COLUMN LOUDSPEAKER DESIGN

The column loudspeaker is an example of a directional sound source which is of special use if acoustic feedback is a problem; it is most commonly found in sound reinforcement or public address applications. David Hornsby describes a novel design that can be made at a fraction of the cost of its commercial equivalent.

A standard loudspeaker tends to radiate sound in all directions, both forwards and backwards. It is helpful to look at this sort of response on a polar diagram (Fig. 1); the circle round the sound source shows that the sound loudness is about the same in all directions. If the loudspeaker is now placed in an enclosure then sound is allowed to radiate forwards only and we have a 'unidirectional' source. The polar diagram for it in Fig. 2 shows a balloon-like shape for the sound radiation pattern, which now covers an angle of slightly less than 180°. The dotted line shows the response if the enclosure lets a little sound out backwards.

If polar diagrams are new to you, these two diagrams will probably have given you a fairly good feel for what they are all about. They are similar to the contour lines on a map, but instead of showing height they show the sound intensity or loudness. The further the line on the polar diagram is from the sound source at the centre then the louder the sound is in that direction.

One-Way Sound

The unidirectional sound source is the one most of us use in our homes and cars but it's not very good for live performances where the microphone(s) is in the same area. Diffraction effects, echoes and reverberations all help to spread the sound back from the loudspeaker to the microphone so that as soon as the sound is turned up, positive feedback makes the system oscillate and howl.

There are one or two different solutions to this problem but the most common and probably the best is to use a highly directional sound source. This tends to concentrate the sound into the area where it is needed, the audience, but well away from the microphone.

One type is the horn loudspeaker which has good directional properties and is also very efficient electrically. Unfortunately it has to be physically large to be effective at low frequencies. The fog horn at your local lighthouse (you do have one, don't you) and the PA in a cinema have space for large horn

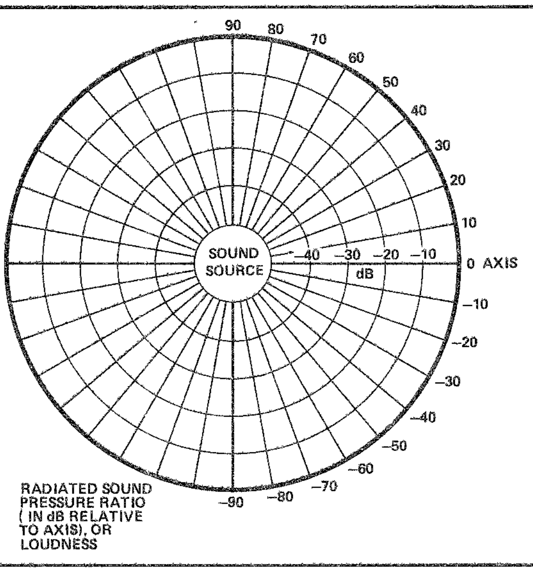

Fig. 1 Polar diagram of a sound source which radiates equally in all directions (approximated by an unmounted loudspeaker). The sound source is at the centre of the diagram.

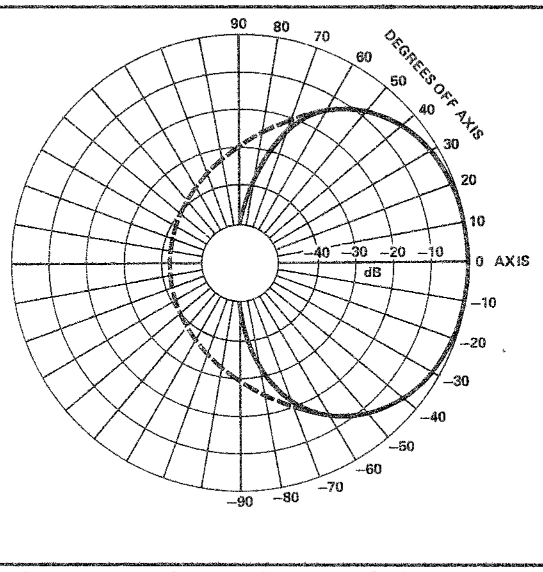

Fig. 2 Polar diagram of a sound source which radiates mostly forwards (approximated by a loudspeaker mounted on an infinite baffle enclosure). If a little sound is allowed out backwards the dotted line applies.

