Performance Loudspeakers

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The Performance loudspeaker is a floorstanding, three-way system loudspeaker of acoustically advanced design. High quality sound reproduction requires an extended bandwidth at both ends of the frequency spectrum and very low levels of coloration and distortion. Improving the room matching characteristics of the loudspeaker was considered important, enabling a high consistency of performance to be achieved in a variety of domestic situations.

The Performance Loudspeakers fulfil these requirements by using a room bass matching system, minimum phase design with time alignment of drivers, a low coloration cabinet and high performance drive units operating across specific frequency bands.

Advanced acoustic theory together with the latest technology has been applied to great effect, resulting in high quality loudspeakers with exceptional performance.

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Design Brief

The design brief was to produce a loudspeaker with advanced performance to realise the full potential of the high quality source signals now available.

Several areas in loudspeaker design which needed to be addressed were identified at the start of the project:

1. The coloration of sound created by the cabinet, which itself has three areas of concern. Firstly, the resonances of the structure. Secondly, internal standing waves and thirdly, the sound radiated into the listening room from the cabinet itself. This is described as the Signal to Noise ratio.

2. The loudspeaker to room interface. Conventional loudspeakers oriented in typical positions in living rooms exhibit variations of the order of 5 to 12dB in low frequency output.

3. Time alignment of drivers, with a linear phase crossover (or uniform-delay) to give better coherence and integration of drivers, resulting in a stable stereo image.

4. Dedicated tweeter, midrange and bass drivers specifically designed to fully meet the design criteria.

Design Solutions — Cabinet Coloration

Cabinet coloration has been reduced by two complimentary design approaches — the use of an Acoustic Isolation System (AIS), to isolate the midrange driver within its own enclosure from the main loudspeaker cabinet and the use of ResinRock®, a low Q material. This is thermoset composite Polyester resin material with a mineral and rubber loading, for the main loudspeaker enclosure.

Acoustic Isolation System (AIS). The midrange driver is fitted into a sealed, non-parallel sided, infinite baffle enclosure, seven litres in volume. The enclosure is constructed from mineral filled Polypropylene, used for its inert acoustic properties. The driver is placed asymmetrically on the baffle resulting in reduced diffraction effects. This also helps to reduce the standing waves inside the midrange enclosure. The enclosure has a filling of Polyester fibres to further reduce and absorb the standing waves.

The midrange enclosure, being of much smaller construction than the overall main cabinet, gives several advantages. Increased structural strength reduces flexing and helps control resonance. The overall surface of the enclosure is also reduced, resulting in a reduction of the acoustic radiation from the enclosure.

The main cabinet has an integral midrange box, moulded-in, which allows the complete midrange enclosure assembly to be located inside. Isoloss Urethane elastomer, a space age material, mounting bushes are used to secure the midrange enclosure into the main cabinet and to provide acoustic isolation of the midrange enclosure from the main cabinet.

This results in a fully decoupled midrange which reduces interaction between drive unit outputs and reduced midband cabinet coloration from the main enclosure.

ResinRock® Low Q Cabinet. A floor standing loudspeaker system, because of its size, is often considered as a piece of furniture as well as a reproducer of sound. Because of this, the base material for the enclosure is usually either medium density fibreboard (MDF) or chipboard. Both of these materials have been universally used in loudspeaker manufacture for many years.

The acoustic properties of both these materials are well understood and various design approaches have been used to optimise their performance. Many designs have specifically been made to reduce the coloration re-transmitted from the wood enclosure. These have been in the form of extensive bracing, very thick wall section, bitumen damping panels and sandwich construction with different filling materials to assist in the absorption of standing waves (constrained layer damping).

Knowing the performance criteria of the wood based materials, it was felt that to achieve our design target of reducing cabinet coloration to below audibility would require careful acoustic design techniques.

The first design parameter to be addressed was the internal standing wave pattern. For a reduction of the standing wave energy to be achieved, a non-parallel sided cabinet was essential. The next requirement was that of non-uniform panel sizes to be used. These two requirements gave the first indication of the cabinet shape.

A sloping front baffle would achieve non-parallel front to back geometry and would also allow time alignment of the drivers. This would also result in different panel sizes for the top and bottom of the enclosure.

