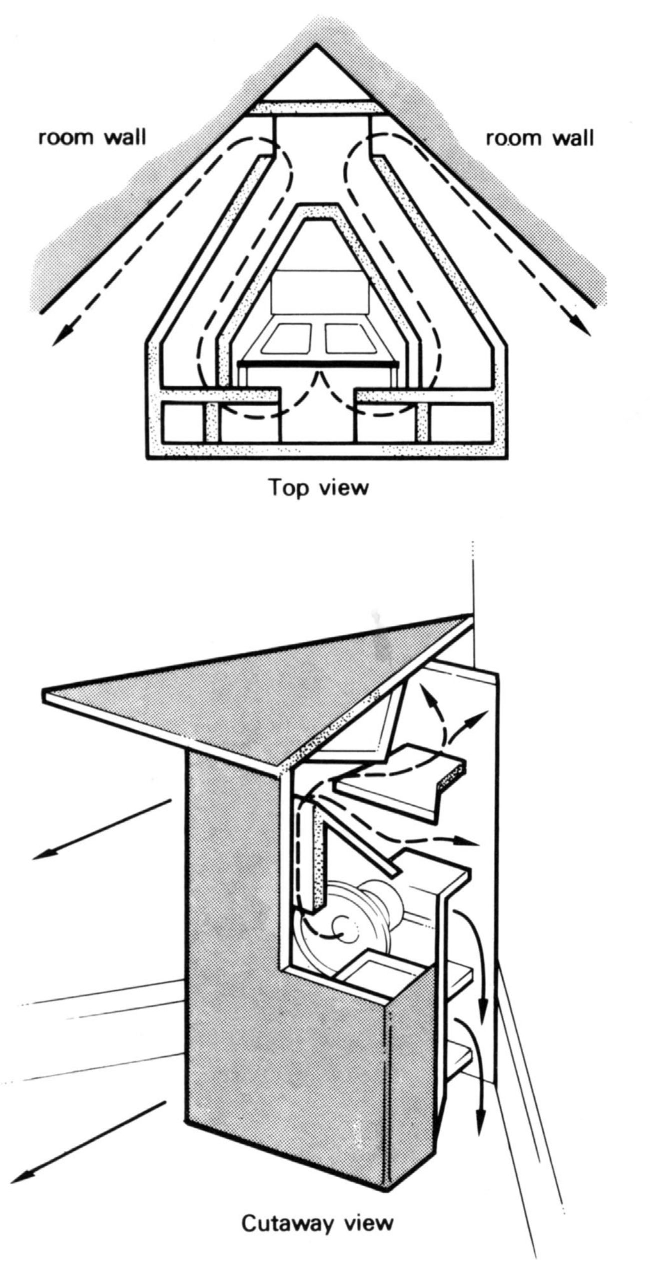
Designing speakers

Part 5 Horns and Efficiency

Horn loudspeakers – love them or hate them they have one thing on their side – efficiency. Peter Comeau explains...



I suspect most hi-fi users have a love or hate relationship with horn loudspeakers, usually because of what they first heard when encountering a horn speaker for the first time.

I was lucky. My first exposure to horns was through hearing a pair of Klipsch corner horns driven by a 2W SE valve amplifier. Frankly I couldn't believe what I was hearing. The sound was effortless, filling the room in a dynamically expansive way that was totally different to anything I had ever heard. And all that from a 2W amplifier? Unbelievable.

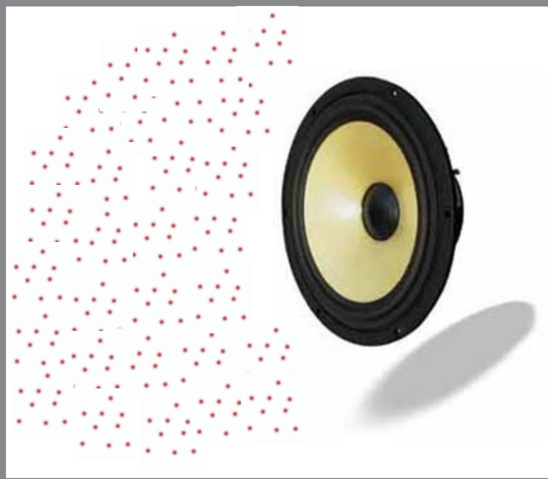
On the other hand I have heard more than a handful of horn designs which have made me leave the room quicker than I entered it. You see a horn speaker is a tough design assignment and, when it goes even slightly wrong, the negatives add up to outweigh the positives.

But I'm getting ahead of myself. Let's look first of all at why we would want to use a horn at all.

EFFICIENCY

We are so used to looking at loudspeaker Sensitivity (Acoustic Output for a reference Electrical Input) that true efficiency gets overlooked. A loudspeaker's efficiency is best expressed as a percentage. How much power you put in versus how much acoustic power you get out. In those terms a typical moving coil loudspeaker has an efficiency of around 1%.

