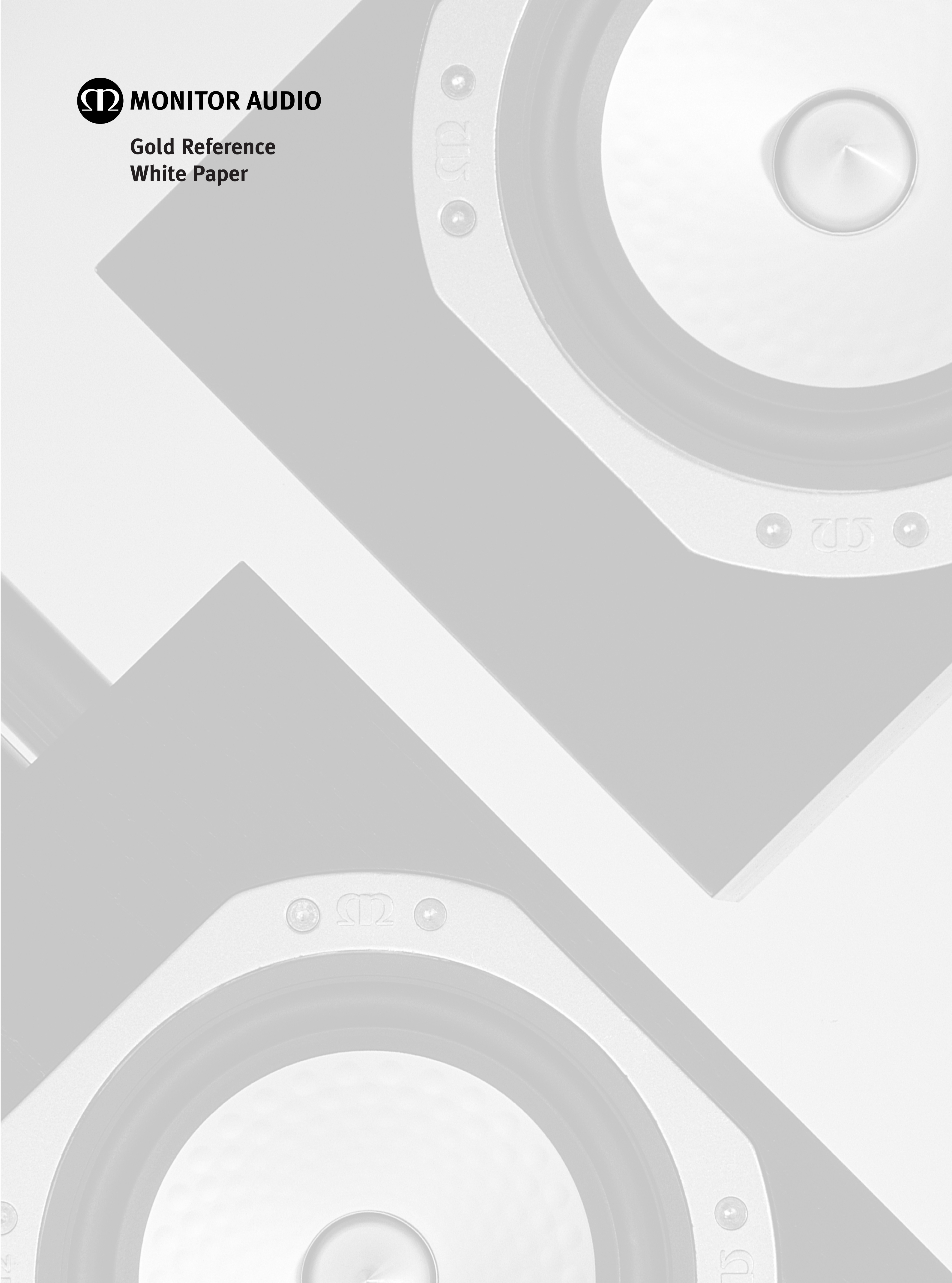
Monitor Audio Ltd.
24 Brook Road, Rayleigh, Essex SS6 7XL. England
Tel: +44 (0)1268 740580 Fax: +44 (0)1268 740589
email: info@monitoraudio.co.uk
www.monitoraudio.co.uk

MONITOR AUDIO

Gold Reference
White Paper



Gold Reference Series
White Paper/ Technical Notes

Drive Unit technology

Cone Material selection

In a traditional loudspeaker the cone may be made from a number of materials, each one selected for its acoustic and mechanical properties. Paper cones have been used for many years and more recently, plastic and composite varieties. These materials work on the principle that a cone can never be rigid, so most designs over the years have been non-rigid. The ideal for a loudspeaker cone is to be perfectly rigid, in order to work as a pure piston throughout its entire frequency range. A conventional cone is purposely allowed to flex, this flexing or break-up is usually within the working band of the loudspeaker unit. Because this can sometimes be at quite low frequencies, the distortion increases drastically to a point of which the sound degradation is all too obvious. A paper cone still remains one of the lightest materials around, however its stiffness is inadequate and it also possesses poor internal damping. Polymer materials such as polypropylene, polythene and PVC have all been used in cone forms, some used in their natural state or in filled varieties. Generally adding chalk or minerals to the material increases the internal damping, at the expense of rigidity. Since PVC and certain forms of plastic have a low melting point, it may be that ambient temperature stability is also a consideration. The latest forms of composites such as carbon fibre and Kevlar ™ (polyamide aramid fibre), offers a slightly better solution to this problem. In theory however the treatment of such materials only results in further compromises. In the case of woven fibre cones carbon, Kevlar ™, the material has no way of supporting itself in a conical shape. This is generally solved by the addition of a bonding and sealing agent, which is usually an epoxy or polyester resin. This resin is much heavier than the fibre and contributes a significant amount of mass to the overall cone. The application of resin can be innacurate and give rise to poor matching and consistency problems. The resulting composite fibre cone is also allowed to flex, although because of its low mass and higher rigidity (compared to previous materials) the frequency range is extended further. So to summarise our ideal material would have the following properties: -