To further enhance the breakup of standing waves, the two remaining sides were angled in toward the top, making both sides non-parallel. To optimise the performance both sides were constructed from two panels joined at an angle vertically, forming a six-sided enclosure. This cabinet shape format realised the design target to reduce the standing wave pattern and give structural rigidity, limiting the resonance of the enclosure.

With the acoustic requirements being paramount, a method had to be found to enable this complex cabinet shape to be constructed. The normal route of MDF or chipboard construction was examined and found to be impracticable. Moulding or casting seemed to be the only way of achieving this shaped enclosure.

This method of construction, which is not usually used in an loudspeaker enclosure of this size, enabled us to consider whether we could also utilise a material with better acoustic damping properties than the usual wood derivatives. If this was possible, the combination of this shape constructed from an acoustic self damping material would result in much reduced levels of cabinet coloration, one of our design brief targets.

Injection moulding with conventional polymers proved to be impracticable. Acoustic properties were poor and the very large tools required were cost prohibitive.

The way forward came from a new Polyester resin based material being developed to control the noise of factory machinery.

Extensive trials revealed that by loading the base resin with different fillers, a material of very high acoustic damping and therefore low mechanical Q resonance was formed. This material lent itself to a casting process which enabled our uniquely shaped cabinet to be made. This material is called ResinRock®.

ResinRock® has a Polyester base resin which is loaded with mineral fillers and rubber strands. By varying the proportions of minerals and rubber to the base resin, the acoustic properties of the material can also be varied.

Figure 1 shows the comparative reactions of MDF and ResinRock® when excited by a know force. As can be seen, ResinRock® has a lower resonant peak than MDF and has a faster decay time. This has the effect of reducing the amount of sound (coloration) that the cabinet adds to the audio signal.

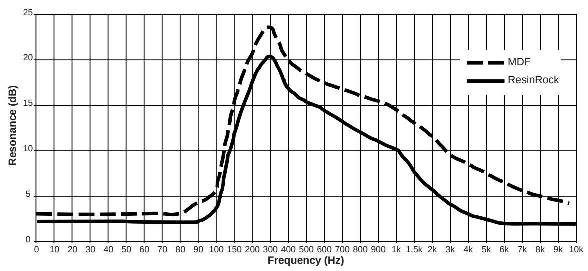

Figure 1. *Comparative reactions of MDF and ResinRock® when excited by a know force.*

The combination of the midrange Acoustic Isolation System (AIS), the acoustic shape enclosure and ResinRock® material results in a loudspeaker system with exceptionally low cabinet coloration. We had achieved one of the advanced performance parameters of the original design brief.

Design Solutions — Low Frequency Boundary Loading

The loudspeaker to room interface is extremely complex but one area that can lead to a substantial improvement in performance is the use of Low Frequency Boundary Loading.

With conventional loudspeakers, placed on stands in typical use positions, at a distance of between 2 and 3 metres away, the listener experiences a large dip in the frequency response. This dip occurs between 150Hz and 350Hz. (Figures 2, 3 and 4) This is due to the reflected wave from the nearest boundary (generally the floor) arriving at the listener later than the original signal and therefore not in phase. This partially cancels out the original signal.

In Figure 2, a bass driver has been placed at a height of 700mm (a fairly representative value) and the output measured at 1 metre distance at a height of 850mm (an average listener sitting position). As can be seen, a dip of 6dB in the frequency response is evident at 175Hz. The driver output is shown, as is the first boundary reflection with some attenuation of the high frequencies, due to the absorption of the floor material or carpets etc. When added together at the listening point, cancellation occurs.

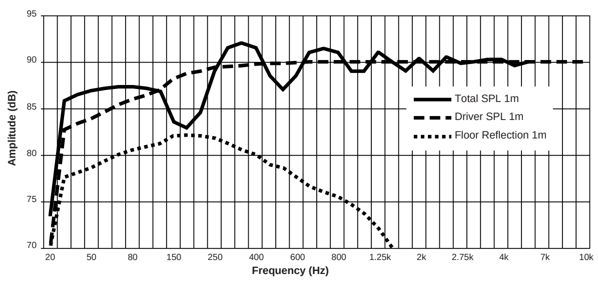

Figure 2. *Low frequency boundary loading. Driver on baffle 700mm above floor. Measured at 1m.*

