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Ovator S-800 White paper

DESIGN, ENGINEERING AND TECHNOLOGY

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The Ovator S-800

Introduction

Many hi-fi companies have a 'top-down' approach to product development, where a flagship model is developed first and its technology spun-off down-range. At Naim we have found that a 'middle out' approach can be just as effective, in which the lessons learnt from developing an initial mid-range product can be applied to both lower-cost alternatives and range-topping models that maximise the performance potential.

So it has been with the Ovator loudspeaker range. First came the S-600 – the first true hi-fi speaker to use a BMR driver in place of conventional midrange and tweeter drivers. The smaller S-400 followed and now arrives the ultimate expression of Ovator design philosophies, the new top-of-the-range S-800. In essence it's a larger S-600 – but with enhancements to drive unit design, cabinet construction and crossover components that raise its performance to a new plane.

High-end hi-fi loudspeaker design is a multidisciplinary endeavour embracing acoustics, mechanics, materials science, vibrational analysis, electronics and musical psychology. Success in speaker design requires that all these elements be thoroughly optimised, but always with a view to communicating as effectively as possible the ideas and emotions expressed through music – the goal that drives all Naim product development.

Key advances over the S-600

• Larger cabinet with a similar overall form to the S-600's (cast aluminium plinth, curved side panels, sloping top panel) but enhanced construction.

• All-new 82mm BMR mid/treble driver which is fitted with a neodymium ring magnet that markedly reduces obstruction of the rear-directed sound from the diaphragm, and has an edge-wound single-layer voice coil to maximise sensitivity.

• Larger 280mm twin bass drivers with flat, sandwich-construction diaphragms that remove the cavity effect of a conventional cone and deliver a sound quality more consistent with that of the BMR. Use of a 10cm diameter two-layer sandwich voice coil minimises power compression effects, and three demodulation rings in the magnetic circuit reduce distortion.

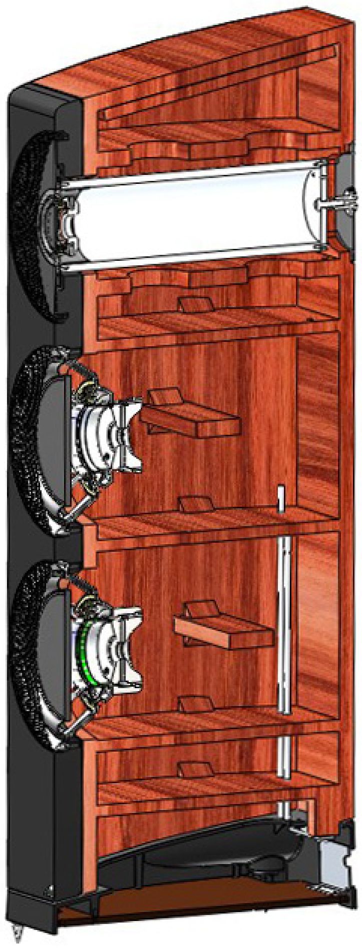
• Revised crossover design that includes high-spec Mundorf resistors and capacitors.

S-800 plinth and cabinet

The foundation of the S-800 is its plinth. An extremely rigid high pressure aluminium die-casting, it supports the cabinet and provides mounting points for the floor spikes, passive crossover module (or active loom interface) and terminal panel. The floor spikes are made from hardened stainless steel and screw into M8 tapped holes at the front and rear.

S-800's cast aluminium plinth

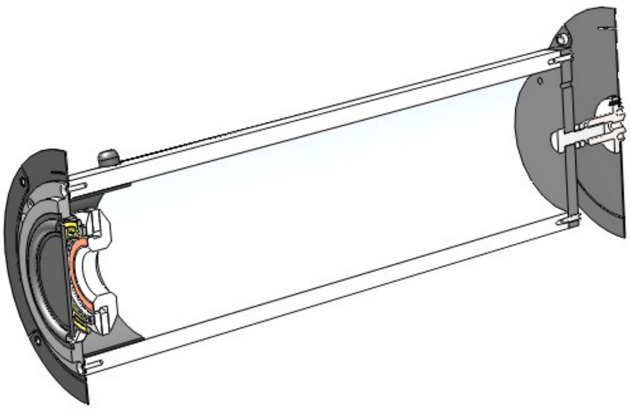
The S-800's cabinet attaches to the plinth at two locations towards the front and via a leaf-spring at the rear. This leaf spring is a 200mm-long non-magnetic stainless steel bar that runs laterally underneath the cabinet and attaches centrally to its underside. At each end the leaf-spring is bolted, via tapped bosses, to the plinth. The front locations comprise stand-off bosses through which a bolt is inserted and screwed into the cabinet. A slot feature on either side of each boss introduces some controlled compliance to the front cabinet locations that, in combination with the leaf-spring, results in the cabinet decoupling from the plinth rotationally (forward and backward) above 12Hz. This prevents vibrational excitation of suspended floors and the coloration that results. The entire plinth and cabinet system was the subject of Finite Element Analysis modelling to predict and fine-tune its vibrational characteristics with the aim of ensuring that any resonant behaviour within the audible band is minimised. Laser interferometry was then used to verify this with a built cabinet. Limited decoupling of the system outside the audible band is inherent in achieving this aim. Although the cabinet/plinth leaf-spring was first introduced on the Naim Allae loudspeaker the leaf-sprung cabinet concept goes back to the Intro and Credo.



