Build a Flat Panel Speaker

This article investigates distributed-mode loudspeakers (DML), a new development in loudspeaker technology, with many desirable attributes and a multitude of practical applications.

By Daisuke Koya

Dr. Ken Heron[1] at the United Kingdom's DERA (Defence Evaluation and Research Agency) worked on composite panels for helicopters. In his research, he found that the panels reradiated significant output in the audio bandwidth. Although this was not desired in aircraft, it was suggested that this could be used in loudspeakers.

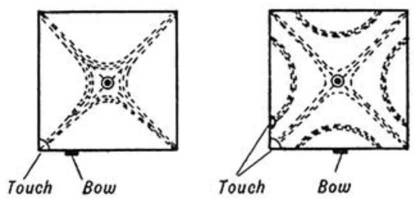

FIGURE 1: Two examples of modal resonance patterns in a free plate (after Chladni 1787)[2].

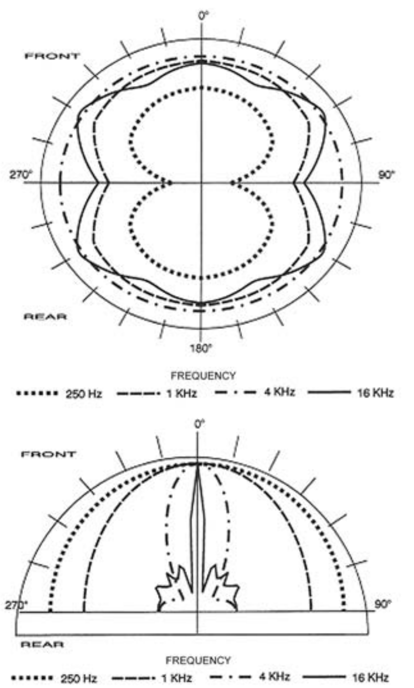

FIGURE 2: Comparison of radiation patterns. Distributed-mode loudspeaker (top) and pistonic loudspeaker (bottom)[2].

COMMERCIAL EXAMPLES

There are quite a few commercial examples of DMLs (distributed-mode loudspeakers) today. I own Sonic Impact's SI-5, Gen2 SI-5, and the amazingly good-sounding cardboard SoundpaX DML speakers. Brookstone, the specialty consumer products store, has a product called the "Wafer-Thin CD System with MP3," which also sounds very nice.

Teac has mini stereo systems that feature DML speakers. NXT, the primary licensee of DML technology, has developed SoundVu, which allows a video display device to double as a loudspeaker providing up to three channels of sound. NEC currently sells desktops and notebook personal computers with LCD displays that incorporate SoundVu technology.

THEORY

Chladni[2] in the late 18th century demonstrated that resonant modes were produced in a glass or metal plate (**Fig. 1**). The plate was fixed at its center, excited by a violin bow, and damped by nodal points by touch, which displayed modes through the medium of sand dusted on the surface.

A DML[3] is a bending wave panel with resonant modes randomly distributed in frequency throughout the vibrating panel. Although for pistonic technology, resonance is damped or generally avoided to prevent unpredictable frequency response, distributed-mode loudspeaker design encourages as many resonances as possible.

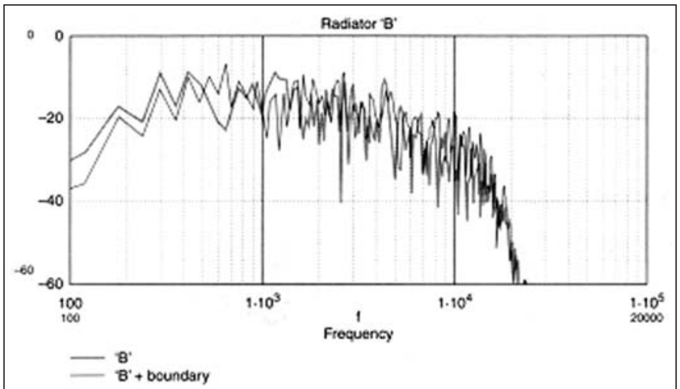

FIGURE 3: Traditional loudspeaker in free space and with boundary[1].