Why so low? The problem arises because the impedance of a moving coil loudspeaker drive unit is much higher than that of the air it is trying to drive. You might know that in electronics driving a low impedance from a high impedance source results in poor transfer of energy and limited bandwidth. It is just the same when we are trying to convert electrical



To look at speaker efficiency in 'common sense' terms imagine this. Sound propagates through the air by air molecules pushing and pulling one another, rather like people surging backwards and forwards in a crowd of football supporters. In order to hear the sound every air molecule in the room needs to be energised by your loudspeaker. Now if your loudspeaker drive unit is 18cm (6 inches) in diameter how many of those air molecules is it going to push and pull when it moves forwards and backwards? Not many.

What is worse is that we are moving a high mass object – the speaker driver cone – into a low mass gas. Try pushing air with your hands. Can you do it? Waving your hand backwards and forwards doesn't create much of a breeze considering the amount of effort you are putting in.

The upshot of this is that we need a lot of electrical power just to push the speaker diaphragm forwards, stop it, and pull it backwards again. Yet the amount of energy imparted to the air is minimal. So the efficiency is very low. In fact most of the energy is used up in heating the voice coil and in starting and stopping the cone!

power to acoustic power through a drive unit.

There are ways that we can improve efficiency. We can make the drive unit diaphragm lighter. This is often done in Full Range drive units such as the Lowther range. It is just a shame that, as we make the moving mass lighter, the bass system resonance increases in frequency. So we lose out on bass extension and power.

We can make the drive unit diaphragm bigger. Think panel speakers, like electrostatics. The problem here is that we tend to have poor electrical to mechanical efficiency – in an electrostatic the charged diaphragm is spaced away from the drive voltage elements, so the required charge field is very large for only a small diaphragm movement.

Whatever we do it seems increasingly difficult to move large quantities of low mass air with relatively high mass pistons. But what if we look at the whole question another way? What if we increase the mass of the air?

What? How can we do that? The answer is surprisingly simple. If we contain the air in a small enclosure in front of the diaphragm then, as soon as the cone starts to move, the air will be compressed and its density, and therefore the mass of air controlled by the diaphragm, will increase. We often call this type of speaker drive unit a 'compression' driver.

So now we have better efficiency of transfer of energy from the diaphragm to our high mass packet of pressurised air, but we still haven't communicated this energy to the air in the room. This is where the horn comes in. By gradually expanding a tube leading from the enclosure in which our air is compressed we can gradually reduce the air density until it matches the density of the air in the room. If you like the horn is an impedance transformer – high impedance at the drive unit and low impedance at the mouth of the horn – just what we need.

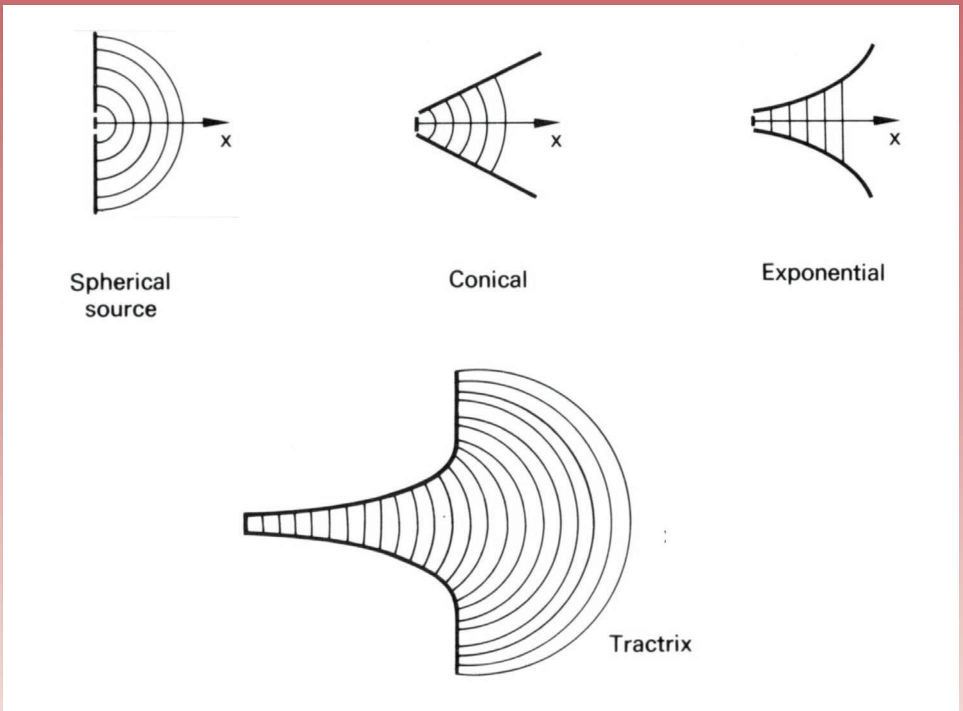
So the horn is now raising the efficiency considerably. Optimised horn design can hit efficiencies of around 50% though for a typical hi-fi design an efficiency of 20% is considered good. The reason for the difference is in accommodating the considerable size necessary to realise a working, wide bandwidth, horn design.

