Design and Construction of

Practical Dividing Networks

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Instructions for making loudspeaker dividing networks without using laboratory equipment.

Although the subject of dividing networks has been covered with considerable thoroughness in the literature over the past few years, much of this material has made it necessary for the builder to make a number of choices as to the circuit used. Few writers on the subject have made definite recommendations, most of them providing details for the calculation of *all* types of network configurations. In addition, the builder who does not have a suitable bridge available for measurement of the required inductances is handicapped because of the difficulty in obtaining ready-wound coils for this application. It is the purpose of this article to describe one particular type of dividing network, the choice having been made on the basis of a number of listening tests. Furthermore, constructional details are furnished which make it possible to wind acceptable coils for these networks without the need for measuring the inductance values on a bridge. Provided the coils are wound exactly as described, the resulting inductance should be within 5 per cent of the required value; this may be of some aid to those who do not have access to the necessary measuring equipment.

Network Design

Dividing networks are designed by two entirely different methods. The most common is based on the filter principle, and the characteristics of the sections resemble those of any other type of filter. The other method is based upon obtaining a constant-resistance characteristic of the sections, and while the configurations are similar, the method of calculating the values for the components differs considerably. Although the idea of maintaining a constant-resistance load on the output of an amplifier, with a consequent stabilization of the source impedance out of which the speakers work, is one which appears to be in the realm of good design, it cannot be denied that no loudspeaker offers a truly constant impedance to its source. For this reason, the filter type cannot be eliminated from consideration, since the impedances resulting from the use of this network do not vary more than 20 per cent throughout the range for which they are designed. More important, however, is the fact that critical listening tests have usually resulted in the selection of the filter network. It is, therefore, the one selected for this article. The principal advantage to be gained from the use of the constant-resistance network is one of simplification of manufacture, since both inductance elements are of the same value, and both capacitors are of the same value. For the constructor who has occasion to make but one or two, this is not an important consideration.

The next step in selection of a network type is based on the required attenuation beyond the crossover frequency. Single L-section networks provide an attenuation of approximately 12 db per octave outside the transmitted band, and if greater attenuation is desired, a full T- or pi-section is used to give a loss of about 18 db per octave. The use of properly designed high-frequency horns will aid in the attenuation of the low frequencies provided the horns are constructed so that there is a natural falling-off of output as the frequency is lowered. Thus, with a crossover at 1,000 cps, for example, the horn itself should be designed to cut off around 750 cps, so that additional attenuation is not necessary. This same consideration applies to some extent with the low-frequency speaker, although unless special speakers are used, they may supply considerable energy well above crossover. Again resorting to the results of listening tests, it is usually sufficient to employ single L-section networks, with their 12-db/octave attenuation. One other consideration in this selection is the loss due to the use of additional reactive elements. If there were no resistive component in the coils and capacitors used in networks, any number of sections could be used without any additional loss. However, with practical coils and capacitors there is always some loss, and even when relatively large wire is used in the inductances, a loss of 0.5 to 1 db must be expected through any network.

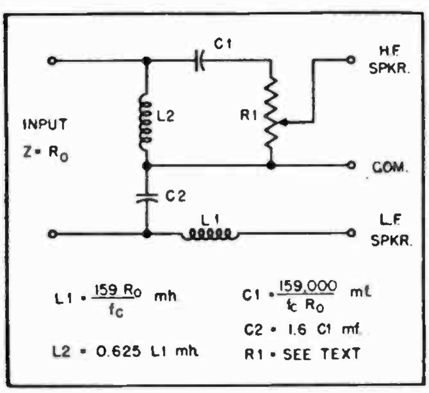
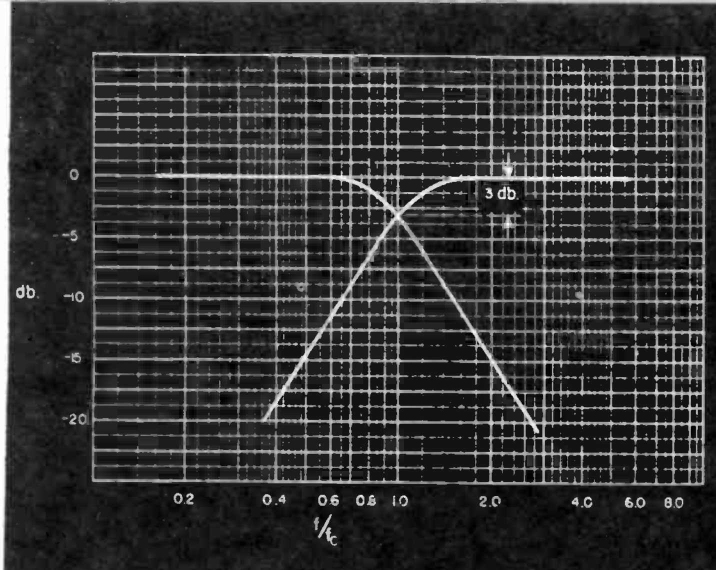


Fig. 1. Schematic of dividing network discussed in this article.

