CONCEPT BLADE

WHITE PAPER

www.kef.com

KEF
INNOVATORS IN SOUND

1. KEF Concept Blade – White Paper

At first sight the task of a loudspeaker seems very simple, the input voltage needs to be translated faithfully into sound pressure. However, the voltage is only a one dimensional signal varying with time whereas pressure has three spatial dimensions as well as varying with time. The Concept Blade loudspeaker system is designed to execute this function while avoiding the complex physical artefacts found in conventional loudspeaker systems. The aim of the project was to produce a source that behaves in the simplest possible manner. A point source that has the smooth decrease in dispersion necessary as required by psychoacoustics to give the most accurate possible reproduction [1].

Normal loudspeaker configurations result in sound that is radiated from different sources spaced apart by some distance. This has a number of consequences: firstly the direction from which the sound arrives at the listener varies, secondly when the distance between the listener and drivers is different the timbre is altered due to acoustic interference and cancellation, finally the transients from the different drivers are misaligned. Linkwitz [2] has shown that when the reflected sound has similar timbrel characteristics to the direct sound the human brain is able to filter out the listening room making it become transparent to the listener.

The Uni-Q® driver array goes some way to addressing this issue, in the most critical middle and high frequency range the problems mentioned above are avoided. With Concept Blade the Uni-Q approach has been extended to its logical conclusion by utilising the acoustic notion of an “apparent acoustic source” first introduced to explain the behaviour of large public address horns [3]. In essence when a sound field is created the wave-front is observed at some distance away and the wave-front curvature used to determine the apparent position of an equivalent source. To an observer a sufficient distance from the source or sources the wave appears to come from this position. In Concept Blade an array of four identical bass drivers are positioned in two pairs, one above and one below the Uni-Q, equispaced in the horizontal and vertical planes. Because the wavelength of sound is much larger than the array, over the working bandwidth and when observed from a small distance from the loudspeaker, the array appears to behave as a single source. This “single apparent source” is precisely on the axis of the Uni-Q and the axial distance between the apparent source of the bass array and Uni-Q array is only a small fraction of a wavelength. To the listener the sources originate from exactly the same direction.

However, this is not the end of the story: the ideal point source produces a coherent sound wave rather than the diffuse sound which can result from cone breakup and enclosure radiation. To complete the concept the drivers of the Concept Blade all behave as rigid pistons until well outside of their working range. This is a key part of the concept since drivers that break-up differently produce a sonic signature that allows the brain to recognise that there are multiple sound sources. The aim with Concept Blade is to produce the illusion of a single source.

There is also the issue of delayed resonance from the enclosure which may colour the sound adding unwanted complication to the simple behaviour of the ideal source [4]. Work by KEF engineers has focused on the three main areas causing this type of colouration:

1. Vibration transfer directly from the drivers exciting the enclosure walls to radiate sound.
2. Sound pressure in the enclosure causing the walls to vibrate and radiate sound.
3. Variation of the acoustic impedance of the enclosure causing the driver motion to radiate after the original signal has stopped.

In the Concept Blade cabinet vibrations due to forces from the drivers, 1 above, have been completely eliminated since the back to back side mounted bass drivers are mechanically linked to achieve force cancellation and the Uni-Q is decoupled from the cabinet using vibration isolation methods. Driver vibration isolation by decoupling was introduced at KEF in the 1970's but for the Concept Blade has been refined with FEM analysis and laser vibrometry to ensure the theory is correctly executed in the real world. The sound radiation due to the acoustic effects, 2 and 3 in the list above, were modelled using FEM. Acoustic absorbent material for the cabinet interior was chosen and positioned to reduce the effects of cavity modes and to force the enclosure to behave, to all intents and purposes, as a pure acoustic compliance. The acoustical transmission of the sound from the rear of the driver through the enclosure walls proved an interesting problem since it is strongly affected by unsuppressed cavity modes. Once these were eliminated, with absorbent material, it was possible to observe the areas of the cabinet responsible for radiating most energy and to add suitable mechanical bracing to the computer cabinet models, adjusting their design so that the enclosure radiation could be minimised. Armed with this detailed understanding of the enclosure's vibroacoustic behaviour, an informed choice of construction materials could be made: the balsa wood/carbon fiber composite was chosen for it's extremely high stiffness and excellent damping properties.

The methodology of modelling the system and it's components with FEM then validating the models with laser vibrometry or acoustic measurements to ensure correct execution in practice is key to the whole development of Concept Blade. Make the design work in theory using FEM, BEM and other suitable mathematical techniques, then validate the theory by making measurements. It seems somewhat ironic that the most complicated and sophisticated techniques are required to produce such a simple end result.

To complete the process extended listening tests were carried out to find any unexpected problems. These could then be isolated by measurement and analysis so the design could be altered to remove such issues. The design iteration was then started again. Perfection is a tough target!

Listening is absolutely key to the design process since it is the audible issues that must be fixed. After all the key purpose of the loudspeaker is to present the music created by the performing and recording artists so the listener gets the full impact of both the audio illusion and emotion from the music. Loudspeaker design is still partly an art but the technology we have applied in the design of the Concept Blade empowers the designer to achieve a far more remarkable result rather than spending his time “balancing compromise”.

