The PRO 9TL Domestic Monitor

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THE PRO 9TL DOMESTIC MONITOR by Chris Rogers

In the three years or so since my original transmission line design appeared in print, (Hi-Fi Answers) there has been considerable advancement in drive unit design and, of course, we have three years further knowledge and understanding of the transmission line principle. This then is the culmination of the last three years presented as a new design.

Monitor

Before going into the design philosophy I feel that an explanation of the title is warranted. In calling the speaker a 'domestic monitor', I do not in any way wish to imply that it is designed as a studio monitor. Professional monitor speakers are designed for one function, and one function only. That is to monitor the studio sound with as much clarity as possible, and usually at high levels (by domestic standards). Surely, you may be thinking, this is what the domestic user requires and to a certain degree this is true, but there are various disadvantages to the professional speaker.

The true professional monitor is big, big, big, it requires driving hard and it sounds comparatively poor at low levels, but the main point is that a studio speaker is optimised for use in the studio. In a domestic environment it sounds harsh or bright, and not very musical.

The requirements of a domestic speaker are considerably different. Size has to be considered, appearance has to be acceptable and harmonious to the surroundings, and, most of all, it has to function satisfactorily in a domestic setting. This is obvious you may think, but is it worth considering what a domestic room is? The answer is any combination of sizes, any combination of building materials, and any reverberation time from nearly anechoic to totally reverberant. Or to be more exact, about the most unfavourable possible conditions for reproducing music! This is where the domestic speaker has its work cut out and where the main difference lies.

The first reason for calling this design a domestic monitor is that it is intended to work into a domestic environment without ill effect. Secondly it is intended to monitor the sound from the rest of the system in use, and in so doing, to produce the best possible musical performance from the *total* system.

Philosophy

Moving onto the design philosophy, I would like to say that in the past three years I have considered just about all the various types of enclosure operation, and this has only served to reinforce my view that for domestic reproduction the transmission line principle is the optimum system. There are many reasons for this, but principally, given that a suitable bass extension is required without too great an efficiency loss, there are few suitable enclosure types. For a good linear bass extension the sealed box (commonly but wrongly called an infinite baffle), is not suitable unless it is very large, and also efficiency falls. This leaves the reflex, in its various guises, or horn loading. Both these types fail in their dependence upon acoustic coupling with the room.

All enclosure types involve a coupling effect with the room in which they are placed but, as will be explained later, I feel that the transmission line is the least troublesome in this area.

On the subject of name, the title of 'transmission line' is basically wrong. This is borrowed from the electrical transmission line and refers to a line of infinite length. This does not strictly apply to a transmission line speaker and so the more correct title should be 'acoustic labyrinth'.

I have often seen descriptions of the acoustic labyrinth which describe it as a long damped line that completely absorbs the rear radiation of the bass unit, though it might be possible to hear a slight grumble from the port at very low frequencies! This statement is totally untrue and infers that it would not matter whether the port was open or totally sealed. I would therefore think it instructive to consider exactly what the labyrinth does.

How it Works

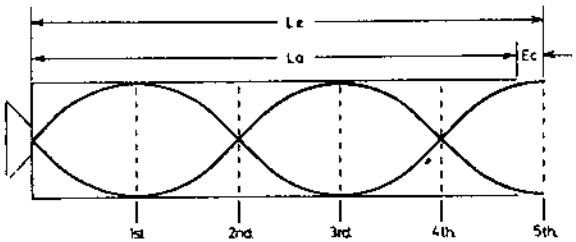
The line has the function of a resonant pipe, and can be compared to any resonant pipe instrument, such as a woodwind instrument, or what probably is an easier comparison, the organ. The main difference of course is that we require our pipe to work over an extended frequency range, and not at a single frequency as in the case of the organ pipe. I feel that when viewed in this light it may be a little simpler to see how the labyrinth functions.

At resonance, which is a quarter of a wavelength of the fundamental frequency, reflection back from the port will reach the rear of the cone in antiphase and will serve to reduce cone movement and control the drive unit resonance, in much the same way as does a reflex enclosure. However, unlike the reflex, the acoustic labyrinth has the effect of directly controlling the output at the various harmonics of the fundamental frequency. The anti-resonances occur at every quarter wavelength and it is therefore the odd order harmonics in which we are interested. Due to the nature of the system, which includes the folding of the line, the third harmonic reflection reaches the end of the line in phase and raises no cause for concern. The fifth harmonic, at approximately 150Hz in this case, reaches the end of the line out of phase and it is this reflection which must be controlled.

In damping a resonance in a pipe, the object is to damp the points of maximum particle velocity. As can be seen from Fig. 1, there are three maximum velocity points in the fifth harmonic resonance, and it is at these points that the damping is required. Due to the nature of the system there is a tendency for the response to rise in the region of 150Hz so some cancellation is helpful in order to control this. If the line were to be totally undamped however, the cancellation would be very severe (in the order of 15dB or more), so the requirement is to damp the resonance to such an extent that it is still able to cancel by about 3dB but no more.

There are also four other factors which influence the working of the line, and must be considered hand in hand with the requirements already stated.

Fig. 1

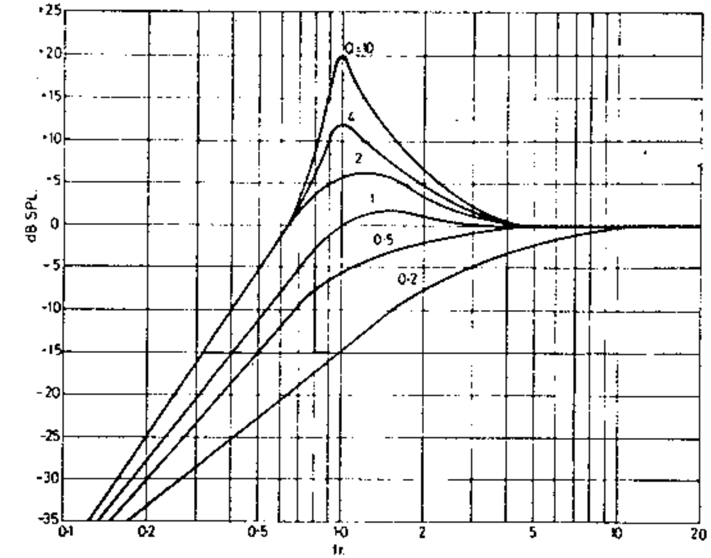


1. END CORRECTION - The length of the line as seen by the sound waves is longer than its physical construction due to the vortex effect at the port mouth, or, to put it simply, as the sound waves rush out of the port it takes them a while to get used to it, and só they see the line as being longer than it is in practice. At the frequencies which we are talking of, the required end correction would be between 4" and 8", so for the purpose of the ensuing calculations an end correction of 6" will be adopted.

2. THE EFFECT OF DAMPING MATERIALS ON THE SPEED OF SOUND - When a damping material is introduced into the line, the air particles passing through it will cause a heat exchange, and give rise to an *isothermal effect*. This in turn will make the volume appear greater or, from the calculation point of view, reduce the speed of sound. It therefore follows that there is an optimum damping which will reap the most benefit from isothermal effects. Too little damping and maximum benefit is not reached. To much and the mechanical restriction does not allow the maximum effect. Under ideal isothermal conditions the speed of sound may be reduced to 950ft/sec. or slightly less, but for our purposes I have worked with a figure of 1000ft/sec.

