B&W Bowers & Wilkins

Kevlar® cones

This article was kindly donated by B&W

Kevlar® is a synthetic aramid fibre, manufactured by DuPont, and probably best known for its use in bulletproof vests. Indeed, those same mechanical properties of strength and the ability to dissipate the energy of a bullet also have benefits for speaker cones. B&W first started using Kevlar® as a cone material in 1976, with the introduction of the DM6 speaker.

At that time, the science of speaker development was rather less developed than is the case today and it was a case of trying out promising materials, measuring the response of the driver and listening to the result. So although we knew that Kevlar® could give better results than other materials around at the time, especially in the critical midrange, we didn't know in any real detail how the cones were actually behaving – in effect *why* they sounded better.

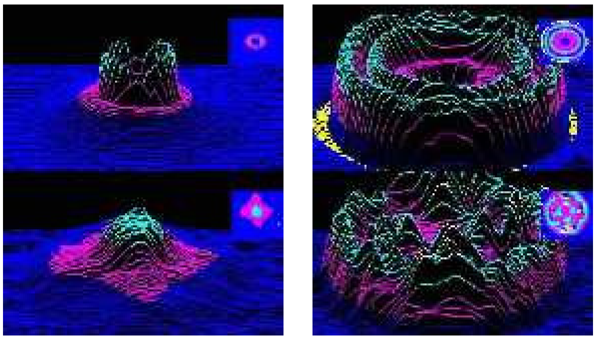
Our Research Director, Dr Peter Fryer, has long been a pioneer in the field of laser interferometry applied to speakers. Using this technique, we can look at how the driver diaphragm moves in response to different signals. Two of the most useful signals are a sine wave – a pure tone at a single frequency – and an impulse – a click sound that contains all frequencies at once. Looking at the behaviour at a single frequency with a sine wave readily shows standing waves or resonances in the diaphragm at that frequency. It also gives an indication of the way the sound disperses as it leaves the cone. For example, at higher frequencies, a semi-flexible diaphragm can exhibit motion where little radiation comes from the outer area and most comes from the central region. This effective reduction in the radiating area has the benefit of widening the dispersion of the driver compared to that of a pure piston. This is exactly what happens with a Kevlar® cone. Its effective radiating area gradually decreases with increasing frequency and, as a consequence, its dispersion is much more uniform with frequency than is the case with a very stiff material. The impulse response of the driver indicates how time-coherent it is. Continued vibration of the diaphragm after the input signal has stopped can often lead to time smearing – a form of coloration – and resultant impairment of the clarity of the signal. However, not all delayed diaphragm motion necessarily leads to delayed sound being broadcast to the listener.

Let's compare the impulse response of two drivers. They are identical apart from the cone material. The first has a plastic cone. The plastic is homogeneous; in other words the mechanical properties are the same on all directions. The second driver has a cone of woven Kevlar®, treated with a resin to control the stiffness and a PVA compound to add damping and seal the fabric. Being woven, the Kevlar® cone's mechanical properties are different depending on the angle to the direction of the fibres. Both cones are terminated at the outer edge in the usual way by a half-roll rubber surround. Look at the 4 images to the left of this text. They are laser scans of the two different cones at different points in time after the impulse signal has been applied. Note that the conical shape of the diaphragm is lost in the process, as the original measurement is of velocity rather than displacement.

The top two images relate to the time just after the signal has been applied and, in both cases, just the centre of the cone has started to move. In the case of the plastic cone at the very top, a circular bending wave has started to spread out from the centre of the cone. However, with the Kevlar® cone in the second image, the wave front has begun to assume a square shape, imposed by the weave. When these bending waves reach the joint between the cone and surround, some of the energy is reflected back into the cone and some passes into the surround. This is because the two materials have different mechanical properties. It's similar to the situation when you look out of a window.