1.1. 10th Generation Uni-Q Driver

For the Concept Blade a brand new 10th generation Uni-Q has been developed. In addition to the original patent, work by KEF Engineers has resulted in four other patented technologies which are all used on this one critical component.

- Optimal Dome Shape
- Stiffened Dome
- Tangerine Waveguide
- Rigid LCP Cone

The addition of these technologies has resulted in a driver with landmark performance, it is a great step forwards for the Uni-Q concept.

1.1.1. Optimal Dome Shape

The great challenge of the Uni-Q concept is to make the drivers in the array compete with the best discrete units whilst facing the extra restrictions that come with trying to fit two drivers into the space of one. This is most apparent with the tweeter of the Uni-Q. For a long time it has been considered that the best situation for a high quality tweeter is in a perfectly flat baffle with no irregularities around to disturb the radiation from the dome. In this context the location of the tweeter in the neck of the midrange cone in the Uni-Q would not seem ideal, however, it is precisely because of the presence of the midrange cone, which acts as a wave-guide for the tweeter, that the dispersion of mid and high frequencies can be matched in the Uni-Q concept. Nonetheless it has always remained a great challenge to design a tweeter positioned at the centre of a cone driver with the same level of smoothness and finesse as the best discrete tweeters.

The real breakthrough in the design of the Uni-Q tweeters came as a result of the Muon project. After many years of looking at the problem, research work carried out at KEF headquarters in Maidstone by Mark Dodd [5] resulted in the surprising finding that provided the shape of the tweeter dome and the midrange cone are exactly correct together their combined performance can beat the conventional ideal of tweeter in flat baffle. This work was published recently at the AES convention in San Francisco.

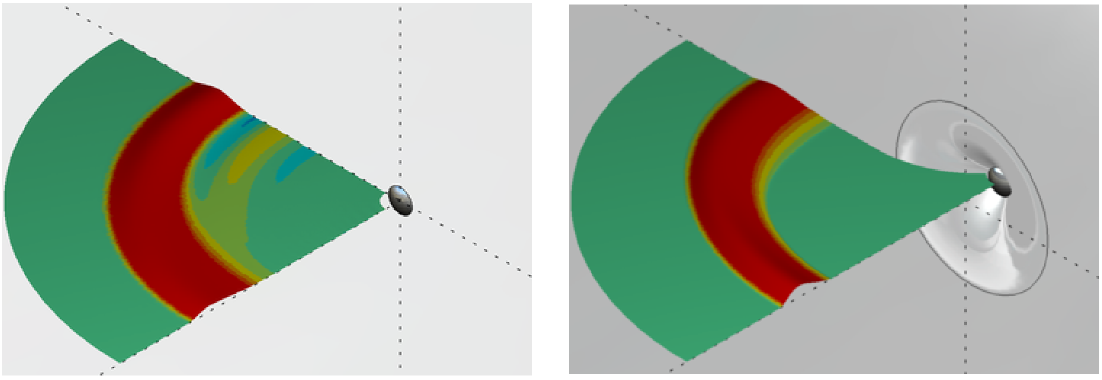

Figure 1.1. Conventional tweeter in a baffle (left). Uni-Q tweeter in a baffle (right).

Figure 1.1 shows an FEA simulation of the sound-field generated when a short pulse is sent to the tweeter for a conventional tweeter in a baffle and a Uni-Q tweeter with Optimum Dome Shape. The sound-field of the tweeter on the right is more distinct with virtually no ringing following the sound-field. With the conventional tweeter layout there is a significant amount of ringing which occurs after the impulse has passed, particularly around the side of the dome.

This finding was a major breakthrough for Uni-Q, the Concept Blade incorporates this technology into the design of the tweeter and the shaping of the midrange cone. Additionally, for absolute optimum performance, the surround on the midrange driver is flat so that the sound-field from the tweeter is completely undisturbed and reaches the listener without reflection or diffraction.

1.1.2. Stiffened Dome

The acoustics of the tweeter is only half of the story, to achieve the highest possible level of performance the Concept Blade uses another patented KEF technology to control the mechanical behaviour of the tweeter dome.

The Tweeter dome is constructed from extremely thin titanium. Titanium is chosen as it has a remarkably high stiffness and also a very low density. This is important for the tweeter dome because for best performance the dome must move rigidly without deforming even at and above the highest frequencies that we can hear. The highest frequency that a human can hear is approximately 20,000Hz. In order to move at these frequencies, the tweeter undergoes some seriously high levels of acceleration. At normal listening levels the tweeter hits peak acceleration levels of around

10,000m/s^2. If your car could accelerate this fast it would do 0mph to 60mph in 0.003 seconds, unfortunately it would be very hard to drive at the time as you would be pinned back in your seat from the 1000G of acceleration.

