From http://www.vxm.com/NXT.html

NXT
When a Little Chaos is Good For You

by Henry Azima

NXT, Background

Much of the past 40-plus years of loudspeaker development have revolved around identifying, understanding and then suppressing diaphragm resonances and their resulting coloration and `smear'. So a new drive unit technology that, rather than attempting to eliminate diaphragm resonance, encourages and exploits it genuinely merits the over-used description `revolutionary'. In a sentence, that's precisely what NXT does. It tears up the loudspeaker rulebook, as we know it.

Audiophiles and audio professionals are understandably suspicious of an idea which so comprehensively inverts the status quo. But suspend disbelief for the course of this article and I will explain why such a crazy sounding idea actually brings major benefits both to loudspeaker users and loudspeaker designers - benefits which have already encouraged major industry players to take out licenses to use the technology.

The first question to answer is: why should we need a new loudspeaker paradigm when so much academic and design effort has been expended on perfecting current technology? To answer that you need go back to the basic principles of how conventional loudspeakers operate and identify the fundamental restrictions on performance that they impose.

Conventional loudspeakers, whatever method of transduction they use (electromagnetic, electrostatic, piezoelectric etc), aim at achieving pistonic motion of the diaphragm, at least over the lower portion of their operating range. By pistonic we mean that the diaphragm moves as a rigid whole. In acoustic terms, such loudspeakers are `mass controlled' over most of their passband. The motor provides a force that is constant with frequency, the diaphragm resists with a mass (its own moving mass plus that of the air load), and so by Newton's second law of motion the diaphragm undergoes constant acceleration with frequency. As a corollary, its displacement reduces at 12dB per octave with increasing frequency (i.e. quarters with every doubling of frequency).

At low frequencies, where the wavelength in air is large compared with the diaphragm dimensions, this is just what we want. The real part of the diaphragm's radiation resistance (Figure 1), into which the driver dissipates acoustic power, increases with frequency at exactly the same rate as the diaphragm's displacement decreases, with the result that acoustic power output is constant.

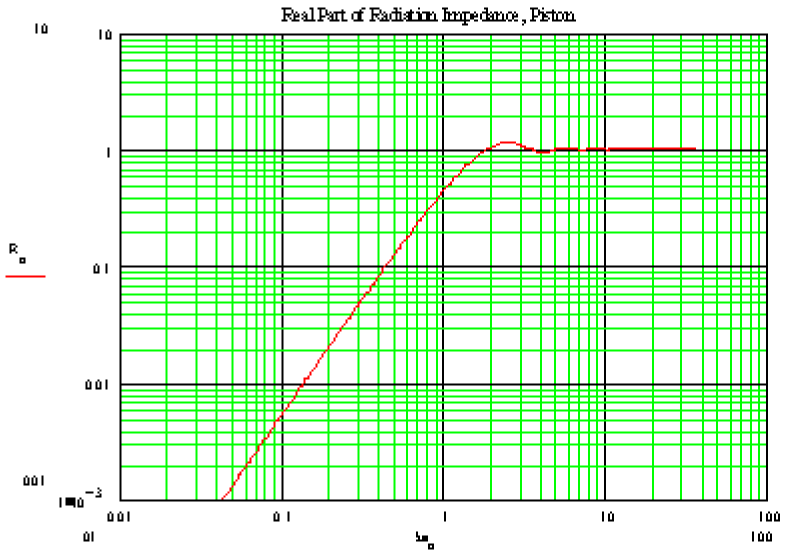


Figure 1. Real part of radiation resistance vs. normalized frequency

As frequency continues to rise, though, and the wavelength in air reduces to the point where it becomes comparable with the diaphragm dimensions, a major change occurs. Instead of continuing to rise, the real part of the radiation resistance reaches a limiting value and essentially becomes a constant for all higher frequencies. Because of this the diaphragm's acoustic power output now begins to fall at a rate of 12dB per octave. This doesn't mean that the on-axis pressure response falls away: what generally happens is that the diaphragm's acoustic output becomes restricted to progressively narrower solid angles. In other words, it becomes directional; it begins to beam.

Variation in directivity with frequency is one of the great bugbears of loudspeaker design. If we listened to reproduced sound in anechoic environments it wouldn't matter: we would hear the diaphragm's on-axis output and nothing else. But conventional listening rooms are far from anechoic, so a loudspeaker's output off the listening axis has a significant effect on what we hear. Because of frequency dependent directivity the direct, reflected and reverberant sounds in a room all have different tonal balances. Even if a conventional loudspeaker had an absolutely flat on-axis response and was entirely free of resonance - a tall order - it would still sound colored and introduce imaging aberrations because of this alone.

An obvious solution would be to use a diaphragm sufficiently small that the `knee' in the radiation resistance curve was forced above the audible frequency range. But such a diaphragm would have to undergo enormous, impractical excursions to produce the volume displacements necessary at low frequencies. So loudspeaker designers are generally forced to compromise and deploy multiple drive units of progressively decreasing diaphragm size. Large diaphragms provide the volume displacement necessary to reproduce low frequencies; small diaphragms take over at higher frequencies before the output of the larger units becomes too directional. Even so the speaker's directivity still varies significantly with frequency, and the use of crossovers to divide up the frequency range brings with it a host of unwelcome side effects: phase distortion, further disruption of off-axis output, more reactive elements in the loudspeaker load, and sound quality issues related to capacitor performance and the saturation behavior of inductor cores.

