783	5,623.4	3.1623×10^7	0.99964	1.00036	0.00017783	5,623.4	1.000000	0.99982	1.00018	0.00017786	75.0
80.0	0.00010000	10,000.	10^8	0.99980	1.00020	0.00010000	10,000.	1.000000	0.99990	1.00010	0.00010001	80.0
85.0	0.000056234	17,783.	3.1623×10^8	0.99989	1.00011	0.000056234	17,783.	1.000000	0.99994	1.00006	0.000056237	85.0
90.0	0.000031632	31,623.	10^9	0.99994	1.00006	0.000031623	31,623.	1.000000	0.99997	1.00003	0.000031624	90.0
95.0	0.000017783	56,234.	3.1623×10^9	0.99996	1.00004	0.000017783	56,234.	1.000000	0.99998	1.00002	0.000017783	95.0
100.0	0.000010000	10^5	10^{10}	0.99998	1.00002	0.000010000	10^5	1.000000	0.99999	1.00001	0.000010000	100.0



(A) Unbalanced.



(B) Balanced.

Figure 16-8 Attenuators connected in tandem.

connected to another, provided that the impedance match is satisfied and the configurations are of such nature that they will not cause an unbalanced condition. Fig. 16-8A shows how an L, a bridged-T, and a plain-T pad may be connected in tandem. Fig. 16-8B shows the method of connecting balanced attenuator configurations in tandem.

16.1 L PADS

L pads are the simplest form of attenuator and consist of two resistive elements connected in the form of an L, as shown in Fig. 16-9. This pad does not reflect the same impedance in both directions. An impedance match is afforded only in the direction of the arrow shown in the figures. If an L-type network is employed in a circuit that is sensitive to impedance match, the circuit characteristics may be affected. An L-type network should not be used, except where a minimum loss is required and a network of the T configuration will not serve because its minimum loss is too high.

For unequal impedances, the impedance match may be in the direction of the larger or the smaller impedance but not both.

The arrows in Fig. 16-9 indicate the direction of impedance match. If the network is designed to match the impedance in the direction of the series arm, the mismatch is toward the shunt arm. The mismatch increases with the increase of loss. At high values of attenuation, the value of the shunt resistor may become a fraction of an ohm, which can have a serious effect on the circuit to which it is connected.

The configuration for an L-type network operating between impedances of unequal value, Z_1 and Z_2, is shown in Fig. 16-9A. The impedance match is toward the larger of the two impedances, Z_1, and the values of the resistors are

$$R_1 = \frac{Z_1}{S}\left(\frac{KS - 1}{K}\right) \qquad (16\text{-}11)$$

$$R_2 = \frac{Z_1}{S}\left(\frac{1}{K - S}\right) \qquad (16\text{-}12)$$

where,

S equals $\sqrt{Z_1/Z_2}$

For a condition where the impedances are equal and the impedance match is in the direction of the arrows, as shown in Fig. 16-9B, the values of the resistors may be calculated by the equation

$$R_1 = Z[(K - 1)/K] \qquad (16\text{-}13)$$

$$R_2 = Z[1/(K - 1)] \qquad (16\text{-}14)$$

For a condition in which the impedances are unequal and the impedance match is toward the smaller of the two impedances, as shown in Fig. 16-9C, the values of the resistors are determined by the equation

$$R_1 = (Z_1/S)(K - S) \quad (16\text{-}15)$$

$$R_2 = \frac{Z_1}{S}\left(\frac{K}{KS - 1}\right) \quad (16\text{-}16)$$

where,
S equals $\sqrt{Z_1/Z_2}$.

For the conditions shown in Fig. 16-9D, resistors R_1 and R_2 may be calculated by the equation