Cross-section of the S-800 cabinet

Ovator S-800's cabinet has 25mm-thick sides produced by laminating nine sheets of MDF which are bonded under heat and pressure and formed into a curve that contributes significantly to the cabinet's overall structural performance. This construction effectively incorporates constrained layer damping within the material to create an immensely rigid and non-resonant panel. A laminate of four 12mm MDF sheets forms the 50mm overall thickness front panel to produce an extremely stiff and inherently well damped baffle whose outside edges are radiused to reduce diffraction effects. Internal bracing and strategic mass damping contribute further to a cabinet that, in acoustic radiation terms, is fundamentally inert. An internal lining of 20mm wool felt controls resonances within the enclosed air.

The lower portion of the cabinet is divided into two separate 40 litre closed box enclosures, one for each bass driver. Closed box loading was chosen because of the distinct advantages it offers over other loading techniques in terms of time domain performance and dynamic compression. Low frequency system resonance is at 26Hz with a Q of less than 0.6, resulting in a free-field -3dB frequency of 35Hz. Separate vent tubes are incorporated for each enclosure to ensure that performance is unaffected by changes in ambient air temperature and pressure.



Cross-section of the S-800 BMR in its mechanically isolated aluminium cylinder

A 12.7mm-thick aluminium alloy cylinder, nested within the cabinet, provides a separate housing for the Ovator BMR. Two four-element duralumin circumferential leaf-springs – one at the front of the cylinder and the other at the back – provide a unique suspension system that decouples the BMR module from the rest of the cabinet. This suspension prevents low frequency mechanical energy from the bass drivers interacting with the BMR and stops mid/high frequency mechanical energy from the BMR being transmitted to the cabinet. The system was Finite Element Analysis modelled and the design optimised to provide decoupling from 4Hz upwards – more than six-and-a-half octaves below the start of the BMR's passband. The BMR enclosure is gradient filled with a meticulously developed mix of felt, long-haired wool and open cell foam and incorporates a vent at the back so that changes in ambient temperature or atmospheric pressure do not impact upon performance.

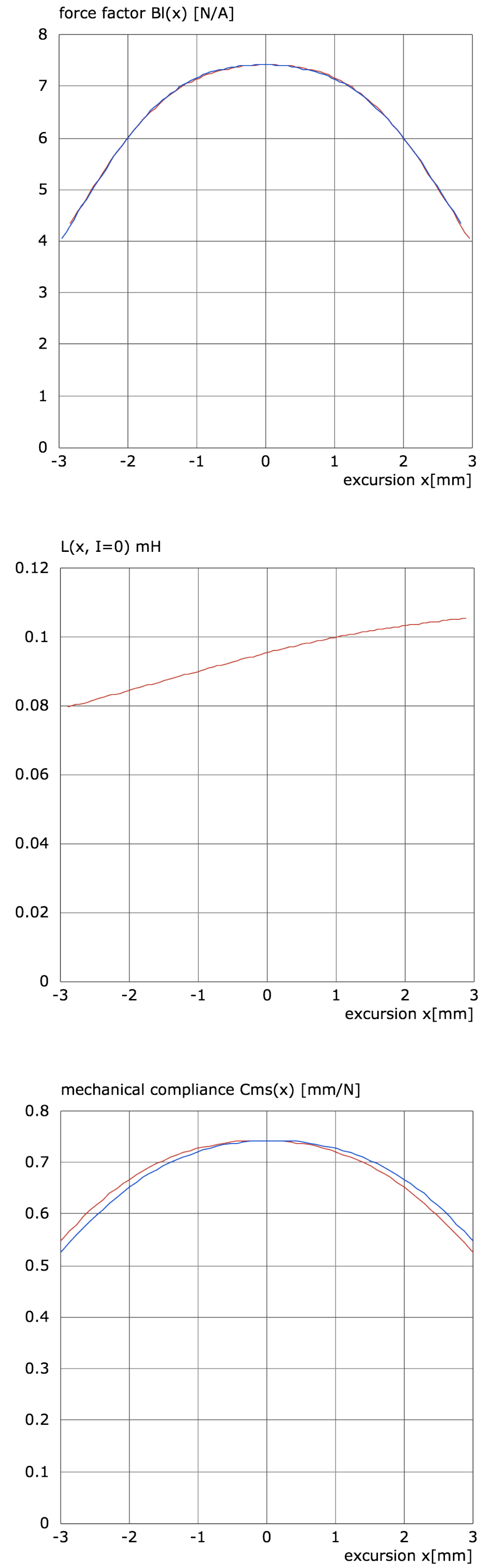
S-800 drive units

Naim's Ovator S-600 was the first commercially available loudspeaker in its class to incorporate a Balanced Mode Radiator (BMR) as an upper-midrange and treble driver. For readers who are interested, the theory of BMR operation is explained in detail in the Appendix. Here it is sufficient to explain that a BMR is able to replace two conventional drive units because, despite being large enough to work down to below 400Hz, it maintains its off-axis output to the highest audible frequencies better than a conventional 25mm dome tweeter.