Low mass
High rigidity
Good temperature stability
Selective damping properties

Fundamental principles

The Loudspeaker is generally known as the weakest link in the sound-reproduction chain. It should create a sound pressure proportional to the electric signal of the amplifier. In general, the basic loudspeaker may be split into two parts: an electromechanical and a mechanical-acoustical part. The latter mostly consists of the moving diaphragm, the vibration of which actually creates the sound pressure. The vibration is provided by the electromechanical driving system, the working principle of which classifies the loudspeaker as being of the electrodynamic (moving coil) variety. One of the greatest difficulties in the conversion of electrical into acoustical energy is the realisation of a prescribed (mostly flat) frequency response in a certain (mostly large) frequency range. The influence of the driving mechanism on the response being generally known, the basic theme of this study however is the vibration of the diaphragm and its influence on the sound radiation. The electromechanical driving system is of secondary importance for the purpose of this study.

We have discussed the loudspeaker cone is far from rigid. Above a certain frequency *fra* (axi-) symmetrical bending and longitudinal waves appear on the cone (the so-called break-up) the surface velocity is then far from uniform. Only symmetric wave motion is of interest here; asymmetric (ie. Not rotationally symmetric) waves already appear at a much lower frequency but they do not influence the sound radiation. Below *fra* the measured sound radiation agrees very well with a calculated rigid-cone radiation. If fc is greater than fra even the rigid-piston approximation gives excellent results for f‹*fra*. When we compare the calculated rigid cone radiation with the measured non-rigid response it appears that the bandwidth of the loudspeaker is increased by cone break-up.

In our study we wanted to select the ideal combination of techniques as to make the cone as rigid as possible. The eradication of bending and longitudinal waves through mechanical design features such as the radially supported inner edge and rigid cone top has made it possible to concentrate on the cone profile and surface wave propagation. Our study has led us to analyse various types of cone deformations created at various frequency points and to use mechanical design features to overcome these problems.

Wave analysis

We may distinguish between two wave types, which will be called bending and longitudinal (or extensional) waves. On a paper plate, the two wave types may exist independently; they do not influence each other. In that case the distinction is very clear. Bending waves have displacements normal to the plate surface; the wave velocity depends on the frequency and the bending stiffness. Longitudinal waves create displacements in the plane of the plate and the longitudinal wave velocity is much higher than the velocity of bending waves because of the relatively low bending stiffness of the plate. Therefore the longitudinal wavelength is much longer than the bending wavelength. For a cone, the situation is much more complicated. In general the two wave motions cannot exist independently. A transverse displacement (normal to the cone surface) automatically leads to a longitudinal displacement (in the plane of the cone) and vice versa. This may be illustrated on the basis of fig1, which shows a conical ring, on the inner edge of which a longitudinal force *fl* acts uniformly (fig1.1). Statically we may explain the coupling mechanism by first allowing the longitudinal displacement *u*, which then instantaneously evokes an azimuthal stress because of the diameter increase. This azimuthal stress leads to a force *Fc* directed towards the ring centre (fig1.2), which can be decomposed into a transverse force *Ft* giving a transverse displacement and a longitudinal force Fl^1 opposing *Fl* (fig1.3). Equilibrium is reached when the azimuthal stress has become so high that Fl^1 equals *Fl*. In the dynamic case the situation is essentially the same, but then the inertia forces must be taken into account. Hence in general, longitudinal and transverse waves are coupled via the cone angle and the idea of pure bending or pure extensional waves cannot be realised from this exercise. We may make a distinction between the two wave types on the basis of the deformation energy of the cone surface. This energy is the sum of the deformation energy of the bending and the deformation energy of stretching of the cone surface. If, for a certain wave, the former part is greater than the latter, we call it a bending wave; otherwise the wave will be called longitudinal.