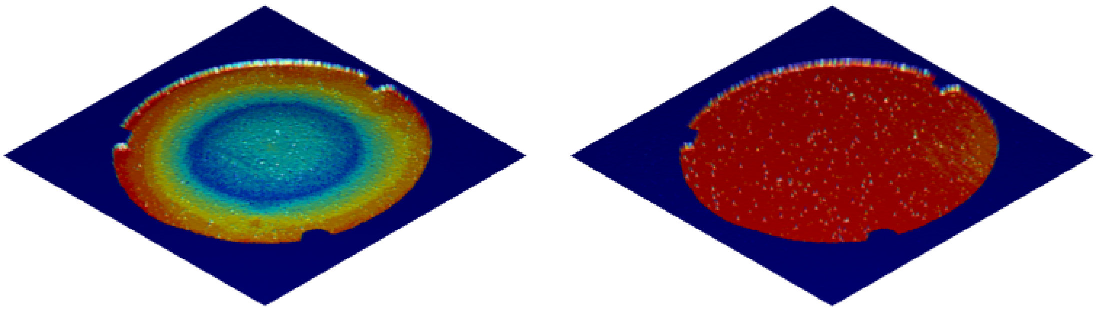

Figure 1.2. Laser vibrometer scan of tweeter dome in breakup (left) and pistonic (right).

At such high levels of acceleration it is extremely difficult for the tweeter dome to remain rigid. The inertia due to the mass of the dome material itself can easily generate enough stress to drastically deform the dome during use. The acceleration of the dome increases with frequency, ultimately there is a maximum frequency at which a dome is able to remain rigid. The dome motion, including these deformations, is too small to see with the naked eye but it is possible to see them using a laser to record and amplify the motion as shown in figure 1.2.

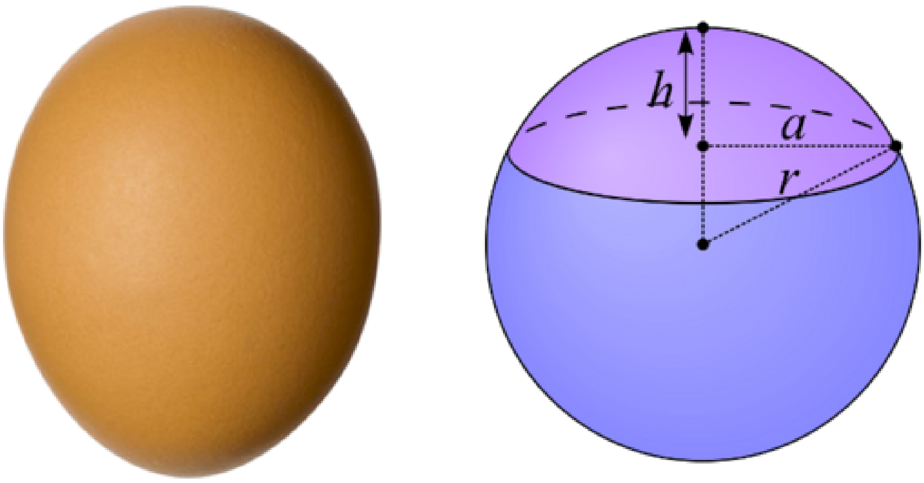

Figure 1.3. The rounded end of an egg (left) is close to the best dome shape mechanically but a spherical cap is the optimum for acoustical performance (right).

Research work was carried out at KEF in the '90s to determine the best dome shape which gave maximum resistance to the acceleration force and maximised the frequency range. The study concluded that the optimum shape for the dome was an ellipse [6]. In-fact the optimum dome shape to resist the acceleration forces and remain rigid is quite close to the shape of the rounded end of a chicken egg. Using this shape it is possible to improve the bandwidth that a dome can be used over by around 75% compared to a conventional dome shape. Unfortunately for the best acoustical performance of the tweeter we have learned above from the Optimal Dome Shape technology that we require a spherical cap shape for the dome.

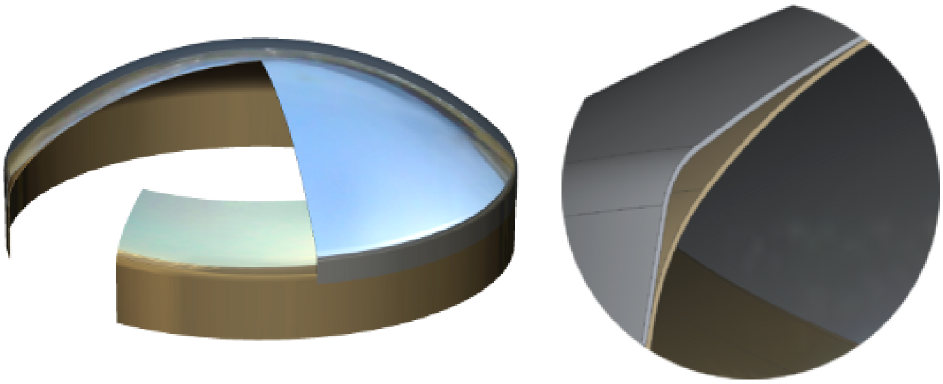

Figure 1.4. The Concept Blade uses a Stiffened Dome from two parts which form a triangular strut massively increasing the rigidity of the dome.

