Two-Way Speaker System

C. G. McPROUD*

PART I

The first of three articles describing the design and construction of an excellent two-way speaker system.

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.

*Managing Editor, *Audio Engineering*

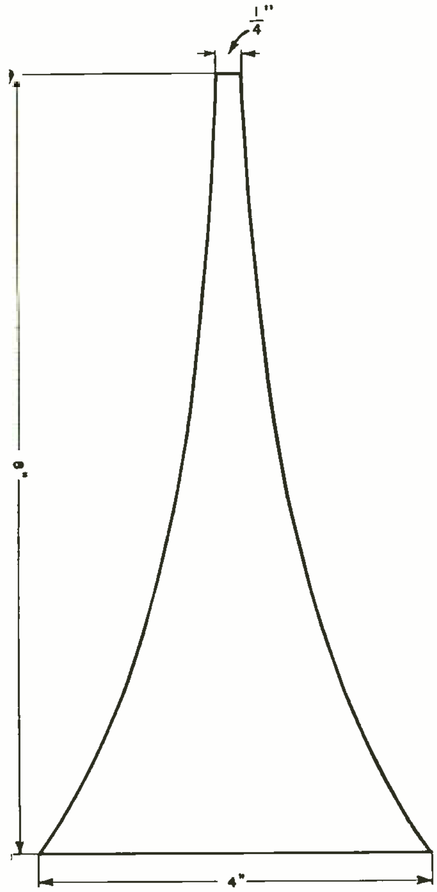


Fig. 1. Developed section of exponential horn, doubling in cross-sectional area for each inch of length along the axis.

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.

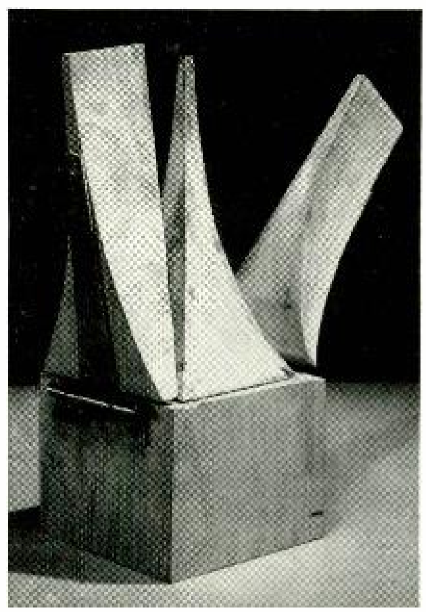


Fig. 2. Wood forming block used for shaping and soldering the individual horn sections to uniform dimensions.

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 has been covered previously in these pages,[1] and will not be repeated 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

[1] "*Design and Construction of Practical Dividing Networks*," *C. G. McProud, Audio Engineering, June, 1947.*

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 ¼ in. square, since any smaller opening would be difficult to work with. This provides a total throat area of 8x¼x¼in., 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