The same loudspeaker was measured again at a more realistic listener distance of 2 metres. (Figure 3). A dip of 8dB is now evident at a frequency of 250Hz, with further ringing going up the band. *NB. There has been no change in voltage level to the loudspeaker so that sound levels equate with the increased measuring distance.*

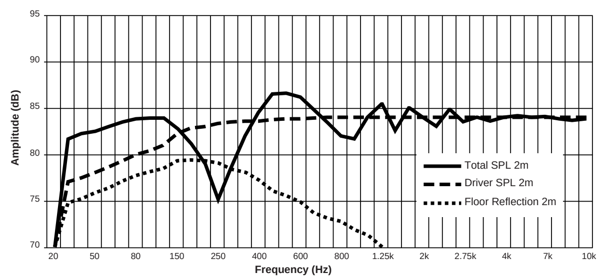

Figure 3. *Low frequency boundary loading. Driver on baffle*

Another measurement is shown in Figure 4. This time the measuring point is now at 3 metres and 850mm in height. The frequency response now has a dip of approximately 8dB at 350Hz with the associated ringing continuing on up the band.

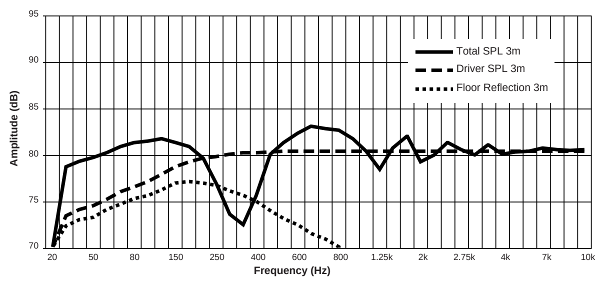

Figure 4. *Low frequency boundary loading. Driver on baffle 700mm above floor. Measured at 3m.*

The Performance loudspeakers utilise the first boundary reflection to give improved bass response. Placing the bass drivers low down on the front of the loudspeaker enclosure will make the source a very small fraction of a wavelength from the boundary and enables the floor area to augment the bass response. The SPL (Sound Pressure Level) response is going towards 2π steradians (half space), rather than 4π (full space) where reflections from the floor introduce dips in the response.

Figure 5, shows the improved bass response of a Performance 860 loudspeaker measured at a distance of 1 metre and a height of 850mm. An average SPL of 90dB is now obtained up to approximately 300Hz without a dip and will allow a smooth transition to the midrange driver. In Figure 5, the measurement point, at 2 metres, is more representative of a domestic environment. This shows further improvement in the response, when compared with Figure 3, although in both cases the overall level has fallen (6dB per doubling of distance) . The SPL is now an average 86dB up

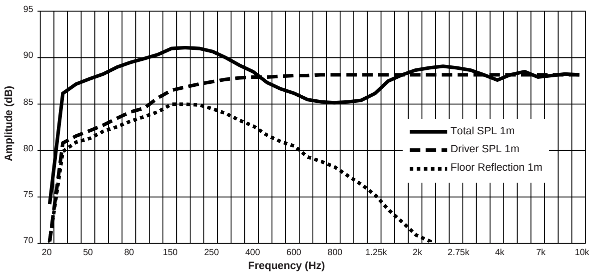

Figure 5. *Low frequency boundary loading. Improved bass response of Performance 860 bass system. Measured at 1m.*

to 500Hz without any dip, whereas the conventional set up in Figure 3 shows a dip at 250Hz and the average SPL 82.5dB between 30HZ and 1kHz.

The 3 metre listening position shown in Figure 7, indicates the consistency of improvement over a conventional loudspeaker. The SPL is an average 83dB up to midrange crossover frequency, whereas in Figure 4, the SPL is 81dB with a large dip in the response.

With this system we have been able to fulfil another design brief target to give improved room interface between

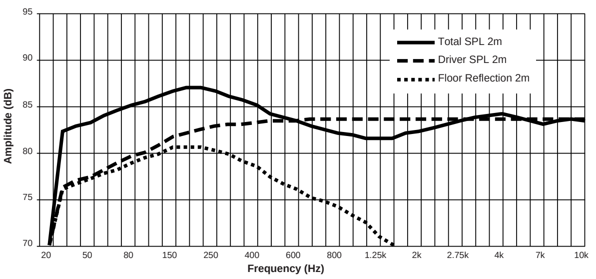

Figure 6. *Low frequency boundary loading. Improved bass response of Performance 860 bass system. Measured at 2m.*

the loudspeaker and the room environment, making the Performance loudspeakers less room dependant.

