how it works

CONTRARY TO CONVENTIONAL UNDERSTANDING, A FLAT SPEAKER CAN BE BOTH A PRODUCT PANEL AND A SOURCE OF HIGH-QUALITY SOUND.

Flat speaker delivers volumes of sound

By Henry Azima, NXT plc

IT'S NOT EASY to overturn 80 years' worth of established thinking on how to reproduce sound and to simultaneously provide packaging benefit. Since Chester W Rice and Edward W Kellogg in the mid-1920s invented the moving-coil-drive unit at General Electric Co, conventional loudspeakers have operated as pistons (**Reference 1**). They operate in this way no matter what their method of transduction is—electromagnetic, electrostatic, or piezoelectric. Like a paddle in water, they move air and so generate sound with a relatively rigid diaphragm. For this reason, most speaker-drive units' diaphragms are cones or, in the case of tweeters, domes to confer on them a much higher stiffness than you could easily achieve with a flat alternative (see **sidebar** "Design tools are special, as well").

In practice, the diaphragm materials that cover bass and midrange frequencies are too limp, even in cone form, to avoid what audio engineers term breakup—that is, the flexure of the diaphragm. This flexure can lead to resonance, a condition that the audio industry traditionally regards as anathema to high-quality sound reproduction. The past 50 years of loudspeaker development has focused on the measurement and suppression of resonance.

But pistonic operation has a significant drawback. As frequency rises toward and beyond the point at which the wavelength in air is comparable with the dimensions of the diaphragm, the acoustic output becomes increasingly directional, and the speaker begins to "beam." You can avoid this problem by making the diaphragm sufficiently small, but, because the wavelength in air at 20 kHz (the nominal high-frequency extreme of the audible spectrum) is only 17 mm, it would have to be too small to enable you to generate useful output at lower frequencies. To generate a given sound-pressure level, the diaphragm's acceleration must be constant, meaning that its excursion must quadruple with every halving of frequency.

This phenomenon explains why high-quality moving-coil loudspeakers usually have two or more drive units: a large, low-frequency driver, which can move enough air to reproduce bass sounds, and a smaller, high-frequency driver, which, because of its reduced diameter, doesn't become too directional in the treble. Even so, the speaker's directivity still changes markedly with frequency with two undesirable effects.

First and most obvious, it constrains the listening area over which you can maintain the desired sound quality. Hi-fi enthusiasts are familiar, from many years of conditioning, with the concept of the stereo "hot seat," but this notion of a sonic sweet spot does not translate well into listening to music or movies or a host of other applications requiring a broad spread of output across all frequencies. Complex drive-unit arrays or special forms of horn loading can tackle this problem in large public-address installations, but these approaches are too bulky and too expensive to apply generally.

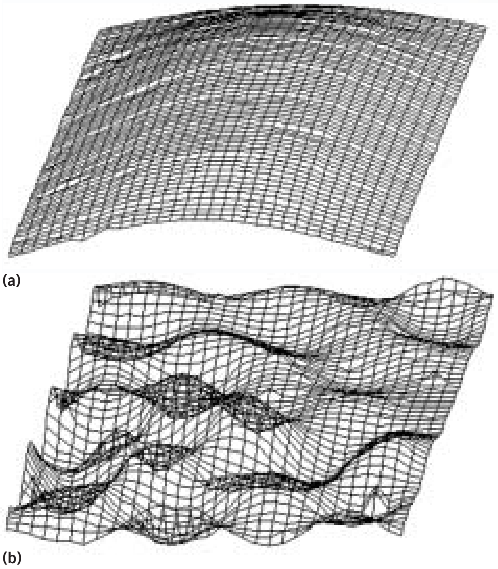

Figure 1 Unlike conventional, established speakers (a), the DML approach uses exciters at key points on the product panel to take advantage of the panel's natural modes of resonance (b).

Second, nonconstant directivity implies a disparity between a speaker's on-axis-pressure-versus-frequency response and its power-versus-frequency response measured over 4π steradians of a solid angle of a sphere. In the normal reverberant listening environment, this variation results in spectral disparities between the first arrival, early-reflection, and reverberant components of the sound reaching the listener, and these components give rise to colorations.

NXT overcomes this frequency-dependent directivity problem and brings other important benefits, as well. The company achieved this goal by tearing up the rulebook that says you must avoid resonance. NXT sound panels achieve their advantages by encouraging and exploiting resonance. Their behavior is inherently modal, which is why they are more formally known as DMLs (distributed-mode loudspeakers).

