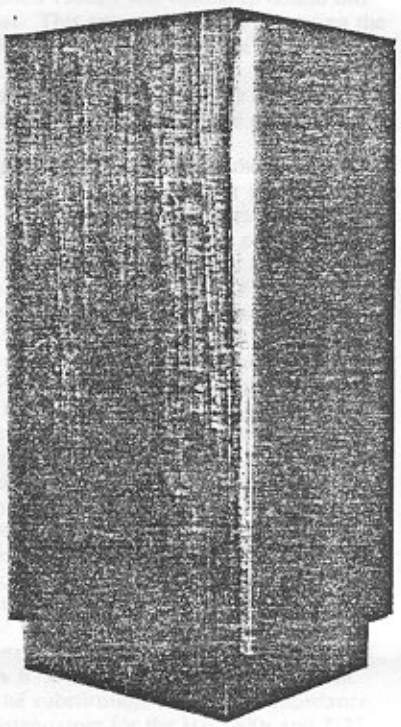
STATE OF THE ART LOUDSPEAKER



A project for hi-fi perfectionists described by P. Atkinson

MY interest in above average' loudspeaker design was first stimulated way back in 1970 by an article in *Hi-fi News* by J. Wright[1] on transmission line loudspeaker development which appeared in the July issue of that year. Both professional and amateur designs which have materialised since then prove that I was not alone in appreciating that and a subsequent article.

With the introduction of commercially manufactured transmission line loudspeakers there followed much listening to various models and comparisons with speakers based on other principles. The good and bad points of the various principles have been dealt with in many articles and suffice to say here that in my opinion the only enclosures to perform completely satisfactorily in the lower octaves are based on the transmission line principle. Unlike other systems the transmission line can actually lower the resonant frequency of the drive unit in the cabinet. If the resonant frequency of the bass driver is sufficiently low in free air, when installed it can be as low as 20 Hz. The purpose of the tunnel or duct is to absorb energy radiated by the cone's rear surface and the two factors which are vitally important are the length of duct and the damping built into the duct.

For a cabinet/driver combination resonance of 25 Hz a pipe length of approximately 3·3 m is necessary to equal the quarter wave length theoretical minimum. Practical designs, however, are often shorter than this, so to make up for the deficiency it is necessary to introduce severe damping and a tapered duct.

Having decided on the transmission line principle the only remaining problems were financial (up to £400 per unit) and domestic (1 m or more high) for commercially available speakers. There followed a close study of current models, hours of pondering and many draft designs before my version was finalised.

The basic terms of reference which I set myself were as follows:

1. The total height must not exceed 90 cm (my wife said so). In practice the height turned out to be 87 cm.
2. The length of transmission line should be at least equal to the larger commercially available enclosures and should rely more on length than heavy damping.
3. The enclosure should be at least as rigid as and preferably improve upon commercially available enclosures.
4. The rear of both the bass and lower mid-range units should not be allowed to drive directly onto the outer rear panel of the speaker (often a major cause of coloration and siting problems).
5. The enclosures should be designed effectively from a constructional point of view in order to avoid the necessity of mounting them on a stand, siting them at given distances from a wall, or suspending them from a ceiling. In my opinion all of these are signs of failure and compromise.
6. The lower mid-range enclosure should use the acoustic suspension principle and as far as possible be of asymmetrical design to prevent reflected radiations reaching the back of the cone or the establishment of standing waves.
7. The volume of the mid-range enclosure should be greater than that used in competitive designs, but should load the B110 to reproduce the lower middle cleanly and clearly.
8. Only the best drive units currently available should be employed, and the number selected to give the smoothness of drive normally associated with electrostatic designs.
9. Coloration and boom were not to be tolerated.
10. Drivers must be sited so as not to create phasing problems and must be in suitable juxtaposition.
11. The rigidity of the front panel should be beyond question in order to provide 'biting' transient responses when required.
12. Finally the finished product must look professional and be aesthetically acceptable.

Several of the above considerations at first appeared to be contradictions to the dimensional restrictions imposed. However, my final design based on the above considerations gives a transmission line of nearly three metres which is almost double that of some larger commercial designs and far in excess of anything I thought possible in such a reasonably sized enclosure.

Fig. 1 shows pictorially how these design concepts were put into practice and it will be noticed that even the plinth has been put to use, obviating the provision of the outlet duct between drive units as is the case in many designs. Such designs considerably weaken the front panel with a corresponding loss of rigidity. The tapered recess at the rear of the plinth is used to accommodate the crossover unit and controls, which is a further useful feature since it allows experimentation with the crossover unit without interfering with the sealed enclosure. Equally, if service is later required, such accessibility will be most useful.