3. THE EFFECT THAT DAMPING WILL HAVE ON THE TOTAL SYSTEM - Q is the name for 'goodness' or magnification factor and gives a factor by which resonance is magnified. If the damping required to optimise point 2 above and also reduce the 5th harmonic resonance is too great, then the system Q will be low, and a dead, thick sound will be the result. If on the other hand the damping is not sufficient to control the Q at resonance sufficiently, then the sound will probably be boomy. If the total system Q is equal to, or greater

Fig. 2.



than, unity there is likely to be a hump in the bass response (Fig.2). If however the Q is less than about 0.5 then a premature bass roll off will be the result.

It would appear that a Q in the region of 0.8 is popular for the vast majority of commercial loudspeakers, and as such a Q of 0.8 achieves the best possible linear bass response without the response curve having any hump. Under optimum conditions such as anechoic or free air this is fine. The problem, however, is that when the speaker is placed in *any room* there will be an acoustic force acting upon it, due to the reflections of the room boundaries (walls etc.) inducing a back e.m.f. (electromotive force) in the speech coil. This is where the reflected sound reaching the speaker cone causes yet another force to act upon it. When the speaker is in an unfavourable position such as in a cube shaped room, the standing wave or eigentone produced by the *room* will have a very pronounced effect upon the speaker at that frequency. I therefore considered that, as one of the design criteria was for the speaker to work well in any room, a slightly lower Q would be aimed for, as this would help minimise back e.m.f. problems. The target Q was therefore set at 0.6.

4. THE EFFECT OF TAPERING THE LINE - Ideally the cross-sectional area of the line should be the same as the effective driving area of the bass drive unit. It has frequently been stated elsewhere that a transmission line can be tapered, but what effect does this have on performance? A progressive reduction in the area of the line

will spread out and reduce the effect of the anti-resonances, but if the reduction is too great, then the bass performance will suffer and a constrained muffled sound will be the result. Therefore the amount of taper that I have included is sufficient to meet the first need without introducing the second effect.

At this juncture I feel that it would be useful to reiterate a little, and I will therefore briefly summarize the foregoing regarding just what the line has to do..

1. Reinforce output below resonance (40Hz) and reduce cone movement.
2. Damp and reduce cone movement at resonance (40Hz).
3. Reinforce and provide linear output between 40-120Hz.
4. Reduce output at 5th harmonic (120-150Hz) by about 3dB.
5. Eliminate output above 150Hz.
6. Suitably control overall and provide the required value of Q.

Practical Design

Moving on now to the practical design the configuration may be seen in the cross section Fig. 10. The external dimensions of the original design are 36" high x 13½" wide x 17½" deep and having been found domestically acceptable were therefore retained. These sizes do not allow for the plinth or front grille.

The line length from Fig. 4 gives an overall length (with end correction of 6") of 90.75" or 7.563 ft. Using 1,000 ft/sec. as the velocity of sound within the line, the fundamental resonance is given by: $\frac{C}{4l}$

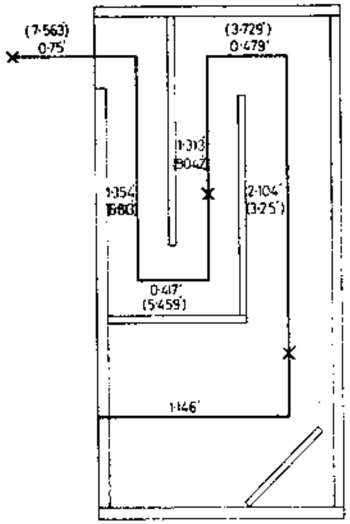
where c is the velocity of sound and l is the effective length of the line. This gives; $\frac{1000}{4 \times 7.563} = 33.06\text{Hz}.$ This figure may seem a little high, but due consideration has been given to the basic theory which governs the length of a resonant pipe by comparison with its cross sectional area. During development of the enclosure it was found that to achieve the required quality of an open bass sound the area at the start of the line needed to be some 50% greater than that of the drive unit. The effective area of the bass unit is 55 sq.in. The start of the line is 72 sq.in. tapering down to drive unit area at the end of the line.

The theory which governs the length l, versus area A, is as follows:

$$l = \frac{c}{2f} - 1.7\sqrt{\frac{A}{\pi}}$$

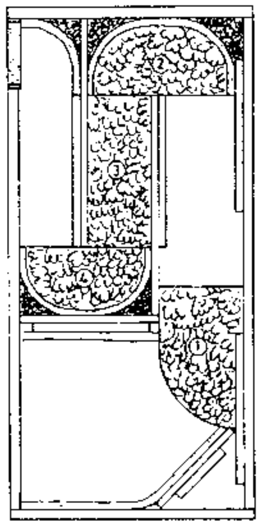
where f is the resonant frequency of the source, which in our case is the drive unit. The resonant frequency of the bass unit is 25hz, giving a required length of 7.3 ft based on the area at the start of the line, and this is the figure chosen. It will be appreciated that the length required based on port area will be shorter and works out to 6.4 ft. Just to complicate matters further, it must also be appreciated that it is not possible to make every single drive unit have the same resonance. As drive unit resonance is a product of cone mass (including voice coil and former), and the compliance of the surround, small variations are inevitable. The consistency of the chosen drive unit is very good and the typical production spread is ±2.4Hz. Although this is a good tolerance (±9.6%) it gives rise to the situation where the required line length (for the area at the start of the line) can vary from 6.6 ft to 8.2 ft.

All of this may seem somewhat confusing and make nonsense of the ¼ wavelength theory, but it must be appreciated that *all* factors have to be considered and a compromise reached. The production spread of the bass unit does not give rise to any problems. The nature of the damping of the enclosure, and the taper of the line give sufficient latitude for a problem not to exist.



dimensions in brackets are the cumulative length
X = damping points
CENTRAL AXIS LINE LENGTH

Fig. 4.



LOCATION OF ACCOUSTIC DAMPING
long haired wool quantities
① 3ozs ③ 3ozs
② 2ozs ④ 1·5ozs

Fig. 5.

Acoustic Damping

The next practical consideration is the damping of the line. First we must establish where the damping material is to be placed. We already know that it is the maximum particle velocity points of the 5th harmonic Fig. 1 that have to be damped. Therefore it is a simple matter to divide the length by 5 in order to find these points. This then gives;

$$\frac{7.563}{5} = 1.5126\,\text{ft}$$

From the above we will have 5th harmonic points at, 1.5126 ft, 3.0252 ft, 4.5378 ft, 6.050 ft, and 7.563 ft. Fig. 1 shows that the 2nd and 4th points are minimum velocity and therefore it is the 1st, 3rd, and 5th points which require damping. These points are shown in Fig. 4. There are many damping materials that could be considered for use in our application, but in finding material which meets all the requirements of damping, isothermal, and Q control, the choice is considerably limited. The most suitable material for damping the 1st and 3rd points is natural long fibre wool. This material has been found by many researchers (particularly Dr. A. R. Bailey of the University of Bradford) to be particularly suitable for the purpose in hand. It has high damping properties for a low packing density, and this is just what we require as it is necessary to damp some frequencies, yet pass others. The next consideration is packing density. With this material a packing density of ½lb/cu.ft is normally prescribed, but this may need varying in the light of practical or subjective tests. The actual amounts vary in packing density from ½ to ¾lb/cu.ft and were finalised by experiment. The final quantities are shown in Fig. 5.