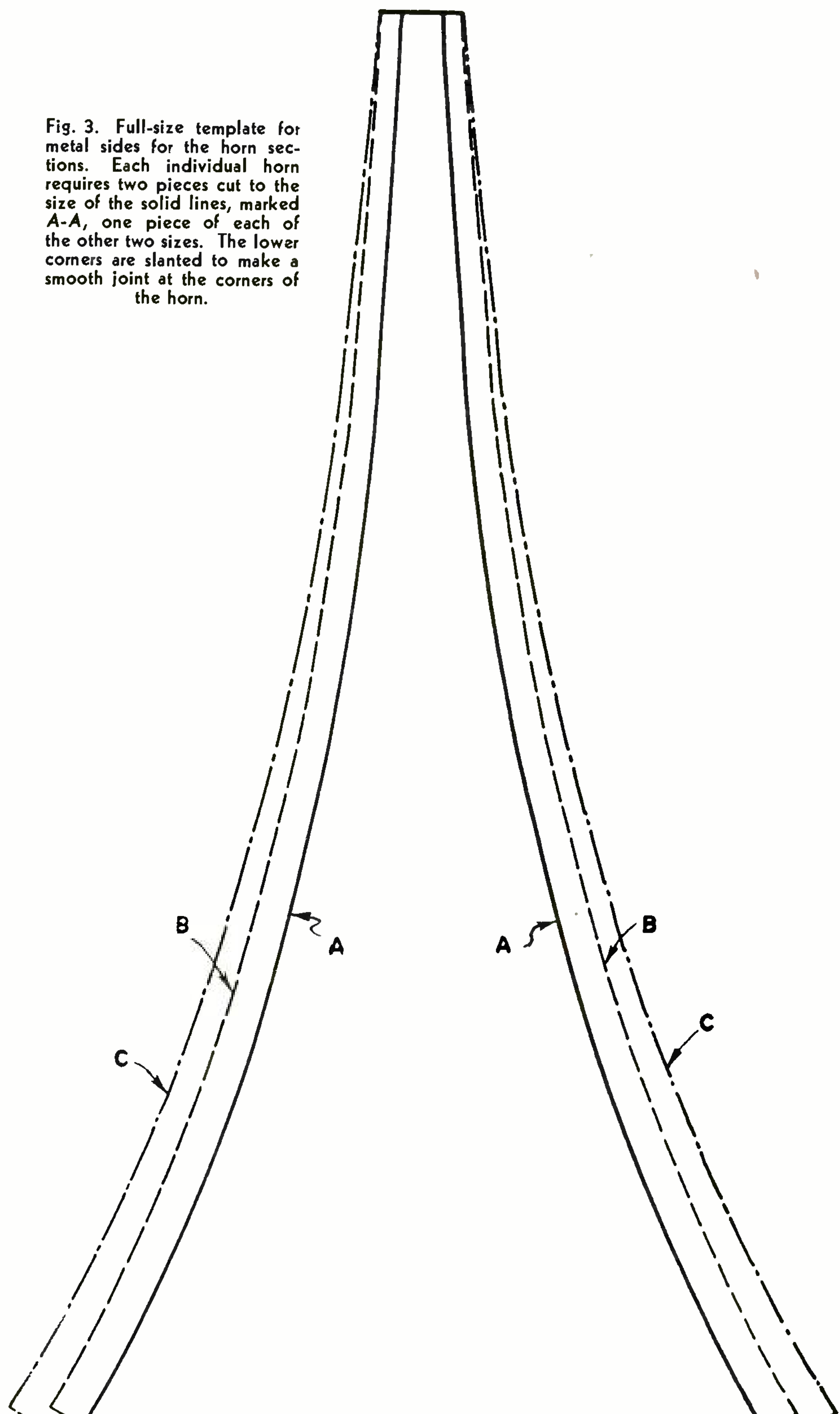


Fig. 3. Full-size template for metal sides for the horn sections. Each individual horn requires two pieces cut to the size of the solid lines, marked *A-A*, one piece of each of the other two sizes. The lower corners are slanted to make a smooth joint at the corners of the horn.

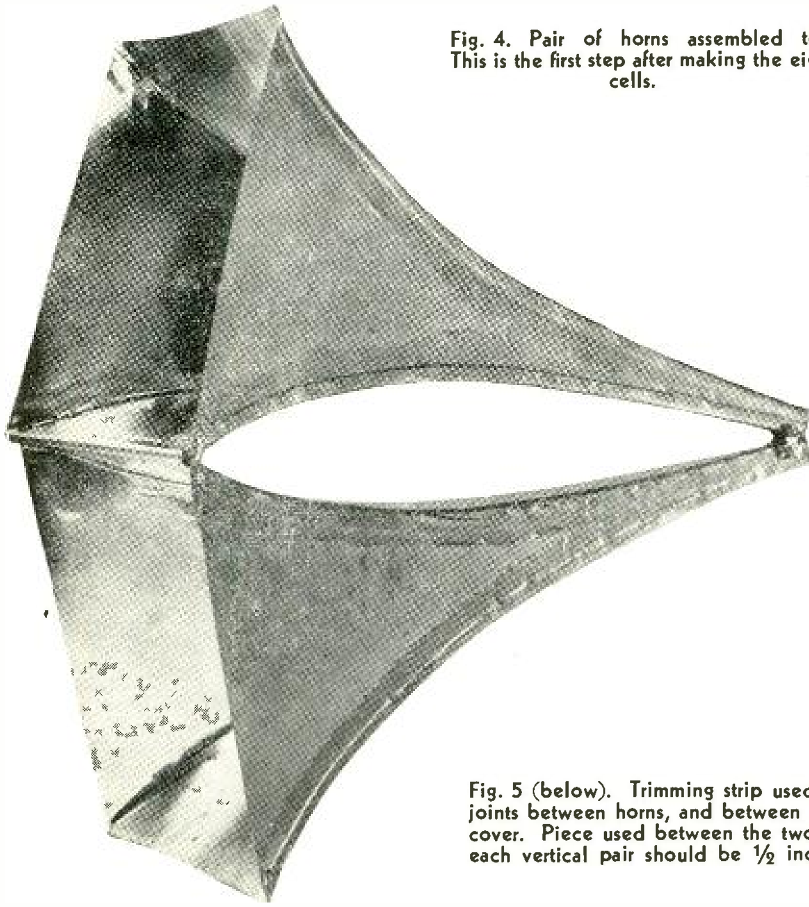


Fig. 4. Pair of horns assembled together. This is the first step after making the eight horn cells.

