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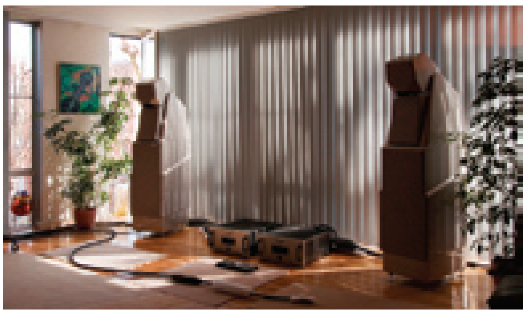

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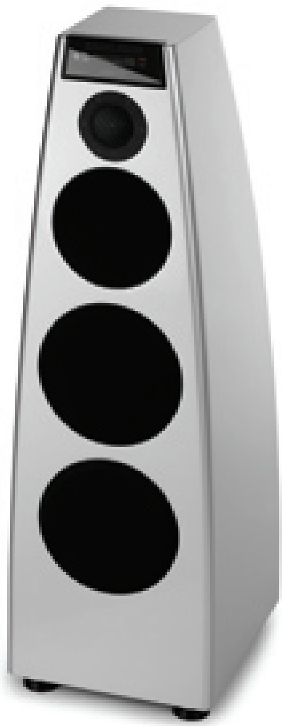

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Milind Kunchur

MEASURING WHAT WE VALUE OR VALUING WHAT WE CAN MEASURE?
AN INTRODUCTION TO THE WORK OF MILIND KUNCHUR. BY GEORGE FOSTER

GEORGE FOSTER

Imagine you are inside a large metal bin. There is a cotton sheet stretched over the opening. Passers-by throw tennis balls onto the sheet. The balls are of different hardness, arrive at different velocities and come from different directions. Some are thrown directly at your sheet; others are tossed on at random. From the impact of the balls you have to identify the individuals throwing them, pinpoint their location, recognise their direction and interpret their attitude toward you. And you have to do all this instantly.

Recognise the process? This description, based on one in Daniel Levitin's book *This is Your Brain on Music*, is an illuminating insight into the complexity of the brain's task in processing the impact of molecules of air against our eardrums. (It's a sobering thought that if my ancestors had not developed these capabilities in their hostile natural environments, some predator would have eaten them, and I wouldn't be around to write this.)

The complexity of this natural attribute is often overlooked, and there's a tendency in hi-fi to underestimate the importance of the brain in listening, because it's notoriously difficult to measure what goes on in your head, particularly when it comes to hearing. Frequently someone claims to hear subtleties that other people either cannot hear, or even refuse to believe exist. The differences between CD transports feeding the same DAC, or sound differences across a range of cables, fall into this contentious group. A debate starts; measurements and proof are demanded; accusations of deafness and charlatanism are hurled; and if the moderators don't step in, then it's pistols at dawn. The internet is full of such examples (the *HIFICRITIC* Forum being, of course, a rare exception).

Bluntly, some members of the hi-fi community place excessive value on the things they can easily discover (amplitude *vs* frequency being the easiest and most common), rather than discovering how to measure what we value in our listening, like musicality, rhythmic quality and pleasure. The evidence, even the proof, must be out there – we just don't, most of the time, have the theory, capacity or equipment to deal with it.

The frequent dismissals of anecdotal listening reports in favour of hi res audio replay are a case in point. A 96 year old neighbour of mine could hear the differences between CD and SACD, and between digital and vinyl sources, though his hearing probably had an upper ceiling of less than10kHz. When tested a few years ago my own hearing was limited to 15kHz, while CD has an upper limit of 20kHz and SACD typically 45kHz. I can't hear dog-whistles, but I sure can hear the differences between CD and higher resolution formats. I can also hear when one CD transport plods through a Bill Evans' piano trio, which had just sounded delicate and swinging on another. I experience these effects, but cannot measure them or satisfactorily explain why in terms that would satisfy those members of the hi-fi community who demand double blind tests for all. I've come across people and writers who see issues which they cannot measure and explain as delusions or deceit, or even worse, as *anecdotal* – which now seems to mean the very opposite of scientific.

(Anyone remember the Guardian's "Bad Science" column on power cables? Be prepared to be incensed by: http://www.badscience.net/2006/01/sounding-out-the-hi-fi-kettle-leads/.)