As well as the view from outside, you can see a reflection from inside the room. In that case it's because glass and air have different *optical* properties. Further reflection occurs where the surround is attached to the chassis or basket of the driver. When these reflected waves reach the centre of the cone, they are reflected back out again and so on, until damping in the materials eventually dissipates the energy. Because the wave front in the plastic cone is circular, these repeatedly reflected waves set up the pattern of concentric rings shown in the third image and radiate delayed sound to the listener that adds to and colours the initial sound received. Although reflections do occur with the Kevlar®, they happen at different times around the edge and the movement pattern of the cone is more random, as shown in the bottom image. In this case, the total area of the cone moving forward at any given time is more balanced by the total area moving backwards and far less of this delayed energy is actually radiated as sound to the listener; the air just shuffles across the surface of the cone.

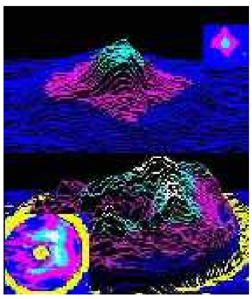
The end result is that the Kevlar® cone sounds significantly clearer and can deliver more fine detail. Remember though that not all Kevlar® cones are created equal. Design details such as the type of weave, cone geometry, resins and damping materials all make a difference to the overall performance. So although B&W is no longer the only manufacturer to offer Kevlar® cones, we've had more experience in fine-tuning the technique. For a further refinement of the Kevlar® cone, see the article **FST midrange drive unit**.

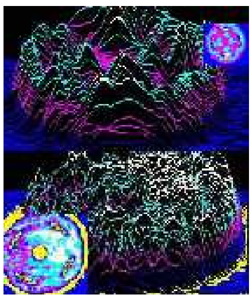


FST midrange drive unit

This article was kindly donated by B&W

Kevlar® cones and you should first read the section **Kevlar® cones** before going on. Laser Interferometry gives us a detailed knowledge about how various diaphragms operate and a much clearer insight into ways of improving their design. With cone diaphragms, the outer surround can be a major cause of problems. Its primary purpose is to maintain an air seal and help keep the voice coil aligned in the narrow magnet gap as the cone moves back and forth. It must be flexible enough to cope with the maximum required movement of the cone. However, this very flexibility is the reason why the surround doesn't always follow the movement of the cone in a coherent manner. Problems start to occur at the so-called surround dip frequency, where the surround begins to move in the opposite direction to the cone and partially cancels its output. There are various design tricks that enable you to smooth out this effect to some extent, but it would be nice to avoid it altogether. There have been driver designs in the past that have done away with the surround altogether – free edge designs had some popularity in the 1950s and 1960s. However, there are a couple of drawbacks with this approach. Firstly, there is no air seal with the cabinet and the driver effectively reflexes itself with a poorly designed port. Secondly, the unterminated edge of the cone allows more severe cone break-up. B&W engineers therefore did a bit of lateral thinking, based on the realisation that if you restrict yourself to mid frequencies, where the required cone movement is small, you can design a different type of suspension. Instead of a normal rolling surround, the Fixed Suspension Transducer (FST) uses a narrow ring of foamed polymer to support the outer edge of the cone. The small movements of the cone lightly compress and stretch the ring. Because the ring's surface area is small, it radiates relatively little sound, and what little movement it does have always follows the cone edge because it is so tightly coupled. But you can go a stage further. By choosing the mechanical properties of the ring to match those of the edge of the cone, more of that bending wave energy travelling up the cone (see the section Kevlar® cones) passes through to the surround. And if those properties are resistive or lossy, the energy can be converted harmlessly into heat. The result is that far less energy is reflected back into the cone than with a similar driver with a normal surround. Look at the 4 laser scans to the left of this text. Images 1 and 3 correspond to images 2 and 4 in the section Kevlar® cones; they are the early and developed cone motion following an impulse input signal to a drive unit having a woven Kevlar® cone with rubber roll surround. Compare these with images 2 and 4 to the left, which correspond to the FST case. Compared to the regular Kevlar® driver, you should note two things. Firstly, the whole cone begins to respond much quicker in a given time. In the time domain this equates to a better transient response. In the frequency domain it indicates a more extended high-frequency response, and indeed the response of this driver is smoother to higher frequencies and allows a better-integrated crossover to the tweeter. Secondly, the final pattern of cone movement is even more random than for the regular driver, with a resultant increase in clarity for the listener. Additional features of this driver, not connected with Kevlar® are the copper sheath on the magnet centre pole - a device for decreasing harmonic distortion - and the skeletal chassis (basket) design, which minimises reflections from the chassis and optimises the coupling between the driver and its enclosure. *"As noted with the (Nautilus) 801, this midrange unit is one of the best in the business, offering exceptional smoothness and vocal purity, allied to high transparency and resolution. Virtually no detail, no matter how subtle, escapes it." Review of the Nautilus™803 in the August 1998 issue of Hi-Fi News.*





