

A Non-resonant Loudspeaker Enclosure Design

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—USING ACOUSTIC TRANSMISSION LINE WITH LOW-PASS FILTER CHARACTERISTICS

OVER the years, the design of loudspeaker units has progressed steadily until some are now available with very good performance capabilities. In particular, the advent of expanded polystyrene as a cone material has greatly reduced the distortions due to cone break-up.

Unfortunately, the design of loudspeaker cabinets has not kept pace with these developments, and there is little doubt that many enclosures now introduce more coloration than that produced by good loudspeakers. The loudspeaker enclosure to be described was developed to give as little coloration as possible, but to understand its evolution it is necessary to return to basic principles.

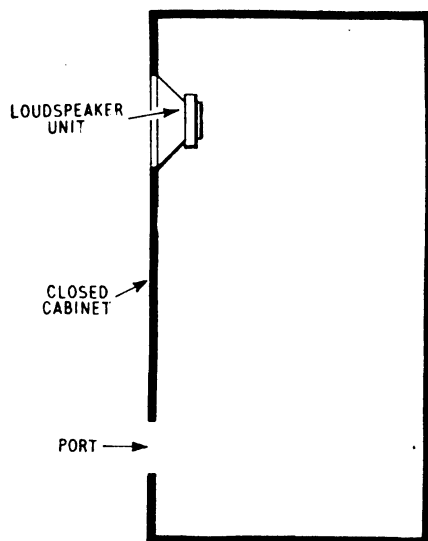


Fig. 1. Section through bass reflex cabinet.

By far the largest number of current loudspeaker cabinets are based on the "bass reflex" cabinet design. This is shown in Fig. 1 as a sectional view. This cabinet appears to have only a relatively short path-length between the back and the front of the cone and would therefore be expected to give relatively poor l.f. response. In fact the response at low frequencies can be quite large, this being due to the cabinet having a Helmholtz air-column resonance at about the lowest frequency being reproduced. In the reference given previously, the theory is well explained.

Unfortunately, this resonance in the cabinet causes coloration in the bass output of the system. This "ringing" or bass transients can be very noticeable, particularly on such instruments as string bass.

In addition the cabinet itself is frequently unlagged and consequently the sound is still emerging long after the original signal has stopped. Very heavy lagging is

necessary to stop this effect and in so doing the cabinet "Q" is reduced so that the bass reflex action is lost.

Sine-wave testing does not necessarily show up the defects of a speaker system. Rapid cut-off at the edges of a flat response can make it sound far worse than a slower rate of fall at the edges of a system with apparently a poorer bandwidth. This is shown in Fig. 2.

The effect of the abrupt change in slope of the amplitude/frequency characteristic is to give "ringing" at the frequency where the slope change takes place. This effect is unavoidable and is the necessary price to pay for the extension of bandwidth by the use of resonance effects. It is for this reason that loudspeaker systems can sound very "boomy" in the bass, even though the measured amplitude response shows no resonant peaks.

One method of testing that has not apparently been widely used is that of impulse-testing of loudspeaker cabinets. This method is very powerful and is described later on. For the moment it is sufficient to state that it confirmed that normal loudspeaker enclosures are not very good.

It is now apparent that it is the sound waves produced at the rear of the cone that have to be absorbed if delayed output and resonances are to be avoided.

Acoustic labyrinths² have been used in the past in an attempt to "lose" the sound down multiple paths. Such an enclosure is shown in Fig. 3, but the size needed is excessive. Unless there is adequate internal lagging, then these cabinets will also possess pronounced energy storage and the consequent lack of sound clarity.

Transmission line approach

The only safe method of removing the rear cone sound energy is by transmitting it down an infinite transmission line. This is obviously impracticable so the nearest approximation was examined.