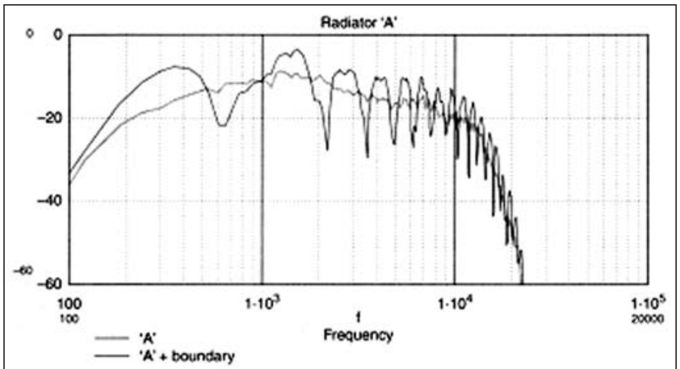

FIGURE 4: DML in free space and with boundary[1].

A DML has these characteristics:

- Wide bandwidth[4]—An optimized DML design can have eight octaves of bandwidth.
- Wide directivity—Compared to pistonic loudspeakers, the DML displays wide directivity (**Fig. 2**), which is generally independent of frequency.
- Boundary reaction[1]—For the

DML, compared to a traditional loudspeaker (**Fig. 3**), there is insignificant correlation between the frequency response measured in free field compared to the frequency response measured with a nearby boundary (**Fig. 4**). This results in improved clarity and intelligibility.

• Maintains loudness better with distance—The SPL reduction of a DML does not follow the inverse-square law. For moderate distances (e.g., 3´ ~ 16´ or 1m ~ 5m), the sound pressure level falls roughly as a linear function of distance[2]. Loudness drop in sones from the front to the back of a room is less for a DML as compared to a conventional direct-radiator loudspeaker. Improved distribution of loudness is also observed for the DML[1].

• Lower distortion[1]—Because the DML is a velocity device, the sound pressure is proportional to mean panel velocity, whereas in a conventional moving-coil loudspeaker, the sound pressure is proportional to acceleration. Thus, at low frequencies, the DML has lower distortion due to lower displacement. For optimized DML designs, the distortion products are typically 10dB lower than a pistonic loudspeaker.

• Acoustic feedback margin[1]—In the presence of microphones, the feedback margin in sound reinforcement systems using DML technology is higher than that of conventional cone loudspeakers.

• Electroacoustical efficiency[2]—The real-world electroacoustical efficiency compares well with moving-coil systems (0.5% ~ 2%).

• Shallow depth—DML construction is generally shallower than conventional direct-radiator moving-coil loudspeakers.

DESIGN

Here are a few points regarding how to optimize a DML design:

• The selection of a light and stiff panel, implying the use of custom composites, will ensure the best results.

• The objective in the design of distributed-mode loudspeakers is to maximize the amplitude and density of resonances.

• For optimal results, the location of the drive point should couple to all the panel modes while ensuring de-correlation between panel velocity and drive point[1].

Si-5, which manufactures the SoundPad exciters, recommended foam-core posterboard as the panel material. Although a professional DML engineer recommended against using foam-core posterboard due to its less-than-ideal

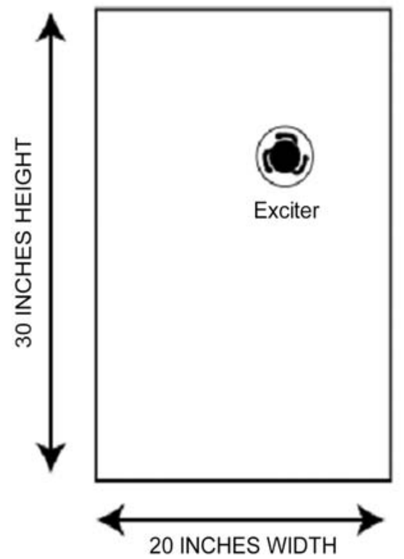

FIGURE 5: Foam-core posterboard and exciter diagram.

PHOTO 1: Foam-core posterboard with SoundPad exciter attached.

PHOTO 2: SoundPad exciter.

high-frequency response characteristics, you cannot purchase better panel materials such as Acoustic M1 and Rohacell foam at local office-supply stores, which precluded their use for this project.