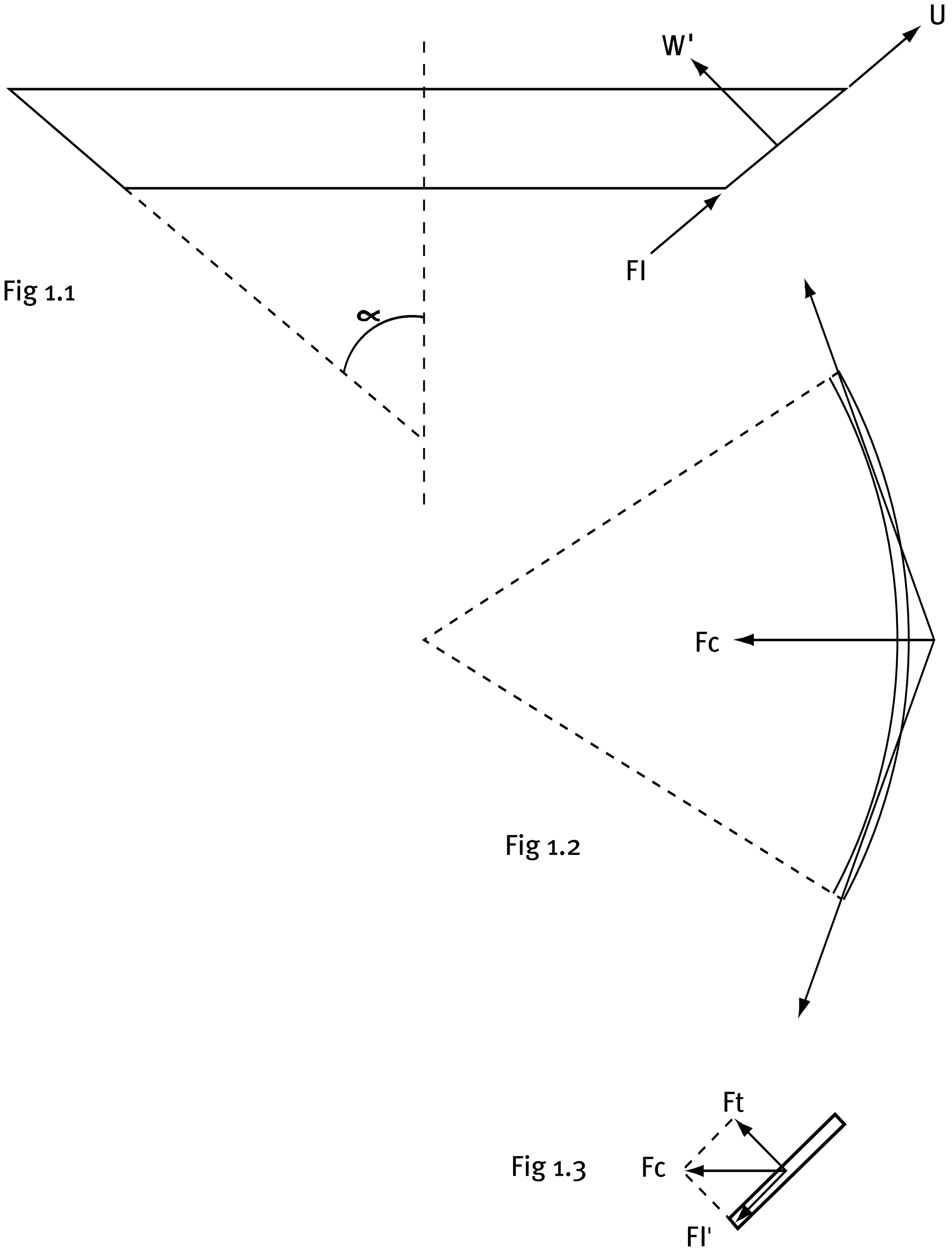


Illustration of the coupling between a longitudinal and a transverse displacement

Both types of waves may travel in azimuthal as well as in meridional direction. Let us first discuss the former. The travelling waves in both the azimuthal directions may cause standing waves with nodal and antinodal lines in a meridional direction (fig2.1) The standing- wave pattern is then called asymmetric (ie. Has no rotational symmetry). Since the bending stiffness of the cone in the azimuthal direction is relatively low, the wave velocity of these asymmetric waves will also be low. Therefore resonant frequencies, at which an integral number of half wavelengths fit on the cone circumference, are low. Because of the small bending wavelength as compared to the sound wavelength these waves are in general acoustically short-circuited. This means that the air is merely pumped to and fro between neighbouring cone parts, which vibrate in antiphase; very little sound is radiated. Apart from that, these waves are exclusively excited by inhomogeneities: if the cone were perfectly homogenous and driven purely axially and uniformly along the inner edge of the circumference, no asymmetric wave motion would appear at all. Therefore the sound radiation of the asymmetric waves will be neglected. In the following we fix our attention exclusively on the symmetric waves, directly excited by the axial driving force and in fact providing the sound radiation. Here too, standing waves may occur, because the waves generated at the inner edge travel to the outer edge and are partly reflected there (part absorbed by the outer suspension) the standing-wave pattern is asymmetric with concentric nodal circles (fig 2.2). In the presence of internal losses travelling waves appear on the cone as well, which blur the standing wave pattern: at the nodal circles the amplitude becomes a minimum.

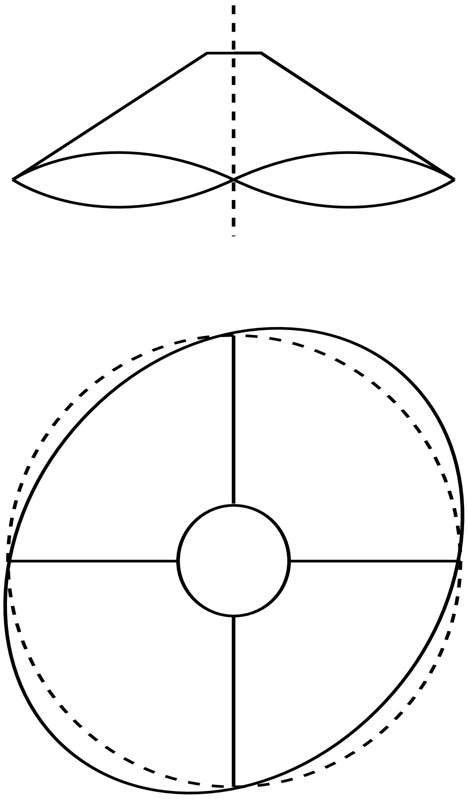


Fig 2.1 Asymetric vibration
with two nodal diameters

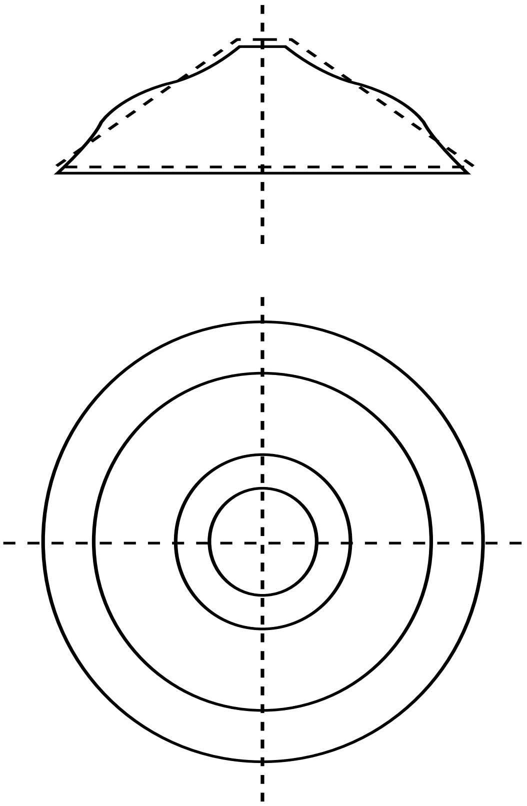


Fig 2.2 Symmetric vibration
with two nodal circles

In the following sections we will discuss special mechanical treatments and cone material selection that has enabled us to benefit from the fundamental understanding of the previous sections.

