Ceramic
Metal
Matrix
Diaphragms

CMMD™

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TECHNOLOGY • PERFORMANCE • DESIGN

A Technical Report on Ceramic Metal Matrix Diaphragms

(CMMD)

By Floyd E. Toole and Allan Devantier

Loudspeaker systems should be neutral devices, converting electrical signals from power amplifiers into exact acoustical equivalents, adding and subtracting nothing. Art is in the music itself, and in the musical sounds from fine instruments, played by talented musicians. The task of loudspeaker systems is to reproduce this art transparently, without “editorial” changes. Our objective is to build loudspeakers that are as neutral as possible, that accurately reproduce the subtle identifying characteristics, or timbres, of voices and musical instruments.

Many factors are involved in the design of a superb loudspeaker system. There are the transducers, or drivers, that convert electrical signals into sound; the electrical crossover networks that divide the frequency range, sending the appropriate frequencies to the woofer, midrange, and tweeter; and the enclosure, which is a critical acoustical part of the woofer system and an acoustical and decorative baffle for the other components. Excellent performance is required of each of these elements if the system as a whole is to be a success, but superb transducers are, in fact, the critical components. They are the heart of a loudspeaker system.

Individual drivers, woofers, midranges, and tweeters are specially designed to convey very specific portions of the audio frequency range. Used in combination, they allow the loudspeaker system to cover the musical frequency range with the necessary timbral neutrality that accurate reproduction demands, and with the uniform dispersion patterns that ensure a "friendly" interface with the listening room.

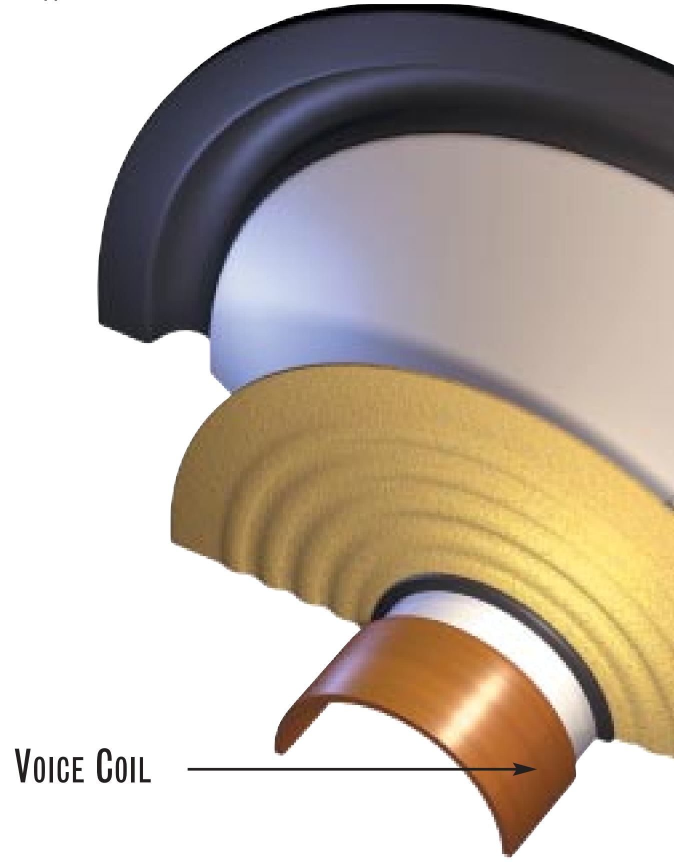
In designing these transducers, we at Infinity® have in mind technically defined "target" performances. Our engineers use magnetic and electro-mechanical modeling programs in computers to predict how the moving parts of the system will function. After prototypes are built, mechanical and acoustical measurements are used to analyze how well they work, employing special facilities which measure the mechanical and acoustical performance variables. We must understand the rules by which the technical data are interpreted so that we can infer how the resulting sounds will be perceived by listeners. This is not easy.

Because listeners are the final judges of how well loudspeakers perform, we have asked them to help us determine what various technical measurements mean. It took many tedious subjective evaluations, with many listeners and different kinds of loudspeakers, to determine the audibility of various kinds of defects. We can now look at a graph and be able to say with confidence that a certain characteristic is, or is not, an audible problem.