I used the following items to construct the DIY DML:

1. Foam-core posterboard—20″× 30″ (50.8cm × 76.2cm), 3/16″ (5mm) thickness.
2. Sonic Impact SoundPads.

The 20″ × 30″ foam-core posterboard (**Photo 1**) is available for around $5 per sheet from most major office-supply stores. Art-supply stores may have these posterboards for even cheaper. For the exciter, the Sonic Impact SoundPads (**Photo 2**) are available for $20 from Sonic Impact Technologies (www.si-technologies.com). I actually found my SoundPads at a local Target discount store.

Because I do not have access to the FEM (Finite Element Modeling) software by NXT called PanSys, which can perform exciter drive-point optimization given the panel properties, I determined the drive point by a heuristic method of DML theory, subjective impressions, and acoustic measurements. The SoundPad instruction manual provided a place to start: “Press the SoundPad, before exposing the sticky surface, against one of the intended speakers and move it around until you are satisfied with the sound balance of treble and bass.”

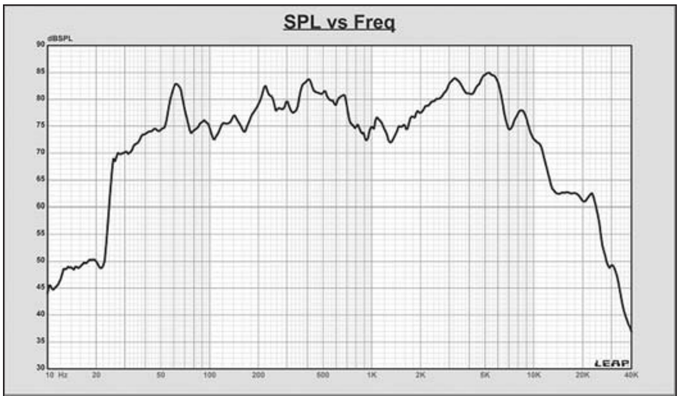

FIGURE 6: DIY DML, on-axis frequency response at 1m and 2.83V RMS drive level. 1/6-octave smoothed.

The objective here was to try to get the best distribution of modes horizontally and vertically. The drive point of the exciter for this project was based on moving the exciter (SoundPad) around the foam-core posterboard while listening to familiar pieces of music (**Fig. 5**). I next performed acoustic measurements based on subjectively preferred exciter locations for confirmation. These preferred exciter drive-point locations and subjective comments are as follows:

- Exciter ½ width, ⅓ height—Good high-frequency response, but low frequencies suppressed.
- Exciter ½ width, ½ height—Good low-frequency response, but high frequencies suppressed.
- Exciter ⅓ width, ⅓ height—Best subjective balance of low and high frequencies.
- Exciter 3/7 width, 4/9 height—This well-defined drive point recommended by NXT[3] seemed to sound just as good as the ⅓ width, ⅓ height exciter position.

In the end, I settled on the final exciter drive-point location of a 3/7 width, 4/9 height location, as the subjective performance was just as good as the ⅓ width, ⅓ height exciter position with less peaking in the measured high-frequency response.

CONSTRUCTION

Construction was easier than any speaker I’ve ever built in my life, past *and* future (probably). After exposing the adhesive surface of the SoundPad, it was attached to the pre-determined location on the foam-core posterboard. Ta da!

MEASUREMENTS

I performed all measurements with the 3/7 width, 4/9 height exciter drive-point location. The DIY DML was suspended (not clamped) from a speaker stand.

Figure 6 displays the 1/6-octave smoothed full-range frequency response of the DIY DML at 1m and 2.83V drive level. Because the frequency response is far from flat (27Hz~11.5kHz ±7.5dB), it is difficult to ascertain the nominal voltage sensitivity for the DIY DML. However, it can be said that at least for this example of a distributed-mode loudspeaker that its voltage sensitivity falls shy of most two-way bookshelf speakers. Although the low-frequency response is excellent, the high-frequency response drops precipitously above 10kHz.

Figure 7 displays the on- and off-axis (15°, 30°, and 45°) frequency response. Between 500Hz and 10kHz, you can observe that the frequency response does not change dramatically. Above 10kHz, the frequency response becomes more directional as the responses for the 30° and 45° curves are gradually more attenuated.

