Scoop!

New trends in loudspeaker testing

Over the past decade a technique has been developed that can truly quantify and plot the performance of a loudspeaker, and which matches the abilities of our ears. The 'cumulative decay response' technique is now available to ETI — we are **the first magazine worldwide** to employ it. Here's how it works.

Louis A. Challis

OVER THE LAST ten years of evaluating the performance of loudspeakers for magazine review articles and for manufacturers wishing to improve their products, I have found significant differences between objective and subjective evaluations. These differences have given rise to many problems, not the least of which is the need to find a set of objective tests which are able to provide a reasonable correlation between these two vastly different approaches of loudspeaker evaluation.

The art of speaker testing is currently a subject of more than just passing interest, for some of the foremost engineers, acousticians, and manufacturers in the world have been applying their knowledge, ingenuity, and financial resources to overcome the criticism heaped upon them by the public and the trade alike. These problems, of course, are being solved, and even we are involved in our own small way in providing new solutions to circumvent the problem.

Loudspeaker testing involves a number of "standard" procedures and "standard" environments. These generally include the use of swept oscillators, synchronised chart recorders — which are capable of measuring the level of the resulting sound — precision laboratory microphones, and suitable amplifiers to power the speaker. A typical setup of the type we use ourselves is shown in Figure 1. Whilst such a system can provide accurate and elaborate information, an additional element is normally required in the form of a suitable test environment. The preferred environment is an anechoic room, which to the uninitiated is an echo free room where all the reflections above a frequency known as the "cutoff frequency" are attenuated. This results in the output of the speaker, rather than the combination of the speaker plus reflections, being recorded and thereby provides an accurate (even if unnatural) evaluation of the speaker's performance.

Another type of environment sometimes used is the hemichoic (or hemi-anechoic) room, which is an anechoic room with a solid, normal floor. This type of environment is often used with speakers requiring a reflection element, such as a floor, for them to function properly. Another type of environment is the reverberation chamber, which is a large diffuse room featuring long reverberation times which make it possible to measure the total acoustical output of the loudspeaker, its electro-acoustic efficiency, and effective sound power generated, with greater ease than in the anechoic room. Whilst we use our reverberation chamber for special speakers, particularly those designed to interact with walls and floor, this type of testing environment is seldom used for conventional loudspeakers of the type most frequently manufactured or purchased by the public.

There are a number of other parameters which are conventionally evaluated and used to test loudspeakers. These include the total harmonic distortion at various power levels, off-axis sensitivity, phase

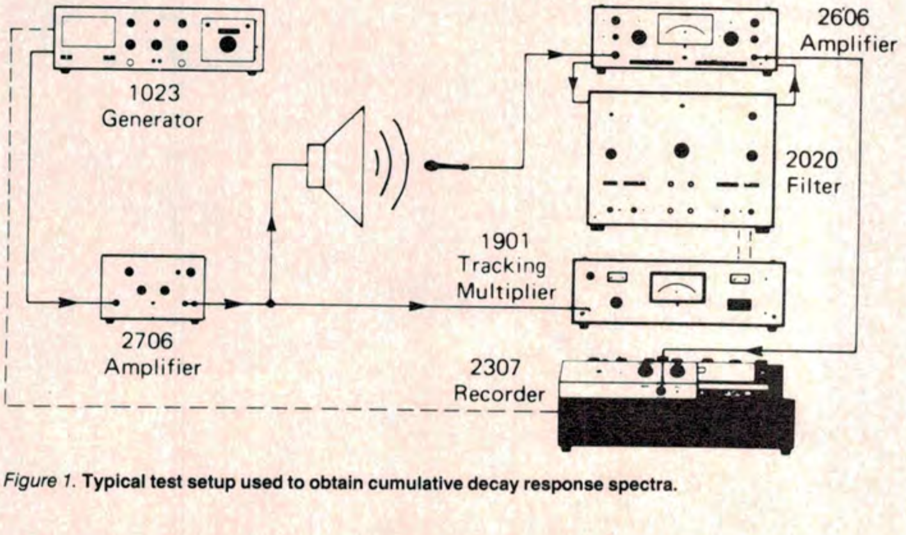


Figure 1. **Typical test setup used to obtain cumulative decay response spectra.**

response, speaker impedance, and electro-acoustic efficiency. All of these parameters are normally evaluated, either as a continuous function and presented as a graph, or sometimes at discrete frequencies, as called for.

