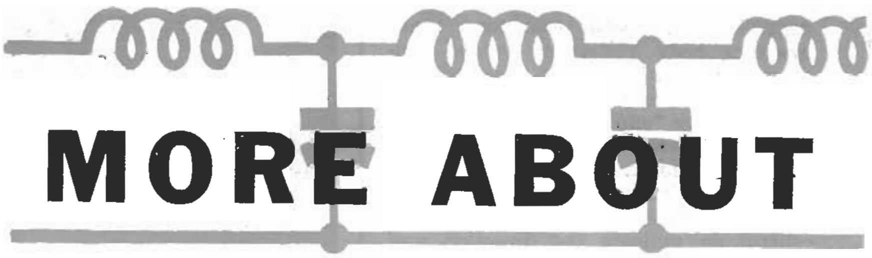
Second of two installments on practical filter design



MORE ABOUT

By N. H. CROWHURST

THERE are definite limits to the use of approximations in designing filters. Even when all the precautions described in last month's installment are observed, the result often falls far short of what is claimed for it.

For example, take the types of high- and low-pass filters—frequently used for loudspeaker crossovers—which have two or three reactance elements in each feed. The low-pass sections which would feed the low-frequency speaker are shown in Fig. 6. They are a form of

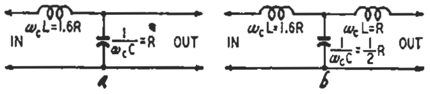


Fig. 6—Low-pass sections of crossover networks based on wave filter design. At *a* is a half-section network with *m* equal to 0.6. A full section, with the same value of *m*, is shown at *b*.

m-derived filter, though they differ from the types already mentioned. Figs. 7 and 8 show (at A) the kind of response curves published for these circuits. The curves B are the actual curves for the filter, feeding a load of R, and with zero source impedance. Curves C are those actually derived for the same circuits by a method of computing that avoids approximation.

The difference is not very great, but the phase characteristic or the impedance characteristic may often be more important than the attenuation or transfer characteristic. The phase shift in the vicinity of cutoff, using these accentuated slopes is much more rapid than with the types employing constant-resistance derivation; also the impedance at the input terminals fluctuates considerably.

Constant-resistance types

Perhaps first the fact that no single high-pass or low-pass filter by itself possesses a constant-resistance characteristic should be emphasized. Constant resistance is only possible by using complementary filters, such as were given in the article "Loudspeaker Crossover Design" (RADIO-ELECTRONICS, July, 1952). Then the impedance at the input terminals to the combined arrangement is a constant resistance.

Mathematically the correct relationship between circuit values for this design can be approached in several ways, because the arrangement possesses several unique features simultaneously. Without going into mathematical details, the important difference from the other types is that no approximations are used, so the result can really achieve all the things claimed for it. These may be summarized as follows:

1. When supplied with a gliding tone of constant voltage at the input terminals, the total energy delivered to the output circuits is constant.
2. The impedance presented at the combined input terminals is constant and resistive.
3. The difference in phase between signals delivered to the two outputs is constant.

Another point to emphasize here is that, for these facts to hold, both circuits must be terminated by the correct *resistance* load.

The mathematical process of finding the correct values consists of developing expressions for the attenuation, phase response, or input impedance, using any complementary values of reactance in the two filters, and substituting the appropriate conditions as stated above into the algebra; this will produce simultaneous equations which when solved give the correct values for a constant-resistance filter. It is not necessary to give all the mathematics here, because the results can always be obtained from someone who has already done it all. As was shown in the author's article "Loudspeaker Crossover Design," constant-resistance types can be derived using up to three elements in each wing of the filter.

Fig. 9 shows a comparison of constant resistance and wave filter derived types using the same configuration. For comparison, Figs. 7 and 8 also show the constant resistance response for the same configurations.

Some questions to ask

Finally, the author would like to suggest some questions that the prospective user of a filter should always seek an answer for before proceeding. These questions have many times proved a safeguard in his personal experience, and for this reason he recommends them to others.