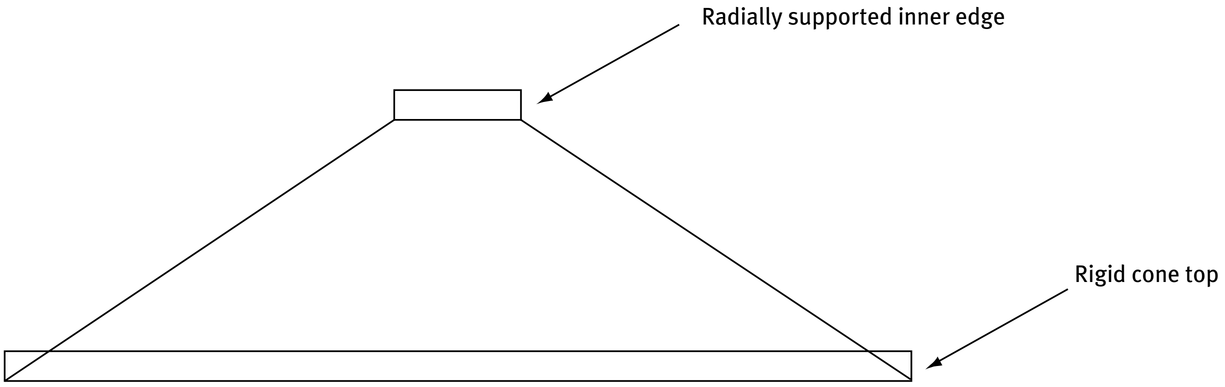


Fig 3.0 Basic cone profile showing Radially supported inner edge and rigid cone top

Radially supported inner edge

This design feature gives radial rigidity to the cone neck and voice coil joint. (fig3.0) The supported inner edge also assists the voice coil to remain perfectly concentric throughout the frequency band. This pre-determined control gives rise to frequency extension much greater than with an un-supported inner edge. Increased radial rigidity, perpendicular to the voice coil motion provides a high degree of support for the voice coil. This mechanical strength enables perfect concentricity of the coil former under excessive load conditions. If the radically supported inner edge was not present, or the cone was not sufficiently rigid enough at this point, the voice coil would not remain concentric. Under these conditions, vibration resulting in nodal circles, fig 2.2, will be encouraged. As a secondary affect the voice coil would become non-linear in it’s motion and insert a degree of modulation artifacts of it’s own.

Rigid cone top

The rigid cone top is another method used to give independent support to the cone and to provide resistance to symmetrical and asymmetric bending. (fig3.0) The addition of a rigid cone top has little influence in the low frequency region, at least if $b \gg a$. In the high frequency region however, the rigid cone top contributes considerably to the sound radiation. It increases the radiation in the direction normal to the cone surface. The rigid cone top provides ideal mechanical support for the cone termination, provided care is taken when matching the edge surround. Asymmetric vibration causing nodal circles to appear as in fig 2.1, will also displace itself on the edge surround. The edge surround will damp a certain amount of this energy , however it will vibrate in sympathy, resulting in the cone edge surround producing anti-phase nodes. A simple analogy could be used to illustrate this action; a stone is thrown into a pool of water, when it gets to the edge of the pool another stone is thrown in. The two wave actions are now out of synchronization and collide to form greater peaks and troughs. A similar situation will be encountered at the cone edge under normal conditions. However by using a rigid cone this cannot happen.

C-CAM™

Our research has led us to develop the material we know as C-CAM™, for use as loudspeaker cones. C-CAM™ (ceramic coated aluminium /magnesium) is an innovative alloy material originally developed by the aerospace industry for its use as blades in jet engines. This material exhibits ideal qualities for use as loudspeaker cones. The C-CAM™ material is extremely rigid, yet is remains light enough to yield high overall efficiency. C-CAM™ is formed from an alloy of aluminium and magnesium, which is made into the cone shape by a two stage high pressure forming technique. The material undergoes stress-relieving processes throughout the manufacture to avoid surface deformation and molecular weakness. After forming the shape, the cone goes through a high temperature anodic coating process. A layer of pure ceramic (alumina) is depleted onto the surfaces, to give a completely rigid exterior. Conventional cone materials operate in the band with which they start to flex, this can be termed as the break-up or bending discussed previously. This results in a large amount of audible distortion. The C-CAM™ cones are designed with the specific intention of bend resistance. The resulting properties of the C-CAM™ material are; increased clarity and reduced distortion compared with conventional polymer or paper cone designs.

RST ™

The dimpled surface provides the conical shape with another degree of resistance to mechanical bending forces. We have already discussed how asymmetric waves may be allowed to travel across the cone surface. The dimpled RST™ pattern effectively displaces any standing waves that can propagate across the cone surface. Although the cone surface is deformed, it has been produced in a regular, predictable manner as to not effect the sound radiation. As in fig 2.2, we see the results of wave bending on a standard paper, plastic or composite cone, without special mechanical treatment. The RST™ cone remains a constant shape and diameter throughout the working frequency range. These deformations actually start from very low frequencies, typically 150Hz in a 6.5″ loudspeaker unit. In fig1.3, we can see that a longitudinal force *Fl*, will result in the cone displacement *u*. However in a conventional cone that is allowed to bend, the deformation will result in a transverse cone displacement. It is true to say that in a typical model of the RST™ cone, the transverse cone displacement, w^1 can be negated; resulting in *Fl* being approximately equal to *u*. So it is true to say that the selection of material, profile and mechanical treatment is critical to almost the full working band of the loudspeaker, and not just the high frequency break-up . To summarise, the RST™ pattern allied to the rigid cone top and radially braced inner edge, generally increases the working band of the loudspeaker in accordance with the rigid piston approximation. Typically the RST™ cone driver is able to work in a system with a wider frequency bandwidth. This may not be necessary in a multi-way system, for reasons such as efficiency and acoustic dispersion. However it must remain an important point that the break-up is pushed much further away from the working frequency band, where it will be naturally attenuated by mass control and additional electronic filtering (crossover). Fig 4. Shows frequency plots of a typical 6.5″ plastic cone woofer/mid in comparison to a 6.5″ RST™ cone woofer/mid. The plots show how the break-up of the conventional cone is within, or extremely close to the crossover point of the system (around 3.7KHz). The RST™ plot shows the break-up much further up the frequency range, and providing better damping of the resonance.