An "ideal" loudspeaker should have no measurable or audible problems. But product lines often include designs in varying price ranges and it should be expected that there will be compromises in quality at the lower price levels. To deliver the best possible sound at every price level, engineers must be able to interpret measured data of the characteristics that color sound in ways listeners find objectionable. This way we always work toward the ideal, approaching it as closely as cost and technology allow, at every price level.

Of all the problems that surfaced in these investigations, resonances stood out as being one of the principal causes of listener dissatisfaction. Why are resonances so important? It is probably because almost all of the sounds we want to hear are made up of resonances. In voices and musical instruments, high-Q (narrow-band) resonances define the pitches (the notes), while combinations of medium- and low-Q resonances add the timbral character that make a violin sound like a violin, and Pavarotti sound like himself. Loudspeakers with strong resonances change the timbre and, therefore, the sound of instruments and voices. We work diligently to eliminate resonances from our transducers and systems.

Figure 1. The construction of a cone assembly, showing the diaphragm connected to the voice coil that drives it, and spider and surround that support it.



It is obvious that audible resonances should not exist within the frequency ranges over which the drivers are used. One might erroneously conclude, therefore, that a resonance at a frequency above a crossover frequency is not a problem. Our sensitivity to resonances is such that they remain audible even after being reduced many dB by the attenuation of the crossover network. The greater the reduction in amplitude, by whatever means, the more neutral the loudspeaker system will sound.

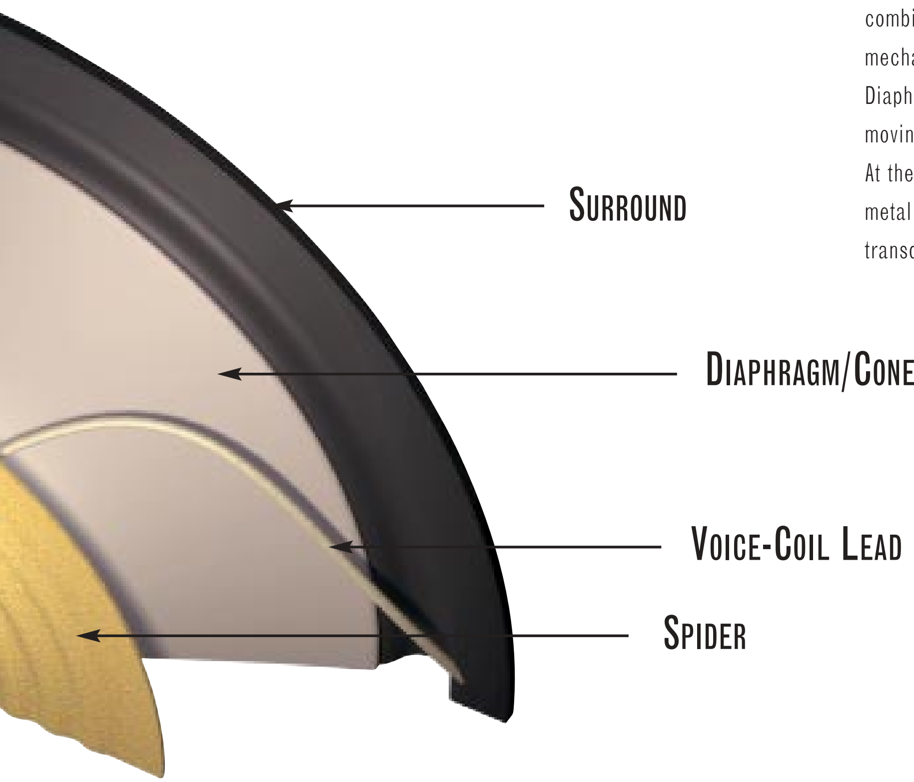
All mechanical structures have natural vibrational modes or resonances. For loudspeaker diaphragms (cones or domes), resonances are the primary source of audible coloration. There are two commonly used methods to handle diaphragm resonances. One is to allow the vibrational modes to exist, but to apply damping to the modes to reduce their Q, or bandwidth. The damping can be a coating applied to the diaphragm material, or it can be an integral part of the material structure. For woofers, popular cone materials are paper, polymers and various “matrix” hybrids because they are inexpensive and supply large amounts of damping.