A full-range drive unit, covering the entire audible frequency range with constant directivity, would banish these problems but, for the reasons outlined, simply isn't achievable using conventional wisdom.

NXT, Breaking the Pattern

We appear to have reached an impasse, but some wonderful things happen if you abandon the concept of pistonic motion and consider instead a diaphragm vibrating randomly across its surface rather than coherently. Each small area of the panel vibrates, in effect, independently of its neighbors, rather than in the fixed, coordinated fashion of a pistonic diaphragm. Think of it as an array of very small drive units, each radiating a different, uncorrelated signal but summing to produce the desired output.

Such a randomly vibrating diaphragm behaves quite differently because power is delivered to the mechanical resistance of the panel, which is constant with frequency. The radiation resistance is now insignificant because the air close to the panel also moves in a random fashion, reducing the effective air load. This means that diaphragm dimensions no longer control directivity: you can make the radiating area as large as you want without high frequency output becoming confined to a narrow solid angle about the forward axis. Such diaphragm behavior clearly opens up the possibility of a full-range driver freed from the familiar restraints and compromises. Nice trick if you can do it: but how can you make a diaphragm vibrate randomly?

Actually you can't, but you can get very close to it by using what we term distributed-mode (DM) operation, on which NXT is based. Essentially this involves encouraging the diaphragm to produce the maximum number of bending resonances, evenly distributed in frequency. The resulting vibration is so complex that it approximates random motion - it is impossible, for example, to identify the point(s) of excitation on a snapshot of the panel motion (Figure 2) - thereby providing the freedom from directivity related problems described above. (See the 3-D polar diagrams of Figure 3.)

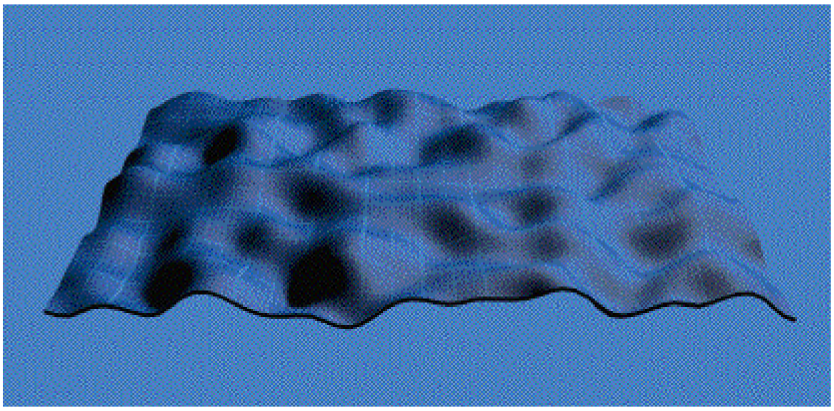
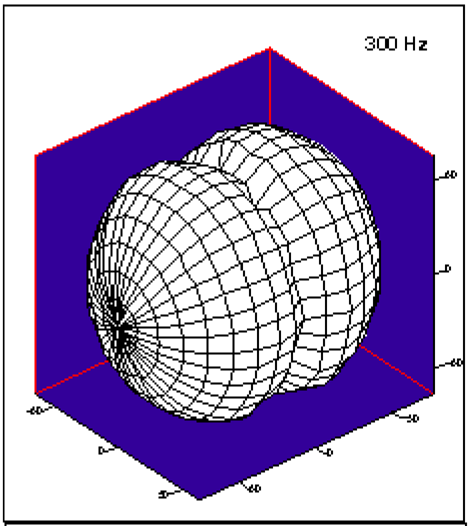
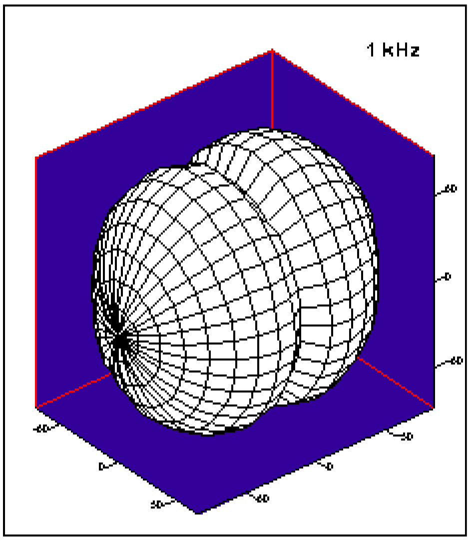
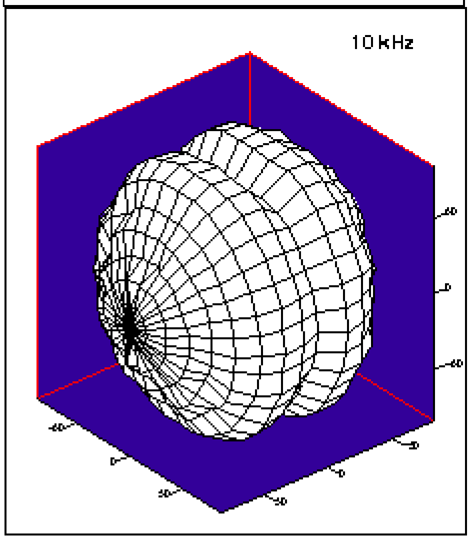


Figure 2. Snapshot of panel motion, shortly after excitation with an impulse





X, Z, Y



X, Z, Y

Figure 3
3-D Polar response of a $0.09 m^2$ NXT panel at various frequencies.