Since the S-600 was first launched, the experience of designing the smaller BMR used in the S-400 and the BMR fitted to the S-600 has added significantly to Naim's knowledge of how to extract the ultimate from this exciting technology. As a result, the S-800 boasts an all-new 82mm BMR that is the best that Naim knows how to make.

Front and rear views of the S-800's new 82mm BMR. Key features include a larger, 55mm diameter voice coil and generous rear venting through the neodymium ring magnet

A large, 55mm diameter voice coil attaches directly to the paper/Nomex honeycomb/paper sandwich diaphragm, obviating the need for a coupler. Whereas previous Naim BMRs have used dual-layer voice coils, the S-800's has a single-layer, edge-wound voice coil that maximises sensitivity (to match the new, larger woofers) and minimises distortion-inducing fluctuations in the gap's magnetic flux that are caused by signal current. Use of an outer neodymium ring magnet allows a large-diameter vent to be incorporated within the magnet assembly to minimise obstruction of the sound radiated from the rear of the diaphragm.



Graphs for the S-800 BMR showing the variation in Bl product (top), voice coil inductance (centre) and suspension compliance (bottom) with excursion

Both the BMR and the twin bass drivers have chassis that are custom-designed high-pressure die-castings modelled using Finite Element Analysis to optimise their performance. The bass driver chassis, for example, has a triangulated structure that provides great rigidity while also maximising the open area behind the cone. Additionally it features minimal-area mating surfaces so that vibration transfer to the cabinet is controlled and predictable.

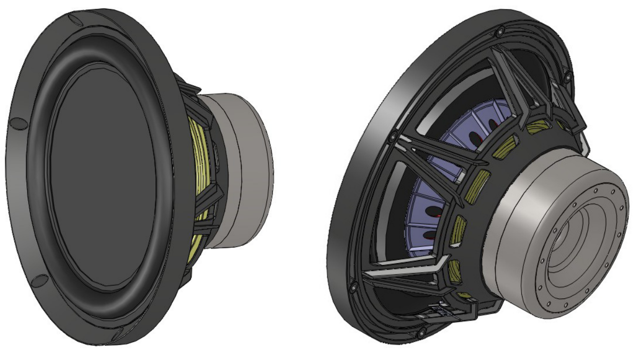
Triangulated structure of the bass driver chassis combines high stiffness with free air flow from the back of the diaphragm and suspension

As in the S-600, the S-800's BMR crosses over to the twin bass drivers at 380Hz. As befits its larger cabinet, the S-800's bass drivers are of larger diameter (280mm compared with 200mm in the S-600, giving them a combined radiating area of 817cm^2) but the most obvious difference between them is that the S-800's woofers have flat diaphragms, rather than the conventional cone diaphragms of the S-600. A flat diaphragm reduces the undesirable diffraction effects that occur when sound waves spreading out across the front baffle from the BMR encounter the cavity associated with a cone diaphragm. It also confers on the bass driver an inherent sound quality that better matches that of the flat-diaphragm BMR.

The principal problem with using a flat diaphragm is that it is inherently less stiff than a cone, so special measures have to be taken to ensure that the first breakup mode still occurs sufficiently above the driver's passband to be effectively attenuated by the low-pass crossover filter. This is achieved in two ways in the S-800 bass driver. First, the stiffness of the diaphragm is increased by bonding together two 6mm-thick sandwich panels with paper skins and a honeycomb aluminium core, to create an overall diaphragm thickness of 12mm. Second, the 10cm voice coil is attached to the diaphragm by means of a coupler that applies the motive force at a critical diaphragm radius, thereby suppressing what would otherwise be the lowest-frequency breakup mode.

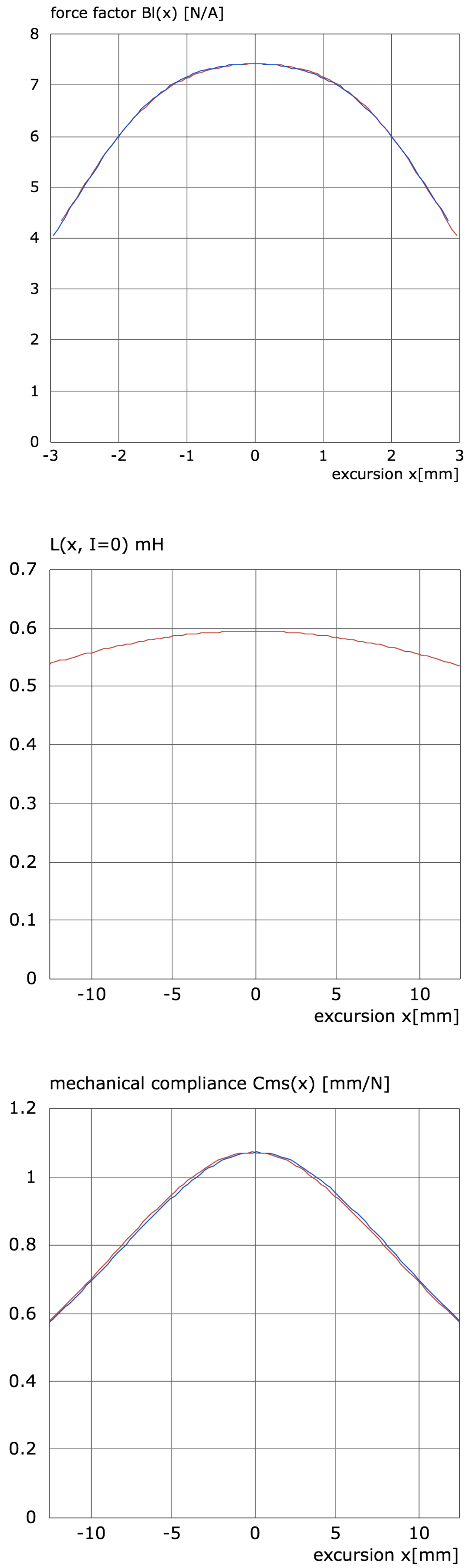
As a result, the first breakup mode is postponed to about 1kHz, at which the low-pass crossover provides an attenuation of over 30dB. Moreover, the breakup behaviour is well damped, obviating the high-Q modes often seen in stiff diaphragms.

