Low-cost Horn Loudspeaker System

Details of successful experiments

by "Toneburst"

As far as the ear can tell, consistently clean and spacious bass can be reproduced only by a driver unit coupled to a horn-type acoustic transformer. This fact has, of course, been known for years and most of the credit must go to Paul Klipsch who in 1941[1] described a split folded bass horn which outperformed theoretical expectations, and set a performance standard that cannot be excelled. If there is any quibble about the performance of such a bass horn it can only be that 'level' response below about 35Hz is difficult to achieve.

In a sense it is unfortunate that Klipsch achieved what he did. Theoretical analysis of the performance of a corner horn has not advanced significantly since. Langford-Smith[2] comments that "The only known method for handling frequencies below the flare cut-off frequency of an exponential horn, with good fidelity, is the use of an enclosed air-chamber behind the diaphragm, resonant at a frequency in the vicinity of the flare cut-off frequency, as used with the Klipsch loudspeaker". This is a very peculiar remark for it implicitly casts doubt on the exact nature and function of the horn mouth. In 1943[3] Klipsch had reported that "The improved horn has a cut-off due to flare of 50 cycles, but the impedance measurements and ear tests show that a strong fundamental is radiated down to 35 cycles. It must be concluded that the computed horn impedances are only qualitatively correct for frequencies within an octave of the low-frequency cut-off."

No experiments seem to have been done since Klipsch's design appeared, in a direct attempt to compromise horn theory without losing quality. Bearing in mind Langford-Smith's condensation of Klipsch's own experience there seems to be a good case for expecting to be able to simplify the design of a split folded corner horn whilst maintaining an acceptable low frequency performance.

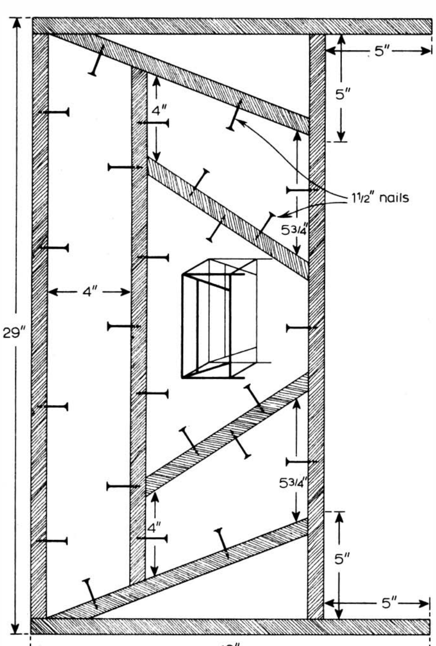

Fig. 1. One of the two side frames. Inset is a diagram of the complete frame. The nails should be knocked in before the two sides are joined together. Nails for the front panel can be added to the complete frame.

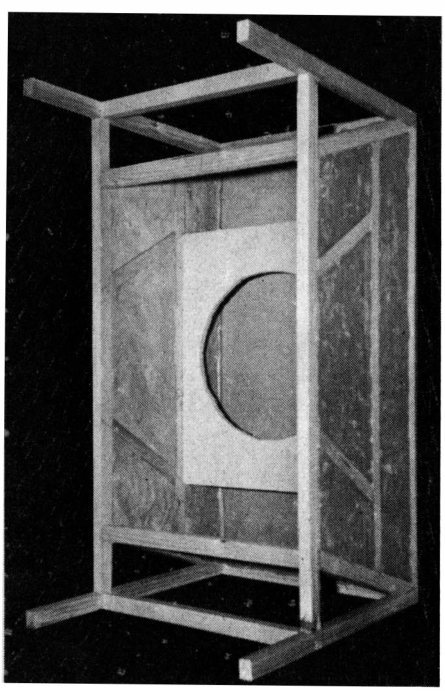

Fig. 2. Enclosure fully concreted and ready to have the bass driver mounted on its board.