It will also be seen from Fig. 5 that the practical damping does not accurately follow the required damping points. The reason for this is conflicting requirements of the damping needed for harmonic control as against that needed for control of Q, which can be determined only by practical experiment.

The final point of maximum particle velocity is at the termination of the line. This of course is where the port meets free air, or more correctly 6" in front of the port (due to end correction). No damping is required at this point, as the junction with free air provides more than adequate damping. In fact it is literally more than adequate in that the termination is too severe, (too high Q), and it becomes necessary to reduce the effect of this damping.

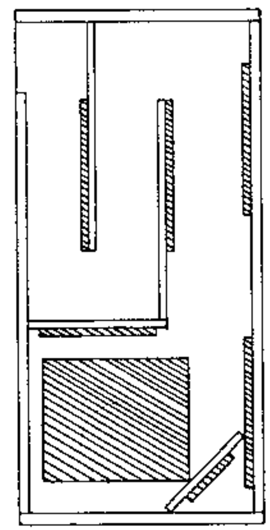
At this point you will probably thinking that, as the damping is air, how can air be reduced? Answer - it can't. What is needed is to place in this position something which will *spoil* the damping by the required amount. Long fibre wool would be far too severe in this application, a more suitable material being chosen the one, polyester foam. (The ordinary cheap, usually yellowish light plastic foam to be found from market stalls, remnant shops and the like. Do not use the heavy foam). A thickness of 1" was found to be correct. This is placed in the port mouth. Next assumption is that the port mouth is the wrong place for the damping! This again is correct, but it would be rather difficult and unsightly to place the foam 6" in front of the cabinet, nor is it necessary. This chosen position of the damping material influences its performance and it has been chosen for this location. Up till now I have stayed away from the effects of the enclosure. We now have to consider some of the nasties imposed by the 'box'. Any enclosure in which there is sound will have its own internal reflections and if the performance is not to be impaired these must be minimised. The damping already discussed is not sufficient to control internal reflections and additional damping is required. The main areas needing attention are those at the bends of the line.

The damping material employed here is carpet underfelt. The type to use is very ordinary ½" thick felt (not foam) type. This is placed in the corners of the line to form a radius and has densely packed long fibre wool behind. To further minimise internal reflections carpet felt is used to line the bass unit chamber, also the sides and top of the first column of the line.

The structure of the enclosure can now be considered. The merits of various cabinet materials have recieved great scrutiny elsewhere, and the fact remains that chip board is the most suitable. It is usually stated that high density chipboard should be used. This is not the case. High density types, by virtue of that high density, tend to have high Q at resonance which is just what we don't want. The lower density grades (of good quality) are made with a small particle high density surface, but the centre is a coarser particle size of lower density. This has the effect of self damping due to varying density, and as the overall density is lower the Q of any resonance will also be lower, and easier to deal with.

Having decided which material will be used for the cabinet, it only remains to decide the thickness required and the panel damping needed. There are various factors involved in selecting the material thickness and two main approaches in dealing with any resultant panel resonance.

Fig. 6.



PANEL DAMPING PAD LOCATION

Panel Damping

There are two schools of thought regarding panel damping. The first method is to make panels sufficiently solid and rigid so that they don't resonate. The other approach involves accepting that panels resonate and making the cabinet in such a way as to easily damp out the resultant resonances.

Both techniques have disadvantages. The former suffers in that it is very easy to end up with a cabinet which is so massive and heavy that a fork lift truck is needed to move it. This is shown up if you do try to find a panel that does not have any resonances. It has to have a very large mass and great density before all resonances are inhibited.

The latter method carries a risk that it is possible to end up with a damping system more bulky and costly than the original panel which is being damped.

The approach which I have adopted, is to endeavour to make the most of both techniques. To this end suitable damping material is essential and this takes the form of ½" thick bituminous laminated felt, a material which has been used by speaker manufacturers for the last decade and a half, but in recent months has been made available to the home constructor. Needless to say it is this material which has been selected, supplied in pieces measuring approximately 8½" x 10½".

In order to make a proper job of damping an enclosure, *every* piece of the cabinet has to be considered both separately and collectively. The first parts to come under scrutiny are the sides. These are made of 18mm board. The top half is sufficiently braced by the internal partition and will cause no problems, but the lower third (the section forming the bass chamber sides) needs additional panel damping as this area could have a resonance in the 1kHz region. Therefore one damping pad is used either side. The bottom of the enclosure needs no additional damping as the plinth provides all the strength needed. Likewise the top is braced by the internal partition. On the subject of the plinth, this is necessary not only to damp the base of the cabinet, but also to raise the speaker off the floor by a small amount in order to achieve the designed speaker/room coupling effect, and it *must not* be omitted. In practice it should be 2" to 3" high.

However, back to the subject in hand. The back of the cabinet (also in 18mm board) is braced in the centre by a piece of 18mm board 4" high. This has the obvious effect of bracing the panel, but in so doing splits the remaining unbraced area into two halves so that resonance will be at twice the frequency (again about 1kHz) and thus easier to deal with. So here two pads are used one at the top and one in the lower half. The reason that higher frequency resonances are easier to damp is because the wavelength is shorter and hence the amplitude will as a result be smaller.

Our attention can now be focused on the internal partitions. These are made from 12mm board since they are smaller and hence easier to deal with. There are three internal partitions and they require a damping pad apiece. The two vertical partitions have their pads aligned vertically whilst the horizontal partition has its pad from side to side.

The use of bituminous damping pads has a dual function. Not only does it inhibit panel resonance, but it has the effect of being a sound insulator and helps to prevent sound escaping through the panels. This effect is very valid as the sound escaping *through* a panel can be 30dB or less down on that emanating from the drive unit.

The final part of the enclosure to require damping is the reflector in the rear of the bass chamber. This reflector is in a very prominent position and is damped with *half* a pad on its rear.

This then totals fifteen pads for a pair of enclosures. Their placement is not critical, but should approximate to Fig. 6. The pads have to be fixed with an appropriate bituminous adhesive in order to work correctly, suitable products being 'Febond' or 'Aquaseal' No. 5, obtainable more easily from a builders merchant than from a do - it - yourself shop. This glue takes a few hours to dry, so it is necessary to hold the pads in place with a few panel pins. The glue is a bit messy, but it should not be skimped or the full effect of the damping pads will not be realised. I should also include the warning that if some other type of unsuitable glue is used *the damping pads just won't work.*

Drive Units

Having made all the theoretical and practical considerations involved in the enclosures, it now remains to provide some drive units, and a suitable cross-over. The bass unit chosen, and the one that the cabinet design has evolved around is the KEF B139. Although it may be thought this is the same unit around which the original was orientated, this is true in name only. The B139 is changed and improved. The first improvement has been in the chassis. This has been made considerably stronger and more rigid, a very desirable improvement. The other area of change is in the power handling, this again has improved. It would therefore seem that the B139 is the best bass unit available on the domestic market.