The drive units selected and the reasons for selection are as follows:

Bass—KEF B139 8 Ω—Almost universally approved as the best currently available and certainly capable of handling the high inputs which this enclosure design requires.

Lower mid-range—KEF B110 8 Ω—Almost equally universally accepted as *the* mid-range unit. It is required by professional designers to perform well in a wide variety of sizes and shapes of enclosure. By providing a geometrically superior shaped enclosure I considered that it would now be capable of equalling and almost certainly be an improvement on anything currently available.

Upper-mid-range—2 Celestion HF1300s—Praised by all reviewers for their smooth output in the upper-mid range. Listening to various speakers suggested that they were at their best in Ditton 25s, but on exploring the market I found that while these were readily available in the 15 Ω form they were unobtainable as 8 Ω units. As I had no wish to introduce matching transformers or balancing resistors in the crossover circuitry I decided to use two 15 Ω units wired in parallel to give an effective impedance of 7·5 Ω. As a bonus the power handling capacity would be increased, a wide angle of dispersion would result and the extra smoothness of suitably located drivers in tandem would be available.

Tweeter—KEF T27 8 Ω—To continue this smoothness into the tweeter range I retained the T 27 which performs so well in my infinite baffle speakers, giving a treble sound which I consider to be superior to either the Coles 4001 or the HF 2000, which are often used as the next on up from the Celestion HF 1300.

Super Tweeter—Coles 4001 K 8 Ω— To perfect delivery in the upper range through into the ultrasonic this excellent little unit was coupled to the T 27. Many speaker designers seem unaware that it is available in the 4001 K 8 Ω form, the 4001 G 15 Ω being almost universally adopted even to the extent of coupling this through a matching transformer, which seems a waste of money—and the introduction of a possible source of trouble.

All but the HF 1300s are readily available as front mounting drivers and although Celestion do apparently produce front mounted 1300s I was unable to obtain this model. This was overcome by mounting the two 1300s on a common piece of paxolin together with suitable spacers. In order to bring the centres more closely together it was necessary to form flats on the mounting flanges of the drive units.

When finally mounted all the drivers were sealed with mastic as used by builders and readily available from builders' merchants.

The final remaining design consideration was the crossover circuit. An article by John Crabbe[2] in *Hi-fi News* of March 1972 solved the problem. His design produced an excellent impedance curve and provided a bass/mid-range crossover frequency of 235 Hz, and a mid-range/treble crossover at 3·5 kHz, figures which I found attractive on two counts. Firstly it means that the range to which the ear is most sensitive is handled without interruption by the B110 and secondly my Sansui AU 999 amplifier has selectable bass turnover frequencies, one of which is 200 Hz. Thus, should it be necessary to modify the drive to the B139, the two crossover figures would match admirably.

The only modifications to the Crabbe circuitry are the removal of all attenuations to the B139, provision for a five-way split and the substitution of constant impedance 8 Ω attenuators for the HF 1300s and T 27. In my listening room best results are obtained with these controls slightly below maximum.

I retained the slight step in the drive to the B110 which Mr. Crabbe introduced to overcome diffraction in his bass horn/IB arrangement and although, as it happens, I have no similar problem with the units mounted in one vertical plane, subjectively I found the arrangement highly satisfactory. I have experimented with various other crossovers including the Frisby[3] variations on the same theme but I always return to the circuit diagram which is shown in fig. 2. Long fibre wool was used on the strength of both the recommendation given by Dr. A. R. Bailey and the convenience with which it can be installed at varying densities.

Materials required include:

High density 12 and 19 mm chipboard. Resin W PVA Adhesive for all wood joints which are also held in place by 1½in × No. 8 countersunk screws (300 per speaker), the Formica is secured with Dunlop Thix-o-Fix, the BAF Wadding can be glued with Copydex latex rubber adhesive and, the Velcro strips which secure the grilles in place are best stuck with Araldite. The sides, top and front rim of the main housing were veneered using Handi-Pak iron-on teak veneer which was subsequently finished with Ronseal Satin Polyurethane but this can be made to suit individual tastes. The main grille comprises a 19 × 19 × 3 mm aluminium