This sounds as though it should work, and it does, like tapping a wine glass to make it ring, and then lightly touching it with the fleshy part of a finger. The ringing is damped, and further taps produce only dullish “thunks.” Two factors prevent this from being the only solution to the problem. One is that damping is a “lossy” process, and damping materials can add mass to critical moving parts. Increased mass reduces the sensitivity, or efficiency, of the driver because of the extra effort needed to move the more massive diaphragm. The other factor is much less obvious: the resonances, even with their reduced Q, can still be audible. The dull “thunk” of the wine glass is still there; it is still recognizable as glass, not cardboard or rubber.

As long as the resonances are present in the frequency range over which the transducer is to be used, damping can minimize their audible effects and, with skill, reduce them to inaudibility, but they cannot be absolutely eliminated.

To our engineers, this was just another challenge. They keep looking for ways to push the frequencies of these pesky resonances outside of the frequency band the driver operates in. For tweeters, metal domes have become common because they are very stiff, moving most of the severe natural modes above 20kHz; thus the modes themselves become inaudible.

Working in collaboration with metallurgy specialists, the resourceful Infinity transducer engineers identified a special combination of materials that exhibit a remarkably useful set of mechanical properties. Infinity’s new Ceramic Metal Matrix Diaphragms are much stiffer than standard metal diaphragms, moving the natural modes significantly upwards in frequency. At the same time, CMMD cones have more damping than metal cones, making this an excellent cone material for all transducers: woofers, midranges and tweeters.



Moving the Modes Up in Frequency

For a given diaphragm geometry, the frequencies of the natural modes are determined by the speed of the sound in the material which, in turn, is determined by the formula at the right. Thus, for every doubling of the speed of sound, we move the cone modes up a full octave.

$$\text{velocity} = \sqrt{\frac{\text{stiffness}}{\text{density}}}$$

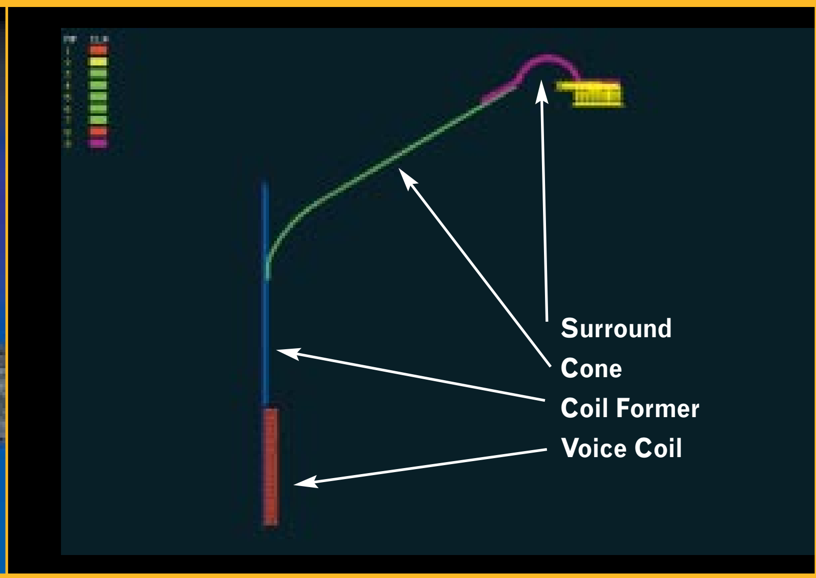


Figure 2. The computational model of the moving assembly of a loudspeaker: voice coil, voice-coil former, cone and surround. The model is used to calculate the resonant modes of the system for different cone materials.

Figure 3. This shows a radial slice through the cone assembly. It shows the voice coil (red), the coil former (the vertical blue line), the cone (greenish), and the surround (purple) attached to the frame.

Sound propagates at a higher velocity in metals than in materials such as polymers and papers. A third class of materials, ceramics, has an even higher speed of sound. Table 1 shows the parameters of several common loudspeaker diaphragm materials.