Finding a mid-range unit is not quite so simple, as there are precious few available on the domestic market. This situation was greatly helped by the availability of a unit from Peerless, the KO40MRF. This unit has its enclosure integrated behind it and is therefore used without any additional enclosure. A useful point, but every improvement invariably has its price. In this case the cost is that of the confines giving rise to two problems.

Because of the comparatively small size of this chamber there is quite a high pressure inside the enclosure, and the reflective paths are short. This causes the two problems. Firstly the amount of sound that will come through the cone itself, and also the resonance of the enclosure. I therefore conclude that the KO40MRF is not suitable in its standard guise. The problems are not insurmountable, and it would seem a little daft to pass by a very good unit for the sake of a couple of mods.

The transparency of the cone is cured by the application of a coat of dope, the type most suitable being Plastiflex P1200. This is not available to the public for two very good reasons. It has to be diluted accurately with a short shelf life in this state, and experience in applying it is necessary before it is possible to put on a coat of the right thickness. It has therefore been arranged for a supply of correctly doped units to be made available.

The ringing of the enclosure is fairly simple to deal with, and requires the use of a special damping compound. This is applied to the enclosure to form a non-hard damping layer. As with doping, this process is somewhat outside the scope of the home constructor so here again the KO40MRF is being supplied with this damping already applied.

There are now a number of good tweeters available that may be used and which do not require the use of a super tweeter to bolster up their falling performance at the extreme top. I have selected three such units, any of which may be used.

These are the Isophon KK8, Seas D86H and Sonaudax HD12 9D25. All of these tweeters are 25mm dome units, the Isophon having a hard melinex dome, while both the Seas and Sonaudax units have soft fabric domes.

The sound difference between these units is small, but sufficient to alter the character of the total system sound. The choice as to which unit to use is personal, but I will try to outline the differences. The Isophon has an analytical nature and has been used in many commercial speakers including the Monitor Audio range and this I feel typifies its performance. The Seas on the other hand has a more mellow voice and is less clinical.

The Seas still retains some of the attacking nature of a hard dome unit, but without the cold clinical sound of a hard dome. Finally the Sonaudax has a very transparent and open nature in advance of both the other units, but without the attacking nature of the other two. It is also now being used by many manufacturers who have previously used other tweeters and has also found favour with the BBC.

The final choice is purely personal, all three sounds appeal to many poeple and I would not care to speculate as to which is the more accurate or correct. It is best to hear all three units and make your decision based on which sound you like the best.

As I am frequently asked which of the three I prefer, I guess I must admit that my preference is for the Sonaudax, but, and this is a big but, I would in no way presume to suggest which tweeter *you* would like best.

Cross-over

Having selected the drive units we now need a cross-over network to combine them. The design of a suitable network has to encompass many requirements and consider the requirements of each drive unit. The decision of where to cross over each section is invariably taken on the basis of where you *don't* want the various drive units to work, as opposed to where you do.

The B139 has ist first problem at around 950Hz, this being where the first mode of break-up occurs. It is therefore desirable to have the unit inoperative at this frequency, but about 25-30dB down is suitable. The lower end of the mid-range should be at a similar rate of attenuation at its resonant frequency of 220Hz (when doped). The upper limit of the KO40MRF is decided by its inability to provide an adequate polar distribution. This starts to fall off at around 4kHz. Although the tweeter will support the polar response it is undesirable to have the mid-range operating much above this as in doing so it tends to produce a nasal sound.

All dome units have a rising characteristic as the response drops towards resonance and tend to sound hollow. It is essential therefore not to operate a dome at less than one octave above resonance and preferably two octaves.

It can be seen from the foregoing that to achieve the desired rates of attenuation it is necessary to have a network with a rate of attenuation approaching 20dB/octave. For this reason 'T' networks have been adopted throughout, and since these achieve a theoretical rate of attenuation of 18dB/octave, the cross-over points were set at 460Hz and 3.4kHz.

To ensure a balance between bass, mid and treble which is suitable for all tastes, room and ancillary equipment, a variable resistive network was added to the mid and treble sections of the cross-over. This of course also allows the sensitivity of the drive units to be matched. Table 1 shows the values of resistors required, and it can be seen from this that for an anechoically flat setting, the Sonaudax and Isophon tweeters are about 1.5dB less sensitive than the Seas.

This then allows for up to +3dB in the mid-range, and +3dB with the Seas tweeter, but only +1.5dB with the Isophon and Sonaudax units. Up to −3dB is shown in the table and this will be quite sufficient for most uses, but further attenuation may be added, by the insertion of 2.4 ohms series resistance for every additional 1.5dB reduction required.

Fig. 7 shows the cross-over circuit in its entirety, and it will be seen from this that two 2.4 ohms resistors have been added for both mid-range and treble. It will be appreciated that from this it is possible to have up to four settings, by linking the resistors for series, parallel, one only and none. For most people this will be more than adequate and once set to suit the room, equipment and taste of the listener, will not require changing, and I would recommend that a start should be made from the 0dB settings.

For those who change their equipment, or room regularly, or who just like to play, it is possible to override the resistive network on the P.C.B., and use a switched network mounted on the front baffle. For this five position wafer switches are used, which allows +3dB, +1.5dB

0dB, and -3dB. If this is used with the Sonaudax or Isophon tweeters however it will give +1.5dB to -4.5dB. This will be described more fully later.

At this stage I would like to make it quite clear that if you're considering making the cross-over from the pile of components that you just happen to have in an odd box somewhere, *it won't work!* Each component is selected for the job it has to do. All inductors are ferrite cored and capacitors are reversible electrolytic, but there are various grades of ferrite used and various tolerance and loss factor capacitors used. I can now hear people saying that ferrite inductors are not as good air cored inductors and that electrolytic capacitors are inferior to paper or polyester types. *This is absolute hogwash!* Modern ferrites and modern reversible electrolytics are equal in every practical way to their bulky, costly air cored or paper counterparts. This of course is only true when the network is designed to suit the components specified. To this end the cross-over will only function correctly when the components are laid out as intended. Therefore arrangements have been made for the provision of complete networks and no kits or components are available.