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 4½ in. on the fourth. The long dimension becomes the dividing line between the two cells of each vertical pair.

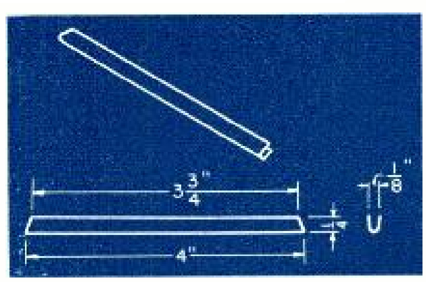
This shaping of the horn section takes place gradually throughout the entire length. Thus at both the mouth and throat ends, the horns join smoothly without any intervening spaces.

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 ¼-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 ¼-in. width at the top and a 4 7/16-in. width at the bottom. This allows for the 4- and 4½ in.

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.



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 ½ 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 ¼-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.

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

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

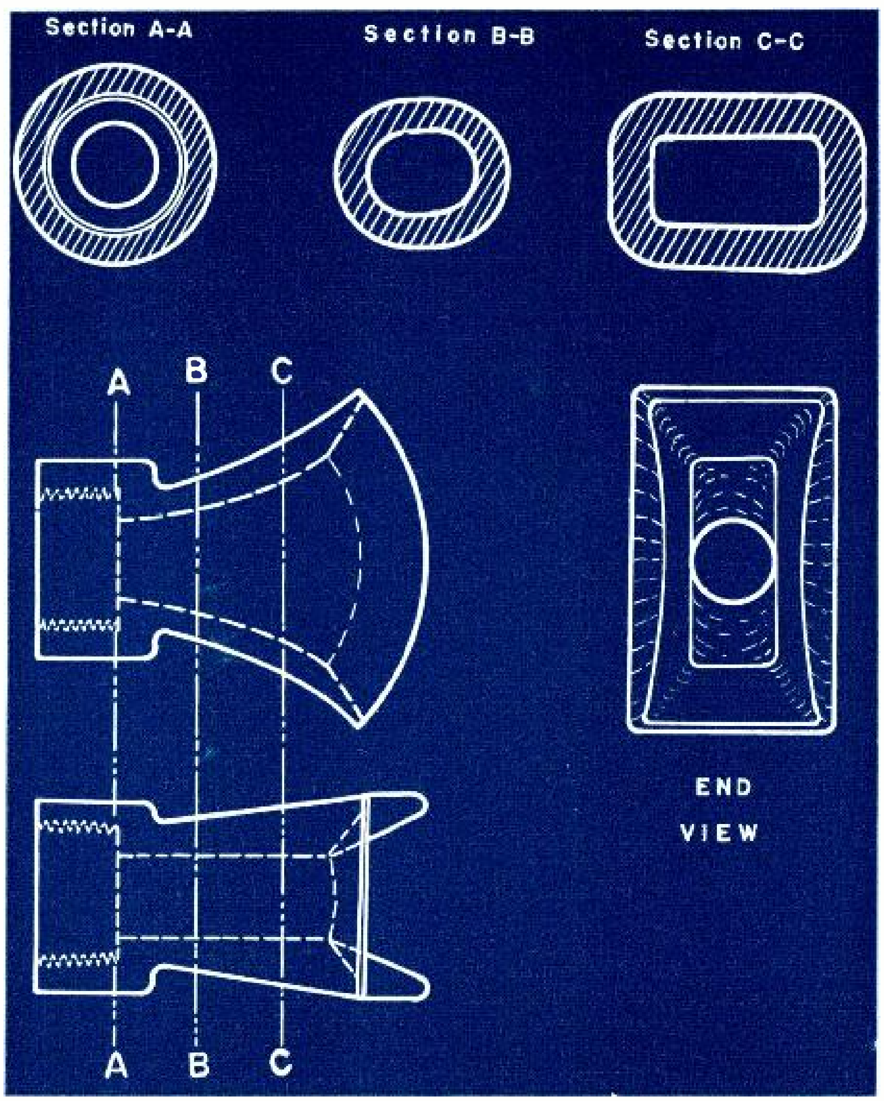


Fig. 7. Plan, elevations, and sections of horn throat coupling, approximately 9/10 full size. Center hole is ½-inch diameter.