The Stiffened Dome is a method that enables us to use both of these optimum shapes at the same time resulting in the best possible dome performance. The Concept Blade Tweeter dome is made from two parts: one elliptical, one a spherical cap. These two shapes are superimposed, one placed on top of the other, forming the patented KEF Stiffened Dome shown in figure 1.4.

At the edge of the dome the two shapes form a triangle. The triangle is a fundamentally strong shape and the edge of the dome is normally the weakest part. Triangles are widely used in many engineering structures because of their inherent strength. The Stiffened Dome gives a far higher performance than either the elliptical dome or the spherical cap shape alone.

1.1.3. Tangerine Waveguide

The Tangerine Waveguide is a patented KEF Technology which is now used in a number of products throughout the range. The technology developed following research work into compression drivers, which are used in high power systems for concerts [7]. Compression drivers are very susceptible to acoustic resonances which occur in front of the tweeter dome. Whilst looking into the behaviour of compression drivers in detail, it was realised that the source of these acoustic resonances is also present in a normal direct radiating tweeter.

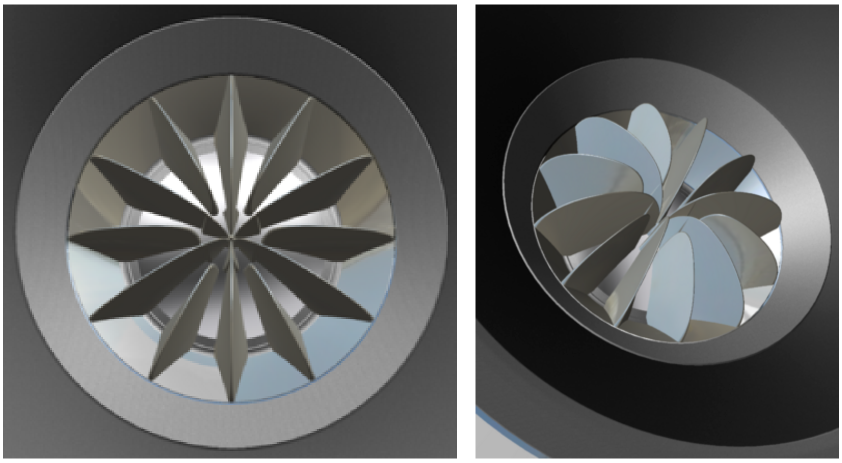

Figure 1.5. Illustrations of the Tangerine Waveguide design used in the Concept Blade tweeter.

The Tangerine Waveguide, shown above, is designed to compensate for these problems, improving the coupling between the tweeter dome and the air [8]: it acoustically optimises the radiated sound from the tweeter so that it appears more like a acoustical point source, this results in increased sensitivity and better dispersion than an uncovered dome.

Whilst tangerine waveguide technology has been used in other KEF products, making this approach work for such a high performance loudspeaker has been a hard challenge and it has taken many months of computer modelling before this distinctive new design was reached. The resulting performance improvement is quite dramatic, figure 1.6 shows the one meter axial frequency response of the Concept Blade tweeter with and without the tangerine waveguide. It may be observed that in addition to the improvement in the sensitivity of the tweeter, the smoothness of the response is also improved.

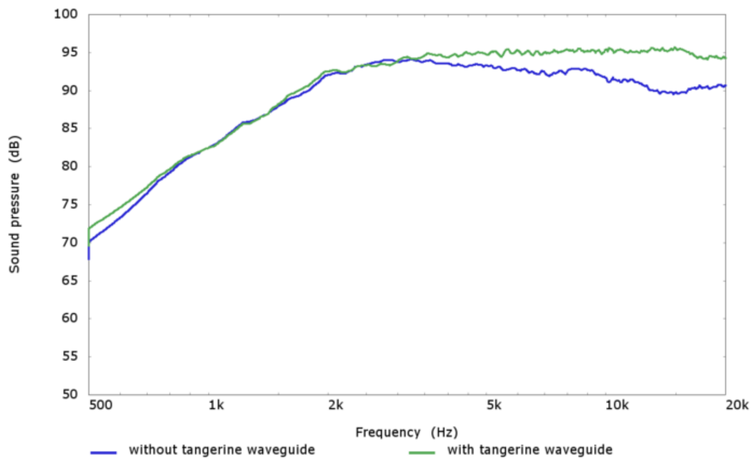

Figure 1.6. Concept Blade tweeter response with (green) and without (blue) tangerine waveguide fitted.

1.1.4. Rigid LCP Cone

Loudspeakers often use a radiating membrane of conical shape. The conical geometry is inherently stiff as axisymmetric external forces are transferred to tensional stresses in the material. This means a very thin material, which has little resistance to bending, can be successfully used. However, cone loudspeakers are often used beyond the limits of this rigidity. Figure 1.2 shows the simulated pressure response of a simple cone loudspeaker of 93mm diameter, radiating into an infinite acoustical region. The pressure is plotted at 46 positions at 1m from the loudspeaker and 2 degree angular increments. It may be observed that above approximately 1.5kHz the pressure response of the loudspeaker becomes irregular and resonances are seen. These resonances correspond to non-rigid behaviour of the cone. Non-rigid behaviour of the radiating diaphragm is undesirable as it results in irregular behaviour in both the pressure and directional response of the loudspeaker. In particular it is interesting to note that while the response on axis is relatively smooth, the response at other angles is extremely irregular.