Experimental work

The first necessary decisions were on size and shape. Klipsch himself gives some support in saying that "The front throat baffle may be rearranged for a simple flare rate working out of a larger cone, in which case the air chamber between the cone and throat may be eliminated."[4] A simple starting point was found in an adaptation of the Ambassador bass horn described by Briggs.[5] There is no compression chamber behind the cone in this design, but after a slightly modified version had been constructed, employing a Fane 122/12 12-in driver, good response down to about 40Hz was heard. Unfortunately there were humps and bumps from about 320Hz upwards. Further modifications, to smooth the flaring rate, removed the trouble above 320Hz but also removed the bass below 100Hz. A compression chamber to Klipsch's specification was constructed by filling up the corner space at the back of the enclosure. The result was, and is, clean bass with response down to below 30Hz.

A description of the final horn structure follows. It is recommended that all instructions are followed at least in spirit, if not to the letter, or significant resonances may be found rather late in the day.

Construction of bass horn

Raw materials required are lengths of 1 × $\frac{3}{4}$in or 1 × 1in wood, 1$\frac{1}{2}$in nails, sand and cement, and pieces of plywood, blockboard, or chipboard. Most of the wood items can be bought as off-cuts and the sand and cement is available in a suitable mix in convenient 7-lb bags costing 2s 6d (Rustins).

Frame. The first step is to put together a rectangular framework into the front and sides of which will be cast concrete panels. Two side frames must be constructed as in Fig. 1, and 1$\frac{1}{2}$-in keying nails knocked in as shown. Cutting the wood should present no problems even to those with no experience. An Eclipse No.66 general purpose saw is recommended to anyone in doubt—it costs just less than £1. (After marking the wood to length remember to cut on the outside of the mark(s) and not to try to make two wood lengths out of a piece exactly the length of the two pieces finally required.)

Assembly should be on a flat surface, on a single layer of paper if need be. The recommended adhesive is Evostik Resin 'W'. The 4 fl.oz. 'oil can' dispenser is ideal for all the joining operations. This may be refilled from a 1-pt pack thus combining convenience with overall economy.

After one side frame is complete, and the resin set, four 13-in lengths are to be stood vertically at the correct positions on one of the frames and the adhesive left to dry. This is the one operation for which square-cut ends are essential.

After cutting each length of wood make sure that no saw-dust is left on the ends when the resin is applied. (A stiff wire brush is useful here.)

If 1 × $\frac{3}{4}$in wood is used the joining should allow the 1-in face to set the depth for the concrete front panel.

Concrete Panels. The front and sides must next be fitted with concrete panels to the depth of the wood limiting each area.

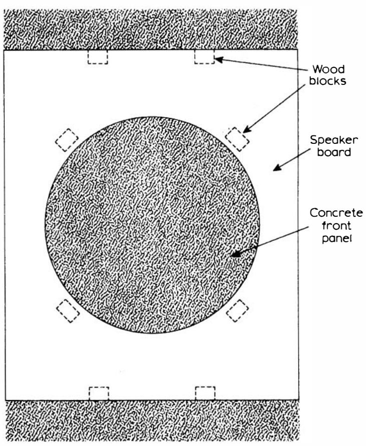

Fig. 3. Diagram of speaker mounting board within the enclosure showing position of wood blocks. These blocks were trimmed to fit—the back of the concrete panel was rather irregular.

The side panels are the smallest and thus the best place to start the concreting. Place about ten layers of newspaper on a flat surface—table or floor—and lay the frame with one of its sides down on the paper.

The cement may be used with or without gravel. If the average particle size of any gravel used is not less than $\frac{3}{8}$in, two or three pounds may be safely added to a 7-lb bag of sand and cement without significantly weakening the binding power. The complete contents of each bag of sand and cement should be used at once or some sandy results may be obtained due to separation of the mix during storage.

Start with 7lb of cement mix (with or without a known amount of gravel) and fill up the panels. It is then just a question of doing some arithmetic to find out how much more concrete will be required to complete the panelling for one or two horn structures.

