Getting the bass right

The rules of good bass don't change much between stereo and surround sound applications. JOHN WATKINSON suggests that this is because the human ear is the same in both cases.

IF WE ARE GOING to reproduce sound properly, the criterion has to be that the system is as accurate as human hearing. Thus I make a habit of attending perception conferences at which it is relatively easy to find the appropriate psychoacoustic research. I soon learned that realistic loudspeaker reproduction requires reproduction of the input waveform, which seems somewhat obvious. I have yet to see a representative of a professional loudspeaker manufacturer at one of these conferences and I wonder how much this has to do with the poor performance of the traditional loudspeaker.

Rice and Kellog of General Electric developed the moving coil loudspeaker we know today in 1925 before going on to develop breakfast cereals. They knew then that it has a fundamental resonance and that its response below resonance drops sharply. Early loudspeaker designers were backed into a corner because if they tried to make the cone light to get higher efficiency, the resonant frequency would rise and spoil the bass response. Unfortunately they needed high efficiency because power available from vacuum-tube amplifiers was limited.

The solution to the problem they then had was to adopt resonant techniques such as the reflex principle. A mass of air in a port is made to resonate with the compliance of the air in the enclosure. If the resonant frequency is set below the resonance of the drive unit, the frequency response is augmented. In a transmission line speaker, a long duct with an open port is placed behind the woofer and delays the back wave from it. This duct is so long that at the frequency the transmission line is designed to augment, by the time the sound emerges from the port the woofer is on the next half-cycle and so the port radiation and the woofer radiation are in-phase and augment. This delay-and-add mechanism is essentially an acoustic comb filter and one response peak is set to augment the falling response of the drive unit.

The response of a drive unit in a large sealed box or baffle above resonance is 180 degrees out of phase with its response below resonance. However, by the time the out-of phase condition is reached, the response is so low that there is little audible effect. The rate of change of phase and the LF response are opposing functions of the magnet strength. There thus evolved two camps of woofer design: those with strong magnets, having better transient accuracy but worse LF response, and those with weaker magnets having good LF response but poor transient response. However, the poor transient response of a sealed box with a woofer having a weak magnet pales into insignificance alongside the wholesale demolition of the waveform that takes place in reflex, bandpass and transmission line speakers.

This is revealed in the phase response, which is really quite terrifying. Traditional manufacturers deal with this in three ways. The first is not to publish the phase response. The second is to claim that the ear is phase deaf. The third is to claim that Watkinson has finally lost his marbles. These are, of course, political solutions by which the laws of physics remain completely unimpressed.

It is now well established that in order to circumvent Heisenberg's uncertainty theorem, the ear changes mode during the perception of a sound. During the bulk of a periodic sound, the ear works in the frequency domain to analyse timbre and in this mode it has little knowledge of the phase relationships between the components. However, during the onset of a sound the ear works in the time domain and uses the waveform to establish the size and location of the source. It is this aspect of perception that requires loudspeakers to be phase linear. Adherents of electrostatic loudspeakers will tell you how much more realistic they sound than conventional speakers. Some of this is due to the fact that electrostatics are phase linear.

A loudspeaker is a communications channel because information passes through it. Communications theory suggests that sine waves carry no information because they have no bandwidth. Thus most of the information in audio is in transients. This is consistent with our knowledge that audio signals have a high peak to mean ratio.

How, then, do we make a linear phase loudspeaker? By treating it as a system from line level in to sound out. Obviously it has to be active and to contain signal processing that removes the phase and amplitude response disturbances due to the fundamental resonance of the woofer. The simplest system to correct in a signal processor and the easiest to make physically is the sealed box or infinite baffle.

The technology is the easy part. The hard part is thinking outside the box. First, we have to recognise that material and technology restrictions that led to the adoption of resonant techniques no longer apply and that it is only tradition that sustains their use. Second, it is important to realise that the cost of advanced materials and technology continues to fall so that there is no economic penalty. For example, the cost of Neodymium magnets has fallen to one half of what it was when I started using them. Third, it is important to look at the whole picture. The traditional manufacturer who buys drive units and puts them in a box would see a woofer with a neodymium magnet as a cost increase. However, the manufacturer of an active speaker

would see that the greater efficiency of the neodymium drive unit allows him to fit a smaller amplifier and power supply for the same SPL and thus sees it as an advantage.

Once a linear-phase woofer is available, it becomes possible to make some meaningful experiments in bass management. It is soon revealed that a separate subwoofer with all LF mixed into it is inferior to each loudspeaker emitting its own LF. This is the reverse of conventional wisdom, which suggests that subwoofers can be put anywhere. If you look at the surround sound research which showed subwoofers could be put anywhere, you will find that the subwoofers used were not phase linear and nor were the crossovers. In other words the timing of the sound from the subwoofer was subject to so much linear distortion that it would be wrong wherever the subwoofer was put.

It should be clear that the waveform is only reproduced properly when the woofer and the rest of the transducers are at the same distance from the listener. When the woofer is phase linear, it also reveals that there is directional information at LF that a common subwoofer destroys. Thus for precision, the LF should be emitted from the same enclosure as the rest of the sound. It seems clear in theory and in practice that full range loudspeakers give better surround performance than small speakers with a separate subwoofer. It seems to me that the separate 0.1 subwoofer channel in DVD is simply there because of traditional cinema practice.

In the cinema the goal of LFE is to stun the audience. In the cinemas I've been to, all the low frequency effects sound exactly the same because one is hearing the impulse response of the subwoofer and the movie soundtrack simply excites another thud. As I've mentioned before, realism is excluded from Hollywood because it interferes with the escapism. This is probably not important for the application, but for those of us who might be trying to reproduce classical music in surround, using a LFE channel would be inferior to mixing full bandwidth main channels. Monitoring full bandwidth main channels with a subwoofer doesn't allow the engineer to hear what directional information is present at LF.

Thus it seems a solution is to have a subwoofer and crossovers that can be enabled or disabled. For precise work, just the main speakers are used with full bandwidth. In order to listen to material with 0.1 content in its native form, the subwoofer could be activated and the bandwidth of the main monitors would be restricted.

With precision loudspeakers, 5.0 sounds better than 5.1 and 4.0 sounds better still. Why are we using all these extra speakers to make the sound worse? Must be tradition. ■

GETTING GOOD BASS:

- **Realistic loudspeaker reproduction requires reproduction of the input waveform.**
- **To prevent audible phase distortion, loudspeakers must be phase linear from their lowest frequency up to at least a few kilohertz.**
- **Use full range loudspeakers for surround in preference to common subwoofers.**
- **Use sealed enclosures: no port – no hangover.**

AVOID THE FOLLOWING:

- **Reflex, bandpass, ABR and transmission line speakers that cannot reproduce the input waveform and which cause serious phase distortion audible as poor LF resolution and hangover.**
- **Passive moving coil loudspeakers driven from general-purpose audio amplifiers that cannot be phase linear.**
- **0.1 subwoofers that destroy low frequency directional information. LFE means low frequency effects; and it is an effect, not a reproduction.**

REMEMBER:

- **Tradition is an easy alternative to thinking what to do.**
- **The difference between many of today's loudspeaker designers and those of 50 years ago is that back then designers understood the basics but didn't have access to advanced materials, whereas today it is the other way round.**