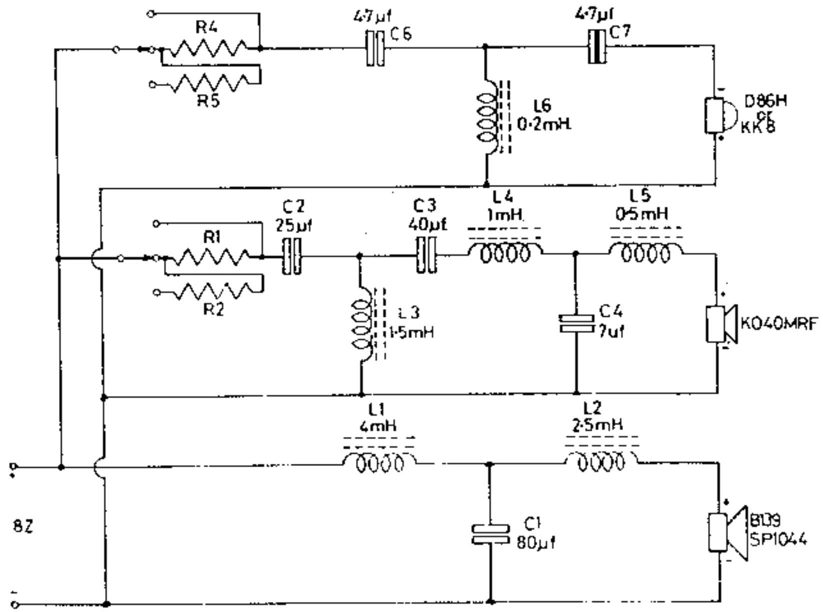


Fig. 7.

CONSTRUCTION

At long last we move onto construction. Fig 8 gives a cutting plan both for the 18mm. and 12mm. chipboard required. This gives the basic pieces required and no allowance has been made for any recess at the front for a grille. The basic cabinet can be made as the cutting plan shows, and the grille made to cover the *whole* front. Alternatively you may wish to have this recessed. If this is your requirement, then I strongly advise that the basic cabinet be made as shown, and a hardwood lipping fitted to the front. In this way the lipping will be far more durable, and it is easier to obtain a good finish. Added to this it is simple to have the edge any reasonable width which you may like, and is not limited to the 18mm. thickness of the chipboard. It will not matter if the lipping slightly overlaps the port.

From the foregoing it can be seen that just about any type of front layout is possible, there being few limitations. Just a few ideas are as follows, total grille with no edge, lipping all the way, lipping at the top only, and lipping at the sides only. The choice is yours!

The method of construction which I will describe and for which the cutting plan is intended, uses simple butt jointing. This is by far the easiest method and that most suited to home construction. Those with access to professional cabinet making facilities will no doubt favour a wrapped mitre and rebate method of construction and will have to adjust the cutting plan to suit, but without the necessary equipment this is right out of the question. Therefore butt jointing it is (as shown by Fig. 3).

Table 2 gives details of all the parts required for construction, so armed with this and the cutting plan Fig. 8, a trip to the local D.I.Y. shop is called for, for the first half of Table 3. The vast majority of D.I.Y. shops these days operate a cutting service, so there should be no difficulty in finding a shop that will *accurately* cut the chip-board for you on a machine saw. This will save a lot of trouble and make construction far simpler.

At this stage an explanation of the cutting plan (Fig 8) is in order. In the complete sheet it can be seen that the sides numbered 1 and 101 respectively add up to 6ft. and the two fronts 5 and 105 make up the length to 8ft. In theory this is exactly right, but in practice it is not possible to achieve this as the combined thickness of three saw cuts has to be allowed for. This is deliberate, and it is the fronts that should be slightly under size. If the two sides are cut to exact size, and the remainder cut in half, you should end up with the fronts about 1/8" too narrow. This is a desirable feature as it allows the front to be a clearance fit and it will not be under any stress. If it were to warp, even slightly, there is a good chance that this would cause the drive unit chassis to distort, the results of which would be horrendous.

One final point regarding the chipboard. I have already stated that it is undesirable to use a high density grade (750 or higher) of chipboard, but a *good* medium density grade should be used. This means 600 grade or similar. The pre-venecred boards such as Contiboard and associated

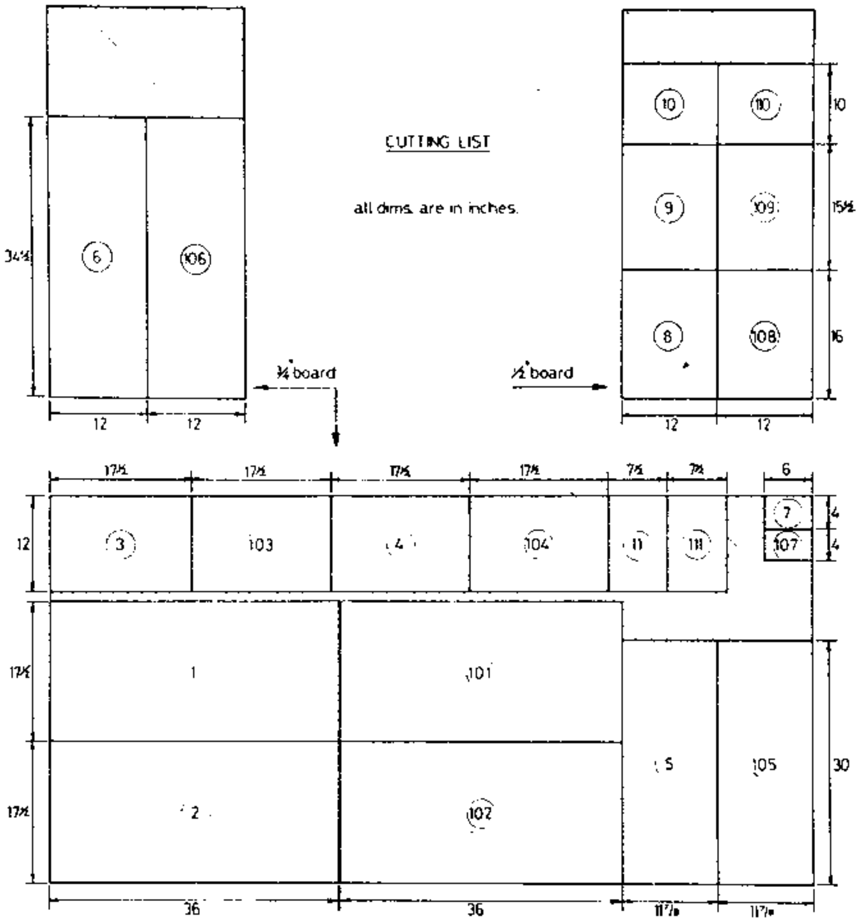


Fig. 8.

Part numbers:

1 & 101	Left Side	7 & 107	Brace
2 & 102	Right Side	8 & 108	Front Partition
3 & 103	Base	9 & 109	Rear Partition
4 & 104	Top	10 & 110	Bottom Partition
5 & 105	Front Baffle	11 & 111	Reflector
6 & 106	Back		

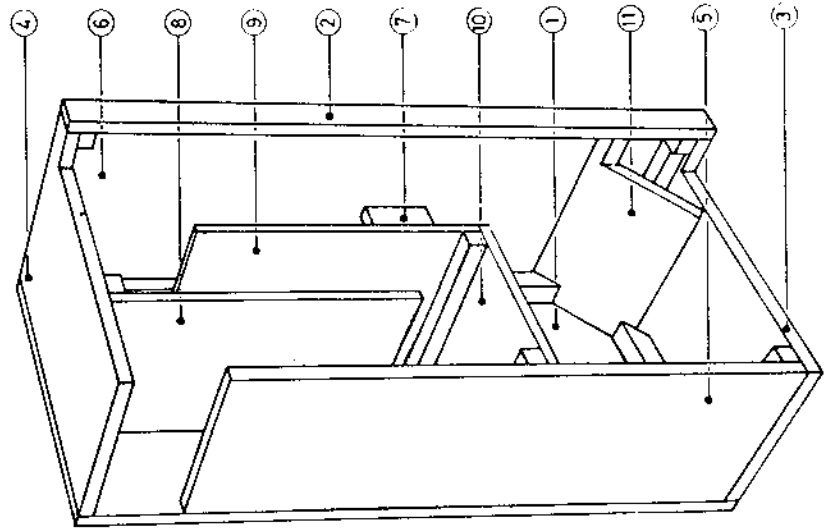


Fig. 9.

