SUPPLEMENTARY DATA FOR ATTENUATOR AND IMPEDANCE - MATCHING NETWORKS

®

the hallicrafters co.
4401 W. FIFTH AVENUE • CHICAGO 24, ILLINOIS

This booklet was developed by Hallicrafters to aid in matching their exciters and transmitters to their linear amplifiers.

When a Transmitter-Exciter is used to drive a Linear Amplifier, swamping or padding of a portion of the Exciter output may be required for optimum performance.

The degree of swamping or padding will depend upon the driving power required by the Linear Amplifier. In general, the swamping between the Exciter and Linear Amplifier should "soak up" the unused driving power so that the driver unit (Exciter) is running reasonably close to its peak power output, and "look into" a stiff load to keep distortion products to the lowest level. This condition will retain the carrier suppression of the Exciter for the over-all system, as well as the signal to noise ratio (ratio of residual noise to maximum power output), which are all related to the peak envelope power.

On page 5, specific information is given regarding symmetrical "T" attenuation for use between Hallicrafter's Transmitter/Exciters and Linear Amplifiers. When using an HT-30 or HT-32 Exciter to drive other type amplifiers, and the drive requirements of the Linear Amplifier are unknown, the following data may be of some assistance.

1. Grounded-grid or cathode driven amplifiers require impedance-matching networks. The input impedance of most grounded-grid amplifiers varies over a wide range depending upon the operating frequency, but on the average, most grounded-grid amplifiers have an input impedance of 300 ohms. Therefore, a simple 50 to 300 ohm "L" network may be used. The network doesn't have to be tunable, since these networks are broad enough, when set for the center frequency of each band.

2. The Class B Linear Zero Bias Amplifiers (811A etc.) require 8 to 20 watts drive power.

3. Pentode or Tetrode amplifiers, which are grid driven through a tuned grid circuit require 3 to 8 watts drive power.

4. Pentode or Tetrode amplifiers, which are grid driven with no tuned circuit, (for example, driven across a resistive load) the RF drive voltage should be equal or slightly less tha[illegible] DC fixed bias. In most cases, a "swa[illegible] resistor across the line is required.

"An attenuator is a network designed to introduce a known loss when working between resistive impedances Z1 and Z2 to which the input and output impedances of the attenuator are matched."[1] Attenuator networks, such as the symmetrical "T", are commonly used for the resistance transformation.

Note: All resistors used in these pads must be non-inductive.

Computation of the resistive values for a symmetrical "T" network are as follows:

$$R_1 = Z\frac{\sqrt{N}-1}{\sqrt{N}+1} \qquad (1)$$

$$R_3 = \frac{2Z\sqrt{N}}{N-1} \qquad (2)$$

$$\text{Attenuation in decibels} = 10 \log_{10} N \qquad (3)$$

where:

Z is the terminal impedance (resistive) to which the attenuator is matched.

N is the ratio of the power delivered to the attenuator from the source to the power delivered to the load.

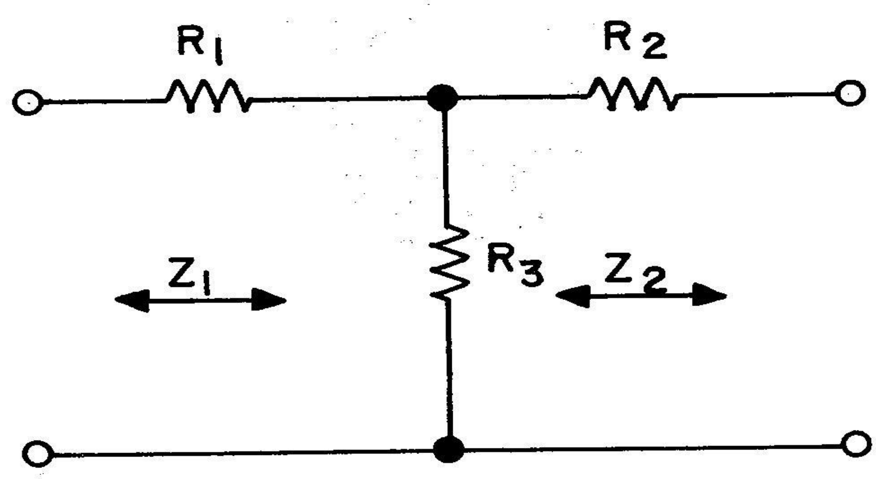

Figure 1. Symmetrical "T" Attenuator (Nominally $R_1 = R_2$; $Z_1 = Z_2$)

---

[1] I. T. and T., "Reference Data for Radio Engineers." January, 1957, Page 247.

