A horn-loaded loudspeaker system

Horn-loaded loudspeaker systems are at present not as popular as sealed or reflex systems, but there is no doubt that they will always have dedicated adherents. The author of this article is very enthusiastic about the system he has developed, which is the product of many years of experiment. While not necessarily agreeing with all of his design philosophy, we present the article for the benefit of those who would like to try out this type of system.

by MALCOLM D. McLEOD*

A good loudspeaker system requires the least imagination on the part of the listener. In this article, it is intended to show the main problems and deficiencies of loudspeakers, and details will be given which if closely followed will give superb results.

The requirements in order of importance are:

a. Low distortion.
b. Freedom from serious peaks and dips in the frequency response.
c. Reasonably wide frequency response.

Let us look at the mechanics of a cone loudspeaker. The paper cone is driven at its apex by a voice coil, and in turn the cone drives the air, i.e., if instantaneously the cone moves forward, the pressure at the front is high and at the back it is low.

As the cone is not absolutely rigid, it does not exactly follow the driving force from the voice coil over the whole surface of the cone, and furthermore resonances within the cone are excited over its whole surface.

The result is that much of the energy now supplied to the air is in the form of frequency components which were not supplied by the voice coil.

This is most severe on transients, and leads to "edgy" reproduction. Let us delve a little deeper. The paper cone of a loudspeaker has a high mechanical impedance, i.e., press it with your fingers — it is relatively hard to push. Now the air it is trying to couple to, has a low mechanical impedance, i.e., it is easy to push. The result is that they are sadly mismatched to each other. If we were to introduce an acoustic impedance transformer to match the high impedance of the speaker cone to the low impedance of the air, we would receive many benefits.

1. A great improvement in the efficiency of converting the electrical signal in the voice coil to acoustic output.
2. By matching the cone more accurately to the air, i.e., presenting the cone with a high mechanical impedance load, the development of spurious resonances over the surface of the cone will be discouraged, and much cleaner reproduction will result.
3. A further gain which will result is that due to the overall increase in efficiency, less input is now required for the same acoustic output, resulting in a further reduction of distortion.

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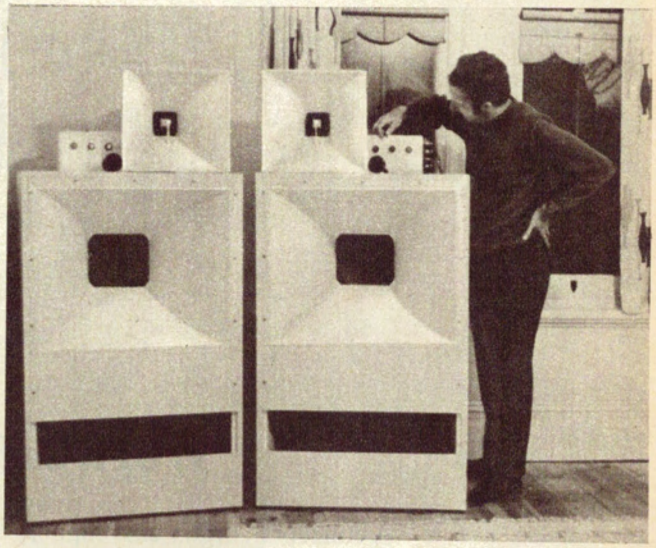
A correctly designed exponential horn is a mechanical impedance transformer.

As most of the information we hear, and of which we are the most critical, occurs in the mid-range, this is where we should start. Therefore the problem is to design a mid-range horn which must have no "character" of its own. It must be completely neutral.

Looking at the overall requirements, 400Hz has been chosen as the most suitable crossover point from the bass speaker. The mid-range horn has therefore been designed for a mouth cut-off of 300Hz which allows ample overlap.



The author shown with two of the loudspeaker systems described in this article. The treble units and crossover networks are alongside the mid-range horns on the top of the bass enclosures.

A total of 21 different mid-range horns were built, the one to be described giving subjectively the best results. It can be truly stated that this unit is quite uncoloured and very clean on all types of program.

Having chosen this as the best design, a duplicate was made, and arranged to switch from one to the other. In this way, one could be compared with the other using different speakers as drivers.

Being connected with the trade, dozens of types of speakers were available for test, and the final choice is a Rola C64G oval speaker. The fact that this is a very inexpensive speaker is irrelevant. It has been chosen on its merits.

One problem was that the high frequency range of the speaker became restricted when put in the horn, and on listening tests left a gap between the top of the mid-range horn and the bottom range of the treble unit.