A DML functions by encouraging and exploiting a bending resonance within the panel material (see **sidebar** "History of DMLs"). You energize these resonances by placing one or more exciters at points on the panel, where they excite many of the panel's natural modes (**Figure 1**). Optimum choice of the panel's aspect ratio ensures good modal "fill" across a wide bandwidth, and correctly dimensioning the panel's bending stiffness, mass per unit area, and internal damping merge the individual modes to create a near-flat power-response curve. Early DMLs were flat and rectangular, but NXT has since developed methods to design panels of different shapes and curvatures.

DML panels exhibit different acoustic behavior from pistonic speakers because of the highly complex, quasirandom nature of their vibration at frequencies sufficiently above the panel's fundamental bending mode. Most significantly, DMLs do not

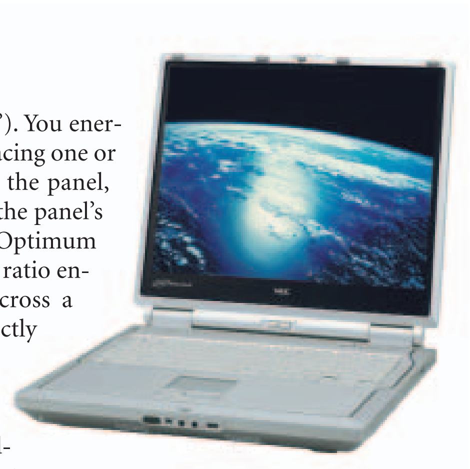

Figure 2

The NXT DML approach is not just a laboratory concept but is built into commercially available consumer products, such as this laptop computer.

DESIGN TOOLS ARE SPECIAL, AS WELL

Because NXT panels operate so differently from pistonic loudspeakers, conventional speaker CAE tools are of no help in the acoustic-design process. NXT's early research into the vibrational behavior of DMLs (distributed-mode loudspeakers) used FEA (finite-element analysis), and this method is still the best for applications requiring an unusually shaped panel. But FEA models take a long time to build and analyze, so this approach in most cases is impractical, even if the NXT licensee who wants to use it has the necessary expertise.

To fill these needs, NXT developed a range of dedicated CAE-design tools, the most important of which is PanSys (**Figure A**). PanSys allows designers to build virtual panels in a drag-and-drop environment, after which it quickly and accurately simulates their performance. Outputs include panel acoustic power versus frequency response and electrical impedance versus frequency. Most important, PanSys incorporates a database of approved panel materials and exciters, all of which NXT's Technology Centre has tested to ensure the accuracy of the simulations. In the case of panel materials, this testing involves determining dynamic stiffness and damping values using a laser interferometer. If stiffness and damping depend on frequency, you can also model this behavior. PanSys extracts the exciters' electromechanical parameters.

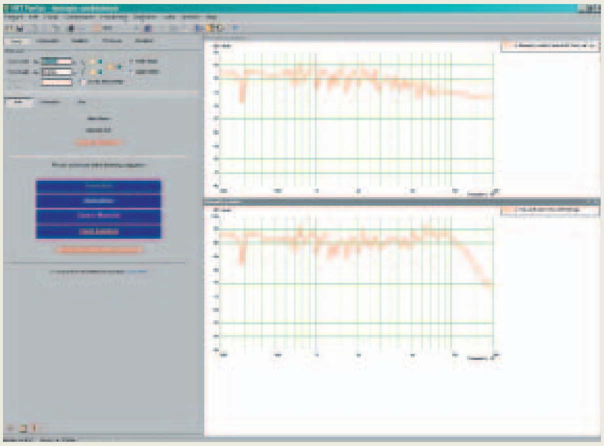

Figure A **The PanSys design and evaluation tool is critical to designing and assessing the DML design for a set of materials, dimensions, and configurations.**

A more recent addition to NXT's virtual prototyping facilitates faster trials with panels of different sizes, shapes, and constructions. Once you specify the panel's dimensions and shape—flat or curved in one dimension—you select boundary conditions from drop-down menus and define the panel material's key physical properties. You find material properties in the associated database, which you use directly or via a composite module that can deal with multilayer materials. The tool then generates model information in various forms, including panel-vibration contours. You can view a simulated power response and drive map; the drive map helps identify the best exciter locations. Once you identify promising panel designs, you can more fully model them using PanSys.

The simulation tool calculates material properties from experimental data. A related module analyzes laser-vibrometer modal data to infer flexural modulus, shear modulus, and Poisson's ratio values for the panel under test, using techniques to quantify panel materials' dynamic properties for the PanSys database. It can characterize both homogeneous- and sandwich-panel materials, including sandwich constructions with anisotropic skins.

Once you design a prototype panel, the tools let you simulate the panel's sound reproduction by convolving the calculated impulse response of the panel with any desired sound file in real time. Thus, you can accurately assess the panel's sound quality without building it. You perform the convolution processing in software, so this module works on any host computer that has a sound card.

tend to beam their output as frequency increases; instead, they retain virtually constant, wide directivity independent of frequency, whatever their size, making them uniquely scalable. Again, because of the complex nature of their vibration, the panels are also diffuse sound radiators, and this diffusivity lessens negative interactions with room boundaries, which act as acoustic mirrors.