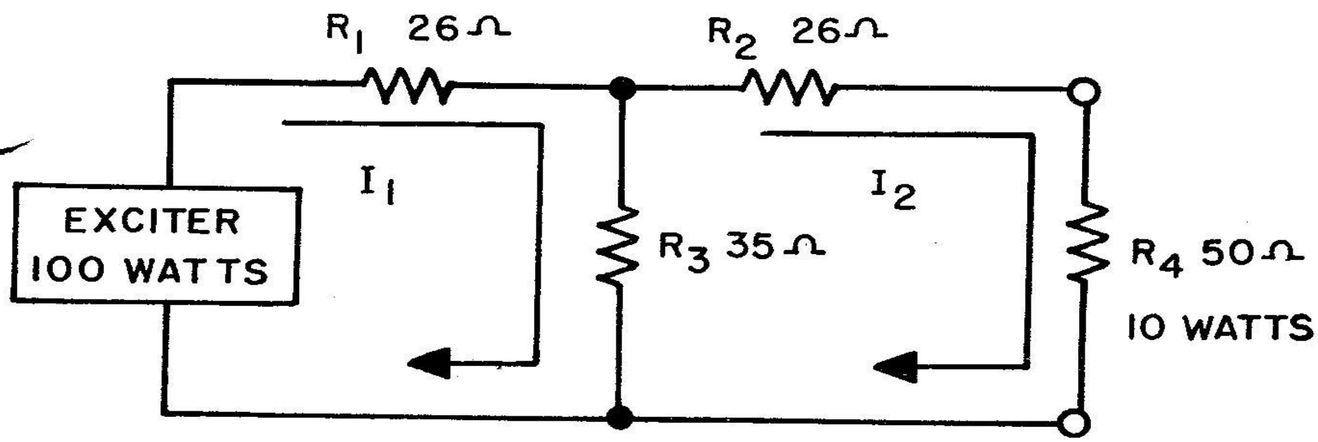

Figure 2. Symmetrical "T" Attenuator

Attenuator designed for use between an Exciter rated at 100 watts to a Linear Amplifier requiring 10 watts drive power, with a terminal impedance of 50 ohms.

To illustrate, let us assume your Exciter is rated at 100 watts power output, and your Linear Amplifier requires 10 watts drive power, with a terminal impedance of 50 ohms. By (Eq. 3), or consulting Table 1, it is readily seen that a 10 DB pad would provide the proper swamping between the Exciter and Linear Amplifier. From (Eq. 1), we can calculate the value of the series arm (R_1).

$$R_1 = 50\,\frac{\sqrt{\frac{100}{10}} - 1}{\sqrt{\frac{100}{10}} + 1} = 25.97 \text{ OHMS}$$

From (Eq. 2), we can proceed to calculate the value of the shunt arm (R_3).

$$R_3 = \frac{2(50)\sqrt{10}}{10-1} = 35.14 \text{ OHMS}$$

The following equation can be used to determine if the resulting values are correct.

$$Z = R_1\sqrt{1 + 2\frac{R_3}{R_1}} \qquad (4)$$

Consideration must also be given as to the power rating of the resistors, in order that they will "dissipate" (carry safely) the 90 watts in the attenuator.