As this appeared to be a cancellation problem in the throat of the horn at high frequencies, a series of phasing plugs were tried in the throat and compared with the other horn.

With the phasing plug shown, the problem was entirely cleared.

Frequency response measurements made on this horn show fairly bumpy results — nothing to indicate why it sounds musically so much better and cleaner than a variety of mid-range direct radiators, some of these units giving a smoother frequency response.

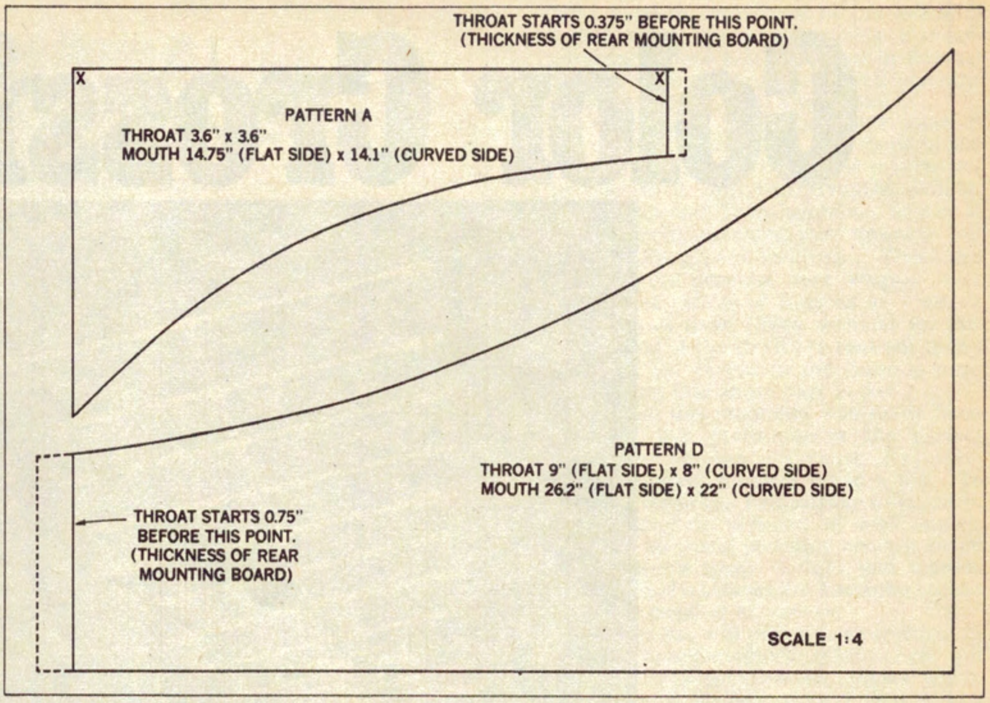
After months of listening, I can only conclude that of all the qualities we can talk about regarding loudspeakers, frequency response is NOT the most important.

It becomes increasingly obvious that a low distortion is the first requirement, and while difficult to prove this point scientifically, the audible improvement with the horn is obvious.

What came as a quite unexpected side effect was a very noticeable reduction in the intensity of clicks and plops from the surface of discs. This helps to support the theory that the increase in the mechanical impedance of the air load offered to the cone by the horn, discourages spurious cone resonances.

Construction of the horn and rear compression chamber is from 3/8" flakeboard. A sheet 6' x 3' will make a pair. Opposite sides of the horn are identical. From pattern A, make a cardboard template. When put on the flakeboard and a pencil run around the template, this will give half a top. The template must now be turned over so that the same edge lines up with the line along x-x, and the pencil run around again.

Repeat this operation three times for two



Templates for the mid-range and bass horns. Both are for only half of a top or bottom, and must be turned over to produce the full outline. They are reproduced here one-quarter actual size. Pattern A is for the mid-range horn, and pattern D for the bass unit.

tops and two bottoms. Cut two pieces according to pattern B. These are the rear mounting boards.

Top and bottom and rear mounting board are glued together as in figure 1. A pair of nails driven into the bench top each side of the top and bottom will locate them while the glue dries. These locating nails must be placed so that the internal space between the top and bottom is 14.1".

It will be necessary to adjust the angle of mating surfaces at points M.

When dry, the sides can be built up. These curve all the way and are made from strips of the same material cut 1" wide and glued and bradded. The angles of adjoining surfaces should be adjusted to fit each other and each face should be flooded with Aquadhere cement and pressed together and a brad driven in each end.