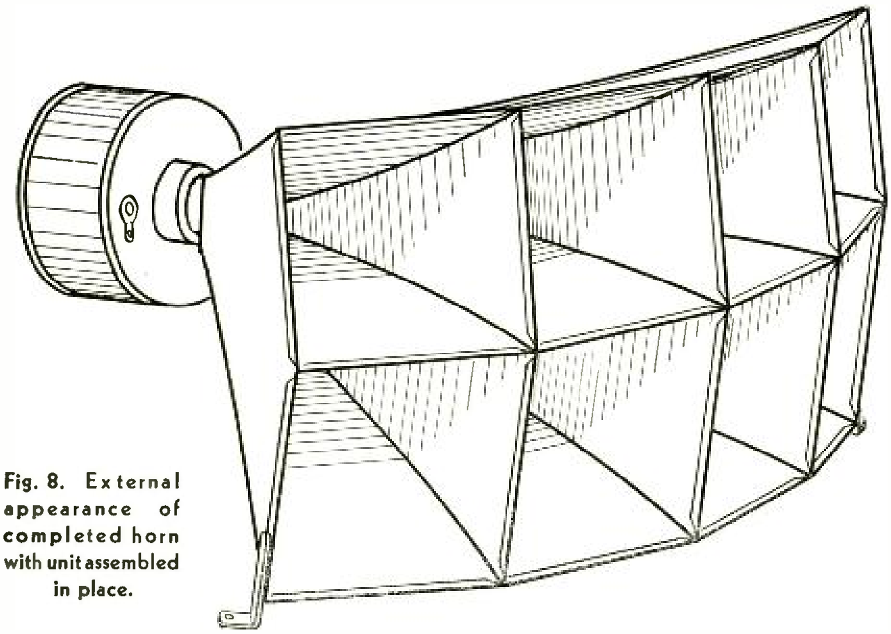


Fig. 8. External appearance of completed horn with unit assembled in place.

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 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.

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*.

The second article of this series will describe the remaining details of the two-way speaker system. Once the high-frequency horn is finished, the unfamiliar part of the work is complete.

IRE-WCEMA Convention

NUMEROUS AUDIO TOPICS were taken up during the combined Institute of Radio Engineers and West Coast Electronic Manufacturers' Association convention in San Francisco, Sept. 24-28. Attendance and interest at both functions were high. Over 750 attendees paid registration fees at the IRE meetings while 3200 registered at the WCEMA exhibit hall.

During the IRE meetings, these speakers made the following points in the course of presenting papers related to the audio field:

John Hessel of the Signal Corps Engineering Labs, Fort Monmouth, said that when war is speeded up, communications problems grow at an even more rapid rate. Considering only the advances made since the war, military communication engineers are presently faced with the necessity of producing communication systems with better performance than existing commercial systems. But at the same time, this equipment must be serviceable under battle conditions and operable by almost totally unskilled soldiers and sailors. This is a severe challenge. He pointed out that a large part of this problem is audio in nature by citing the fact that during the late war, 95 per cent of all communication traffic was by wire line.

Ralph D. Bennett, of the Naval Ordnance Lab., Washington, D. C., in discussing applications of electronics to underwater ordnance, spoke of the hydrophone and bridge circuits used in the study of underwater sound. The frequency spectrum from zero to 100 cps is split into two ranges: 0-1 and 1-100. The high section is recorded directly on disks and the low is pen-recorded through combination in a bridge with a 1000-cps tone.

J. W. McRae, Bell Telephone Labs., New York, described early tests now being made on the AT&T New York to Boston frequency-division multiplex telephone system and said that a month's operational experience has now been had on the first, longest, and (presumably) most difficult link of the chain—New York to Jackie Jones, Conn. During the month he reported a total of 3 minutes during which the signal faded below the 20-db level provided for in the repeater. He also mentioned the fact that in production tests the flat characteristic of the system is held within 1/10 db over 12 mc. This is necessary where any number of repeaters operate in cascade.

John K. Hilliard, from Altec-Lansing Corp., Hollywood, provided the details on several of the high-quality speaker systems produced by his company. In discussing cabinets and enclosures, he stressed the fact that no substitute has

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