Aluminium Diaphragms

This article was kindly donated by B&W

It is commonly believed that the best materials for speaker diaphragms, be they cones or domes, are those that exhibit high stiffness. The principle is that the diaphragm then behaves as a perfect piston and does not suffer the time-smearing problems associated with diaphragm break-up. Like many things in life, this simplistic approach has a good deal of truth, but is by no means a universal panacea.

No material has infinite stiffness and there will eventually be a frequency at which the diaphragm will cease to behave as a perfect piston. Because very stiff materials also tend to have low internal damping, the break-up, when it occurs, can be very severe. The resulting resonances have what is called a high Q. The term Q has two meanings in acoustics. It can refer to the directivity of a speaker – the higher the Q the narrower the spread of sound – and you will most often see this meaning used in public address speaker specifications. In this case, however, Q refers to the sharpness of the resonance – the higher it is, the more the resonance is highly tuned around a single frequency, putting a large peak in the frequency response. As with a bell, a high Q resonance will ring on long after the applied signal has stopped. This is not good and the designer should make sure that the driver's response in the region of these resonances is well attenuated by the crossover. In practice this means that the nominal cut-off frequency of the crossover filter should be set at least 1½ and preferably 2 octaves below the lowest resonance frequency.

Another potential problem with stiff diaphragms concerns directivity – how much the off-axis response differs from the on-axis response. The broadness of sound dispersion depends on the ratio of the wavelength of sound to the diameter of the diaphragm. The higher the frequency, the shorter the wavelength, and the narrower the beam of sound becomes. Excessive variations in the spread of sound with frequency will lead to listeners sitting away from the central 'hot spot' position hearing a different sound balance and a change in the character of the various instruments. It will also impair the sound image. In severe cases, the position of an instrument may appear to change with frequency.

So how does the designer avoid these problems? Making the diaphragm smaller will both raise the lowest resonance frequency and broaden the dispersion. Unfortunately, small diaphragms have to move further than large ones to produce a given level of sound and so tend to produce higher levels of harmonic and intermodulation distortion. The solution therefore is to use more drivers, so each covers a fairly narrow bandwidth and output levels can be kept high, dispersion more even and distortion low. How many drivers? To do the job properly over the full audio band really requires a minimum of four and it is no coincidence that our Nautilus™ speaker, in which all the diaphragms are aluminium, is 4-way.

For other speakers in our range, the use of aluminium is generally restricted to tweeters and bass drivers. A stiff material is essential if one wishes to make a moving coil tweeter that extends well into the ultrasonic region. In the bass, a stiff material is better able to withstand deformation from high pressures inside the cabinet and impulsive forces from the voice coil, thereby giving the best dynamic response.

In the midrange, when one driver is used to cover a wide bandwidth, a more flexible material with a specifically controlled break-up behaviour, such as **Kevlar®** remains a better option. With combined bass/midrange drivers, preference must be given to the requirements of the midrange, where the ear is at its most sensitive.

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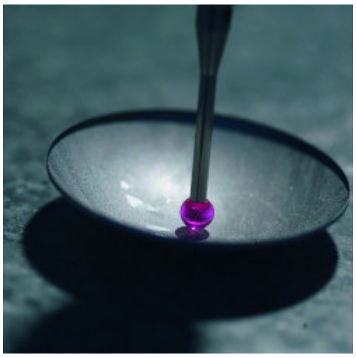
Diamond Dome Tweeter

This article was kindly donated by B&W



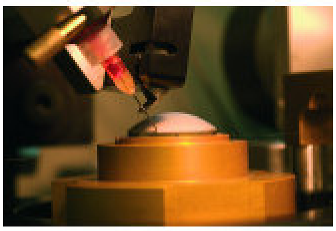
The core engineering challenge in accurately reproducing audio above and beyond the limits of human hearing is as easy to describe as it is difficult to meet. The challenge is to find a material that is infinitely stiff and can be accurately formed into a wafer-thin, lightweight tweeter dome. That's all there is to it. It's that easy.

