Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Corporation, the contents of this issue of the Aerovox Research Worker.

The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 8, NO. 1 JANUARY, 1936 50c per year in U.S.A. 60c per year in Canada

Reactance and Resistance in Parallel

By the Engineering Department, Aerovox Corporation

COMBINATIONS of reactance and resistance in parallel are used frequently in radio circuits, for instance when bias resistors or voltage dividers are bypassed. Yet the subject is not clear which results in imitating someone else's design rather than calculating the required constants. The reason is of course that the equation for parallel reactance and resistance is rather cumbersome. Those who are acquainted with it, think it takes too much time while there are those who do not know the equation and would not be able to solve it if they did know it. The chart in this article, it is hoped, will painlessly answer all problems regarding parallel circuits.

When a resistance is in parallel with a reactance (either inductive or capacitive), the resultant impedance of the combination is found from the expression

$$Z = \frac{XR}{\sqrt{R^2 + X^2}}$$

Sometimes Z and R are given and X has to be found or Z and X are given and R is the unknown. In that case the equation can be solved for X and R and we have

$$X = \frac{ZR}{\sqrt{R^2 - Z^2}} \qquad R = \frac{ZX}{\sqrt{X^2 - Z^2}}$$

In all three of the above equations X can be either inductive reactance (X=6.28 fL) or it can be capacitive in which case X=1/(6.28 f C) where f is in cycles, L in henries and C in farads.

To make a chart which will solve these equations is not easy, due to the peculiar form of the expression. Also, most readers would no doubt like to be spared the calculation of X before using the chart. This would mean that there are three independent variables, which ordinarily cannot be solved in one operation in a two-dimensional medium. So, in order to reduce the number of independent variables to two, X and R are measured along the coordinate axes but alongside the X scale are shown two other scales, which give the corresponding values of fL and fC for each value of X. Since f and C are generally very simple numbers, it will not be difficult to multiply them mentally before solving the problem with the chart. Incidentally, f is in cycles, C in microfarads and L in henries for the scales shown.

Full logarithmic paper has been used because it permits the coverage of a more extended range with the same accuracy everywhere. The range of the chart can be further extended by multiplying Z, X and R by the same factor. fL would have to be multiplied with the same factor too but fC would have to be divided by it. A few examples will no doubt clarify the procedure.

EXAMPLES

Example 1: A 1000 ohm bias resistor in an audio amplifier is bypassed by a condenser of 8 mfd. What is the resultant impedance between cathode and ground at 100 cycles.

Solution: Obviously, fC is 800; entering the chart at fC=800 on the horizontal axis, follow the vertical line until it intersects with the horizontal line R=1000. The point of intersection lies between the curves Z=100 and Z=200. Estimating the value of Z we obtain 195 ohms. It shows that the condenser is an unsatisfactory bypass at 100 cycles and this will be worse at lower frequencies which can easily be seen from the chart. At 30 cycles there is practically no bypassing effect and the impedance is nearly 1000 ohms.

Note that in this example, X was 199 ohms which is about one fifth of R and that Z is but slightly less than X. This will always occur when either one of the quantities X and R is much larger than the other. The reader might memorize the following useful rule: When one of the two quantities X and R is more than five times as large as the other the resultant impedance is nearly equal to the smallest of the two quantities. The error made in this way is very small: two percent when the ratio is 5 and one half percent when the ratio is ten.

Example 2: The capacity across a diode load resistor of .5 megohm is 100 mmfd. How much does this decrease the impedance of the load at 5000 cycles?

Solution: In this case fC equals .5 and X equals 320000 ohms. These values are beyond the range of the chart, so divide both R and X by 1000. Locate the intersection of the lines R=500 and X=320. This is between Z=200 and Z=300. By estimation: Z=260. The answer to the question is then, Z equals 260,000 ohms. The result shows the disastrous effect of having so much capacity across the resistor; it will cut the signal voltage in half at 5000 cycles but not at the lower frequencies.

Example 3: What is the resultant impedance of a 100 henry choke in parallel with a .25 megohm resistor at 1000 cycles. Solution: In this case fL is 100,000 and X is 628,000 ohms. Dividing both R and X by 1000, find the intersection of the lines R=250 and X=628; Z is then 235.

The answer is 235,000 ohms. It is now very simple to find the complete frequency characteristic of the parallel combination. Following the horizontal line R=250 it is found that at 500 cycles (fL=50,000) Z equals 190,000 ohms and at 100 cycles Z=93000 ohms, etc. This type of parallel load is often used in impedance coupled amplifiers. The parallel resistor has the effect of flattening out the frequency characteristic if the values are properly chosen. In the above example the constants are apparently not right. Either the resistor should be smaller or the inductance larger.

