KEF R&D

R Series with MAT

CONTENTS

Introduction

R Series was first introduced in 2011 as a high-performance speaker range that benefits from the technology developed for the Reference Series but in a more affordable package.

R Series, thus, takes on the main acoustic principles of the modern Reference Series:

- A slim rectilinear cabinet heavily braced with internal constrained layer damping
- A Uni-Q driver array dedicated to midrange and high frequency surrounded by a Shadow Flare to reduce baffle edge diffraction
- A D'Appolito symmetrical array configuration of low-frequency drivers around the Uni-Q [1] for a smooth and symmetrical vertical directivity in the floorstanding models and horizontal directivity in the centre channel models
- Rear-firing bass-reflex ports with optimised positions to minimise the leakage of the enclosure's internal standing waves and flexible port walls to damp the ports' inherent acoustic resonances

These principles provide a solid foundation for an acoustical system that can deliver music reproduction with extremely low colouration and a smooth off-axis response in all directions, allowing it to work well in a wide variety of rooms.

In its second iteration in 2018, R Series further became a vessel of innovative technology development, introducing the first 12th generation Uni-Q featuring the Tweeter Gap Damper.

'Meta'

R Series with MAT is the sixth model range to be launched by KEF since 2020 (LS50 Collection, Blade and The Reference with MAT, LS60 Wireless and Ci250RRM-THX) to incorporate MAT (Metamaterial Absorption Technology).

KEF's MAT is employed as an acoustic absorber behind the tweeter diaphragm and is the main technology improvement featured in the new R Series. Every speaker in the range thus carries the moniker 'Meta' in its name.

'Meta,' nonetheless, reflects much more than the application of MAT. It implies a full research and development project has been undertaken to redesign all critical components in the speaker systems to achieve a considerable leap forward in performance. This is now what has come to be expected from any KEF speaker with 'Meta' in its name and R Series is no exception.

Philosophy

"Of all art, music is the most indefinable and the most expressive, the most insubstantial and the most immediate, the most transitory and the most imperishable. Transformed to a dance of electrons along a wire, its ghost lives on. When KEF returns music to its rightful habituation, your ears and mind, they aim to do so in the most natural way they can... without drama, without exaggeration, without artifice."

Raymond Cooke OBE, KEF Founder

Loudspeakers are the final stage in the sound reproduction chain. It is down to the loudspeaker to generate the sound that the listener will hear. While other pieces of audio equipment have clearly defined roles, and it is easier to outline how they would ideally perform, the ideal loudspeaker is more difficult to define. It is simpler to first consider what the complete audio system is trying to achieve. The ideal audio system should be able to recreate a live sonic event so that it is indistinguishable from the original. The listeners should be transported to the environment of the live event. They should be convinced that they are sitting in the actual concert hall in which the live event occurred. They should experience the acoustics of the space, perceive the locations of the instruments, interact with the space, and hear the change in the sound as they turn their heads towards the soloist.

Many recordings are available that never existed as live events. For example, a rock band captured in a studio or music with synthesised instruments. Nevertheless, the same objective applies for these situations: the sonic event that we wish to hear is the one that was envisaged by the musicians and producers. For this to be achieved, there are implications for the fidelity of the replay system: it must not colour the sound with the introduction of distortion or dynamic range compressions; it must have a neutral timbral character, without resonance or imbalance; it should have a good temporal resolution such that it does not "smear" the sonic event. Each of these fidelity requirements provide clear targets for the loudspeaker designer.

However, this ideal audio system has two further implications that are more difficult to handle. Firstly, the spatial information of the original event should be captured and replayed. Secondly, the listeners should hear only the acoustic space of the original event and not the acoustic space in which they are located.

Technically, neither stereo nor conventional multichannel playback are sufficient to recreate the exact sound field of an event. However, our perception is not exact: our auditory system builds a scene in our mind based on cues in the signals reaching our ears. Cues such as the relative arrival time and level of the sound at each of our ears. Stereo playback provides a simple means by which the artist or recordist may communicate these cues to the listener. The listener builds a picture of the sonic event in their mind and emotionally connects with the experience of listening to the original.

Loudspeakers must be designed to maximise the communication of these spatial cues. To do this, a loudspeaker must have a response that does not change rapidly with direction. An irregular directivity can result in the loudspeaker communicating spatial cues that conflict with those in the recording.

Controlling the loudspeakers' directivity is also key to avoiding loss of midrange and treble fidelity, which can happen when loudspeakers are placed in a real listening environment. One of the features of our auditory perception is that we are well used to hearing sounds that include reflections off close surfaces. Our auditory system can identify the direct sound and separate out reflections to the extent that we do not perceive the early reflections as separate events. The listener will attribute any timbral imbalance in the reflections to the original source. This means that loudspeakers must have a frequency response that is good in all directions, not simply in the direct path to the listener. Loudspeakers must have a smooth and balanced frequency response on-axis and in other directions. If this is achieved, the listeners will be able to "hear through" the room in which they are located and perceive the acoustic space captured in the recorded sound.

In summary, loudspeakers must be designed to have a smooth and balanced response both in terms of frequency and space. The sound from loudspeakers should emanate from the drivers themselves and not from other components, such as resonating panels or openings. The drivers should operate in a well-controlled manner throughout and beyond their band. Loudspeakers should have low distortion and compression and a good temporal response.

R Series with MAT

Figure 1. 12th Generation Uni-Q with MAT for R Series

The development of the new R Series with MAT began with the design of a new Uni-Q, which belongs to the family of KEF's 12th generation Uni-Q driver arrays. This Uni-Q directly benefits from the research carried out during the development of the high-performance Uni-Q for the Blade and Reference Meta.

Integrating this new Uni-Q into the speakers prompted the redesign of key system components, including new crossover filters that benefit from new and extended measurement and simulation tools developed for LS50 Meta, Blade Meta, and Reference Meta.

Furthermore, many of KEF's technologies present in R Series with MAT have been carried over from R Series 2018 [2]:

- Tweeter Gap Damper
- Tangerine Waveguide and Tangerine Waveguide Stiffening Ribs
- Stiffened Tweeter Dome
- Uni-Q Shadow Flare
- Midrange Cone Neck Decoupler
- Low frequency drive units with hybrid aluminium diaphragm and low-distortion motor
- Flexible Wall ports
- Cabinet bracing with Constrained Layer Damping

The result is a range of seven speaker models that reproduce music in a cleaner, more natural, and more realistic way, and which better interact with typical listening rooms to recreate a more holographic stereo image from a recording.

The range consists of three floorstanding models (R11 Meta, R7 Meta, R5 Meta), one standmount model (R3 Meta), two LCR models (R6 Meta, R2 Meta) and one Dolby Atmos® certified model (R8 Meta). Additionally, the new S3 stand is now offered for the R3 Meta standmount speaker.

12th Generation Uni-Q with MAT for R Series

In this iteration, the Uni-Q driver array incorporates a new tweeter and tweeter motor with MAT, a completely new midrange motor with a low-distortion, split top plate design, KEF's unique Flexible Decoupling Chassis and a smaller higher-excursion suspension for the midrange driver (Figure 2). More information on the fundamental concepts underpinning the Uni-Q arrangement can be found in the 2014 Reference White Paper [1].

High Frequency Driver (Tweeter)

The tweeter in the new Uni-Q contains a unique technology package that deals with the front and rear sound produced by the dome in a way that no other manufacturer does.