Once a diaphragm is attached to a surround and a voice coil, the frequencies of the natural modes of the entire moving system become difficult to predict. To calculate the natural modes of the entire moving assembly, Infinity engineers use a computational tool known as Finite Element Analysis (FEA). FEA breaks a mechanical system into thousands of small elements and then calculates the behavior of the total system based on the properties of the elements.

Material
Polypropylene
Kevlar® Fabric
Paper
Titanium
Aluminum
Alumina

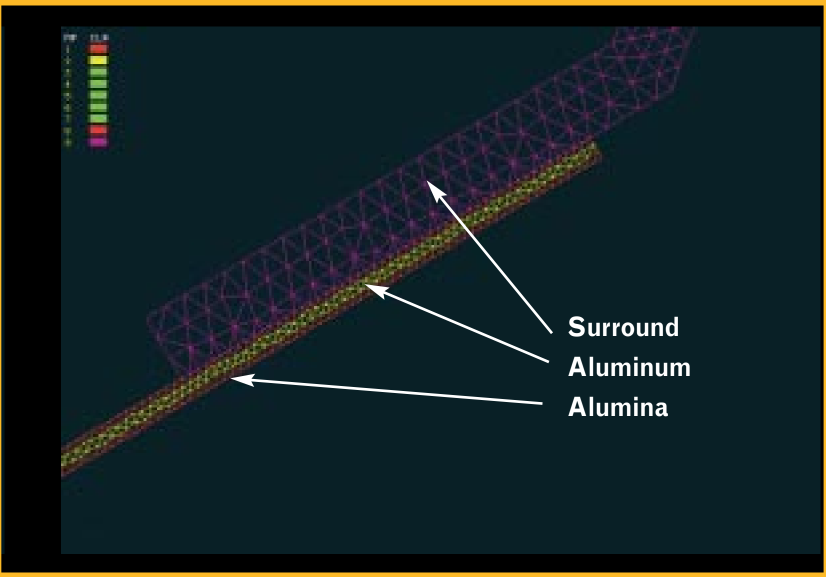


Figure 4. Shows detail of the modeled structure. One can see the ceramic (alumina) outer layers of the diaphragm (red), the aluminum core (green), and the much thicker surround material (purple).

Figure 4b. An electron microscope photograph showing a cross section of a CMMD cone.

Material Class	Young's Modulus (stiffness)	Density	Speed of Sound
Polymer	1.5 x 10^9 Pa	0.9 g/cm^3	1300 m/s
Composite	3.1 x 10^9 Pa	0.9 g/cm^3	1860 m/s
Composite	4 x 10^9 Pa	0.7 g/cm^3	2390m/s
Metal	110 x 10^9 Pa	4.5 g/cm^3	4940 m/s
Metal	70 x 10^9 Pa	2.7 g/cm^3	5100 m/s
Ceramic	340 x 10^9 Pa	3.8 g/cm^3	9460 m/s

Table 1. The speed of sound in several common diaphragm materials. The figures chosen are representative of specific types of materials, but individual examples may differ slightly.

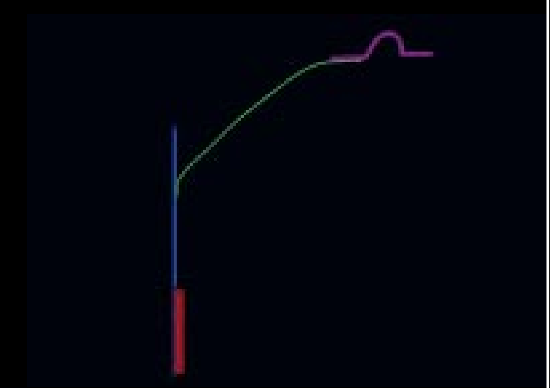


Figure 5. The shape of the first mode with a polypropylene cone, at 1500Hz.

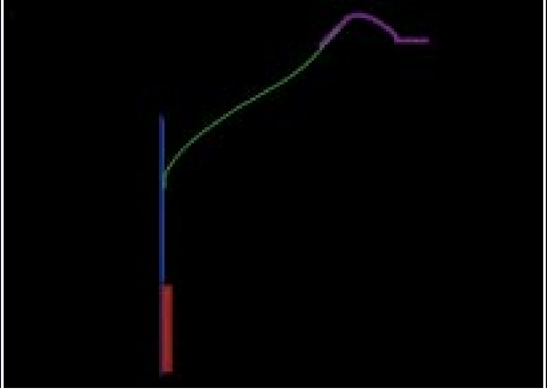


Figure 6. The shape of the first mode with a Kevlar fabric composite cone, at 1920Hz.