The equation for Power (P) is:

$$P = EI \qquad (5)$$

Substituting Ohm's Law equivalents for E and I, the following formula's are obtained for power:

$$P = \frac{E^2}{R} \qquad (6)$$

or

$$P = I^2R \qquad (7)$$

To find the power rating of R_2, we must determine the current flow, I_2. (See Figure 2). Knowing that R_4 is equal to 50 ohms (resistive) and rated at 10 watts, then by rearranging (Eq. 7);

$$I = \sqrt{\frac{P}{R}}$$

and $I_2 = \sqrt{\frac{10}{50}} = .447$ AMPS.

$$\therefore P_{R_2} = (I_2)^2 \times R_2 = (.447)^2 \times 26 = 5.2 \text{ WATTS}$$

A 27 ohm, 10 watt (closest RETMA value) resistor is the nominal value of R_2.

TABLE 1

DECIBEL-VOLTAGE, CURRENT AND POWER RATIO TA

− 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}

To find the power rating of R_3, the voltage drop across R_3 is calculated.

$$E = I_2 \times (R_2 + R_4) = .447 \times 76 = 33.97 \text{ VOLTS}$$

and $$I_{R_3} = \frac{E_{R_3}}{R_{R_3}} = \frac{33.97}{35} = .971 \text{ AMPS}$$

$$\therefore P_{R_3} = (.971)^2 \times 35 = 33.01 \text{ WATTS}$$

A 35 ohm, 50 watt resistor is the nominal value of R_3.

To find the power rating of R_1, total current flow in the circuit is added.

$$I_1 + I_2 = .447 + .971 = 1.418 \text{ AMPS}$$

$$\therefore P_{R_1} = (1.418)^2 \times 26 = 52.28 \text{ WATTS}$$

A 27 ohm, 75 watt resistor is the nominal value of R_1.

As a final check, the resistors should dissipate 90 watts (100-10) in the attenuator. By adding the total power rating of R_1, R_2 and R_3;