To start with we need to consider the size of the mouth of the horn as it is this that is energising the air in the room. Ideally the mouth should be large enough that the radiation impedance is largely resistive for the speaker bandwidth. We can easily derive the equation for this as Circumference/Wavelength>1. For a bandwidth down to 50Hz the Circumference of the horn mouth should be 2.2m. Now you can see why full range horns are so big.

We also need to look at the rate of expansion of the horn. The shorter the horn the worse the linearity of the transformer and short horns produce big ripples in the response

We can see horns working most easily in musical instruments, like the French Horn. If you press your lips lightly together and blow you can make a buzzing sound, but it's not very loud is it? But if we contain all the air molecules that are in contact with your lips in a small enclosure so that you can energise all of them quite easily,

then let those air molecules energise more air molecules, still enclosed in tube but expanding so that each air molecule gets the chance to bounce off an increasing number of air molecules. Then, at the wide mouth of the French Horn you've converted a small number of air molecules energised by your lips into thousands upon thousands energising the air in the room. So your small buzzing sound is now ear piercingly loud. And you really haven't had to do all that much work to create such a loud sound.



Wavefront performance from different flare styles of horns. The Tractrix has the benefit that the wavefront is always perpendicular to the walls of the horn. Thus resonances are almost entirely eliminated, and the final reflection from the edges of the mouth of the horn can be resolved by a large 'baffle' area at the exit.

as the frequency decreases. Ideally we want a very long, and very large, horn, both of which take up space in the living room. But there are ways round this.

An exponential rate of expansion, or flare, in the horn, for example, will extend low frequency performance by about 3 octaves compared to a conical horn of the same dimensions. A hyperbolic flare does even better but its rate of flare at the mouth is large, has a fast roll-off rate below cut-off and a corresponding higher level of distortion. A Tractrix flare, following Paul Voight's 1927 British Patent, has similar properties to the exponential but is shorter, more difficult to calculate, and ideally requires an expanded 'baffle' round the horn mouth to eliminate the last traces of diffraction reflection.

But, remember, we are not designing our hi-fi speaker for open air use. It will be in a room and, as with other enclosure designs, the room acoustics and room gain can come to our rescue. Chief among these are using the room boundaries to extend the mouth of the horn. The floor is the obvious contender but if we put the horn in a corner then we can easily use the floor and walls to extend the mouth of the horn.

A long, flared horn will not easily fit into any room, of course, unless, as R. N. Baldock once did, you build the horn in a cellar with the mouth exiting in your listening room! As a result most horn designs are folded, and this is where the problems start.

Another way of looking at horns is to view them as waveguides. In a typical closed box or reflex speaker the drive unit radiates a spherical wavefront into the room. It is this rapidly expanding sphere that dissipates the energy quickly in the room. A horn, however, tightly restricts the radiation and therefore funnels all the energy to the mouth of the horn where, in an exponential horn, it emerges with close to a plane wave front.

Long wave guides like this suffer from resonances due to reflected sound. Unless the horn is infinitely long with an infinite mouth, there will be a reflection back down the horn from the radiation impedance change at the mouth. And if the horn is folded there will also be reflections from each boundary corner. It is not uncommon to see response ripples with huge peaks and troughs from horn designs.

These resonances are easily heard as colorations and have given horns, in general, a bad name in hi-fi loudspeakers. Other problems concern the naturally limited bandwidth of horns. The reflected acoustic impedance and mass reactance of the horn increase with frequency and are in parallel with the radiation impedance of the mouth. So high frequency output is limited according to the dimensions of the horn – we need a big horn for bass but a small one for treble! It is not surprising that many horn speakers are three way designs.

Taking all this into account it is still perfectly possible to make a horn speaker with a relatively wide bandwidth, smooth response and high efficiency. The Paul Klipsch Tractrix corner horn was just one example of a successful commercial design from the past that has continued unchanged for 60 years, but you would be hard put to find many corner horns in production today. One reason may be that there are not many homes which have two suitable corners free, and this makes such a design not particularly commercially viable. But it is not going to stop us!

Finally don't forget that a loudspeaker is only as good as the quality of the signal it is fed. This is especially true of horns. With ultra-high sensitivity, often over 100dB for 1 Watt input, horn speakers expose the listener to all the low level distortion, hum and noise that many amplifiers produce but which are usually 'hidden' by insensitive speakers. As Paul Klipsch once said "What this country needs is a good 5 watt amplifier"!

Next month:
Crossover design