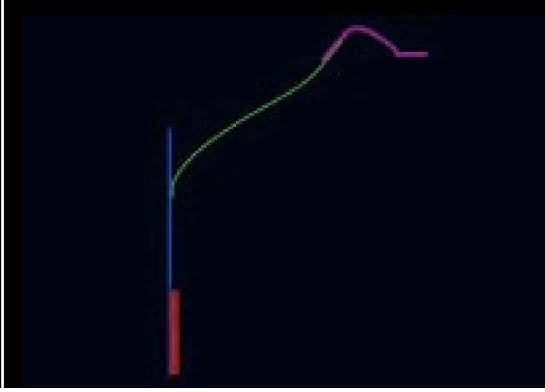


Figure 7. The shape of the first mode with a paper cone, at 2160Hz.

Figure 8. The shape of the first mode with a titanium cone, at 7440Hz.

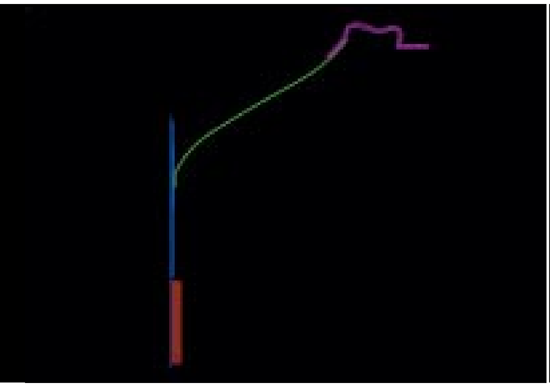


Figure 9. The shape of the first mode with an aluminum cone, at 6700Hz.

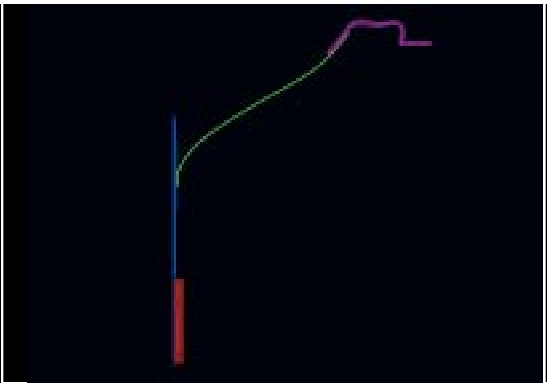
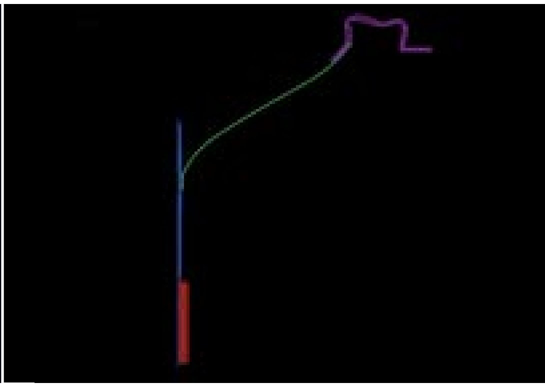


Figure 10. The shape of the first mode with an alumina (ceramic) cone, at 10,800Hz.



Figures 5 through 10 show the shape of the first natural cone-bending mode for each of the cone materials.

From this data it is evident that, with a typical 3kHz crossover to a tweeter, a mid-bass driver constructed of paper, Kevlar® or polypropylene would be operating in resonant "breakup" over a large portion of its range. The metal cone drivers would operate as perfect pistons over the operating band but they would have flexural modes near the crossover due to the mechanical resonances. As a result, a complex crossover would be needed to filter out the frequency-response and time-domain aberrations, so that they will not be heard. Such complicated networks are costly, and can introduce other problems.

However, it is also evident that the first modes of the alumina cone are so high that they can be filtered out with traditional, simpler and less costly crossover techniques. Clearly, alumina would offer performance superior to any of the other materials. Unfortunately, pure ceramics are also very brittle, and a diaphragm made of pure alumina would "shatter" under normal operation, a good reason why such materials are not popular for loudspeaker diaphragms.