$$52.28 + 5.2 + 33.01 = 90.49 \text{ WATTS}$$

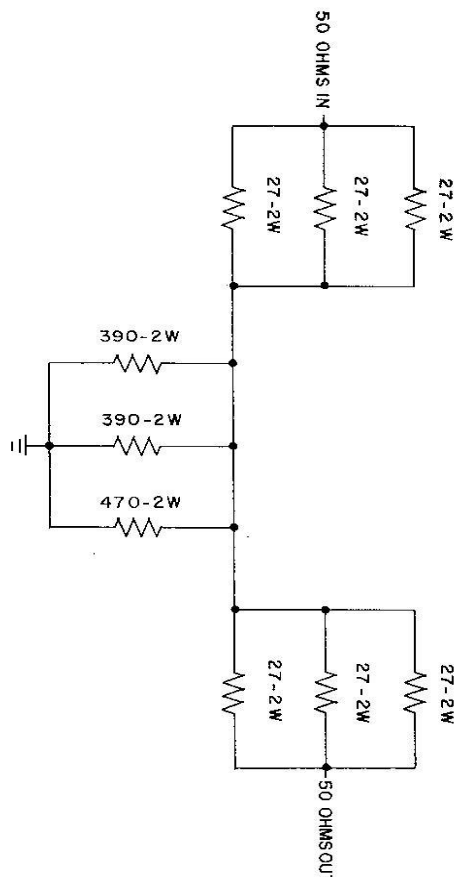

Figure 3. HT-30 50 ohm Attenuator

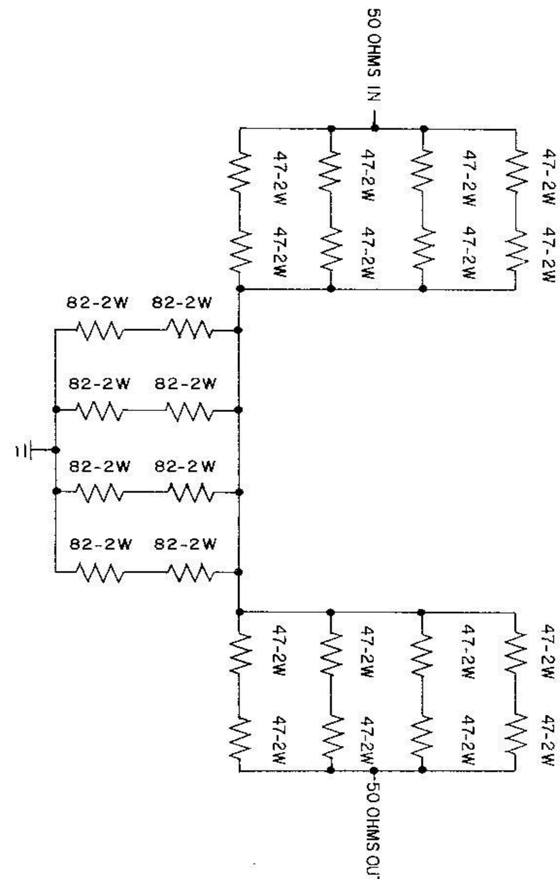

Figure 4. HT-32 50 ohm Attenuator

A 3DB pad is recommended for use between a HT-30 SSB Exciter and the HT-33 Linear Amplifier. The pad may be conveniently wired in a metal box (6" x 2" x 2") with a removable cover. Amphenol Type SO-239 receptacles should be installed at each end.

A 9DB pad is recommended for use between a HT-32 SSB Exciter and HT-33 Linear Amplifier. The pad may be conveniently wired in a metal box (8" x 3" x 3") with a removable cover. Amphenol Type SO-239 receptacles should be installed at each end.

NOTE: Nearest standard RETMA value may be used. Use only non-inductive resistors.

NOTE: These pads are suitable for SSB, Radio-Telegraph, and AM operation; however, steady full level C. W. excitation should be avoided except for very brief test periods as the dissipation rating of the resistors will be exceeded.

TABLE 2

Symmetrical "T" Attenuator Values. Z = 50 ohms

Attenuation In Decibels	Series Arm R_1 In Ohms	Shunt Arm R In Ohms
0. 1	0. 287	4342. 85
0. 2	0. 575	2171. 3
0. 3	0. 863	1447. 35
0. 4	1. 15	1085. 0
0. 5	1. 438	868. 1
0. 6	1. 73	723. 0
0. 7	2. 013	619. 75
0. 8	2. 3	542. 0
0. 9	2. 588	481. 685
1. 0	2. 88	433. 0
2. 0	5. 73	215. 2
3. 0	8. 55	141. 9
4. 0	11. 31	104. 8
5. 0	14. 01	82. 2
6. 0	16. 61	66. 9
7. 0	19. 12	55. 8
8. 0	21. 53	47. 31
9. 0	23. 81	40. 59
10. 0	25. 97	35. 14
12. 0	29. 92	26. 81
14. 0	33. 37	20. 78
16. 0	36. 32	16. 26
18. 0	38. 82	12. 79
20. 0	40. 91	10. 1
22. 0	42. 64	7. 994
24. 0	44. 07	6. 335
26. 0	45. 23	5. 024
28. 0	46. 18	3. 987
30. 0	46. 93	3. 165
35. 0	48. 25	1. 779
40. 0	49. 01	1. 0
50. 0	49. 68	0. 316
60. 0	49. 9	0. 1
70. 0	49. 968	0. 031
80. 0	49. 99	0. 01
100. 0	50. 0	0. 001

