Current Affairs

In his latest technical exposé Keith Howard examines the theories of speaker impedance and tests out how these can be accurately measured to prove conventional hi-fi wisdom

Around 20-odd years ago there was a flurry of activity in audio's more academic circles trying to bridge a yawning divide that had split the hi-fi industry during the 1970s. At the start of that decade the world of high-quality audio was as well ordered as a Victorian drawing room. Equipment reviews in hi-fi magazines were based around a few standard measures of performance and quality, and on the basis of those figures a conclusion was reached as to the item's worth. If a new amplifier delivered 40 watt into 8 ohm at 0.01% total harmonic distortion and did so for three quid less than its competitors, plaudits were assured.

But during the 1970s a growing number of voices were raised in protest. Actually the foundations of what was to become known as subjectivism were laid much earlier, but it was during the mid-'70s that the idea really took hold. Around the world, a cadre of manufacturers and reviewers overturned audio's applecart by claiming that measurements told you little of how a piece of equipment performed in its primary role of reproducing music and were, therefore, little better than useless.

Suddenly it wasn't necessary to own a lab full of expensive measurement gear to pontificate on equipment quality. Reviews that were based solely on listening impressions become increasingly common, and concepts like musicality moved the assessment of hi-fi equipment to a new dimension.

A lot of traditionalists cried foul, and so was established the subjectivist-objectivist divide, across which were lobbed – and occasionally are still lobbed – barbed comments from propagandists on either side. It was to build bridges across this rift that various novel distortion mechanisms were exposed during the late '70s and early '80s, in the hope that they might offer at least partial reconciliation of measurement and listening experience. In the vanguard of this was Matti Otala, a Finnish academic who, among other things, introduced the terms transient intermodulation distortion (TID or TIM) and interface intermodulation distortion (IID) to the audio lexicon.

DIFFICULT TO DRIVE

Otala's primary interest was amplifiers, which inevitably led him to consider why it was that certain loudspeakers had a reputation for being difficult to drive. There was a growing consensus that a good power amplifier should have prodigious output current capability but it wasn't clear why.

On the face of it Ohm's Law made the calculation of output current requirement a simple one: if, for instance, you wanted an amplifier rated at 70 watt into 8 ohm to be able to deliver its full voltage output capability into a 4 ohm load then its output stage would need to deliver a peak current of 8.4 amps. Where was the mystery in that?

Matti Otala and two colleagues, Ilpo Martikainen and Ari Varla, answered that question in 1983[1] in one of those delicious moments of audio history where a prevailing certainty is suddenly undermined. What Otala and his co-workers showed was that if a complex impedance, such as that presented by most loudspeakers, is subjected to the right (or wrong) input signal, its effective impedance can, for short periods of time, be much lower than revealed by conventional steady-state measurements.

An example, based on a much-simplified simulation of the impedance presented by a moving-coil loudspeaker, is shown in Figure 1. Here the blue line represents the current in a pure resistance equal to the speaker's voice-coil resistance, while the red line shows the actual current through the speaker. Current in the latter case peaks at about three times that in the resistive load.

Here, it seemed, was an explanation for the observed importance of amplifier current capability. If an amplifier with just sufficient output current to drive the resistive load of Figure 1 were used to drive the speaker load instead, it

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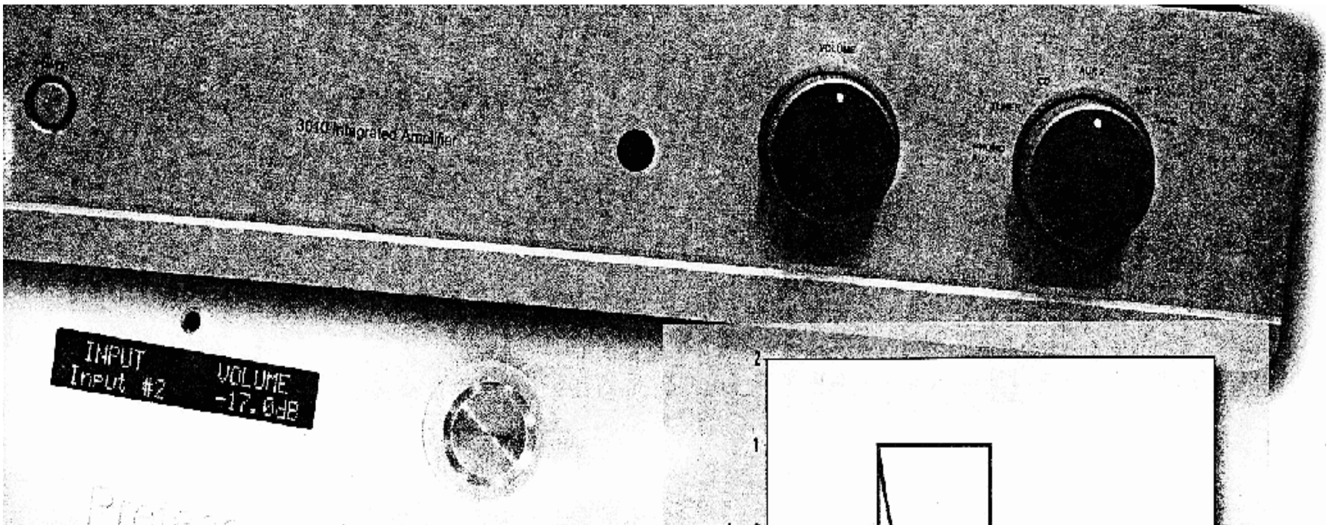