The evaluation of these parameters has been the backbone of laboratory testing for more than forty years, and whilst such tests do tell you a great deal about the loudspeaker, they do not really tell you enough. Put another way, if the results are all bad the speaker most probably sounds terrible, but if they are all *good*, there is still absolutely no guarantee that the speaker will *sound* good. Obviously, if you think about it, all these parameters fall into the realm of "steady-state" parameters, whilst the loudspeaker in reality is fed with signals which are seldom steady-state. What this amounts to is a situation in which we tend to be comparing apples with pineapples; they may both be fruit but that is where the similarity begins and ends.

About two decades ago some bright engineers decided to try and evaluate the transient performance of their loudspeaker with bursts of sine wave using a device which is now commonly known as a tone-burst generator. The results of this evaluation when viewed on a cathode ray oscilloscope synchronised to the mark-space ratio of the signal, exhibited a number of exciting and different visual features.

The first of these features was that when the evaluation was performed in an anechoic room, particularly at high frequencies, it was possible to produce different results for different speakers. The results depended on the exact frequency chosen, the type of crossover network, and other factors which could not be readily explained at that time. Thereafter, most researchers and many reviewers, ourselves included, made extensive and sometimes outrageous use of tone-burst evaluations.

The problem with tone-burst evaluations was that they introduced new information content, created as a result of the step process initiated at the start and finish of each cycle. This information was in many respects more dangerous and often more confusing than it should have been, as it produced unwanted effects which often masked the phenomena which were actually being searched for. It did not take long for a number of researchers to produce a clear exposition of the problem, resulting in tone-burst testing being labelled as unfair, inaccurate and often biased unless certain precautions were taken which would be likely to nullify the objectivity of the test anyway.

Around about the beginning of the 1970s one clever scientist, Laurie Fincham, who is well known at the International Electro-Technical Commission TC29 meetings, presented a series of papers on a new method of evaluating loudspeaker performance. His procedure was only made possible through the release of a range of new powerful computers and associated fast Fourier analysers. These made it possible to generate, sample, store and analyse copious quantities of analogue data, which was converted into a digital format prior to the complex procedures which followed.

The basis of Fincham's system was to feed the loudspeaker with a series of specially shaped transient signals, which were then recorded by a laboratory microphone with a flat frequency response and known phase response extending from 20 Hz to beyond 25 kHz. The results were sampled and averaged before being converted by the computer into a signal on which a complex frequency analysis was performed. The analysis was far more complex than a conventional Fourier analysis, for it set out to produce a series of sequential Fourier analyses which presented the frequency response of the loudspeaker at a number of increments in time from time zero (the actual creation of the pulse) to some subsequent time after the signal had died away.

Obviously, with the power of a computer and the flexibility of a digital plotter it was possible to summate all this information and present it as a three-dimensional plot — which is frankly the *only* way in which it could be readily assessed.

Fincham's interest in this approach was far from academic. As the Technical Director of K.E.F. Loudspeakers in the United Kingdom he was searching for the solution to the enigma which had troubled him and all other speaker manufacturers, that objective testing and subjective testing were still so far apart that they could not reliably base manufacturing or marketing on the results of their laboratory testing. What he had developed, of course, was the first objective test which presented a graphical presentation of the transient sound produced by the speaker, taking into account both frequency and time (see Figure 2).

A typical analysis produced by Fincham revealed a strange and almost unbelievable picture of what the typical loudspeaker does to its emitted sound after being excited by a transient. The picture takes the form on the time zero line of a smooth frequency response (with a linear frequency scale) of what the speaker produces under steady-state conditions.

With increasing increments in time after switch-off this sound dies away, producing various decay times which are obviously a function of frequency, but more importantly, a function of the natural resonance characteristics of the loudspeaker itself. Here for the first time it was possible to *see* what could previously be *heard*, but which did not show up in conventional steady-state objective testing. The typical mountain peaks or spurs radiating out at discrete frequencies constituted resonances of ▶

