Moving Air

The multiple challenges of subwoofer design

AN INTEGRAL PART OF MOST MULTICHANNEL SYSTEMS, SUBWOOFERS DIVIDE OPINION WHEN IT COMES TO MUSIC IN STEREO. KEITH HOWARD CONSIDERS THEIR PROBLEMS

Today's design imperative to make loudspeakers more sensitive than their forebears has had a number of less welcome consequences. Major among them is that, as designers have lowered impedance in order to up sensitivity, so they have made loudspeakers, as a whole, significantly more difficult to drive than were previous generations (some notable exceptions apart). Throw it over the fence and make it the amplifier designer's problem seems to be the mindset of many.

A second casualty has been bass extension: in any given speaker design, sensitivity and bass extension have to be traded off because high sensitivity and low bass corner frequency are mutually exclusive. If greater emphasis is placed on sensitivity then bass extension must suffer.

A decade or two ago the solution seemed simple: add a subwoofer to fill in the lower audible octave or so. It's a plausible answer still, and subwoofers continue to have enthusiastic proponents. PS Audio co-founder Paul McGowan is a prominent example: in his daily blog he often mentions the importance of reproducing the lowest audible frequencies.

To a degree he and others like him are probably preaching to the converted: most audiophiles, I imagine, either know or at least believe that low-bass capability is desirable. And yet it seems the enthusiasm there once was for subwoofers has waned. Is it simply that fashion has turned against them? Or that audiophiles believe better bangs for their buck are to be had by investing elsewhere? Or could it be that – in an attempt to be as inconspicuous as possible – subwoofers have failed to deliver on every important facet of performance and too often disappointed, if subtly, as a result?

I suspect that last reason forms at least part of the explanation because designing a really good subwoofer is not a walk in the park. And designing one which fits into so small a box that you can more or less hide it away – yet which is still able to deliver the very best sound quality – may well be asking the impossible.

Making Yourself Heard

A fundamental problem of subwoofer design is moving enough air. There are two aspects to this challenge: physical and psychoacoustic.

For simplicity's sake let's consider a closed-box subwoofer for the moment, meaning one unaided by a reflex port or auxiliary bass radiator (ABR) – items that we'll get on to later. In order to maintain flat acoustic output (*ie* constant sound pressure level versus frequency), the diaphragm of such a subwoofer has to increase the volume of air it displaces four-fold for every halving of output frequency. In other words, cone excursion at, say, 20Hz must be quadruple that one octave higher at 40Hz. And 16 times greater than at 80Hz.

If we put hard figures to the cone excursion, we quickly see how burdensome this requirement is. Let's assume we want to achieve a modest 90dB SPL at 20Hz at 3m listening distance – ignoring, for now, any room effect – and we have a subwoofer (or main speaker) with a 12-inch bass driver. What is the required cone excursion? Taking the effective piston diameter to be 250mm (pretty typical for a 12-inch driver), the answer – shockingly – is just over 36mm peak (i.e. one way) or double that, 72mm, peak-to-peak (both ways). Bear in mind here that most bass drivers have a maximum linear excursion capability of 8 to 10mm, and even specialist subwoofer drivers rarely exceed 20mm peak (40mm pk-pk).

Loudness is relative

You might suppose that 90dB SPL is actually pretty loud, but at 20Hz it isn't. At 20Hz the loudness of a 90dB SPL tone is roughly 21 phon, *ie* about that of a 1kHz tone at 21dB SPL – which is probably quieter than the background noise in your listening room. This is the second, psychoacoustic problem I mentioned: the fact that the human ear is much less sensitive at low frequencies than it is at higher frequencies. As the equal loudness contours from ISO 226:2003 show (Figure 1), to achieve 90 phon at 20Hz requires about 124dB SPL – at which the cone of our poor 12-inch driver would be moving back and forth by about 3.5m total!