The mix should be fluid and can be spooned into the spaces. The newspaper will quickly absorb any excess water, and it should be possible to lift the frame after about 18 hours though it is better to leave it for 24 hours. (The concrete will take up to a week to dry out completely.)

The front panel should be cast next in exactly the same manner as described, but should not be lifted from the paper for about 48 hours. Finally the other side panels may be cast.

Speaker Board. The 16$\frac{1}{2}$in × 13in panel carrying the bass driver should be not less than $\frac{1}{2}$in thick and may be made of plywood, blockboard or chipboard. A 10-in diameter hole must be cut in the middle. It is quite easy to drill holes round the edge of a 10-in circle (as close together as possible) and then to drill round again in both directions at 45° to the surface. Finally, a sharp knock on the centre of the circle with a hammer should remove the disc and the edge of the hole can be cleaned up with a rasp or file.

The speaker board should be fitted into the concrete framework using Resin, as shown in Fig. 2. Once dry, wooden blocks should be glued as shown in Fig. 3. These blocks remove all significant resonance from the speaker mounting board.

Top and bottom concrete flare-panels. Using the same woodworking techniques as before two wooden frames should be made, using the main frame as a vice. When the joints are dry these frames should be removed and after positioning carefully on newspaper (with one wooden edge of each necessarily overhanging the table, if constructed as revealed in Fig. 4) concrete mix should be spooned in. Again, if 1 × $\frac{3}{4}$in wood is used the 1-in face should give the thickness of the panel. When dry these panels can be glued into the main frame—which should be placed on its side. Next the speaker can be screwed down, as tightly as possible, using four 1-in screws. The terminals should face the middle of one side of the enclosure.

Wooden flare-panels. Simple rectangles of $\frac{1}{2}$-in plywood will do for these—it does not matter at all that the junction with the speaker board is along a 'sharp' edge—a similar edge will also be 'flush' with the rear of the enclosure so far built. To fix these panels the enclosure should be turned on its side and each panel glued along the edges that will lie along the wood strips in the sides. When the joints are dry turn the enclosure on its front and glue along the junctions between the panels and the speaker mounting board.

Back panels and duct. The details of the remaining panels ($\frac{1}{2}$in to $\frac{3}{4}$in thick) are deducible from Figs. 4 and 5. The angle pieces forming the 3-in high vent to the rear of the cone should be drilled so that they can be screwed down while the glue is still wet. The two panels completing the