Diameter of the voice coil is unusually large at 10cm to obviate power compression effects caused by voice coil heating, aided by a dual-layer sandwich voice coil – with one layer on the outside of the former and the other on the inside – which improves heat dissipation to the magnet pole piece. The large coil diameter and inner neodymium ring magnet also allow the pole piece to be vented to prevent build-up of pressure behind the diaphragm. The vent is generously dimensioned and carefully profiled to prevent turbulent airflow at large diaphragm excursions.



Front and rear views of the S-800 bass driver showing the flat, sandwich-construction diaphragm and generous venting of the magnet pole piece

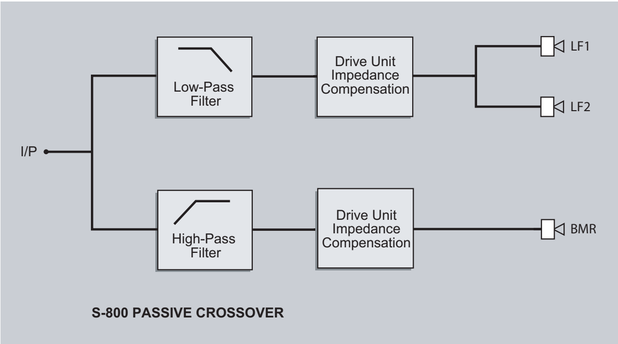
In-depth finite element simulation of the woofer's magnetic circuit was conducted to ensure that it is optimised for a symmetric force versus excursion characteristic over a linear excursion range of ±10mm (with a physical limit at ±20mm). The driver's suspension system was also subject to mechanical finite element optimisation, resulting in a spider-surround design which features a symmetric compliance versus excursion characteristic. As each S-800 woofer is housed in a separate closed box the compliance of the enclosed cavity is dominant, so the progressive compliance characteristic of the suspension serves only as protection for the driver when very large excursions are reached.



Graphs for the S-800 bass driver showing the variation in Bl product (top), voice coil inductance (centre) and suspension compliance (bottom) with excursion

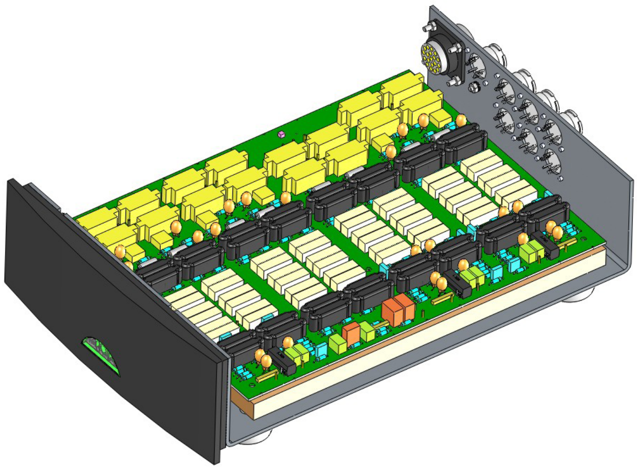
S-800 crossover

A significant benefit of using a BMR to cover the entire upper-midrange and high frequency band is that the typical 2kHz–3kHz crossover, with its unavoidable phase and dispersion discontinuities, is eliminated. The S-800 crosses over between its bass drivers and BMR at 380Hz with fourth-order acoustic slopes and minimal phase disruption. Because of the similarly wide dispersion of the bass drivers and BMR at crossover there is no discontinuity in dispersion (directivity).



Circuit diagram of the S-800 passive crossover

The crossover module is attached to the underside of the plinth and comprises an MDF panel carrying a glassfibre printed circuit board. It is suspended from the plinth via an elastomeric mounting system and selected crossover components also benefit from discrete mechanical decoupling. Topology of the printed circuit board borrows many of the layout and earthing principles from Naim power amplifiers. Components are all of extremely high quality, each selected following extensive technical analysis and listening tests, and include Mundorf resistors and Mundorf MCap Supreme Silver/Gold and MCap Supreme Silver/Oil capacitors in critical locations. Crossover filter and equalisation curves were extensively computer modelled and correlated with measurement and listening. The crossover presents a benign load to the driving amplifier with a minimum impedance of 3.9Ω at 100Hz and a maximum phase shift throughout the audible band of ±30°.