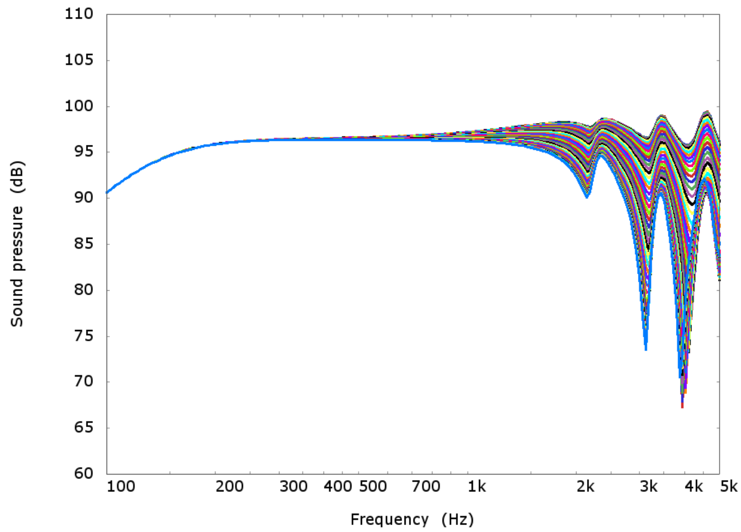

Figure 1.7. Simple cone loudspeaker 1m polar response at 2 degree angular increments.

It is desirable for cone and dome radiators to move rigidly over their entire working band so that response and dispersion irregularities, such as these, can be avoided. However, achieving this ideal on a midrange driver is particularly difficult. For example, one approach would be to simply change the material from which the cone is made to one which has a higher stiffness. A material such as titanium would be a likely candidate. For the cone described above which begins to bend at 1.5kHz, this would extend the rigid response up approximately 4 times in frequency to around 6kHz. While this is likely to be above the range in which the cone driver is used in a system, the change of material creates an additional problem: as titanium has very little inherent mechanical damping, once the cone begins to move non-rigidly it will resonate severely. This severe resonance can cause very large peaks in the response which are problematic even above the region that the driver is used.

For the Concept Blade Uni-Q we wanted to create a midrange driver which was able to work rigidly within the working band but without any of the compromises of other approaches. One well known method for extending the bandwidth of rigidity in a loudspeaker diaphragm is to drive the diaphragm at a resonant node. A resonant node is a position on a structure which does not move when the rest of the structure is resonating. For each resonance in a structure there can be several nodes and the position of these resonant nodes can be found by computer analysis.

Figure 1.8 shows a computer analysis of the cone which was used to calculate the response in figure 1.7, the position of the resonant node of the resonance at 1.5kHz is marked on the diagram. If we increase our voice coil diameter so that it attaches to the cone at this node of resonance we can prevent this particular resonance from being excited.

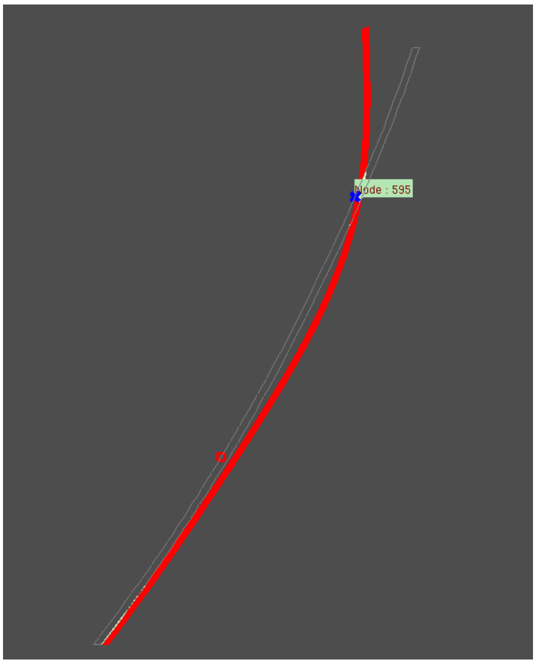

Figure 1.8. FEA Modal analysis to determine the nodal position of the cone at first resonant frequency.

Figure 1.9 shows the new response of the cone loudspeaker driver using this new voice coil diameter. From this response curve it can be seen that the irregularities that could be seen when the cone was driven conventionally from the neck, shown in figure 1.7, now begin at a higher frequency, approximately 3.5kHz, because we have prevented the first resonance from being excited.