Once the commercial potential of the DML became clear, Verity Group in 1996 formed a company, now NXT plc, to further develop the technology and license it to a broad range of applications. The first NXT-equipped product was a notebook computer that NEC launched in Japan in 1997. NXT has concentrated on expanding its IP (intellectual-property) base through fundamental research, developing its licensee training and creating CAD tools that allow a licensee to autonomously develop NXT products, although NXT's Technology Centre in Huntingdon, England also offers a range of design and prototyping services.

NXT at first constructed its panels of opaque materials, but it quickly became apparent that extending DML technology to transparent plastics would create a new area of IP and product potentials. By driving a transparent panel from its periphery, you can combine the functions of a loudspeaker and a visual display in one component. This SoundVu panel maintains all the acoustic advantages of DML operation, but it has almost no footprint, adding just a few millimeters to the overall thickness of the display. Users have built it into both large and small systems, ranging from a home multimedia center, in which it places the audio and the video source in one location, to a cell phone, in which the ability to operate the display as a loudspeaker both improves audio quality and creates opportunities for product-appearance design by eliminating the conventional microspeaker and its grille.

Larger panels generally use moving-coil exciters, but designers want a more compact and efficient alternative for products in which space is at a premium. To fit SoundVu into these compact devices, NXT scientists developed the DMA (distributed-mode actuator), a unique piezoelectric exciter, which is a modal device, just like the panel it drives. Operating the exciter at a resonance higher than its fundamental bending resonance circumvents the difficulty of coupling a displacement device (the piezoelectric transducer) to a velocity device (the NXT panel), which would normally require the use of substantial equalization and hence large signal-voltage capability at low frequencies.

A fundamental limitation of NXT speakers is that they operate higher than the fundamental bending resonance of the panel. Large panels can operate at frequencies lower than 100 Hz, but smaller panels are limited to commensurately higher frequencies. So, despite the unusually wide-bandwidth capability of NXT panels—typically more than eight octaves, or 2.4 decades—in an optimized design, it is often necessary in full-range applications to partner them with a conventional woofer or subwoofer. NXT scientists appreciated early on that they could avoid this complication if a single panel could operate as a piston at low frequencies but as a DML at high frequencies, thereby achieving unprecedented bandwidth and maintaining wide sound dispersion.

Seamlessly executing this handover is difficult, but NXT two years ago succeeded in creating this pistonic/DML hybrid, or AFR (audio full range). NXT recently developed the 2.5-in.-diameter Mini-AFR unit for in-car use; it has an operating bandwidth of 120 Hz to more than 20 kHz, yet has such broad directivity that you can mount it almost horizontally on the top of an instrument panel. It still delivers this frequency range to the car's occupants, whose ears may be 80 to 90° off the unit's forward axis. You cannot achieve comparable performance with a conventional drive unit.

The ability to use the product's enclosure and front panel as a quality sound source is not just an academic exercise. The list of licensees for this technology includes NEC, 3M, Acer Computers, DaimlerChrysler, Fujitsu Ten, Intier, LG Electronics, Matsushita MEI, Pioneer, Siemens, Sony Ericsson Mobile Communications, TDK, and Visteon, and many products are available in stores (**Figure 2**).

REFERENCE

1. Rice, Chester W and Edward W Kellogg, "Notes on the Development of a New Type of Hornless Loudspeaker," *Transactions of the American Institute of Electrical Engineers* No. 44, 1925, pg 461.

AUTHOR'S BIOGRAPHY

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HISTORY OF DMLs

DML (distributed-mode-loudspeaker) technology began in the early 1990s as a research project of the United Kingdom's DERA (Defence Evaluation Research Agency), now QinetiQ. The research aimed to reduce the level of internal noise in military aircraft. As part of this research, DERA's scientists tried lining cockpits with high-stiffness sandwich materials but discovered that, rather than lowering the noise level, they increased it. As this effect might have significance for loudspeaker design, they filed a speculative patent. DERA itself had neither the resources nor the experience to develop this application, so it advertised for an audio-industry partner to license it.

This advertisement came to the attention of Farad Azima of Verity Group, who in 1994 initially took out a nonexclusive license and entrusted initial R&D to Verity Labs, which had considerable experience designing conventional loudspeakers for Mission Electronics.

At this early juncture, scientists knew little about how a DML, as it would become known, operated, and prototypes were far from becoming commercially viable. The first step was to identify and then mathematically model the vibrational behavior of the panel, so that they could optimize its physical properties and method of excitation.