First, *what impedances does it work with—both ends?* Usually some characteristic impedance will be stated, but information may not be given as to whether this characteristic impedance is for terminating the filter at the output end or the input end, or both.

The next question is, *what impedances does the filter itself reflect when correctly terminated?* Usually the most important reflected impedance is that presented by the input of the filter when it is correctly terminated at its output. However, in some circumstances reflection the other way may be important; for example, if the filter is feeding the input of an amplifier, the frequency response of the amplifier depends on its being correctly terminated at its input end; the circuit connected to the input transformer of the

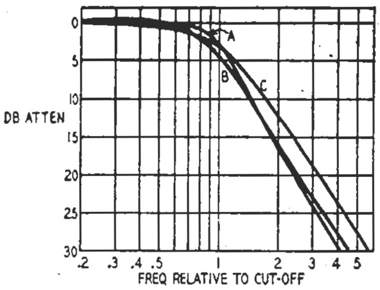


Fig. 7—The above curves show the response of the low-frequency section of Fig. 6-a. *A* is the curve usually published for the values shown; *B* is the actual curve for the filter; *C* is the circuit's response with the constant-resistance filter values of Fig. 9.

amplifier must have the stated source impedance value. When the input circuit is a filter it follows that the user should be satisfied that the filter reflects the correct terminating impedance throughout the frequency range.

A third question is, *Am I using the correct impedances throughout the fre-*

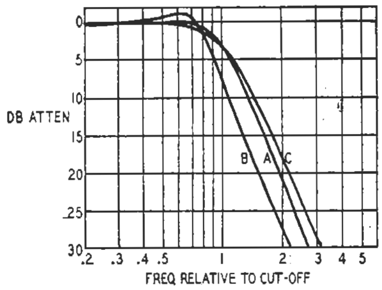


Fig. 8—Response of low-frequency section of crossover network of Fig. 6-b. *A* is the curve usually published for the values given in the figure; *B* the actual curve, feeding load R, source impedance zero; and *C* the response with values for a constant-resistance filter.

FILTERS

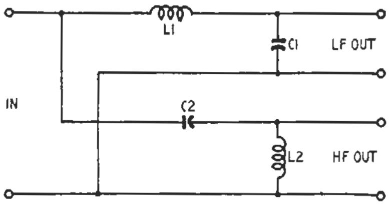
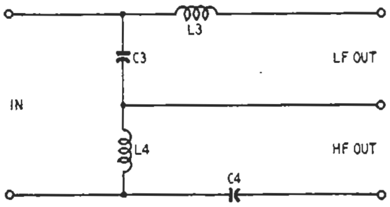
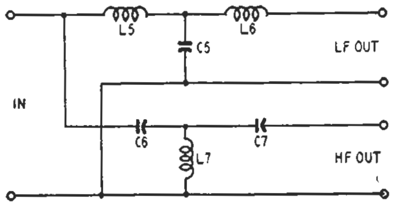
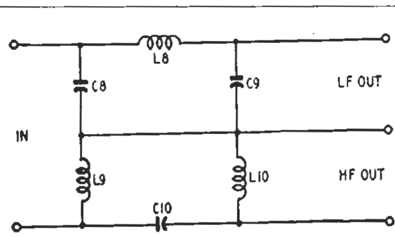
Constant-resistance crossover networks are easy to design with these formulas

quency range? Even the constant-resistance types achieve their true properties only when they are both terminated by the correct constant-resistance loads. As was explained in the author's earlier article, loudspeakers do not do this, although selection of the right filter configuration may compensate for this shortcoming.

A reader recently asked if a constant-resistance type could be designed to feed a 15-ohm low-frequency unit and a 3-ohm high-frequency unit. This is quite impossible unless the filter incorporates an impedance-matching transformer, or pads out one of the values. In the low-frequency band the impedance at the input terminals will be 15 ohms, while in the high-frequency band it must be 3 ohms. Obviously constant resistance is impossible. However, the author has designed a unit that will achieve this result, incorporating the functions of push-pull or single-ended output transformer, variable crossover frequency and individual voice-coil matching; all in one component, little larger than a normal output transformer. This is the subject of a current patent application.