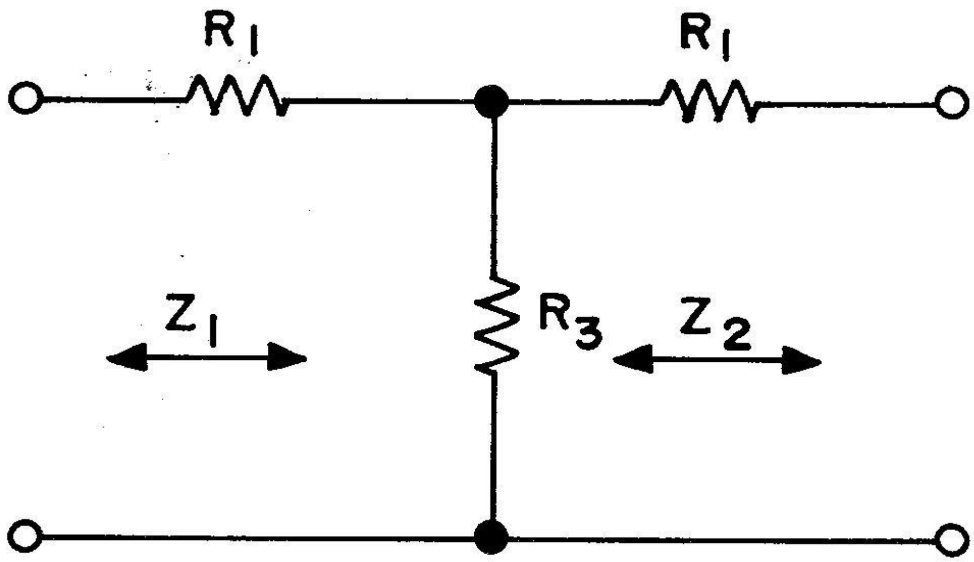

Figure 5. Symmetrical "T" Attenuator
($Z_1 = Z_2$)

Symmetrical "T" Attenuator values are calculated in Table 2. Impedance (Z) = 50 ohms resistive.

The basis for various impedance-matching networks is the fact that for any circuit consisting of resistance and reactance in series, there can be found a similar circuit consisting of resistance and reactance in parallel, that will have exactly the same impedance and phase angle.

Thus, the series and parallel circuits shown in Figure 6 are equivalent, when a voltage of fixed magnitude and frequency is applied to either circuit. A simple series combination of resistance and reactance can be lifted out of a more complex circuit, and its parallel equivalent substituted for it without in any way affecting the over-all operation of the circuit. It is necessary to specify that the frequency remain fixed, because the reactance values change with a change in frequency.

When series and parallel circuits are equivalent, Q has the same value in both, (Bear in mind, the Q under consideration is the "operating" Q of the circuit, not the Q of the component, such as a coil).

From AC circuit theory it can be shown that a parallel circuit is equivalent to a given series circuit when;

$$R_P = R_S \ (Q^2 + 1) \qquad (10)$$

and

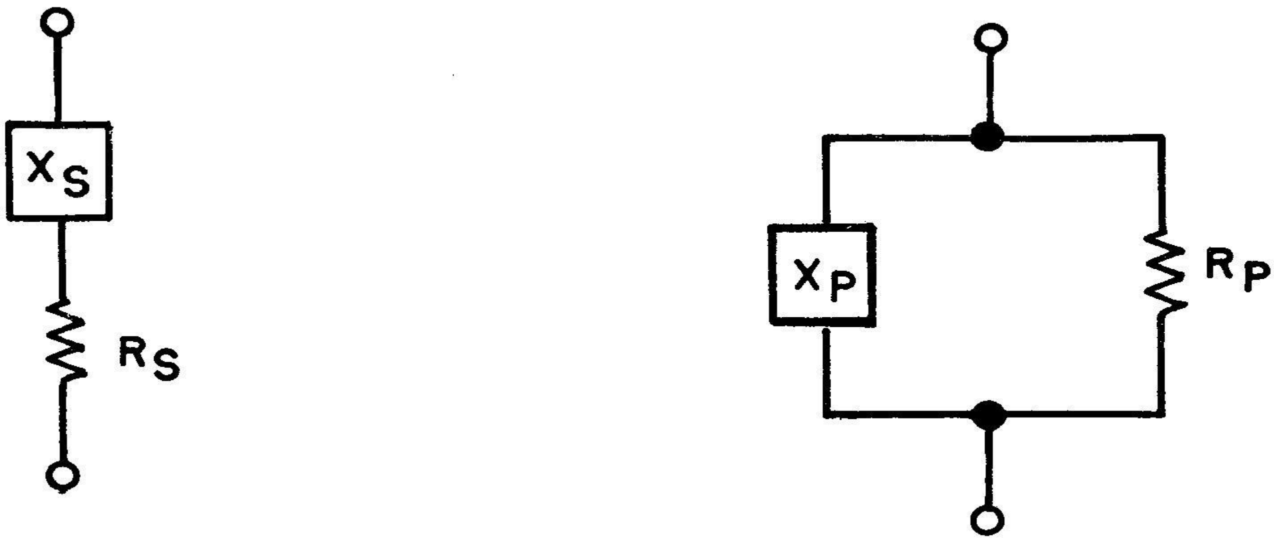

Figure 6. Series and Parallel Circuits Containing Resistance and Reactance.

