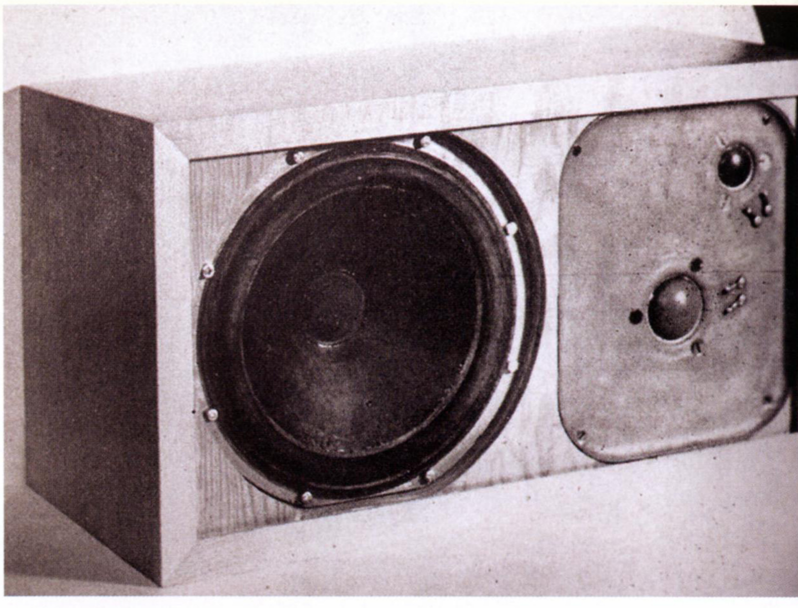
Designing speakers

Part 2 - Which Enclosure

This month Peter Comeau discusses the closed box or 'infinite baffle' speaker as part of his series on loudspeaker design



AR-3 prototype – an 'acoustic suspension' speaker that redefined loudspeaker design in the '50s.

As we have seen Open Baffle speakers tend to be rather large. This wasn't too much of a problem in the days of mono where Gilbert Briggs of Wharfedale launched a commercial design, the SFB3, which used a 15" and 8" bass units and a 3" treble unit mounted on a twin wall baffle with sand filling to eliminate panel resonance.

But room real estate has always been at a premium and large loudspeakers were confined to the domain of the audiophile. To achieve good bass performance the baffle was first of all extended into an open back box, then closed into a full box. At this point unusual things started to happen to the performance.

First of all, in a closed, airtight box, the system resonance goes up. This, in itself, has a deleterious effect on bass performance. Not only is the bass extension curtailed, as SPL drops at 12dB/octave below system resonance, but also the resonance becomes more audible.

What do we mean by system resonance? For any moving mechanical system there is a moving part, which has mass, and a suspension part, which has springiness or compliance. In a speaker drive unit the cone or panel has mass and the surround or suspension has compliance. You can think of this as a weight suspended on a spring. Pull the weight down and release it and it starts to oscillate up and down at a single frequency. This is called the system resonance. Increase the weight and the system resonance goes down in frequency. Similarly, increase the spring compliance and the resonant frequency is lowered. In a speaker in a box the mass and compliance of the air in the box have to be added to that of the drive unit. The mass of air is small but the air in a closed box is under compression and so reduces the springiness (or increases the stiffness) forcing the resonance upwards in frequency.

For example, if we take a bass drive unit with a 30Hz fundamental free air resonance and put it in a small closed box the system resonance will be raised to around 60Hz. Without any damping, a system resonance this high will be audible as a reinforcement of some notes on bass guitar and as an overhang on drums (at 30Hz it would be out of harm's way musically). We need to add damping either via an amplifier with a low output impedance (high damping factor), or via a large amount of cabinet absorbent stuffing - or both. Thankfully, most modern amplifiers have a high damping factor and will control the excess motion of the drive unit quite well. Valve (tube) amps with limited feedback and resistricted damping factor may not work as well at controlling the resonance, however, so we have to check the audibility of the system resonance with the amplifier the speaker is going to be driven by.

How does speaker damping, either via the amplifier or absorbent stuffing, work? Let's go back to our weight on a spring concept. Let's say we put a cloth sleeve round the spring. Then every time the coils of the spring start to move they will encounter a resistance. Now if you pull the weight down, the oscillation still occurs but it dies out in a few seconds instead of going on for minutes. The cloth has added a resistance to the system and damped the system resonance.

The temptation is always to put a speaker drive unit in too small a box with the minimum of internal damping. This is prevalent in today's commercial speaker designs where the focus is always on the customer requirement for minimalistic speakers with impressive bass. Don't go this way. The point of DIY is that you can build something better, for less cost, than the commercial products. Choosing too small a box may give you an initially impressive bass output (anything with a peak in its response tends to sound impressive on immediate listening) as the output peaks up before it starts to tail off. But accurate it is not and it is very often tiring to listen to in the long run.