would clip the current peaks on this type of signal and in all probability sound inferior as a result. In a follow-up paper, Otala and another co-worker tested three speaker systems from Infinity, Yamaha and Heco and found that, on the worst test signal they could devise, these would draw peak currents of 6.6, 3.8 and 5.1 times greater respectively than an 8 ohm resistance[2].

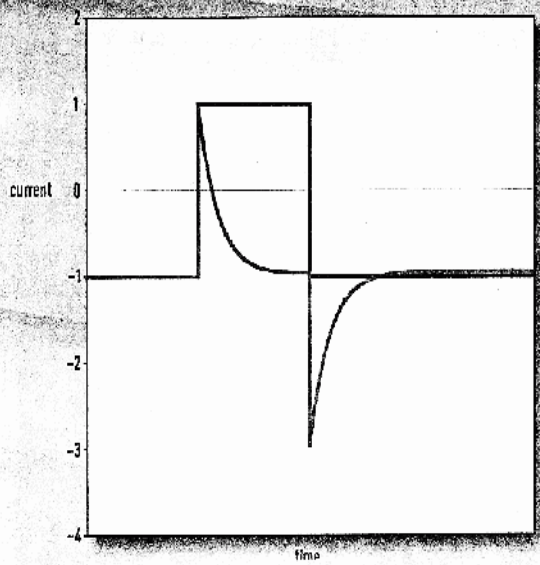
Shortly thereafter other researchers demonstrated a method for calculating peak current draw from a speaker's conventionally measured impedance characteristic[3] (rather than determining it by trial and error), and this method was then developed into a (just) practicable measurement technique[4].

'In 20 years nobody has tried to verify if speakers draw unexpectedly high currents on music signals'

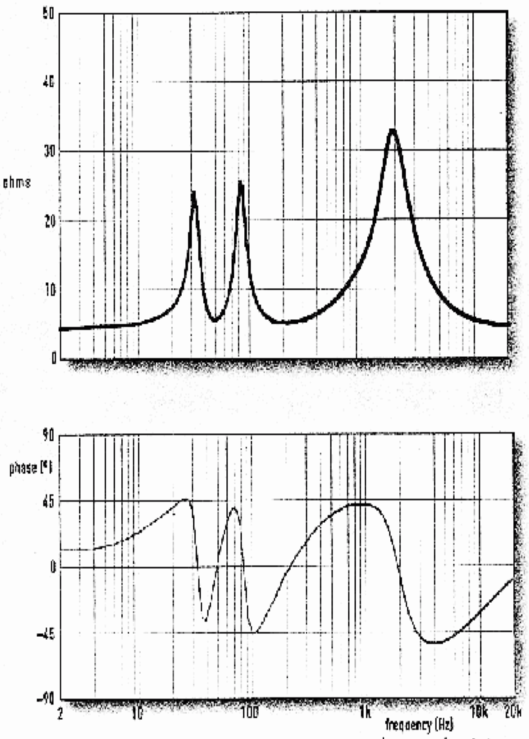
Exciting as this all seemed, from the outset questions were raised about the validity of Otala's findings to the replay of music signals. It was all very well synthesising a square-edged test signal with transitions timed in such a way as to cause inflated current draw, but did such signals actually occur within music programme and if so how often? It was crucial to Otala's thesis that these unexpectedly large current flows would occur in the course of replaying music, and that they would occur sufficiently often to present a practicable problem.