NXT, How it Works

The diaphragm of a Distributed-Mode Loudspeaker (DML) vibrates in a complex pattern over its entire surface. Close to the diaphragm the sound field created by this complex pattern of vibration is complex also, but a short distance away it takes on the far-field characteristics of the DML radiation. This is close to the directivity of a true point source - i.e. approaching omnidirectionality - even when the diaphragm is quiet large relative to the radiated wavelength.

How is it that a panel, which is vibrating in a complex, pseudo-random way, can radiate sound evenly in all directions, without mutual cancellation?

Let us distinguish two extremes of the velocity distribution across a diaphragm surface. At one extreme is the rigid surface in pistonic motion, where the magnitude and phase of the motion is constant across the surface. In this case directivity depends only on the path-length between each small element of the diaphragm and the receiving point (Figure a1). At radiated wavelengths that are small relative to the diaphragm dimensions, interference takes place between the radiation from different regions of the diaphragm, and this increases in severity off-axis. So the characteristic radiation pattern exhibits strong beaming (Figure a2).

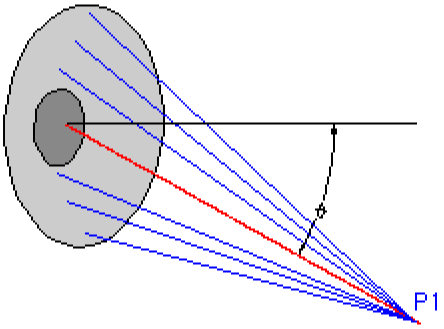


Figure A1. Specular direct radiator

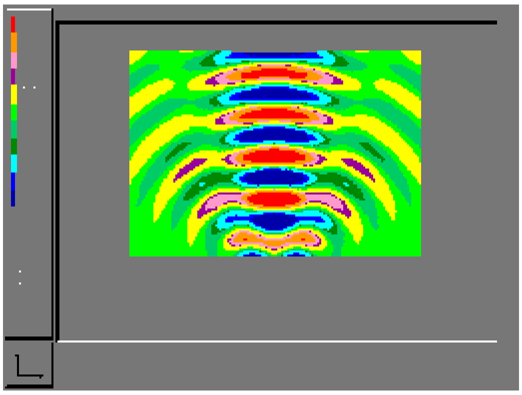


Figure A2. FE-simulated soundfield of an ideal piston of 160 cm^2 surface area

Figure A. An ideal piston.

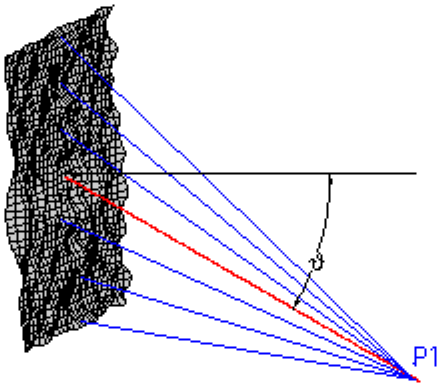


Figure B1. A Diffuse direct radiator

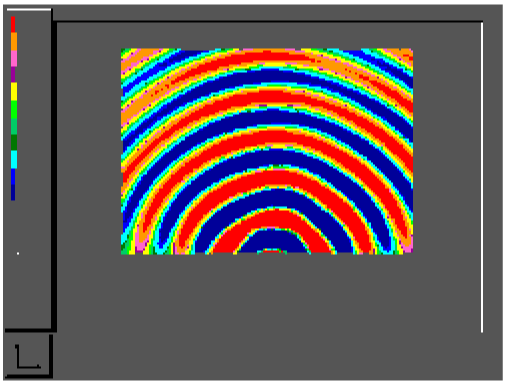


Figure B2. FE-simulated soundfield of a randomly vibrating panel of 120mm x 136mm.

Figure B. A randomly vibrating panel.

At the other extreme, in a randomly vibration panel, there exists a random distribution of diaphragm velocity with respect to magnitude and phase. The disparity in path-length between different areas of the diaphragm and the receiving point is still present, but because there is now no correlation between the source points' output, there can be no global interference (Figure b1). Hence the radiated sound is dispersed evenly in all directions. Diffuse radiation of high order (Figure b2) becomes omnidirectional in the far field.

An NXT panel closely approximates a randomly vibrating diaphragm, and so behaves similarly. Distributed Mode operation is therefore ideal for a loudspeaker: it guarantees consistent output level and undistorted time response in all directions. In other words, all the radiated energy appears to originate from a single point. Despite this the DML is able to produce high broadband acoustic power because its diaphragm is not size constrained. With pistonic diaphragm motion, these characteristics are mutually exclusive.

NXT, The Benefits

There are also numerous spin-off benefits to a DML loudspeaker. As well as being insensitive to diaphragm size, the acoustic behavior (other than sensitivity) is unaffected by diaphragm mass. In a conventional diaphragm, moving mass determines the upper limit of the frequency response - another reason why tweeters must be small. With an NXT panel there is no equivalent restriction, so the technology is truly scaleable: you can make the panel large without directivity or treble response suffering. In fact it actually improves in performance as it is increased in size because the frequency of the fundamental bending resonance is lowered, which not only extends the bass response, but also increases modal density in the mid and high frequencies.