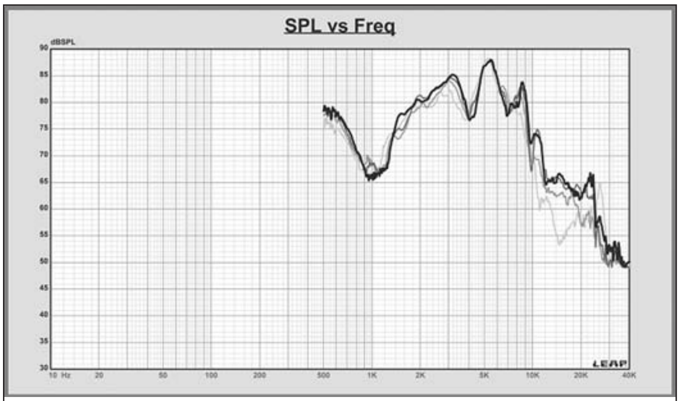

FIGURE 7: 0°, 15°, 30°, 45° on- and off-axis frequency response at 1m and 2.83V RMS drive level.

Figures 8 and **9** display the 360° polar response curves for the horizontal and vertical orientations of the DIY DML. The curves span from 700Hz to 20kHz. Generally, you can observe omnidirectional behavior between 1kHz and 7kHz for both the horizontal and vertical polar responses. You can see for both horizontal and vertical polar responses that omnidirectional behavior does not hold true at frequency extremes. **Figures 10A** and **10B** are plots of the horizontal and vertical directivity index (DI) and is another method to view the polar data in **Figs. 8** and **9**.

Figure 11 displays the impedance response of the DIY DML, and it looks nothing like a conventional moving-coil loudspeaker! The impedance plot is rife with multiple resonances, which is expected behavior in a distributed-mode loudspeaker. It is surmised that the peak lowest in frequency (26Hz) is the fundamental resonance of the DIY DML. The modal density increases at higher frequencies, which you can see by the multiplicity of peaks in the impedance response. Above 2kHz, the impedance response increases dramatically due to the inductance in the voice coil of the SoundPad exciter.

SUBJECTIVE IMPRESSIONS

Equipment used:

- Sony DVP-650V SACD changer
- Onkyo TX-SR501 receiver
- Cheap interconnects and speaker cables

Most of the listening was done with the Onkyo receiver's 12dB/octave Dolby Digital high-pass crossover set to 80Hz, because sending a full-range signal to the DIY DML tended to overload the exciter and panel, which resulted in perceived harmonic distortion. Despite its 25Hz low-frequency extension, the DIY DML was not capable of playing low frequencies at realistic levels. Alleviating the DMLs of low-frequency duties and having a subwoofer take over may be more effective in full-range sound reproduction.

It is important to note, though, that some home theater receivers, for some reason, disengage the high-pass crossover to the main speakers in stereo (2-channel) mode. Fortunately, the Onkyo does not, but if this is the case, you can try the Dolby Pro Logic "Music" modes, which may restore high-pass crossover functionality.

The following is a list of stereo music tracks I used during the listening session, followed by comments:

Flim & The BBs, *Tricycle*

• Very nice visceral low-frequency transient response and extension

• Lacking some high-frequency extension

Paula Cole, *Tiger*

• Excellent low-frequency extension but levels must be kept low to prevent distortion

• Again, lacking some high-frequency extension

M-Pact, *Prince Medley* (recording not commercially available)

• Somewhat defined soundstage, doing justice to the original recording which was done, I believe, with five Shure SM 58 microphones panned across the five a cappella singers

Madonna, *Holiday*

• QSound reproduction was accurate (i.e., synthetic widening of soundstage)

Rebecca Pidgeon, *Spanish Harlem*

• The acoustic double bass tends to overload the DML panel and exciter at realistic levels, even with the 80Hz high-pass crossover

• The phantom image was solid even when I moved my head ±15° horizontal from between the speakers, demonstrating relative insensitivity to listener placement

Ludwig van Beethoven, *Symphony No. 9 in D Minor ('Choral'), Op. 125, Movement 4: Ode To Ludwig* as played by Don Dorsey

• The transient attacks in this piece were very accurately reproduced

CONCLUSION

This article examines an approachable method to distributed-mode loudspeaker (DML) construction and evaluation. For the cost of two CDs, you can construct a pretty decent example from readily available parts. What is most impressive about the DIY DML is its stable imaging and visceral transient response.