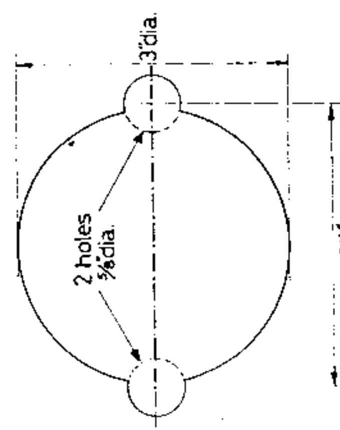


Fig. 11
Cut-out for Sonaudax and Seas Tweeters

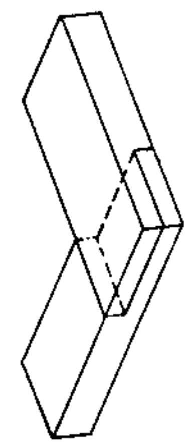


Fig.12.
Halving Joint

makes should not be used. These are based on a 600 grade board which is suitable, but of the incorrect thickness for the job in hand.

Note by Badger Sound Services:- Those constructors planning to visit us may like to know that a first-class cutting service is operated FOR CALLERS ONLY by Keith Barnacle at the nearby St. Annes Timber Supplies, 43, St. David's Road South, St. Annes, Lytham St. Annes, phone St. Annes (0253) 721069. Keith knows the requirements of the PRO 9TL and supplies chipboard panels of the correct grade, accurately cut.

You should by now have returned from the shop with a large collection of bits. The next requirement is somewhere to assemble the cabinets. Whether this be the kitchen table, garage or workshop, it should be tidy or you are destined to disaster before you start. A vast collection of tools is not required to assemble the cabinets, but one or two items will make the job a lot simpler. Firstly an electric drill is very helpful as there are nearly 400 screws in a pair, holes having to be drilled for each one. Allied to this a Stanley 'Screwmate' or 'Screwsink' will make drilling screw holes far easier as these small devices drill the pilot hole, clearance hole and counter sink in one operation. Next item is a means of fitting the screws, and a "Yankee" (pump action) screwdriver is the most useful tool for the job. Other tools required are minimal and are normal workshop items, such as a tenon saw, 'G' clamps, hammer, rule, square, chisel and jigsaw or keyhole saw.

Fig 9 shows the numbering of the parts of the enclosure corresponding with the numbers shown on the cutting plan, Fig 8. Parts numbered from 101 are for the second enclosure. I feel that constructors would be well advised to make one enclosure at a time, so that any problems encountered will not have to be duplicated.

With reference to Fig 10 the location of all the various parts should be drawn on the sides 1 and 2. Also the location of the various battens should be marked on the sides 1 and 2. The next step is to mark out the position for the batten screws on the sides. These should be placed centrally along the battens and located 1" in from either end, and spaced at no more than 5" intervals on each respective batten. Each hole should now be drilled with a 1/8" drill. This done the battens may now be fitted. They should be stuck with a good P.V.A. glue such as Evo-Stik "Resin W" woodworking adhesive.

Each batten should in turn be glued and clamped into position, and then it can be drilled with the 'screw-mate' from the other side and the screws fitted. It can be seen that this way of working will save having to mark out both sides of items 1 and 2.

With the battens fixed to both items 1 and 2 our attention can now be turned to the plinth. This is made from 3" x 2" planed deal, and may be fitted so it is either 2" or 3" high whichever way you find most pleasing. The corners of the plinths should have mitred joints, and these need not be fixed apart from gluing as when they are fixed to the base (item3) they will be adequately rigid. Fixing to the bases should now be done with glue and three screws per side, making a total of 12 screws per plinth.

The next job is to mark out the screw positions in the base 3, top 4, internal partitions 8, 9, 10 and reflector 11. The same principle of 1" from each end and a maximum of 5" spacing should be observed, but slight adjustments will have to be made in order to prevent screws from colliding. With this done, each piece in turn can be glued and clamped in place, then drilled and screwed to *one* side. With this done the other side may be fitted in a similar way, but of course it must be all glued in one operation, so I suggest the base and top be screwed first. The front 5 and back 6 should now be dropped into place to ensure squareness and the assembly set aside to dry.

When dry there are still a few items to be fitted to the main cabinet. These are the battens at the top and bottom, front and back, the batten across the front of the partition 10, and finally the brace from the back 7. With these parts glued and screwed, this completes the main cabinet.

The back should now be marked out and drilled in place. To complete the back all that remains is to cut the hole for the input panel, many types being available.

Attention can now be turned to the front baffle 5. This should be marked out for the screws and drive units af Fig. 10. KEF supply a template with the B139 and this should be used. The mid-range unit initially requires a 4½" diameter hole. With this cut out the KO40MRF can be dropped in and drawn around to mark out the rebate. Likewise if the Seas or Sonaudax tweeters are used an initial cutout as shown in Fig. 11 will be required. If the Isophon tweeter is used a 3" diameter hole will be needed. Whichever tweeter is used it can now be dropped in and drawn around for the rebate.

The rebates required for the drive units must now be made. A router is very useful here but if one is not available, it is only a short job to perform this operation with a chisel. All the drive units must be rebated so that they end up flush with the baffle surface. When doing this, do not forget that the fronts are handed, so you should end up with one front with tweeter on the left and mid-range on the right, and the other front should be the reverse (a mirror-image') of this. All the fixing holes for drive units should be drilled ¼" diameter, and the fixing holes for baffle drilled as before. Also required will be six holes to fix the grille frame, if used. These should be drilled for plastic grille fixing studs. The holes required for these are 3/8" diameter with 5/8" diameter counter-bore 3/32" deep. With this done the woodwork is complete apart from the grille frame, should it be required.

A grille frame should be made of ramin, a smooth, knot-free wood found in most D.I.Y. shops, the sides being of 1½" x ½", and the top and bottom 1" x ½". The grille frame should be 1/8" overall smaller in both directions than the size required, to allow for the grille cloth wrap-round. The frame is constructed with a simple halving joint as shown in Fig. 12. Holes should now be drilled for the other half of the fixing studs. They should be marked through from the front baffle in order to make sure that they line up. The holes required are 3/16" diameter with a counter-bore ½" diameter and 3/32" deep.

A touch of luxury can be added by making a small grille to house the polyester foam used in the port. This is of course not essential but does add an attractive appearance under the grille. It is made of 1" x ¼" ramin with mitred corner joints. This too has to be made 1/8" overall smaller to allow for grille cloth.

