Two-Way Speaker System

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A three-part article describing the design and construction of an excellent two-way speaker system.

PART I

THE THEATRE-TYPE loudspeaker system, commonly called "two-way," has long been recognized for a number of reasons as the optimum arrangement for the reproduction of speech and music. By providing separate speakers for the low- and high-frequency ranges, each designed for its own particular duties, no compromises are necessary in either to cover an extremely wide band of frequencies. The clarity of speech reproduced by the two-way system is undoubtedly the result of a small, relatively stiff diaphragm which handles the bulk of the speech frequencies, or at least their harmonics. The distribution of sound energy over a wider angle than is possible with a single-cone direct radiator gives a more uniform characteristic over an entire room, and the low-frequency cone can be sufficiently flexible to permit the wide excursions necessary for efficient bass reproduction.

Many experimenters, engineers, and ordinary listeners would use the two-way system if it were not for its relatively high cost. The simple baffle or the reflexed enclosure can be constructed easily by almost anyone who is reasonably handy with tools, but the problems of multicellular horn construction appear to be difficult. However, once the method of building the horn is learned, it is seen to be quite simple. After getting together the necessary tools, a complete horn should be built in about eight hours' time. If the constructor plans to make a number of sets of horns, he will do well to make his own patterns for the throat coupling. For the builder who wishes only one such unit, it is simpler to buy the throat ready-made.

Description

For the benefit of the newcomer, a two-way system consists of a low-frequency cone speaker in a suitable baffle, a high-frequency diaphragm-type unit with a suitable horn, and a dividing network to channel the low frequencies to the cone and the high frequencies to the horn unit. The design and construction of dividing networks is discussed in the article on page 101, and will not be covered in this series. The bass speaker may be housed in a conventional reflexed cabinet, or in an infinite baffle, or in one of the more elaborate horns such as the Klipsch. The last is ideal, but it is bulky, requires a cross-over at least as low as 500 cps, and since the walls of the room become a part of the horn, its use in apartments is frowned upon—usually quite vigorously—by one's neighbors.

The high-frequency section of the speaker comprises the unit itself, coupled to a horn which serves to load the diaphragm and to distribute the sound over a wide angle. The dividing network is a relatively simple circuit arrangement which can be assembled quite easily by the average constructor.

Of all the components required for a two-way system, the only ones offering any apparent difficulty are the high-frequency unit and the horn. The information contained in this article covers the construction of a multi-cellular horn, and satisfactory speaker units are available at a cost of about $15. Allowing about $5 for the shaping block, and $3 for the throat casting and the machine work on it, the total cost of a high-frequency horn and unit should be less than $30. The quality of reproduction which can be obtained from a system of this type should easily justify the cost and labor involved.

Horn Requirements

Two basic types of horn construction have been used to provide exponential loading for the high-frequency unit. One comprises a single exponential horn with a number of partitions which aid in the distribution, while the other consists of a number of individually-exponential horns mounted in a group with their throats and mouths joined to provide, essentially, a single opening at each end. Thus, the unit is coupled to the joined throats, and the joined mouths serve as the distributing area. This latter form of horn appears to be the simpler to build, since each separate horn cell is identical with every other one.

One manufacturer of these horns has built dies in which the entire assembly can be molded of Bakelite in one piece, but this is out of the question for the builder of one set of horns. A die for this purpose costs upward of $5,000. Once the die is made, however, horns can be turned out quite cheaply.

The grouped horn sections must be coupled to the opening in the high-frequency unit. This opening is usually circular, and the outside of the throat fitting is threaded. Joining the throats of the separate horns to the speaker units requires a throat casting. This casting may be made by any foundry from a pattern which is not hard to make. The first pattern the writer ever made was for a horn throat, and the casting obtained was perfectly satisfactory, much to the amazement of the writer (and probably the foundry).

Horn Design

Without going into the primary development of the number of individual cells required to obtain a suitable angular distribution (since it was assumed that if one commercial two-way system had eight cells, the same arrangement should be suitable for the homemade set), let it be said that the desired grouping was the 2x4 horn, consisting of eight cells. This gives a distribution of approximately 100° in a horizontal plane, and about 50° in a vertical plane. It also furnishes a reasonably-sized unit which is not too bulky for the average living room, and which provides satisfactory coverage of most of the listening area.

The formula for an exponential horn is based upon the requirement that the area of the cross-section must double in a given length along the axis of the horn. This length controls the cut-off frequency. A second requirement for the individual horn sections is that the perimeter of the mouth shall be not less than one wavelength of the lowest frequency to be reproduced. The cross-over frequency was selected at 900 cps on the premise that this value approximated the more conventional 800-cps cross-over, yet provided a slightly smaller horn with a wider angle of distribution.

With the 900-cps cross-over frequency, a mouth perimeter of 14.9 in. is indicated. Thus if the mouth were 4 in. square, the horn size will be sufficient. At the throat, it should have a dimension of not less than 1/4 in. square, since any smaller opening would be difficult to work with. This provides a total throat area of 8x1/4x1/4in., or 0.5 square inches.

It has been determined that when an exponential horn doubles its area every 12 inches of length, it will reproduce satisfactorily a frequency of 64 cps. If it doubles its area every 6 inches, its cut-off frequency is 128 cps, and so on. For a horn capable of reproducing a minimum frequency of 900 cps, the area should double at intervals of 0.854 in. Resorting to round figures, a suitable interval is selected as 1 in., which corresponds to a frequency of 768 cps.

Using these figures, and contemplating the use of a horn of square cross section, the over-all length of each section is determined to be 8 in., and the longitudinal section of the individual horn may be plotted as in *Fig. 1*, which is half scale.

Now comes a gimmick which simplifies the construction of a set of horns. When perfectly square horns are joined, with the center lines of the various horns each being radii of a sphere, there is a narrow diamond-shaped opening between adjacent vertical pairs of horns at the mouth. This opening must be covered, since some deadening material must be employed around the horn sections to prevent resonances. However, if the shape of the mouth is changed slightly to a trapezoid, the diamond-shaped opening between the pairs reduces to a straight line, and the assembly is simplified considerably since a simple folded strip of metal may be used to fasten the units together. By a series of calculations, it has been determined that the mouth of the individual horn should be 4 in. on each of the three sides, and 4 1/2 in. on the fourth. The long dimension becomes the dividing line between the two cells of each vertical pair.

This shaping of the horn section takes place gradually throughout the entire length. Thus at both the mouth and throat ends, the horns join smoothly without any intervening spaces.

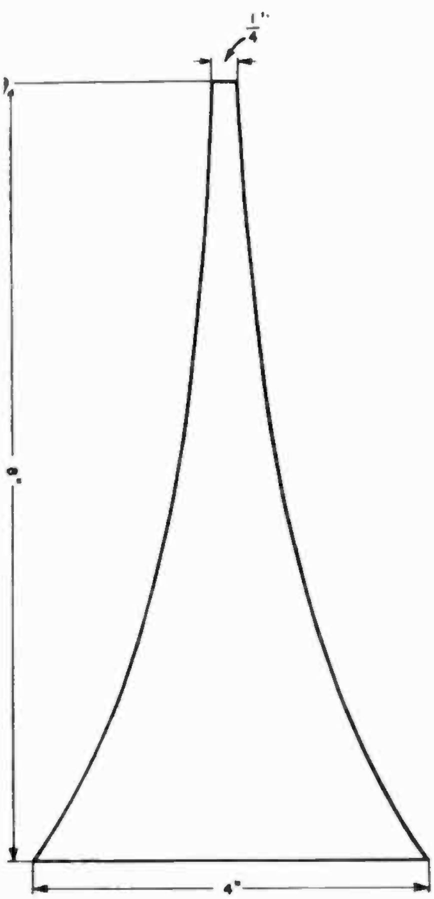


Fig. 1. Developed section of exponential horn, doubling in cross-sectional area for each inch of length along the axis.