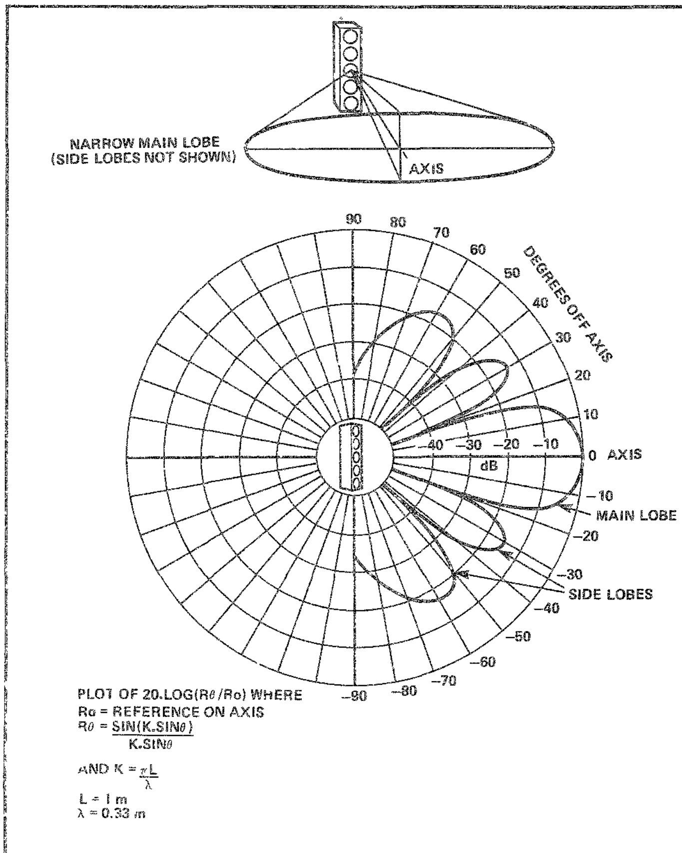

Fig. 3 Polar diagram of a column loudspeaker at 1 kHz.

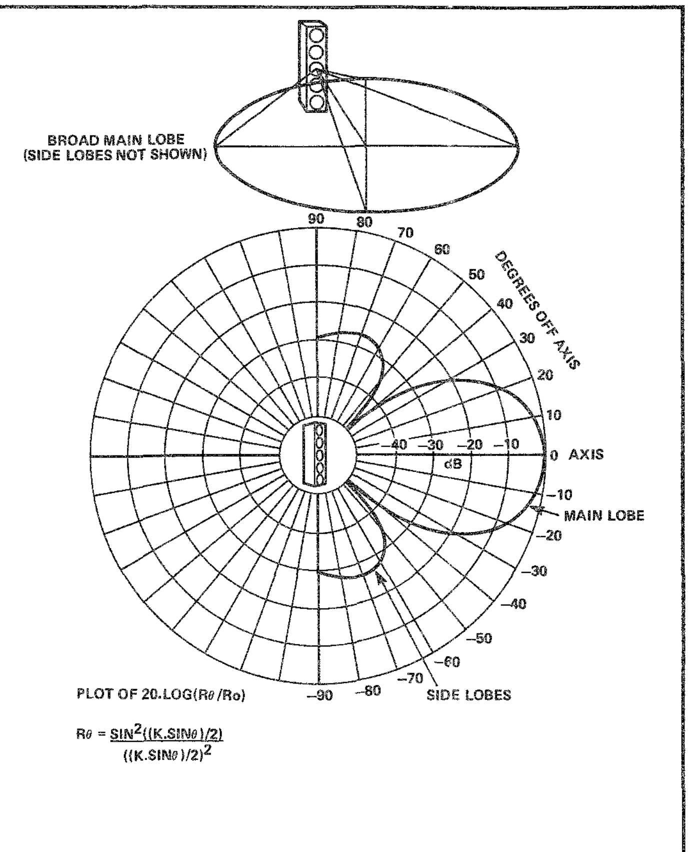

Fig. 4 Polar diagram of a column loudspeaker at 1 kHz with graded aperture.

units, but in the domestic scene we either have to use a folded horn design or just use tiny horns for high frequency tweeter applications.