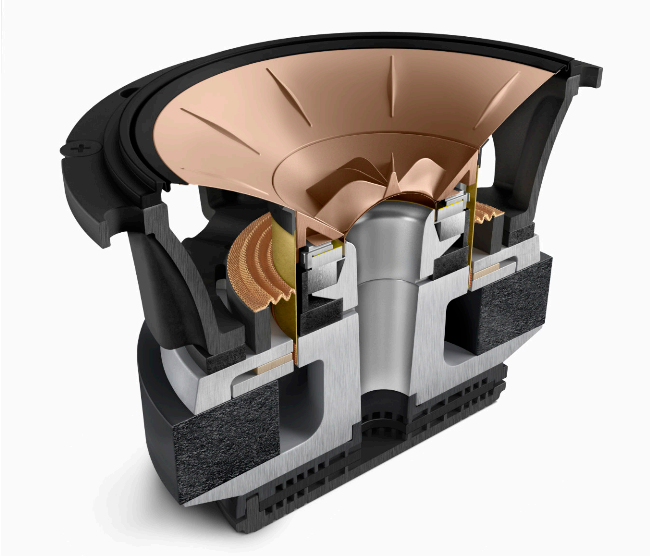


Figure 2. Cutaway of the 12th Generation Uni-Q with MAT for R Series

Figure 3 shows a simplified section view of the tweeter's acoustical system. The front of the stiffened aluminium dome radiates into a small compression chamber loaded by the Tangerine Waveguide, a sophisticated waveguide and phase-plug geometry that works together with the spherical profile of the dome to help it radiate more like a true pulsating sphere at high frequencies, where pistonic domes become considerably directional [3]. This waveguide smoothly flares out onto the enclosure baffle using the midrange cone as a part of its profile. An outer trim, the Shadow Flare, continues this waveguide and terminates it smoothly, while recessing the Uni-Q from the front baffle, effectively 'shadowing' the baffle edges from the tweeter output and virtually smoothing the edges of the cabinet. This carefully optimised geometry ensures the front sound waves from the dome propagate evenly into the listening room with a wide and smooth directivity.

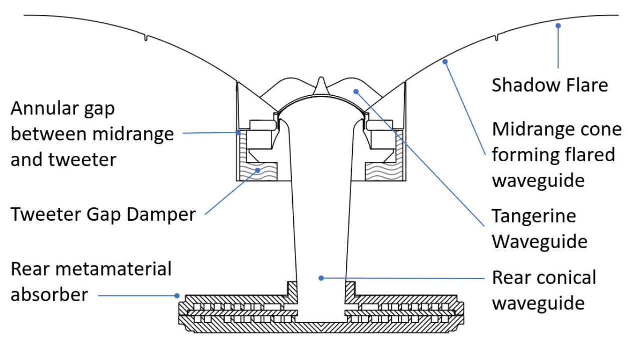


Figure 3. Simplified view of the tweeter's acoustical system

The rear surface of the dome radiates sound directly into a wide conical waveguide that is acoustically terminated by the acoustic metamaterial absorber, where it is absorbed almost completely.

Between the tweeter and midrange voice coil an annular gap is formed to allow the free movement of the latter. This gap creates an undesirable resonator. The Tweeter Gap Damper resides inside a tuned cavity behind the tweeter and is coupled to this gap to reduce the resonance by providing absorption.

Metamaterial Absorption Technology

Metamaterial Absorption Technology (MAT) is the name given to a metamaterial absorber disc that is acoustically coupled to the rear of the tweeter dome. Its function is to absorb the rear sound waves radiated by the tweeter dome which would otherwise be a source of distortion when reflected back into the dome.

This disc comprises 30 channels of differing lengths, formed into tubes, sharing an opening at the centre of the disc (Figure 4). The tubes act as quarter-wavelength resonators or absorbers, each tuned to a different frequency with a high Q, which effectively absorb a narrow frequency band and its harmonics (Figure 5). The absorption of these channels is tuned to overlap in frequency, leading to almost complete absorption across the spectrum above 620Hz - well below the lower threshold of the tweeter's working bandwidth (Figure 6).

At 11mm deep, its performance is comparable to a well-designed tapered tube absorber measuring 50cm long. This allows its inclusion into loudspeakers of any size, without taking up significant space in the cabinet [4][5].

Coupling MAT to the tweeter dome

Of equal importance to the application of MAT is how the back wave is directed into the absorber. This requires a large waveguide opening through the middle of the midrange motor stretching from the back of the tweeter dome to the rear of the midrange motor, where the absorber disc is situated.

The conical waveguide's length, angle and opening diameters on both ends are specific to this new Uni-Q since the acoustic impedance of the waveguide must match that of the opening of the tweeter absorber to avoid a reflection of the wave back into the tweeter dome.

Figure 4. Metamaterial Absorption Technology

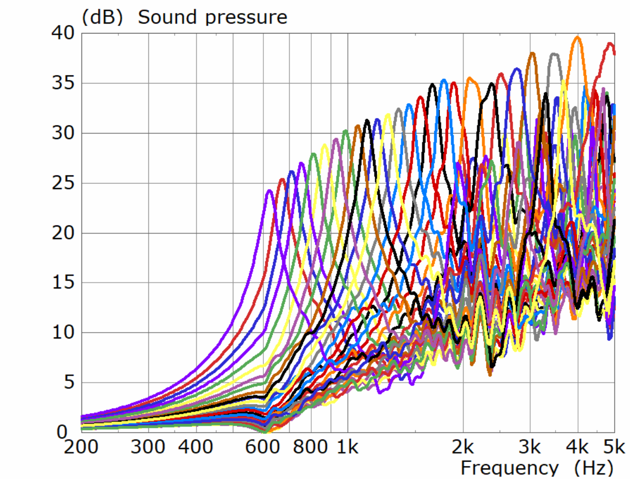


Figure 5. Pressure response at closed end of each absorption channel

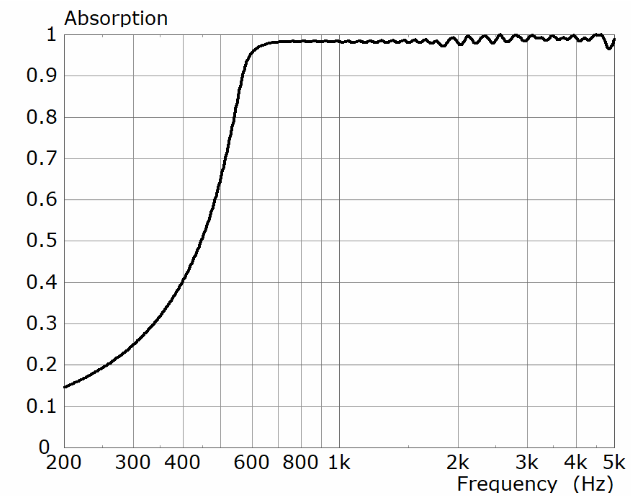


Figure 6. Absorption at the entrance of the conical duct, immediately behind the dome

This waveguide is a tapered duct with a conical profile, which reduces in diameter towards the absorber's opening. A detailed explanation and the mathematics behind MAT and its coupling to the tweeter dome can be found in the original Audio Engineering Society scientific paper [4].

Figure 7 shows a diagram describing the geometric relationship between the spherical dome tweeter, the conical waveguide, the aperture angle to the metamaterial absorber and the absorber's length related to one quarter of the wavelength of its cut-on frequency. The principle being that a spherical wave travelling along a conical horn will avoid reflection at the horn-absorber interface if the interface radius is equal to a quarter of a wavelength of the metamaterial cut-on frequency.

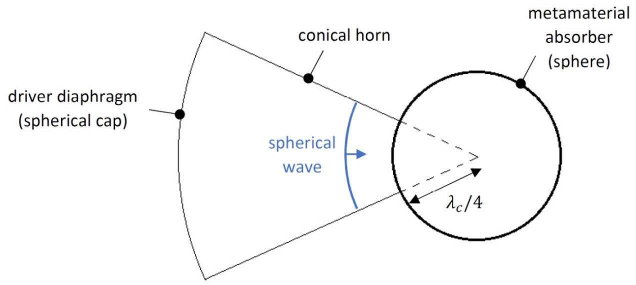


Figure 7. Geometric principle behind the coupling of the tweeter spherical dome to the metamaterial absorber

This arrangement further allows for an easier accommodation of the absorber into the driver package and reduces the size of the MAT disc itself. In addition, the increase of acoustic volume behind the tweeter due to the presence of the waveguide reduces non-linear distortion associated to the spring effect of compressing the air in this cavity.

HF Motor System

The tweeter motor vent hole, forming a part of the conical waveguide that couples the tweeter dome to the metamaterial absorber, has been maximised to allow the rear sound wave to travel as freely as possible. This required the design of a new motor with a Neodymium magnet and a steel geometry optimised to offer a high force factor to maintain the tweeter sensitivity and high steel magnetic saturation to reduce distortion due to magnetic hysteresis.