Forming the Horns

The method of forming the individual sections ensures that each will be of the proper shape, and that the joints are well soldered. Early attempts at horn making without the forming block resulted in poorly shaped sections, and they were difficult to solder together without any leaks.

The forming block, shown in *Fig. 2*, consists of a solid block of wood, preferably maple or birch, shaped to the predetermined curves, and equipped with two clamping blocks. To make such a block, use a piece of wood 5 in. square and 12 in. long. On one side, lay out the horn shape commencing with a 1/4-in. throat at the top and a 3 15/16-in. width at the lower end. The shape should be centered vertically on the block, with the throat at one end. On the opposite side, lay out the horn shape again, using a 1/4-in. width at the top and a 4 7/16-in. width at the bottom. This allows for the 4- and 4 1/2 in. widths when the sides of the trapezoid are extended to the 5-in. square of the block. The curves marked *A-A* on *Fig. 3* may be used, since they have the correct shape and are of full size. The additional length of the sides for the one wider section may be compensated for by a slight elongation of the curve at the throat end.

With the two opposite sides marked, the block is then cut in a band saw, being tilted slightly as the cut progresses so as to join the lines with the saw cut. This work had best been done in a cabinet maker's shop. The sides are not cut off completely, but are left joined to the block by the sections approximately 1/2 in. wide at the lower end.

Now slip a piece of cardboard into the two saw slots to make the block solid, and lay out the horn shape on one of the remaining sides, using a 1/4-in. throat and a 4-in. mouth. Mark these two sides for identification both above and below the base line so that the correct parts will be retained for later use, after the cutting is completed. Then, still using the band saw, cut along the lines just drawn. The block is now left flat on the saw table, since these two cuts must be parallel. Then cut along the base lines just far enough in to free the outside sections, leaving only the form corresponding to the horn shape, resembling a concave-sided pyramid.

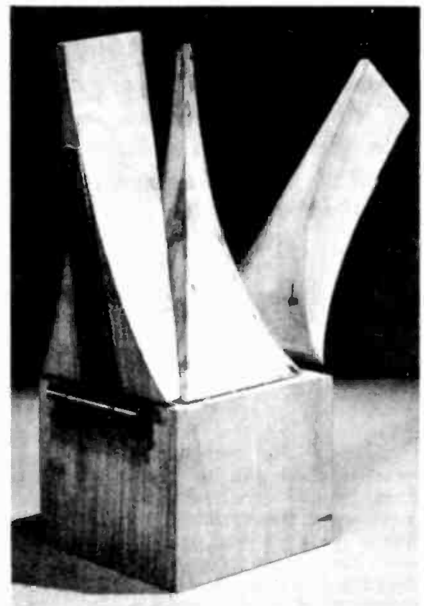


Fig. 2. Wood forming block used for shaping and soldering the individual horn sections to uniform dimensions.

The final operation is to take the two marked sections and mount them back in place, using heavy T-hinges, as shown in *Fig. 2*. The remaining pieces may be discarded.

The method of using is simple. Pre-cut pieces of sheet metal are placed between the clamp blocks and the center form, leaving the metal extending equally on each side, and a large C-clamp is applied at the top of the form and tightened securely. Two additional pieces of sheet metal are then placed on the open sides between the extending lips, and the latter are peened down tightly over the form, thus providing a perfectly shaped section. Solder the four sides carefully, using 50-50 solder. Release the clamp blocks, and remove the completed horn section. The time required to make a single section should be less than five minutes.

Preparing the Sheet Metal

To expedite the assembly of the horn sections, it is advisable to cut all the sheet metal first. Since the final horn assembly will be filled with a deadening material, the only duty of the sheet metal horns is to hold this material in place while it cools, and there is no need to use heavy sheet metal. The recommended material is known as "Coke Tin" in the lightest grade obtainable, being approximately 0.010 in. thick. This material is easy to cut, easy to form, and thin enough to solder rapidly, yet is sufficiently heavy for this application. It comes in sheets

20 x 28 in., and for the entire set of horns, three sheets are required.

Three sizes of metal are necessary for each individual horn section, since two of the sides lap over the others, and because of the trapezoidal shape. *Fig. 3* is a full-size pattern for the three required pieces. For each section, two of the narrowest shape are required, and one each of the other two. Thus, for an eight-cell horn, sixteen pieces are necessary of the smallest size, and eight of each of the others. Once the pieces of tin are cut out, the assembly of the horn sections should proceed rapidly.

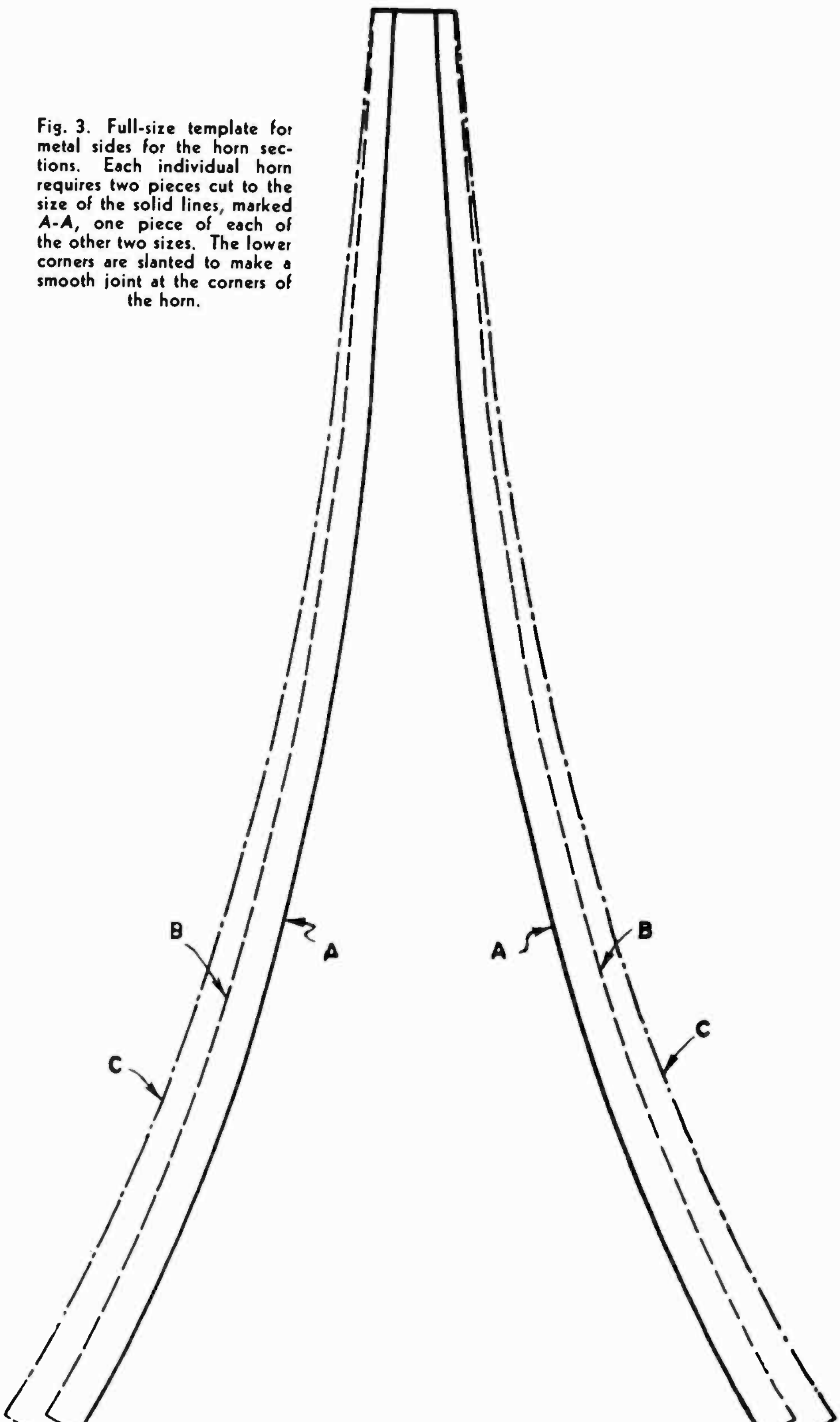


Fig. 3. Full-size template for metal sides for the horn sections. Each individual horn requires two pieces cut to the size of the solid lines, marked A-A, one piece of each of the other two sizes. The lower corners are slanted to make a smooth joint at the corners of the horn.