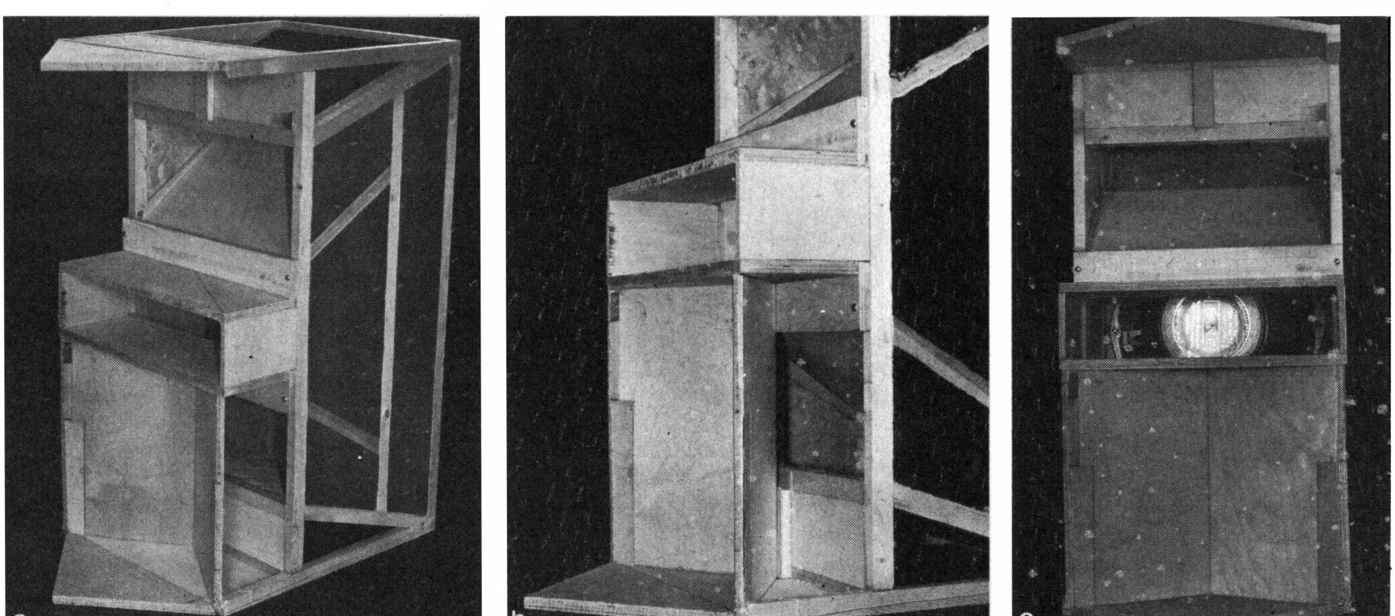

Fig. 4. Advanced stages in construction. (a) and (b) give details of the back panels and vent. The upper horn opening must be finished as the lower. (c) shows the appearance from the rear. The rectangular panels forming the exit path from the horn can be cut larger than required and trimmed with the saw when glued in place.

compression chamber should be of $\frac{3}{4}$-in ply. (The drive unit must be wired to external terminals before fitting the second panel.)

Resonances. Any concrete flanges that overlap the wood should be knocked off gently with a hammer. When satisfied that the concrete edges are clean, turn the enclosure on one side and run a stream of glue along all the wood-cement junctions. This procedure must be followed for each side, allowing each 'run' to dry while the enclosure is horizontal.

Now, standing the enclosure upright, tap the front panel with a finger. Note the dead sound—it is high-pitched, metallic and of no perceivable duration. Test each concrete panel in turn. The same should be done for the plywood panels.

If a resonance is found which suggests hollowness, then bracing must be fixed as in the case of the speaker mounting board. Such resonances, if left, will seriously colour upper bass frequencies.

Finally, the external concrete surfaces can be painted.

Fitting against skirting boards. There are four possibilities:

1. Cut out a suitable section from the back compression chamber.
2. Stand the enclosure on a triangular plinth raised above the skirting board.
3. Remove the skirting that is in the way.
4. Stand the enclosure against the skirting and fit wood strips in the gaps between the walls and horn.

The latter is the simplest way.

Treble speaker

In deciding what treble unit to use with the bass horn the main criteria for consideration are sensitivity, distortion, sound dispersion and frequency range.

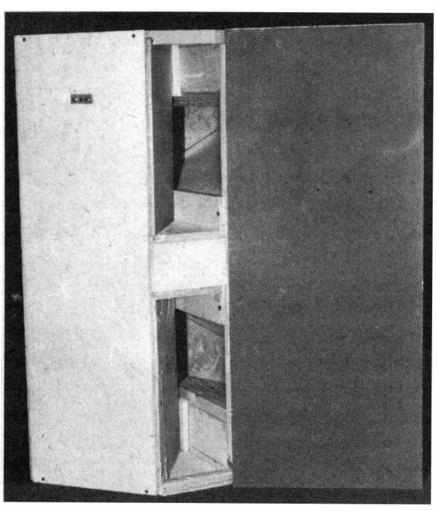

Fig. 5. Two panels of $\frac{3}{4}$-in ply complete the compression chamber. The angle formed by the apex of the triangle must of course be $\geqslant 90°$ and 9-in wide panels were satisfactory. When one panel has been screwed and glued bracing blocks can be liberally fitted internal surfaces of the chamber. The drive unit must be wired up to external terminals. The compression chamber must be airtight. www.keith-snook.info

Horn loading a treble driver raises its efficiency, linearizes its response, and allows the dispersion pattern to be controlled. Again I had recourse to the work of Klipsch. In 1963 Klipsch[6] published details of a high-frequency horn with a cut-off below 300Hz, and off-axis response correct for good stereophony. This horn was driven by a pressure unit from a throat 1in or less diameter. The area doubled approximately every $2\frac{3}{4}$in and ended in a rectangular mouth $5\frac{1}{2}$in × 17in. Obviously if a suitable small cone speaker can be found the horn structure can be very simply shortened to match the cone diameter.

