Design and development of the

KEF R109 / ‘The Maidstone’ Loudspeaker

Introduction

This report is a technical discussion on the design and development of the KEF Reference 109 / ’The Maidstone’ loudspeaker system. It outlines the principles and goals behind the new system and describes the various technical methods used to achieve them.

For the last four years the KEF Reference Series has demonstrated to the marketplace the KEF philosophy of loudspeaker design, namely that superior sound quality comes through careful, thorough technical design and good production techniques. This range of speakers is designed around two of KEFs technical innovations: the ‘Uni-Q’ coincident source midrange/high frequency driver array, and the ‘Coupled Cavity’ low frequency system. Another KEF feature, the ‘Systems Approach’, is used to specify what would be the ideal behaviour of the system: the component parts of drivers, cabinets and crossover network then being designed and optimised to meet this target. All production pairs are carefully assembled and tested in production to ensure the customer receives a pair of loudspeakers that are indistinguishable from the ‘Design Reference’.

The Uni-Q driver array has demonstrated the superior stereo imaging that comes from the midrange and high frequency drivers being at the same point in space, and the Inter-Port Coupled Cavity band-pass low frequency method has displayed its low distortion, high output characteristics which in twin driver form lends itself beautifully to the tall slim enclosures so popular in the modern environment. With the Reference range firmly established as a benchmark in the marketplace the opportunity arose to design a new system that would take the company one step closer to its goal of perfect sound reproduction. That system would become the Reference 109/Maidstone.

System concept

Subjective and Objective Targets

The R109/Maidstone system had a serious goal - to reproduce the full bandwidth and dynamics of music signals. When developing larger speakers the aim is for the system to go louder with more low frequency extension, with greater accuracy, lower distortion and lower colouration. A compromise in one of these is not acceptable. The combination of more LF extension and greater output level puts a double target on the low frequency system - it means a big increase in the ‘volume throw’ of the LF radiators, the volume of air that must be displaced at maximum output. Lower colouration means a rigorous analysis of the motion of diaphragms, enclosure walls and the sound fields within the enclosures. The maximum output target also places a demand on the input impedance of the system - to reach its maximum output level the loudspeaker must not demand more current than a good amplifier can provide. Overall then, the ‘Systems Approach’ needs to be taken to the design of a loudspeaker of this type - a design methodology that KEF has used successfully for many years.

Examining Current Technology

A rigorous analysis of the Reference range revealed that the 4th generation Uni-Q driver array was a significant step forward from previous models. Both the imaging and tonal balance were greatly improved, further demonstrating the fundamental ‘rightness’ of the coincident source principle. This was a Uni-Q design that would give superior performance in KEF systems for a considerable time.

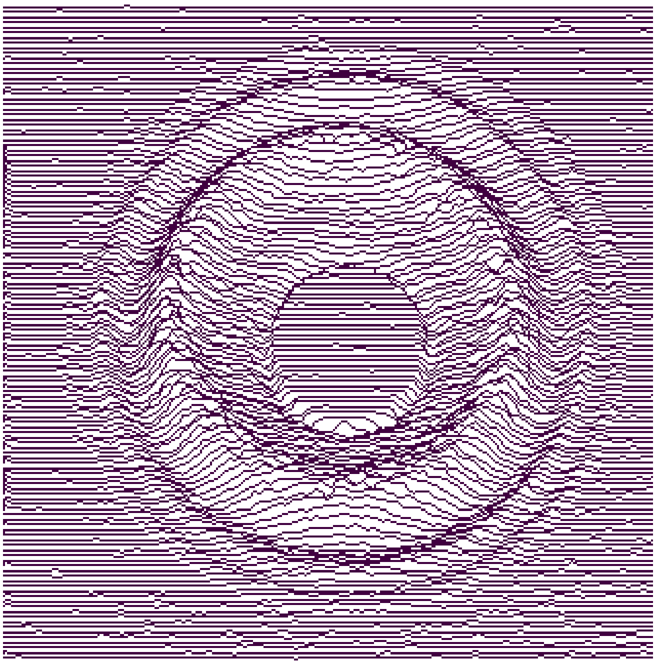


Figure 1. Laser scan of the midrange cone in the SP1415 Uni-Q driver array. The scan shows the motion of the cone at 3.1 kHz. Bending waves in the cone travel outwards from the coil to the surround where they are damped-out by the lossy surround material. This gentle ‘ripple’ effect is the ideal behaviour known as ‘controlled break-up’.

Taking a close look at the low frequency end of the spectrum revealed that the ‘Inter-port’ Coupled Cavity system was fulfilling its role of providing accurate, well defined bass in a compact enclosure. However, when the possibility of designing a new High-End Uni-Q based system came along the KEF engineers thought long and hard about the best way of reproducing the frequency range below 400Hz. Without any major constraints on system cost and the physical size and shape of the cabinet, a number of serious possibilities arise. Concepts used in older KEF speakers like the Reference 105 and KM1, for example, were re-evaluated to test their suitability. Finally a decision was made, the R109 would use direct radiators for the low frequency and lower midrange. New drive units would be specially designed to best exploit the direct radiator principle.