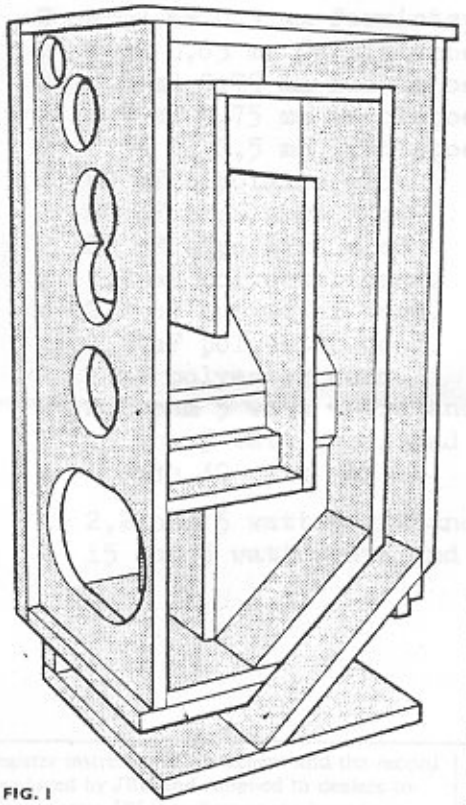


FIG. 1

frame with 16 mm square wood on to which is fixed the grille cloth. The grille to the outlet duct is slightly different in so much as the aluminium angle frame is fixed to the front of the duct and the grille cloth attached to a 3 mm hardboard former which is a good fit inside the angle housing. Velcro was found to be unnecessary for this small grille.

Construction should commence with the lower mid-range chamber followed by the inner-core of the transmission line. All the baffle plates and the back and base must be exactly the same width and not less than the nominal 33 cm. The rear curved surface in the mid-range housing can be formed by hand from Polyfilla which adheres very securely to chipboard. BAF wadding and long haired wool should be installed in the mid-range housing.

If it is decided to dispense with the aluminium angle frame for the main grille then provision must be made to receive a wooden structure by increasing the width of top, sides and base, forming a deeper recess at the front.

The top and vertical webs should be cut slightly oversize, fixed in place and then planed flush with the outer panels. The vertical webs can be glued to the Formica lining at the back using Thix-o-Fix. Two separate pieces of 3 mm hardboard are used to face the 19 mm chipboard front panel in order to provide a smooth outer surface—a very rigid lamination and an easy means of ensuring that all drive units are recessed to the correct depth.

The outer skin of Formica on the rear panel should be fixed after the back has been finally secured to the cabinet but before the veneer is used. During construction provision must be made for the internal wiring of the drive units. The lower base unit was sealed and lined with car body underseal.

I consider a power drill to be essential and I found my jig-saw, circular saw and orbital sanding attachments of immense value. Pilot holes are essential for all screws in chipboard which in turn must be opened up to clearance and countersunk. An excellent tool for the secondary operation is a Stanley Screwmate. The wood should be sprayed with Cooper's moth-proofing solution.

All assemblies and sub-assemblies should be tried and any corrections made before attempting to glue. The hardboard front should be sprayed or painted matt black before assembly. Screw heads and/or holes should be filled with Rawlplug Plastic Wood and sanded before the cabinet is veneered. Several coats of Ronseal should be applied, rubbing down all intermediate coats with steel wool, while the final coat should be thinned with turps substitute.

While it is impossible to provide constructional details in full in a single article the views and notes given should provide sufficient information for the enclosures to be constructed by an experienced D.I.Y. enthusiast.

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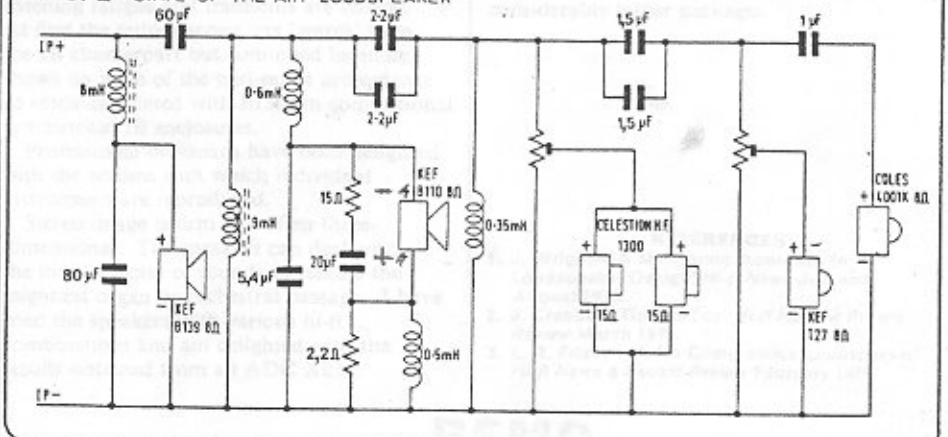
FIG. 2 STATE-OF-THE-ART LOUDSPEAKER



STATE OF THE ART L.S.