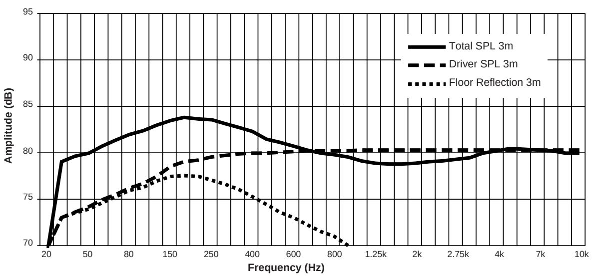

Figure 7. *Low frequency boundary loading. Improved bass response of Performance 860 bass system. Measured at 3m.*

Design Solutions — Minimum Phase System

The modern day hi-fi loudspeaker is now receiving far more information in the form of electrical signals to translate into sound than ever before. This is mainly due to the Digital revolution, particularly Compact Disc. When designing a new advanced performance loudspeaker system, full attention must be placed on the loudspeakers' ability to reproduce these much more detailed and complex signals.

When laying down the design brief, it was decided from the start that a minimum phase design loudspeaker system would give the best performance. By keeping the phase response of the whole system as linear as possible, better integration of the drive units would be achieved. This would give better directivity patterns and have the advantage of improved detail signal reproduction. Also, the stereo soundstage would be improved, with lower coloration due to a reduction in phase interference patterns.

The first requirement to achieve minimum phase is that the acoustic centres of all the drive units should ideally be the same distance from the listener. This avoids interference effects in the crossover regions through unequal time delays.

As previously mentioned in the section on the design of the optimum cabinet shape, it was decided that a sloping baffle offered the best solution. This had the benefit of not only correcting the time delay characteristics of the drivers, but also of reducing the internal standing waves inside the main enclosure by not being parallel with the rear panel.

Given the requirement of a minimum phase design, to augment the time corrected driver positioning, a suitable phase linear crossover would also be required.

In crossover theory there is generally only one design that has a true minimum phase characteristic and that is a first-order Butterworth. As shown in Figure 8, the first-order filter (6dB per octave) produces a summed zero phase response which is flat at all frequencies and has a flat amplitude. Albeit that the first-order filter is phase coherent and in theory produces no phase distortion, it generally does not provide sufficient slope rates to permit the drivers to operate in their optimum frequency band.

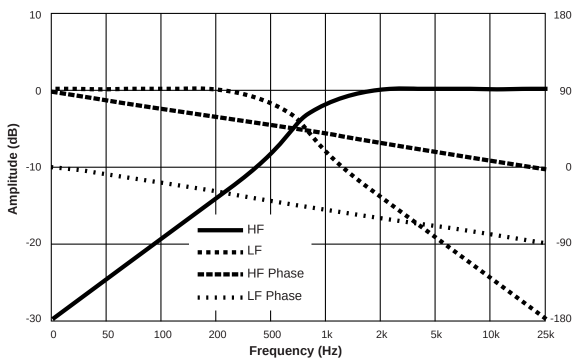

Figure 8. *Minimum Phase Crossover — 1st order Butterworth*

We therefore examined all aspects of modern crossover design theory and found one other filter system that would fulfil our requirement. This is called an asymmetrical constant voltage crossover. Figure 9 graphically depicts how this filter gives increased slope rate whilst maintaining a phase coherent relationship. This filter topology gives a third-order Butterworth characteristic which will be phase linear if the complementary filter is of first-order 6dB per octave Butterworth.

To maintain the premise of keeping the crossover as simple as possible means using the least components with the minimum electrical insertion loss. It was decided to use the third-order on the bass driver at 350Hz, thus preventing an overlap into the sensitive voice area of the midrange driver. This would also reduce the output of midrange frequencies into the bass enclosure that can cause standing waves and could color the important midband. To realise the crossover minimum phase requirement of a first-order matching filter with the inherent low slope rate, the midrange driver was designed to perform down to at least two octaves below the crossover point. This would then allow the use of a first-order filter on the midrange at 350Hz without any resonances or colorations in its pressure response.