Figure 8 shows a comparison of the new geometry with the previous design where the increased rear vent area is clear.

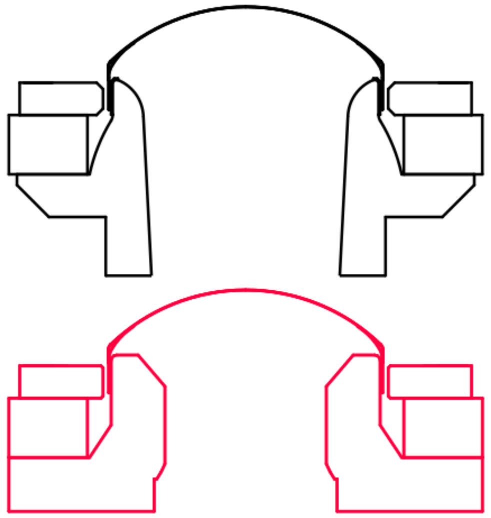


Figure 8. Comparison of tweeter motor geometries for R Series (2018) (red, bottom) and R Series with MAT (black, top)

Tweeter Gap Damper

The Tweeter Gap Damper has been redesigned to fit between the midrange and tweeter motors (Figure 3) following the same approach as the Blade and Reference Meta Uni-Q.

The gap that forms between the tweeter waveguide and the midrange cone extends down to the midrange motor and acts like an organ-pipe resonator that is excited by the output of the tweeter, affecting its response. The Tweeter Gap Damper expands this annular gap into an acoustic cavity that works as a tuned Helmholtz resonator and then adds acoustic damping to control its resonance. This way the resonance is dissipated and its effect on the tweeter response is reduced (Figure 9).

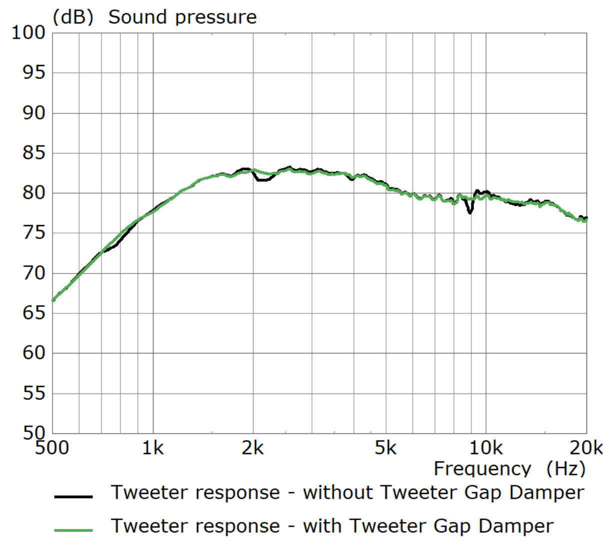


Figure 9. Improvement in tweeter frequency response due to the Tweeter Gap Damper

Tangerine Waveguide and Shadow Flare

The Tangerine Waveguide, midrange cone, and Shadow Flare together form a smooth axi-symmetric waveguide that is designed to propagate spherical sound waves from the tweeter into the listening room in a controlled way [6].

However, due to its pistonic motion, the spherical tweeter dome does not produce an even, normal surface velocity across its entire surface. To overcome this, the Tangerine Waveguide works as a phase plug that creates a small, low-compression chamber in front of the dome, allowing it to radiate through nine computer-optimised radial channels. It transforms the axial air particle motion near the diaphragm into a close approximation of a true pulsating sphere at the end of its fins (Figure 10). The result is a wide and close to constant directivity pattern for the tweeter at high frequencies (Figure 11). Furthermore, the compression chamber has the secondary effect of boosting the tweeter sensitivity from around 7kHz upwards (Figure 12).

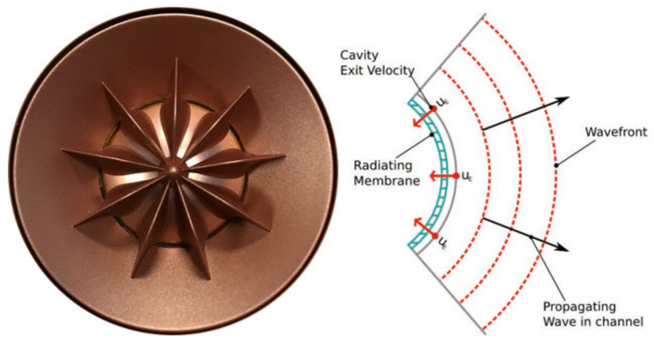


Figure 10. Tangerine Waveguide geometry

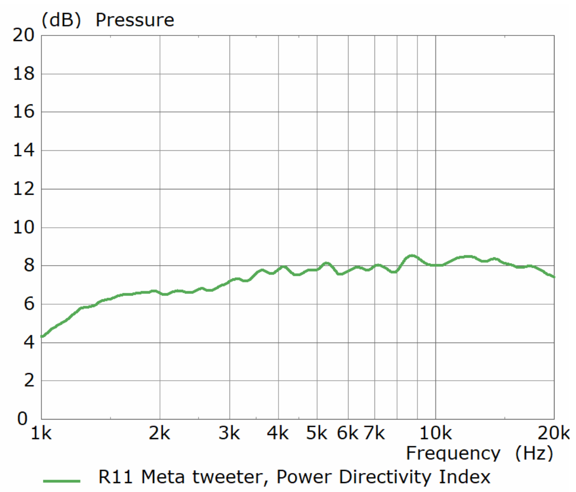


Figure 11. Tweeter Power Directivity Index (without crossover) as measured on R11 Meta

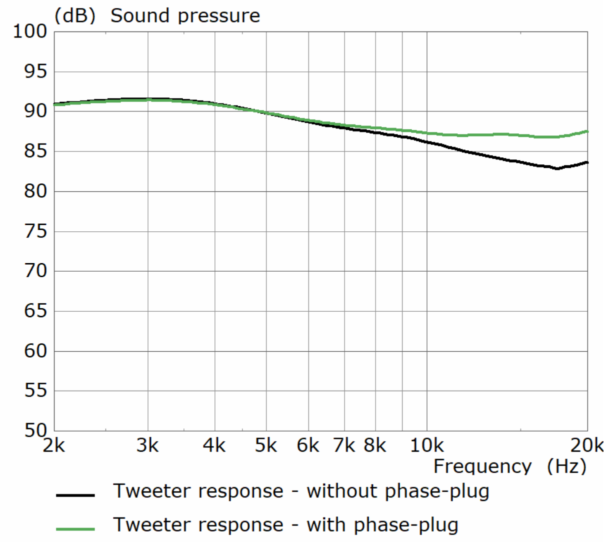


Figure 12. Effect of the Tangerine Waveguide compression chamber on the tweeter's axial response

The Shadow Flare further controls the directivity of the tweeter and recedes the Uni-Q into the enclosure by 5mm, enough to create an acoustic shadow at the baffle edges closest to the driver. The result is a substantial reduction in frequency response ripple of both midrange and tweeter (Figure 13).

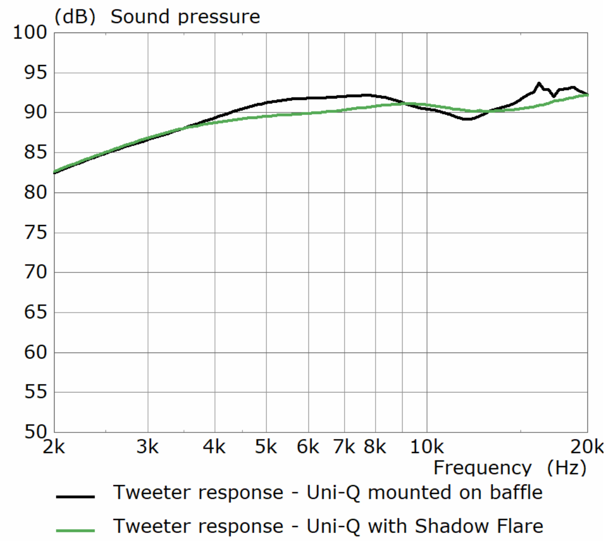


Figure 13. Comparison of Uni-Q driver HF response with and without Shadow Flare

Tweeter THD Performance

Figure 14 shows a comparison of THD (%) between the 2018 R Series tweeter and the R Series with MAT tweeter. For this measurement, the same second-order high-pass crossover with a cut-off frequency of 2 kHz has been used to protect the tweeters from damage and to keep their output constant around 90dB at 1m up to 20kHz. Both tweeters have been measured in an R11 enclosure.