Another major benefit is that the panel's acoustic output from both sides of the NXT panel is useful. In applications where the panel is not required to be baffled, as in high-end free-space loudspeakers, the power radiated from the back face sums up constructively with radiated power from the front face of the panel. This is due to the complexity of distributed-mode radiation and the uncorrelated phase of the individual radiating elements as seen from the far-field point of view. Terms such as bipolar or statistically bipolar have been used in the past to explain such complex behavior; however, they do not describe this unique property of a diffuse direct radiator accurately. This is clearly a very positive aspect of NXT loudspeakers as there is not an intrinsic need for containment of the rear radiation through baffling or the use of enclosures which have their own resonances, colorations and cost penalties.

But the panel itself operates wholly in resonance of course, which is one of the features of NXT that most concerns audio people raised to regard resonance as anathema. Doesn't all this resonance in the panel color the sound unacceptably? The surprising answer is no, it doesn't, because of the highly complex nature of the panel's vibration. The impulse response of an NXT panel (Figure 4) displays a long resonant `tail' which would damn any conventional loudspeaker, but in fact the sound quality has extraordinary clarity and transparency confirming the measured flat frequency response (Figure 5).

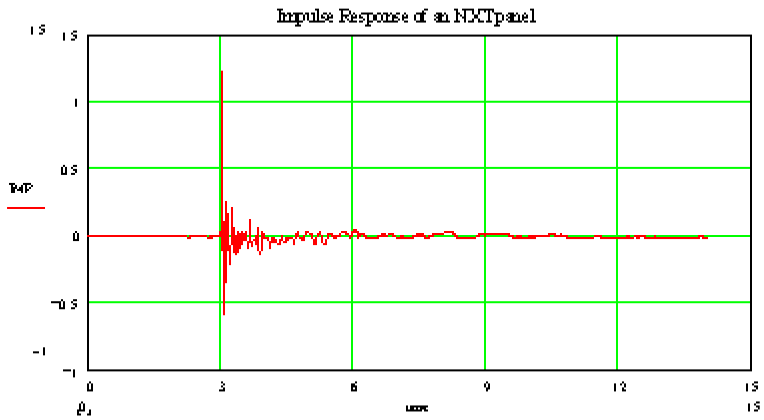


Figure 4. Typical impulse response of *NXT* panel

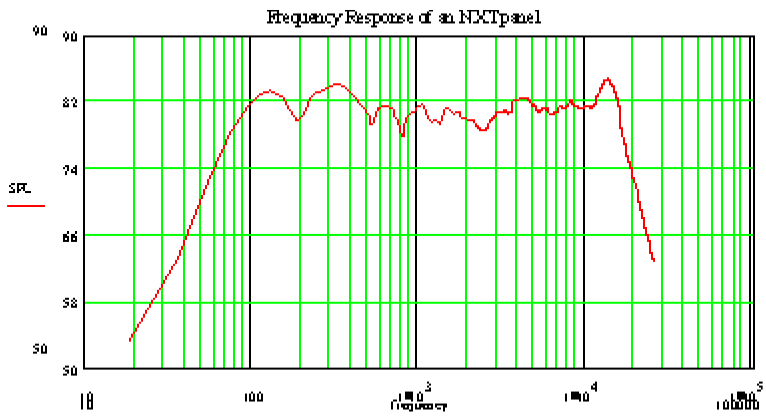


Figure 5. Frequency response of a typical NXT panel

Another common expectation is that NXT panels will only function properly at high frequencies, where the resonant modes are very densely packed. Acousticians familiar with requirements for diffuseness of room resonances often voice this concern, but the two cases are not equivalent. The velocity of sound in air is independent of frequency, whereas the velocity of bending waves in an NXT panel is frequency dependent (i.e.

bending waves are dispersive. This works in our favor, making a well-designed NXT panel sufficiently modal for use as a loudspeaker by a frequency only twice that of the panel's fundamental bending resonance (Figure 6). Small NXT panels still have to be combined with a conventional woofer to cover the lowest two or three octaves in high quality applications, but the necessary crossover is far removed from the ear's most sensitive region around 3kHz - precisely where most conventional loudspeakers are forced to hand over to the tweeter.

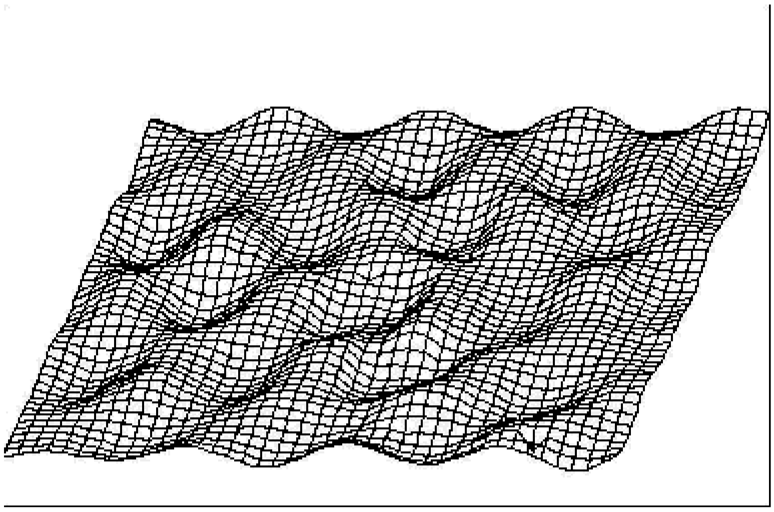


Figure 6. Bending waves in an NXT panel measured by Laser Interferometer

What about distortion? Again our painstaking research has shown that an NXT panel performs as well or better than conventional alternatives (Figures 7). This is because, in the frequency range of interest, panel vibrations are very small in amplitude, putting much reduced demand on the coil excursion, with the panel remaining well within its linear elastic range. NXT's great adaptability has lead some to suppose that it is better suited to public address, in-car and general audio applications than it is to high fidelity, but that just isn't the case.