Assembly of Sections

After the eight horn sections are completed, they must then be assembled into pairs. It will be noted that each horn mouth is trapezoidal in shape. Holding a pair of horns together with the long sides of the openings adjacent to each other, and the throat ends aligned, solder the corners of the mouth openings. Then solder the throats together, and the pair appears as shown in *Fig. 4*. This completes the preliminary joining of the vertical pair, and all four pairs should be so soldered. For this operation the use of rosin-core solder is recommended, since it will reduce the tendency to loosen the other joints. Flow solder on the sides of the horns at the throat and file flat so that a straight edge along the sides touches only the edges of the mouth and throat openings. Using the same method as for joining the individual sections together, assemble the four pairs into a single unit, keeping the edges of the throats as close together as possible. Use plenty of solder at the throat so as to make a solid structure. The use of a fine-pointed flame from an alcohol torch simplifies this operation, although it is not essential. After the eight sections are assembled together, use a square file to clean up the throat openings and make the edges come together with a sharp dividing line.

The front or mouth edges of the horn are now trimmed by the use of folded strips of tin such as those shown in *Fig. 5*. These are slipped over the adjacent edges of the horns, clamped down in a vise, and soldered in place, again using 50-50 solder. The reason for using hard solder is that when the horns are completed and covered, the space between them is to be filled with melted roofing tar. When sufficiently hot to flow easily, this tar will melt rosin-core solder. If the joints are loosened, the tar will leak out, and additional work is required to remove it.

After the assembling operation is finished, place the narrow side of the horns on a piece of tin and cut the two side covers, leaving a ¼-in. overlap to bend over the top and bottom covers, and bringing the ends flush with the mouth openings. The throat end should be ¼ in. short of reaching the end of the horns. Before soldering on, bend the upper and lower lips over at an angle of 90°, toward the inside of the cover. Folded trim pieces, similar to those used to cover the joints between the mouth openings, are used to finish the edges between the side cover and the end pair of horns.

Now cut similar covers for the top and bottom of the assembly, allowing enough metal to make a smooth concave surface, although not so deep a curve as to touch the horns. Cut a 1-in. diameter hole in the piece that is to be the bottom, centered from side to side, and about 3 in. from the throat end of the horns. This hole is used for filling with the tar. The top and bottom are then slipped under the lips on the side, soldered in place, and trimmed along the front edges with the bent strips. This completes the assembly of the horns into a single unit, and the remaining work consists of preparing the horn throat and soldering it in place, and filling the spaces between the cells with the deadening tar. Make sure that all openings at the corners of the horns are soldered closed. Any surplus can be filed off after the horns are filled.

The High-Frequency Unit

The selection of a suitable high-frequency unit can become involved. Some speaker unit manufacturers advertise models designed to cover the range from 1,000 to 15,000 cps, 3,000 to 16,000, and so on. While good performance to over 10,000 cps is important, it is also important that operation be satisfactory down to at least an octave below the cross-over frequency. Thus a unit which is capable of handling 300 cps will perform better in the octave between 1,000 and 2,000 cps than a unit designed to extend down to 1,000 cps as a minimum. In the writer's opinion, the principal advantage of a two-way system is its ability to handle the upper-middle frequencies adequately, even at the expense of the range above 10,000 cps. Although many f-m programs exceed this frequency, and wide-range a-m receivers are capable of it, few phonograph records have any appreciable signals of higher than 10,000 cps.

The throat coupling on the high-frequency speaker unit has a 5/8-18 thread, and the hole has a diameter of 0.5 in. The area of the opening is therefore $\pi\ (0.5)^2\ /4 = 0.19635$ sq. in. This area must double with every inch of length, and it must join with the throat area, which is 0.5 sq. in. Thus the length between the opening in the unit to the throat of the horn can be determined by calculation to be 1.35 in. and the hole must therefore gradually change its shape from a 0.5-in. circle to a 0.5 x 1.0-in. rectangle, distributed in a circular arc.

This is done in the throat, which is a brass casting also serving as a mechanical coupling between the unit and the horns. *Fig. 7* shows side and plan views, together with sections at various points. From this detail, the pattern can be made readily by anyone familiar with pattern making. However, since it is believed simpler to purchase the throat casting ready made, no instructions are given for making the pattern. The constructor who wishes to make his own is referred to books on the subject. Suffice to say that the pattern consists of a wood replica of the finished coupling, so arranged to part in the center, using short lengths of dowels to keep the two halves in alignment, and having two extensions for the core. The core itself is moulded, also in two parts, and baked before the mould is

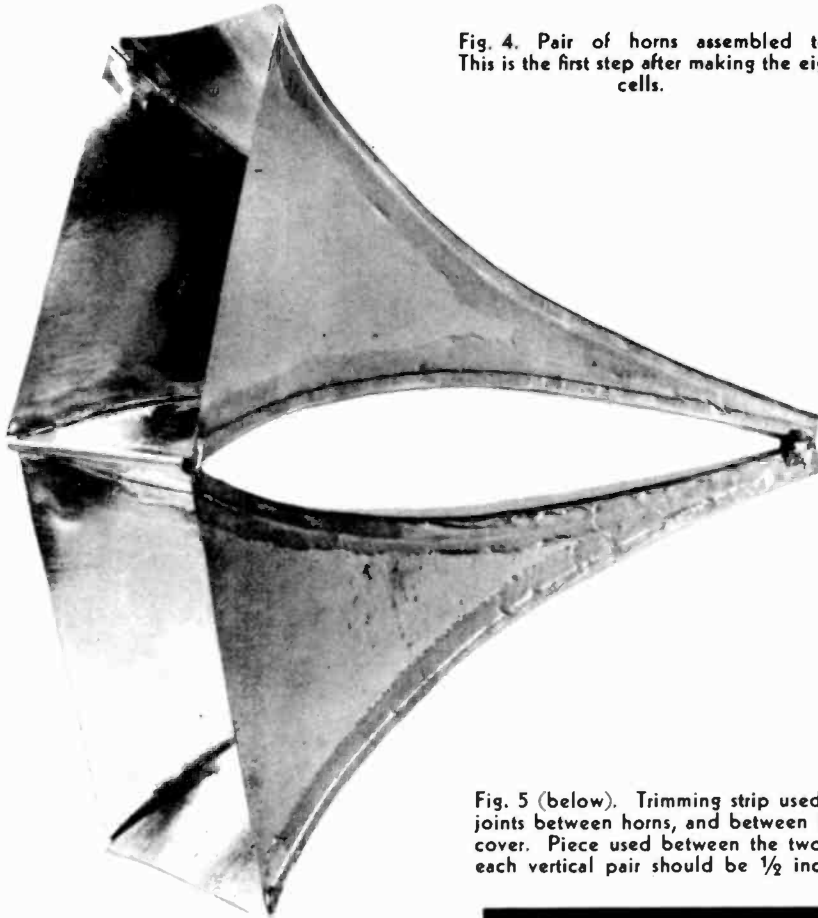
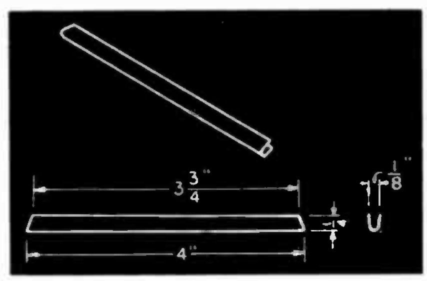


Fig. 4. Pair of horns assembled together. This is the first step after making the eight horn cells.