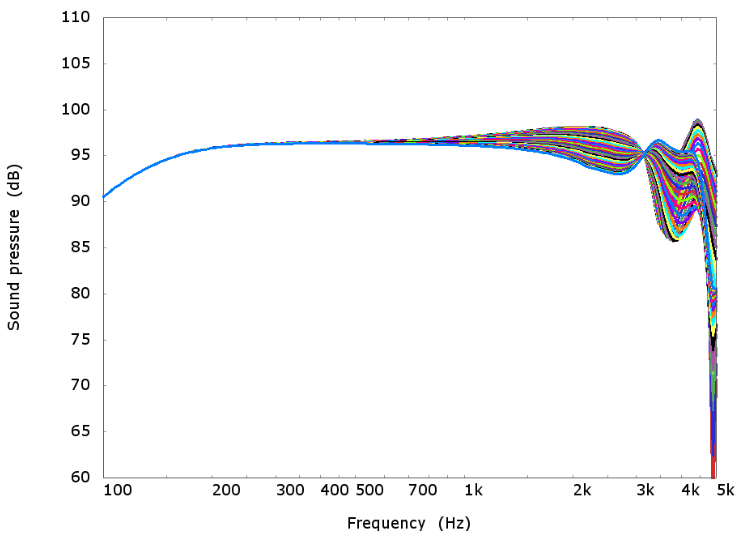

Figure 1.9. Cone loudspeaker driven at node of first resonance, 1m polar response at 2 degree angular increments.

While this is quite an interesting idea, it is not tremendously useful as with a cone geometry the resonances are closely spaced to one another and while we have managed to increase the bandwidth where the cone is behaving rigidly it is only a moderate increase to the next resonance.

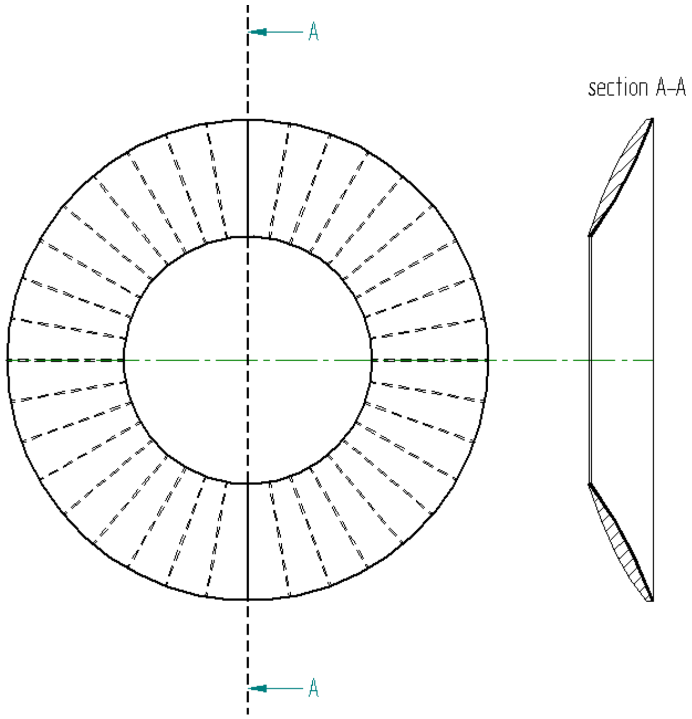

Figure 1.10. Loudspeaker cone with reinforcing ribs.

KEF engineers have discovered a method to dramatically increase the improvement that nodal drive gives. Adding carefully positioned ribs to the rear of the cone, as depicted in figure 1.10, the resonances can be increased in frequency, at the same time the nodal position of the first resonance is adjusted so that it is at a more convenient smaller diameter that the cone without the ribs. Figure 1.11 shows a computer analysis of this new ribbed cone to determine the nodal position of the first resonance.

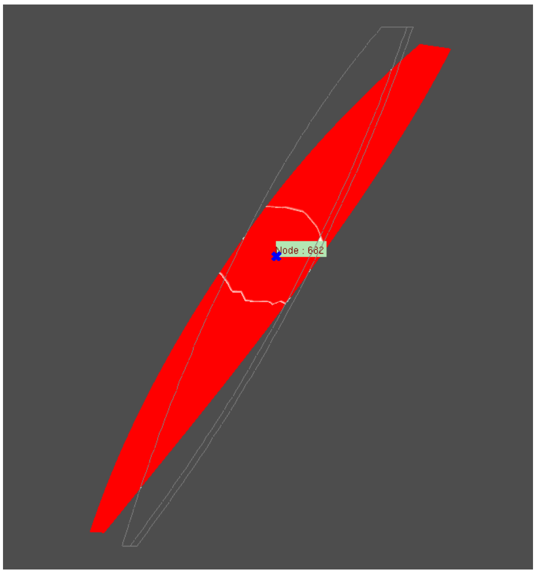

Figure 1.11. FEA Modal analysis to determine the nodal position of the ribbed cone at first resonant frequency.

The computer analysis can also be used to compare the resonant frequencies of the unsupported and supported cones.

	Unsupported cone	Ribbed cone
Resonance 1	2268Hz	2995Hz (+32%)
Resonance 2	3414Hz	6069Hz (+77%)

The resonances have all shifted up but interestingly the second resonance of the cone has shifted much higher than the first. This is extremely useful, by driving the cone at the nodal position of the first resonance we can prevent any resonance until the second resonance which is now much higher at 6kHz. The simulated frequency response of this ribbed cone, driven at the first node of the first resonance is shown in figure 1.12. The response is remarkably smooth and well controlled compared to the starting point of a conventional cone as shown in figure 1.7.