Arrangement

The final choice in the network selection is that of the arrangement of the sections. Either parallel or series connection may be employed, with differing results. The characteristic of the parallel network provides that the impedance outside the transmitted band rise to infinity, thus offering little or no damping to the speaker unit at these frequencies, even though they are not in the transmitted band for that particular speaker. The objection to this circuit may be questioned, but again basing the selection upon the all-important listening test, the series network is chosen for this discussion. The impedance of each section of the filter network falls to zero outside the transmitted band.

The final form for the network under consideration is shown in *Fig. 1*, together with the formulas for the calculation of the various components. The constructor will have selected the desired crossover frequency based upon the efficiency of either or both speakers throughout the audio band. Crossover frequencies below about 800 cps require the use of larger and longer horns, if the multi-cellular type of horn is used. If the low-frequency speaker is of the folded-horn type, the transmission may be limited to as low as 500 cps, requiring the lower crossover. In general, it is usually considered advisable to make the crossover frequency as low as possible in order to get as much of the mid-range frequencies out of the high-frequency unit, particularly if a metal-diaphragm unit is being used with a multi-cellular horn. Very satisfactory results have been obtained with crossovers ranging from 800 to 1,000 cps, while if the space permits,



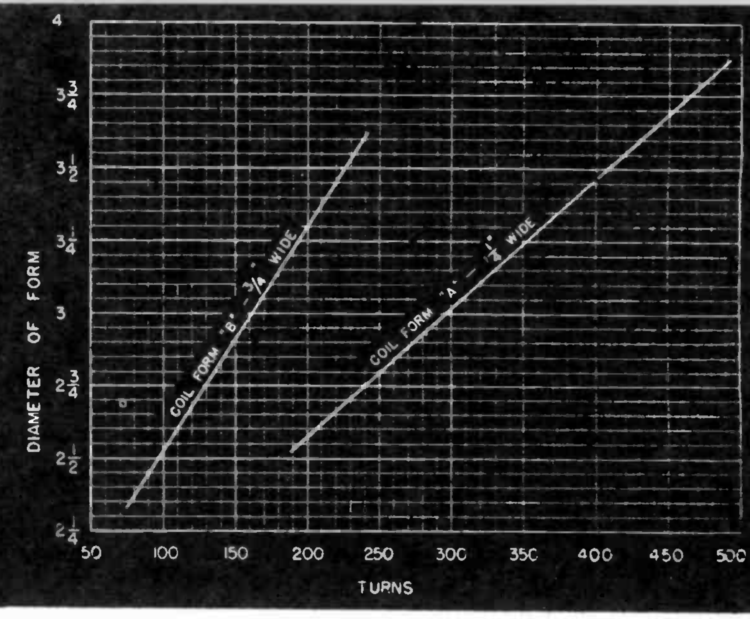


Fig. 2 (left). Frequency-response characteristics of dividing network of Fig. 1.
Fig. 4 (right). Flange diameter required for coil forms for coils having given number of turns of No. 17 DCE wire.

still better results can usually be obtained from a crossover at 500 cps. Some high-frequency units are designed for crossovers of 1,200, 2,000, and 3,000 cps, and while the output in the upper ranges is improved by the use of a two-way system with the higher crossover, greater intelligibility and naturalness is obtained with the middle speech-frequency range (1,000 to 2,000 cps) supplied by the metal-diaphragm unit. These factors must all be considered in making any choice.

Configuration

The network configuration arrived at through these choices is shown in *Fig. 1*, which is an L-section series network. It is designed to feed two speakers of the same impedance, at any crossover frequency desired, with the components calculated against these parameters. If the high-frequency unit is of a different impedance from that of the low-frequency speaker, the additional efficiency of this unit may be used to permit the matching to the impedance of the low-frequency speaker by the proper choice of value for R_1, as will be described later.