SNAXO BMR active crossover

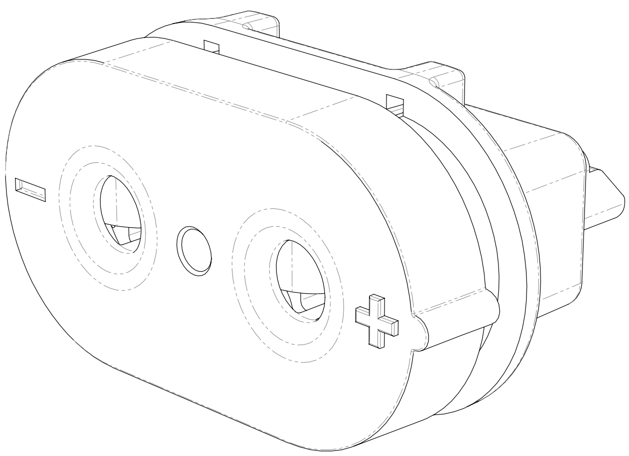
As an option, the passive crossover can be removed from the plinth and replaced with a three-way loom that provides separate, direct connection to each drive unit for active operation with either two or three power amplifiers using the SNAXO (BMR) active crossover. SNAXO (BMR) uses Sallen-Key active filters throughout which apply frequency-selective feedback around Naim's proven four-transistor unity gain buffer circuit and features the transistor "quiet room" thermal isolation technique originally developed for the NAP 500. Separate output buffers are provided for each of the power amplifier feeds in each channel, with relay muting included. SNAXO (BMR) also incorporates compliant isolation of its circuit board which is mounted on a heavy brass subchassis suspended above the base of the case on four steel springs. The rate of these springs is matched to the mass of the subchassis to provide a mechanical resonance frequency well below the audible range. Although SNAXO (BMR) can be used with the FlatCap XS or HiCap external power supplies, normally at this price and performance level it will be powered by the SuperCap.

The Ovator connectors

The S-800 features custom-designed input terminals that offer a significant advance on conventional items. Design of the terminals was informed by experience gained from the Naim Hi-Line and Power-Line projects to generate an innovative and high performance speaker connection solution. Although designed to work optimally with the new Naim high conductivity copper speaker pin, the terminal can also accept standard banana plugs.

Sprung contacts – manufactured from a unique grade of copper alloy that has an IACS (International Annealed Copper Standard) of over 90 per cent and enhanced spring properties – optimise contact pressure and minimise contact resistance. The terminal housing is designed to eliminate eddy currents and allow the contacts to float in order to minimise microphonic effects. The complete housing is also decoupled within the aluminium back plate of the plinth.

Silver plating on both the contacts and the pins was chosen on the basis of listening tests, which confirmed the findings from previous projects. Use of the same plating on both pin and contact minimises the potential for galvanic corrosion.



Naim-designed input terminals

S-800 in use

Installing and setting-up the Ovator S-800 is simplified by the fitment of a pair of castor trolleys which, with the speaker's carton upright and opened at the front, allow it to be easily wheeled into position. Once the optimum room position is decided the castor trolleys can be removed and the Ovator S-800 lowered on to its pre-fitted floor spikes. Spike adjustment and levelling is simplified significantly by the rear spikes' top adjustment and locking access.

The S-800 is a wide bandwidth, neutrally balanced and uncoloured speaker capable of very high volume levels without significant compression or distortion even in large rooms. Its exceptional time domain behaviour and extremely low noise floor mean that fine musical detail is reproduced naturally, with coherence and clarity. It is designed primarily for 'free-space' use within the listening room, well away from walls, but because of its consistent and wide dispersion it is relatively insensitive to positioning. Its listening sweet-spot is also considerably wider than that of most conventional speakers, allowing more than one listener at a time to experience it at its best.

Appendix – The Balanced Mode Radiator (BMR)

A BMR is a circular flat panel loudspeaker that covers much of the audio bandwidth with exceptionally wide sound dispersion. It employs components similar to those of a conventional moving coil drive unit (a surround attached to the rear of the panel to join it flexibly to the frame, a voice coil coupled directly to the panel and centred via a spider, and a moving coil actuator that provides motive force) but its vibrational behaviour is quite different.

In a traditional moving coil loudspeaker the diaphragm acts as a 'rigid piston' at low frequencies but becomes a multimodal (complexly resonant) object as it enters its so-called breakup region. At this point it normally becomes suboptimal because the frequency response becomes very uneven and the sound highly coloured.

In a BMR there is no breakup region. Instead a limited number of evenly spread resonant modes (usually two to four) are carefully positioned within the frequency band such that modal, bending-wave operation starts in the frequency range where piston-like operation of the panel would otherwise cause the driver to 'beam' its output over a progressively narrower angle as frequency increases. The result is a drive unit that operates like a piston at low frequencies but becomes a bending wave device at high frequencies, thereby maintaining wide dispersion across the entire frequency range. Acoustically, the behaviour of a BMR approximates that of an ideal 'point source'.