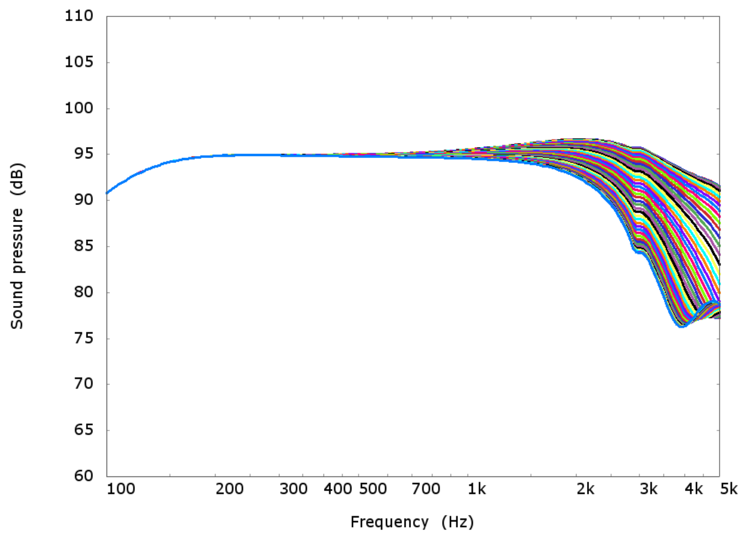

Figure 1.12. Ribbed cone loudspeaker driven at node of first resonance, 1m polar response at 2 degree angular increments.

All of the improvement discussed above has been achieved without any change of material. Not content with this improvement, for the final driver a brand new material was used for the cone. Liquid Crystal Polymer, or LCP, a partially crystalline aromatic polymer which is extremely inert and has an exceptionally high ratio of stiffness to density was chosen for the cone material.

This new material brings several advantages to the Concept Blade MF driver. Firstly it can be moulded into a cone with integral ribs and a location for the voice coil. Secondly because it has a high stiffness the moulded cone is exceptionally rigid and the resonances are pushed even higher in frequency. Finally, it has very good levels of internal damping so that even above the frequencies where the cone is working as a rigid piston it is very well controlled and does not resonate severely like a metal material.

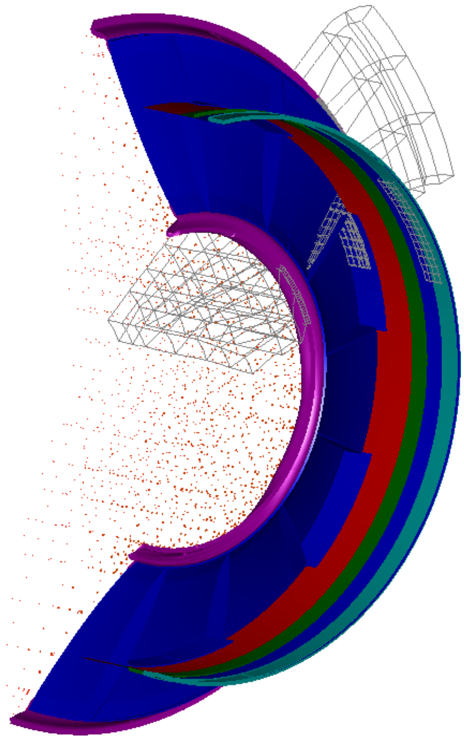

Figure 1.13. Rear sectional view of the Concept Blade midrange cone, taken from a computer model.

The measured response of the midrange driver mounted in the Concept Blade cabinet is shown in figure 1.14 – this measurement is taken at 2m with a resolution of 48 points per octave, it is not smoothed.

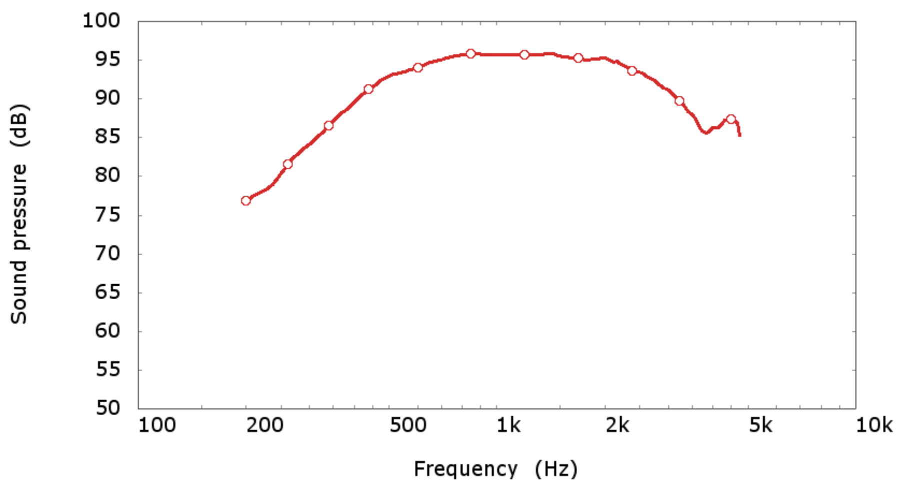

Figure 1.14. In cabinet measurement of midrange driver frequency response.