Fig. 5 (below). Trimming strip used to cover joints between horns, and between horns and cover. Piece used between the two horns of each vertical pair should be ½ inch longer.



made, and is placed in the sand mould to provide the opening through the casting. It is moulded in a "core box" which is also made of wood to provide a form of proper shape. After the casting is made, it is machined to make a tight joint at the shoulder, and threaded to fit the speaker unit. The castings made available with the unit have this mechanical work completed.

The throat casting should be thoroughly tinned on the inside, then soldered to the throats of the assembled-and-covered horns. This job requires a lot of heat, and again the small alcohol torch is helpful. Solder should be flowed smoothly to make a neat joint. After cooling, clean up any lumps of solder in the inside of the throat coupling using a round or square rattail file, as the location indicates. Solder two 1 x 1½ in. angle brackets to the sides of the assembly at the front corners for mounting.

Deadening the Horns

At this point, the deadening material is poured into the opening in the bottom cover. Ordinary roofing tar is suitable; once it cools, the entire horn assembly is a solid structure. Melt the tar in an open-topped container, taking care not to get it too hot. It is advisable to melt only a small quantity at a time, adding more chunks as the liquid tar is poured into the horn. A two-pound coffee can makes an ideal container. *Melted tar can cause painful burns, and considerable caution should be exercised in handling it.*

As the tar melts, pour a quantity into the opening and tilt the horns to fill all the corners first, then the throat end. It would suffice to have a coating on the outside of each horn section, but there is no way to make sure of a thorough coating except to fill the entire space. After it is filled and cooled, solder a round tin cover over the opening. Any tar that may have leaked out at the joints can be removed by using gasoline on a rag.

Fig. 6. Special model of "Baby" speaker unit designed for use with high-frequency horns.

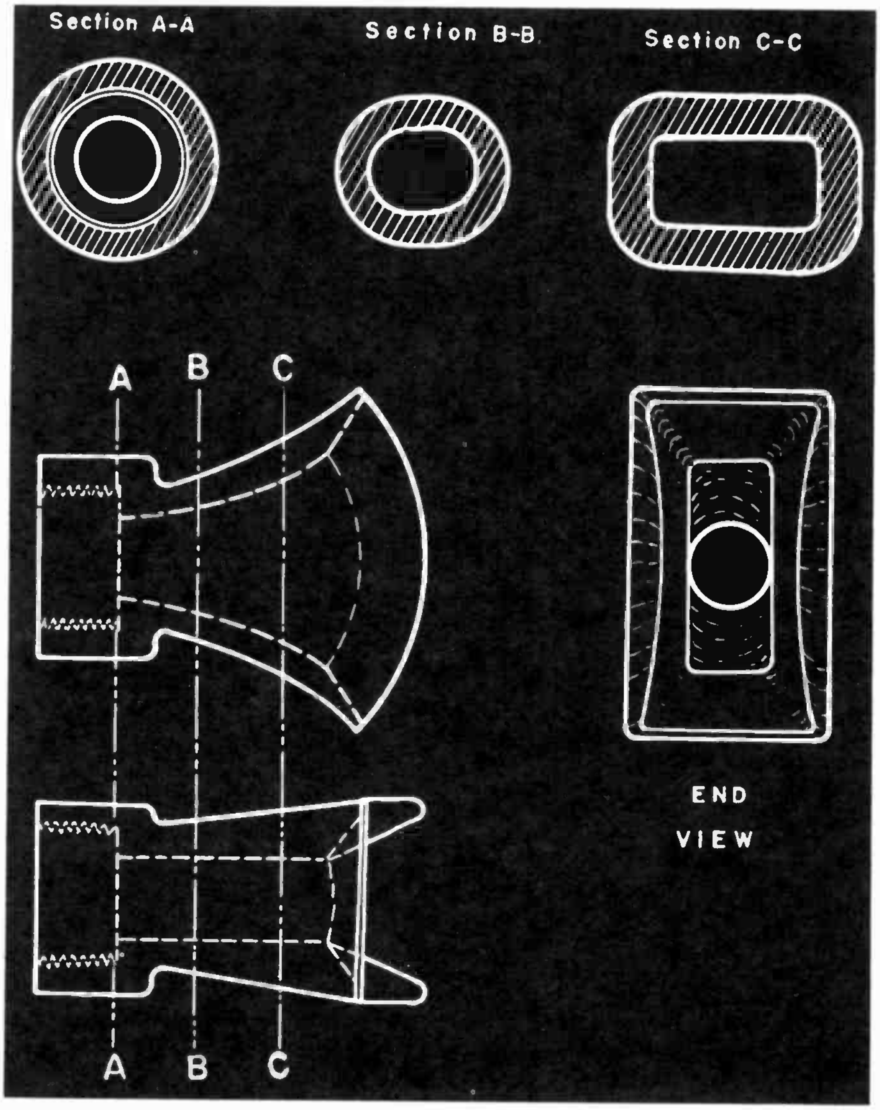


Fig. 7. Plan, elevations, and sections of horn throat coupling, approximately 9/10 full size. Center hole is ½-inch diameter.

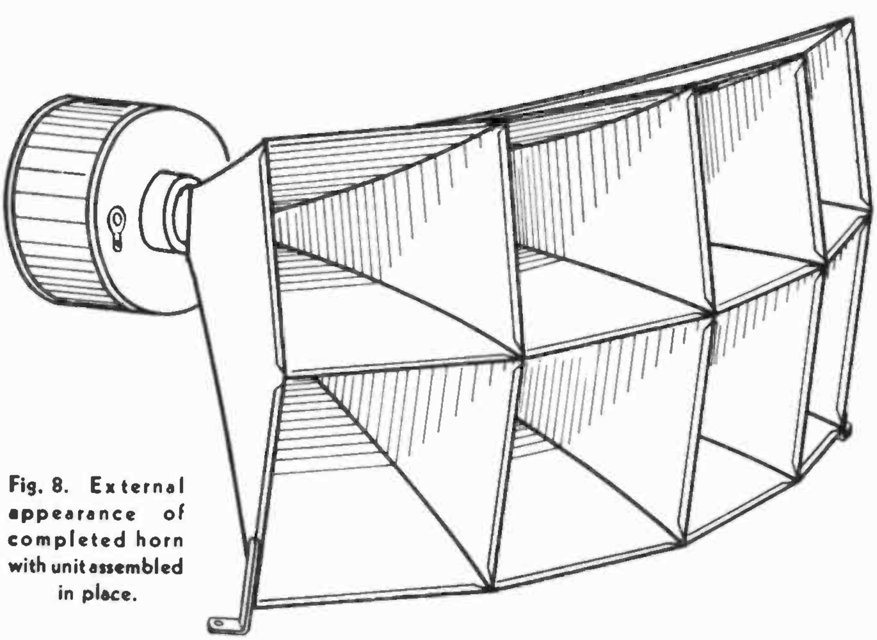


Fig. 8. External appearance of completed horn with unit assembled in place.

An air brush is helpful in painting; however, a small brush can be used to reach the small ends of the horns if no air brush is available. The object of painting is to forestall rust and to give a suitable outside appearance. When dry and the speaker unit is screwed on tightly, the high-frequency speaker is complete, resembling *Fig. 8*.