Many common loudspeaker designs have used different materials for low, middle and high frequencies. This is generally because one type of material has for example, better internal damping of high frequency resonance. We have not even covered the way in which materials impart a different sonic character on the

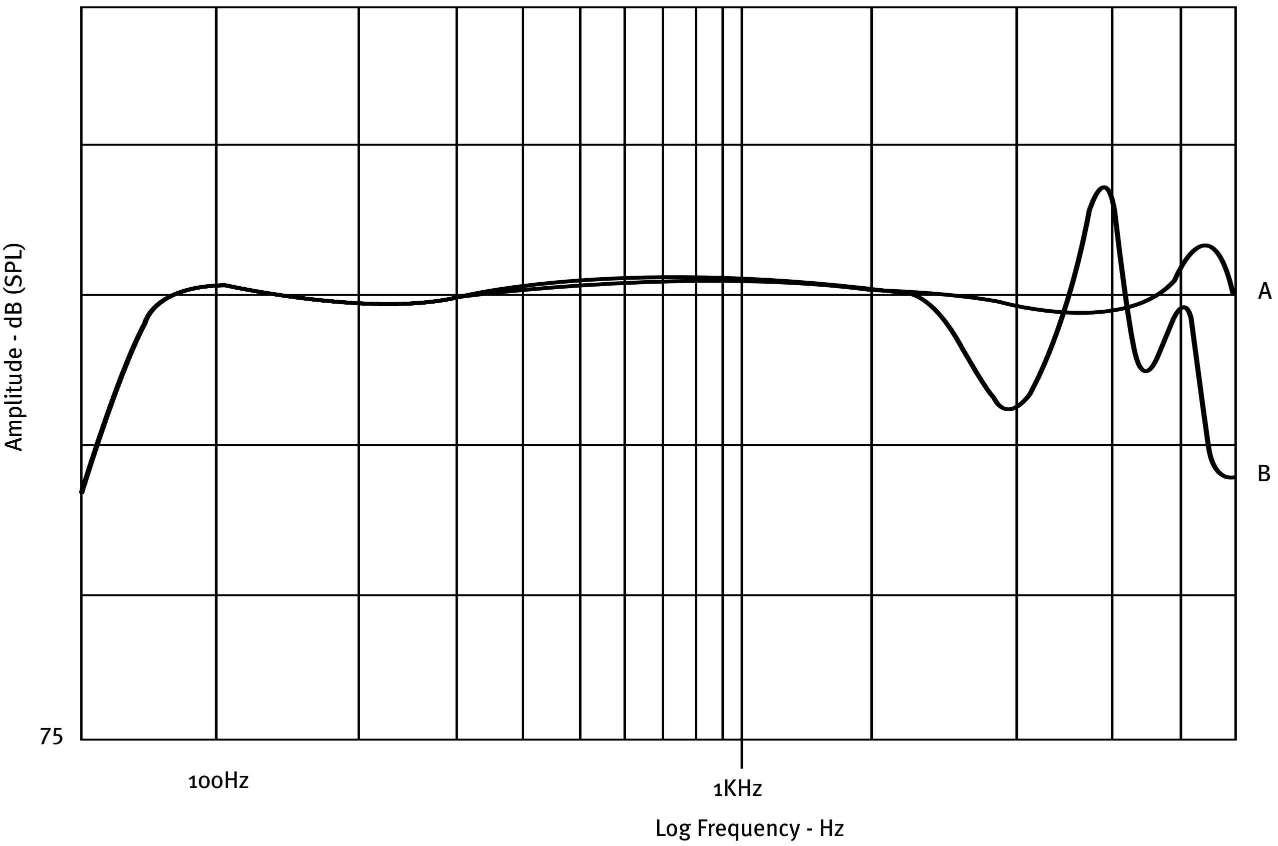


Fig 4. Comparison between a typical 6.5" conventional cone woofer (Curve B)
and a 6.5" RST™ Cone woofer (Curve A) in a typical enclosure,
showing response without crossover filtering.

overall sound. As a result we have chosen to use a material and forming techniques that enable its use of the C-CAM™ material over the entire frequency band on the loudspeaker system. In multi-way systems such as the Gold series models it is extremely important to have this synergy between the sonic signatures of independent drive units. This allows the system designer to achieve an overall signature that is consistently accurate.

List of Symbols

a	meridional coordinate of the inner edge
b	meridional coordinate of the outer edge
f	Frequency
fc	Characteristic cone frequency
fra	Ring anti-resonance frequency
u	Cone displacement in the meridional direction
ft	Transition frequency for the rigid piston
w	cone displacement in the transverse direction

Kevlar ™ is a registered trade mark of DuPont
RST ™ is a trade mark of Monitor Audio Ltd
C-CAM™ is a registered trade mark of Monitor Audio Ltd.