The other directional type of loudspeaker in common use is the 'line source' or column loudspeaker, and that's the one we're going for here. The theory tells us that all we need is a loudspeaker with a cone which is long and narrow, rather like an elliptical loudspeaker taken to the extreme. Put that in a similarly long and narrow enclosure and that should be it! We do still have the problem that unless we allow the length to be at least a few feet then we will lose the beaming effect on the low frequencies, but there's a far worse problem — how do we actually get hold of our crazily-shaped loudspeaker? Does such a beast even exist? Actually it probably could be made with an electrostatic speaker but that's not for us Instead we can approximate a line source with several conventional round speakers stacked in a line. Commercial designs use three or more, often quite a few more, and this works well. Our design uses five speakers spaced evenly along an enclosure of one metre length.

Directional Characteristics

It is at this stage that we must look again at a polar diagram for our design, Fig. 3, and this is where this diagram begins to give us some useful information. The first thing to note is how the shape is drastically changed from a balloon to a series of fingers of various sizes. The largest finger is the main beam or lobe of our column loudspeaker while the smaller fingers are unwanted side lobes. If you have seen interference patterns on a ripple tank then you will probably understand the reason for this sort of pattern. To improve the directional properties of the speaker system still further, we want to reduce the side lobes and enlarge the main lobe. It would probably also be useful to have a slightly broader main lobe, since it is unlikely that we can arrange for the audience to be confined into too narrow a region.

Without going into all the maths of the solution, both these aims may be reached by a process known as 'grading' or 'tapering' the aperture. This is a little trick that is used in all sorts of situations, not just column loudspeakers. Microwave dish aerial systems often do just the same, for example. In our case, tapering the aperture simply means that we must arrange to evenly decrease the power fed to each of the individual loudspeakers as we move away from the central one on the column. The effect of this is shown in Fig. 4. Note that these diagrams both apply only at one frequency, 1000 Hz. At higher frequencies the lobes are narrower and more numerous, but they become wider and less numerous at lower frequencies until below about 500 Hz, the wavelength of sound is comparable with the length of the column and the beaming effect begins to fail. Fortunately acoustic feedback is likely to be worst at frequencies well above 500 Hz so one metre is as long as we need to make the column.

You may occasionally come across giant column loudspeakers which are also curved so that they look concave from the listener's vantage point. This produces the same effect as tapering but is not necessary except for systems much longer than one metre.

Electrical Design

So now a way of arranging the power feed to each speaker has to be devised. If series resistors of appropriate values are wired in with the speakers, then, although things work well enough acoustically and electrically, we will have an inefficient design which wastes much of the power of the amplifier as heat in these resistors. The common commercial solution is to forget about tapering altogether, or for expensive units to use a special matching transformer with tappings for each individual speaker. This not only adds to the cost but also to the weight of the final product. Don't forget that no transformer has yet been designed which gives zero distortion, so that's yet another problem. While pondering this (in the bath — where else!) the author devised what seems to be a splendid engineering solution; that is, one that cheats the situation by winning several points at one go but without making any serious concessions. The key is to use identical speaker units but with different coil impedances. After many calculations with a range of different combinations, one design stood out as being almost ideal. It produces an effective impedance of 6.15 ohms, gives an even tapering and uses just 8 ohm and 15 ohm speaker units which are readily available.