PART II

The Low-Frequency Section

The low-frequency section of a two-way system may consist of a folded horn, a plain baffle, an infinite baffle, some form of acoustic labyrinth, or a reflexed enclosure. While the best performance can usually be obtained by the use of some form of folded horn, there is some question as to whether the response between about 400 and 900 cps is satisfactory, since the upper frequencies passed by the low-frequency speaker are required to traverse the turns in the horn, and some loss may be expected in that region.

The flat baffle is the simplest arrangement, but it is deficient in the very low register, even if it becomes of large dimensions. The infinite baffle, such as the wall of a room with the speaker itself being in another room, or in an attic, is reasonably satisfactory, and is preferred to the plain baffle.

The acoustic labyrinth type of speaker requires a lot of complicated design and construction, and it is doubtful if it is any better than a cabinet form of mounting, provided some means is taken to reduce the effect of cone resonance. Some speakers are suited for mounting in a completely enclosed cabinet of smaller dimensions than normal, with the stiffness of the enclosed air serving as the damping.

For over-all use, considering the space required, the radiation efficiency of the speaker at low frequencies and the external appearance—which must be considered unless the user is a bachelor—make the reflexed cabinet a logical choice. It should not be assumed that this is the ideal speaker housing for the reproduction of low frequencies, but considering the compromises that must be made occasionally, it has certain advantages.

For these reasons, the low-frequency speaker selected for use with the two-way system described here is of the reflexed type, of a size consistent with the speaker selected.

Reflexed Cabinet Design

The design of a suitable reflexed cabinet requires the possession of considerably more information than is usually available to the constructor, besides requiring a knowledge of the basic principles of acoustics and the methods of calculating acoustic compliance, mass, and a variety of other characteristics. Among this data that must be at hand is the resonance frequency of the loudspeaker cone, and in only a very few instances is this figure available from the manufacturer without considerable trouble.

On account of this, a much simpler empirical method of determining the size of a cabinet is suggested. This method is based on the physical size of the speaker, and while it may be far from the classical method of designing a box, it is a slight improvement over one method employed in the design of an early commercial speaker enclosure. The engineer in charge of this design admitted that the box was as big as he could make it and still get it into the back of his sedan.

Unfortunately, this particular box was not sufficiently large, and the over-all result of the device was to introduce a peak in the response at about 70 cps, but in spite of that, the speaker was better than any others then available.

The empirical method is based on the following figures: Use a box which has a volume in cubic feet which is numerically equal to the nominal radius of the speaker in inches. Thus, using this method, a 15-inch speaker requires a cabinet volume of 7.5 cubic feet. This is not too far from a reasonable proportion, as has been determined by experiment. The port area is claimed by good designers to be equal to the actual radiating area of the cone, which is somewhat less than that calculated from the nominal diameter of the speaker. For example, a certain 15-inch speaker requires a 13½-inch hole for mounting, but the actual diameter of the conical section of the cone itself is only 12½ inches. Thus the suggested port area should be 123 square inches. Experiments have indicated that this is somewhat too large for the average speaker and enclosure, so resorting to an empirical formula again, the port opening may be taken as 0.8 times the area of the loudspeaker opening, to allow for adjustment to the optimum size.

While the design of a suitable box may be done by means of a number of complicated formulas, the final result—as with anything in the audio field—is how it sounds when completed. Therefore, having decided upon a reasonable port size, it is much simpler to make the box and then experiment with the output until the result is satisfactory. This may be done by simple experimentation with the box, an amplifier, and an audio oscillator, in a method to be described later.

The reflex cabinet serves principally to increase the radiation of a loudspeaker at frequencies below those where it normally loses its efficiency. A secondary reason for the box is to alleviate the effects of cone resonance, which normally occurs at a frequency where it is objectionable. If the increased impedance at resonance can be corrected by the design of the cabinet, the response is sure to be better in that region.

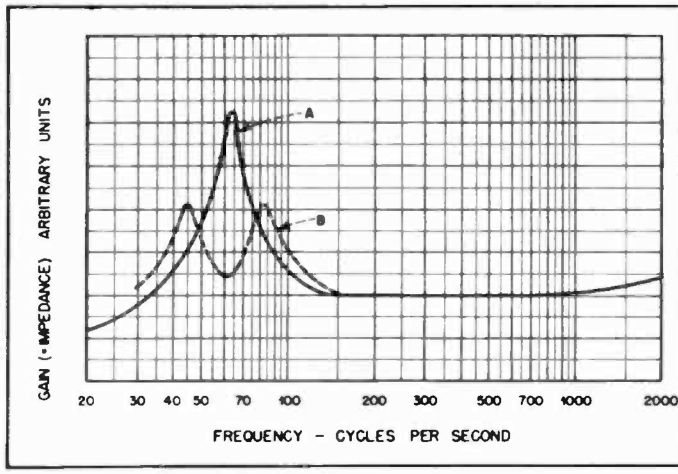


Fig. 9. Curves indicating speaker impedance obtained by measurement of gain of an amplifier with pentode or beam-power output tubes. A represents curve of speaker mounted in open back cabinet, showing effect of cone resonance. B represents curve of speaker mounted in reflex cabinet with port adjusted so that both peaks are of equal amplitude.

Resonance Effects

The effect of speaker resonance manifests itself as an increase in impedance at the resonant frequency. While this in itself is not particularly important if triodes are used in the output stage, it makes a considerable difference when pentodes or beam tubes are used, unless there is a sufficient amount of inverse feedback to stablize the output impedance of the amplifier. If a curve of the impedance of a speaker is made with an open-back cabinet, it will be found that it resembles that shown in *Fig. 9* Such a curve can be made by measuring the gain of a beam-power or pentode amplifier with the speaker as the termination, and covering the frequency range from about 30 cps to at least 300 cps. The impedance of the speaker affects the gain of the output stage, and consequently the gain-frequency curve represents the variations in impedance.

When the back is put on a ported cabinet, the gain-frequency curve exhibits two peaks, one above the resonant frequency, and one below. Optimum results are obtained when the two peaks are of equal amplitude, as shown at (*B*) in *Fig. 9*. The relative amplitude of the two peaks can be varied by changing the size of the port, and the port opening should be so arranged that the two peaks are equal.

With this in mind, it is seen that the entire speaker enclosure may be constructed with a number of empirical formulas, and then by changing the size of the port to obtain the correct response curve, the optimum performance can be obtained. From a construction standpoint, it is advisable to make the port somewhat larger than the anticipated final size, so that the effective opening can be reduced by the use of an additional piece of wood mounted inside the cabinet.

Any *good* 12 - or 15-inch speaker may be used with this system. In order to simplify the dividing network, it is necessary that the impedance of the low-frequency speaker be 8 ohms, since that is the impedance of the high-frequency unit selected for use with this system. While it is possible to design a dividing network which will feed two speakers of differing impedances, it is much simpler to select a low-frequency speaker of the correct impedance in the first place.

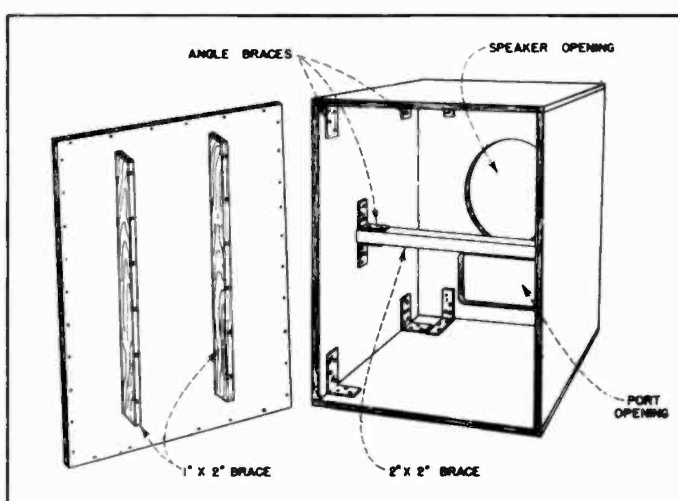


Fig. 10. Internal bracing of heavy plywood cabinet used for low-frequency speaker. All joints should be glued, and assembly should be made with woodscrews rather than nails. Back must be thoroughly braced, and should have adequate number of screws to hold it securely to prevent vibration.