Since odd values may often be obtained from the formulas for C_1 and C_2, a simple artifice may make it possible to use standard, commonly available values for the capacitances. Suppose, for example, that the formulas yield values of 14.2 and 22.7 μf for the two capacitors for a crossover frequency of 800 cps. Capacitors having even values can be substituted for the calculated units, maintaining the same ratio between the two values, so that 15.0 and 24.0 are usable, resulting in a change of the crossover frequency from 800 cps to 845 cps. This figure is then used for calculations for the inductances, and little change in the performance of the system should be observed. The advantage of such a change lies in the use of capacitor values more easily obtained, without the necessity of building up the required total capacitance with a number of small units.

It is considered good practice to be able to radiate power from a loudspeaker to at least half an octave beyond the crossover point in order to provide satisfactory operation in the crossover region. Thus, if the crossover is to take place at 1,000 cps, output from the high-frequency unit is necessary down to 1.5 (0.5 x 1,000) or 750 cps. Any shift in the predetermined crossover frequency should take this into account.

Figure 2 shows the transmission curves for both sections of the network of *Fig. 1*. It will be noted that at crossover each circuit has a loss of 3 db, making the total output power at crossover equal to the input power. This may necessitate some compensation for the increased efficiency of the high-frequency unit, and R_1 is provided for this purpose. For nominal differences in efficiency of the two speakers, of the order of 6 db, the value of R_1 may be chosen at 1.5 times the impedance of the network or speakers, assuming that both speakers are of the same impedance. This will allow a reasonable margin for adjustment of the relative level fed to the high-frequency unit, without greatly disturbing the load impedance on the h-f branch of the network. For more critical applications, the resistor R_1 can be replaced by an L-pad, or with fixed resistors calculated from the desired attenuation and the impedance of the speaker.

When the high-frequency unit has an impedance differing materially from that of the low-frequency speaker, as is often the case when 8-ohm speakers are used for the low-frequency unit and 16-ohm high-frequency units are employed on a horn, the difference in efficiency permits the adjustment of impedances by the use of a simple shunt resistor at R_1 without the use of a tap. Thus, if the efficiency differs by 6 db, the 16-ohm unit should be shunted by 16 ohms, and fed from an 8-ohm network, when used with the 8-ohm low-frequency speaker.

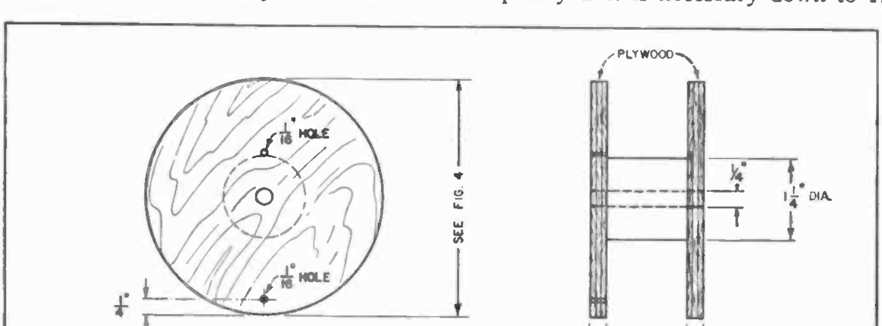


Fig. 3. Coil forms used in winding inductances in accordance with curves of Figs. 4 and 5.

Coil Construction

The principal objective of this article is to simplify coil construction to the point where reasonably good results may be obtained without resorting to a bridge for the measurement of inductance values. With this in mind, therefore, the coil forms shown in *Fig. 3* are used as the standards for these data, two sizes being provided to take care of a wide range of inductances while maintaining a reasonable form factor for the coils. Therefore, it is recommended that coil form "A", with a winding space of 1¼" be used for coils ranging from 2.0 to 8.0 mh, and that coil form "B", with a winding space of ¾" be used for coils of 0.5 to 2.0 mh. Assuming that the constructor has determined the inductance values required for a network and selected the form most suitable for winding the coils, he may determine the maximum outside diameter for the flanges from *Fig. 4*. These values, together with the information provided in *Figs. 5* and *6* are predicated upon the use of No. 17 DCE wire.[1]