The Eagle FR4 driver, although sold as a full-range unit for use in a bookshelf enclosure, has excellent characteristics for use as a mid-range and treble speaker, with horn loading. The manufacturer's frequency response chart shows a ±5dB variation in the range 100Hz to 9kHz, and a steady decay out to about 17kHz. A concrete horn was therefore designed to match this drive unit.

Construction of treble horn

Cardboard mould. The horn has flat top and bottom, and curved sides. The diagrams of Fig. 6 show the exact shape and dimensions of the four cardboard pieces required. The templates may conveniently be drawn on thin card—only one of each shape being required. These can be drawn round to transfer the shape to the thick cardboard needed to make the mould. The best cardboard for the mould is the $\frac{3}{16}$-in thick "grocery box" stuff with a corrugated middle layer sandwiched between two thin flat sheets. In preparing the sides of the mould it is helpful to ensure that the corrugations assist rather than hinder the folding. The dimensions given allow for the thickness of the concrete layer and the thickness of the cardboard where the joints are made.

Once the pieces are cut glueing can begin. Evo-Stik "impact" adhesive is best for this, the sides being stuck between the top and bottom.

Although the mould can be used as it stands, it is recommended that the inside be given a layer of varnish so that the wet cement does not cause deformation.

Casting. Concreting is in four stages using a gravel-free mix. The mould should be placed on a flat surface and the bottom surfaced with a $\frac{1}{2}$-in layer of cement. It is a good idea to mark a small screwdriver $\frac{1}{2}$in up the blade and use this as a probe to ensure a more or less uniform layer. The work must now be left to dry out completely. Next, one of the curved sides can be cemented, in exactly the same manner, but first a layer of Evo-Stik Resin 'W' should be applied to the side of the dried concrete to help bond the new to the old. The mould should be turned on its side while the side piece dries out. Do the other side piece and then the remaining flat piece, applying the wood resin as each new section is formed. Finally, the cardboard may be stripped off.

Throat section. Stand the horn throat down on a piece of $\frac{1}{2}$-in blockboard 6in

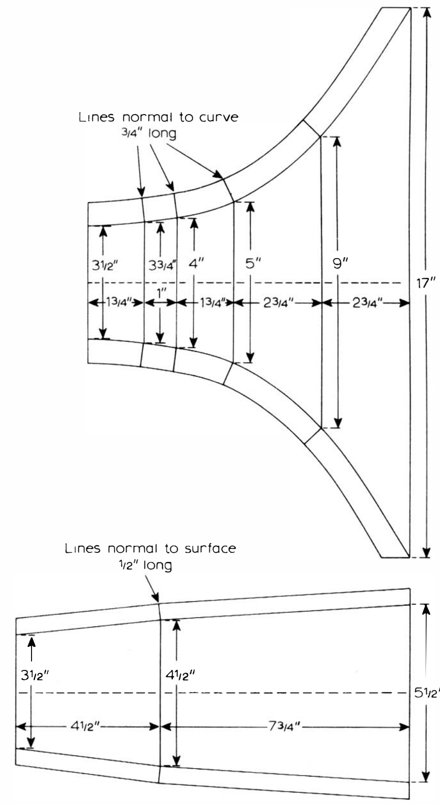

Fig. 6. Dimensions of templates for constructing treble horn cardboard mould.