If a transmission line for acoustic waves is filled with

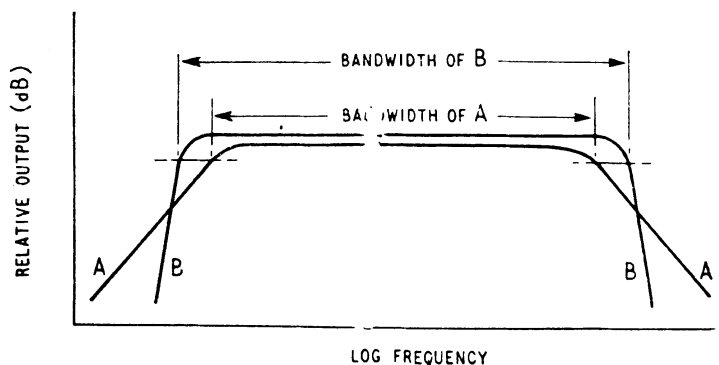


Fig. 2. Response curves having different transient responses.

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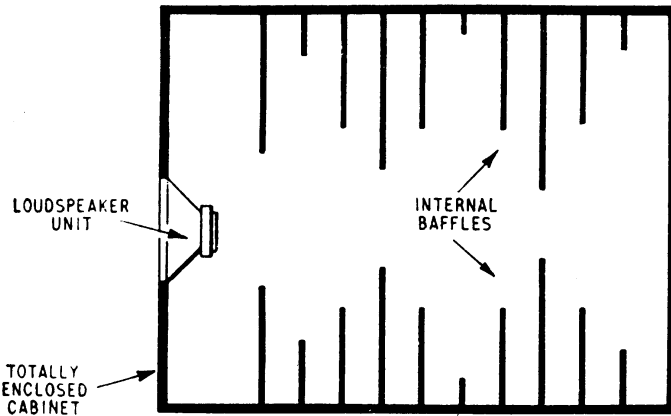


Fig. 3. Section through acoustic labyrinth cabinet.

a light acoustically-resistive medium, then the transmitted wave will be rapidly attenuated. After a certain distance the wave will be so weak that a blockage of the line will give only a minute reflected wave back to the speaker cone. The magnitude of the reflected wave can be determined by the standing-wave ratio immediately behind the speaker.

The choice of acoustic absorbing material will greatly affect the final performance so an initial investigation was made into the reflecting properties of various acoustic transmission line terminations. Many materials including glass fibre were tried, but the best results were obtained from long fibre wool. This gave a remarkably good absorption down to quite low frequencies. A typical set of the curves obtained is shown in Fig. 4.

For practical purposes a long pipe is not desirable so experiments were then made with a folded pipe of total length of about 8ft. This was built as shown in Fig. 5, the far end of the pipe having a pivoted flap so that characteristics could be taken with both open and short-circuit terminations. The results proved most interesting.

With the port closed the loudspeaker gave a very good

performance with a slightly weak bass response. Since-wave testing confirmed that the bass response fell by several dB below 60 c/s although the cone amplitude doubled for a halving of the input frequency. The trouble was finally traced to diffraction effects, the radiated wave-front changing its polar response at low frequencies. The effective bass response could be changed very markedly by positioning the cabinet away from a wall. The bass response then fell even further due to the increased diffraction at low frequencies. For test purposes a plain wall backing was used.

Opening the port had two effects. First, the bass response was improved to become approximately flat and secondly the cone excursion was greatly reduced between 30 and 50 c/s. The bass improvement was due to the line length being such that the delayed bass wave from the line was in phase with that radiated by the front of the cone. Also as the bass frequencies were radiated from two spaced sources, the diffraction effects would be reduced.

As the wool-filled line acts as a low-pass filter, the radiation from the vent cuts off before cancellation can occur at the higher frequencies. The rapid cut-off of this acoustic line is shown in Fig. 6. This shows the sound pressure at the port end of the line with the port closed.

Impulse response

As the performance so far appeared to be satisfactory it was decided to investigate the impulse response of the loudspeaker cabinet. The square-wave testing of loudspeaker units had previously shown that it was not possible to generate a good square-wave of sound pressure, let alone an impulse. Several mechanical methods were then tried but none proved to be really satisfactory. The author is therefore indebted to his colleague, R. V. Leedham, for suggesting the use of exploding wires as a standard impulse source.