Table 2. The first cone-bending modes for various moving assemblies. Table shows the frequency of the first natural cone-bending mode for the entire moving assembly of a 5-1/4" driver for each of six different cone materials attached to a typical voice coil and surround.

Cone Material	Frequency of First Cone-Bending Mode (Hz)
Polypropylene	1500
Kevlar®	1920
Paper	2160
Titanium	7440
Aluminum	6700
Ceramic	10800
Ceramic Metal Matrix Diaphragm (CMMD)	10190

Laminated Materials

Stiffness is most important at the surface of a material. Two common "large scale" examples illustrate this concept. The first is the ubiquitous I-beam used to construct skeletons of buildings and bridges. The top and bottom parts of the "I" offer increased stiffness due to their physical separation. The farther apart they are, the stiffer the beam. Another more esoteric example is the new class of "honeycomb" panels used in aerospace applications and to construct the walls of these same skyscrapers. Here two stiff membranes are attached to a light honeycomb structure. The distance between the membranes provides much more resistance to bending than a solid sheet of the same weight.

Infinity's new Ceramic Metal Matrix Diaphragm material scales this simple principle down to the microscopic level. The diaphragm is made of two layers of ceramic separated by a light metal substrate. Of the common metals, aluminum has the lowest density, making it the ideal substrate. A CMMD cone is made by first forming the cone to shape in aluminum. A unique patented process is then used to "grow" a skin of alumina on each side of the aluminum core. The alumina supplies strength and the aluminum substrate supplies the resistance to shattering. The resulting laminated material is less dense and less brittle than traditional ceramics, yet is significantly stiffer than titanium or aluminum, and much stiffer than nonmetallic materials.

Figure 11. The shape of the first mode with a CMMD cone, at 10,190Hz.

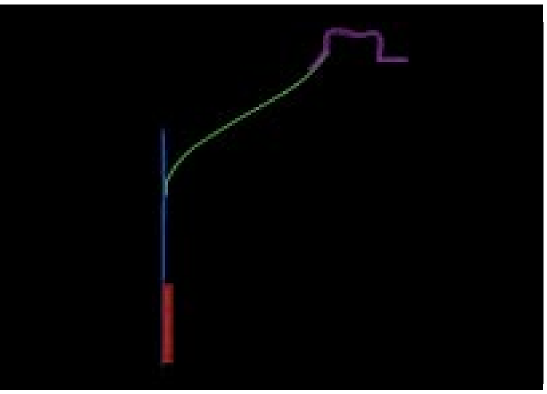


Figure 12. Frequency response of Infinity 6-1/2" mid-bass driver when built of aluminum cone (black curve) and CMMD cone (green curve). The first resonance in the CMMD cone is higher in frequency and lower in both Q and amplitude than the corresponding one in aluminum.

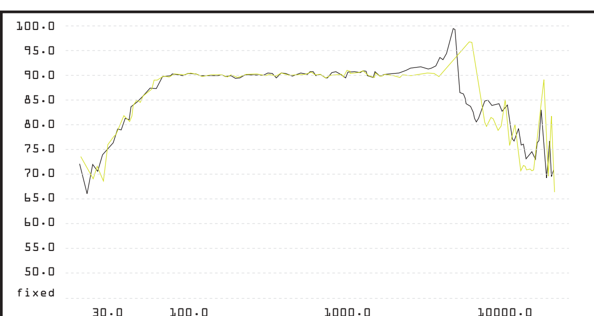


Figure 13. When the attenuation of the crossover network is added to the curves of Figure 12, the result is that, in the CMMD cone, the amplitude of the first bending resonance is about 10dB lower than that in the aluminum cone – this is not a trivial improvement. The final frequency-response curve approaches the theoretical ideal very closely indeed, even far beyond the crossover frequency.