With all the wood work completed, the next job is the fitting of the various damping materials. Firstly the bituminous pads have to be glued in place. The fitting of these has been well covered in the theory of their use.

This can be followed with the carpet felt, the sizes of the various pieces as given in Table 4. When all the pieces have been cut they must be fitted, this being most easily done with a staple gun, but if one is not available ¾" carpet tacks are quite suitable. The carpet felt should not be compressed but fitted loosely to the sides of the enclosures. The pieces which fit into the side of the bass chamber should not have their corners cut off, but these corners should fold inwards, over the reflector. The quantities of long haired wool to be placed behind the carpet felt to form the corner radii are 1½ ozs. for two radii at the top of the first column and the rear of the second bend, and 1 oz. for the front of the second bend and the last bend behind the port.

The long fibre wool can now be fitted. On the subject of long fibre wool only the genuine article will work correctly. I am however aware of various other products sold, which are called long fibre wool, but are in fact *short* fibre wool and these must be avoided at all costs. To return to the fitting of the wool, the various quantities are shown in Fig. 5. The use of 'Netlon' (a nylon net material for gardeners which should not be confused with a similarly named fence mesh) makes the job very straight forward. Taking quantity 1 first, a piece of Netlon is stapled in to form the radius of the lower limits of this section. The wool is then well *teased* out, and placed within the constraints of the Netlon.

Moving on to quantity 2, a piece of Netlon is stapled to the partition, item 8, and to the top of the partition item 9. The quantity of wool is then placed in the compartment which has been formed by the Netlon and the compartment closed by stapling the Netlon to the sides of the cabinet. Ideally the Netlon should be stapled to the rear of the cabinet, but of course this is not possible, and no ill effects are caused by not doing so. To form the sections for quantities 3 and 4, a piece of Netlon is first stapled to the front side of the partition item 9, and quantity 3 is inserted. This section is then closed by stapling the Netlon to the lower edge of item 8, and quantity 4 is placed in. This section is then closed by stapling the Netlon to sides of the cabinet and the fitting of the long fibre wool is complete.

The next job is the internal wiring. A ¼" hole must be drilled in the front edge to one side of item 10 for the mid-range and tweeter wiring to pass through. The wiring should commence by cutting the various coloured wires to length, these are as follows. Bass 1½ ft, orange, mid-range 3 ft, blue, treble 3 ft, yellow and input 1½ ft, red. All of these will be accompanied with a similar length of green. If attenuator switches are used on the front baffle then an additional four 3 ft lengths each of yellow and blue will be required. The cut lengths of wire should now be soldered to the cross-over network. If fitted, the leads for switched attenuators should be soldered to the respective points marked A, B, C and D on the network circuit board.

The cross-over network is then screwed to the base of the cabinet. The various leads are for the moment left free.

The back and front baffles are now fitted. A layer of draught excluder strip should now be stuck round the battens to make an airtight seal for the back and front. The back and front may now be screwed into place. With this done the input leads are brought out through the hole for the input panel and soldered into place, the input panel then being screwed into place. In a similar way the leads for the respective drive units are brought through their holes and soldered into place, the drive units then being screwed into place.

There is personal choice in the extent and method of adding attenuator switches, if these are required, and the constructor with some experience of these things will have no difficulty in making a suitable arrangement by referring to the cross-over circuit and remembering that every further 2.4 ohms added in series with R1/R2 and R4/R5 changes the level by about 1.5 dB.

I cannot be specific here since it all depends on the type of switch offered by your supplier. However, Badger Sound Services supplies a pack of *all* the extra switching components needed and this includes detailed instructions on wiring their particular type of switch, prepared for the novice. The switches should be fitted to the front baffle in a convenient spot alongside the tweeter.

It only remains to place the piece of foam into the port mouth and you have a working speaker!

Now to the matter of finish. Firstly the grille frame construction has been described and this may be covered with a good quality grille cloth. This is stuck to the grille frame with impact adhesive as tightly as possible. In a similar way a covering is fitted to the small frame for the port grille if you have included this. It is advisable to paint the grille frame with a matt black paint or black stain before fitting the grille cloth, in order to prevent the wood showing through the fabric.

With regard to finishing the main cabinet, just about *any* form of finish may be used. Any one of many wood veneers can be used, the enclosures can be painted, covered with some type of fabric, or strange as it may sound, they can be wallpapered! The latter has been done very tastefully with one of the washable vynil papers, the choice is yours. The finish which I find most suitable for the plinth is eggshell black paint. This is suitably unobtrusive, whilst a little more attractive than a complete matt finish.

Hopefully by now you have a complete pair of speakers and are ready for switch on. There is no special way that the attenuators (if fitted)

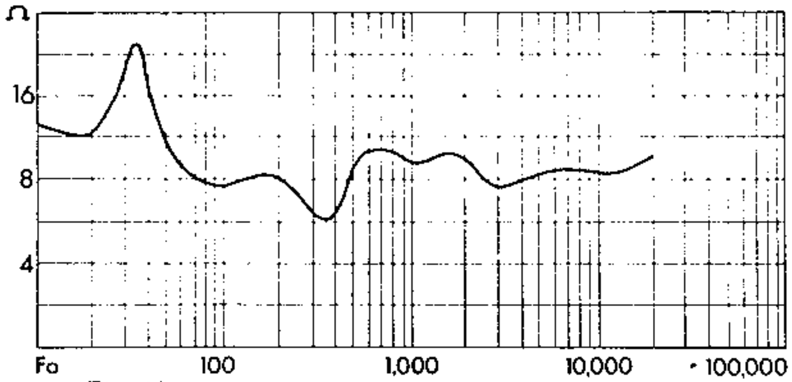


Fig. 13.

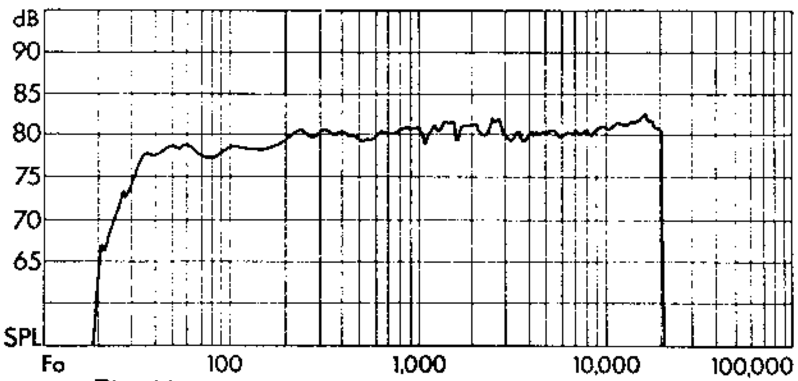


Fig. 14.