In Figure 6, the reactances are shown as blocks, since the same principles apply whether the reactance is inductive or capacitive. However, if the series reactance X_S, is inductive, the parallel reactance, X_P, in the equivalent parallel circuit must also be inductive, and vice versa. Their values, however, are not identical; that is X_S is not equal to X_P, and R_S is not equal to R_P. R_S will always be smaller than R_P, and X_S will always be smaller than X_P.

In determining the resistance and reactance values in equivalent circuits, it is necessary to introduce the quantity Q. Q has the same meaning as the one ordinarily associated with that letter. That is, in a series circuit;

$$Q = \frac{X_S}{R_S} \qquad (8)$$

and in a parallel circuit;

$$Q = \frac{R_P}{X_P} \qquad (9)$$

$$X_P = \frac{R_P}{Q}$$

While a series circuit is equivalent to a given parallel circuit when;

$$R_S = \frac{R_P}{Q^2 + 1} \qquad (12)$$

and

$$X_S = QR_S \qquad (13)$$

When the values of resistance and reactance satisfy these equations, the two circuits will have exactly the same impedance and phase angle at the frequency considered.

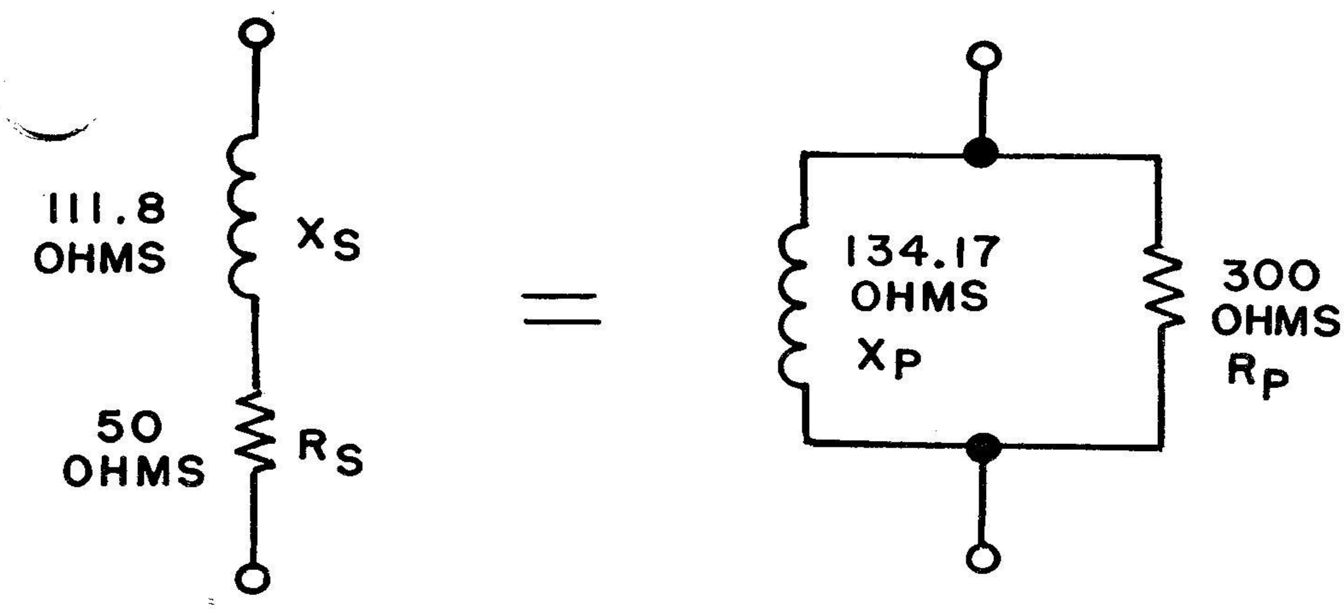

Figure 7. Equivalent series and parallel circuits.