Returning to *Fig. 4,* if the flanges for the coil forms are cut to the dimensions shown, they will allow suitable winding space with about ¼" overlap, thus giving coils of uniform appearance. The curves of *Figs. 5* and *6* may be read directly to determine the number of turns of wire to be wound on each coil form for the required inductance value. Note that twenty-three turns are wound per layer on the large form, and that thirteen turns are wound on each layer of the small form. If wire of other size must be used, comparable values for the number of turns required will be obtained if the number of turns per layer is held to either of these values. This will, however, require a recalculation for the width and diameter of the forms. The curve of *Fig. 5* covers inductance values from 1.0 to 8.0 mh, while the curve for *Fig. 6* covers values from 0.2 to 2.0 mh. When carefully layer-wound by hand or on a lathe, Q values of the order of 20 to 25 should be obtained, which are adequate for dividing network coils.

It goes without saying that no iron should be used in the construction of these coil forms but that all parts of the form are of wood or plastic. It is recommended that they be made by gluing the flanges to the core. A ¼" hole through the center may be used for mounting the forms by means of large brass wood screws. Some constructors prefer to wind coils on a demountable form, and after winding to remove the coil from the form and tape it up. This is somewhat of a refinement, and when only one set of coils is required, it is

[1]This may appear to be an unusual size, but many experimenters may have the field coil from a discarded Western Electric 555 unit, which is wound with wire of this size. However, if either #16 or #18 wire is used, and wound with the indicated number of turns per layer, the inductance values obtained by following the charts will be sufficiently close for practical purposes.

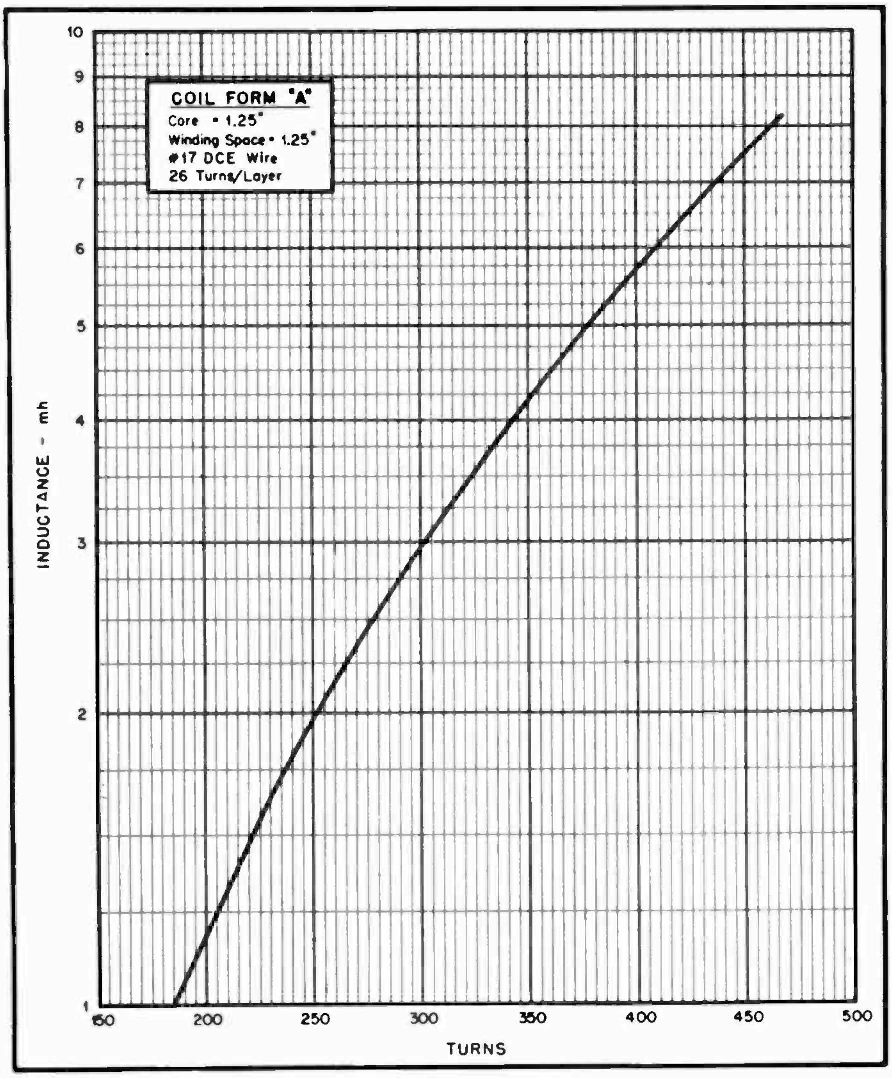
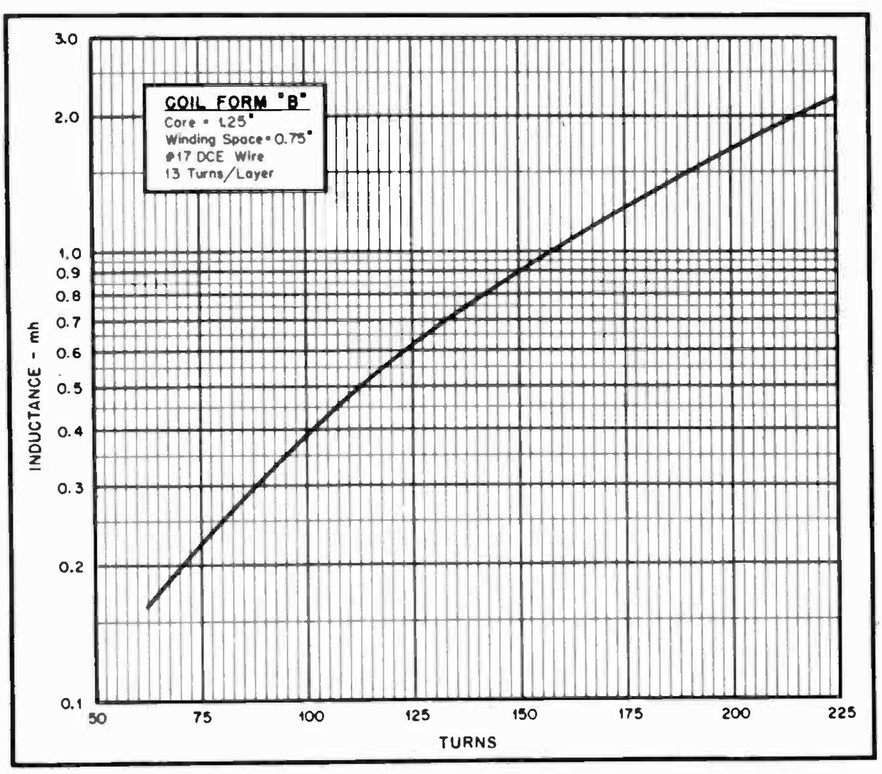