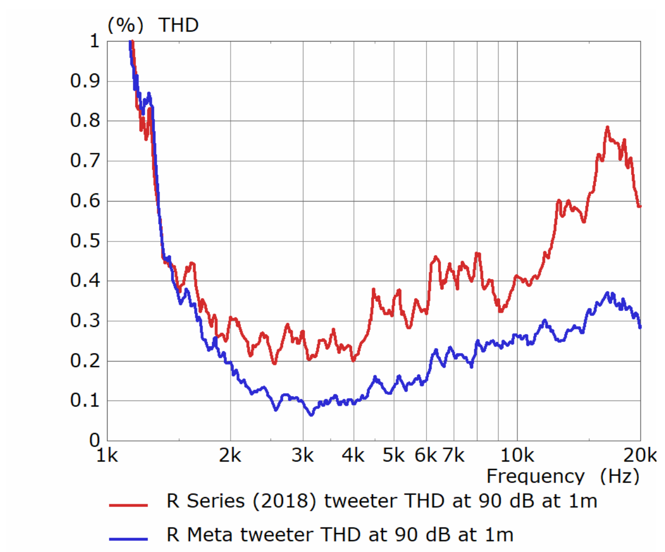


Figure 14. Comparison of the tweeter measured THD (%) between R Series (2018) (red) and R Series with MAT (blue) as measured in an R11 enclosure at 90 dB SPL at 1m with the same second-order high-pass crossover with a cut-off frequency of 2kHz

Midrange Driver

Ultra-low distortion midrange motor system

The new midrange motor is closely based on the one developed for Blade and Reference Meta. It has been specifically designed to eliminate force factor modulation with displacement, minimise voice coil inductance magnitude and minimise inductance modulation with displacement. These are the primary factors responsible for midrange harmonic and intermodulation distortion.

The motor top plate is an unconventional design consisting of two sections separated by an air gap. A short voice coil moving within forms an underhung arrangement. Inside the gap, and slightly indented, sits a copper ring which is aligned with the centre of the voice coil.

The motor pole also now accommodates the tweeter rear waveguide inside it as well as the Tweeter Gap Damper above it. Figure 15 shows a section view of the Uni-Q highlighting the midrange motor system and its split top plate design.

Figure 16 shows the magnetic circuit of the Uni-Q midrange and tweeter motors. The behaviour of the magnetic flux at the split top gap is observable.

The motor force factor *BL* is the product of the flux density *B* of the magnetic field crossing the voice coil gap, and the voice coil length *L* immersed in that magnetic field. *BL* is a function of the voice coil's displacement. Typically, as the voice coil moves away from the gap, *BL* decreases as the length of coil present in the gap is reduced. This modulates the force applied to the voice coil and thus distorts the signal being reproduced. This is one of the main sources of harmonic distortion in drivers.

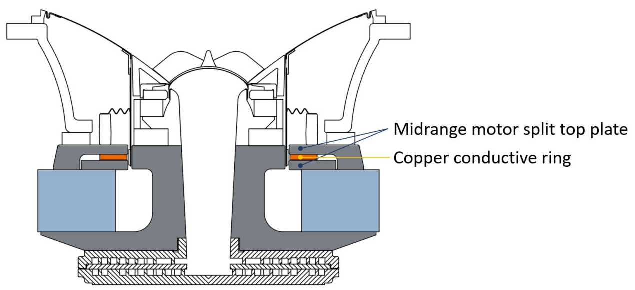


Figure 15. Detail of the midrange motor within the Uni-Q

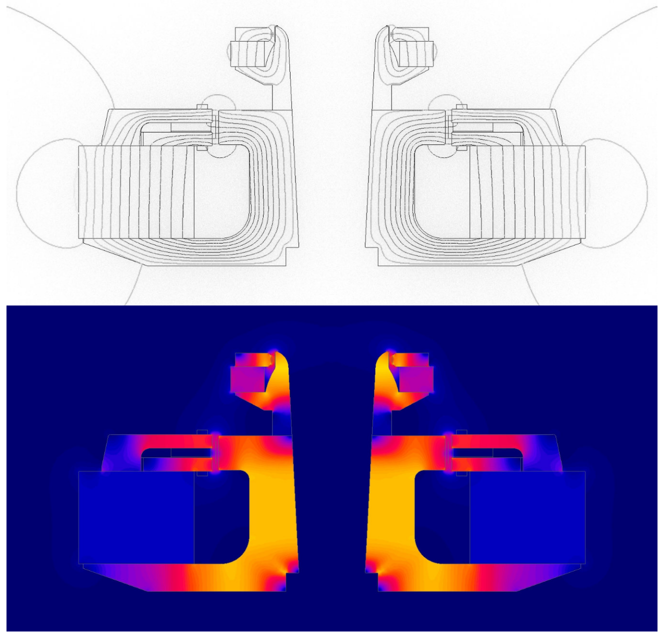


Figure 16. Uni-Q motor system magnetic circuit. Magnetic field lines (top) and flux isovalues (bottom)

The new split top plate design focuses the magnetic flux available from the motor's ferrite magnet away from the centre of the voice coil towards its ends. This creates an M-shaped magnetic flux density profile *B(x)* that decreases around the voice coil's rest position (Figure 17).

The resulting *BL(x)* is thus flatter along the voice coil's excursion of +/- 2mm compared to the previous motor (Figure 18). A flatter *BL(x)* means the force applied to the voice coil will more closely follow the applied signal as the voice coil moves from its resting position.

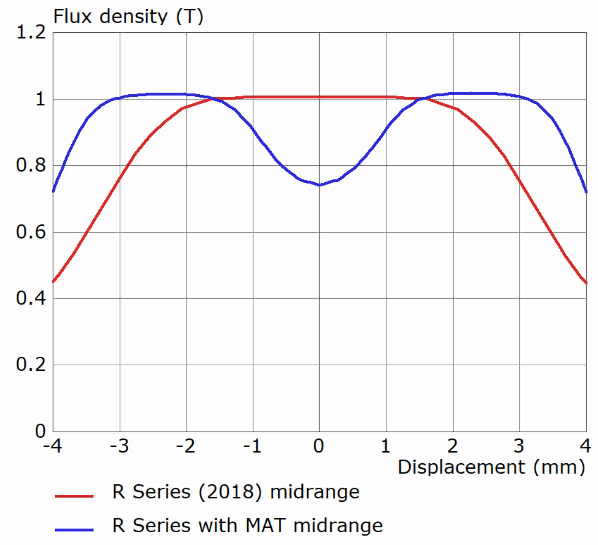


Figure 17. Midrange motor flux density B(x)

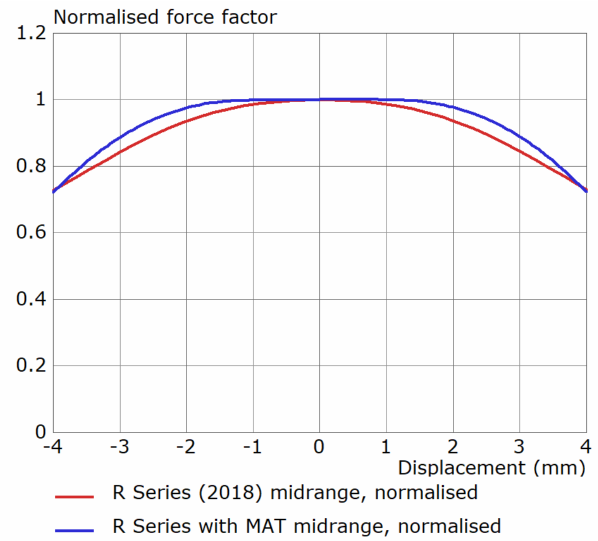


Figure 18. Midrange motor force factor BL(x) normalised to 0mm displacement

As AC current flows through the voice coil, an alternating magnetic field is produced. Its strength depends on the inductance of the voice coil, with higher inductance producing a stronger field. This AC magnetic field is conducted by the steel in the motor system and superimposed on the DC field produced by the permanent magnet.