Exploding wires proved to be a delightfully simple and accurate method of generating an acoustic impulse.

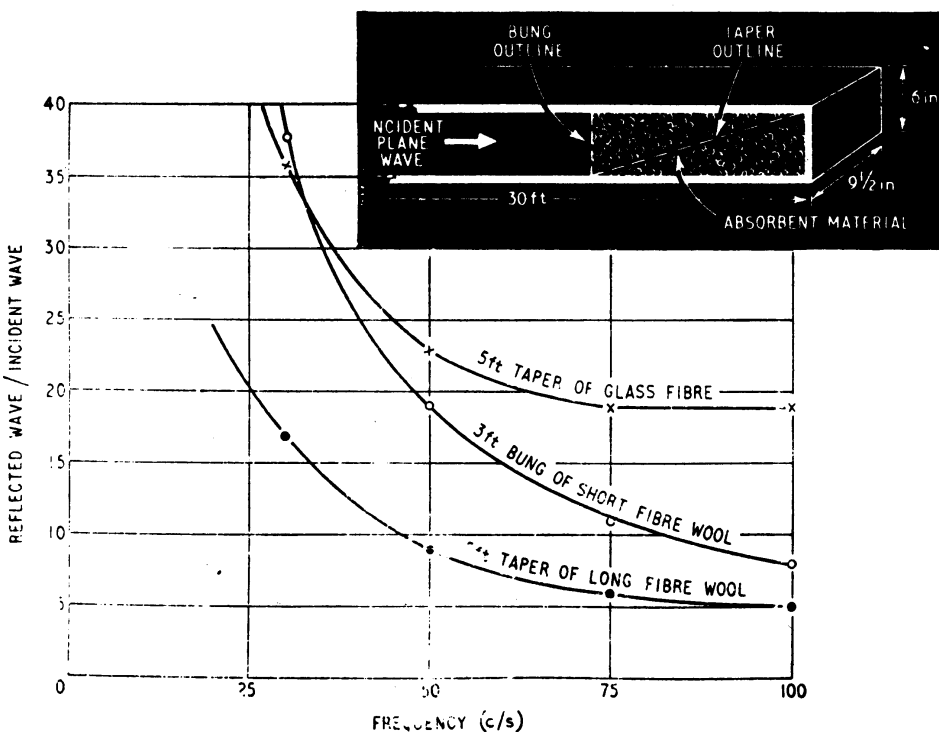


Fig. 4. Reflection characteristics of acoustic absorbers.

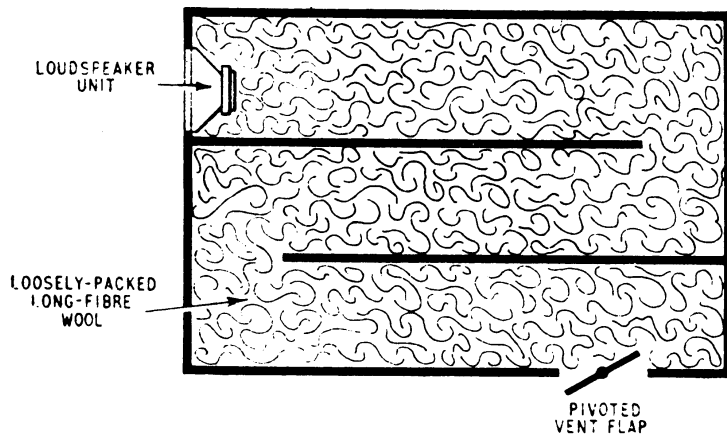


Fig. 5. Experimental acoustic transmission line cabinet.