Infinite stiffness is clearly impossible, but there is one material that, because it is so much stiffer than the materials traditionally used for tweeter domes, potentially offers a genuinely significant advance in performance - pure diamond. There are few materials stiffer than diamond, and there are few materials that present a stiffer challenge to fashion into a tweeter dome. A degree of difficulty however has never stopped us trying to do the right thing, and the engineering case for a diamond tweeter dome is overwhelming.

The basic measurement of how well a material works as a tweeter dome, assuming it is light enough to do the job in the first place, is the dome's break-up frequency. This is the frequency at which, thanks to the accelerations and forces involved, the dome stops moving as a coherent whole and, potentially, begins to distort the audio signal. Before the advent of practical metal domes in the 1980s, a typical plastic or fabric dome would break-up at below 10kHz - well within the audible band, and easily audible too. Metal domes, sometimes of copper but more usually of aluminium or titanium, raised the bar to around 20kHz - at which point tweeters became significantly more accurate. Advances in manufacturing since, many developed at B&W, have seen the highest break-up frequency raised to around 30kHz for the best metal dome tweeter - our 26mm Nautilus™ aluminium dome.

Diamond in limited size and shape has been made artificially since the 1950s and we realised some time ago that if a diamond dome could be made it would potentially raise the break-up frequency to around 70kHz. All we could do however was wait for diamond manufacturing techniques to catch-up with our aspirations. That happened recently in the guise of Chemical Vapour Deposition. CVD is a technologically sophisticated technique that enables pure diamond to be "grown" in complex shapes. The CVD principle is analogous to ice-crystals forming on a window. In CVD however the temperatures involved are equivalent to those on the surface of the Sun, and the role of water is taken by carbon. Intensive development with the World's foremost industrial diamond producer finally bore fruit and we created a tweeter that literally approaches perfection. In two decades we have advanced the dome tweeter from something little more than a simple mechanism capable only of reproducing an approximation of the acoustic signal, to a sophisticated precision engineered device that is almost perfectly accurate.

But what does a diamond tweeter do for the sound? Like the diamond technology, it's easy to ask and difficult to answer - far better you hear it for yourself. The smart response is that the near perfection of a Nautilus™ diamond dome tweeter means simply that music sounds like it ought to. Nothing added, nothing taken away. In practice it means clarity, detail and a lack of distortion or coloration well beyond anything heard before.



B&W Bowers & Wilkins

Paper/Kevlar® cones

This article was kindly donated by B&W

The production of bass – good bass that is – involves a driver being able to move relatively large volumes of air with accuracy and precision. This process involves high forces, not only the voice coil pushing the diaphragm back and forth, but also pressure changes inside the cabinet acting on the whole diaphragm surface. In order to withstand these forces without deformation, a stiff, strong cone is required and our paper/Kevlar® cone is one way we realise this.

The advantages and disadvantages of stiff diaphragms are discussed in the article on **aluminium diaphragms**. Although not a suitable material for tweeter diaphragms, paper/Kevlar® is equally suitable for bass drivers and there are instances where aluminium is difficult to implement.

Paper pulp has been used as a cone material from the early days of moving coil drivers. Because of that, it is often thought of as old technology and not very exciting. But the laws of physics do not change and paper continues to have very desirable properties. It can be made to be extremely stiff by the application of resins and the fact that it is a bulky material helps in this respect too. One of the difficulties with aluminium is in making a large diameter cone that is not too heavy to maintain a reasonable sensitivity. Make the metal thin enough and it will tend to split when formed. Paper then comes into its own.