Steel is highly magnetically non-linear, and the superimposed AC magnetic field causes some of the magnetic domains within the steel to reorient. This results in a shift in the permeability of the steel, leading to modulation of the DC magnetic field, and a modulation of the motor *BL*. These sudden shifts in the magnetic domains are also picked up as induced voltage signals in the voice coil, corrupting the music signal. This behaviour is highly hysteretic, and the generated distortion has a particularly unpleasant characteristic.

This is not the only issue, however. Inductance itself varies with the position of the voice coil - where the voice coil is constantly being pulled towards where inductance is highest. This is known as 'reluctance force' and is highly non-linear as it is proportional to the square of the current flowing through the voice coil.

To address these issues, the motor geometry has been optimised to increase saturation of the steelwork to reduce its magnetic permeability, thus decreasing its susceptibility to be magnetised by the voice coil's AC magnetic field.

The wide copper insert placed within the air gap created by the split top plate works as a conductive region and it couples to the voice coil allowing the flow of induced current through it. This produces an opposing magnetic field to the one created by the voice coil, further reducing the ability of the voice coil to magnetise the motor steel.

This arrangement is particularly advantageous. Sitting right in the middle of the two top plate sections and aligned with the voice coil's centre along its length, the conductive copper ring's effect on lowering distortion is much greater, and symmetrical with displacement.

Finally, an added benefit of the copper ring being so close to the voice coil is that it efficiently dissipates heat away from it. This reduces thermal compression of the signal whilst improving efficiency.

Figure 19 shows a visualisation of the flux density modulation regions present in the steelwork of the motor near the voice coil gap at 500Hz, a representative frequency in the midrange. A considerable reduction can be observed when the optimised conductive region of copper is added to the motor.

Figure 20 shows a comparison for the previous and new motors of the voice coil inductance across frequency for several voice coil positions ranging along +/-2mm where the reduction in inductance modulation with displacement is observable.

Taking a slice of Figure 20 at 500Hz reveals that inductance modulation is almost eliminated across voice coil displacement (Figure 21).

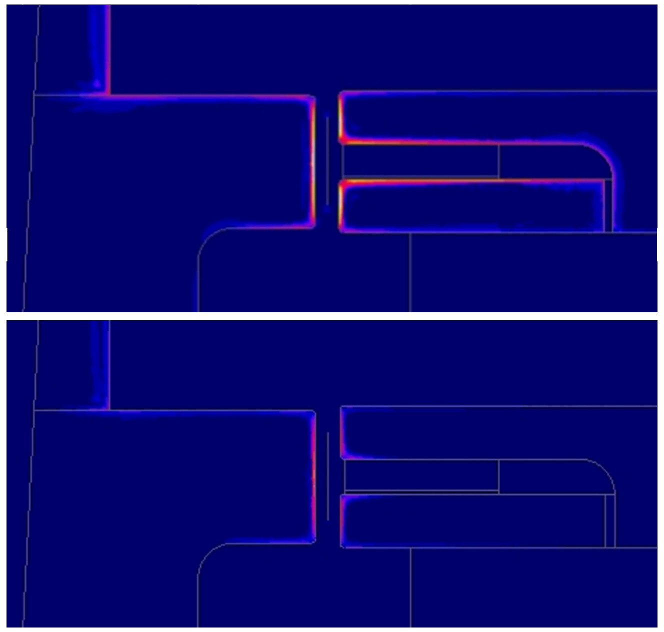


Figure 19. Midrange motor flux density modulation at 500Hz without (top) and with copper conductive region (bottom)

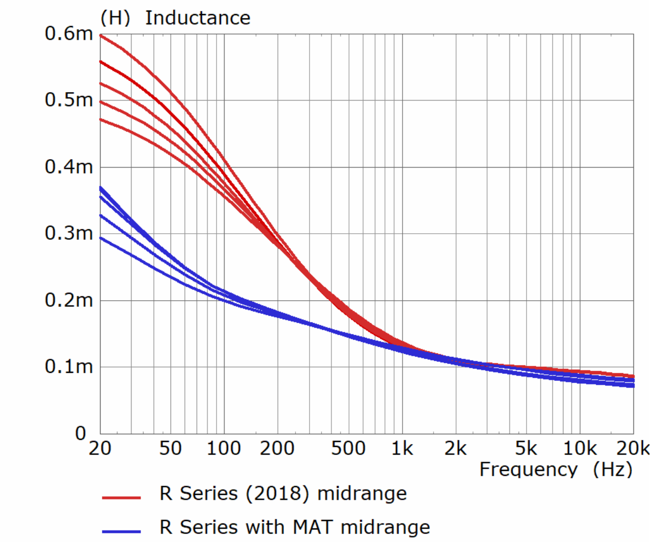


Figure 20. Comparison of midrange voice coil inductance modulation with displacement

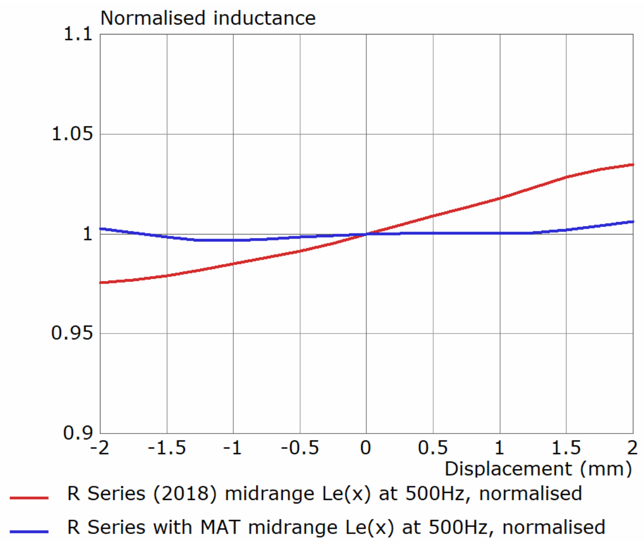


Figure 21. Comparison of normalised midrange voice coil inductance modulation with displacement at 500Hz

Flexible Decoupling Chassis

Another technology directly carried over from Blade and Reference Meta is KEF's Flexible Decoupling Chassis.

The new Uni-Q chassis is constructed of a composite material. While its outer rim is directly attached to the front baffle through a stiff steel plate, the chassis legs incorporate eight flexible spring elements connecting the rigid portion of the structure to the midrange motor. In parallel to the flexible spring elements a set of four damping material pads provide mechanical damping to the springs. Figure 22 shows this arrangement together with a diagrammatic representation of the mechanism involved in the decoupling.