square and draw round the edge. Drill out the middle section (as specified for the bass speaker board) and fit it like a collar round the throat—a hammer can help if used with due care. When the throat opening is flush with the top of the collar, wood resin should be run round the joint and left to dry. A 6-in square of $\frac{1}{4}$-in plywood, with a $3\frac{1}{2}$in-diameter hole in the centre (again drilled out) can be screwed or glued down over the throat opening. When dry (if glued) the inside of the throat must be concreted to give a proper exponential transition from circular to rectangular cross-section. Wet cement can be applied with an old knife, the four cement "fingers" stopping about $3\frac{1}{2}$in from the now circular throat. A file can be used to remove gross roughness on the inside of the horn. One or two coats of paint can be applied to give better smoothness. The FR4 unit can now be screwed on to the horn, and the final assembly is shown in Fig. 7. Sound absorbent material must be fixed over the back of the speaker chassis to prevent unwanted wall reflections.

Crossing over between drivers

The treble horn loads its drive unit quite satisfactorily down to about 300Hz. The bass horn delivers its output with an increasing amount of distortion as the frequency rises above about 500Hz. It seems correct therefore to cross over at about 400Hz and at a rate of not less than 12dB/octave.

In constructing a crossover network of the constant resistance variety (where the impedance seen by the amplifier remains more or less constant right through the crossover point) there are four variables to

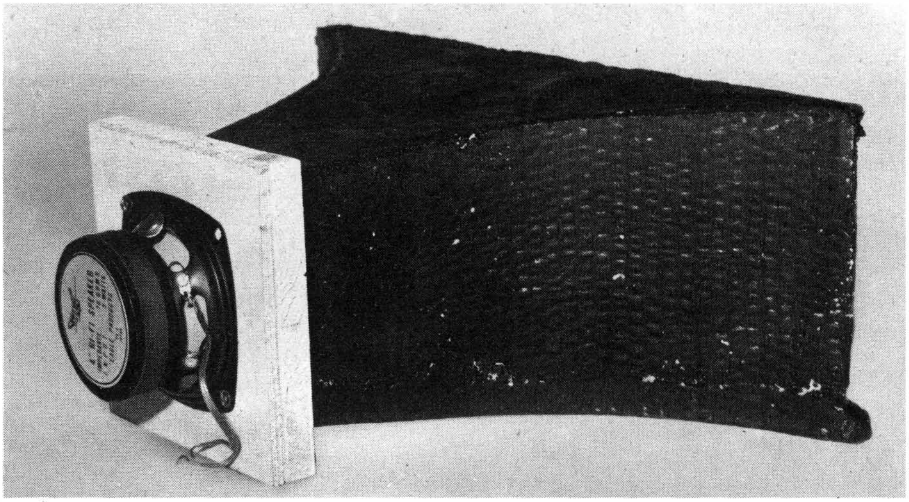

Fig. 7. Completed treble horn.

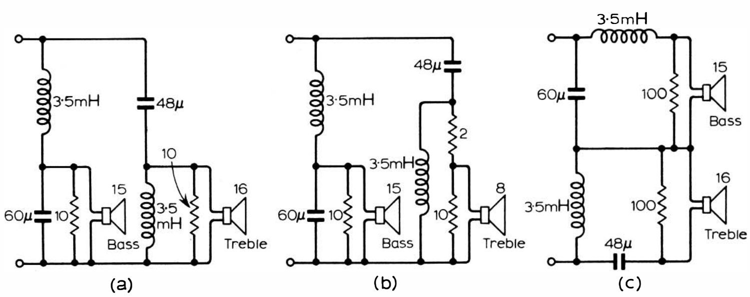

Fig. 8. Crossover circuits: (a) $\frac{1}{2}$-section parallel network arranged for 16-Ω treble driver; (b) $\frac{1}{2}$-section parallel network arranged for 8-Ω treble driver; (c) $\frac{1}{2}$-section series network that can be used with 16-Ω treble driver—this is the most efficient circuit but unfortunately the FR4 is no longer being produced in the 16-Ω version. Resistors can all be $\frac{1}{4}$W.