Sorting the Format

To best exploit the benefits of the Uni-Q driver array it is used only for frequencies above 400Hz. This limits the movement of the midrange cone the absolute minimum, thus reducing distortion and eliminating any possibility of the high frequency radiation being influenced by a ‘moving boundary’.

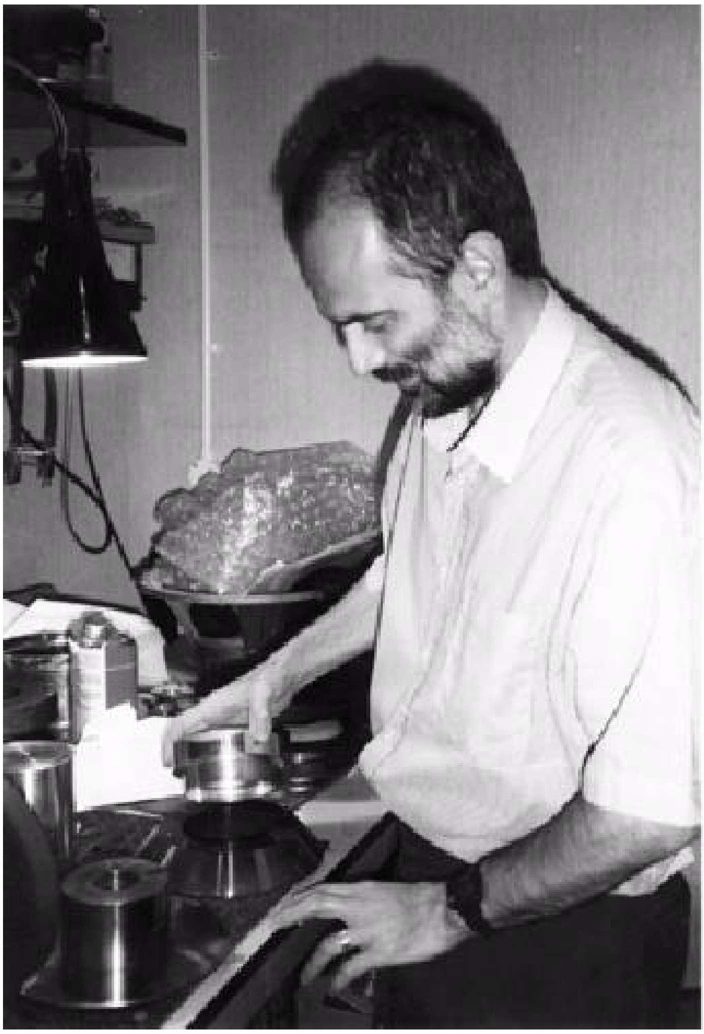
The low frequency end of the spectrum needs to be considered from a number of standpoints. The system must achieve a given target for the low frequency roll-off. The key points are (i) extension (-6dB point), (ii) damping (shape of the roll-off), and (iii) the maximum output level (for a given distortion level). It was decided that a single, top quality 15” driver in a reflex enclosure would be ideal.

To operate the 15” woofer right up to the midrange crossover at 400Hz would not be a good solution, the step between the 15” and 6” units would be too subjectively obvious. A lower midrange unit is therefore the correct way to go, and a similar analysis of excursion requirements relative to distortion and cleanness of the sound at the upper crossover point lead to the decision to go for a single 10” unit in a sealed enclosure.

The system format is then fixed: a 15” reflex up to 100Hz, a 10” sealed from 100 to 400Hz and the Uni-Q driver array from 400Hz to 20kHz with a mid/treble crossover at 3kHz. The designers were then able to start work on the new drivers, using all the latest modelling techniques to optimise all the various parts.

Designing the new SP1405 15” and SP1406 10” units.

KEF has a long and illustrious history of designing and developing market leading drive units utilising the latest in materials technology and production techniques. Classic units like the B139, B110 and T27 right up to the latest developments in neodimium magnets which lead to the Uni-Q drive unit array. KEF is at the forefront in using Finite Element Modelling for the analysis of loudspeaker components. The bass unit magnet structures, for example, were modelled using this technique. The facility is also available to analyse enclosure vibrations, diaphragm behaviour and acoustic radiation.



Drive Unit designer Enrico Cecconi

SP1405 Low Frequency Unit

A key decision was taken very early on in the design process - both units would use the short coil-long gap motor system. In this method the coil is always within the constant region of the magnetic field thus achieving lower distortion for the same excursion. This is often viewed as an expensive technology but the use of FEA techniques allows the unit to be designed in the most efficient way. The metal parts are specially shaped to give optimum control of the magnetic field around the critical gap region.