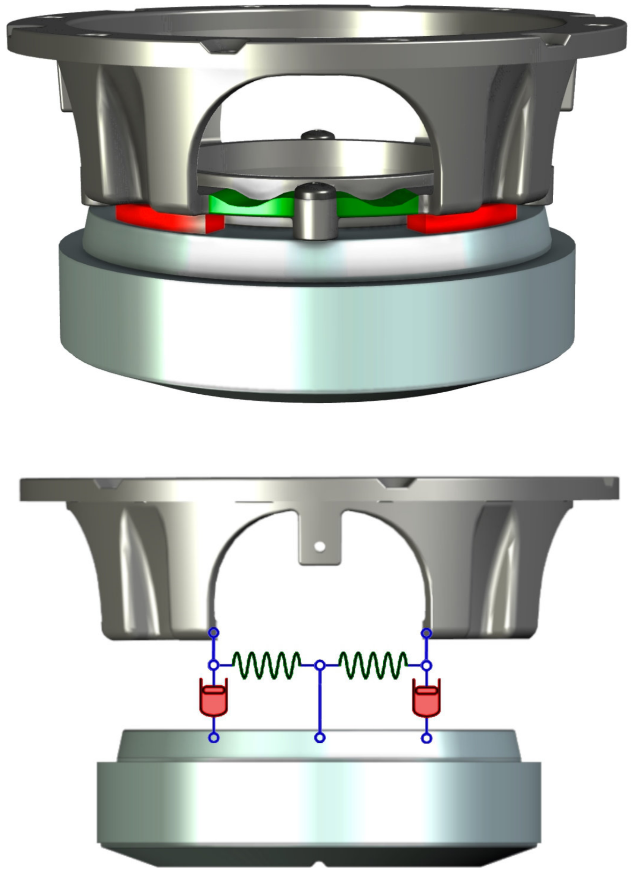


Figure 22. R Series with MAT Uni-Q Flexible Decoupling Chassis (top) and diagrammatic representation (bottom) showing the flexible spring elements highlighted in green and damping material highlighted in red

In comparison, Figure 23 shows the previous design from R Series (2018), where the aluminium chassis is bolted directly onto the midrange motor.

When the mass of the midrange motor vibrates when excited by the reactive force from the moving voice coil, this vibration is 'decoupled' or disconnected from the enclosure by the flexible spring elements and quickly

dissipated by the damping pads. The result is the motor vibration cannot leak into the cabinet and be re-radiated as sound into the listening room. Furthermore, the back of the Uni-Q, previously anchored to the rear wall of its own enclosure through a damping pad, is no longer connected to it in order to allow the decoupling chassis to work as intended.

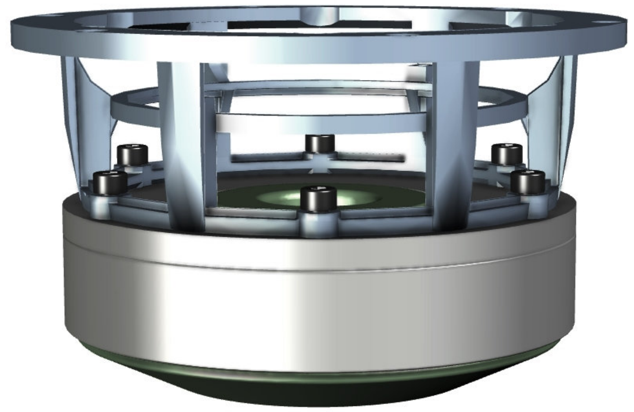


Figure 23. R Series (2018) Uni-Q rigid aluminium chassis directly affixed to motor

A more detailed description of driver decoupling approaches can be found in the Blade and Reference Meta white paper [7].

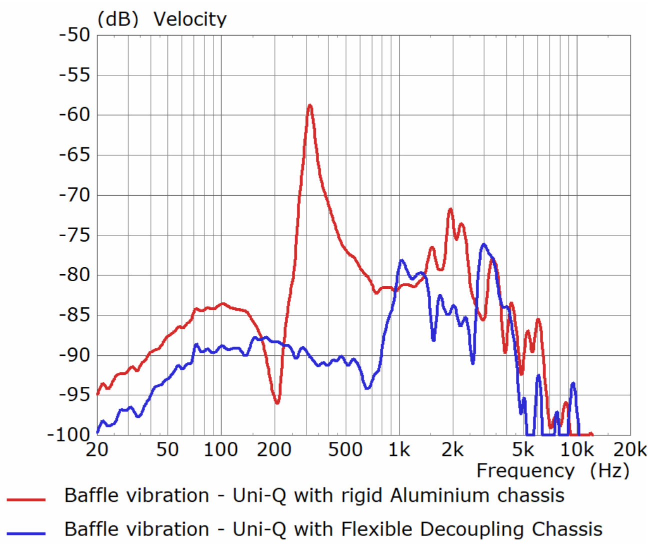


Figure 24. Effect of the Flexible Decoupling Chassis on baffle vibration

Figure 24 shows a comparison of the rigid chassis and the flexible decoupling chassis performance through a point velocity measurement made with a laser vibrometer on a speaker baffle when the midrange driver is excited by a sine sweep. In the case of the rigid chassis, the measurement clearly shows the motor mass resonance, around 310Hz, has leaked onto the baffle. This leads to the baffle radiating this as sound. In contrast, in the case of the Flexible Decoupling Chassis, the measurement shows no trace of the motor mass resonance leaking to the baffle, having been reduced by more than 30dB.

Midrange suspension

The suspension centres the voice coil in the magnetic gap and provides a high restoring force that protects the voice coil from damage at extreme displacements.

A large suspension with more rolls allows a greater range of motion, which is essential for high performance low frequency drivers. However, large suspensions suffer from mechanical resonance within the driver passband. When this happens, a glitch or dip forms in the driver's frequency response, which is undesirable and easy to perceive as the ear is most sensitive in the midrange frequency region.

Shifting the suspension's resonance out of the midrange operating frequency band is challenging since it requires a very low mass while still allowing the driver to move its full linear excursion.

The suspension profile (Figure 25) has been redesigned to reduce its width to 0.69cm (0.27"), which has the effect of decreasing its mass and increasing its resonant frequency out of the passband while still allowing a linear excursion of more than +/- 2mm.

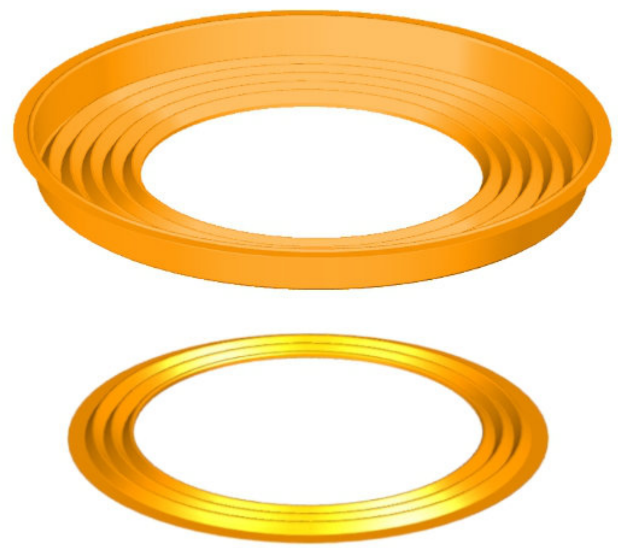


Figure 25. Comparative view of midrange suspensions. R Series (2018) (top) and R Series with MAT (bottom)

Figure 26 shows a comparison of the FEA-simulated frequency response of the 2018 R Series midrange driver and the new midrange driver demonstrating the disappearance of the dip at 950Hz caused by the suspension resonance.

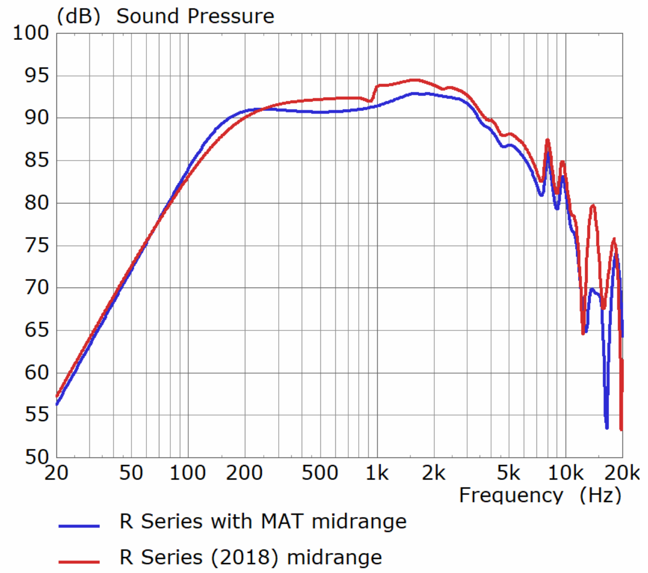


Figure 26. Midrange frequency response FEA simulation on an infinite baffle showing the disappearance of the 'dip' caused by the suspension resonance around 950Hz

Midrange Cone Neck Decoupler

The midrange cone is made from an aluminium alloy to ensure low mass and high rigidity. This results in pistonic behaviour throughout the passband, which is an essential requirement of a high-performance driver design. However, due to low internal damping, aluminium midrange cones typically break up in the tweeter frequency region, resulting in severe peaks in the frequency response and directivity aberrations that remain audible despite the low-pass crossover on the midrange.