Onderdelen voor 2 speakers.

2 Kef B139
2 Kef B110-SP1057
2 Kef T27
4 Celestion HF 1300 15 ohm òf
2 stuks van 8 ohm
2 Coles 4001K = 8 ohm

2 ½ kg. Dr.Bailey's longhair
1 meter x 1.40 m Baf
2 100 x 45 cm luidspr. doek
1 meter Velcro klitband
2 entrée's òf 2 kroonstrips
met 10 units

houtlijm
siliconenkit
600 houtschroeven 40 x 4 mm VK
60 houtschroeven 25 x 3 mm VK
fineer of deurplaten van 3 mm
zijdeglans vernis
aluminium hoekstrip
Gupa kneedbaar hout
matzwarte lak

Onderdelen voor 2 scheidings-filters.

2 8 mH HP 0,9 mm ferrietspoel
2 9 mH 0,63 mm ferrietspoel
2 0,6 mH 0,75 mm luchtspoel
2 0,5 mH 0,75 mm luchtspoel
2 0,35 mH 0,5 mm luchtspoel
2 80 uF bipolaire elco
2 60 uF bipolaire elco
2 20 uF bipolaire elco
4 2,7 uF polyester cond.
4 2,2 uF polyester cond.
4 1,5 uF polyester cond.
2 1 uF polyester cond.
2 2,2 ohm 5 watt weerstand
2 15 ohm 5 watt weerstand
4 L Pads 30 watt òf:

4 2,2 ohm 5 watt weerstand en
4 15 ohm 5 watt weerstand

State of the Art

Recent investigations by the author of our April '76 article on the above LS have shown that, while the amount and location of the damping material described was the result of much experiment and is therefore critical, the frequency balance and efficiency of the system can be changed without reduction in quality by its complete removal. This has the effect of significantly increasing the relative bass output, which might be useful in some rooms, and subjectively improving the overall efficiency. Partial removal of damping material from the enclosure only results in a drop in quality, although it is possible to adjust the relative efficiency of the mid-range independently of the bass by adding or removing damping.

State of the Art Loudspeaker

The required finish was only obtained after some experimentation but the final product in no way looks 'homemade' as the illustration shows. They have been accepted into the household by the lady of the house and are regularly anointed with Teak Oil along with the rest of the furniture. Strength and rigidity are beyond question and it is difficult to imagine how this could be improved upon. Each speaker weighs over 45 kg so that neither concrete lining or stands are required.

And what of the results?

Efficiency is low as it always is with this type of speaker and any room large enough to enable the lower octaves to be produced will require an amplifier of at least 35 watts RMS per channel. My own room is 9·2 × 3·7 × 2·6 m and the 50 watt per channel Sansui is quite adequate. In common with most of the better designs available today the AU 999 has a direct coupled (no output capacitor) power amplifier. This feature is a great asset when it is required to provide high power at low frequencies. The usual lighting flex leads from amplifier to speakers should be replaced by leads of lower impedance. Thirteen amp cable is much better. A high damping factor is another very desirable amplifier attribute.

Given these conditions bass is smooth, deep and beautifully clear. No boom, no excess upper bass, and distortion is undetectable. The separation of the lower register instruments is excellent and the record produced by JBL and supplied to dealers to demonstrate JBL speakers might have been made for my units. The individual instruments and combinations recorded on Side 2 are exciting to listen to, whereas on my IB enclosures the record sounds very ordinary.

The lower mid-range performance fulfils all my expectations. The human voice is reproduced most naturally and the problem of sibilants experienced with the B110 in a symmetrical enclosure no longer exists.

Compared with the performance of similar drive units mounted in the IB enclosure there is a vast improvement all round. The upper-mid, tweeter and super tweeter outputs are as smooth and untiring as expected, with wide dispersion at all frequencies. It seems impossible to induce listening fatigue and transients are terrific. At first the output seems less 'warm' than the IB counterpart but continued listening shows up none of the mid-range prominence so often associated with B110s in conventional symmetrical IB enclosures.

Professional musicians have been delighted with the realism with which individual instruments are reproduced.

