In defence of conventional loudspeakers

In last month's *Audio Video Lifestyle* (Issue 174), Robert Smith outlined why he believes flat panel loudspeakers are better than conventional loudspeakers. In this article I (Dr Rod Crawford of Legend Acoustics) explain why I am convinced that conventional loudspeakers are more accurate than flat panel loudspeakers.

Of course, as a conventional loudspeaker manufacturer I have a vested interest in this debate but I hope it will be judged on the relative merits of the arguments presented. I will try to explain what I believe are the actual reasons some people prefer panel loudspeakers and how they differ from the stated reasons – which in practice often favour conventional loudspeakers.

A Critique of panel loudspeakers

Let me begin by saying why I think that some people actually prefer flat panel loudspeakers. I believe it is mainly due, either singly or in combination, to two factors:

1. they are usually (although not always) open-backed;

2. they have decay characteristics similar to many acoustic instruments.

As discussed below in more detail both these factors can lead to planar loudspeakers sounding 'warm', 'sweet' or 'full-bodied'. However, whether they are 'high fidelity' in the sense of being 'faithful' to their input signal is another matter.

A friend of mine has Magnaplanar loudspeakers. When I first heard them playing simple acoustic music, such as acoustic guitars and small chamber music, I was seduced by their 'pleasantness'. However, when they also sounded 'pleasant' with Peter Gabriel's *Sledgehammer*, I was less convinced about their accuracy.

I often used *Sledgehammer* at Linn Products in Glasgow to check the accuracy of loudspeakers - in it Gabriel deliberately seems to push the "hardness" of the sound to its limits (unlike some of his other tracks such as *Mercy* Street which are the syrupy converse). If they did not sound almost unlistenable with *Sledgehammer* then there was something fundamentally inaccurate about the loudspeaker.

Open-backed

This first property of most planar loudspeakers means that sound waves generated from the back of the panel are radiated into the room, in addition to those from the front surface. This 'dipolar' nature of panel loudspeakers produces a number of effects including their usually poor bass performance mentioned by Robert and the so-called 'Haas effect' of reverberant sound fields.

Bass Performance

The poor bass performance of panel loudspeakers is readily explained. The sound waves generated from the back of the panel are out of phase with those from the front. At low frequencies, where wavelengths are long, the waves from the back can 'bend' around the panel and therefore cancel out those at the front before they reach the listener.

The frequency below which this occurs corresponds to the wavelength being roughly half the minimum dimension of the panel. For example, if this minimum dimension is 0.5 metre, then this frequency will be about 300Hz, not very deep bass (just above middle C).

In conventional loudspeakers the rear waves are absorbed inside the cabinet and so this cancellation does not occur. This is why conventional loudspeakers are sometimes called 'infinite baffle' and go much deeper than panel loudspeakers.

Conventional loudspeakers are therefore often used to supplement panel loudspeakers at low frequencies to improve the latter's bass performance. The problem with this is that the 'join' can often be heard due to the different characteristics of conventional and planar loudspeakers including their different decay properties and radiation patterns.

Haas Effect

Above the frequency where the rear waves cannot 'bend' around the panel, they will travel in more or less straight lines until they hit the rear wall of the listening room and are reflected back towards the listener. These reflected rear waves arrive at the listener's ear after the direct waves radiated from the front of the panel. The time difference depends on how much further the rear waves have to travel. It is about 1 millisecond per foot of difference, ie. about 3 milliseconds for a metre difference in distance.

Haas and other acoustic researchers have found that if the time difference is less than about 20 milliseconds (ie. the distance difference is less than about 6 metres) the ear integrates the direct and reflected waves into a single sound. Indeed, it interprets the combination as having extra 'warmth', 'sweetness' or 'body' compared with just the direct sound, a bit like adding extra reverberation.

If the time difference is greater than about 20 milliseconds, depending on the relative sound levels of the direct and reflected waves, the ear will hear the reflected sound as a distinct separate echo which is less realistic. Thus the location of panel loudspeakers in listening rooms is critical, particularly their distance from the rear wall.