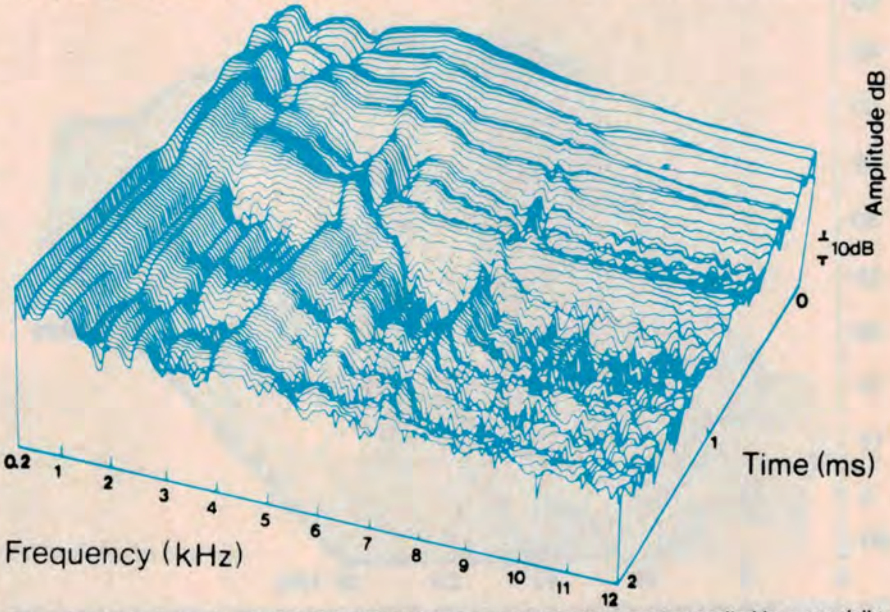
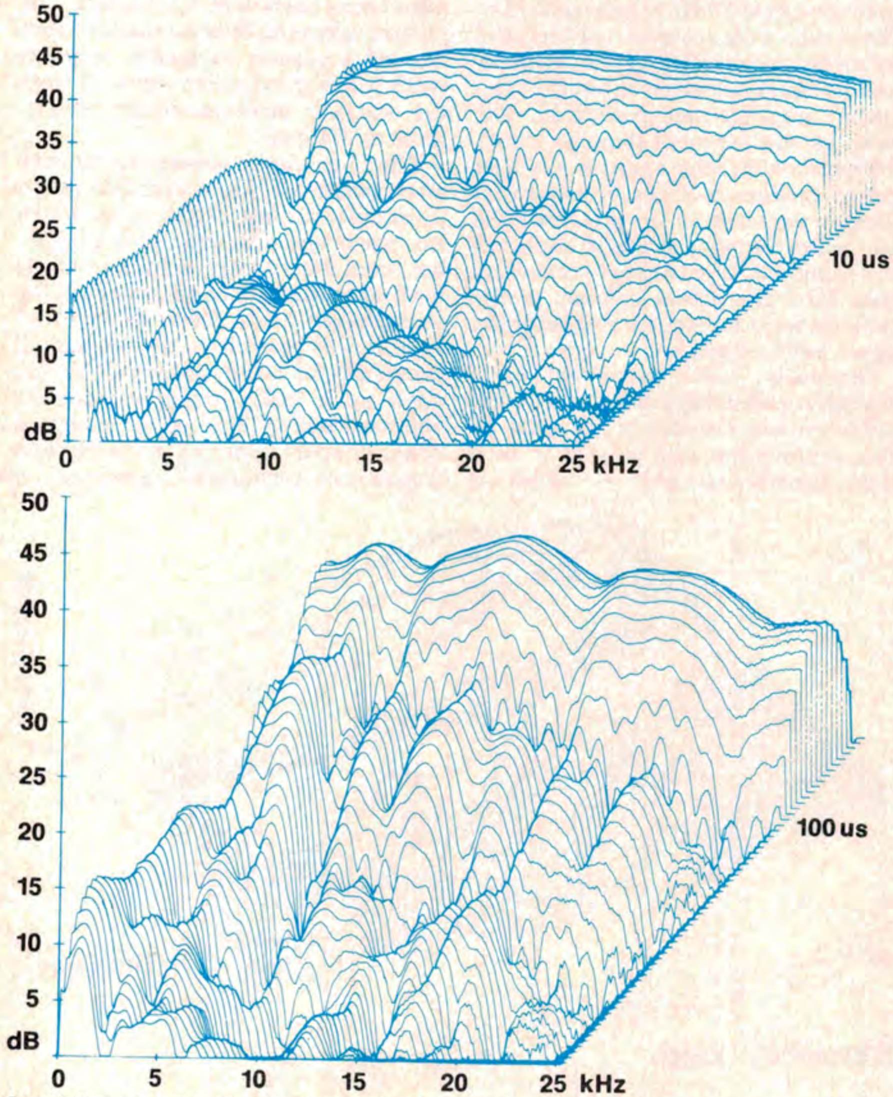


Figure 2. **'Three-dimensional' plot of the 'decaying' response of a loudspeaker excited by a specially-shaped pulse, as produced by Laurie Fincham.**

A view of Louis Challis' laboratory. All ETI's objective equipment measurements are carried out here, loudspeakers of course in the anechoic chamber, which is a few metres away.