Key drive unit features

Solid aluminium de-coupled phase plug

The solid aluminium de-coupled phase plug has been specifically designed to work with the gold series bass/mid-range drivers. In the higher frequency section, a centre cap directly coupled to the voice coil/ cone apex, can affect the phase response off axis. The directly coupled centre cap radiated sound of its own, sometimes uncontrolled. At higher frequencies sound distribution emanates from the centre ring/apex, this technique is sometimes used to extend the high frequencies purposely in low cost ‘so-called’ full range drive units. The de-coupled phase plug is used to preserve the off axis phase integrity. A thin directly coupled centre cap will resonate in sympathy with the driving system to a point at which its own internal resonance will superimpose a larger output on the overall response. It is also of major importance that the de-coupled phase plug is made from a non-resonant material with pre-determined mechanical/ acoustic properties. We chose to machine the phase plug from solid $1\,^{1}/_{2}$″ solid pure aluminium bar. The solid structure ensures a non-resonant nature, which results in an acoustically inert part of the system. Whilst the solid phase plug is ideal for the purposes mentioned, the manufacturing cost implications can be prohibitive and in part is restricted to high-end drivers. However to realise the benefits from this small part of the system can far outweigh the cost implications. Our calculations predicted the ideal phase plug should reduce to a point at a pre-determined distance from the centre ring/apex. To attempt forming this part from sheet material would be almost impossible, in any case would also negate the benefits from having a non-resonant material. The machining process we chose allows the phase plug to be manufactured to a perfect point.

The solid phase plug also has other hidden benefits, which are nevertheless equally as important. In a moving coil driver the voice coil will generate heat, this is simple physics and can be directly apportioned to I^2R losses. We will discuss this topic in the next section, however this activity leads directly to what is termed as thermal power compression . This is the biggest problem that the professional audio sector has to face, however it is still a major issue in a domestic situation. The solid aluminium phase plug provides another means for the voice coil to get rid of heat build up. Aluminium is a good conductor of heat and due to the close proximity placement between the voice coil and phase plug, this heat-sinking occurs through close proximity convection.

Another important feature of the solid aluminium phase plug is the affect it has on hysteresis. The aluminium effectively works as a pole shading or inductance cancellation ring. This technique is used to reduce the rate of which inductance rises dramatically with rise in frequency. The solid aluminium phase plug reduces this rise and produces a smoother impedance curve. The result enables the designer to select a simpler approach to crossover design, and realise improved dynamic response.

Thermal power compression

This phenomenon occurs in all dynamic moving coil transducers, and is directly related to the sections above and below. In a dynamic moving coil system the voice coil is used to translate electrical current into magnetic energy, which is used to generate a mechanical movement, based on first principles. This would be perfectly correct of course, would it not be for losses in the system. These losses are generally created by resistive losses in the copper voice coil windings, released as heat. This theory does not take into account other losses due to inductive reactance. However it can be expressed in the simplest form of AC theory for the purpose of this explanation. In a purely resistive system, power can be expressed as V^2/R (i.e./ The square of the voltage supplied divided by the resistance) So for 50 Watts into an 8 Ohm load, the voltage required would need to be 20 Volts. If the load resistance were increased to 10 ohms, for the same 50 watts you would need to supply 22.4 Volts.

Thermal power compression occurs when the voice coil gets hot, this gives rise to an increase in resistance due to losses and expansion of the wire. It may well be that, in the case above; the system does not express any further sound pressure level above this point. At this point an increasing amount of electrical energy will be turned directly into heat. In practice the sound pressure level will drop because the voice coil is allowed to heat such that its resistance increases from 8 Ohms to 10 Ohms, the amplifier will then only be supplying 40 Watts. The sound pressure level will then decrease. However in certain cases the power may be turned up to attain the same sound pressure level, most of this power will be wasted and result in thermal overload of the drive unit. This is probably the single biggest cause of drive unit failure, related to voice coil burning.

Vented Chassis design

The vented chassis design has been developed also to combat the problems of thermal power compression. This new chassis development allows air to flow around the voice coil freely. Between the magnet and lower suspension an array of holes in the chassis vent the inner parts of the voice coil area, which provides the same air pressure as the outside. In conventional drive units, this section is sealed, which causes build up of heat and pressure in this area. Conducting destructive tests and plotting amplitude against power input have proved this to be the case. A special piece of equipment was designed to measure the rise in voice coil resistance, which can be directly transposed into temperature rise, given the start temperature. These tests have shown that thermal power compression is reduced drastically using the new chassis design, compared to a conventional sealed chassis design.

Another benefit of this venting arrangement is the lack of pressure inside the voice coil/ lower suspension compartment. A sealed chassis design may create a large pressure vacuum within this area, leading to in-appropriate compliance. This affect drastically reduces dynamics as power is increased. However, in the case of the new-vented chassis, the voice coil/ lower suspension area is under equal pressure at all times. This preserves the dynamic qualities of the driver right up to its maximum working power range. A simple solution in this case enables the Gold Reference series drivers to perform at a higher level than previously expected.

Tweeter/ High frequency design

Exercises conducted recently on the bass/mid-range cone design has led us to understand more about the constructive elements of the tweeter and how it integrates into the system. As a rule most tweeter designs are used around the fundamental low frequency resonance of the unit. This can be around 1800Hz for a typical 25mm dome tweeter. At this point in the frequency spectrum, the resonance can be poorly damped and is definitely audible in the system. Many loudspeaker systems have just this problem, where the sound appears to ‘squawk’ at a particular frequency. Unfortunately this is around the point of which the ear is most sensitive. It goes without saying that we wanted to eliminate this low frequency resonance, or rather shift it much further away from the crossover point of the system. With this in mind we designed a tweeter to have a damped rear resonance chamber in order to lower the fundamental resonance to around 500Hz. This new feature has not only given smoother response but has again made it possible for the system designer to simplify the crossover filter.