The fourth question is one the user would probably have asked anyway: *What is its attenuation characteristic?* And perhaps this one: What is its phase characteristic? Some form of attenuation characteristic is usually published for the filter. The author has found by experience that, if the conditions under which they are taken are not precisely specified (if the input and output impedances with which the filter works are not given) such characteristics are usually somewhat less than dependable, to say the least.

This statement is not accusing the manufacturers of misrepresentation in issuing such characteristics—the characteristic probably does give quite accurate information about the filter under *some* conditions. The real question is *whether those conditions are the practical ones which the user will apply.* The discussion in this article has shown what a variety of possible conditions could be assumed for the purposes of calculating response, or actually used for measuring one. Even if the response is the result of actual measurement, the conditions used for measurement may differ from those which the user is going to apply. END

Data for Wave-Filter Derived Types		*Data for Constant-Resistance Types*
$\omega_c L_1 = 1.6R$ $\quad \frac{1}{\omega_c C_1} = R$ $\frac{1}{\omega_c C_2} = 1.6R$ $\quad \omega_c L_2 = R$ Attenuation at $\omega_c = 4.65$ db Phase difference at $\omega_c = 219°$ Input impedance at $\omega_c = 1.44R$		$\omega_c L_1 = 1.414R$ $\quad \frac{1}{\omega_c C_1} = 1.414R$ $\frac{1}{\omega_c C_2} = 1.414R$ $\quad \omega_c L_2 = 1.414R$ Attenuation at $\omega_c = 3$ db Constant phase difference 180° Constant input impedance R
$\omega_c L_3 = R$ $\quad \frac{1}{\omega_c C_3} = .625R$ $\frac{1}{\omega_c C_4} = R$ $\quad \omega_c L_4 = .625R$ Attenuation at $\omega_c = 4.65$ db Phase difference at $\omega_c = 219°$ Input impedance at $\omega_c = .695R$		$\omega_c L_3 = .707R$ $\quad \frac{1}{\omega_c C_3} = .707R$ $\frac{1}{\omega_c C_4} = .707R$ $\quad \omega_c L_4 = .707R$ Attenuation at $\omega_c = 3$ db Constant phase difference 180° Constant input impedance R
$\omega_c L_5 = \frac{1}{\omega_c C_6} = 1.6R$ $\frac{1}{\omega_c C_5} = \omega_c L_7 = .5R$ $\omega_c L_6 = \frac{1}{\omega_c C_7} = R$ Attenuation at $\omega_c = 7.15$ db Phase difference at $\omega_c = 390\frac{1}{2}°$ Input impedance at $\omega_c = 2.6R$		$\omega_c L_5 = \frac{1}{\omega_c C_6} = 1.5R$ $\frac{1}{\omega_c C_5} = \omega_c L_7 = .75R$ $\omega_c L_6 = \frac{1}{\omega_c C_7} = .5R$ Attenuation at $\omega_c = 3$ db Constant phase difference 270° Constant input impedance R
$\frac{1}{\omega_c C_8} = \omega_c L_9 = .625R$ $\omega_c L_8 = \frac{1}{\omega_c C_{10}} = 2R$ $\frac{1}{\omega_c C_9} = \omega_c L_{10} = R$ Attenuation at $\omega_c = 7.15$ db Phase difference at $\omega_c = 390\frac{1}{2}°$ Input impedance at $\omega_c = .385R$		$\frac{1}{\omega_c C_8} = \omega_c L_9 = .67R$ $\omega_c L_8 = \frac{1}{\omega_c C_{10}} = 1.33R$ $\frac{1}{\omega_c C_9} = \omega_c L_{10} = 2R$ Attenuation at $\omega_c = 3$ db Constant phase difference 270° Constant input impedance R

N.B. Throughout the above tabulation R represents the working impedance and ω_c stands for 2π times the crossover frequency. Thus $\omega_c L$ means the reactance of L at crossover.

Fig. 9—Comparison of wave-filter and constant-resistance derivations for crossover networks using the same circuits.