$$R_1 = Z(K - 1) \quad (16\text{-}17)$$

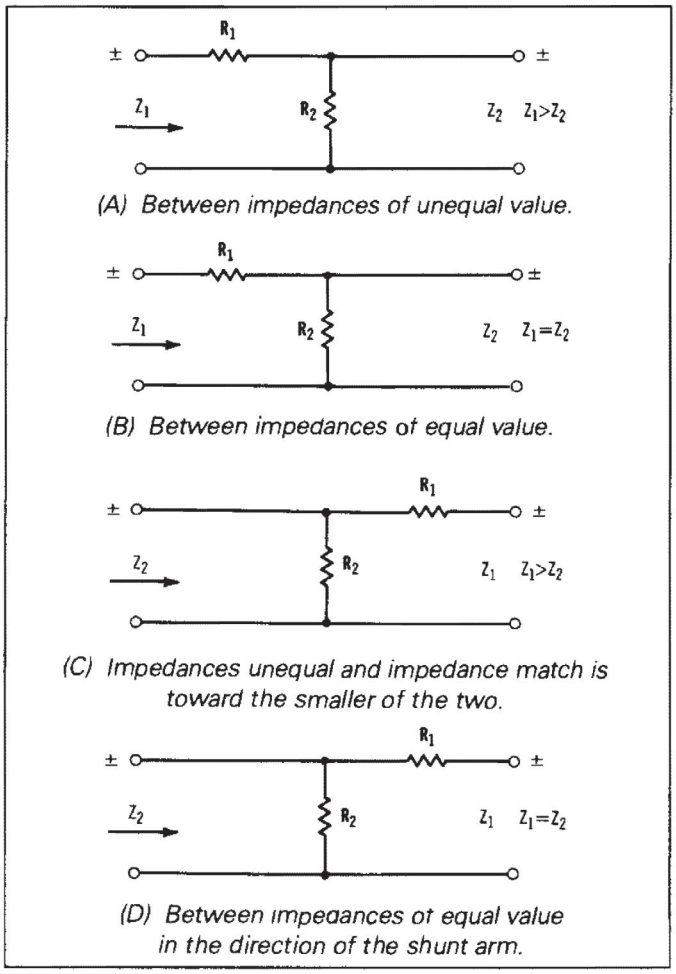
$$R_2 = Z[K/(K - 1)] \quad (16\text{-}18)$$

If a minimum-loss L attenuator is used to match two impedances of unequal value, as shown in Fig. 16-9A, the resistor values will be

$$R_1 = \sqrt{Z_1(Z_1 - Z_2)} \quad (16\text{-}19)$$

$$R_2 = Z_1Z_2/R_1 \quad (16\text{-}20)$$

where,
R_1 is the series resistor connected in the side of the larger impedance,
R_2 is the shunt resistor.



(A) Between impedances of unequal value.

(B) Between impedances of equal value.

(C) Impedances unequal and impedance match is toward the smaller of the two.

(D) Between impedances of equal value in the direction of the shunt arm.

Figure 16-9 Configurations of L-type networks.

The loss through the attenuator will be

$$dB = 20\log\sqrt{Z_1/Z_2} + \sqrt{(Z_1/Z_2) - 1} \quad (16\text{-}21)$$

16.2 DIVIDING NETWORKS

Dividing or *combining networks* are resistive networks designed to combine several devices or circuits, each having the same impedance, as shown in Fig. 16-10A. The resistors may be calculated as follows:

$$R_B = [(N - 1)/(N + 1)]Z \quad (16\text{-}22)$$

where,
R_B is the building-out resistor,
N is the number of circuits fed by the source impedance,
Z is the circuit impedance.

The loss of the network is

$$dB = 20\log(N - 1) \quad (16\text{-}23)$$

where,
N is the number of input or output circuits.

Unused circuits of a dividing or combining network must be terminated in a resistive load equal to the normal load impedance.

This same circuit can be reversed and used as a combining network.

Combining or branching networks may also be designed as a series configuration, as shown in Fig. 16-10B. For equal impedances the equation is

$$R_1 = [(N + 1)/(N - 1)]Z \quad (16\text{-}24)$$

where,
R_1 is the terminating resistor,
N is the number of branch circuits.

The insertion loss may be calculated

$$dB = 20\log(N) \quad (16\text{-}25)$$

where,
N is the number of branch circuits.

A series configuration can only be used in an ungrounded circuit. The insertion loss of a combining network may be avoided by the use of an active combining network.

16.3 T ATTENUATORS

A T-type attenuator is a network consisting of three resistors connected in the form of a T as shown in Fig. 16-1. The network may be designed to supply an impedance match between circuits of equal or unequal impedance. When designed for use between circuits of unequal impedance, it is often referred to as a *taper pad.*