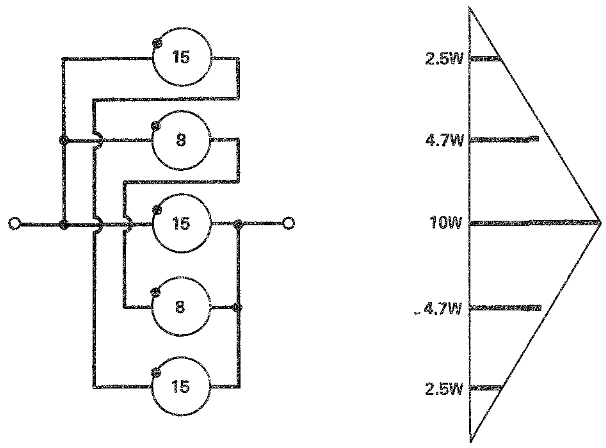

Fig. 5 The wiring diagram for the 8 and 15 ohm speakers. Note how each speaker is wired in phase. For 10 W speaker units the power handling is about 25 W (actually 24.375 W). At right is shown the profile of the graded aperture.

The electrical set-up is given in Fig. 5 and for nominal 10 W units produces a speaker system of 25 W capability. The actual make of loudspeaker unit doesn't really matter provided you can get both 8 and 15 ohm units in the same style. The original design used R.S. Component's wide-range six-and-a-half inch loudspeakers which have given reliable service for over four years now. Some may object that five 10 W speakers ought to give a system capable of more than 25 W. It is, of course, the tapering of the system which causes this reduced power rating, but its electrical efficiency is fair and there is no real problem. It is in fact possible to rewire the individual units so as to increase the power rating to 40 W, as shown in Fig. 6, but the tapering goes out of the window with this arrangement and it is not recommended.

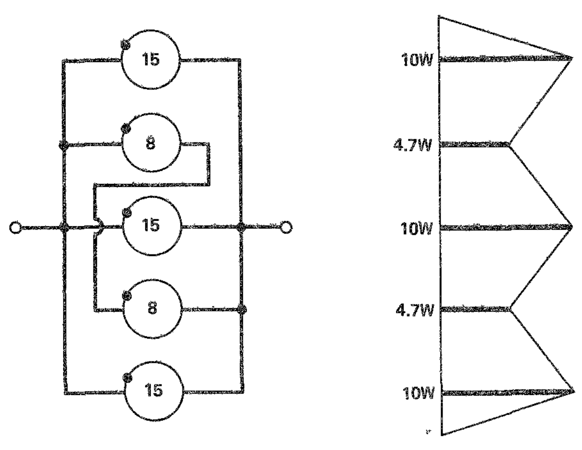

Fig. 6 An alternative way to wire the speakers. This gives a power handling of nearly 40 W but is not recommended as the aperture is not correctly graded. The profile of the aperture is irregular, as shown.

Calculations show that the series/parallel combination of speaker units in our design gives an effective impedance of 6.15 ohms. This is just about ideal and suits the 4 to 8 ohm range that most power amplifiers are designed to feed. If you happen to have one which cannot drive impedances less than 8 ohms then you will need to add a 2 ohm series resistor to get things right. However, most column loudspeakers are necessarily mounted some distance from the amplifiers and the leads' resistance may provide some or all of this extra 2 ohms if you are lucky.

A Case In Point

The cabinet for the design may be made from chipboard. Three-quarter-inch thick is about the right grade for this job. If you are going to use the R.S. speaker units then, provided your woodworking skills are fair, it is only necessary to refer to Fig. 7 for all the details. If you have or can gain access to a circular saw (what about woodwork evening classes?) the task is that much easier. None of the dimensions are that critical, but the overall volume has been designed to match the suspension characteristics of the speakers themselves and should be kept the same. The unusual cross-sectional shape is not an essential