The idea is to make X considerably larger than R at low frequencies, in that case Z will be nearly equal to R throughout the range. The d. c. resistance however, is equal to that of the choke which avoids the loss in voltage as in resistance coupled amplifiers.

As an example of how the chart can also be used backward. Suppose in the above example the resistance value is retained, how large should the choke be in order that at 100 cycles Z will be 200,000 ohms? Dividing all values by 1000 again, follow the horizontal line passing through the point R=250 and find its intersection with the line marked Z=200, then follow the vertical line downward from this point and read X=330. So the reactance of the choke should be 330,000 ohms, fL should be 52,500 and the inductance 525 henries.

THE TABLE

For those who wish greater accuracy than the chart affords, the table has been calculated. The table again has been prepared so as to permit the finding of any one of the three quantities X, R or Z when the other two are given. When X and R are given, divide the larger of the two quantities into the smaller one and thus get a ratio less than 1. Find this ratio in the left column and multiply the number obtained in the second column by R or X whichever is the larger and find Z.

The same can probably be understood better by saying that the column shows the corresponding values of X and Z when R equals one, or the values of R and Z when X = 1. Obviously, since it is always possible to divide the larger of the two quantities X and R into the smaller one or vice versa, the table needs to be calculated only for values from 1 down or up but not both ways. It was intended to calculate the table only for values of R/X or X/R from 1 to .1 but it was found that in that way it is not possible to work the problem backwards, that is, when Z is given. So, it became necessary to extend the table above 1 but only a few values between 1 and 10 are given; enough to provide nearly every value of Z/R but not enough to provide all values of R/X above 1. Therefore one should divide R into X or X into R so as to get a ratio less than 1.

Suppose R equals 1000 ohms and X is 200 ohms, which makes X/R = .20. The table shows us that Z/R is then 0.1961. Multiplying by R, we have Z = 0.1961 x 1000 = 196.1 ohms.

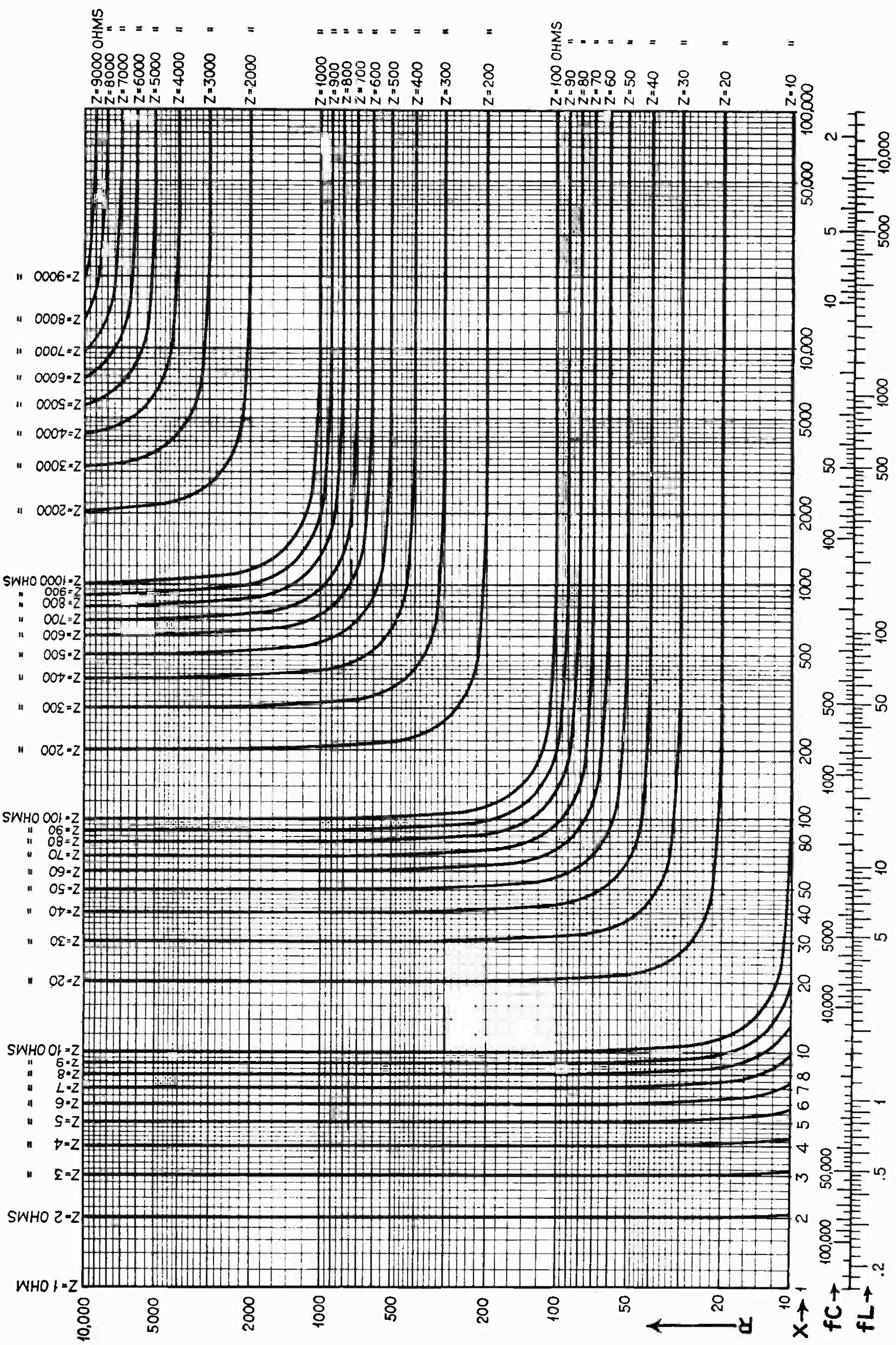
Similarly, in the last example of the choke, R was 250,000 and Z 200,000 ohms. Then Z/R = 0.80. Entering the table now by the second column, we find that X/R is between 1.3 and 1.4. Interpolation is necessary if greater accuracy is desired; this yields the answer X/R = 1.33. Then X equals 1.33 x 250,000 = 332,000 ohms.