Enter Milind Kunchur

Milind Kunchur is a physics professor at the University of South Carolina. Besides teaching a course called *Physics 155: Musical Acoustics*, he divides his time between researching superconductivity in nanowires (*ie* measuring tiny currents in tiny structures), and looking at the capabilities of the hearing system and the brain to process information, measuring the human perception of threshold differences. This work belongs to psychophysics, auditory neurophysiology, and not least high fidelity audio. Kunchur has an experienced group of researchers and has gone through rigorous procedures to test the capacities of listeners to perceive differences in the sounds of audio systems.

Kunchur is well published in US Academic Journals on the subject of High End audio (his website has a list of his publications almost as long as Martin Colloms'). These are mostly in subscription-only journals which charge you 35USD a time to download an article (unless you have access to a university library), but three free PDF downloads of relevant papers documenting his research group's findings may be found at: http://www.physics.sc.edu/kunchur/ (note 1)

Although Kunchur writes in an enviably clear style, these papers make for difficult reading, since they are published in peer reviewed academic

Kunchur sometimes likes to large it

journals where their scientific and statistical validity must be beyond reproach, and where much of the papers go into detail on the methodology used. However, I found them well worth the effort, because they changed my understanding and attitudes to sound, and signalled new directions for trying to improve my hi-fi system.

I will therefore attempt to summarise what Kunchur has found, and discuss some of the implications. I think that the intro to the first paper immediately explains why both I and that 96 year old could tell hi res digital audio from CD: it's the temporal resolution – not the frequency acuity – which we are experiencing, and although our ears have aged, our brains can still process the information with awesome accuracy. To quote Kunchur:

"Many misconceptions and mysteries surround the perception and reproduction of musical sounds. Specifications such as frequency response and certain common distortions provide an inadequate indication of the sound quality, whereas accuracy in the time domain is known to significantly influence audio transparency. While the upper frequency cut-off of human hearing is around 18 kHz (or even lower in older individuals), a much higher bandwidth and temporal resolution can influence the perception of sound. Non-linearities and temporal complexities in the auditory system negate the simple f ~ 1/t reciprocal relationship between frequency and time. In our group's research – which lies at the intersection of psychophysics, human hearing, and high-end audio – we measure the limits of human hearing and relate them to the neurophysiology of the auditory system. These experiments also help to define the criteria for perfect fidelity in a sound-reproduction system. Our recent behavioral studies on human subjects proved that humans can discern timing alterations on a 5 microsecond time scale, indicating that the digital sampling rates used in consumer audio are insufficient for fully preserving transparency."

Audibility of temporal smearing and time misalignment of acoustic signals (2007)

In this paper Kunchur looks for the minimum time differential that a range of subjects aged between 20 and 47 can detect. He does this by mounting two Aurum Cantus *G2Si* ribbon tweeters (much beloved by the DIY Audio community) at the far end of a 6.5m room. One tweeter is in a fixed position while the other, directly above it, can be moved backwards and forwards by remote control. To minimise difficulties with harmonics, he uses a 7kHz square wave as his stimulus, selected because its odd order products (*ie* 21kHz and above) are smaller than the single tone aural detection threshold pertaining in the presence of the 7kHz fundamental. Rigorously monitoring the accuracy of this tone, he then exhaustively works out how to quantify and compensate for strays – reflected signals and harmonics. This covers several pages of advanced maths that are beyond me, but which seem to establish the required credibility. After dealing with all the problems that might affect his results, he then tests a range of individuals for their ability to distinguish time smearing of the stimulus when the upper tweeter is moved out of alignment with the lower. Several pages are devoted to the methodology, its limitations (more on this later) and a thorough statistical analysis. He discovers that the minimum detectable misalignment is 2mm and that all subjects can detect 2.9mm. His subjects scored 80% detection for 2.3mm displacement. Calculated for time differential, this is less than 6μs – that's 6 millionths of a second, which is a much smaller figure than found in other published results.

Temporal resolution of hearing probed by bandwidth restriction (2008)

The second paper asks the same question about hearing but via a parallel route and is still denser and more technical. Instead of moving one tweeter in and out of time alignment, he tests the audibility of a low-pass filter applied to a 7kHz tone burst signal (a low pass filter incurs an inherent time delay). Again he arrives at near enough the same result: that 6μs is the best temporal resolution, and suggests this should be regarded as a parameter that is indicative of high quality sound reproduction.