To avoid these issues, a lossy interface between the voice coil and the cone called the Cone Neck Decoupler has been tuned to disconnect, or decouple, them just below the break-up frequency (Figure 27). Figure 28 shows the effect of the Cone Neck Decoupler on the midrange axial frequency response.

Midrange THD Performance

Figure 29 shows a comparison of THD (%) between the 2018 R Series midrange and the R Series with MAT midrange, level-matched at 90dB at 1m, both measured on an R11 enclosure without a crossover.

The following features can be highlighted:

- The distortion is considerably lower at the lower midrange frequencies as a result of the new split top plate design.
- The overall drop in THD across the driver's wide passband owing to the new motor design
- The disappearance of the glitch around 310Hz where the new decoupling chassis takes effect
- The disappearance of the glitch around 950Hz where the suspension resonance has been dealt with by the new midrange suspension design

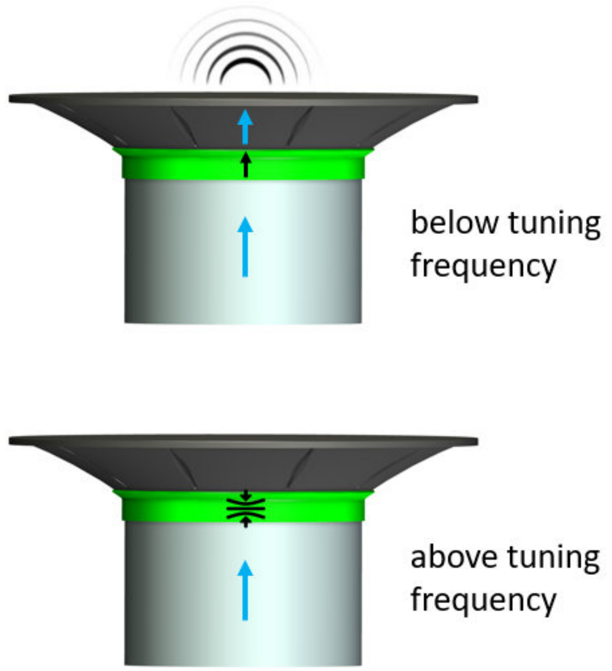


Figure 27. Behaviour of the Cone Neck Decoupler (highlighted in green) around tuning frequency

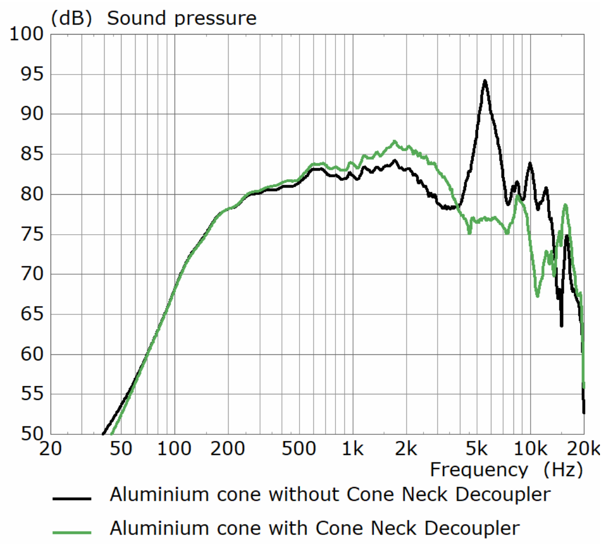


Figure 28. Aluminium cone midrange axial frequency response with and without Cone Neck Decoupler

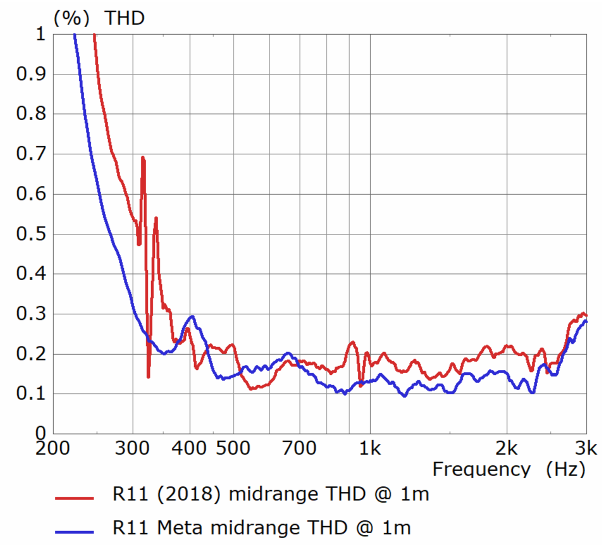


Figure 29. Comparison of measured THD (%) between R Series (2018) (red) and R Series with MAT (blue) as measured on an R11 enclosure without crossover at 90 dB SPL at 1m

Low Frequency Drivers

The low frequency drivers in R Series (Figure 30) provide high output and low distortion with high power handling as well as pistonic motion well beyond their crossover frequency.

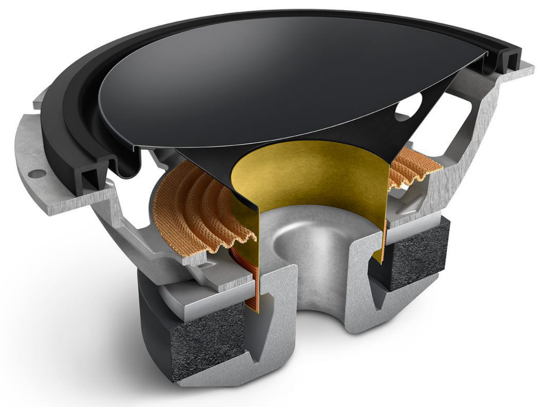


Figure 30. R Series LF driver

They employ a lightweight and highly rigid moving structure comprising an aluminium diaphragm coupled to the voice coil through a paper cone with an angle and coupling radius optimised to push the first break-up frequency as high as 2.3kHz, by which point the driver output is attenuated more than 30dB with respect to the system output.

A sizeable 50mm (2”) voice coil is employed for high power handling. The motor employs a highly saturated undercut pole design to reduce inductance and its associated distortion and a wide central vent to reduce turbulence noise and acoustic loading from the air trapped inside the voice coil.

The surround is a linear-excursion inverted half-roll design that reduces the effect of diffraction for the neighbouring Uni-Q by not protruding from the speaker baffle.

System and Enclosure

Figure 31. R11 Meta system inside view

Constrained Layer Damping

One of the main goals in high-performance loudspeaker design is for all sound to emanate from the drivers, and not from any other parts of the loudspeaker. Good enclosure design is key to achieving this goal, as it must remain as inert as possible without reacting to excitation from the drivers.

At low frequencies, the whole enclosure tends to move in the opposite direction to the low frequency drivers' diaphragms. To ameliorate this, the enclosure is built of thick 25mm (1") MDF and 30mm (1.18") on the bottom face and front baffle and anchored to the floor via four protruding aluminium feet fitted with adjustable spikes. The LF drivers are mounted on the front baffle and are constrained at the back with a transverse brace and a proprietary damping material layer, effectively coupling them with the mass of the enclosure.

At higher frequencies, even thick enclosure panels tend to flex and resonate like the walls of a musical string instrument. To reduce this effect, the inside of the enclosure is heavily braced. However, bracing mostly provides stiffness and some mass to the panels. This reduces the velocity of the resonating panels to some extent but mainly shifts their resonance frequencies to higher frequencies.