POWER FACTOR

It should be clear that the above calculations assume the power factor of the reactance to be zero, or that the reactive branches have no resistance. This is of course not the case with any practical reactance. However the error is surprisingly small when the power factor is no more than 10 percent, or the Q of the coil not less than 10.

TABLE OF REACTANCE AND RESITANCE VALUES IN PARELLEL

X/R or R/X	Z/R or Z/X	X/R or R/X	Z/R or Z/X
0.10	0.0995	0.68	0.5623
0.11	0.1093	0.69	0.5679
0.12	0.1191	0.70	0.5735
0.13	0.1289	0.71	0.5789
0.14	0.1386	0.72	0.5843
0.15	0.1483	0.73	0.5895
0.16	0.1580	0.74	0.5948
0.17	0.1676	0.75	0.6000
0.18	0.1771	0.76	0.6051
0.19	0.1867	0.77	0.6101
0.20	0.1961	0.78	0.6150
0.21	0.2055	0.79	0.6199
0.22	0.2149	0.80	0.6246
0.23	0.2242	0.81	0.6289
0.24	0.2334	0.82	0.6341
0.25	0.2425	0.83	0.6387
0.26	0.2516	0.84	0.6432
0.27	0.2607	0.85	0.6477
0.28	0.2696	0.86	0.6520
0.29	0.2785	0.87	0.6564
0.30	0.2874	0.88	0.6606
0.31	0.2961	0.89	0.6648
0.32	0.3048	0.90	0.6690
0.33	0.3134	0.91	0.6730
0.34	0.3219	0.92	0.6771
0.35	0.3304	0.93	0.6810
0.36	0.3387	0.94	0.6849
0.37	0.3470	0.95	0.6888
0.38	0.3552	0.96	0.6925
0.39	0.3634	0.97	0.6963
0.40	0.3714	0.98	0.6999
0.41	0.3793	0.99	0.7036
0.42	0.3872	1.00	0.7071
0.43	0.3950	1.10	0.7400
0.44	0.4027	1.20	0.7682
0.45	0.4103	1.30	0.7926
0.46	0.4179	1.40	0.8137
0.47	0.4254	1.50	0.8320
0.48	0.4327	1.60	0.8480
0.49	0.4400	1.70	0.8619
0.50	0.4472	1.80	0.8742
0.51	0.4543	1.90	0.8850
0.52	0.4613	2.00	0.8944
0.53	0.4683	2.20	0.9104
0.54	0.4751	2.40	0.9231
0.55	0.4819	2.60	0.9333
0.56	0.4886	2.80	0.9418
0.57	0.4952	3.00	0.9487
0.58	0.5017	3.20	0.9545
0.59	0.5082	3.40	0.9594
0.60	0.5145	3.60	0.9635
0.61	0.5208	3.80	0.9671
0.62	0.5269	4.00	0.9702
0.63	0.5330	5.00	0.9807
0.64	0.5390	6.00	0.9864
0.65	0.5450	7.00	0.9902
0.66	0.5508	8.00	0.9921
0.67	0.5566	9.00	0.9939
		10.00	0.9950


Z=9000 OHMS
Z=1000 OHMS
Z=100 OHMS
Z=10 OHMS
Z=2 OHMS
Z=1 OHM
R
X→
fC→
fL→