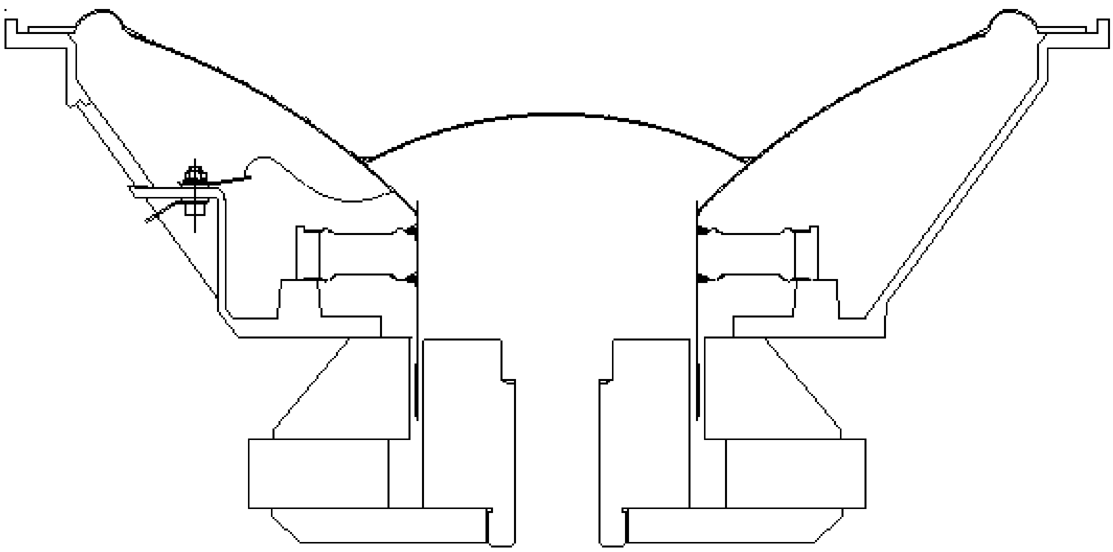


Figure 2. Cross-section of the new SP1405 Low Frequency Unit.

The SP1405 gains extra performance by using a double suspension, this gives extra stability and ensures pure piston motion with no ‘rocking’. The diaphragm is made of a special treated paper compound, still an excellent cone material when carefully designed. The diaphragm is conical in shape for rigidity, and terminated with a robust rubber surround which does not deform at high levels. The diaphragm displays the ideal characteristic of low frequency units, pure piston motion, well beyond the 100Hz crossover to the lower midrange unit. The unit is housed in a rigid cast aluminium chassis which when securely mounted allows the moving parts to act as in ideal fashion with minimal mechanical energy leaking into the solid structure.

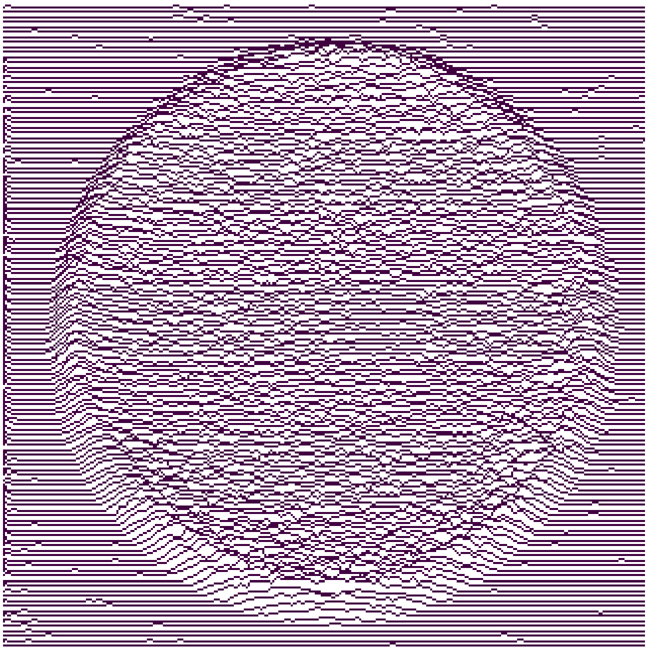


Figure 3. Laser scan of the SP1405 bass unit at 300Hz. The slight deformation of the surround is the first indication of non-piston behaviour, this is well above the crossover point of 100Hz.

SP1406 Lower Midrange

The SP1406 also uses a short coil-long gap motor system, treated paper cone and cast aluminium chassis. In addition it has an edgewound coil which provides greater stiffness of the coil structure. Its role in the R109 as a dedicated lower midrange driver means a slightly different approach is taken from the SP1405. The diaphragm behaviour at the higher frequencies becomes more critical, a balance must be achieved between piston motion in the passband (100 to 400Hz) and controlled break-up at the higher frequencies, as the unit rolls-off and crosses over to the Uni-Q array.

Designing the cabinets

The aim of the cabinet design is very simple: it must rigidly hold the units in space so that the only moving parts are the diaphragms (and air motion in the ports), the radiation from the rear of the diaphragms should be properly controlled and not interfere with the front radiation and the baffle design should aid the even dispersion of sound into the listening room.