Dispersion patterns of planar loudspeakers

This is probably a good point to digress briefly to discuss the dispersion pattern of sound of panel loudspeakers, which is both a strength and a weakness.

The dispersion of sound of loudspeaker drivers (how they radiate sound in different directions in space) depends largely on the dimensions of the driver compared to the wavelength of the sound being generated. At wavelengths much longer than the dimensions of the driver, the waves are radiated omni-directionally i.e. equally in all directions. As discussed in slightly different terms above, this leads to the waves from the rear of the driver canceling with those form the front at these low frequencies if allowed to do so, as in panels.

On the other hand, at wavelengths much smaller than the dimensions of the driver, the waves are highly focused in a direction perpendicular the driver. It means at these higher frequencies there will be less reflection off side walls and ceilings, which may be a positive. However, it also means that the listening position for flat frequency response is extremely narrow, which can be a problem with panel loudspeakers, as Robert pointed out.

Conventional drivers are subject to the same physical principles except that they are usually much smaller than panels and so remain omni-directional to much higher frequencies. For example, a typical 25 mm tweeter corresponds to a half wavelength of 50 mm and so a frequency of about 6 kHz before it will start to become more uni-directional, a process which only becomes nearly complete above about 20 kHz. This may limit their effectiveness slightly with SACDs and DVDAs, unless listened to precisely on axis.

Decay of panel loudspeakers

The second main characteristic of panel loudspeakers that some people like is their slow decay of sound which mimics many acoustic musical instruments. As with the Haas effect above, this can create apparent extra 'warmth', 'sweetness' or 'body'.

Many acoustic instruments decay quite slowly, that is, the instrument keeps producing sound long after it is played. For example, the guitar string keeps vibrating long after it is plucked, unless deliberately stopped. Similarly with piano strings, drum heads, etc.

These are all examples of a general physical phenomena called 'resonance'. The resonant frequency in solids depends on the size, density and strength/tension of the body (string, drum head etc). The lowest (fundamental) resonant frequency gives the sound its pitch while the higher frequencies (harmonics) give the instrument its tone. The overall 'body' of the sound also depends on how quickly the resonances decay.

In many acoustic instruments this overall resonance is deliberately enhanced and prolonged. For example, in guitars the strings are attached to a wooden body with an internal cavity that is deliberately designed to also resonate and give the sound even more body. The question is whether, if the loudspeaker additionally resonates and decays slowly, it is adding to the sound quality. The "high fidelity" paradigm would argue not so because any which differs from the original signal is by definition "distortion" and even "benign distortion" stops us getting closer to the original recording.

Some people assert that, in any case, planar loudspeakers are better than conventional loudspeakers in their resonance and decay. Neither theory nor experiment supports this conclusion.

Planar-philes assert that, because the planar diaphragms (membranes or ribbons) are lighter than conventional diaphragms (cones and domes) they decay more quickly, at least partly because they are better controlled by their force fields (electrostatic or magnetic). However, this ignores the fundamental nature of "resonance" – once excited, resonances exist largely independently of their initial driving forces and are little controlled by them.

It is a bit like saying that a drum head, if excited by an object like a stone falling on it, decays rapidly because the drum head is still subject to the force of gravity. Of course it does not. The drum head keeps vibrating (resonating) at frequencies depending on its boundary restraints (size, tension, density etc) until all its energy is dissipated, partly by the sound energy moving away but mainly by friction generated inside the membrane or with the surrounding air.

Similarly, the membranes of planar loudspeakers, once excited by an electrical signal, will start to resonate, at frequencies depending on their boundary conditions – their size, how they are held, tension, density. And will continue to resonate, irrespective of the force field, until all the energy is dissipated, partly by the sound energy moving away but mainly by friction generated inside the membrane or with the surrounding air.

In the case of electrostatic loudspeakers, the energy of resonance is probably dissipated mainly by friction with the air because of their large surface area. And like most air friction it will be velocity dependent, just like wind resistance on a car. Thus when the vibrations are large and surface velocity fast, the frictional damping will be greatest and so the resonances will start to die away quickly. However, as the vibrations become smaller and the surface velocity slower, the effectiveness of the air friction is less and the vibrations die way more quickly.