But Otala never demonstrated that this was actually the case, and neither did Vanderkooy and Lipshitz in their paper on how to compute a speaker's peak current demand. Their paper did include an example waveform, culled from a CD, which was square-edged enough to resemble Otala's test signals but, as the authors noted, this was almost certainly due to clipping somewhere within the recording chain. The irony of invoking an already clipped signal as a valid example of one that might cause amplifier current clipping downstream was apparently lost on them.

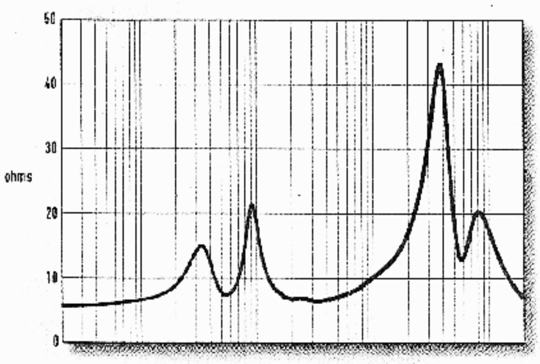
I find it hard to believe that, in the 20-year interim, nobody has attempted to verify



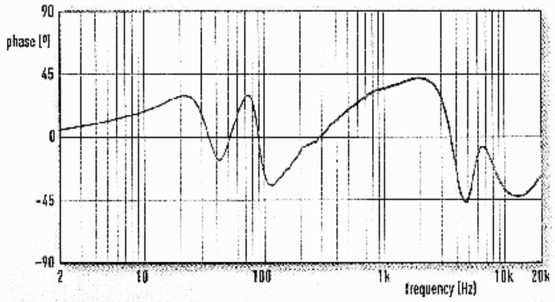
ABOVE: Fig 1. Simulation of excess current draw by a simplified speaker load impedance. The blue trace represents the current in an equivalent resistance, the red trace that drawn by the simulated speaker load, the peak value of which is three times greater



ABOVE: Fig 2. Graphs showing impedance modulus (top trace) and phase (bottom trace) for the B&W 805 speaker used in the testing

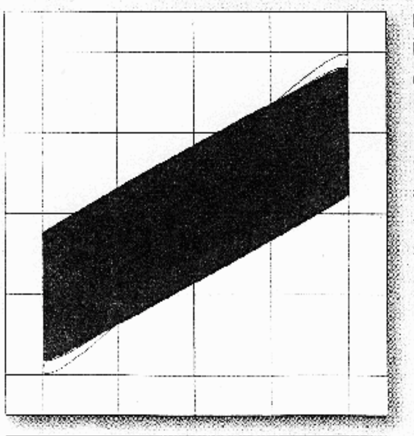


LEFT & BELOW: Fig 3. Graphs showing impedance modulus (top trace, left) and, below, phase (bottom trace) for the MonoPulse Model 22 speaker

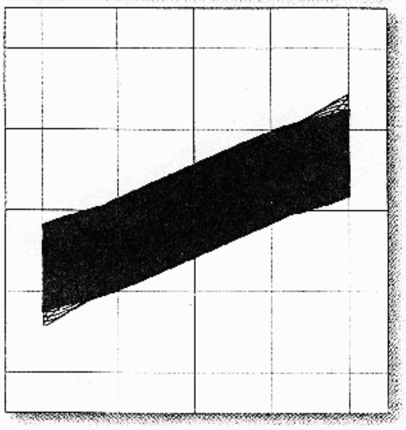


whether or not speakers draw unexpectedly high currents on music signals, but if they have then I'm unaware of it. Those who have raised doubts about the significance of Otala's findings on real world music signals, such as the late Peter Baxandall[5] and Douglas Self, have done so on the basis of observing music waveforms for sections that resemble Otala's test signals, and failing to find them. This barely comprises hard evidence, so how can the issue be settled?

The first thing to appreciate is that it is impossible to determine a loudspeaker's instantaneous impedance on the basis of the voltage across and current flowing through its terminals. In the case of a resistive load, where the voltage and current waveforms are always in-phase, dividing the instantaneous voltage by the instantaneous current will give the resistance value, provided that the signal's zero crossings are avoided. But this is not the case with a complex impedance, like that of a loudspeaker, where there is generally a phase difference between voltage and current, and the two waveforms are consequently out of step. In this case dividing instantaneous voltage by instantaneous current gives nonsense results.