When completed and dried, use a coarse sandpaper to round the curved sides of the inside of the horn. All cracks should then be filled with "Agnews" water putty, which when cut back will give a smooth surface ready for finishing.

Build the box onto the rear mounting plate with internal measurements of 8¼" x 8¼" x 3". A removable back is screwed onto the back of the box and lined with 1" absorbent. The speaker is mounted with the long dimension vertical.

The phasing plug which is of square section, is made to pattern C and centrally mounted with about ⅛" clearance from the centre of the loudspeaker cone. The wide end of the phasing plug is nearest the cone.

All surfaces should be undercoated before finishing coats are applied.

Construction of the bass horn is the same in principle as the mid-range horn, this time using pattern D.

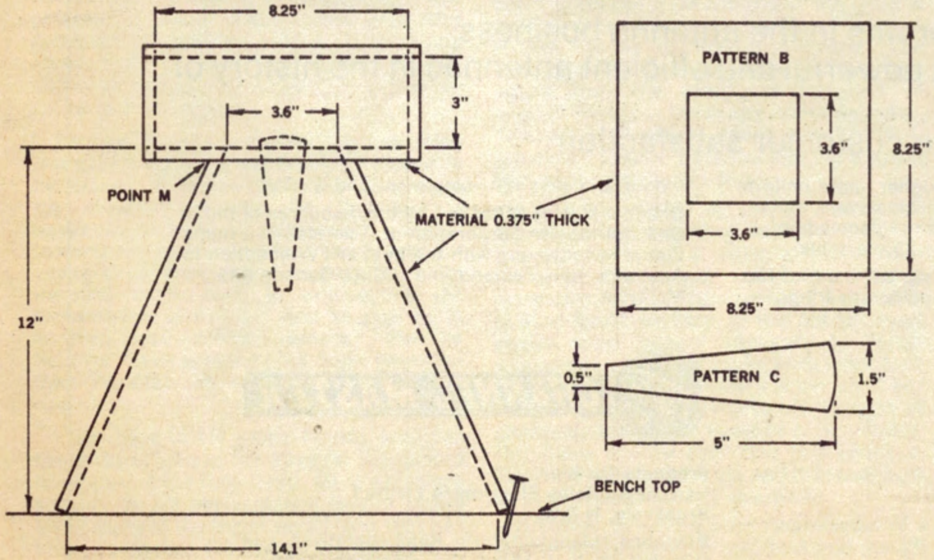
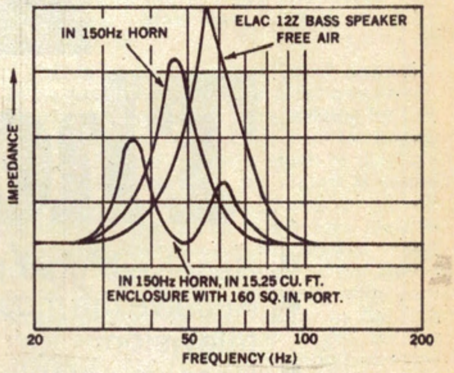


Figure 1: Dimensions of the various parts used to make up the mid-range horns. The diagram on the left is in effect a vertical cross-section through the horn. Pattern "C" is for the HF phasing plug.

The diagrams give all measurements for construction of the main cabinet. Three quarter inch flakeboard is used for both the horn and cabinet. All parts of the cabinet are glued and nailed together, the only removable part being the horn itself. The part which is 6" x 28½" is left open. All internal surfaces must be lined with 1 inch absorbent such as bonded acetate fibre.

The internal volume of the cabinet is



Curves illustrating the effect of the bass horn and enclosure, using a fairly typical 12-inch speaker unit.

about 15 cu.ft. This is necessary to obtain high efficiency in the low bass range in keeping with the high efficiency of the upper bass range due to the horn loading.

Sweeping down from 400Hz with a signal generator, the response is smooth, and full efficiency is maintained to 32Hz, below which frequency doubling starts.

No internal bracing is required. The shape of the cabinet gives ample strength. Furthermore, instantaneous pressures are not high due to the large cabinet volume.

Do not attempt to simplify construction by making the back of the cabinet straight. This is a refinement on an earlier model to reduce the average depth front to back and improve tuning.

There is no tendency at all for male voices to be boomy. At the same time, when there is low frequency energy in the program results are smooth and full. I cannot imagine any conditions ever needing bass boost. If the condition did arise I would suspect the amplifier or pickup. Wonderful definition is heard in the bass instruments on good records — alas, not all records are good.

Regarding bass speakers, most suitable types will have resonances between 45 and 60Hz as a generalisation.