This is consistent with respected reviewer and engineer Martin Colloms' measurements of the Quad ESL63 loudspeaker in *Hifi News and Record Review* in 1991. Using the then newly developed MLSSA software to measure their "waterfall" decay properties, Colloms found the "the initial decay is tidy and rapid but levels out at around -40 dB, this continuing for at least 8 ms ...... The speaker does not quieten as much as one would hope – compared with, for example a dynamic B&W804 design .... I feel this is associated with my subjective characterization of the Quad treble mildly masking the depth and transparency, with a hazy veiled effect."

Such slow decay, with its associated masking of detail, can make 'nasty' recordings sound more 'pleasant' but it can rob the music of life, particularly good recordings which do not require such masking. And it is not 'high fidelity' to the original recording.

A good loudspeaker

What makes a good loudspeaker? For me it is one that reproduces all signals accurately (high fidelity) and allows one to get as close as possible to the original recording. And if it will do this for all music, given the wide range of music from simple acoustic music through opera to rock concerts, then it will certainly reproduce accurately all sounds from DVDs etc - provided of course it is fed accurate signals by equipment before it in the reproduction chain.

Music usually consists of at least one or more of the following elements:

1. melodies (tunes)
2. tonal 'colours'
3. dynamic contrast (micro and macro)
4. rhythm

For a loudspeaker to be high fidelity for the first 2 elements (tunes & tone) it must have a good frequency response. In general, I believe that well design panel and conventional loudspeakers are little different in this respect, at least for their on axis response where +&- 3 dB over most of the range of human hearing is not difficult to achieve and +&- 1 dB is possible in the best cases. For example, Legend's *Kumbar Wirri (Big Red)* conventional (dynamic) loudspeaker uses DEQX digital crossovers and room equalization to achieve +&- 1 dB from 20 Hz to 20 kHz but similar results could be achieved with panel loudspeakers using the DEQX processor. Therefore, for brevity, I will not discuss frequency response further (perhaps they may be the subject of a future article).

Speed of loudspeakers

The latter 2 elements of music (dynamics and rhythm) rely on a loudspeaker's 'speed' – what Linn used to call 'foot-tapping' ability. It is in this respect I believe that that panel & conventional loudspeakers most differ, but, as stated earlier in this article, not in the way suggested by planar-philes.

The 'speed' of a loudspeaker is characterized by how it handles a very short impulse of signal (music) fed to it by its driving amplifier. The results can be viewed in 2 parts:

1. the response to the initial rise of the impulse – its 'attack'
2. the response to the fall of the impulse – its 'decay'

Because part of the earlier part of this article deals with decay of panel loudspeakers I will be dealt with first, summarizing the conclusions for panel loudspeakers and looking in more detail at conventional loudspeakers.

Speed of 'decay'

As stated previously, I believe panel loudspeakers have relatively poor decay properties relative to conventional loudspeakers, in general terms if not for some types of music. This is ultimately due to their larger size and their non-rigid structure and is only partly compensated for by their (sometimes) lower mass.

Conventional (dynamic) drivers tend to be the converse. An attempt is made to keep them as small and as rigid as possible, so that they remain 'pistonic' over their operating frequency range and do not 'break-up' to form resonances which must then decay over time. They will then simply move in total unison with the supplied signal and have high fidelity with the supplied signal forces (music etc).

Low frequency resonance

Before I look at 'break-up' resonances of conventional cone and dome drivers at higher frequencies, I perhaps need to briefly distinguish this from the other sort of (pistonic) resonance to which they are subject at low frequencies. This latter is caused by the (rigid) mass of the cone/dome being attached to the (largely) elastic suspension that keeps the dome/cone in place. Just like a lead mass being attached to a spiral spring and then being displaced vertically, such systems have a natural frequency of oscillation (its resonance frequency) that depends on mass and stiffness.