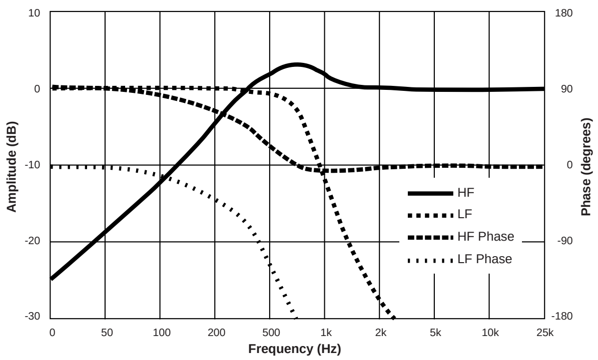

Figure 9. *Minimum Phase Crossover — 1st order/3rd order Butterworth asymmetric*

The midrange to tweeter crossover follows the accepted Mordaunt-Short practice of using minimalist filters to maintain maximum detail retrieval and therefore a first-order phase linear design was implemented. Both tweeter and midrange drive units have been designed to work well beyond their crossover points so that the 6dB per octave attenuation rate can be used.

To further enhance the crossover performance all components are of audiophile grade quality and are hard wired using their own termination leads. The Performance 820 has a bi-wire input whereas the 860 and 880 models have a full tri-wire input.

This optimised phase linear crossover system compliments the time aligned drivers to realise another advanced design characteristic of the Performance loudspeakers.

Design Solutions — Drive Units

In order to realise the full potential of these design innovations, new high performance drive units were required. The ability to build drive units in-house has enabled the development of dedicated frequency band, high specification drivers.

Dome Tweeter. A new Damped Control Pressure Loaded (DCPL) 25mm aluminium dome tweeter has been designed. With the crossover filter slope of only first-order 6dB per octave attenuation, and with a crossover frequency of 3.5kHz, the tweeter units lower frequency response cut-off had to be free of any irregularities or distortions down to at least 1kHz. This meant controlling the frequency and the damping of the resonance of the unit.

As one of the requirements of the design was accurate reproduction of signal detail, a low mass assembly was designed, consisting of a 50 micron thick aluminium dome fitted with a double layer voice coil wound onto a Kapton® former. This low mass assembly increased the acceleration, therefore the speed and attack, and extended the frequency response to 25kHz. But consequently this also had the undesirable effect of increasing the frequency of resonance to above the design parameter of 1kHz.

In order to resolve this problem we needed to reduce the frequency and damp the excursion at resonance. To achieve this, a pressure relieving chamber was formed under the rear of the dome in the centre of the pole piece. This reduces the resonant frequency and by fitting damping material in the chamber controls the pressure and thereby limiting the excursion. Magnetic damping fluid is applied in the magnet gap to reduce the voice coil temperature and give added damping at resonance. To further enhance the performance, a second magnet is fitted to increase SPL, increase the magnetic flux and to reduce the stray magnetic field.

Midrange Driver. The midrange, between 300Hz and 3.5kHz, is where the largest amount of musical information is concentrated. A midrange driver must therefore be able to handle these frequencies with minimum distortion and maximum clarity.

The first parameter to be ascertained is the overall size of the piston. Although a large piston would be more efficient, the horizontal dispersion characteristics approaching the upper crossover area would be poor. Ideally the horizontal dispersion of both midrange driver and tweeter at the crossover point should be identical. This of course is not practicable due to the difference in size of the two drivers. Dome tweeters being generally 19 to 25mm in diameter and midrange drivers being between 80 to 110mm in diameter.

Generally a large radiating area driver will have a narrowing dispersion with an increase in frequency. This would mean the off-axis response between the midrange driver and the tweeter will be uneven. The sound spectrum will therefore be different between on and off-axis.

Apart from the obvious change of sound with different listening positions, it would also manifest itself as increased coloration. As one of the requirements of the Performance loudspeakers is to reduce coloration, a smaller rather than larger piston should be used.