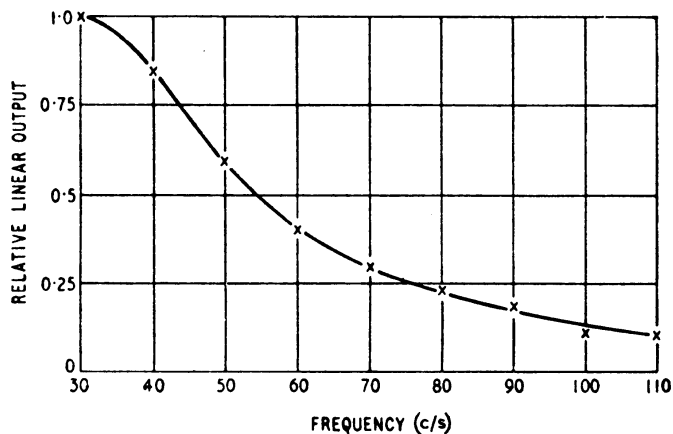


Fig. 6. Sound pressure in closed vent of experimental cabinet.

Basically the method involved discharging a low inductance capacitor of high value (1000 μ F) charged to about 250 V through 1 cm of 40 s.w.g. tinned copper wire. The wire is vapourized almost instantaneously and the acoustic impulse produced had a rise time well into the supersonic region. Spark-generated impulses could have been used, but a high-voltage source is necessary of considerable stored energy if an adequate impulse is to be produced. As exploding wires were less lethal experimentally and only needed standard power supplies, the use of a spark source was not pursued.

The measuring microphone used had a working bandwidth of 30 to 10 kc/s and was used inside the cabinet at a distance of 18 in from the exploding wire source. The exploding wire was operated at the position where the loudspeaker would be used, the loudspeaker opening being blanked off.

The results appear in Fig. 7a, the initial impulse being just discernible. The results were felt to be very creditable, the large damped oscillation being the flexure of the $\frac{1}{2}$ in blockboard immediately behind the exploding wire. The experiment was then repeated with a bass-reflex cabinet of identical size having a port area of some 24 in² and unlagged internally. The results were markedly dissimilar. Acoustically a much louder hollow explosion could be heard and the microphone pickup showed a far larger spurious output for a much longer time. This is shown in Fig. 7b, the sensitivity and time scales being identical with that of the previous test.

The cabinet was then lagged internally with sound absorbent and the test was repeated. The result is shown

in Fig. 7c, the resonance obviously being better damped but still far worse than the line type of cabinet.

Listening tests proved that the cabinet had a "cleaner" sound than the bass reflex type, the effect of the line being very noticeable in its lack of coloration on speech. Transient response was definitely better on the line speaker, the sound being more "tight" and natural.

For obvious reasons it is preferable to have the long axis of the loudspeaker in the vertical plane. The cabinet ducting arrangement was therefore rearranged and one commercial form is as shown in Fig. 8. To make the most of the cabinet it is obvious that the loudspeaker units must not possess large colorations of their own. The units quoted give very good performance although other equally good units may be available. The cross-over frequency used is 1500 c/s.

The frequency-amplitude response of the complete loudspeaker system is shown in Fig. 9. The rate of