Although my example was not faithful to the best examples of DML speakers, this is unsurprising, because I could not utilize the best materials and computer optimization. The future holds promise for this new technology, and I hope to see more applications for home, portable

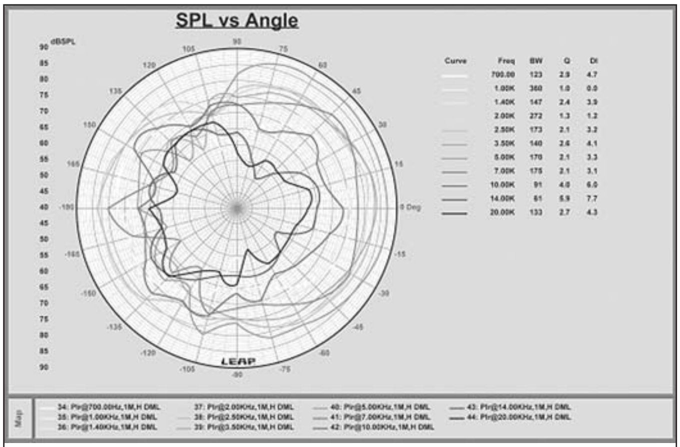

FIGURE 8: Horizontal polar response.

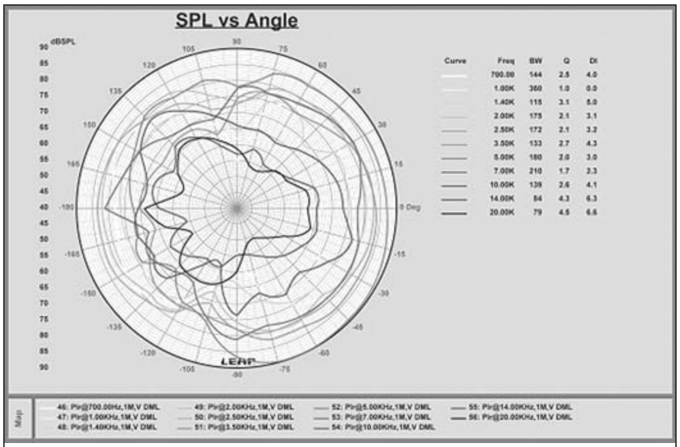

FIGURE 9: Vertical polar response.

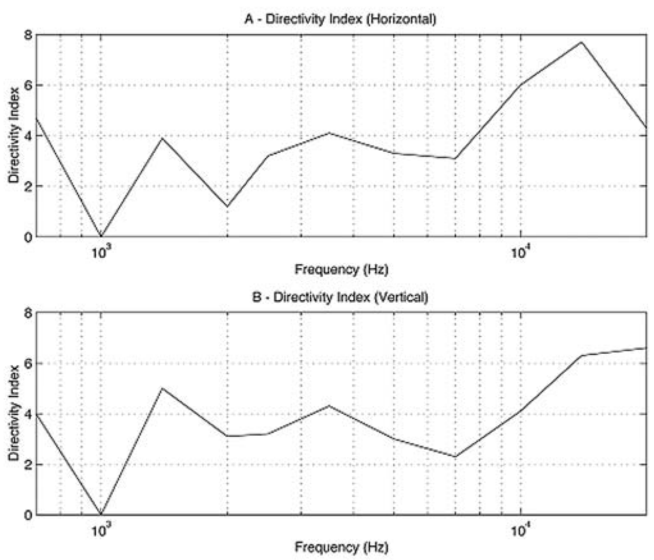

FIGURE 10: Directivity index; A-horizontal, B-vertical.

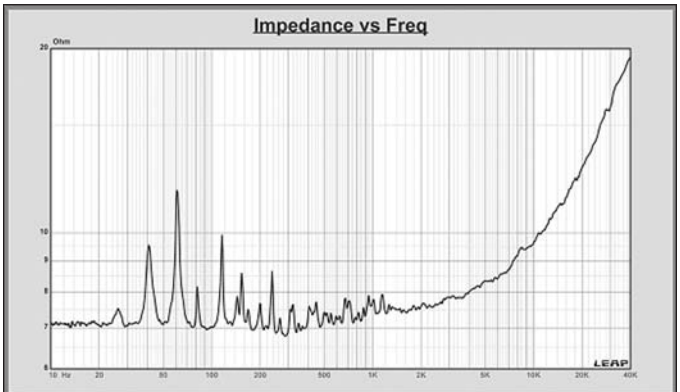

FIGURE 11: Impedance.

sound, personal computing, automobile, and sound reinforcement. *aX*

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