If the mass is increased and the stiffness of the spring suspension is reduced, this pistonic resonance frequency decreases – this is the principle behind conventional bass drivers that go down to low frequencies. In principle, such resonance is subject to the problems of slow decay of energy discussed earlier. However, it is rarely a problem in practice except in badly designed dynamic drivers. The energy is quickly dissipated partly viscously by the suspension (as measured by its 'mechanical quality' Qm) and partly by electrical damping (as measured by its 'electrical quality' Qe). When properly designed, these can combine (measured by its total Qt) to damp out the resonance. For example, if Qt=0.5 then the system is 'critically damped' and no resonance occurs. – and the system will sound 'fast' at low frequencies.

Note that in practice that, as discussed earlier, such conventional bass drivers are mounted in (more or less sealed) boxes so that the sound waves emitted from the rear of the driver not to cancel those emitted from the front. However, by putting them in a (more or less sealed) box, the elastic stiffness of the resonant system is then usually dominated by the stiffness of air being compressed in the box, rather than the elatic suspension of the driver. Thus the resonant frequency will rise and the bass does not go as low – unless the box is made very large.

I have used the phrase '(more or less sealed) boxes' because they can have small ports which generally do not allow the rear waves escape - only at certain frequencies which, because the port inverts their phase again, mean that they actually add rather than cancel. But this addition only occurs over a small frequency range just below resonance and so slightly extends the bass response at low frequencies. However, ports add extra resonance to the system and so they do not sound quite as fast as totally sealed boxes.

High frequency resonance

The other sort of resonance to which cones/domes are liable at higher frequencies is 'breakup' i.e. the cones/domes cannot keep up with the signal forces being imposed on them and they vibrate more or less uncontrolled by the signal forces. This is the same sort of behaviour discussed earlier for panel speakers and likewise depends on the physical dimensions of the driver, their stiffness/rigidity and density/mass. However, where conventional cones and domes can win out over planar drivers is that they are generally smaller and can be made much more rigid, which more than compensates for their (sometimes) larger mass.

Indeed much of the improvement in conventional 'dynamic' drivers over recent tears has come from using better cone/dome materials. These materials include Kevlar and carbon fibres, either separately or in combination; light strong metals such as aluminum, magnesium and beryllium alloys; and more recently ceramics and diamond polycrystals. All these materials allow the domes or cones of conventional 'dynamic' drivers to be made lighter and stiffer so that their 'breakup' resonances occur at higher frequencies. The drivers can be used over a wider range of frequencies in their purely pistonic (non-resonant) high fidelity mode.

The shape of the domes/cones is also important in their superior resonance characteristics over planar drivers. As is well known, an arch is stronger (stiffer) than a planar surface – and a dome is just a 3-dimensional arch. Unfortunately, such domes tend to become very bulky for large, low frequency drivers and they are then sort-of turned inside-out so that the curved surface is concave rather than convex. This is not as rigid as a dome – but still much more rigid than a planar surface (of the same diameter and thickness).

Thi above theory is backed up by some recently published 'waterfall' decay measurements by Olson. These show that a modern well designed conventional dynamic driver, such as Eton's 100mm cone unit, has faster decay than a planar driver over much of its operating range. Eventually at higher frequencies where the cone does start to 'break-up' then the decay is less good – and this driver must be 'crossed over' to a smaller more rigid dome tweeter. Much of the art of designing good conventional loudspeakers is deciding how this 'cross-over' is implemented – as well as the original choice of the drivers.

Speed of 'attack'

Having considered 'speed of decay' let us now consider the 'speed of attack' i.e. how quickly the speaker driver reacts to an incoming signal. Actually this 'speed' is really its 'acceleration' under the signal forces. And elementary physics teaches us that acceleration = force/mass i.e. acceleration increases as the force increases and mass decreases.

Planar speakers can have lower mass than conventional drivers, though this is not always the case. For example, a modern polymer or light metal alloy dome tweeter may be just as light, even lighter, than some magnetic planar speakers. However, electrostatic membranes will generally be lighter than most conventional drivers.