LEFT: Fig 4. Calculated load line traces for the B&W 805, calculated from the data of Figs 2 and 3 respectively. Instantaneous voltage is plotted on the horizontal axis, instantaneous current on the vertical axis, and the scales are chosen such that a 4 ohm impedance produces a load line at 45 degrees



LEFT: Fig 4. Calculated load line traces for the Model 22, calculated from the data of Figs 2 and 3 respectively. Instantaneous voltage is plotted on the horizontal axis, instantaneous current on the vertical axis, and the scales are chosen such that a 4 ohm impedance produces a load line at 45 degrees

CHARACTERISTICS

By borrowing a technique used by Baxandall[5], in which instantaneous voltage and current are plotted on an XY graph, we can perform a much more relevant measurement. To introduce this, let's first look at the conventionally measured impedance characteristics of the two loudspeakers that we're going to test here using music programme: the B&W 805 and MonoPulse Model 22, which were chosen because they were both on hand awaiting review.

The impedance modulus (magnitude) and phase versus frequency for the B&W are shown in Figure 2, and for the MonoPulse in Figure 3. Using these results we can calculate a load line for the loudspeaker at each of the frequencies at which the modulus and phase were measured, and plot this on an XY graph where the horizontal axis represents voltage and the vertical axis represents current. Except at those few frequencies where the speaker presents a purely resistive impedance, each load line will be an ellipse and superimposing them across the measured frequency range gives the results shown in Figure 4. The axes are scaled here such that if the impedance modulus is 4 ohm then the major axis of the load line ellipse will lie at 45 degrees to the horizontal.

If Otala was right and these two speakers do present an unexpectedly low impedance on certain signals – and if, just as importantly, those signals are of high enough amplitude to cause unexpectedly high currents to flow – then if we plot instantaneous voltage versus current with the speaker playing music programme we can expect to see results falling beyond the area occupied by the load lines in Figure 4.

Alternatively, if the traditional measurement of loudspeaker impedance accurately represents the speaker load encountered in practice, then the plot of instantaneous voltage and current will stay within the load line envelope.

It's an inescapable problem of doing such a measurement that you can never be certain whether you have chosen a piece of music that will expose a particular loudspeaker's worst impedance behaviour. Otala's test signals had to be individually tailored to each speaker, which means that every speaker will behave differently on a given music signal. By choosing music which combines strong bass and treble content we stand a good chance of observing any tendency to excess current draw.

'By choosing that combines strong bass and treble content we stand a good chance of observing any tendency to excess current draw'

With this in mind I chose two tracks for the testing: Jennifer Warnes' 'Way Down Deep' (from *The Hunter*, Private Music 261974) and Jim Keltner's 'Drum Improvisation' (from *The Sheffield Lab Drum & Track Disc*, LIM XR 005). These were

READING REFERENCES

1) M. Otala et al, 'Input Current Requirements of High-Quality Loudspeaker Systems', Preprint 1987, 73rd AES Convention, March 1983 (available from www.aes.org)
2) M. Otala and P. Huttunen, 'Peak Current Requirement of Commercial Loudspeaker Systems', Preprint 2293, 79th AES Convention, October 1985 (available from www.aes.org)
3) D. Preis and J. Schroeter, 'Peak Transient Current and Power into a Complex Impedance', Preprint 2337, 80th AES Convention, March 1986 (available from www.aes.org)
4) J. Vanderkooy and S. Lipshitz, 'Computing Peak Currents into Loudspeakers', Preprint 2411, AES 81st Convention, November 1986 (available from www.aes.org)
5) P. Baxandall, 'Amplifier Output Related to Loudspeaker Requirements', Journal of the AES, vol 36, no 1/2, Jan/Feb 1988 (from www.aes.org)

replayed, in mono, through each of the two speakers, with the signal current monitored via a 0.11 ohm series resistance. Voltage and current waveforms were recorded as 16-bit, 44.1kHz Wave files via a Lynx Audio Technology L22 sound card and the results analysed and graphed by software written specifically for this article.

Together these two tracks comprise almost 13 minutes of music, equivalent to about 34 million voltage-current measurement points for the analysis. A Rotel RA-1062 was used to drive the speakers, with its volume control set such that it would deliver 20 volt peak on a full-scale input.

CURRENT DRAW

The results are shown in Figs 5 and 6 (B&W 805) and 7 and 8 (MonoPulse 22). In each case the blue line represents the envelope of the load lines from Figure 4, and the speckle pattern of red dots represents the combinations of voltage and current measured while replaying the chosen tracks.