If paper pulp has a deficiency in bass drivers, it is that a cone can buckle close to the neck if subjected to a powerful impulsive signal – a kick drum and bass for example. This is especially a problem with high power applications such as studio monitor and musical instrument speakers and it was in those applications that Kevlar® fibres were first added to the paper mix. They add tensile strength as opposed to stiffness. That means the fibres are extremely difficult to break in tension. It is this property that makes Kevlar® an excellent material for bulletproof vests – it can dissipate impulsive energy. Likewise, in a cone, the fibres help dissipate the impulsive forces throughout the cone, away from the most vulnerable part, the neck.

One might reasonably ask why Kevlar® does not form 100% of the mix. The reason is the structure of the fibre. It is a monofilament and therefore smooth. The more ‘hairy’ nature of paper fibres is far better at binding the cone together. Typically, Kevlar® fibres form between ten and twenty percent of the total.

Some of our powered subwoofers use a cone that has a paper/ Kevlar® base, on top of which is bonded an aluminium layer. Here, the aluminium is applied only from the outer edge of the cone to just under the dust cap. There is no danger of the neck splitting during forming and the cone visually matches the bass drivers used in the associated main speaker series.

Rohacell®

This article was kindly donated by B&W

Our outward looking and innovative approach to materials engineering is illustrated perfectly by the application of Rohacell® structural plastic foam to the construction of bass drivers. We found Rohacell® being used extensively in the high performance automotive and aerospace industries, where its unusual combination of very low weight and very high resistance to bending stress make it the ideal choice for a multitude of applications. Those very same characteristics also make it an ideal material for the structural heart of a bass driver.

If a bass driver cone is to perform at a level commensurate with our Kevlar® FST midrange drivers and Nautilus™ tweeters it must excel in three vital characteristics:

First, it must not bend significantly, even under huge dynamic loads. Second, it must have high self-damping so as not to display any significant resonance. And last, it must offer good acoustic attenuation so that sound energy within the speaker cabinet cannot leak out and besmirch the music radiated forward. Combining those three characteristics, which in a multitude of respects are conflicting (light materials are rarely strong, often ring like bells and almost never resist sound transmission), is a tall order. Rohacell® is the key.

Viewed from the front, a Rohacell® driver doesn't look significantly different from many others. The real difference, where the Rohacell® foam can be found, is around the back of the cone. Rather than an overall cone thickness of perhaps one or two millimetres, typical with conventional bass drivers, a B&W Rohacell® cone is significantly thicker. The Rohacell® foam is used as meat in a carbon-fibre skinned sandwich. The result is a cone that displays bending strength, self-damping and sound attenuation that are each an order of magnitude or more higher than conventionally manufactured cones. The potential downside of increased cone thickness is weight gain, but thanks to the low density of Rohacell®, that's not a problem and low frequency cut-off and sensitivity targets can still be met. Rohacell® isn't a free lunch for bass drivers, but it's not far off.

Of course, while the look of a Rohacell® bass driver isn't out of the ordinary, we don't design speakers to be looked at, we design them to be listened to. Bass from a Rohacell® equipped speaker system takes on a whole new quality - deep, fast, dynamic and wholly untainted by the distortions and dynamic slurring that perhaps we've come to accept as part of the deal with moving coil speakers. In the same way that Kevlar® FST midrange drivers and Nautilus™ tweeters strip a layer or two of artifice from their respective segments of the audio band, so Rohacell® does for bass.

Planar Passive Radiator

This article was kindly donated by B&W

Passive radiators are a useful alternative to the more usual reflex ports for special applications. They operate in essentially the same way, except that the sound comes from a solid vibrating diaphragm rather than a slug of air. Two such applications might be:

1. To tune a small cabinet, where a port would be too large to physically fit in the cabinet. This takes advantage of the ready ability to add mass to the passive radiator's diaphragm without altering its size.
2. To prevent the ingress of water in the design of a waterproof speaker.

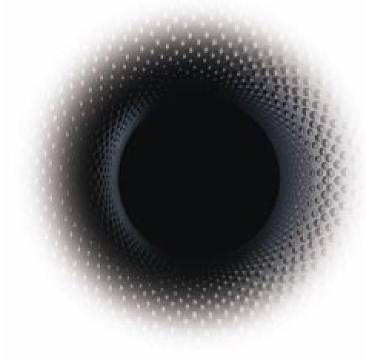
It was this last application that prompted the use of a passive radiator in the WP 1 speaker.