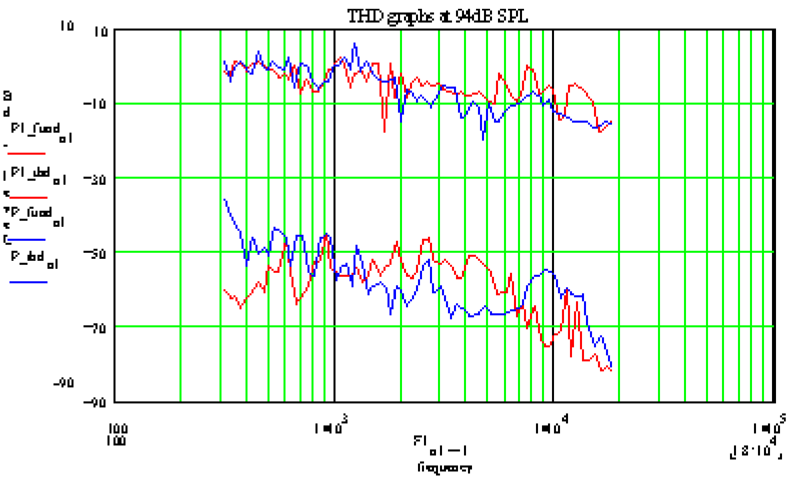
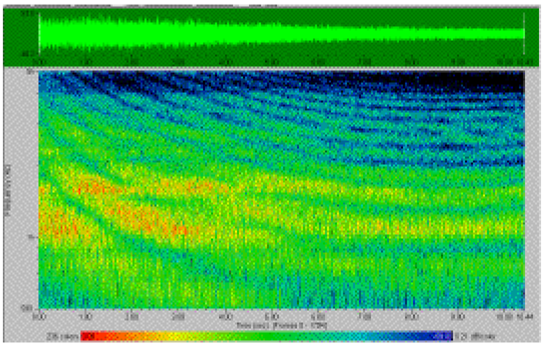


Figure 7 Total harmonic distortion, *NXT* panel versus a 6-inch cone loudspeaker at 94dB SPL, 1m.

Stereo imaging is another common concern. Anyone who has heard conventional wide-dispersion (omnidirectional) loudspeakers will know that they produce a large, blurred stereo image rather than the precise, tightly defined sound stage of more directional designs. Again NXT panels confound expectations here because, while maintaining a wide radiation pattern, their diffusivity helps reduce destructive boundary interactions (Figure

8). Our research has shown that stereo imaging, in typical domestic surroundings, is at least as well defined and stable as with conventional directional loudspeakers listened to from the stereo `sweet spot'. Outside this small area of optimum stereo the NXT panel is much superior because of its better maintained off-axis performance and reduced of room interaction.



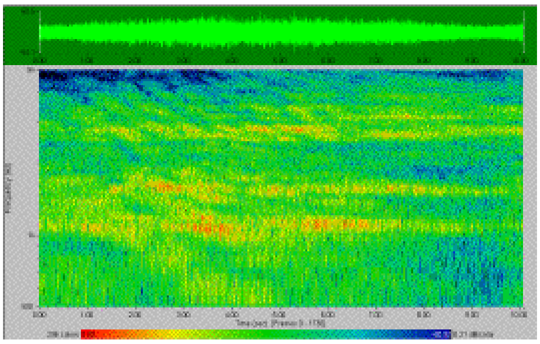


Figure 8. Anechoic interference pattern of a loudspeaker with a hard reflecting surface. Audible interference is seen in the form of deeply defined pattern of peaks and nulls.

With conventional wide-directivity loudspeakers you also tend to hear much more of the room: standing wave resonances are more pronounced, so the tonal balance varies significantly as you change listening position, and interaction with room boundaries is worsened too, making speaker placement more critical. NXT panels behave quite differently because of the diffuse nature of their radiation: their sound does not emanate from a fixed, well-defined point in space. As a result the distribution of sound within a room is actually much more even with an NXT panel than with a conventional loudspeaker (Figure 9): room interaction is reduced.

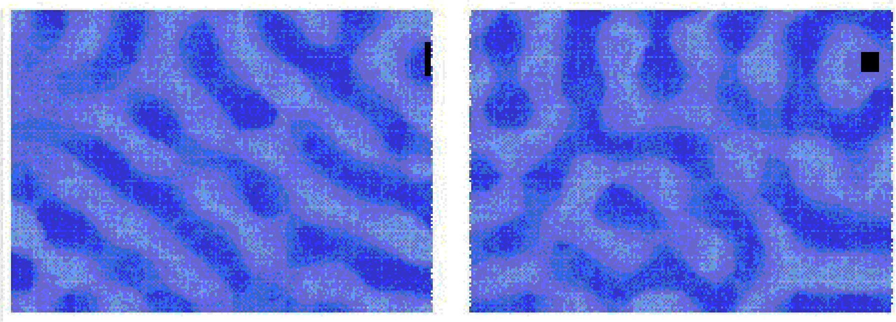


Figure 9. Finite Element simulation comparing in-room radiation of an *NXT* panel (Left), having essentially plane-wave radiation and a conventional loudspeaker (right), producing standing waves.