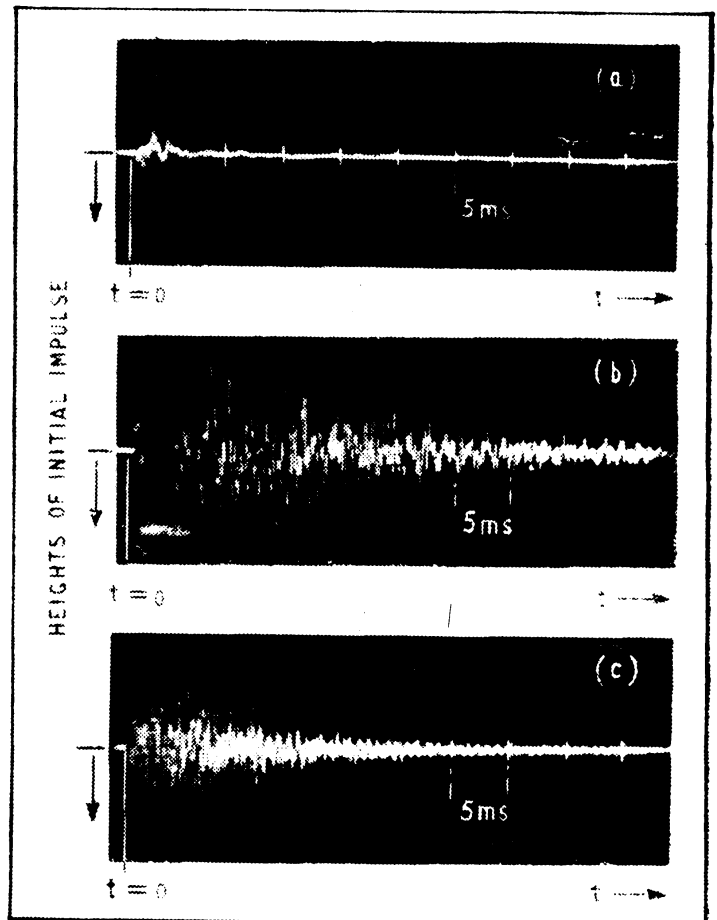


Fig. 7. (a) Impulse response of acoustic transmission line loudspeaker cabinet. (b) Impulse response of bass-reflex cabinet identical in volume to (a). (c) Impulse response of bass-reflex cabinet with internal lagging.

fall at the low frequency end is creditably slow and far better than the majority of systems in use. It is not unknown for rates of cut-off to be as high as 18 dB per octave and to start very rapidly. This gives rise to a "heavy" bass effect that some people prefer; it is, however, not natural.

The bass resonant frequency of the speaker unit is below 15 c/s in the enclosure (about 30 c/s in free air) and quite well damped, so this will have no noticeable effect on the output. As the acoustic loading of the pipe

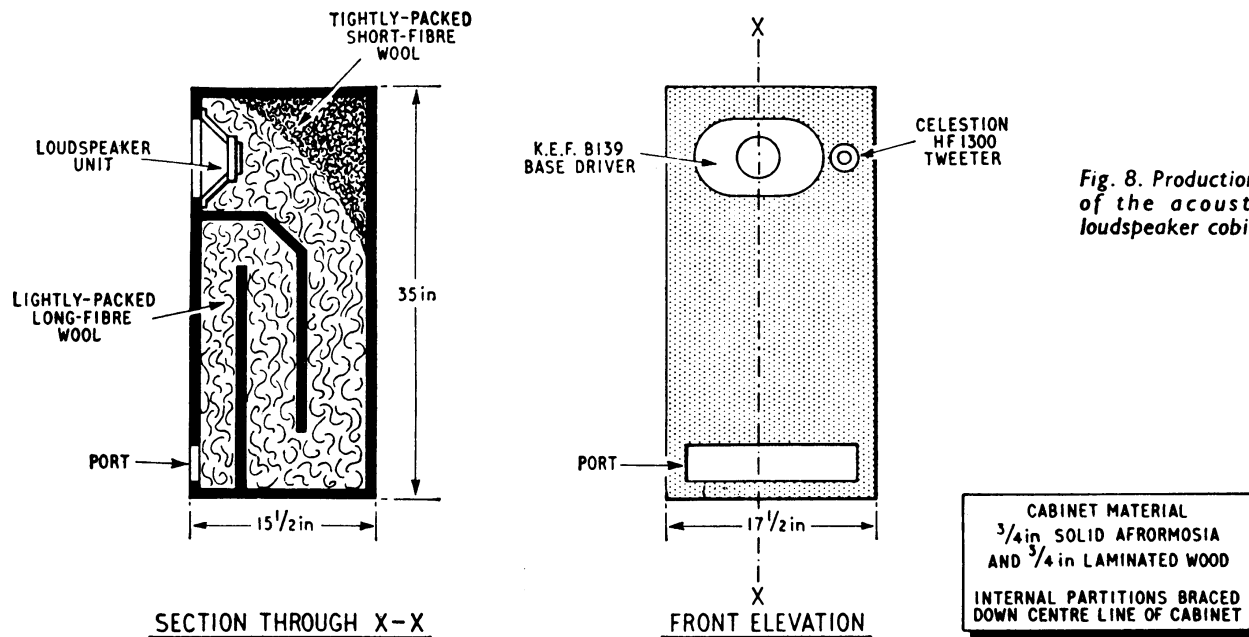


Fig. 8. Production version of the acoustic-line loudspeaker cabinet.