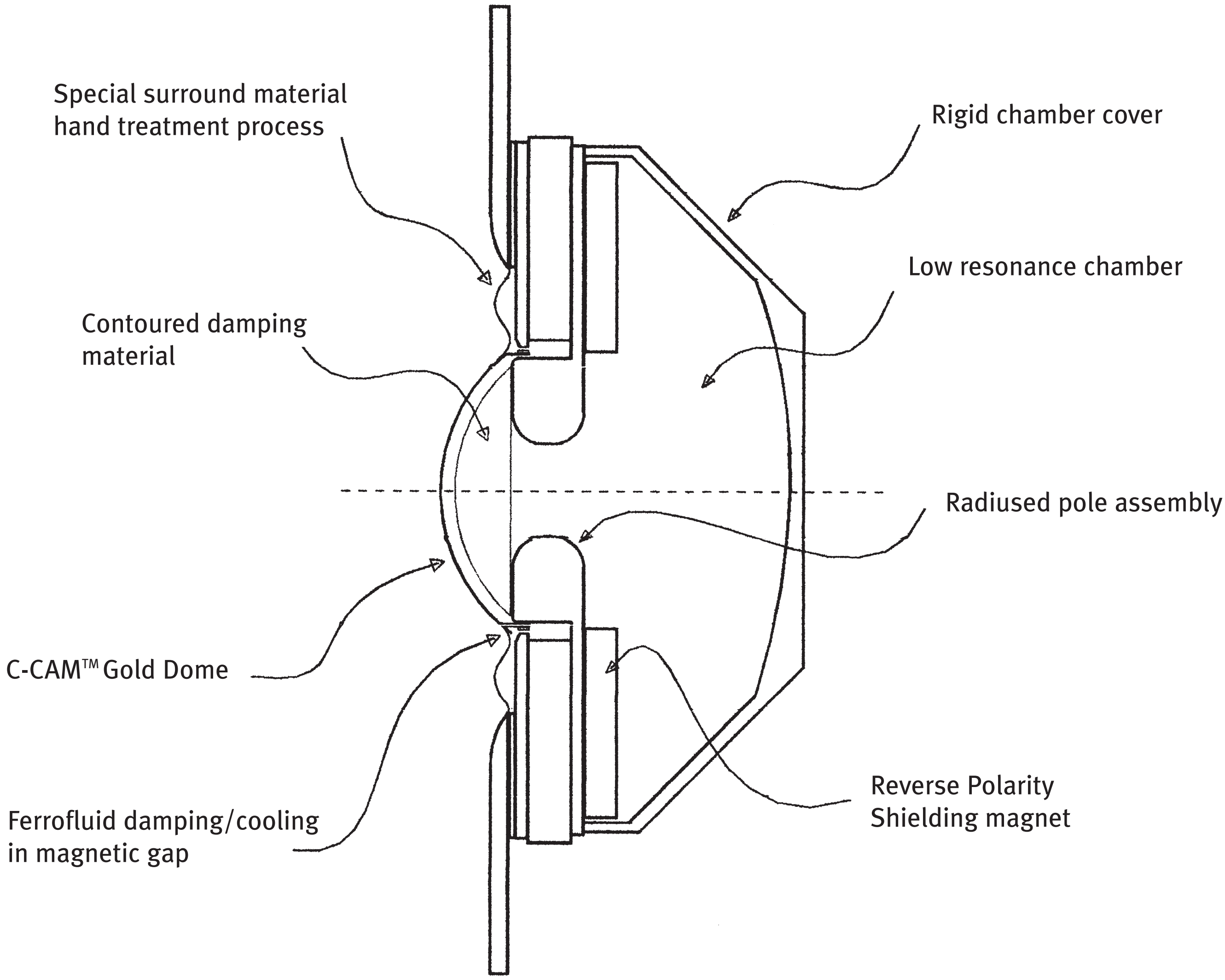


Fig. 5. Section detail of tweeter assembly

Fig 5. Shows the rear chamber, where the whole section is actually loaded with a glass fibre damping material to provide excellent damping of rear waves. A radiused pole assembly has been used to give even flow and reduce turbulence through the magnetic structure. Non-regular shapes have been selected to reduce standing wave propagation. The magnetic system uses a reverse polarity rear magnet to buck stray magnetic field from the main magnet. This principle allows the magnetic structure to be efficient and free from leakage, which normally causes problems with TV s in conventional tweeter units. The gold dome is made from a variant of our C-CAM™ material that is treated in exactly the same way as the bass/ midrange cones. The very thin C-CAM™ alloy is only 30uM (0.03mm/ 0.0012″) thick, and weighs a fraction of a gram. This lightweight material possesses ultimate strength when formed into the dome shape and treated with the ceramic coating process. This Gold C-CAM™ dome is light, strong and possesses the ideal characteristic properties to enable the tweeter to work right up to 30KHz before any sign of break-up occurs. A new type of ferrofluid is incorporated in this design to damp resonance further. Ferrofluid acts as an efficient magnetic energy transfer between the magnetic gap and voice coil windings. Another effect is that it conducts heat away from the voice coil, such to increase the power handling of the unit to well above the system limit. Many key features have been developed for this design to enable easier system design and increased performance. Our design philosophy and target of eliminating resonances, or at least taking them away from the working band has brought us to re-evaluate the design of the tweeter.

System Design

System design is made much easier, and better results are achieved with correctly designed drive units. Most speaker systems on the market use off the shelf drive units and claim their design advantages are in the cabinet construction or crossover design etc. Whilst this may be true to a degree, they generally neglect the fact that the system could be a lot better. We are fortunate enough to be able to design and build our own driver units in house. This understanding of driver design and cabinet construction gives better synergy between the parts of the system and generally gives unique performance characteristics. We feel we have achieved with the gold series a successful marriage of; drive units, cabinet and crossover and have made it possible to attain a higher performance level. We will briefly talk about the cabinet and system configuration with specific reference to key features

Puresound™ crossover

In a conventional multi-way system, the mid-range section is generally filtered using at least one series capacitor. Typically these capacitors are of a large value compared to the ones used for series high frequency filtering. Using conventional methods the system designer may choose to use an electrolytic type capacitor in an attempt to keep the material cost down. High internal losses coupled with large reactive elements within an electrolytic capacitor have serious effects on the overall sound character. The results include irregular phase response/ time delay, which induces itself as smearing or blurring of the sound. Electrolytic capacitors are actually polarised, and as such as not well equipped to cope with the passing of alternating currents. In reality such things as bi-polar electrolytic capacitors are only two polar capacitors back to back . In any case, whilst the electrolytic is good for storage of electrical charge and smoothing in power supplies, completely the opposite is required for series filtering. Another option would be to use a plastic type capacitor such as polyester or polypropylene, the latter being extremely cost prohibitive due to manufacturing complexity.