The problem we had with the application was that even passive radiators are usually fairly deep, in order to accommodate two suspensions. With only one suspension in a single plane, there is a tendency for the diaphragm to rock instead of simply moving back and forth in a coherent way. However, in the small cabinet of the WP 1, space was at a premium.

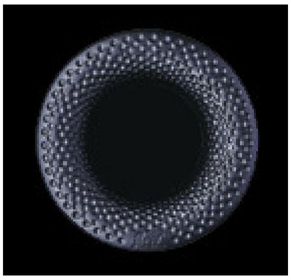
The solution was to abandon the standard form of roll surround in favour of a hinged design, which allows a single plane suspension, but totally eliminates rocking.

Flowport

This article was kindly donated by B&W



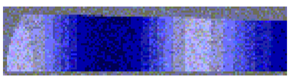
If golf balls did not have a dimpled surface, even Tiger Woods would have difficulty reaching 200 metres with his best drive. Dimples improve the way the air flows over the surface of any object. In the case of reflex ports, they offer a significant improvement over simply flaring the port ends in reducing air flow turbulence at each end of the port; so you get less chuffing noise and less compression at high sound levels.

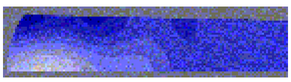


Nautilus tapered tubes

This article was kindly donated by B&W

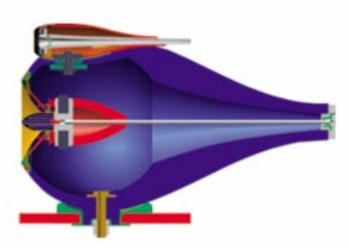
When a driver is loaded by a tube of a similar diameter to the diaphragm, sound propagates down the tube as a series of simple plane waves. When the sound reaches the other end of the tube it is reflected back up the tube towards the driver. If it reaches the driver it causes delayed radiation that time-smears the original signal, blurring the clarity of the sound. If, however, you fill the tube with absorbent material and the tube is long enough, you can dissipate the energy before it reaches the end of the tube. The sound from the driver then remains clean and true to the input signal. Tapering the tube enables you to make it shorter for the same level of absorption. It acts like a horn in reverse - reducing the sound level instead of increasing it. The upper image to the left of the text shows a computer simulation of plane waves in a damped tapered tube. To reduce computing power, only half the diameter is shown. The simulated driver in this case is a dome midrange drive unit. The limit of this type of loading is reached when the wavelength gets small enough to be comparable with the diameter of the tube. Above a certain frequency, the sound ceases to propagate as a simple plane wave and a series of cross-mode resonances are set up which can re-radiate through the driver diaphragm (see the lower image). So to maintain the effectivity of tube loading, you must restrict the bandwidth of each driver. This is one reason why Nautilus is divided into a 4-way system. A more complex type of loading is required to cover a wider bandwidth and the **Sphere/tube enclosure** was developed for the Nautilus 800 Series.



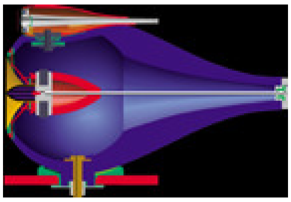


Sphere/tube enclosure

This article was kindly donated by B&W



It was pointed out in the section **Nautilus™ tapered tubes** that the technique is limited in bandwidth by the onset of cross-mode resonances as the wavelength gets smaller. It has long been known from horn theory that, if there is a cavity between the driver and the throat of the horn, high-frequency performance is limited. While undesirable in standard horn design, this effect is just what is needed to attenuate higher frequencies before they enter the Nautilus™ tube and cause any cross-mode resonances. Cavities, of course, have their own internal resonance problems. Indeed, it is to get away from these that we use tubes in the first place. However, for once physics is on our side. Extensive computer modelling and practical experimentation showed that, if the cavity is a sphere with a particular diameter ratio to the driver diaphragm diameter and has a hole directly opposite the driver, with the same diameter as its diaphragm, leading to a tapered tube, the internal resonances are to a large extent eliminated. Any residual effects are readily mopped up by wadding inside the sphere and tube. The sphere also has the ideal shape for avoiding diffraction effects on the outside of the enclosure, with consequent benefits to the imaging.