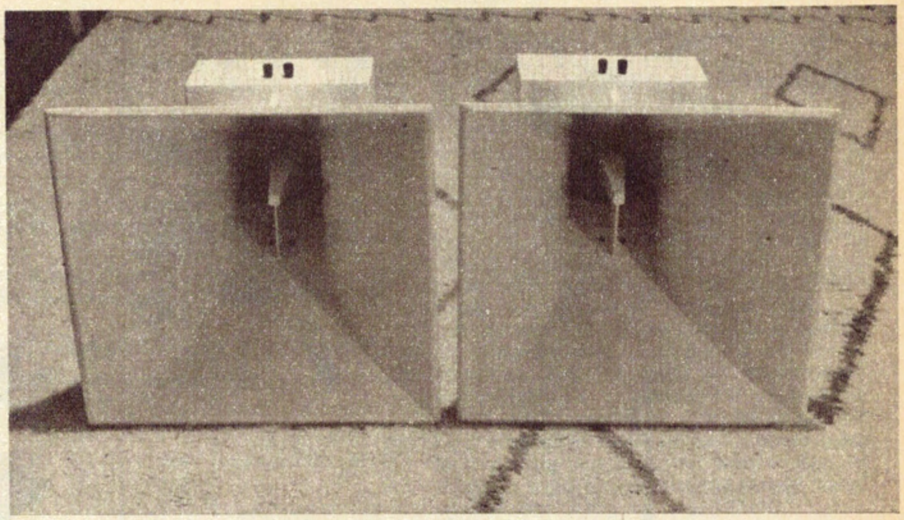
The long throw, very low resonance types are quite unsuitable.

Best results in order of preference were from the following types. They are all 12 inch units. Elac 12z, MSP 12UA, Rola 12PEG or 12PX. However, these are only mentioned as a guide. Other types may be found equally suitable.

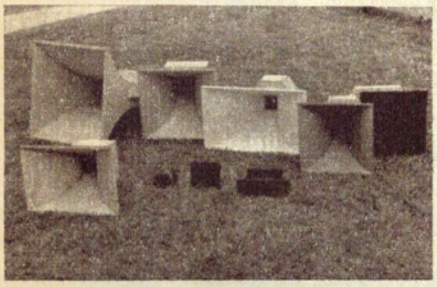
Many high frequency horns were tried, and in my opinion the Goodmans Trebax 100 is the most suitable. It is interesting to note that this same unit can sound completely foreign in a direct radiator system. In this all horn system the overall blend is very good.

Crossover between each speaker is at 400Hz and 5000Hz and the slope rate is 12 dB / octave.

All capacitors in the crossover network must be non polarised, with preference for paper dielectric. Good non-polarised electrolytic capacitors may be used for C1, but not for C2. This item should be paper or plastic dielectric. The use of back to back electrolytic capacitors is not recommended.



A picture of the prototype mid-range horns, to indicate how the reader's horns should appear when completed. Note the HF phasing plugs.



A selection of horns made by the author during the evolution of the design described on these pages.

All coils are air wound on formers made from 1 inch broomstick with masonite or plywood ends. Dimensions must not be changed and wire should be 18 B and S enamel or a little heavier if on hand.

Glue the cheeks to the 1 inch dowel and secure with a brass screw.

Normal steel screws must not be used. Layout is not critical but coils should be spaced by not less than 3 inches.

As the high frequency range of the mid-range horn does not extend beyond 5KHz, no restriction on the HF range is necessary in the crossover network.

The values of L1, C1, L2 and C2 are selected from the chart according to your choice of 8 or 15 ohm speakers.

In case of the use of a Trebax 100 HF horn which is only available in 15 ohms, it is quite in order to place a 16 ohm resistor in parallel with it and treat it as being 8 ohms from the point of view of crossover design and bearing in mind that this has reduced its sensitivity by approximately 3dB.

In the crossover circuit, 3 resistors appear in the mid-range circuit and the same in the treble circuit.

These form an attenuator of constant resistance, and from the chart the appropriate resistor values are chosen for the degree of attenuation required at the impedance you have used.