Other speakers suitable for this type of enclosure are the Jensen P12-N and P15-N in the 12- and 15-inch sizes, or the PMJ-18 in the 18-inch size, although the latter is quite expensive. The General Electric 1201C is an excellent 12-inch speaker, and the Lansing Signature D-130A is preferred by many constructors. Another extremely efficient speaker for this purpose is the Altec-Lansing Model 803, which is used in their Model 800 two-way system shown in *Fig. 11*. However, any of the speakers listed will give good results provided the enclosure is adjusted to work with the unit selected.

Several manufacturers also make suitable reflex enclosures, and one of these may be used instead of going to the trouble of making the housing. However, in order to obtain the best results, the housing selected should be one which is intended for use with the particular speaker chosen for the system.

Cabinet Construction

The actual contruction of the cabinet presents no particular problems. Considering, for example, an enclosure for a 15-inch speaker, it is desired to have a volume of approximately 7.5 cubic feet. The cabinet proportions required to make an over-all structure which is pleasing to the eye are such that the height must be approximately 1.5 to 1.6 times the width. Since the upper section must contain the high-frequency horn and unit, the top 10 inches of the entire speaker must be deducted from the total height in calculating the possible size of the enclosure itself. Thus, assuming a 7.5-cubic foot box the net proportions of the enclosure may well be approximately 1:2:2½, and from this proportionality the actual dimensions of the box can be determined. Allowing a wall thickness of one inch, the outside of the box for a 15-inch speaker arrives at a size which is approximately 16 x 30 x 35.

The construction should be as solid as it is possible to make it within practical limits. Three-quarter or seven-eighth inch five-ply is suitable, and while somewhat difficult to obtain under present conditions, is recommended for the enclosure. If the plywood panels are assembled with glue and wood screws and braced with steel angle brackets on the edges of sides and front, it will be sufficiently sturdy. It is a good plan to install a 2 x 2 brace through the center of the box from side to side, making it detachable so the speaker may be mounted. Such a detachable brace, however, must be solid when in place, and heavy bolts should be used for attaching it.

The back cover for the box should be arranged to be attached with heavy wood screws, and should preferably be braced with two pieces of 1 x 2 mounted edgewise, running from top to bottom. *Figure 10* shows the suggested bracing for the entire cabinet.

After the box is completed, it should be given a coat of shellac on the inside, and then lined with a sound absorbent material. Rock wool blanketing of 2-inch thickness is especially desirable for this purpose, but if it is not readily obtainable, the box may be lined with two thicknesses of Ozite, the padding material used under rugs. This material should be glued to the cabinet, and tacked with large-headed nails at six-inch intervals. Sufficient clearance should be left around the speaker opening to permit its installation directly against the front of the cabinet, and since the port opening is not yet determined finally, it is suggested that the space between the bottom of the port and the bottom of the front panel be left uncovered.

Before mounting the speaker, a circle of expanded metal should be obtained for installation in front of it as a protection against damage to the cone. The speaker is best mounted with "T"-nuts on the outside, using 10-24 screws through the speaker frame and the front of the cabinet. This type of mounting permits the removal of the speaker, whenever desired, with the greatest ease. When the speaker is in place, with a suitable lead extending through the port, the back may be screwed on.

Adjusting the Port

Assuming that the port has been cut in rectangular shape with an area of approximately 0.8 times the speaker opening, the speaker is connected to an amplifier and a gain-frequency curve made. Assuming also that the amplifier is flat to below 40 cps, the resulting curve is then inspected to determine if the two peaks are of equal amplitude. If they are, the construction is completed, and no further adjustment will have to be made to the box. If, however, the two peaks are dissimilar, experiment with a piece of wood in front of the port until they are alike. Noting the amount of the port area that is covered by the external wood, remove the back and install an equal sized block of wood on the inside of the cabinet over the opening, with another piece of expended metal covering the port. Then finish the lining of the front panel.

It may possibly be found that the port is too small, and it will then be necessary to enlarge it to obtain the desired result. However, this is a matter of experimentation, and will vary with each speaker used. No specific instructions can possibly be given unless the exact dimensions of the cabinet are known, together with the resonant frequency of the low-frequency speaker.

When the port dimensions are completely determined, the exterior of the box may be painted, stained, or finished in any way desired. However, since the high-frequency unit and horn are to be mounted on top of it, it may be that some other housing must be provided in order for the entire speaker to have a passable eye appeal. *Fig. 11* shows a typical arrangement for the complete speaker, without any provision for improving the appearance. Before going further with the steps necessary to complete the external appearance, it is desirable that the final design be determined. The complete speaker is to consist of the reflex cabinet for the low-frequency speaker, the high-frequency unit and horn, and a dividing network.

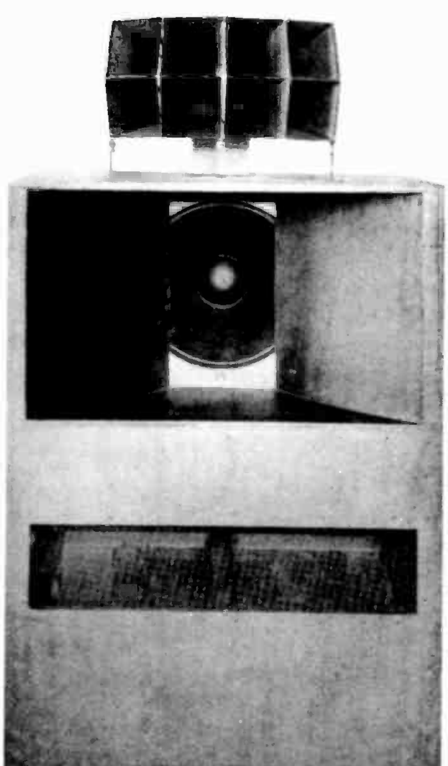


Fig. 11. Typical commercial form of two-way speaker system employing separate high- and low-frequency speakers.

PART III

Dividing Network

The dividing network consists of two coils and two capacitors, and serves to feed the low frequencies to the cone speaker and the high frequencies to the horn speaker. There are several reasons for this—the most important being to prevent the high-frequency unit from being damaged by the high amplitude of the low-frequency excursions which would be set up in the small diaphragm, inadequately loaded for those frequencies. A second reason is to prevent the high frequencies from reaching the cone and causing the inevitable breakup which occurs in that type of speaker unless it is especially designed for the purpose.

The dividing network used with this

system is the series filter type, with the circuit shown in *Fig. 12*. Since both the specified high-frequency unit and the low-frequency cone type suggested for this system were eight-ohm units, the dividing network is calculated for an eight-ohm circuit, and the input to the network should be connected to an eight-ohm winding of the output transformer.

The choice of network circuits is discussed in the article on page 101, to which the reader is referred for further details, but formulas for the four components of the dividing network are as follows:

$$L_1 = \frac{159\ R_o}{f_c}\ \text{mh}$$

$$L_2 = 0.625\ L_1\ \text{mh}$$

$$C_1 = \frac{159{,}000}{f_c\ R_o}\ \mu f$$

$$C_2 = 1.6\ C_1\ \mu f$$

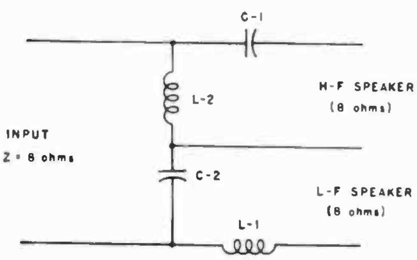


Fig. 12. Basic dividing network circuit used for this speaker system. This is the series filter type.