Now, that we have a simple knowledge of the equivalence of series and parallel circuits, we can proceed in calculating a concrete example. Let us assume your Linear Amplifier is a grounded grid type, having an input impedance of 300 ohms, while your Transmitter/Exciter requires a load of 50 ohms to deliver its rated power at good efficiency. To transfer the 50 ohm output power from the Exciter to the Linear Amplifier's 300 ohm resistive load, the "L" matching network must transform the 300 ohm actual load into a 50 ohm load.

NOTE: The following procedure can also be used in matching transmission lines, antennas, etc.

ferring to Figure 6, let us assume that 50 ohms sponds to R_S. From our discussion, we may state that if a suitable value of reactance, X_S, is added in series with 50 ohms resistance, the resulting circuit is equivalent to a resistive load of 300 ohms in parallel with some value of reactance. By rearranging (Eq. 10);

$$Q = \sqrt{\frac{R_P}{R_S} - 1} = \sqrt{\frac{300}{50} - 1} = 2.236$$

The required value of series reactance X_S is found by (Eq. 13);

$$X_S = 2.236 \times 50 = 111.8 \text{ OHMS}$$

By (Eq. 11),

$$X_P = \frac{300}{2.236} = 134.17 \text{ OHMS}$$

Thus, a reactance of 111.8 ohms in series with the 50 ohms resistance will make the circuit "look like" a resistive load of 300 ohms in parallel with a reactance of 134.17 ohms. The equivalence is shown in Figure 7, assuming that inductive reactance is used; however, capacitive reactance of the same value would do equally as well.

The question arises as to what must be done with the 134.17 ohms reactance that is in parallel with the series combination of 50 ohms resistance from the exciter and 111.8 ohms reactance. By placing a reactance having the same value of X_p (134.17 ohms) but of the opposite sign, in parallel with X_p, the reactance is effectively cancelled. For instance, consider in Fig. 7, we have 134.17 ohms of inductive reactance in parallel with the series combination of 111.8 ohms reactance and 50 ohms resistance. Adding a capacitive reactance of 134.17 ohms in parallel with the series combination of 111.8 inductive reactance and 50 ohms resistance cancels the reactance, yielding the 50 ohms resistance. Fig. 8 illustrates our resulting circuit, which is called a "L Section" circuit, developed from series and parallel circuits.

The following formulas are used to convert the reactances to capacitance and inductance. See Table 3.

$$C = \frac{1}{2\pi f X_C} \quad (14)$$

$$L = \frac{X_L}{2\pi f} \quad (15)$$

where;

C = Capacitance in farads

X_C = Capacitive reactance in ohms = 134. 17

2π = 6. 28

f = Frequency in cycles per second

L = Inductance in henries

X_L = Inductive reactance in ohms = 111. 8

TABLE 3

METERS	MID-FREQ. IN MCS.	C IN UFD.	L IN UH.
160	1. 9	. 0006	[illegible]
80	3. 75	. 0003	[illegible]
40	7. 15	. 00016	2. [illegible]
20	14. 2	. 00008	1. 25
15	21. 25	. 00005	. 8
10	28. 35	. 00004	. 628