Speaking as a loudspeaker designer of twenty years' experience, I am excited by the prospect that the NXT design process is deterministic in a way that conventional loudspeaker design is not. Provided you know a few key parameters - the size and shape of the panel (it can be curved in one or more plane), the position of the exciter(s) and the bending stiffness, surface density and internal damping of the panel material - it is possible to predict the acoustic performance with a high degree of accuracy. To facilitate this process, we have developed and continue to refine a software suite called NXT Designer, which all licensees receive, together with training in its use.

A variety of exciter technologies are appropriate for energizing the panel, including piezoelectric transducers, but today's most preferred option is a moving coil motor (Figure 10). This confers three principal advantages. First, it ensures compatibility with conventional amplifiers. In fact NXT panels with moving coil exciters present notably benign amplifier loads, being essentially resistive at low and mid frequencies (Figure 11). As frequency rises the inductance of the voice coil becomes significant, the modulus of impedance increases and the load becomes reactive. But nowhere is there low modulus and high phase angle in combination. Second, it permits the utilization of the existing manufacturing base. Third, it allows exploitation of the full bandwidth potential of an NXT panel.

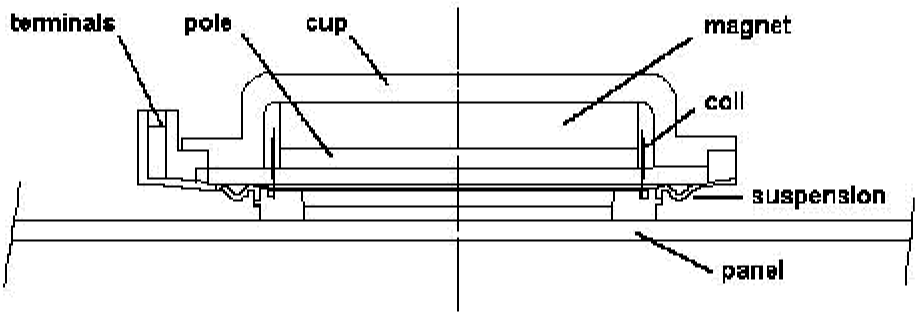


Figure 10. Cross-section of a typical moving coil NXT exciter.

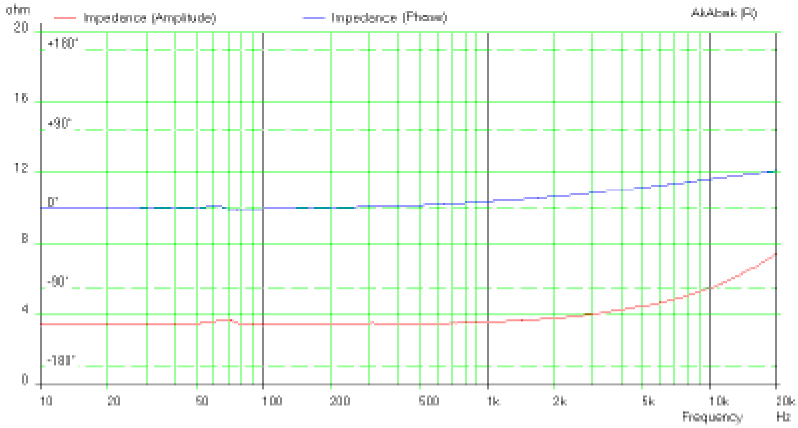
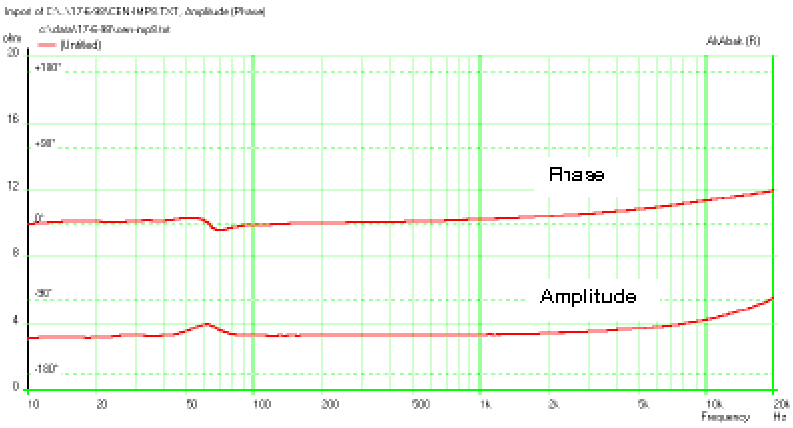


Figure 11. Magnitude and phase of the electrical impedance of a typical *NXT* panel.



Many of NXT's benefits to the hi-fi end user we have already touched on. It does away with the audible consequences of crossover networks; its wide, essentially frequency independent directivity removes a pervasive source of coloration; despite this, room interaction is reduced and stereo imaging remains sharp over a large listening area; NXT panels are thin and can either be used in free space or wall-mounted, so their footprint and visual impact are reduced; cabinet resonances are no longer an issue because there is no need for a cabinet.

The unique ability of NXT panels to fill a room with a sound field which alters very little as the listener changes position is further enhanced by the reduced fall-off in sound pressure level with distance compared with a conventional loudspeaker (Figure 12).