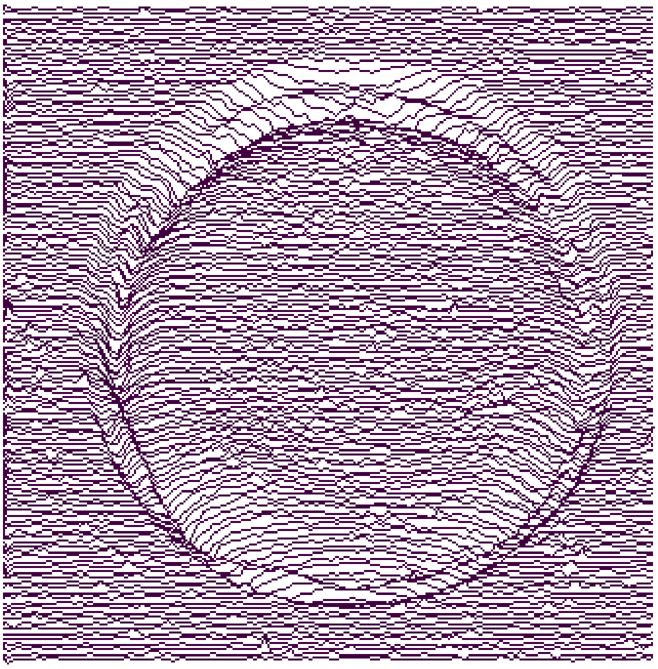


Figure 4. The first break-up mode in the SP1406 lower midrange unit is at 560Hz where the surround displays controlled resonance.

The R109 has a ‘modular’ construction: each unit has its own separate cabinet to minimise coupling effects, the radiation from each section should then be independent of the others, each cabinet then being optimised to be a rigid structure. With each cabinet designed to be a rigid structure the three cabinets can then be assembled with minimal risk of interaction. Even so, where the cabinets meet they do so via a finite point coupling technique, which minimises the contact area between them. The LF module couples to the floor via four spiked feet and provides a stable platform for the LMF and Uni-Q modules which are rigidly coupled together and mount on the LF module via three spiked feet. To give time alignment of the drivers the whole system is tilted back by 6 degrees.

The attention to detail extends to the internal structure of the cabinets. All of them are made from MDF, 25mm throughout except for the LF baffle, which is 50mm, to ensure a solid mounting surface for the SP1405 15” unit which alone weighs 17.5kg. Each cabinet is extensively braced for rigidity, which is further increased by the curvature of the front and back panels.

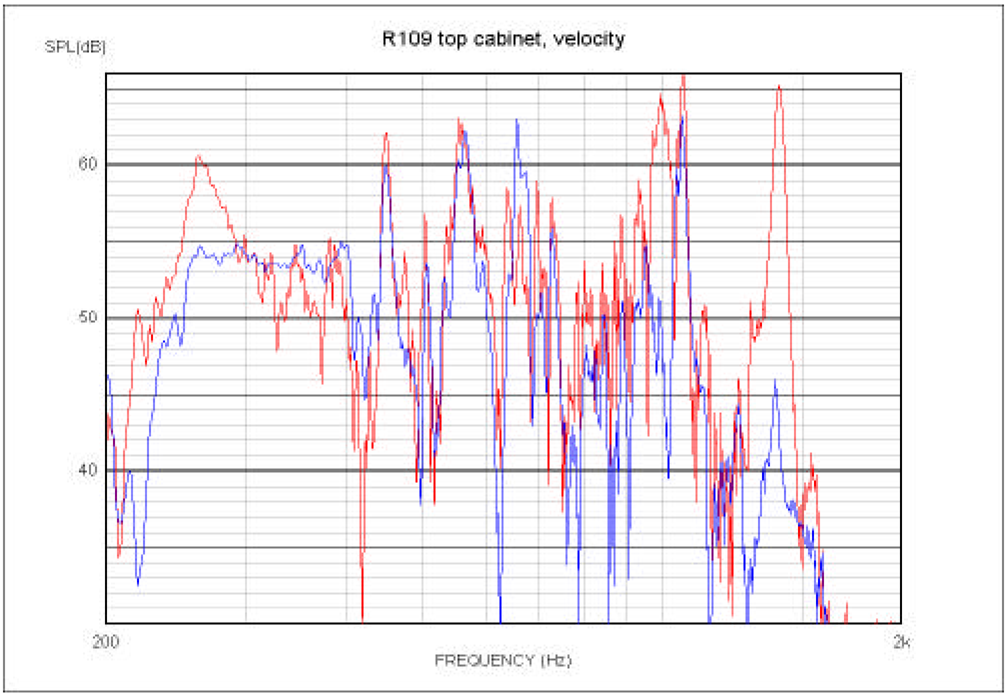


Figure 5. Comparison of the performance of braced and unbraced Uni-Q cabinets. The data is the velocity of front panel vibration due to excitation from the Uni-Q driver array. The braced cabinet (solid line) shows considerable improvement at 250Hz, 1kHz and 1.4kHz.

Internal acoustic damping is critically judged for each section. There are three reasons for having acoustic damping in the enclosures (i) to absorb standing waves (ii) to absorb travelling waves at the higher frequencies, and (3) to add damping to the LF roll-off. In the R109 the LF section has no damping - it is not required at such low frequencies and is only going to create an acoustical impedance mixture which will over-damp the roll-off. The lower midrange section has a medium filling of BAF wadding, just enough to kill the standing waves but not enough to thicken and slow the sound. The Uni-Q section has a combination of foam around the unit and wadding to the sides. The choice of damping is determined as much by listening as by measurement.