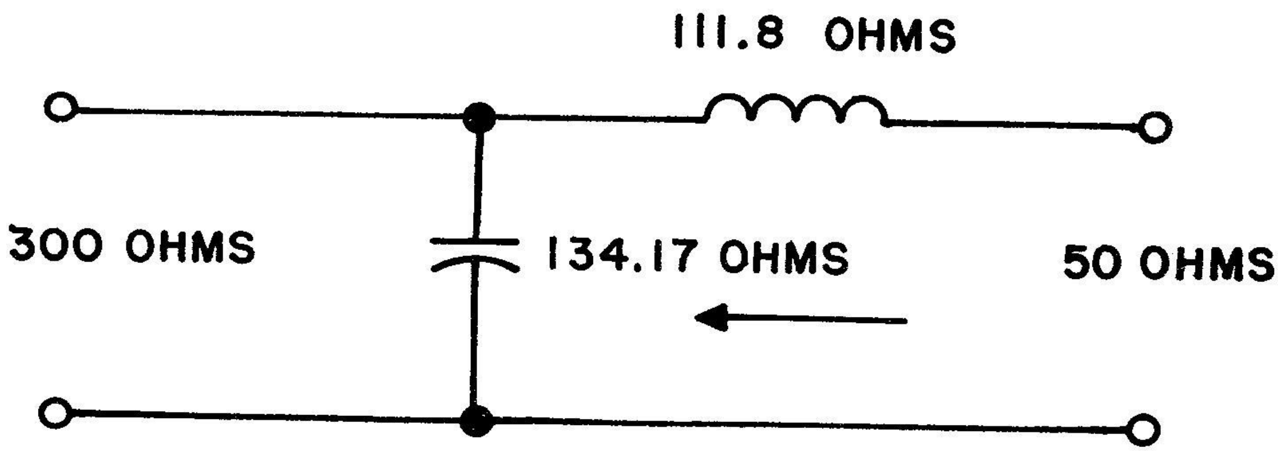

Figure 8. "L Section" circuit.

COIL WINDING DATA

The following approximations for winding R-F coils are accurate to within approximately 1% for nearly all small air-core coils.

$$L = \frac{(rN)^2}{9r + 10l} \qquad (16)$$

and

$$N = \frac{\sqrt{L(9r + 10l)}}{r} \qquad (17)$$

where;

L = Self-inductance in microhenries

N = Total number of turns

r = Mean radius in inches

l = Length of coil in inches

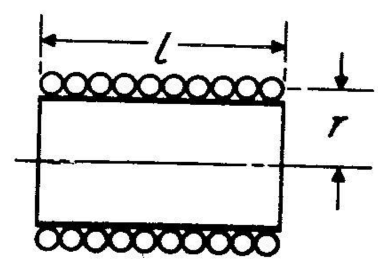

Figure 9. Single-Layer Wound Coil

Note: For information regarding pre-wound coils, see "The Radio Amateur's Handbook," 1957 Edition, Page 28.

Gauge (AWG) or (B&S)	Number of Turns per Linear Inch			
	Enamel	S.S.C.	D.S.C. and S.C.C.	D.C.C.
1	—	—	3.3	3.3
2	—	—	3.8	3.6
3	—	—	4.2	4.0
4	—	—	4.7	4.5
5	—	—	5.2	5.0
6	—	—	5.9	5.6
7	—	—	6.5	6.2
8	7.6	—	7.4	7.1
9	8.6	—	8.2	7.8
10	9.6	—	9.3	8.9
11	10.7	—	10.3	9.8
12	12.0	—	11.5	10.9
13	13.5	—	12.8	12.0
14	15.0	—	14.2	13.8
15	16.8	—	15.8	14.7
16	18.9	18.9	17.9	16.4
17	21.2	21.2	19.9	18.1
18	23.6	23.6	22.0	19.8
19	26.4	26.4	24.4	21.8
20	29.4	29.4	27.0	23.8
21	33.1	32.7	29.8	26.0
22	37.0	36.5	34.1	30.0
23	41.3	40.6	37.6	31.6
24	46.3	45.3	41.5	35.6
25	51.7	50.4	45.6	38.6
26	58.0	55.6	50.2	41.8
27	64.9	61.5	55.0	45.0
28	72.7	68.6	60.2	48.5
29	81.6	74.8	65.4	51.8
30	90.5	83.3	71.5	55.5
31	101.	92.0	77.5	59.2
32	113.	101.	83.6	62.6
33	127.	110.	90.3	66.3
34	143.	120.	97.0	70.0
35	158.	132.	104.	73.5
36	175.	143.	111.	77.0
37	198.	154.	118.	80.3
38	224.	166.	126.	83.6
39	248.	181.	133.	86.6
40	282.	194.	140.	89.7