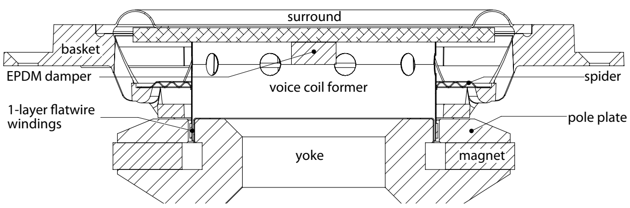


Figure 1. Cross-section of the S-800 Balanced Mode Radiator

Free disk driven by 'ideal' force

The underlying operating principle of a BMR can be explained using simulation results obtained for an isotropic disk of 85mm panel diameter. The disk is driven at its first nodal line (a circle with a diameter 68 per cent that of the panel) with an 'ideal' force that has no associated mass or damping.

The resulting on-axis frequency response is shown in Figure 2. Under these conditions the flat disk shows a naturally balanced response with only small dips at the second and third modes (the first mode is fully suppressed because the panel is driven at its nodal line).

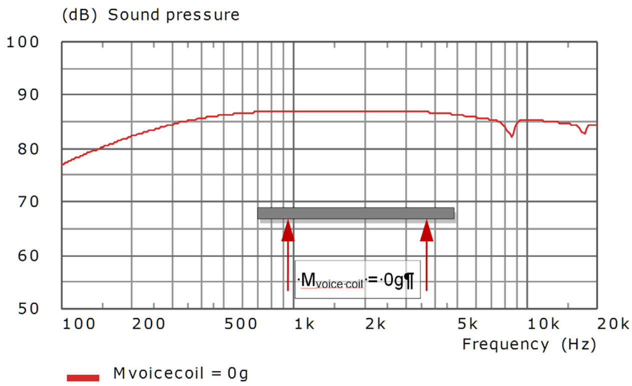


Figure 2. Free disk driven at the first nodal line by an ideal, mass-less force

Free disk driven by 'real' force

Of course, in the real world there is always a mass associated with the voice coil that applies force to the panel. A voice coil mass of only 1g is assumed for the simulation result plotted in Figure 3, which shows that even such a small mass can destroy the natural balancing of the disk.

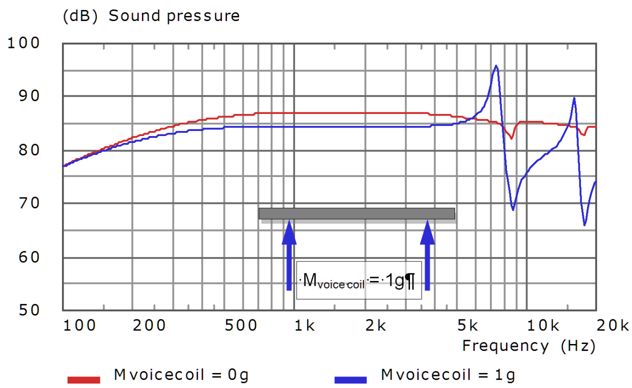


Figure 3. When a motor with finite mass is substituted, the natural balancing of the disk is lost (blue curve)

Balanced disk driven by 'real' force

The acoustical behaviour of the free disk is restored, though, if additional masses, called balancing masses, are placed at pre-determined diameters (Figure 4). Note that the masses are not normally added at the centre or the edge, since these are always anti-nodes of all modes.

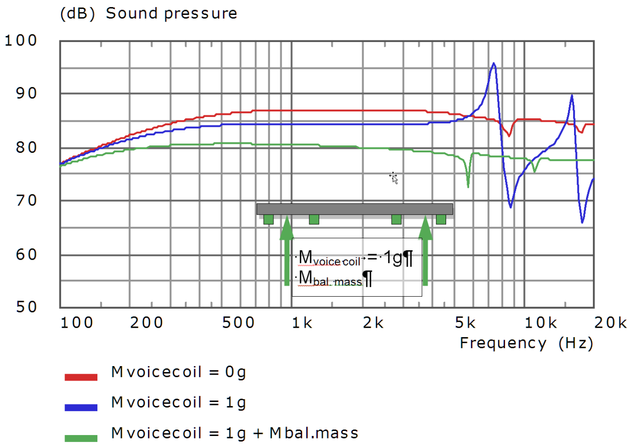


Figure 4. Adding balancing masses restores the behaviour of the free disk (green curve)

From the above simulations it is clear that it is only when a mass-carrying voice coil is attached to the disk that its previously faultless acoustic behaviour is disturbed. But the performance of a free disk can be restored by balancing the voice coil mass with additional masses. This operating principle gave the Balanced Mode Radiator its name.

Technical Aspects

Conventional loudspeaker

Evaluation is a fundamental part of the creation of any new loudspeaker. Traditionally, a uniform response over the audible range has been an obvious aim for the designer. This is usually verified by acquiring the on-axis frequency response together with one or two off-axis responses. The on-axis response is measured in front of the loudspeaker, usually level with the tweeter at a distance of 1 to 2 metres. Horizontal off-axis responses are measured at the same height but with the microphone offset from the speaker's forward axis by a given angle (eg 15°, 30° etc). With conventional drive units this method is sufficient since the on- and off-axis responses look very much alike, except that the output level drops with increasing measuring angle.