The width of the front baffle is determined by the size of the 15” driver, this dimension is carried up onto the lower midrange and Uni-Q modules. There are obvious cosmetic reasons for doing this, but it also functions well acoustically. There are certain baffle shapes which work well acoustically and some which don’t, the main theoretical solutions being the ‘piston in the end of a tube’, the ‘piston in a sphere’ and the ‘infinite baffle’. In reality one is always dealing with something in between these so it is necessary to fully investigate the effects the baffle is going to have on the system performance. Finite Element techniques can be used to model the behaviour of the baffle and allow the designer to get the best result from a particular concept. KEF has used similar shaped baffles before, as in the 200C centre channel and the Reference

105/3 (albeit vertically rather than horizontally). In the case of the R109 the baffle is curved back towards the sides to reduce the effect of diffraction from the cabinet edges. The result is a baffle shape that is more directional than average below 1kHz but contributes to a smooth Uni-Q off-axis performance at the higher frequencies.

The increased directivity below 1kHz adds to the unique sound of the R109. Normally in a slim enclosure the system has wide dispersion up to around 1kHz, becoming progressively more directional as the frequency increases (due to driver directionality). The wide baffle of the R109 imparts an extra directivity on the lower midrange section which helps to match it to that of the Uni-Q section. This means the system directivity is controlled over a much wider frequency range than a conventional slim speaker. The result is an increase in the ratio of direct to reveberrant sound, thus increasing clarity and reducing the influence of the listening room. The uniformity of the dispersion pattern with frequency contributes to the R109's incredibly 'life-like' reproduction.

Figures 6 to 8 show data for the Finite Element Analysis of the R109 baffle shape. The physical structure is first approximated by a mesh, a piston radiator is modelled as an array of point sources over the area of a 6" drive unit, and then the acoustic radiation is calculated over a range of angles. It is clear from the data that the off-axis response falls-off in a much smoother way with the curved baffle shape. The directivity at 1.5kHz is the same as that at 300Hz, this baffle effect helps to match the directivity of the 10" lower midrange unit to that of the Uni-Q.

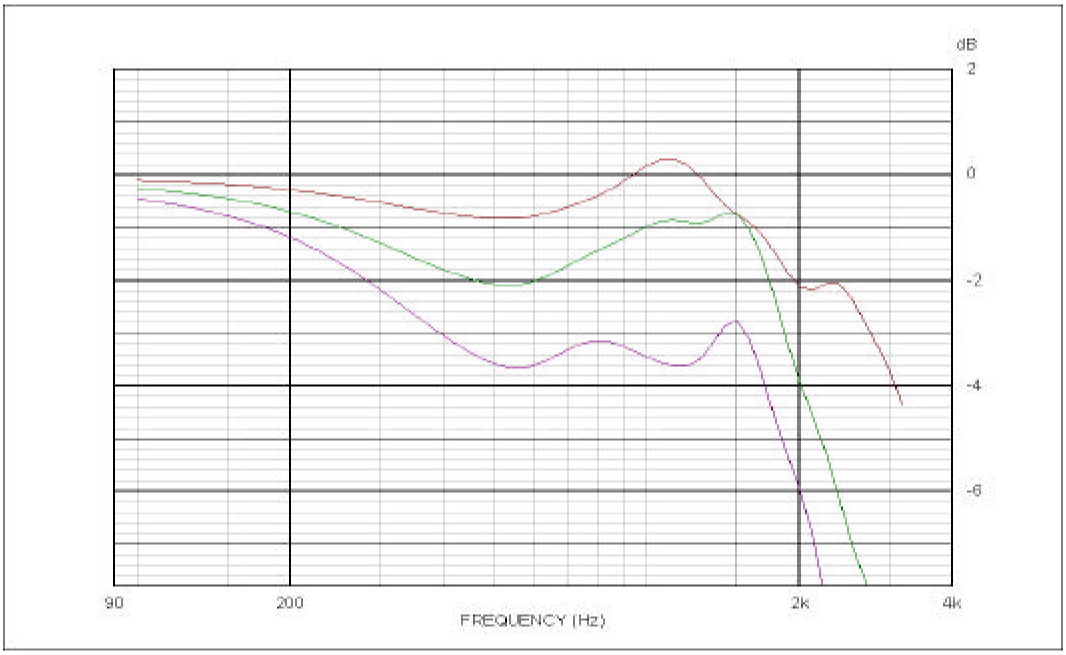


Figure 6. Off-axis response of a piston in a flat baffle, same dimensions as R109 uni-Q cabinet. The curves are the acoustic pressure response at 15, 30 and 45 degrees horizontally off-axis, all relative to on-axis.