If you want an accurate, hear through and musically enjoyable (and informative) bass performance then you are better off choosing an enclosure where the bass smoothly rolls off below resonance. Why? Well remember from the OB exercise that the typical room plays a large part in the SPL below 100Hz and starts to dominate the speaker output below 40Hz. If you design a speaker that has a maximally flat response to a system resonant frequency around 40Hz it will sound unbearably bass heavy in most rooms, will be difficult to position in any room as it will be exciting room modes quite strongly, and will need to be kept well away from the walls in order to sound anywhere near as good as the theoretical graph displays.

There may well be a case, however, for designing a speaker system where the system resonance is higher than that of the first room standing wave mode. If you can design that accurately then a speaker system with a Q around 0.8 – 0.9 will maintain a maximally flat bass response that will be augmented by room gain below the system resonance. A relatively small, closed box, speaker designed for wall loading can work very well in larger rooms as a result.

There's another problem too. If we consider the bass performance at and below resonance to be a high pass filter, and we should do, then we can see that the speaker system obeys all the characteristics of a filter, including its phase shifts and ringing. A sharp 'knee' to the response, coupled to a rapid initial rate of roll-off below resonance, will have a tendency to sound lumpy, ill-defined and blur the definition of transients from percussion instruments.

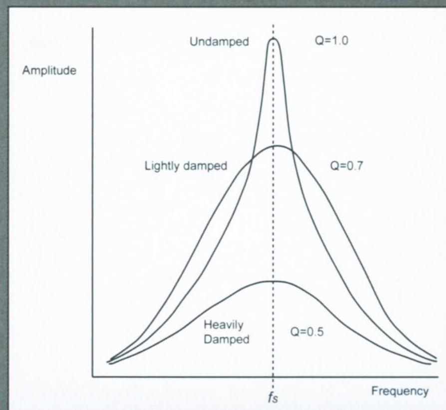
If we are really clever we can complement the probable level of room gain by providing an equal and opposite characteristic in our high pass filter response. I'm not going to go into the technicalities of that here but will cover it as part of designing for room interaction later in the series.

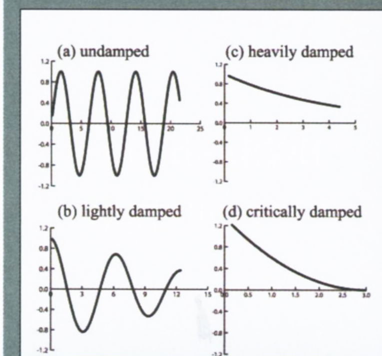
Suffice it to say that putting our drive unit in a larger closed box and aiming for a gentle roll-off and gradual initial slope, taking into account a fair amount of damping in the box from absorbent stuffing, will yield results which are easy to achieve by the first time DIYer.

THE IMPORTANCE OF Q

Q (in radio tuner circuits the narrower the resonance of the tuning circuit the higher the Quality factor or Q) is an indicator of the strength and sharpness of resonance. Look at this graph which shows how the sharpness of tuning is indicated by the Q value.

Q is varied by the damping applied to the resonance, the higher the level of damping the lower the Q. If there is little damping the Q is high, the peak of resonance very sharp and the effects of the resonance can be heard very clearly but over a narrow range of frequencies. If damping is high, Q is low, the peak of resonance is very shallow and the effects of the resonance are not very noticeable but the energy of the resonance is spread over a wide range of frequencies.





These graphs show the effects of damping. In a) there is no damping and the oscillation of resonance continues for a considerable time after the initial pulse of energy has passed. Add a little damping and the oscillation dies out more quickly as in b). The resonance is critically damped when there is no oscillation and the moving part settles quickest to the rest postion d). Overdamp and the moving part takes too long to settle back to the rest position.

How does Q affect us in speaker design? First of all we can use the value of Q to show us how big a box and how much damping to use for a given drive unit. The following graph shows the difference in bass extension for different values of Q.

In an undamped box Q may well reach the 1.2 value. As you can see this response has a big peak before roll-off and results in the 'one note bass' that we hear from poorly designed/very cheap speakers. If you want an 'impressive' bass then Q of 1.0 lifts the output before roll-off but you won't be able to hear much bass definition – small, commercial speakers are often aligned this way. Note that the rate of roll-off at these alignments quickly reaches 12dB per octave.

A Q of 0.7 (0.707 is a Butterworth alignment) is often considered optimal for commercial speakers as it gives the best extension and power compromise and still manages to sound impressive whilst providing good bass clarity. Note that the rate of roll-off is initially slower, and it is this that achieves better bass extension.

At first sight a Q of 0.5 does not look particularly promising. The output starts falling at quite a high frequency and is -2dB at a higher frequency than any other alignment. However this is an anechoic response graph and does not show the effect of room gain. When room gain of +3dB is dialed in at 80Hz, rising to +9dB below 30Hz, it not only makes up for the early 'droop' in output but offers the greatest bass extension. In addition a system Q of 0.577 is a Bessell alignment with the most linear phase response.