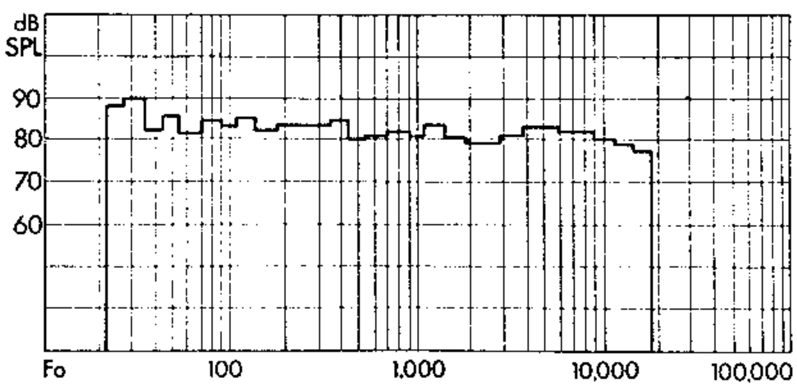


Fig. 15.

should be set. I would advise that you initially set both the mid-range and treble to the flat or 0dB positions and then listen. If you like what you hear then leave well alone. Should you however consider that the mid-range or treble is either too forward, or a little dim then adjust to personal taste. Also of course if both the mid-range and treble are raised or lowered together then this will have the effect of applying lift or cut to the bass.

With regard to room position, the speakers will tolerate any reasonable position, but here it is worth experimenting to achieve the most satisfactory stereo performance. Personally I prefer to position the speakers so that their axes cross in front of the listening position.

On the question of measured performance the impedance curve is shown in Fig. 13 and the free air response curve shown in Fig 14. Other parameters appear in the specifications, Table 4. These various measurements will of course give some indication of performance, but will *not* tell you how the speakers will compare with other leading brand names.

The impedance curve shown was measured in free air. This will differ when measured in a room, and will indicate a difference in the value of Q obtained. Q will usually reduce with reducing room size, and in this way the bass will become progressively more damped, so maintaining a comparable performance in different rooms. Fig. 15. shows a pink noise curve measured in my listening room from my listening position, with both speakers driven. This indicates a reasonably smooth response, falling with increasing frequency, a desirable and correct phenomenon.

I feel at this stage a few words regarding ancillary equipment would not go amiss. The speakers will work well with any amplifier of 25 watts or more, but as is common with most speakers, a transistor amplifier of 40 watts or more, or a value amplifier of 20 watts or greater, would be the most suitable. Amplifiers do without doubt have a very great influence on performance of *any* loudspeaker, and to this end a good valve amplifier is second to none. As it is not now possible to purchase valve amplifiers there is one make of transistor amplifier which comes close to the valve performance and I would recommend that the performance of not only the speaker in hand, but of *any* speaker will be better realised with a Naim amplifier.

On the subject of signal source, I do not think that from a domestic viewpoint it is possible yet to better the record, and to this end good disc reproduction equipment is required. It is quite evident that turntables *do* affect the sound to a large extent, from the point of view of obscuring information, and to this end I would recommend a Linn LP12 as the turntable most capable of minimizing these losses. Allied to this a good *moving coil* cartridge will also enable the maximum information to be extracted from the grooves. My own favourite is the Supex 900 mounted in a Grace arm.

These recommendations are made in the light of listening for many months and represent my own idea as to the ultimate presently available, but I would not wish to deter anyone who does not have or cannot afford the above mentioned equipment from building these speakers. Quite the contrary in fact, for I feel that the speakers will realize the potential of any equipment.

During development I have made many experiments and I feel that all the critical areas have been covered, No doubt there are constructors who will feel the urge to vary things and to you I would say "go ahead", as only in this way can we achieve any improvement. I will of course be glad to answer any correspondence on the matter, but *I am not able to predict the result of all experiments and I would like to make this quite clear.*

Finally for those who do not wish to make the cabinets, but would like to have the speakers, a supplier of cabinets has offered to make these available.

It only remains for me to wish potential constructors luck with the project, and to hope that these speakers bring other constructors as much pleasure as they have given me.

TABLE 1

	Peerless KO40MRF R1 & 2	Seas D86H (R4 & 5)	Isophon KK8 & Sonaudax HD12.9D25 (R4 & 5)
+3dB	0Ω	0Ω	
+1.5dB	2.4Ω	2.4Ω	0Ω
0dB	4.7Ω	4.7Ω	2.4Ω
−1.5dB	7.1Ω	7.1Ω	4.7Ω
−3dB	9.4Ω	9.4Ω	7.1Ω

2.4Ω = 2.4Ω   7.1Ω = 2.4Ω + 4.7Ω

4.7Ω = 4.7Ω   9.4Ω = 4.7Ω + 4.7Ω

TABLE 3

CARPET FELT SIZES

Base and Reflector	12" x 17"
Bass Sides	13" x 15" (2 off)
Bass Top	12" x 9"
Rear Sides	6" x 16" (2 off)
Rear Sides (top)	5½" x 11" (2 off)
Rear Top	12" x 16"
Base of last duct	12" x 15"
Last bend (behind port)	12" x 8"

TABLE 2

MATERIAL AND COMPONENT LIST

1¼ sheet	18mm Medium Density Chip-Board
¼ sheet	12mm " " " "
20mtr.	1" x 1" Soft Wood Batten (planed)
3mtr.	3" x 2" " " " "
4mtr.	1½" x 1½" Ramin
1½mtr.	1" x ½" "
2mtr.	1" x ¼" "
	Ramin Lipping
400	1½" x No. 8 Wood Screws (countersunk)

Evo-Stick Resin W Wood Adhesive

¾" Carpet Tacks or Staples

Evo-Stick Impact Adhesive

25sq. ft Carpet Felt (not the foam type)

2pkt Draught Excluder Strip

1pkt Netlon Gardeners Netting

1ltr. Aquaseal No. 5

2-KEF B139	6amp cable as follows:
2-Peerless KO40MRF (special)	2yds Yellow
2-Isophon KK8	2yds Blue
or Seas D86H	1yd Orange
or Sonaudax HD12.9D25	1yd Red
2-Cross-Over Networks	5yds Green
2-Input Panels	*4yds Yellow*
2lb.-Long Haired Wool	*4yds Blue*
15-Bituminous Felt Panels	*4-wafer switches*
12-Grille Fixing Studs	*4-knobs*
Grille Cloth	
16-'T' Nuts	

All the above items in italics are optional

Cabinets may be obtained from:

Nippro Acoustics,
101, Westridge Road,
Southampton. SO2 1HJ.
Telephone: 0703 551279

TABLE 4

SPECIFICATION LIST	
Size	38" high - 13½" wide - 17½" deep 965mm x 343mm x 445mm
Weight	80lb. (36kg.)
Nominal Impedance	8Ω (see curve)
Maximum power handling	150watts - music and speech
Continuous sine wave	50watts rms.
Sensitivity	84dB SPL for 1watt in
Frequency Response	35Hz – 22kHz ±3dB (see curve)
Enclosure Type	Acoustic Labyrinth
Drive Unit Bass	KEF B139 SP1044
Mid	Peerless KO40MRF 8Ω
H.F.	Isophon KK8 or Seas D86H or Sonaudax HD12.9 D25 8Ω
Cross.Over	16 elements 18dB/octave @ 460Hz & 3.4kHz
Adjustments	±3dB Mid-Range and Treble
Distortion	
Amplifier Requirements	20watts to 150watts. Optimum Minimum 40watts transistor or 20watts valve
System Resonance	38Hz Q = 0.7 (free air)
Finish	Optional

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