The predictable frequency response and dispersion which this new approach gives the midrange driver has allowed us to match the response of the Uni-Q tweeter and midrange sections better than ever before. With the crossover in place it is impossible to determine where one driver stops and the next begins.

1.1.5. Other Features

There are a great many other features of this new driver which we have carefully tailored for optimal performance from the computer designed neodymium magnet systems to the rear tube venting on the tweeter.

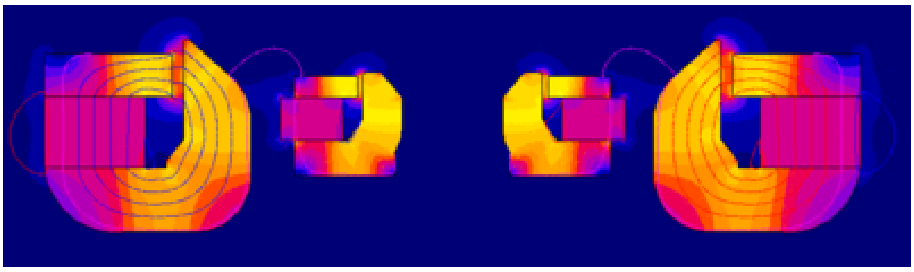

Figure 1.15. Computer analysis of Uni-Q magnet system

Computer analysis was used extensively to explore the design of this driver. More than any other before it, this design has been carefully scrutinised in concept using our FEM and BEM modelling tools to design and prototype the parts virtually before selecting the best to build.

The resulting driver is remarkable and sets new standards for dynamics, smoothness, dispersion and clarity. It is the key component in the Concept Blade, all other parts are subservient to it – we have concentrated on putting together the rest of the loudspeaker to complement and optimise the performance of this keystone part.

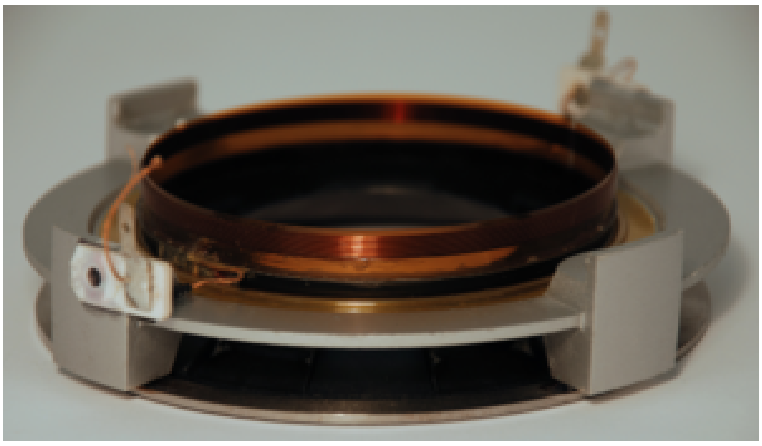

Figure 1.16. Rear view of midrange front assembly showing voice coil.

1.2. Conclusion

The acoustic design of the Concept Blade has presented some demanding challenges. Meeting these challenges has required an intuitive approach to problem solving only possible when the bones of the physics are exposed by carefully considered modelling and measurements. Modern materials have also played a key part in this work allowing the combination of form and properties necessary to achieve rigid piston drive over the whole audio range from an apparent point source. The creation of Concept Blade is the result of many man years of work by KEF's dedicated engineering team and their unflagging passion for audio perfection.

1.3. References

[1] F. E. Toole, "Loudspeaker Measurements and Their Relationship to Listener Preferences: Part 1," *Journal of the Audio Engineering Society*, vol. 34, no. 4, pp. 227-235, Apr 1986.

[2] S. Linkwitz, "Room Reflections Misunderstood?," presented at The 123rd Convention of the AES, 7162, Oct 2007.

[3] M. S. Ureda, "Apparent Apex Theory," presented at The 61st Convention of the AES, 1403, Nov 1978.

[4] D. A. Barlow, "The Sound Output of Loudspeaker Cabinet Walls," presented at The 650th Convention of the AES, L-17, Mar 1975.

[5] M. Dodd, "Optimum Diaphragm and Waveguide Geometry for Coincident source Drive Units," presented at The 121st Convention of the AES, preprint 6886, Oct 2006.

[6] P. Anthony and J. Wright, "Finite Element Analysis in the Design of High-Quality Loudspeakers," presented at The 108th Convention of the AES, preprint 5162, Feb 2000.

[7] M. Dodd and J. Oclee-Brown, "A New Methodology for the Acoustic Design of Compression Driver Phase Plugs with Concentric Annular Channels," presented at The 123rd Convention of the AES, preprint 7258, Oct 2007.

[8] M. Dodd and J. Oclee-Brown, "A New Methodology for the Acoustic Design of Compression Driver Phase Plugs with Radial Channels," presented at The 125th Convention of the AES, preprint 7532, Oct 2008.