Figures 5 and 6 show response curves for a typical two-way loudspeaker comprising a 165mm bass-midrange driver and 25mm dome tweeter. The crossover frequency is around 3kHz, as is typically the case. Figure 5 shows frequency response curves measured at 0°, 30°, 60° and 90°. Figure 6 shows the horizontal frequency/directivity plot, where the level is colour-coded and plotted against frequency and measuring angle over the range –90° to +90°.

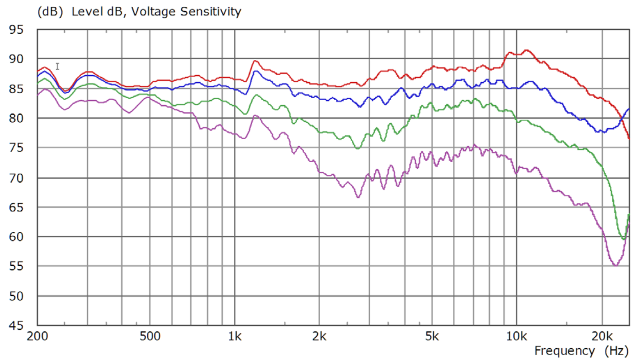


Figure 5. Sound pressure level versus frequency for a two-way speaker at horizontal angles of 0° (on-axis, red), 30° (blue), 60° (green) and 90° (purple)

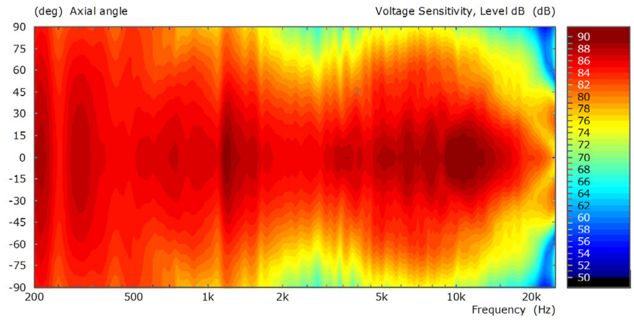


Figure 6. Sound pressure level versus frequency versus angle for the same two-way speaker as Figure 5

The frequency/directivity plots reveal that with increasing frequency the 165mm bass-midrange driver starts projecting sound more to the front. When the tweeter takes over at around 3kHz the directivity widens again until the tweeter itself begins to become directional above 8kHz. The general characteristic of the frequency response at various angles remains unchanged, so that the on-axis frequency response gives a good indication of the tonal balance of the loudspeaker.

Balanced Mode Radiator

In Figures 7 and 8 the on- and off-axis responses and frequency/directivity plot are shown for the Naim BMR. From the colour-coded directivity plot one can see that the BMR radiates much more broadly than the two-way loudspeaker discussed above. Due to its combination of piston-like operation at low frequencies and bending wave radiation at higher frequencies, the BMR drive unit sustains very broad radiation up to 25kHz. Even at 90° measuring angle the high-frequency level is only 10dB below the on-axis reference level.

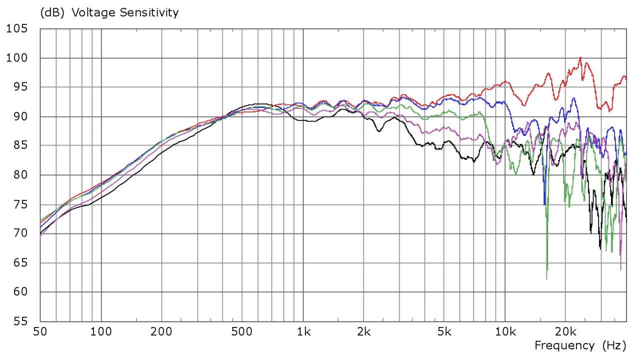


Figure 7. Sound pressure level versus frequency for the S-800 BMR at horizontal angles of 0° (on-axis, red), 30° (blue), 60° (green) and 90° (purple). Contrast this with Figure 5

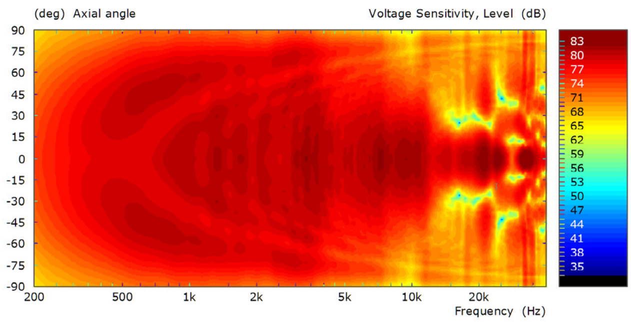


Figure 8. Sound pressure level versus frequency versus angle for the S-800 BMR. Contrast this with Figure 6

Since the BMR unit can operate down to 100Hz, the loudspeaker system designer is free to choose a crossover frequency that fulfils the requirements of the cabinet geometry and the low frequency driver.

What is a meaningful measurement for a BMR?