With a crossover frequency of 900 cps and an impedance of 8 ohms, the values are determined to be as follows: $L_1 = 1.413$ mh; $L_2 = 0.883$ mh; $C_1 = 22.1\ \mu f$; $C_2 = 35.3\ \mu f$. Taking refuge again in empirical values, it may be stated that the two inductances may be made by winding on forms 1-¼" in diameter and ¾" in width, using wood flanges to keep the windings in place. This size of form, when used with No. 17 DCE wire—as used in the field coil of Western Electric 555W units—will wind about 13 turns per layer. Referring to the charts shown on page 103, it is determined that L_1 requires 185 turns and L_2 requires 146 turns. For optimum results, these should be adjusted with the aid of an accurate bridge, but with reasonable care in the winding the coils to these specifications, the results should be acceptable.

The accumulation of sufficient capacitance was considerable of a problem until surplus material became available. The writer had an arrangement with a capacitor manufacturer long before the war to provide the values required for dividing networks at eleven cents per microfarad, furnished to exact required values. However, since 10-and 15-μf capacitors are now readily obtainable at six to eight cents per microfarad, it is much easier to use these units. Two 10-μf units and one 2-μf unit should suffice for the 22.1 μf capacitor, while two 15-μf units and 5-μf unit approach the 35.3-μf capacitor. The final values can be built up by the use of smaller units to the correct values, using a bridge for the measurement.

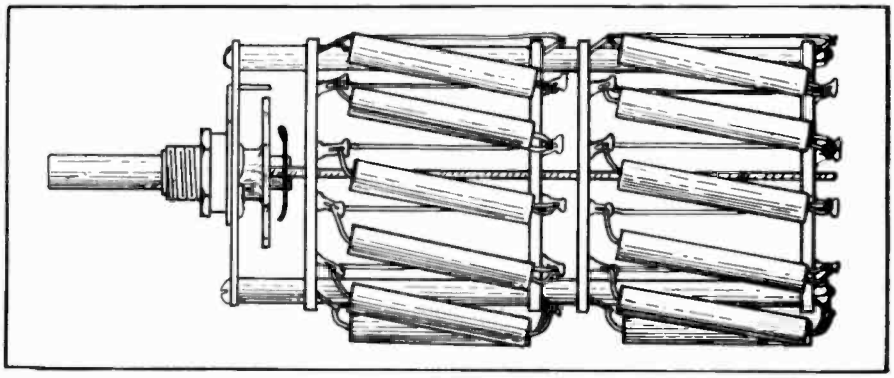


Fig. 13. Method of arranging switch sections to support the resistors for the 1 db/step attenuator in the h-f speaker circuit.

High-Frequency Attenuator

Since the high-frequency speaker unit is more efficient than the low-frequency cone, an attenuator will be required in the h-f output of the network in order to balance the sound output from the two speakers at crossover frequency. The simplest arrangement is to use a 10-watt adjustable resistor, with a value of 10 ohms, connecting the speaker unit to the tap. However, this does not give an easily variable adjustment, and in general, those who experiment in audio equipment prefer rather more flexibility than is afforded by a semi-permanent adjustment.

The recommended high-frequency attenuator is a step potentiometer, with attenuation values of zero to 6 db in 1-db steps. Such a device is not readily available on the market, but may be constructed on a standard switch. The switch required is a Centralab K-123 index assembly with two "A" decks and two "B" decks. The switch should be assembled with the two "A" decks spaced about 1-½" apart, followed by the two "B" decks also spaced 1-½" apart, and with a ¼" spacing between the two pairs. This construction, shown in *Fig. 13*, permits the mounting of 1-watt resistors directly on the switch, and parallels two decks for each circuit, thus increasing the current carrying capacity. The circuit of the attenuator is shown in *Fig. 14*, the resistors being IRC Type BW-1 in the values shown. *Fig. 14* also shows the connection of the various switch sections.

A simpler arrangement for the high-frequency attenuator is to employ a 6-ohm L-pad in the circuit shown in *Fig. 15*. The regular L-pads provide attenuation from zero to infinity in their total rotation, which is more than is desirable for this application. When connected as shown, the total loss is approximately 12 db—still more than necessary, but an improvement over the usual connection.

10-kc Suppressor

When the speaker system is to be used for reproduction of radio programs from a high-fidelity receiver, some trouble may be experienced from the 10-kc interchannel squeal. A simple suppressor can therefore be installed in the high-frequency horn circuit, and if properly adjusted, it will suppress 10 kc quite effectively without appreciably affecting the remainder of the frequency band.

This suppressor takes the form of a null circuit, shown in *Fig. 16*. The coil is a 0.5 mh unit, composed of 110 turns of No. 17 DCE wire wound on the same type of form as used for the dividing network coils. The two capacitors resonate with the coil, forming a low-impedance shunt across the h-f speaker circuit. The resistor, 10-ohms, 10-watt adjustable, provides resistance neutralization for the coil, and makes the attenuation curve of the equalizer extremely sharp, as shown

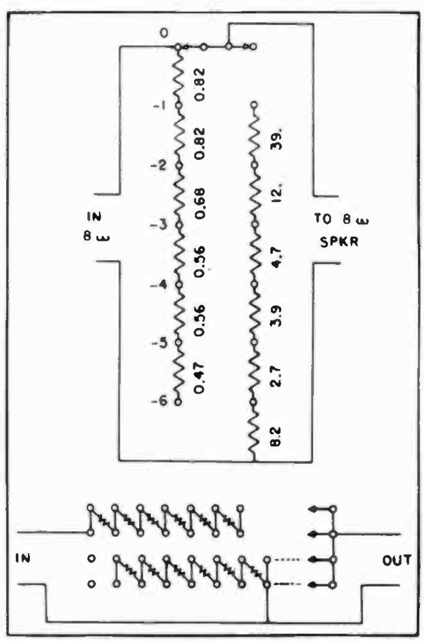


Fig. 14. Circuit arrangement for h-f attenuator, showing resistor values for an 8-ohm circuit.

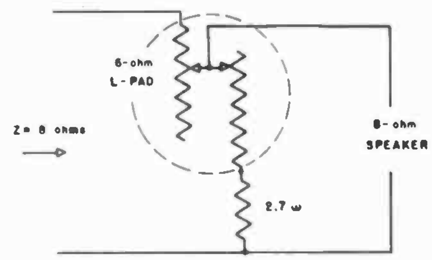


Fig. 15. Alternate arrangement showing the use of a 6-ohm L-pad in an 8-ohm circuit to provide a maximum loss of 12 db.

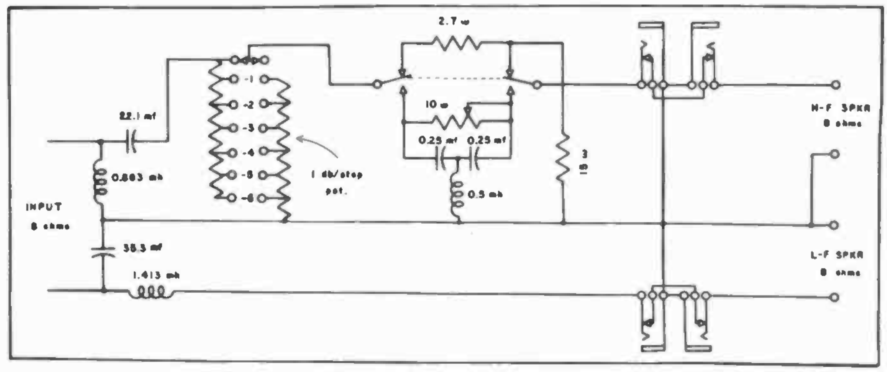


Fig. 17 Complete circuit of dividing network, h-f attenuator, 10-kc suppressor, and jacks to permit access to the various circuits.