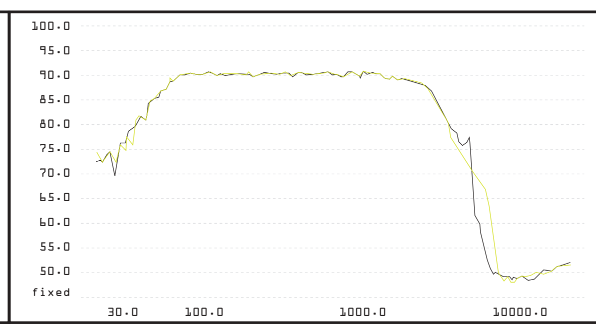


Figure 14. A scanning-laser vibrometer measurement of cone movement for a 6-1/2-inch Kevlar weave cone, at a frequency of 3.5kHz.

Figure 15. A scanning-laser vibrometer measurement of cone movement for a 6-1/2-inch CMMD cone, at a frequency of 3.5kHz.

Damping

For a given geometry, we know that the frequency of the natural modes is determined by the speed of sound through the material. The amplitude of these modes, and thus their impact on the loudspeaker's frequency response, is dependent on the damping of the material. Polymers have very high amounts of damping, and metals have almost none at all. Ceramic diaphragms have significantly more damping than metals.

CMMDs have damping characteristics similar to ceramics, but have a distinct advantage over them. Because of the sandwich "constrained layer" construction of the diaphragm (see Figure 4b on page 7), and because the speed of sound in the CMMD substrate is different than the speed of sound on the surfaces, there is additional damping. Indeed, when properly engineered, a CMMD cone can be designed to have no frequency-response peaks in the entire audible range. Figure 12 shows a comparison of 6-1/2" cones made of aluminum and of CMMD. Figure 13 shows the same comparison after the crossover network has been added.

A Comparison of Approaches

As mentioned earlier, there are two options in cone design: reduce the amplitude of the in-band resonances by using material with high internal losses, or move the resonances out of the frequency band over which the driver is used. Figure 14 shows the bending activity in a 6-1/2 inch Kevlar® cone at 3.5kHz, near the upper end of its useful range. As can be seen, the diaphragm is anything but "pistonic," showing an interesting rectangular flexure, obviously following the stiffness lines of the rectangular fabric weave. In contrast, at the same frequency, the CMMD cone, shown in Figure 15, is perfectly pistonic, showing no sign of flexure – there is no resonance. Whatever one may claim about the damping of in-band resonant modes, it is clearly better to simply not have any to deal with. This is the philosophy on which Infinity's CMMD is based.

Environmental Performance

Ceramic materials can withstand extreme temperatures, moisture, humidity and sunlight, and Ceramic Metal Matrix Diaphragms share these properties. Finally, because the metal substrate is protected by a "skin of ceramic," CMMD cones do not deteriorate even under extreme humidity, salt and moisture.