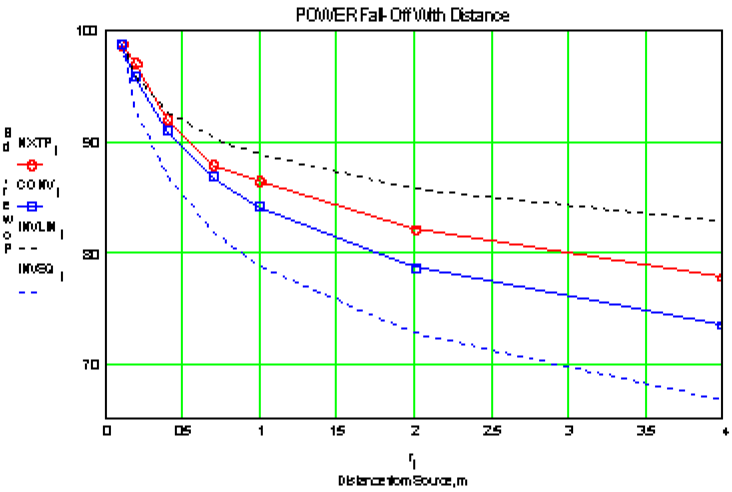


Figure 12. Power fall-off with distance, measured in a typical listening room, comparing *NXT* with a traditional 2-way loudspeaker

These attributes serve to make NXT an exciting proposition in any conventional two-channel music system, but in a multichannel home theater set-up the benefits are even greater. In addition to their wide listening area and reduced visual impact, NXT panels offer further particular advantages here. First, the inherently diffuse nature of their sound radiation assures the required surround channel diffusion - with an NXT installation you aren't conscious of the rear speakers as distinct entities. Second, with a projection television the viewing screen itself can be a large NXT panel, which provides perfect locking of voice to picture.

Taken as a whole, these features sum to a powerful argument for using NXT panels in high quality music and home cinema systems. Distributed mode operation may be shockingly different to the current state of the art, and without question it has many applications where demands on sound quality are less stringent.

NXT, Summary

In summary, it is true to say that the design goals for a conventional loudspeaker have to be a compromise. You are trying to deliver acoustical output across a wide bandwidth, yet when the radiated wavelength becomes smaller than the diaphragm circumference the loudspeaker's power output begins to fall. Because of this, and the need to provide sufficient volume velocity to reproduce frequencies at the lower extreme of its passband, a conventional drive unit's power bandwidth is typically limited to four to five octaves. This is a physical fact that remains a limitation with pistonic speakers even if we could design and make a perfect pistonic radiator. Consequently conventional drive unit design always embodies trade-offs between bandwidth, directivity and smoothness of frequency response. In the finest conventional loudspeakers these engineering compromises are skillfully struck, but they remain compromises. NXT panels could not represent a greater contrast. The modal behavior of the panel gives us diffuse behavior, and maximizing panel modality ensures a broad passband of greater than eight octaves. As we refine panel material, exciter location, boundary conditions etc., we approach the behavior of an ideal randomly vibrating panel whose power output is largely independent of size. Separating output directivity from the panel dimensions releases us from the traditional compromises loudspeaker designers have faced for more than 70 years. Smooth, dense modal behavior confers on NXT predictable, deterministic, scaleable behavior that, until now, has been the loudspeaker designer's unfulfilled dream.

NXT's History

The potential for complexly vibrating panels to act as loudspeakers emerged serendipitously in the course of research conducted by Dr Ken Heron of Britain's Defence Evaluation & Research Agency (DERA) into using lightweight composites in military aircraft. Once they saw how composite panels acted as efficient sound radiators, after some research the DERA filed the first patent application for a panel form loudspeaker. That was in 1991.

DERA itself wasn't best equipped to realise the concept's full potential, but Verity Group - one of the UK's largest hi-fi companies, owning the Mission, Quad, Wharfedale and Roksan brands - learnt of the discovery, recognised its potential and took out a licence with DERA to develop the technology for commercial use. Fundamental research at Verity identified the key operating principle for loudspeaker use. This led to the creation of a new class of sound radiator operating under this *distributed-mode principle*. On 27 September 1996 Verity publicly announced the establishment of a new arm - New Transducers Ltd, a technology company, now known simply as NXT - to develop and licence the product as the intellectual property holder.

In the interim NXT has fully explored the technology, developed new applications and know-how, investigated a broad range of suitable panel materials, related technologies and the manufacturing base, and put in place comprehensive world-wide patent protection, on which $4m has been spent already. More recently it began licensing the technology to companies operating in various market areas where NXT's unique attributes promise significant advantages over conventional alternatives.

Note: NXT Designer

As explained in the text, NXT is a highly deterministic technology: the acoustic performance of an NXT panel can be very accurately predicted once a few key parameters are specified relating to the size and shape of the panel, the positioning and electromechanical properties of the exciter(s), and the material properties of the panel material itself.

To aid the design process, licensees are provided with NXT Designer, a software suite that offers three layers of sophistication according to user requirements. At the simplest level you can input target specifications and the software will design a solution for you. Or you can delve deeper into the design process by specifying different panel material properties and performing sophisticated `what if' analyses in which different aspects of the design are altered and the outcomes assessed.