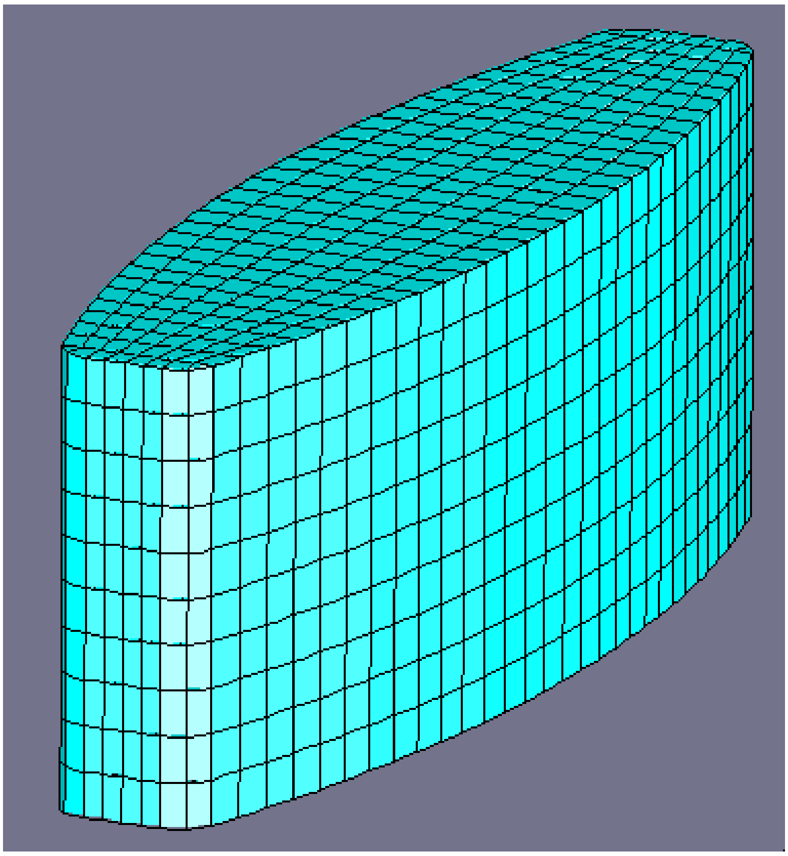


Figure 7. Finite Element Model of the Uni-Q enclosure.

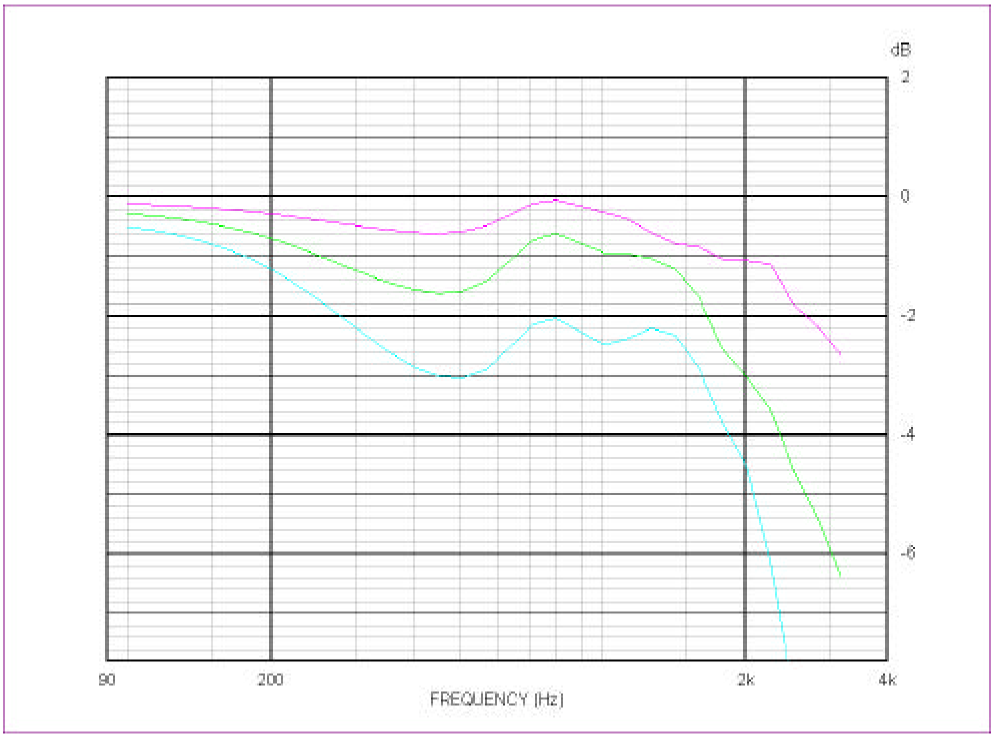
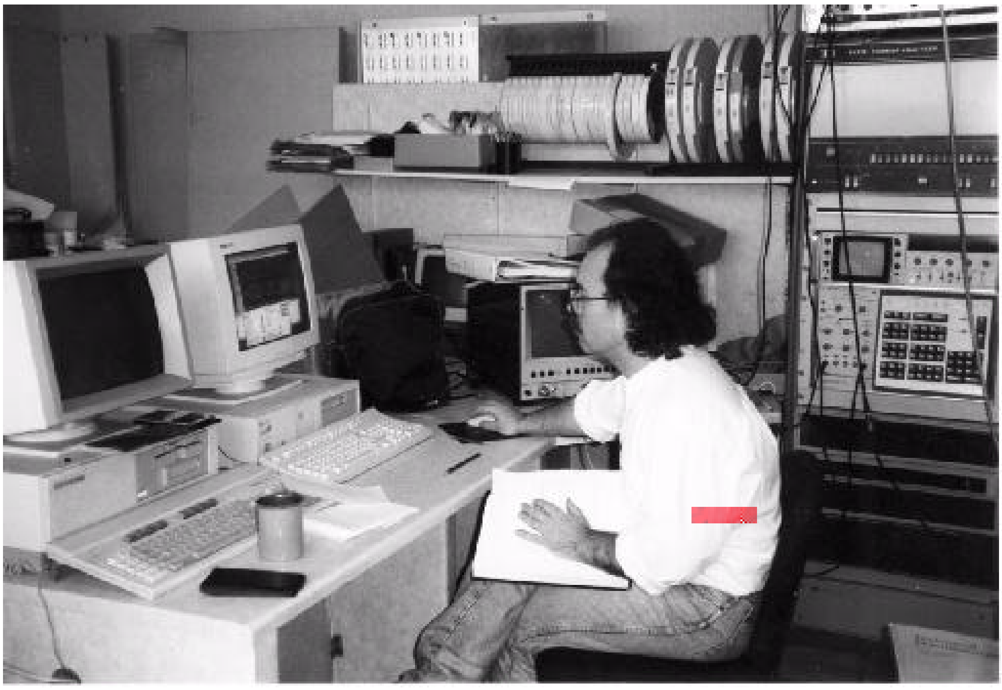