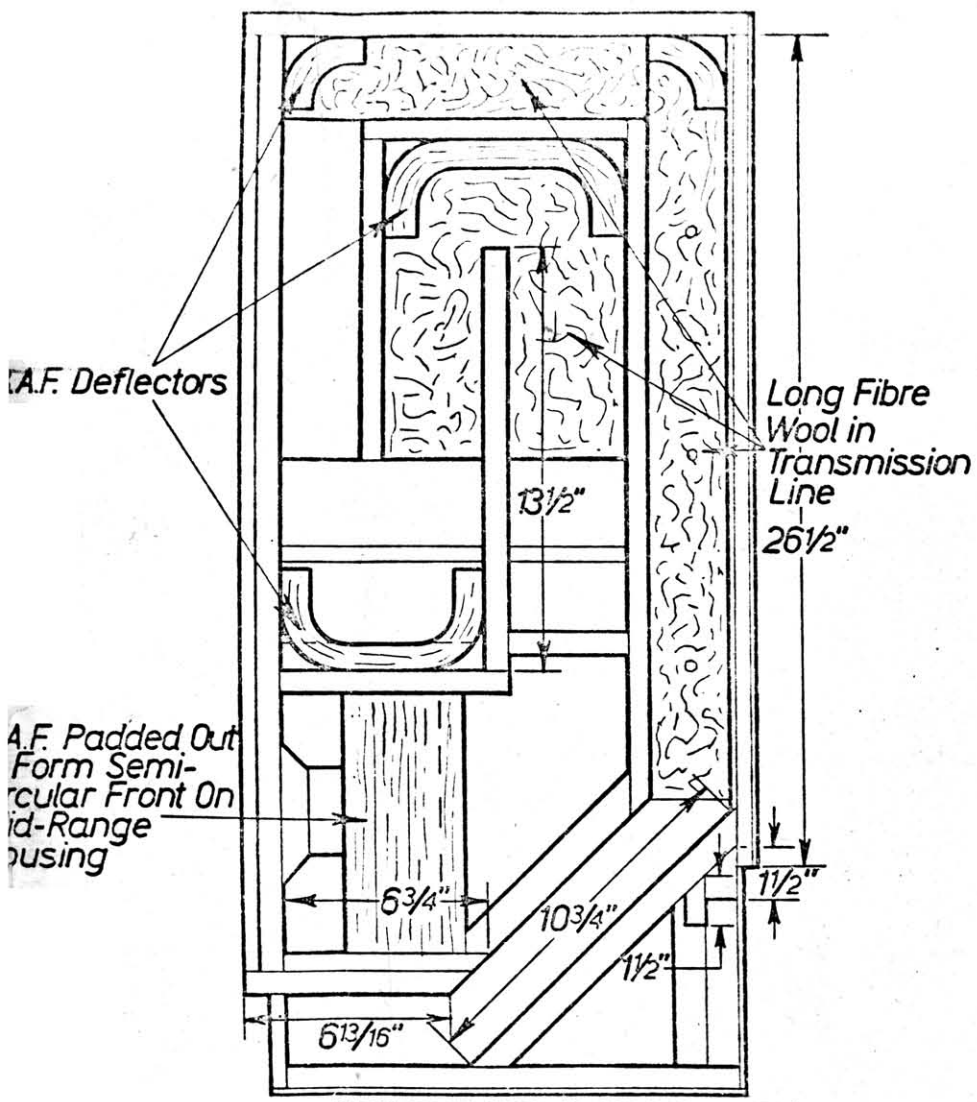
Stereo image is firm and often three-dimensional. The speakers can deal with the most delicate of sounds or handle the mightiest organ or orchestral passage. I have tried the speakers with various hi-fi combinations and am delighted with the results obtained from an ADC XLM cartridge mounted in the fixed headshell of an SME arm on a Thorens TD150 deck through the AU 999 amplifier.

With top quality supporting equipment there is no evidence of the 'terrible trio'—muddle, beaming and coloration. However, those who have grown accustomed to booming bass may at first think there is something lacking in the lower octaves, but it is soon obvious that it is only the boom which is not there. When there is bass on the record it is reproduced faithfully and in the case of test recordings this can be well below 20 Hz.