Although exact values of resistors are

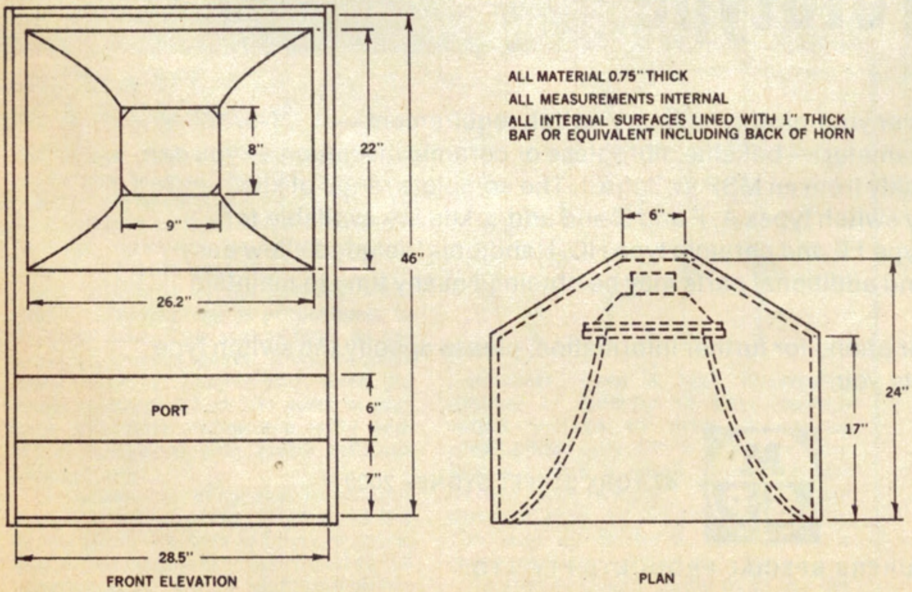
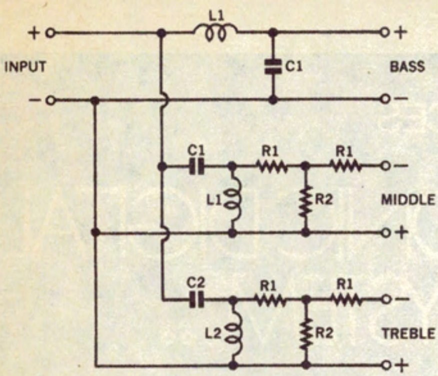


Figure 2: Details of the bass enclosure, which uses horn loading down to 150Hz, and becomes a reflex system below this frequency. Note the "chamfered" cabinet back, important for its tuning.

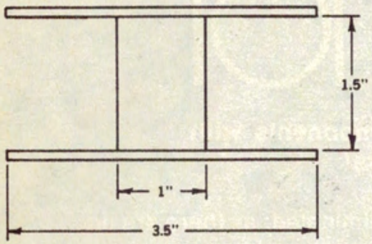


	8 OHM	15 OHM
L1	4.3mH	8.5mH
L2	0.36mH	0.67mH
C1	32μF	16μF
C2	3μF	1.5μF

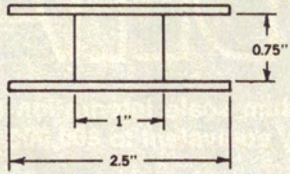
ATTENUATOR RESISTORS

dB ↓	8 OHM SYSTEM		15 OHM SYSTEM	
	R1	R2	R1	R2
2	0.92	34.4	1.73	64.5
4	1.8	16.8	3.4	31.5
6	2.6	10.7	5	20
8	3.5	7.5	6.5	14.2
10	4.2	5.6	7.8	11

ALL VALUES IN OHMS



4.3mH = 460 TURNS 8.5mH = 600 TURNS



0.36mH — 120 TURNS 0.67mH — 160 TURNS
18 B & S ENAMELLED WIRE FOR ALL COILS

Figure 3: Details of the crossover network for the system, including resistor values for the equalising attenuators.

shown, it is not implied that this degree of accuracy is required. Ten percent variations are quite permissible. Many of the values will not be available as such and will need to be made up from combinations. Use resistors of 1 watt rating or higher.

Regarding values of capacitors C1 and C2, 20 percent tolerance is in order.

In the case of the prototype, 6dB attenuation is used on the mid-range and 4dB on the treble.

However if your bass speaker is of a different sensitivity, the attenuation of the mid-range and treble will need to be altered.

Room absorption can have a marked effect so only regard the suggested attenuation figures as a guide.

As a further guide, assume you are building an all 8 ohm system. You will be making 4 coils of 4-3mH and 2 coils of .36mH.

Using 18 Band S enamel wire, you will need approximately 6 lbs.

When connecting speakers to the crossover network observe the polarities.

It will be noticed on the crossover circuit the opposite connections to the bass speaker compared to the mid-range and treble. Due to phase shift in the crossover network this is necessary so that they are acoustically in phase at the crossover point.