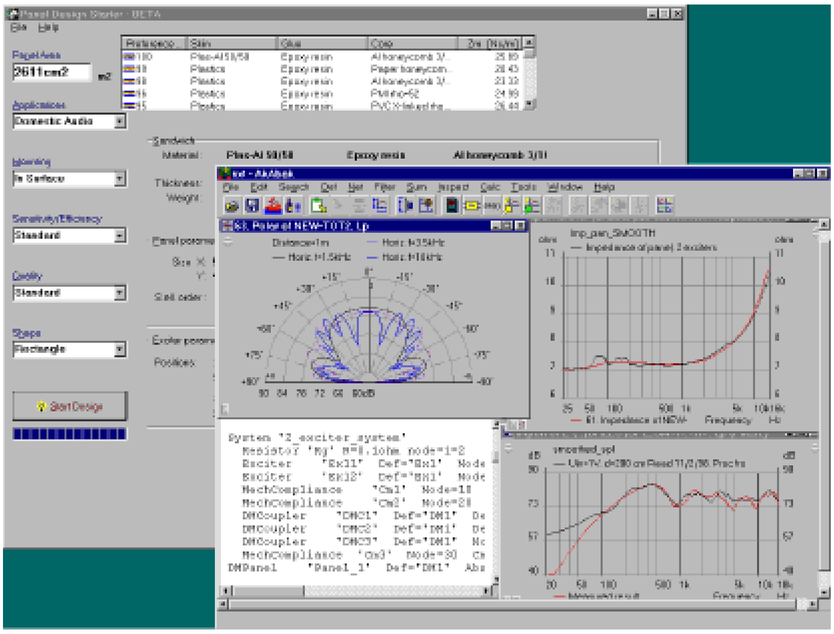


Figure C. Screen capture of NXT-designer CAD package, comparing simulation with measurement.

Further Reading

NXT's intensive research and development has furnished a deep understanding of distributed-mode operation, much of which remains proprietary knowledge. Details which can be revealed have been charted in a total of 12 papers to date delivered at the Audio Engineering Society conventions in New York (September 1997) and Amsterdam (May 1998), in addition to others delivered in different forums. Here are the details of the AES convention papers, together brief descriptions of their content. All are available as preprints from the AES. Further papers will be presented at the San Francisco convention in September 1998.

103rd Convention, New York

Harris N and Hawksford M O, The Distributed-Mode Loudspeaker (DML) as a Broad-band Acoustic Radiator, Preprint 4526 -- *Description of the basic operating principles and performance benefits of NXT*

Tashiro M, Bank G and Roberts M, A New Flat Panel Loudspeaker for Portable Multimedia, Preprint 4527 -- *NXT's first commercial application in an NEC notebook computer*

Colloms, M and Ellis, C, Diffuse Field Planar Loudspeakers in Multimedia and Home Theatre, Preprint 4545 -- *An examination of how NXT's wide sound distribution makes it particularly well suited to home cinema applications*

Mapp, P and Colloms, M, Improvements in Intelligibility through the Use of Diffuse Acoustic Radiators in Sound Distribution, Preprint 4634 -- *Investigation of NXT's use in public address systems with particular emphasis on its off-axis performance and fall-off in sound intensity with distance*

Azima, H and Harris, N, Boundary Interaction of Diffuse Field Distributed-Mode Radiators, Preprint 4635 -- *Description of how the diffuse radiation characteristics of NXT panels affects loudspeaker-room interactions*

104th Convention, Amsterdam

Harris, N, Flanagan, S and Hawksford, M O, "Stereophonic Localization in the Presence of Boundary Reflections, Comparing Specular and Diffuse Acoustic Radiators", Preprint 4684 -- *Investigation of the in-room stereo imaging capability of NXT panels compared with conventional loudspeakers*

Panzer, J and Harris, N, "Distributed Mode Loudspeaker Simulation Model", Preprint 4739 -- *Description of the electro-mechano-acoustical model used for computer simulation of NXT panel performance*

Bank, G, The Intrinsic Scalability of the Distributed Mode Loudspeaker (DML), Preprint 4742 -- *Confirmation of the constancy of NXT panels' behaviour as their size is altered*

Roberts, M, Exciter Design for Distributed Mode Loudspeakers, Preprint 4743 -- *Details of how moving magnet motors can be adapted to excite NXT panels, and how their design parameters affect panel performance*

Colloms, C, Panzer, J, Gontcharov, V and Taylor, V, Distortion Mechanisms of Distributed Mode (DM) Panel Loudspeakers, Preprint 4757 -- *In-depth investigation of the distortion performance of NXT panels compared with conventional moving coil cone loudspeakers*

Mapp, P and Gontcharov, V, Evaluation of Diffuse Mode Loudspeakers in Sound Reinforcement and PA Systems, Preprint 4758 -- *Further investigations of the advantages of NXT's reduced boundary interaction and wide sound dispersion in public address applications*

Azima, H and Mapp, P, Diffuse Field Distributed-Mode Radiators and Their Associated Early Reflections, Preprint 4759 -- *An investigation of how the diffuse radiation characteristics of NXT panels reduce their interaction with early reflections from room boundaries compared with conventional loudspeakers*

Titles of three papers to be presented at the 105th AES:

Panzer, J and Harris, N -- *"Distributed-Mode Loudspeaker Radiation Simulation"*

Harris, N, Flanagan, S and Hawksford, M -- *"Stereophonic Localization in Rooms, Comparing Conventional and Distributed-Mode Loudspeakers"*

Mapp, P and Ellis, C -- *"Improvement in Acoustic Feedback Margin in sound reinforcement systems"*

Where to Get More Information:

Web site: www.flatspeaker.com
Or write to: NXT, Stonehill, Huntingdon PE18 6ED, UK

A version of this article also appeared in Audio magazine