Fig. 5 (above). Turns necessary to obtain various inductance values on coil form "A".

Fig. 6 (below). Turns for various inductances on coil form "B".



simpler to wind the form with the required number of turns and leave the winding in place. The start and finish of the winding may be brought out through holes in the flange and attached to suitable terminals. Two or three coats of lacquer will furnish a protective coating for the coils, but if they are to be used in humid climates, they should be baked out and impregnated with varnish.

After winding the coils, the network should be assembled on a wooden base, making sure that the two coils are not mounted closer than six inches from each other, and that their axes are at right angles. If it is desired to enclose the entire network in some fashion, a wooden box is recommended; the use of metal in proximity to the coils tends to reduce the Q, and may affect the over-all performance.

Tests

If an audio oscillator and gain set is available, the constructor will wish to make measurements of the transmission characteristics through each section of the network, the other section being suitably terminated. If such equipment is not available, it is possible to make a reasonable adjustment solely by means of the ear, which is the ultimate instrument for which the speaker system is designed. For the constructor who makes several speaker systems, the test unit shown in *Fig. 7* will prove an aid in balancing and phasing.

The two-pole, three-position switch permits the feeding of either speaker independently, or both together. When either section is cut off, the circuit is terminated properly. The 1-db/step pot provides for the attenuation of the high frequency unit for determination of the required amount which must be introduced by the resistor R_1 in *Fig. 1*. The DPDT switch in the leads to the high-frequency unit provides for reversing the