But electrostatic speakers can only generate weak forces. This is demonstrated by the low maximum sound pressure levels (SPL) that electrostatic speakers can generate before arcing between the membrane and fixed plates occurs. The review of the Quad ESL-989 in *Stereophile* (2002) found that this was as low as 85 dB under some conditions and only 95 dB under the best conditions. The reviewers concluded that they were fine for simple music by had difficulty coping with complex music.

The force on the electrostatic membrane is proportional to the applied voltage (Fe=qE/d where q is the charge on the plates, V=voltage and d=distance between the membrane and the stator plate). If this voltage cannot be increased because of arcing, then the force is necessarily limited. Thus the speed of attack is also necessarily limited in addition to the dynamic range (maximum SPL).

Conventional drivers, even though they may have higher masses, can also generate much higher magnetic forces (Fm) – basically by increasing the length of wire (l) or current (i) in the magnetic field (B) where Fm=Bil. This leads to higher dynamic range (SPL levels over 110 dB) as well as higher speeds of attack.

Other resonances in conventional loudspeakers

Conventional loudspeakers are often criticized by planar-philes for two other types of resonance - of the cabinets holding the drivers:

1. resonances of the cabinet panels

2. resonances in the air column inside the cabinet (standing waves).

In both cases I believe they can be made much less than the resonance of the diaphragms of planar loudspeakers.

Cabinet panel resonances

These are similar in source to resonances of the drivers themselves – any solid body with some elasticity will have natural frequencies of vibration (just like a mass on a spring). The frequencies and extent of the resonances will depend on the size, shape, stiffness, density and damping of the panels.

They are rarely a major problem with well designed and built speaker cabinets, a conclusion often verified by John Atkinson of *Stereophile* when he attaches measurement probes (accelerometers) to the cabinet panels. It just requires that the panels have asymmetric shapes, are of sufficient thickness, well braced and of rigid, high damping material. One of the best materials is fibre-board (MDF) because it combines the stiffness of wood fibres with the damping properties of the glue that holds the fibres together. Other good composite materials used in high-end speaker cabinets include polymer concretes.

It should also be noted that planar speakers are themselves not free from potential resonances of this type – of the structures and frames that must hold the membranes and diaphragms in position.

Standing waves

The other type of resonance, standing waves in the air column of the cabinet, will not affect open-backed planar loudspeakers. But nor are they really a problem in good conventional loudspeakers.

Standing waves are caused by sound waves from the rear of the drivers as they are radiated into the cabinet being reflected by parallel surfaces inside the cabinet. When of the required frequency, the reflected waves reinforce the incident waves and 'standing' waves build up with increasing (resonant) energy.

When designing the *Keltic* loudspeaker at Linn Products in Glasgow, I did some measurements on these standing waves by inserting a microphone a various positions inside the cabinet. I found that the standing waves could be reduced to negligible levels by breaking up the cabinet volume, making the cabinet walls non-parallel and by adding sufficient damping material inside the air column. The damping could be foam lining the cabinet surfaces to reduce the reflections and fibrous material such as fiberglass or, better, fluffed-out wool in the air column.

Conclusions

I therefore believe that there is very little evidence that planar loudspeakers are 'faster' than conventional loudspeakers. To the contrary, I believe all the real evidence, both theoretical and measurement, favours conventional loudspeakers in this regard. The higher SPL levels as well as higher speeds of attack and decay of conventional speakers give them greater dynamic range and rhythmic ability – which is why they are sometimes referred to as 'dynamic' speakers.

In addition, I believe that the real reason some people prefer planar loudspeakers is that their relatively slow speed of decay mimics some acoustic instruments and their open-back leads to reverberant sounds fields that are psycho-acoustically interpreted as 'pleasant', 'sweet' or 'full-bodied'. However, such reverberation is ultimately 'distortion' and not 'high-fidelity' in the sense of being true to the original recording. And if it leads to Peter Gabriel's *Sledgehammer* sounding 'nice' then it is plain wrong.

If people require 3 tea-spoons of sweetness to be added to a particular recording (or even most of their recordings), such reverberation would be better added in the digital or pre-amp stage during playback where it can be better and more discriminately controlled. And then they can stick to good dynamic loudspeakers which are fundamentally more accurate and "high fidelity".