Tweeter on top

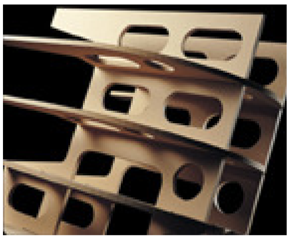
This article was kindly donated by B&W

B&W's tweeter on top technology has two benefits. It avoids the situation with normal cabinet construction, where sound waves from the tweeter not only radiate towards the listener but also travel along the baffle surface towards the cabinet edges. When they meet the sharp cabinet edges they re-radiate (a process known as diffraction) and, due to the time delay, interfere with and time-smear the sound coming directly from the drive unit. Having the tweeter separate from the main cabinet also allows it to be set back and time-aligned with the acoustic centre of the bass/midrange cone, which is located behind the plane of the front baffle. The effects of this improvement in time-coherence are greater clarity and the formation of a more convincing three-dimensional image.

Matrix

This article was kindly donated by B&W

Cabinet panel vibration can be a significant cause of sound coloration. Even though the amplitude of the vibrations is small, the large radiating area means that the sound output from the panels is significant and adds a bloom to the overall character. There are two main techniques used to reduce cabinet coloration – damping and bracing. The adding of damping panels to the inside of the enclosure walls, usually in the form of bituminous pads, does much to reduce resonance hangover, but not much to reduce panel flexing while still being excited by the driver. The flexing is non-linear and the distorted harmonic structure of the total output from the speaker changes the timbre of the sound. Stiffening of the panels reduces the amplitude of flexing and this can be done by a combination of increasing the panel thickness and bracing. Matrix is an interlocking grid of panels arranged in two orthogonal planes – rather like a bottle crate. It is easily the most effective method yet devised of bracing a cabinet. The thickness and spacing of the panels can readily be altered, depending on the frequency range of interest and the panels are perforated acoustically to connect the individual cells and allow the driver to see the whole volume inside the cabinet. To prevent resonances in and Helmholtz tuning between the cells, each cell is filled with absorbent wadding, usually open-cell foam. Matrix was developed by and remains exclusive to B&W.



B&W Bowers & Wilkins

Decoupling

This article was kindly donated by B&W

Imagine driving a car where the engine is rigidly mounted to the bodywork. Now try to imagine actually liking the experience. Difficult, isn't it?

Isaac Newton (who gave his name a force, approximately equal to the weight of an apple) reasoned that every action has an equal and opposite reaction. So it is that when a driver diaphragm vibrates, there is a reaction on the chassis, which has the potential to transmit this vibration through to the enclosure walls. Voilà - cabinet coloration.

Mounting the driver compliantly greatly reduces the degree of transmission of this vibration. The softer the material used for isolation, the more effective it is. B&W extensively use a material called IsoPath®. Manufactured by Raychem, this gel material was originally developed to isolate microphones in mobile phones from handling noise. It can be made much softer than rubber without losing dimensional stability.

Decoupling can be extremely useful in conjunction with stiff enclosures. The stiff walls resist deformation under internal pressures at lower frequencies, but any tendency to ring at higher frequencies is prevented because the exciting force is decoupled. That's why you should always be careful in judging an enclosure's quality by knocking the walls (I know, we all do it). The driver will not "hit" the enclosure in the same way if it is decoupled. Try hitting the enclosure with the fleshy part of your hand instead of the knuckles. That will give you more of an indication.

The combination of stiff enclosure and decoupling is exemplified in the midrange and tweeter head assembly of the Nautilus™801 and 802 speakers. The head is made from an extremely hard resin called Marlan® (a registered trademark of Polylac Holland Bv). Both drivers are decoupled from their enclosure and the enclosures are decoupled from each other and the bass cabinet below using IsoPath® components.