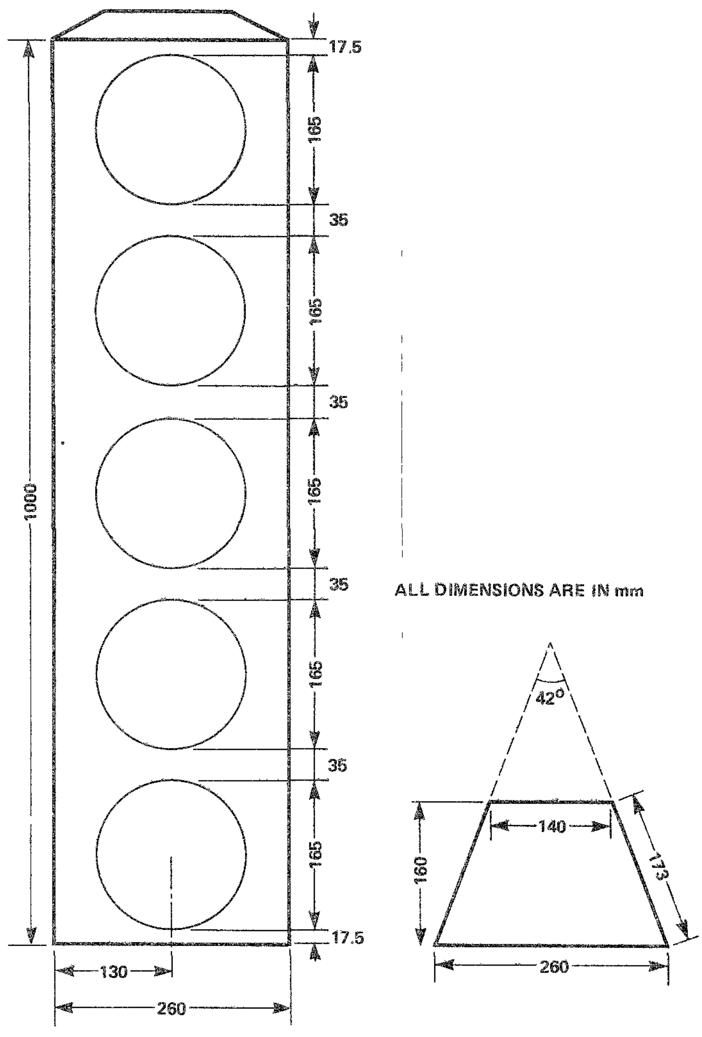

Fig. 7 Cabinet details — all dimensions are in millimetres. The total cabinet volume is 0.324 cubic metres. A suitable material to use is ¾" chipboard and this thickness needs to be added to the dimensions shown where appropriate.

part of the design either but was chosen so that the column could be neatly and permanently mounted on a wall and still point in the right direction If your intended use is stage work then a square or rectangular cross-section giving the same volume would be easier to make.

Take care to close all joints with enough glue to make the unit reasonably airtight since this is a requirement of this type of speaker unit's cone suspension. The inside of the cabinet is filled with acoustic wool or similar sound-absorbing material so as to reduce internal sound reflections which otherwise give an unnatural colouration to the performance. I once knew a musician who insisted that internal lining of an enclosure reduced the high frequency response, but he had simply come to enjoy a particular type of distortion — don't leave it out! The best way to fix it is to tack it on lightly before the front is put on the enclosure. If it is not fixed it will soon fall to the bottom and lose most of its effect; if it is glued it tends to become compressed on to the glue which again cuts down on its absorption properties. Similarly, use a proprietary make of grille material for the front rather than any old material or again you will distort the sound. Most probably it will be the high frequencies that you lose this time if you are tempted to use the spare curtains because they are the right colour!

If the final unit is to be attached to a wall, a small screw recess can be provided near the top of one side for this. Most ironmongers stock screw-on brass plates that are ideal as a reinforcement for this. Don't forget to provide electrical connections on the back before the unit is assembled. Suitable types are available from the same sources as supply the acoustic wool and grille material (and the speakers themselves for that matter). The finish on the outside of the cabinet is obviously a matter of personal choice. If you wish to make a feature of it you can use a wood veneer or vinyl covering to achieve a smart appearance. The original design was made to appear unobtrusive (if that's not a contradiction in terms) by simply painting it the same colour as the wall it was to hang on, and this worked very well.

Performance

In assessing how well the design works we must first decide what it is we are looking for. With a speaker system intended for hi-fi applications we might look at the frequency response and phase linearity, for instance, but this design is for sound reinforcement purposes. The chief needs are to reduce acoustic feedback by efficient beaming of the sound and to improve the audibility of whatever is behind the microphone. The design was originally made to meet the needs of a church of moderate size (about 50 by 30 feet) for both music and singing from the music group at the front, and for speech from the pulpit (but not both at the same time!).