However, he found considerable initial difficulty in trying to set up the test with digitally derived signals, as they were of insufficient 'quality' to achieve the required test sensitivity. It took several months of frustrating effort to solve the problem:

"In the present work, many different approaches were initially tried and abandoned, including using digital synthesis (with 24-bit/96kHz sampling) for the production and ramping of signals. It was found that such a digital method had far too inadequate temporal definition for this purpose. So instead an analog signal generator was used to produce a 7 kHz square waveform that had fast 20ns rise/fall times (a thousand times faster than the 23µs rise/fall times that characterize the 44.1kHz sampling rate of the digital compact disc)."

So in order to corroborate his first view about the inadequacy of most (if not all) consumer digital audio equipment standards, he has to go back to an analogue signal source and, as it turns out, he also ends up building much of the audio chain to a standard that will warm the heart of any DIY amplifier builder. In fact most ordinary switches and relays distorted the test signal sufficiently to impair the test thresholds, and the finest audiophile quality switches and hardwired connections had to be adopted.

He also adds a most measured and carefully worded criticism of other researchers who base their results on equipment with such inherent limitations: *"It is hoped that this result will bring awareness of the possible benefits of higher instrumentation bandwidths for certain psychoacoustic experiments…"*

Probing the temporal resolution and bandwidth of human hearing (2008)

The third paper is the most daunting of the lot and the mathematical content in the first few pages is very high. However, this is a conference paper and has more approachable conclusions, which also summarise and discuss the findings from the two previous papers. If you skip the equations, view the illustrations and read the text, you'll get a pretty good summary of his findings and views on this subject.

There are many implications arising from this time resolution investigation. For me, the major ones are:

- Kunchur makes a strong case for high resolution formats since CD sampling rates can only resolve timing differences down to 11µs, but clearly we need much higher resolution playback at least 24/192kHz-to reach levels where time smearing will be inaudible. This is especially the case when listening to percussion where transients lasting less than 10µs are common. The Red Book CD standard was never good enough from this particular viewpoint.

- I feel that speaker buyers, builders and designers need to think small. Large cones or panel diaphragmss will mean that the different parts of the speaker will be at different distances from the ear. Kunchur calculates that for a 1.5m tall electrostatic panel 5m from the listener, the sound from the panel edge will take 650µs longer to reach the ears than from the centre – a figure 100 times the minimum audible delay criterion. This may explain why small drivers (eg my Jordan *JX92*s) give such a clear sound on transients.

- The time alignment of drivers and the time resolution of the system are of great importance.

- It throws up questions about the wisdom of bi-wiring; it is easy to lose the time coherence of the signal with small errors in connection practice.

- Many of our established criteria and explanations may be based on results which were obtained using insufficiently sensitive test arrangements. What we take as established fact may well be the result of an inability to measure properly.

There are also two cheering conclusions. The older members of the test group showed very little difference from the young in hearing timing differences. Age may bring on a loss of high-frequency hearing, but it has much less impact on the ability to hear smearing and time differences. This is because the brain distinguishes between frequency and distance from the reactions of the cochlear cilia (tiny hair-like structures) in the inner ear. These lose suppleness and sensitivity to frequency differences as we age, but they continue to react to timing, and the brain reads the sequence in which they react and uses this to assess the distance the sound has travelled.

Thus I believe that my 96 year old neighbour and I could both hear the differences between CD and hi-res digital formats because our brains could distinguish them by their time resolution differences, rather than the high frequency energy of the sound. We can't always tell how hard the tennis balls are hitting that sheet, but we can time the intervals between them almost as well as the younger listeners.

Finally, he vindicates what much of the audiophile community have been saying all along: anecdotal does not mean dismissible. We can hear differences and we can trust our own ears, even in the face of existing scientific findings. To quote Kunchur:

"The present experimental result thus provides a concrete basis for the anecdotal claims by audiophiles of sensitivity to very short time-domain errors (such as an insufficiency of some commonly used digital sampling rates)."

Here's a man who has set out to understand and measure what he values – and has succeeded. I will definitely be keeping an eye on his work.

Note 1

1. Audibility of temporal smearing and time misalignment of acoustic signals
M. N. Kunchur, Technical Acoustics, 17 (2007).

2. Temporal resolution of hearing probed by bandwidth restriction,
M. N. Kunchur, Acta Acustica united with Acustica 94, 594–603 (2008).

3. Probing the temporal resolution and bandwidth of human hearing
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M. N. Kunchur, Proc. of Meetings on Acoustics (POMA) 2, 050006 (2008)