A 90mm diameter piston gave the best all round performance. A positive roll surround to reduce termination distortion was utilised with a talc loaded Polypropylene cone using Mordaunt-Short's patented Moulded Cone and Surround (MCS) technology. This technology ensures controlled drive unit piston performance and brings benefits in transient response and midband dispersion. To further enhance the high frequency dispersion characteristics a precision profiled phase plug is fitted to the centre of the drive unit, instead of the more conventional dust cap.

The required excursion of a midrange driver is considerably less than that of its bass counterpart, therefore the motor system can be made more efficient. By using a short coil and large magnet system an increase in magnetic flux density (Bl) is achieved which improves the speed and attack of the driver. With less weight on the speech coil, the moving mass is also reduced, again producing better acceleration.

Again, as in the tweeter design, a second magnet is fitted to the rear of the driver. This gives a further increase in SPL, increases the magnetic flux and has the benefit of a reduced stray magnetic field. A rubber damped screening can is then fitted over the motor system to further reduce the stray magnetic field.

Bass Driver. Generally, in order to reproduce the longer wavelengths encountered in the bass registers, a large cone diameter is required. This is because the output generated at a given frequency is proportional to the area of the cone and its maximum excursion. The required excursion is doubled for each halving of frequency given a specific cone piston diameter. By using a large diaphragm, excursion is reduced, which lowers distortion and improves efficiency.

The Performance loudspeakers are designed for domestic use and are therefore required to be as unobtrusive as possible. Modern styling trends in loudspeaker design take this point into account by making the footprint of the loudspeaker as small as possible. Making the width of the front baffle as small as is practicable results in lower cabinet diffraction and is also therefore beneficial to the sound quality. One area where a narrow front baffle is not optimum for performance is in the lower bass region: as mentioned earlier, a large driver with small cone movement gives the best performance.

The solution to this problem of a small cone driver working very hard is to double its cone area, thereby halving its excursion. This can be achieved using two smaller bass drivers, one above the other. The two drivers must be as close together as possible on the baffle so that, at the listening position, they combine their outputs to perform as one unit.

In order to reduce the cone excursion further (which in turn reduces distortion and increases power handling), a vented (bass reflex) enclosure is used. Poor transient performance is a hallmark of vented designs, although increased output with a lower distortion is an advantage. The best transient response is obtained with an 'infinite baffle' (IB) closed box enclosure design. The Low Frequency Boundary Loading system, as mentioned earlier, has the benefit of increasing the bass SPL. We therefore do not require the extra output afforded by a vented enclosure, but we do require the lower distortion levels.

With a conventional bass reflex design enclosure the output from the vent augments the output from the driver, thereby increasing the overall SPL output. As we do not require the output of the vent to augment the driver we can therefore change the tuning of the reflex system to a lower 'Q' than optimum ie. a Quasi Third-Order alignment (QB_3). This bass alignment has a transient response whose characteristics are similar to a sealed box (IB), but retain the advantage of reduced cone movement and increased power handling.

The narrow front baffle of the main enclosure predetermines the piston size of the bass drivers. With the bass alignment also decided, the final parameters of a suitable bass driver can now be established.

Mordaunt-Short's patented Moulded Cone and Surround (MCS) technology is used to ensure the bass drive unit's cone operates in optimum piston mode. The 'Q_{ts}' (the total Q of the driver at F_s (Resonant Frequency) resulting from all driver resistances) of the driver to fulfil the QB_3 alignment needs to be in the region of 0.3. A large twin magnet system is employed to obtain the required 'Q_{ts}'. An aluminium voice coil former is used to improve the electrical damping of the driver.

A porous dust cap is fitted and, in combination with a ventilated rear suspension, prevents air being trapped in the cavity created by the dust cap. A rubber damped screening can is then fitted over the motor system to reduce the stray magnetic field.

Conclusion

These high specification, dedicated frequency band drivers, are utilised to optimum effect by the Performance loudspeaker system. By using the dedicated driver units, Acoustic Isolation System (AIS), ResinRock® low 'Q' cabinet, Low Frequency Boundary Loading and Minimum Phase Crossover, the original design brief to produce a superior high performance loudspeaker using good acoustic theory with advanced technology has been achieved.

ResinRock® is a registered trade mark of Mordaunt-Short Ltd.