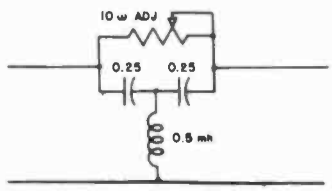


Fig. 16. Circuit of 10-kc suppressor useful for eliminating interstation squeal from wide-range radio receivers.

by the curve of *Fig. 18*. This suppressor should be arranged for switching in or out of the circuit by means of a switch, Mallory 2006-L push-button type which locks in either position. Since the suppressor causes a loss of approximately 3.5 db throughout the transmission band, an additional fixed pad of this value should be connected across the switch terminals in the filter-out position, to equalize the levels. This pad is shown in *Fig. 17* and consists of two resistors, each being a BW-1, 1-watt type.

The Complete Circuit

The combined circuit of the dividing network, the attenuator, the 10-kc suppressor, and the other connections are shown in *Fig. 17*. Note that four jacks are inserted between the output of the switching circuit and the speakers, two in each circuit. This permits the insertion of a plug into either circuit for measurement purposes, or permits feeding a signal to either speaker without using the dividing network. This provides sufficient flexibility for the most enthusiastic experimenter.

After the completion of the entire switching circuit, it is advisable to make frequency-response measurements of both legs of the dividing network and the 10-kc suppressor. The resulting curves should resemble those of *Fig. 18*, with the voltage across the two sections being equal at points removed from the crossover frequency, and with both outputs being down 3 db at crossover. The 10-kc suppressor should be adjusted for frequency by adding or removing turns from the coil, assuming that the capacitor values are reasonably close to the specified 0.25 μf in each section. After arriving at the correct attenuation peak, the maximum attenuation may be obtained by an adjustment of the 10-ohm shunting resistor. When correctly adjusted, the attenuation at 10 kc should be approximately 40 db, with the response flat at about 9,000 and 11,000 and down 6 db in the vicinity of 9,600 and 10,600 cps.

Final Assembly

The dividing network, attenuator, and 10-kc suppressor—if used—should be mounted suitably on or in the low-frequency baffle cabinet. If the entire speaker is to be hidden from view, it is possible to mount these parts on top of the cabinet at the sides of the high-frequency unit. In any case, the controls should be accessible, but the special requirements of the physical design may dictate the actual placement of the parts and the controls. It should be remembered that the currents involved in a low-impedance speaker circuit are relatively large—at one watt, for example, the current in an 8-ohm circuit is approximately 0.35 amps. On account of this, the wire used for the connections should be relatively heavy, particularly when higher powers are involved. The choice of switches for such circuits is important—ordinary toggle switches are not satisfactory for speech circuits at these low impedances.

The high-frequency horn and unit should not be permanently mounted until the exact location is determined. To make this determination, it is desirable to have a microphone and an amplifier, together with an output indicator, for best results. With the h-f horn and unit connected to the circuit, and placed on top of the low-frequency cabinet, the two should be energized by a signal at crossover frequency. Then, with the microphone about six feet in front of the combined speakers, move the high-frequency horn and unit back and forth until the maximum output is obtained, as indicated by the output meter on the amplifier connected to the microphone. If the position of the horn is too far forward or too far back of the front of the cabinet, the two leads to the high-frequency unit should be reversed and the procedure repeated. This will give a new position to the horn approximately 7.45 in. from the first position.

The correct position for the h-f unit can be determined roughly by calculation. The dividing network used causes a phase shift of 221° at crossover, which corresponds to 9.2 in. at 900 cps. Thus the two diaphragms must be displaced by that amount, or the phase of the h-f unit may be reversed, requiring a dis-

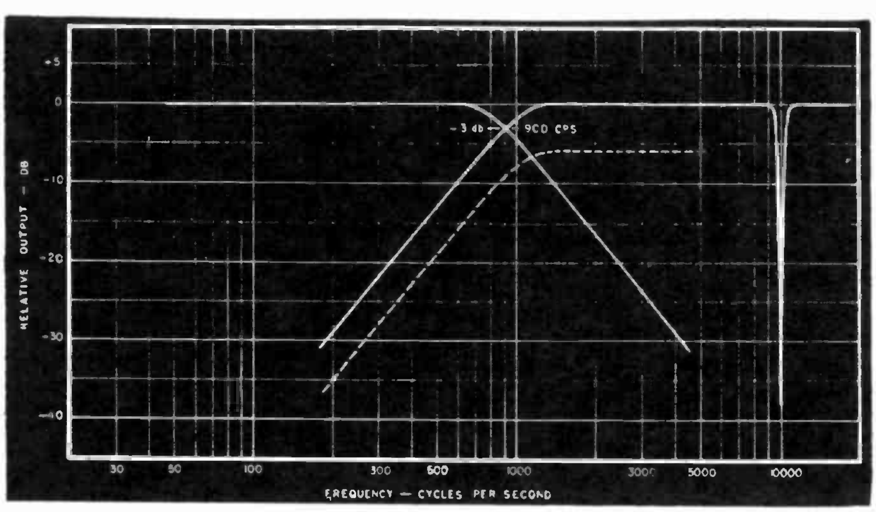


Fig. 18. Curves of typical response from dividing network, and attenuation to be expected from 10-kc suppressor. Dotted curve shows range of adjustment furnished by 1 db/step attenuator.

placement of 9.2—7.45 in. or 1.75 in. However, the diaphragm of the low-frequency cone is not a plane surface, and the exact point of measurement may not be definite, although there is some evidence to support the choice of the voice-coil position as the measuring point. The best method of adjusting the two speakers is by using the microphone, as previously described.

Actually, a trained ear will suffice to select the correct location of the two speakers, although it may require more time and experimenting. It is necessary to play the same selection from a record through the speaker over and over, moving the high-frequency horn slightly each time. The best quality will be heard when the adjustment is correct, and after all, the ear is the best judge of the performance anyhow.

After the correct position of the high-frequency horn is determined to the user's satisfaction, the horn should be permanently mounted.

Operational Readjustments

One of the bad features of many two-way speaker systems is that the new experimenter is apt to run the system with the high-frequency speaker operating at levels considerably above the correct balance, on the theory—probably—that "now I have a tweeter and you're going to hear the high frequencies, or else." This is a natural fault, and is generally overcome after using the speaker for some time. The best test for any speaker is how well it "wears" although many authorities advise us that the ear can become accustomed to any speaker, and when it does, any other reproduction sounds wrong. However, if the user makes a point of attending a live concert occasionally in order to keep his perspective on a reasonable balance, he should be able to adjust the operation of a two-way speaker system so that it is capable of giving increased realism over any single-unit speaker available. The "presence" afforded by the reproduction of the frequencies above 900 cps on a small, well-loaded diaphragm makes listening a pleasure, and the time and effort spent in constructing a speaker of this type will be well repaid.

The use of the attenuator in the high-frequency speaker circuit permits a small variation in the level of the frequencies above crossover, and this will be set at a point that appears to give the correct balance. The average difference between the two outputs is of the order of 4 to 8 db, and with the 3.5 db fixed pad to replace the 10-kc suppressor when it is out of the circuit, this indicates that from 0.5 to 4.5 db will be required in the variable pad. It may be desirable to remove the suppressor from the circuit when using the speaker for reproduction of phonograph records, but in general, the band suppressed is so narrow that it is difficult to detect, and little harm is done by leaving it in the circuit at all times. It does help on AM radio, however, when the output of the tuner contains any of the objectionable squeal which goes with the usual high-quality tuner.