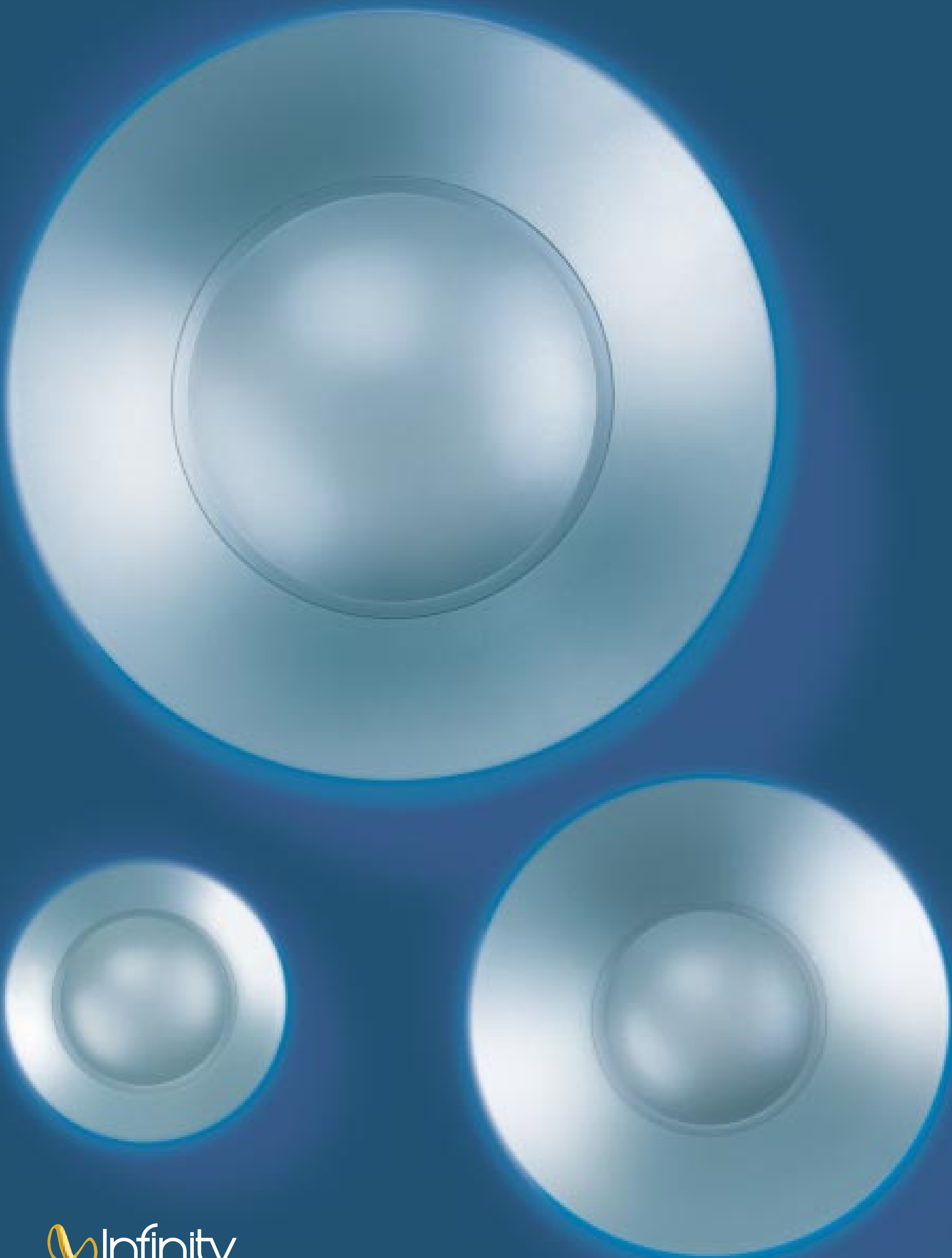
Infinity's Ceramic Metal Matrix Diaphragm material is a major breakthrough in transducer-diaphragm technology. For tweeters, it offers superior stiffness and damping compared to traditional metal domes, moving the first significant mode to the 30kHz region. For woofer and midrange applications, it offers pistonic operation over the entire usable range of the driver, completely eliminating colorations due to cone modes and thus dramatically reducing distortion. Finally, diaphragm performance is not deteriorated by exposure to moisture, sunlight, or extreme temperatures, making CMMD the first diaphragm material suitable for both automotive and marine applications, as well as high-end home audio.

Naturally, neither CMMD nor any other diaphragm material can magically transform a loudspeaker system into a perfect reproducer. The other variables referred to at the beginning of this article are also critical, and top-notch engineering of every element of the system is needed in order for the integrated system to "shine."

"The proof of the pudding is in the eating," as they say, which in audio terms translates into "it isn't good until it sounds good." Engineering concepts and technical data are topics for intellectual discussion but, in the end, we simply want to know how it sounds. In our characteristically thorough manner, all Infinity loudspeakers are put through a demanding battery of listening tests, using a variety of rooms, music, listeners and configurations (mono, stereo, multichannel). The "acid test" is a proper double-blind listening evaluation in our unique, positional substitution, Multichannel Listening Laboratory (MLL), where every Infinity product is compared with the best products we know how to build, and the best of our competitors' products. The listeners are the most experienced, fastidious, nit-picking critics we can find.

And, what did they think of CMMD? We don't actually know, because they apparently couldn't hear it. All they could do was rave about the excellence and transparency of the musical experience – the lack of coloration, the abundance of timbral nuances, natural voices, deep, tight bass, clear imaging, realistic depth and space, and so on . . . and so on. . . .

CMMD? It Works!



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Infinity Systems, 250 Crossways Park Drive, Woodbury, NY 11797 USA 800.553.3332 Fax 516.682.3523 www.infinitysystems.com

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