Fig. 5 shows the result from the 805 playing the Jennifer Warnes track. All the red points are contained within the blue envelope with the exception of a few that just bust the positive voltage limit, probably due to signal-related changes in the speaker's voice-coil resistance. There is no indication here of unexpected current draw.

Much the same applies to Figure 6, obtained from the 805 playing the Keltner drum improvisation. In this case there are a couple of red dots just outside the upper and lower bounds of the blue envelope but only just (these will probably be invisible in the printed version of the graph). The MonoPulse is even better behaved, with no excess current episodes recorded on either music track.

It's important to repeat that these results cannot be definitive because there may be other pieces of music that would cause these speakers to behave differently. Moreover, there may well be other speakers that are more prone to episodes of excess current draw. Vanderkooy and Lipshitz's work suggested that three- or four-way speakers are likely to have lower instantaneous impedance than two-ways, so the two two-way speakers assessed here may not be the most prone to this effect. As other speakers come my way I'll measure them to see whether substantially different results are obtained.

That said, on the basis of these results it looks as if Otala's whistle-blowing on the subject of speaker impedance was an interesting academic episode but of little relevance in practice. There is no evidence here that traditional steady-state measurements of speaker load impedance underestimate a speaker's hunger for current, or that they should be junked for something more exotic. □

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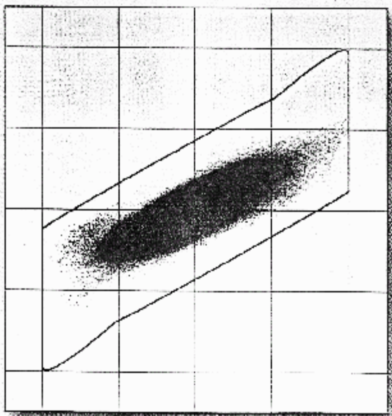
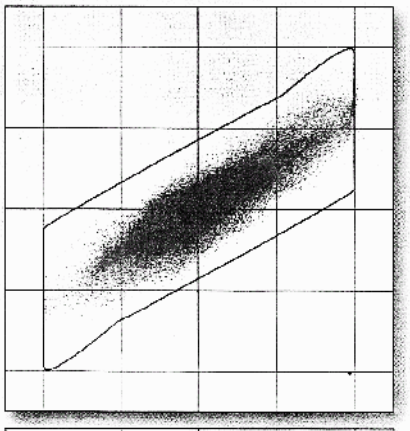
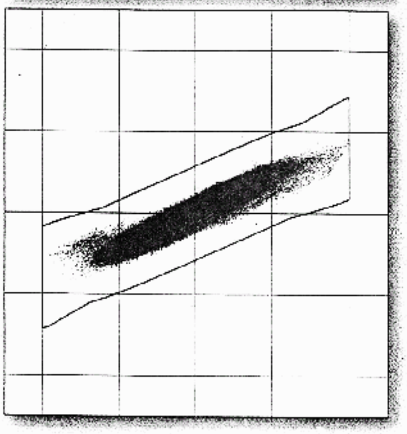


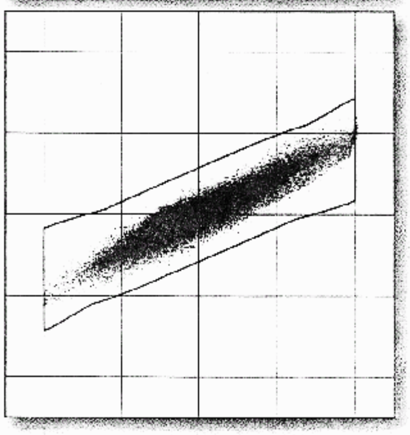
LEFT: Fig 5. Instantaneous voltage across and current through the B&W 805 speaker playing Jennifer Warnes' Way Down Deep (red trace), with the speaker's load line envelope included for reference (blue trace)



LEFT: Fig 6. Instantaneous voltage across and current through the B&W 805 playing Jim Keltner's Drum Improvisation (red trace), with the speaker's load line envelope included for reference (blue trace)



LEFT: Fig 7. Instantaneous voltage across and current through the MonoPulse Model 22 speaker playing Jennifer Warnes' Way Down Deep (red trace), with the speaker's load line envelope included for reference (blue trace)



LEFT: Fig 8. Instantaneous voltage across and current through the Monopulse Model 22 speaker playing Jim Keltner's Drum Improvisation (red trace), with the speaker's load line envelope included for reference (blue trace)