Because of the BMR driver's different vibrational behaviour, the on-axis frequency response curve is no longer an accurate indicator of the tonality of the loudspeaker. In fact during the development of the Naim BMR it became clear that the on-axis response is as good, or bad, an indicator as any other single frequency response measured at any arbitrary angle.

A meaningful assessment of a BMR-based system can only be performed on the basis of a range of measurements including the on-axis response, the acoustic power response and dispersion data acquired for the horizontal and vertical planes. The acquisition of this data takes more time than the measurement of a single response curve, consequently the development time for a BMR is considerably longer than for a conventional cone-based woofer or dome tweeter, since each step in the development cycle needs to be verified by all the above-mentioned measurements.

A smooth on-axis response is desirable since it defines the tonality of the direct sound when sitting in the near-field of the loudspeaker. But the BMR's broad radiation makes it necessary that the off-axis radiation should be free of any strong side-lobes, otherwise the spectrally modified off-axis sound reflected from the side walls or ceiling of the listening room will cause audible colorations. Thus for a BMR-based loudspeaker it is necessary to measure both the horizontal and vertical frequency dispersion and the acoustic power.

The acoustic power (or sound power) response describes the total acoustic energy the loudspeaker radiates into the room versus frequency. It is an essential measurement for characterising loudspeakers with broad dispersion or a large radiating area – like large dipole loudspeakers, omnidirectional loudspeakers or BMR-based loudspeakers. But the measurement is not easy to make.

In the past, we averaged two directivity measurements taken in the horizontal and vertical planes to come up with a measure for the acoustic power. This process is time consuming and slows down the development process. So a faster, more accurate method has now been developed using a reverberation chamber.

A reverberation chamber is a room with hard, reflective surfaces throughout and hence very low acoustic damping. Ideally the damping should constant over the entire audible frequency range although this is difficult to achieve, especially at frequencies above 5kHz. Because it lacks absorption a typical reverberation chamber has a decay time of 3 seconds or longer, so it has the effect of integrating a loudspeaker's output over all angles. Measuring with pink noise in such a room, spectral analysis of a 3-second interval represents a good approximation of the total radiated acoustic power. To average out position-related artefacts a total of eight microphones are distributed throughout the room, all eight signals contributing equally to the average which is used as a measure of the acoustic power output.

The Ovator S-800 BMR and what is so special about it

Development of the latest S-800 BMR driver took more than five years. Every part has undergone an extensive evaluation regarding its influence on the sound. This includes the motor, the membrane (panel), the surround, the voice coil and the spider.

The motor

Although the BMR crosses over at 380Hz in the S-800 and so experiences peak diaphragm excursions of less than 1mm, the motor was intensively optimised using Finite Element Analysis.

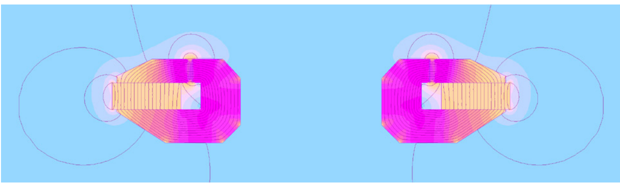


Figure 9. Finite element simulation of flux density within the BMR magnet system

Several aspects needed to be addressed during the motor's development. First of all, it had to generate a certain magnetic flux density in the air gap since this influences the final sensitivity of the drive unit. Another requirement for the motor was that it should not interfere acoustically with the sound radiated from the rear of the panel, thus a very compact form factor was mandatory. Furthermore the motor should provide sufficient cooling that the voice coil's operating temperature remains low, which prevents the driver from running into thermal compression.

The finalised motor design uses a double neodymium magnet configuration positioned outside the voice coil. Neodymium was chosen because of its ten-fold higher energy product compared to ferrite. This allows for a very compact design with the two magnets placed above and below the pole piece. A copper shield covering the pole piece helps reduce distortion and also controls the amount of high frequency output due to its influence on the driver's impedance.

The voice coil

Voice coil mass is a crucial design variable in a BMR design. The lower the mass, the less additional balancing mass is required. For this reason the Naim BMR's voice coil is wound from copper-clad aluminium instead of pure copper. After evaluating a range of possible voice coil former materials, we selected glassfibre as giving the best sounding result. Technically its good heat resistance and high stiffness make it an ideal choice for a BMR.

The membrane (panel)

A BMR's membrane material has a large impact on its sound – if not the largest. Various panel combinations were evaluated before we settled on a sandwich material based on a Nomex honeycomb core covered by paper skins on either side. This combines low weight with good damping and high stiffness, the panel's stiffness being chosen such that the first bending mode occurs in the frequency range where the panel would otherwise start to beam its output.

The surround

In a conventional cone drive unit the surround fulfils two functions. At low frequencies it helps controls the movement of the diaphragm, while at high frequencies it terminates the diaphragm in order to control breakup modes. In a BMR used as a mid/high frequency driver the requirements are completely different. With 1mm maximum excursion there is no need to control the movement at low frequencies and when the panel becomes modal the surround acts as a balancing mass. Thus the weight, diameter and damping of the surround are chosen such that good control of all bending modes, in particular the first, is achieved.