Figure 8. Off-axis response of a piston in R109 uni-Q cabinet. The curves are the acoustic pressure response at 15, 30 and 45 degrees horizontally off-axis, all relative to on-axis.

Crossover Network Design

The function of the crossover network is to integrate the outputs of the four drive units to provide a system response that meets the idealised target function. After initial studies it was decided to use a fourth order acoustical crossover for the Uni-Q section, second order between lower midrange and Uni-Q and an asymmetrical fourth/second order between the low frequency and lower midrange. Once the drive units are mounted in the enclosures and their acoustic responses measured the data is downloaded onto the computer system where a suite of design packages allow the engineer to set about the network design. Target functions are specified for each section of the network and a combination of computer optimization and 'hands-on' adjustment and tweaking by the engineers leads to a theoretical solution for the network which can then be built up for testing and listening.



System designer Andrew Watson

The network is designed to be as efficient as possible with no superfluous components in the signal path. Component choice is important in maintaining the highest sound quality. Polypropylene capacitors with their reduced loss factors are used wherever possible as are air cored inductors, preferable to ferrite cores due the lack of saturation distortion. The printed circuit boards are of high-grade fibreglass with gold plated tracks.

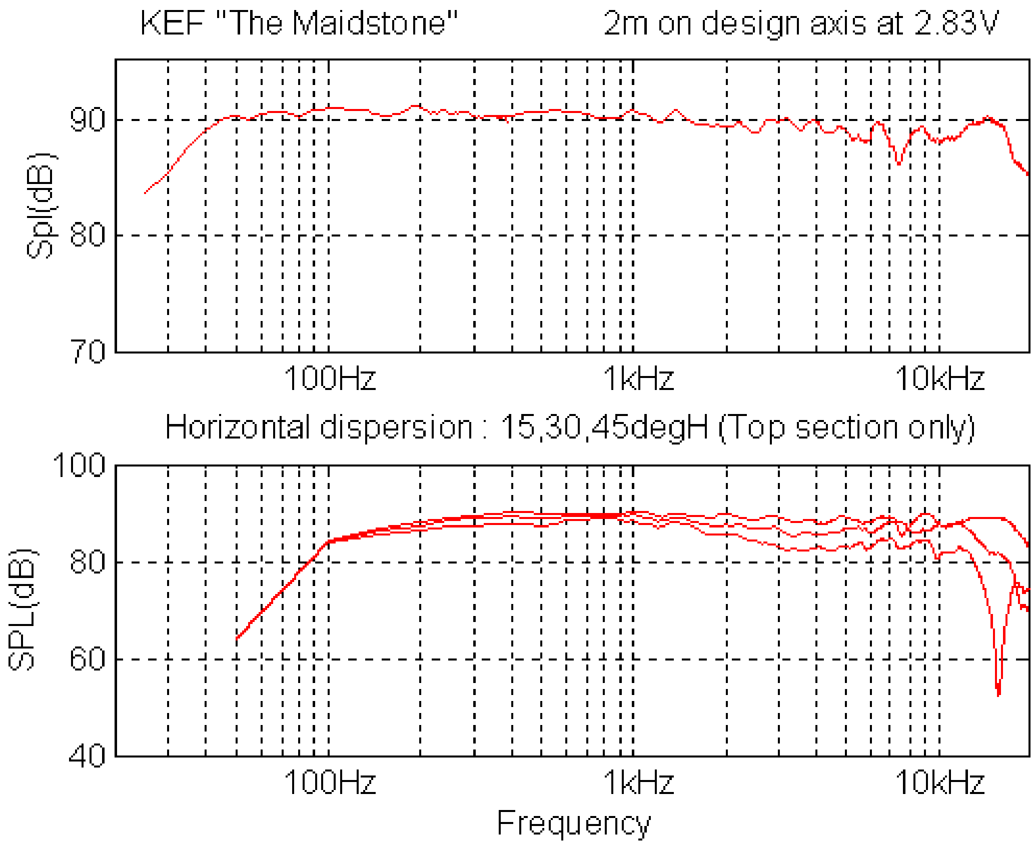