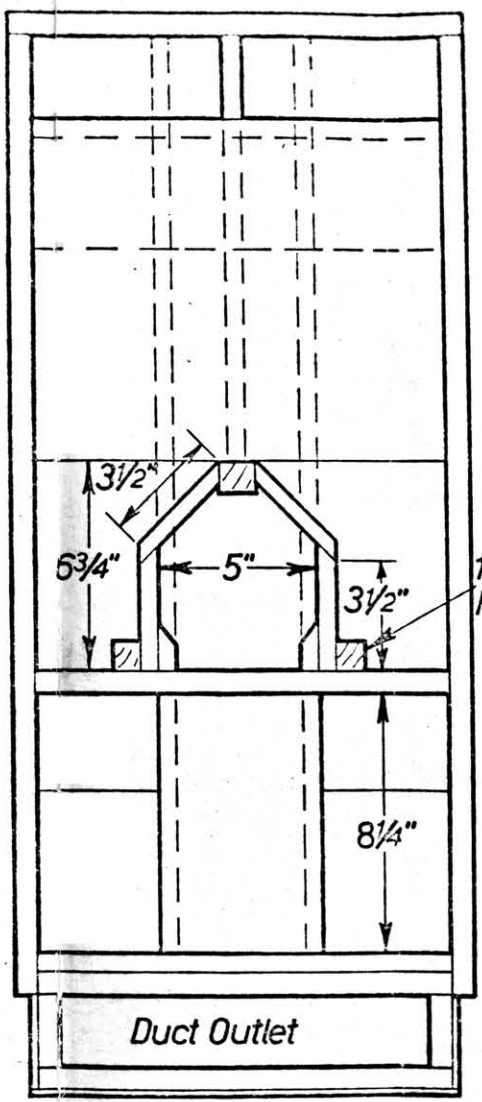
To those prepared to spend the necessary time on the construction of these speakers I would suggest that here is an opportunity to produce transducers to a standard at least as high as that which can be purchased at considerably greater expense and in considerably larger packages.

REFERENCES

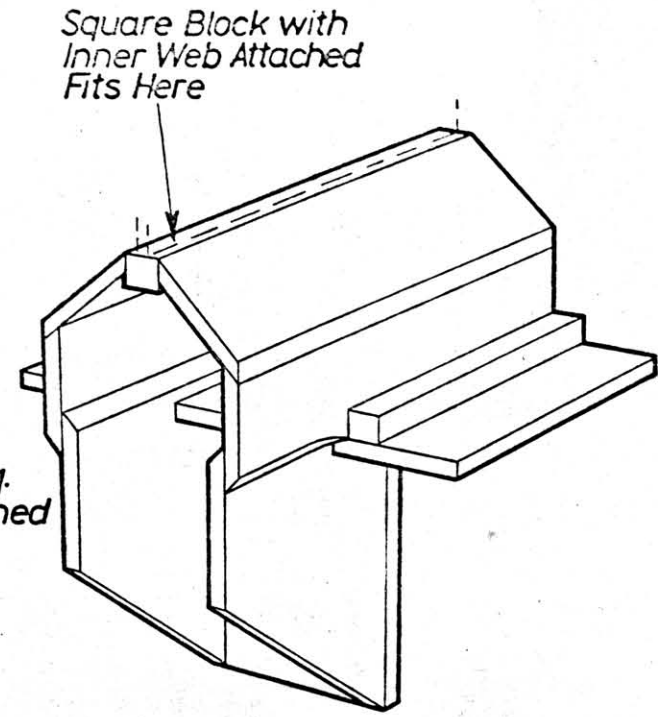
1. J. Wright—'A Monitoring Approach to Loudspeaker Design' *Hi-fi News* July and August 1970.
2. J. Crabbe—'Tip-top Top' *Hi-fi News & Record Review* March 1972.
3. L. R. Frisby—'A No Compromise Loudspeaker' *Hi-fi News & Record Review* February 1974.