Our initial trials with Gold Reference 20 & Gold Reference 60 used a large value polypropylene capacitor, of around 100uF. During the sound testing we realised that the sound was degraded when the capacitor was placed in circuit. A simple trial was conducted using a switch to directly compare the system with or without the capacitor. Whilst this method is not a true reflection on the overall characteristics, the increase in clarity and small-scale detail was duly noted to be far superior without the capacitor in the system. Deciding to opt for a capacitor-less mid-range posed a major problem, this is one of low frequency power handling and distortion. With this in mind the way we thought about the overall systems design had to be re-evaluated and re-worked to take this development into account.

Differential tuning method

The Gold Reference 20 & Gold Reference 60 use a differential tuning method to control the low frequency sections. Differential tuning can only be used when two or more bass drivers are to be used in the same enclosure. In a conventional ported (Hemholtz resonator) system, a speaker with two bass units would normally share the same air space. This would be tuned to a frequency usually optimised to give a desired response and damping. Various degrees of tuning can be expressed as a value of Q, maximally flat butterworth response being around a value of Q=0.707 In a differentially tuned system, two or more bass units work into separate chambers; one chamber will be larger than the other and they will be tuned to individual frequency points. The results are such that the two individual responses add together to form enhanced low frequency extension and higher system efficiency can also be realised

The simulated frequency plot below shows the relationship between a speaker cabinet of the same total volume, with and without the differential tuning method. Note that plot A is a typical response of a conventional system. The two other plots, B and C, show the response of the two bass sections individually and also the combined response total, plot D. Notice how the differentially tuned system has better low frequency extension and higher overall efficiency.

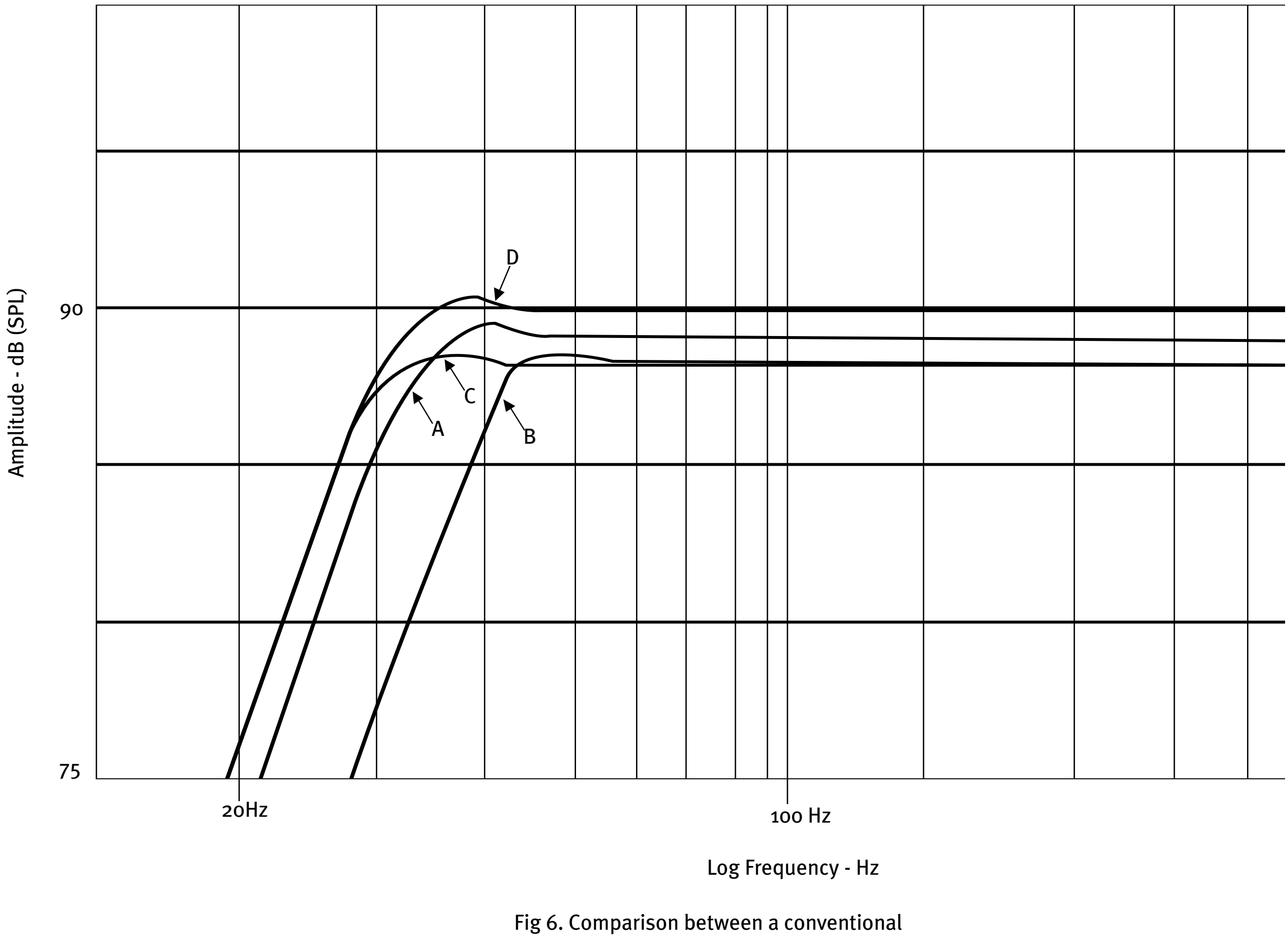


Fig 6. Comparison between a conventional ported system and a differentially tuned system