Figure 9. Acoustic Response of the R109, reference forward response and horizontal dispersion.

Listening Tests and Crossover Development

The system undergoes extensive listening tests in a number of listening rooms, with a range of electronics. At KEF a number of subjective criteria are set for each system designed and a skilled listening panel checks whether these have been met or whether modifications need to be made. In some cases the number of crossover variations will

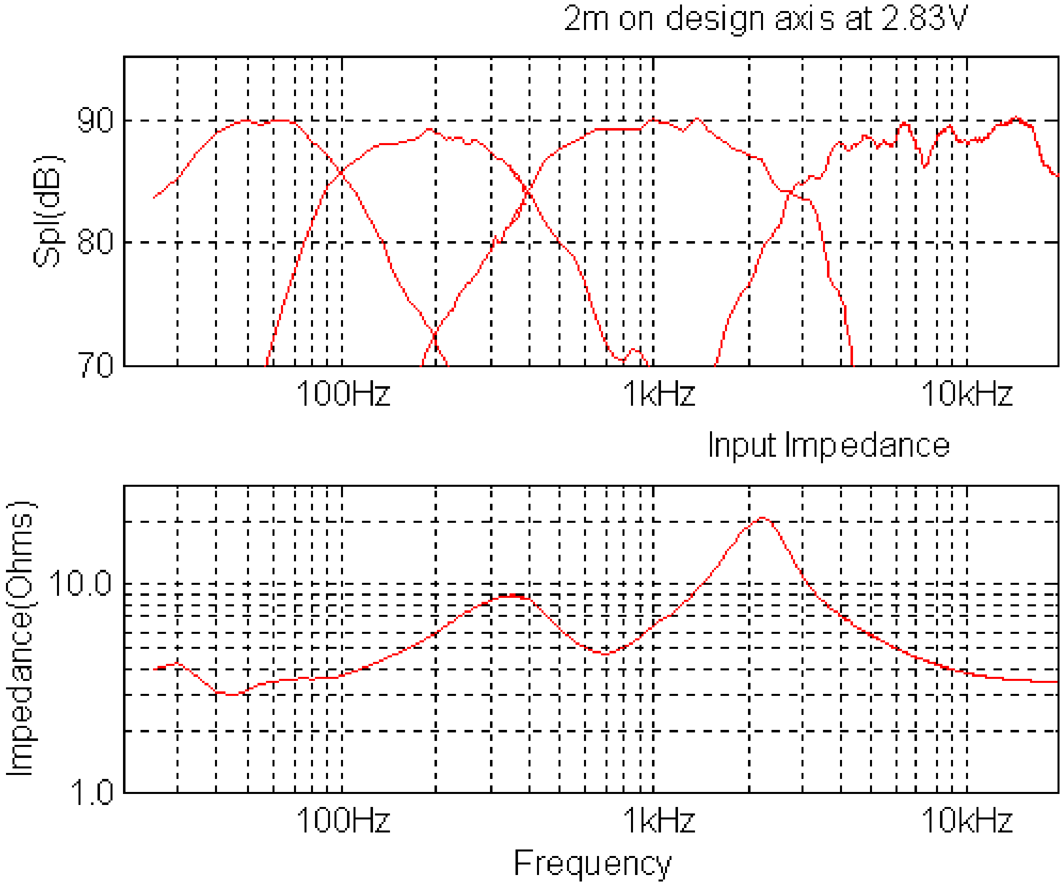


Figure 10. Individual unit responses and Input Impedance.

Extra features

Included on the system is a facility to tilt the high frequency output from 5 to 20kHz by +/-1dB. This has been found to be useful in matching the system to particular listening environments. Also included is the facility to bypass the internal passive crossover and replace it with an active crossover system. All drive unit inputs can be accessed directly and the user is free to experiment with their own electronic filters. Attention to fine detail means careful thought has gone into all the fixtures and fittings on the system such as terminals, shorting bars, spikes, cups and cones etc. All parts are gold plated for sonic integrity.

Summary

The R109 has been several years in the making. During that time the KEF engineers have studied all aspects of loudspeaker design to create a loudspeaker that can justifiably be rated as one of the best in the world. It is a loudspeaker for the committed music listener who demands a system that can faithfully reproduce the full bandwidth and dynamics of musical signals.

A.P.Watson, September 1999.