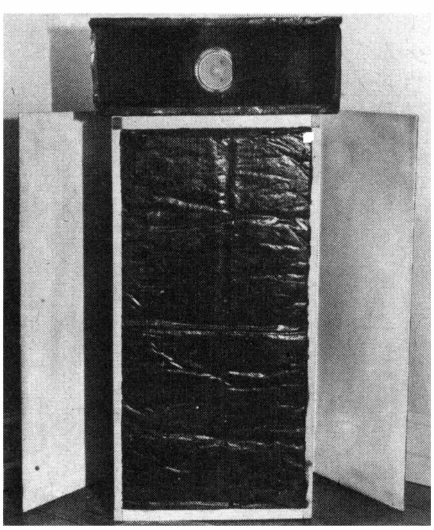

Fig. 9. A speaker in its corner showing hardboard guides fixed with hinges—shown from the side in Fig. 5.

consider—the crossover frequency, the load impedance, and values of *L* and *C*.

The most difficult component to obtain is a suitable capacitor. Non-polarized electrolytic types specially made for crossover networks come in a very limited range—at the large value end of the scale the choice is either 60μF or 100μF. If these capacitors are not used the alternative is a monstrous parallel-array of ex-W.D. paper types which will at the same time be quite expensive. To cut a long story short values of 60μF and about 3½mH give a network which in theory crosses over symmetrically at about 430Hz with load impedances of 12Ω or 6Ω depending on whether a series or a parallel $\frac{1}{2}$-section network is employed. The capacitor on the treble side was reduced to 48μF (3×16μF) to reduce a slight peak in the treble-horn response at the crossover point. Resistors across the driver voice coils, whilst reducing the overall impedance, also reduce the significance of changes in voice coil impedance from the point of view of the crossover network.

Three crossover circuits are shown in Fig. 8. These allow different impedance treble units to be used—I have 8Ω in one channel and 16Ω in the other. Crossover circuits (a) and (b), which I use, may be doctored further still. A small choke—say 250μH—placed in series with the 10Ω resistor across the treble unit will remove the shunting effect at high frequencies, thus extending the top. In circuit (b) the 2Ω series element can be bypassed by a 2–4μF capacitor as well.

Winding the chokes. A 2-in piece of $\frac{3}{8}$-in diameter ferrite rod (with cardboard discs glued on at the ends) can be wound with 37ft 6in 24 s.w.g. enamelled copper wire to give an inductance of about 3½mH. The turns must be close and the layers neat. Careless winding will give a sadly low value. The treble boost choke can be wound similarly—about 10ft close wound will give 300μH.

Notes of the final assembly

Fig. 9 shows the composite horn in its corner—the total cost of materials, including that of the two driver units, amounted to about £17. The bass enclosure is properly called a driver, the bass horn being formed in conjunction with the walls and the floor.

Three points are worth making in conclusion.

1. The most striking characteristic of the treble unit is a reduction in background noise, for example when playing worn discs, compared with direct radiator treble units. Where there is a significant background noise level this seems to separate out from the music, and any odd clicks are peripheral to the sound image.

2. Provided the bass-horn driver makes fair contact with the corner walls the bass performance is not affected by the hardboard guides which theoretically define the horn mouth and the final flare rate. Considering the size of the enclosure this is an inducement to further experiment. The question remains—"What defines the actual lower limit of the bass response?"

3. If the bass enclosure is constructed to the width of the treble horn the whole system can be "cased" to give a very acceptable rectangular structure.

Crossover components

Ferrite rod of $\frac{3}{8}$-in diameter is available from G. W. Smith (Radio) Ltd. Four-inch lengths cost 1s 3d, and six-inch lengths 1s 6d each. To break the rod, first file a shallow notch 2in from one end. Place a pin on a hard surface, such as a metal ruler, and with the notch facing upwards press the ends of the rod downwards with the pin lying exactly below the notch. This should result in a clean break.

If choke-winding is considered tiresome, 5mH chokes are available from K.E.F. Electronics Ltd, Tovil, Maidstone, Kent, for 9s 6d each. Removing 8ft of wire will reduce inductance to about 3½mH.

60μF and 16μF non-polarized 50V capacitors are also available from K.E.F. for 4s and 2s 6d each respectively.

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