SIDE ELEVATION(SIDE REMOVED)
Hardboard Front Panels Not Shown

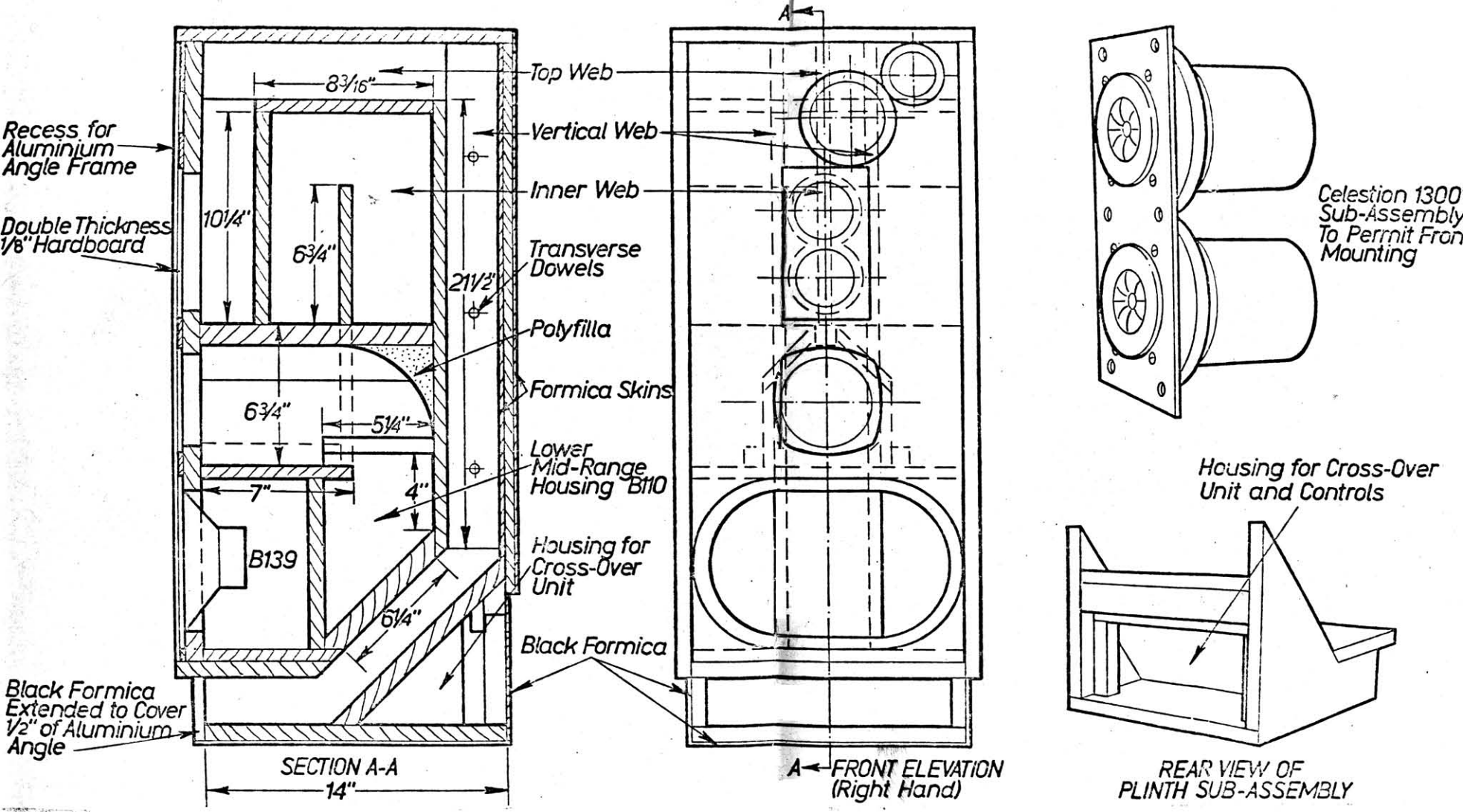


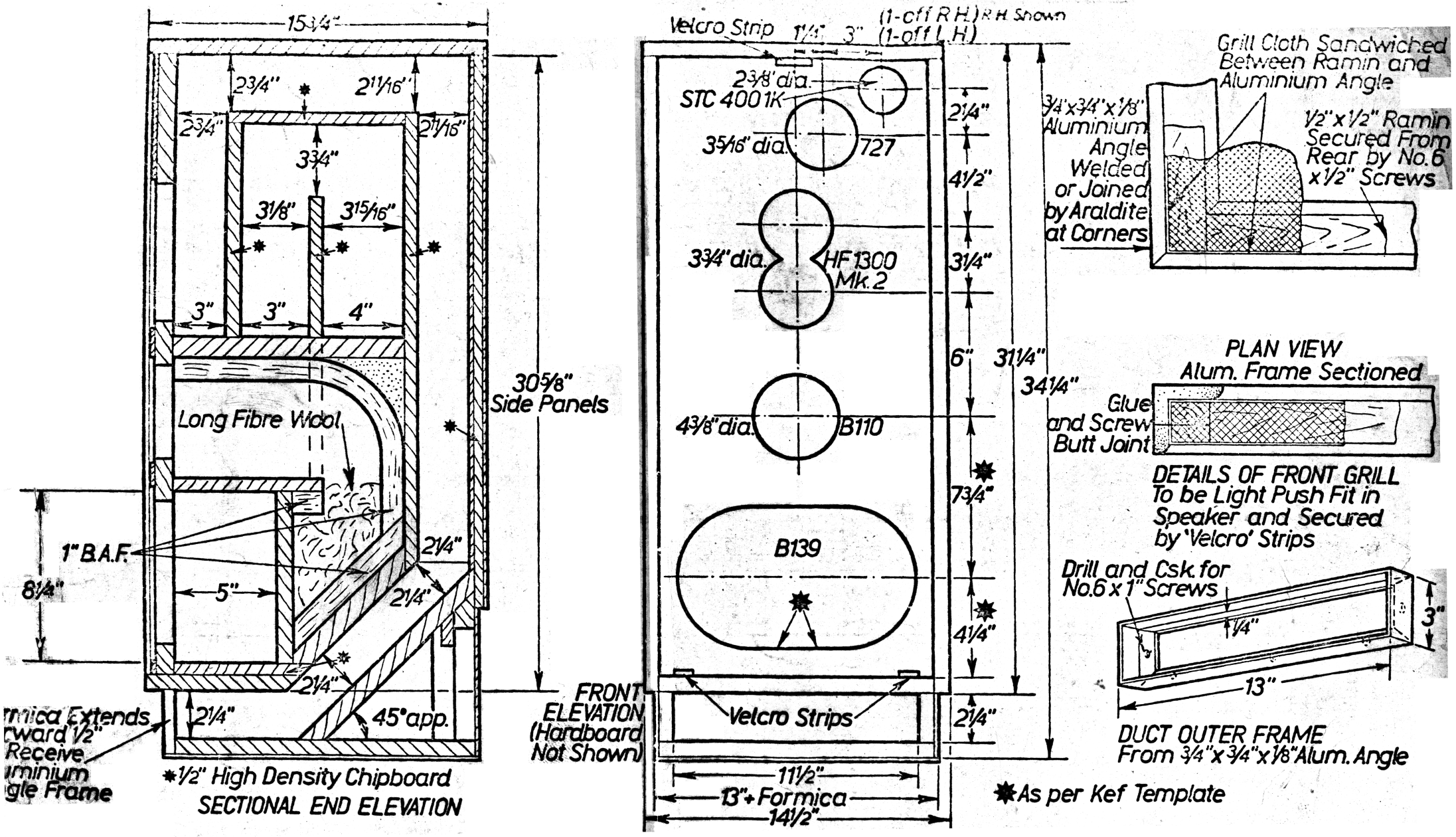
FRONT ELEVATION
(Front Removed)