is, therefore, dominating the speaker unit, the low-frequency waveform will be better as the non-linearity in the loudspeaker unit suspension will be swamped by the linear acoustic loading.

The final subjective tests were very good. The sound quality is effortless and natural. At first hearing the bass sounds to be deficient but extended tests show that this is not so, it is merely that one has been conditioned to hearing resonant bass. The overall effect is surprisingly unexciting—only natural. In over a year's use of the system the author has noted, however, that musical listeners were very impressed with the result.

Practical Points

The cabinet design is not critical, and many variations are possible. The only cardinal point is that of keeping the pipe area above that of the cone. A rather strangled result can occur if an attempt is made to save space by restricting the pipe area much below that of the speaker cone. It must also be noted that a poor speaker does not usually sound much better in a good cabinet as the speaker deficiencies dwarf the improvement.

The application of the principle of the design is the subject of a Patent, but there is no restriction, of course, on private individuals making cabinets for their own use. For the amateur constructor the following points may be of use:—

(1) The cabinet should be made of thick acoustically dead material, chipboard being generally better than plywood. Due to the absence of high internal pressures

and the absorbing effect of the wool, the cabinet thickness and bracing are not as important as in the case of the bass-reflex.

(2) Acute bends in the pipe should be arranged to occur as far from the loudspeaker cone as possible to reduce the magnitude of standing waves due to reflections.

(3) The wool should be of long fibre length and packed fairly loosely, about one pound to every two to three cubic feet. The grade of wool is still being investigated for the optimum specification.

(4) Either spray the wool with mothproofer or take other suitable action or the cabinet performance may suffer from an ageing process.

The author has constructed several different cabinets of totally different sizes and geometry, and apart from narrow pipes and badly angled bends the performance has been remarkably similar. In fact a low resonance 4in unit has been used effectively and gave a good output at 35 c/s. The power handling capacity was, however, limited.

Acknowledgements.—In conclusion the author would like to thank Radford Electronics Ltd. for permission to give the details shown in Fig. 8. Also thanks are due to R. V. Leedham and other colleagues for their help and criticism.

REFERENCES

1. "Sound Reproduction" G. A. Briggs, p. 62.
2. *Ibid*, p. 56.

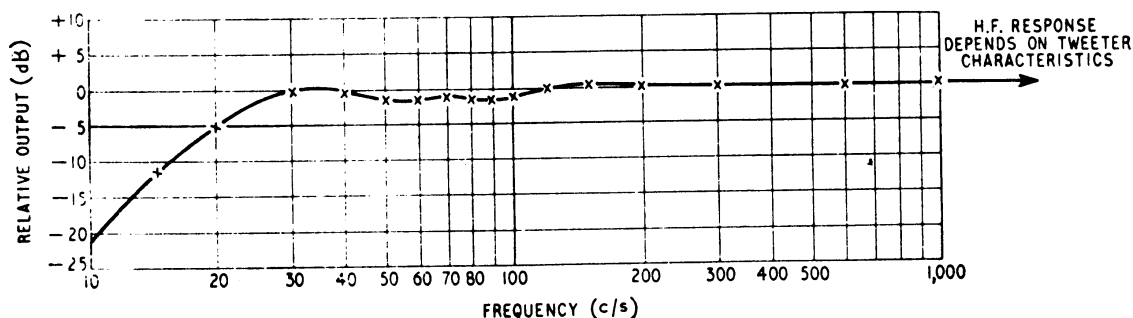


Fig. 9. Overall sine-wave response of Fig. 8.