TABLE I

10-ohm T-pad Resistance Values

Loss db	Series Arm (2 required)	Total Shunt Arm
1	0.58	86.7
2	1.14	43.0
3	1.71	28.4
4	2.26	20.9
5	2.80	16.4
6	3.32	13.4
7	3.82	11.2
8	4.30	9.45
9	4.76	8.13
10	5.20	7.02

phase. In operation, this test unit is set for transmission to the low-frequency speaker, and the acoustic output at the crossover frequency is measured using a microphone and amplifier with an output meter. The switch is then thrown to the high-frequency position and the pot is adjusted to obtain the same acoustic output from the high-frequency horn. Then, with the switch in the center position, both speakers are energized at the crossover frequency and the DPDT thrown from one position to the other to obtain the maximum output as measured by the microphone and amplifier. Fine adjustment of phasing is then made by moving the high-frequency unit and horn back and forth relative to the low-frequency unit to obtain the maximum output from the combination. The relative positions of the two speakers are then noted and final assembly of the speakers is arranged to maintain these positions. If maximum output should happen to be obtained with the high-frequency horn extended beyond the front of the low-frequency baffle, this condition may be corrected by reversing the DPDT switch and sliding the horn back one-half wavelength at the crossover frequency. *Table 1* gives values suitable for constructing the 1 db/step "scaling hook" pot for an impedance of 10 ohms. For any other impedances, Z, the values given should be multiplied by Z/10.

Such an elaborate device is not necessary, however, for making final adjustments to two-way speaker systems. The acoustic outputs of the two speakers can be balanced close enough by ear, using the tap on the resistor R_1 of *Fig. 1* for adjusting the relative levels.

Phasing

Phasing adjustments between the two units may be arrived at by listening, preliminary settings being obtained by a simple reversal of the leads to the high-frequency unit, and final positioning being determined by continued listening. It will be noted that when the optimum point is located, the maximum realism will be heard from a two-speaker combination. With crossover in the vicinity of 500 to 1,000 cps, a reversal of the leads will give the effect on speech of jumping back and forth between the two speakers, completely eliminating the illusion of a single source of energy.

Final adjustments on any two-way speaker system should be made with whatever screening material is to be used in place, for two reasons. Most important, there is certain to be some attenuation of the high frequencies, and this should be compensated by adjustment of the resistor R_1. In addition, however, the illusion of a single sound source is often destroyed when both units are separately visible, and the covering with suitable grill cloth will eliminate this effect and blend the two sources into one apparent source, provided the phasing is correct. It is suggested that no adjustments to a system of this type be considered final until the listener has "lived with" the speaker for several days, and it should be expected that gradual improvements may be obtained in the over-all performance for the first two or three months after its installation as the user becomes familiar with its characteristics.

With this simplification of dividing network design and coil construction, it is believed that the average high-fidelity enthusiast should be able to obtain reasonably good results with a minimum of equipment being necessary to make adjustments. A loudspeaker system is designed primarily as a medium for transmitting sound to the ear, rather than to a microphone and a group of measuring instruments, and while no deprecation to the value of measurements is intended, it must be realized that the ear is actually the final judge of the performance of any loudspeaker system. If the constructor is able to obtain satisfactory results from the information contained in this article, its function is fulfilled completely.

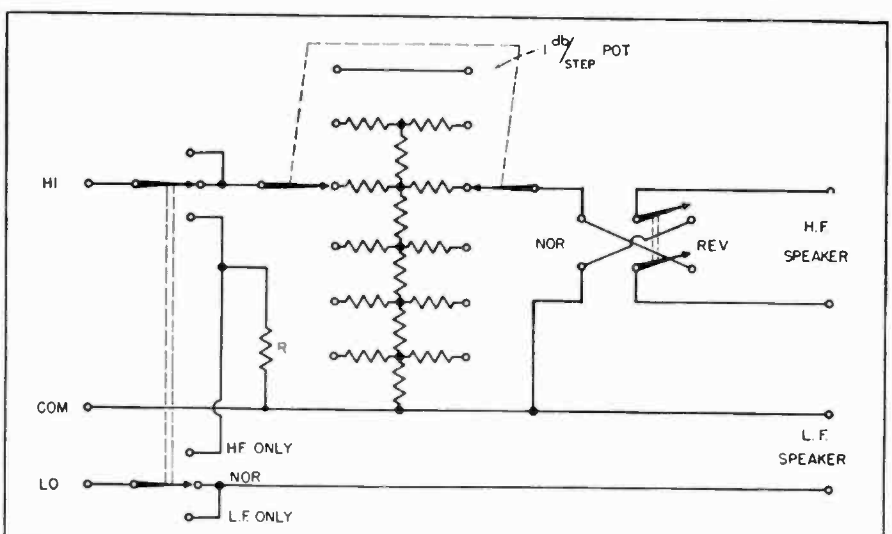


Fig. 7. Test unit for simplifying the balancing and phasing of l-f and h-f speakers.