Judged by these standards the final product is totally effective; the beaming effect is very noticeable. When it was tested in the living room at home before installation the sound appeared to be thrown forwards towards the listener in a way that the conventional speaker cannot achieve. With a pair of speakers now hanging on side walls each side at the front of the church, their base being six feet from the floor and the axis of each speaker pointing towards the floor at the mid point of the back wall, the comparison with the old temporary single speaker units is really quite spectacular. At the front of the church the sound is beamed high over people's heads and so is not deafeningly loud. At the back, however, the beams reach down to ear level and the sound seems every bit as loud as at the front even though you are further from the speakers. What is more, the sound, particularly speech, is strangely clearer. The effect is perhaps not unlike that in the Whispering Gallery in St. Paul's Cathedral, where you might be surrounded by background noise yet can hear a whisper with startling clarity from a spot exactly opposite. The speakers do not whisper but the sound seems to surround you in the same way.

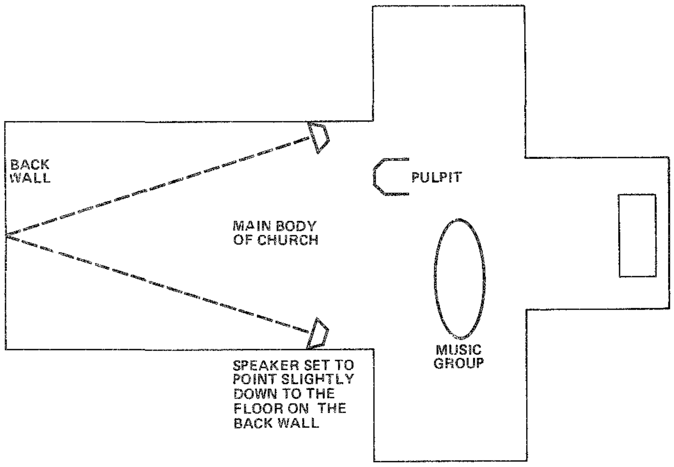

Fig. 8 The working layout of the speakers in the church.

The power handling of the column loudspeaker, 25 W, is more than adequate. The two units are driven by mere 15 W amplifiers but even these are never turned up anywhere near full volume. Acoustic feedback is no longer a critical problem, no mean achievement in a stone church building. The improvement is so pronounced that the music group now need to be provided with extra speakers to provide foldback.

The frequency response of the units is essentially that of the individual loudspeakers — about 70 to 16 kHz for the R.S. units in an enclosure of this volume. Purists will notice and object to the lack of the extreme high frequency element, but this is unimportant in this application. In fact a design of this type will have rather better characteristics than the straight theory predicts since the matching of the system to the air is improved with the larger surface area of many loudspeaker cones. At low frequencies in particular it appears the response goes down well below 70 Hz although no measuring equipment was available to make quantitive measurements. If operation above 16 kHz is important for you don't despair: add a horn tweeter and mount it on top of the cabinet.

The overall impression of the speakers is of clean effortless performance, lacking only in that extreme high frequency content. They have been used regularly for four years now with 100% reliability. Applications have included not only the live sound sources mentioned earlier but also the playing of taped music and use for film shows. Once when playing back a tape-recorded voluntary from the pipe organ, several members of the congregation admitted to me afterwards that they had to look at the organ to check that it was not live playing — quite remarkable really when you think that the organ is at the back of the church and the column speakers at the front! This is the result obtained with directional sound: it seems to come directly to you. If you want to test for yourself and are in range of North Buckinghamshire, why not pop into Holy Trinity Church, Deanshanger and make up your own mind?

One last note of caution for you: do position your column speaker the right way round, that is vertically. You will have seen from Figs. 3 and 4 how the sound beam spreads out from the system. Possibly because this spreading is the opposite of what might at first be expected or perhaps because of plain ignorance, column loudspeakers are occasionally positioned the wrong way round! In fact I know of one not many miles from my home, where, in a specially converted stable, a column speaker is attached horizontally to an old oak ceiling beam. Wild horses wouldn't drag the exact location of the stable from me (pun intended — groan); I enjoy the little theatre too much to want to upset them

ETI