PICTORIAL VIEW OF
LOWER MID RANGE HOUSING
Seen From Rear
(with back removed)
½" Chipboard

Note Rear panel, ½in. chipboard laminated Formica on both surfaces. Front panel, ¾in. chipboard clad with two layers ⅛ in. hardboard.


8 3/16"
Top Web
Recess for Aluminium Angle Frame
Vertical Web
Inner Web
Double Thickness 1/8" Hardboard
10 1/4"
6 3/4"
Transverse Dowels
21 1/2"
Polyfilla
Formica Skins
6 3/4"
5 1/4"
Lower Mid-Range Housing B110
7"
4"
B139
Housing for Cross-Over Unit
6 1/4"
Black Formica
Black Formica Extended to Cover 1/2" of Aluminium Angle
SECTION A-A
14"
A
A FRONT ELEVATION (Right Hand)
Celestion 1300 Sub-Assembly To Permit Front Mounting
Housing for Cross-Over Unit and Controls
REAR VIEW OF PLINTH SUB-ASSEMBLY


15¾"
2¾"
2 11/16"
2¾"
2 11/16"
3¾"
3⅛"
3 15/16"
3"
3"
4"
30⅝" Side Panels
Long Fibre Wool
1" B.A.F.
8¼"
5"
2¼"
2¼"
2¼"
2¼"
45° app.
Formica Extends Forward ½" To Receive Aluminium Angle Frame
*½" High Density Chipboard
SECTIONAL END ELEVATION
Velcro Strip
1¼"
3"
(1-off R.H.) R.H. Shown
(1-off L.H.)
2⅜" dia.
STC 4001K
3 5/16" dia.
727
3¾" dia.
HF 1300 Mk. 2
4⅜" dia.
B110
B139
Velcro Strips
2¼"
4½"
3¼"
6"
7¾"
4¼"
2¼"
31¼"
34¼"
11½"
13" + Formica
14½"
FRONT ELEVATION (Hardboard Not Shown)
Grill Cloth Sandwiched Between Ramin and Aluminium Angle
¾" x ¾" x ⅛" Aluminium Angle Welded or Joined by Araldite at Corners
½" x ½" Ramin Secured From Rear by No.6 x ½" Screws
PLAN VIEW
Alum. Frame Sectioned
Glue and Screw Butt Joint
DETAILS OF FRONT GRILL
To be Light Push Fit in Speaker and Secured by 'Velcro' Strips
Drill and Csk. for No.6 x 1" Screws
¼"
3"
13"
DUCT OUTER FRAME
From ¾" x ¾" x ⅛" Alum. Angle
*As per Kef Template