Cumulative decay response spectra graphs for two different loudspeakers, produced in the Challis laboratory. Note these are somewhat different to Fincham's isometric plot, but the details are clearly shown nevertheless.

the speaker system, either from the speaker diaphragm, the speaker basket or the enclosure itself. These resonances decay more slowly than the other responses do at other frequencies and thereby create the tonality, colouration, and consequently the abnormal sounds that separate one speaker from another and more importantly, the best speakers from the rest.

When Laurie Fincham presented his first papers at the A.E.S. in America, the technical world was agog. Whilst Fincham himself is modest and unpretentious, he realised the value of what he had produced as did the firm for whom he works.

Here for the first time was not only an objective test method by which speakers could be evaluated, but more importantly, an objective test method through which they could be improved and by which those improvements could be objectively as well as subjectively assessed.

Before you could say "Fourier transform" or even "Jack Robinson", half a dozen other manufacturers, most notably in Japan, were working on their own versions of the Fincham technique, for here quite obviously was the greatest thing that had yet happened in the world of objective loudspeaker testing. It is now no secret that the latest generation of superlative K.E.F. loudspeakers are the direct result of the Fincham technique, and that quite a few of the best Japanese speakers are able to ascribe their quality to the use of an 'eastern' version of the same technique.

For more than six years the editors of ETI and I have realised that it was only a matter of time before we too would have to join the ranks of the "me too's" and emulate Fincham. It had to await my purchase of a new digital narrow band Fast Fourier analyser, which could be interfaced directly with my existing computer and real time analyser, before I could start to contemplate reproducing the Fincham technique. We already had our anechoic room, which is one of only a handful in Australia, and this simplified the task, for Fincham had already found and recorded that the lack of an anechoic room had initially made his task very much more difficult.

The research and development of our system had to await the completion of more urgent work which seemed to keep the equipment busy week after week. In the end, when it was clear that this situation was not going to change, a decision was made to transfer the research and development work to weekends and thereby make it possible ▶

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to complete this development work.

The results were better than expected and the program was soon churning out (albeit slowly) beautiful cumulative decay response spectra for all the loudspeakers in the office and laboratory, listening rooms and from my home.

These results looked different to what we were used to seeing, as the frequency response was linear as opposed to logarithmic, but fortunately our Bruel & Kjaer oscillator can also produce linear sweeps from dc to 20 kHz as well as the preferred log sweeps. Each time we produced a cumulative decay response spectrum we produced a linear swept frequency response for the same speaker set up in the anechoic room. The results were remarkably faithful reproductions of the cumulative decay response spectra at zero delay time. Here at least was the first positive confirmation that the program was working correctly (even if only at the start of the decay).

We then resorted to conventional tone-burst testing at those frequencies where the nasty resonances showed up on the digital analysis and, lo and behold, achieved a remarkable correlation between the two techniques even though we had been fully prepared to discount the accuracy or validity of the conventional tone-burst method.

The most important confirmation, however, came from our ability to hear on normal program content what we could "see" on the cumulative decay response spectrum. All the speakers which sounded coloured exhibited this colouration on the cumulative decay response spectra, whilst those speakers which sounded clean or true to life and provided a degree of realism greater than their poor brothers were found to have cleaner cumulative decay responses, flatter frequency responses, smoother phase responses, and if one resorted to them, even better conventional tone-burst responses.

Fincham's technique is now available not only to K.E.F. in the U.K., Matsushita and Sony in Japan, but more importantly, to ETI in Australia. In future, it is our intention to evaluate all loudspeakers and headphones using this technique and present the results with suitable commentary so that our readers will be in a position to assess a loudspeaker without necessarily being able to hear it. We have already assessed most of the loudspeakers that we have reviewed over the last few months and all those awaiting publication at this moment. The results are exciting and we believe that you will find this analysis technique to be just as exciting and informative as we have. ●

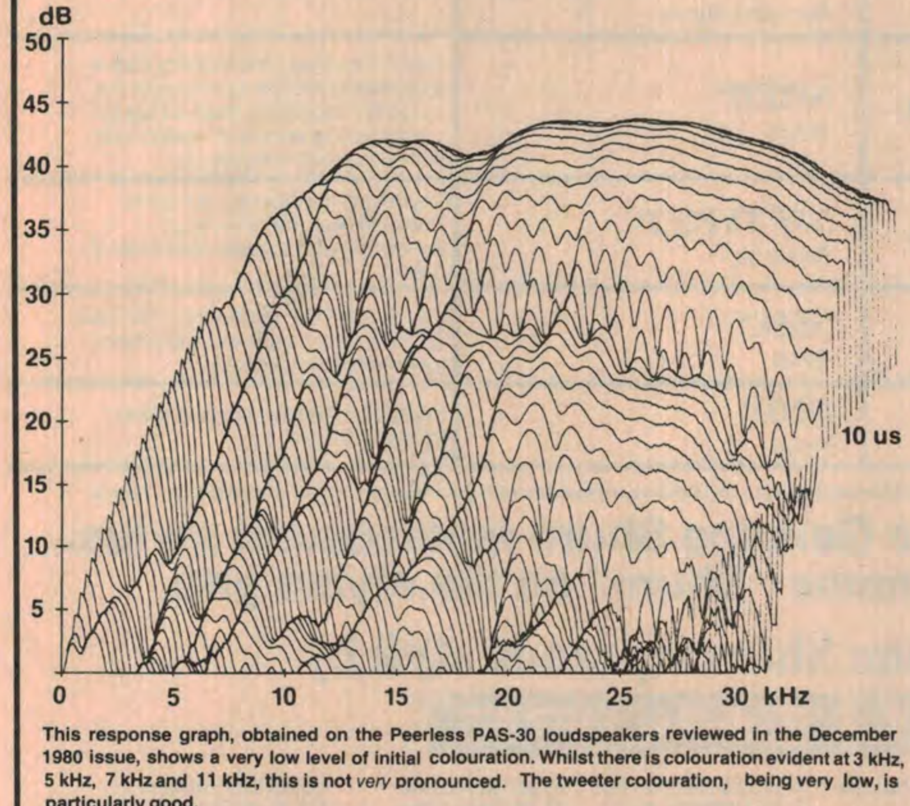
INTERPRETATION OF CUMULATIVE DECAY RESPONSE SPECTRA

The cumulative decay response spectrum is presented as a three-dimensional plot of the smoothed response of the computer's interpretation of how a broad band signal dies away at discrete increments of time following its excitation. The two mutually perpendicular axes plotted have 5 dB increments on the Y axis and typically 5 kHz frequency increments on the X axis. It should be noted that the analysis uses a linear bandwidth in lieu of the more typical logarithmic analysis used in our conventional level recordings. The Z axis is not drawn but the interpretation and presentation uses a typical increment of 10 microseconds for the 25 kHz bandwidth analysis. The topmost line is the smoothed frequency response interpretation derived from the impulse response, whilst the individual lines plotted thereafter are the smoothed interpretation of how that frequency response dies away with increasing time (in increments of 10 us).

If a speaker introduces colouration or effective frequency modification because of self-resonances, reflections or general non-linearities in performance, then these show up as transverse ridges radiating from the top of the graph down towards the bottom. The steepness of the ridge is a measure of how rapidly the resonance dies away; if the ridge extends from the very top to the very bottom of the graph then the colouration is pronounced and most probably clearly audible. The more ridges there are, the greater the extent of the colouration, and if they are apparent in the steady-state signal then it is clear they are affecting and modifying the normal level recording response as well as the transient response.

The ridges on the extreme left hand side of the cumulative decay response spectrum should not be interpreted as a rising low frequency response; they are created primarily by the real-time analyser, whose output gives rise to this anomalous response. On the very best and cleanest loudspeakers, at the very lowest levels and typically after 300 us it is possible to discern low-level reflections from the structure supporting the wedges in the ceiling of our anechoic room. This problem will be obviated in future analyses.

It is observable that a good speaker produces a cumulative response spectrum which 'looks good' and a poor speaker or one that in simple terms does not sound good produces a plot which looks like the 'mountains of the Moon'.



This response graph, obtained on the Peerless PAS-30 loudspeakers reviewed in the December 1980 issue, shows a very low level of initial colouration. Whilst there is colouration evident at 3 kHz, 5 kHz, 7 kHz and 11 kHz, this is not *very* pronounced. The tweeter colouration, being very low, is particularly good.