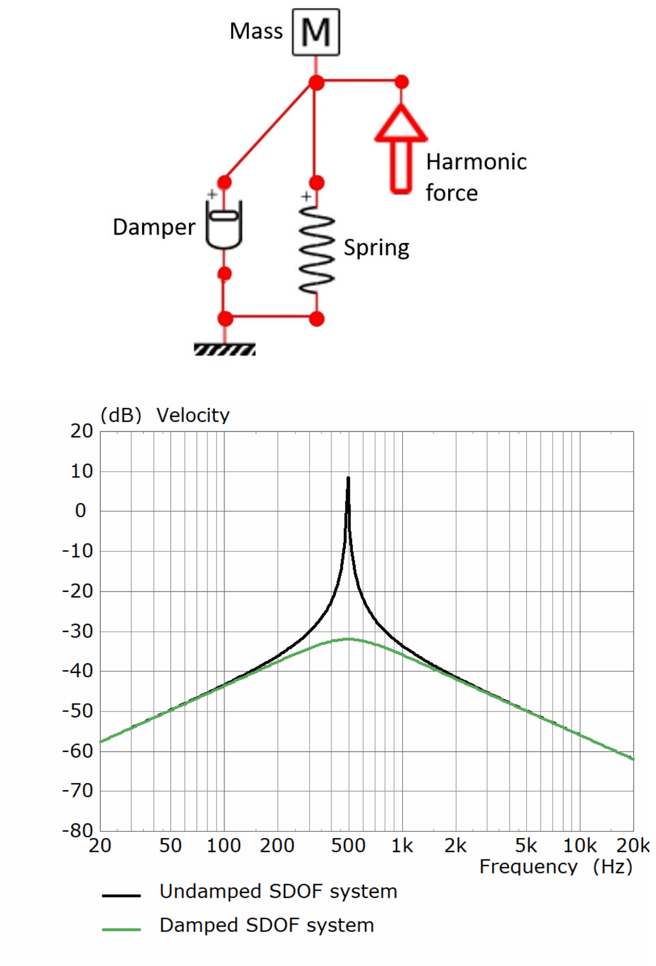


Figure 32. Single-degree-of-freedom system and its velocity with and without damping

Adding resistance (damping) to a resonating system reduces its velocity, just like a car suspension's shock absorber (damper) reduces the velocity of the suspension's resonance after a bump on the road. Figure 32 shows a diagram representation of a simple single-degree-of-freedom (SDOF) resonating system and its associated fundamental resonance velocity behaviour to illustrate the effect of damping.

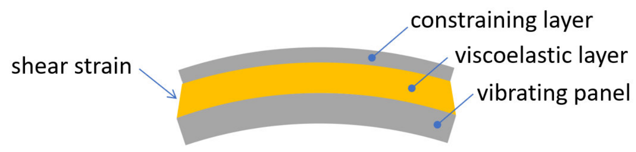


Figure 33. Diagram of a constrained layer damping arrangement

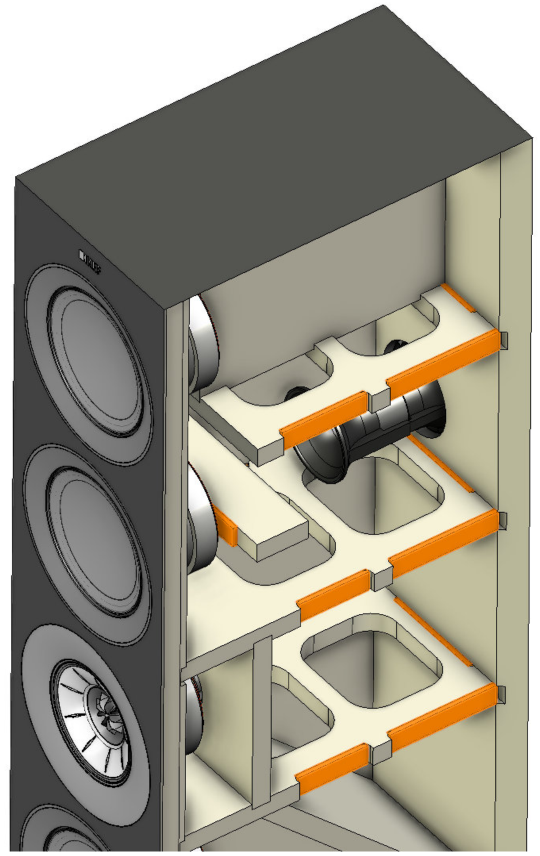


Figure 34. R11 Meta enclosure showing the bracing and viscoelastic material highlighted in orange forming the Constrained Layer Damping arrangement

To dissipate energy away from the resonances and reduce their amplitude, mechanical damping can be provided by adding a layer of viscoelastic material to the vibrating panel. An arrangement that is well known in acoustics to deal with vibrating panels involves employing a second layer of a stiff material that constrains the viscoelastic one. This top layer causes shearing of the viscoelastic layer, increasing its damping effect (Figure 33). Original research done during the development of LS50 [8] showed a similar effect can be achieved by using the cabinet braces as the constraining top layer while a layer of viscoelastic damping material is used only in the interface area between the panels and the braces (Figure 34). This layout outperforms lining the entire inside area of the panels while making a more efficient use of the material.

Figure 35 shows a comparison of an enclosure wall vibration measurement with and without bracing incorporating Constrained Layer Damping. The velocity of the panel reflects the appropriate broadband attenuation of panel resonances.

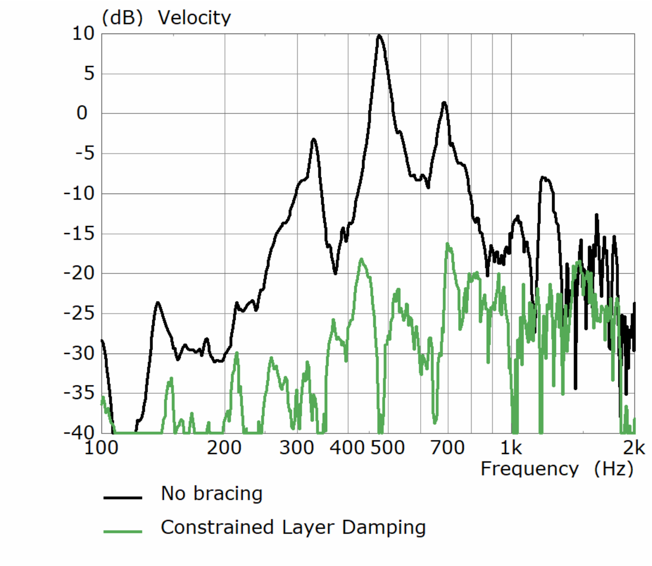


Figure 35. Enclosure wall vibration comparison when adding the Constrained Layer Damping arrangement

Damping of standing wave resonances

Another type of resonance that can occur within speaker enclosures are acoustic standing waves. These acoustic resonances take place when the air inside the enclosure resonates when excited by the driver at frequencies whose wavelength is relatively small compared to the enclosure size. Due to the enclosure internal dimensions and the position of the drivers, one or several standing waves may be excited, and they can easily colour the sound from the speaker as they escape into the room through the driver diaphragm, ports, or by exciting the enclosure walls.

The most effective way to mitigate standing wave resonances is to avoid exciting them in the first place. This is achieved through positioning the driver at the resonances' sound pressure nodes, i.e. where the sound pressure is zero. In cases where drivers must be positioned away from the pressure nodes due to their exterior arrangement, other techniques must be used. Acoustic damping materials, like wadding or foam, provide a tortuous path for sound to travel through, i.e. providing resistance (damping) to the air particles' velocity.

When the air inside the enclosure is resonating, the damping provided by the wadding is maximised when it is positioned at the resonance's highest velocity point. This optimisation is relevant to avoid stuffing the enclosure with wadding in inefficient positions which reduce the enclosure's internal volume, thus decreasing low-frequency output with no other benefit.

The Reference white paper from 2014 provides a detailed description of the behaviour of standing waves in enclosures and the effect of adding damping material in different positions within the enclosure [1].

Figure 36 depicts a simplified long enclosure closed at both ends with a suboptimal asymmetric driver position along with the sound pressure and air particle velocity profiles of the first longitudinal mode. The compromise between driver position and exciting and treating the standing wave can be visualised.

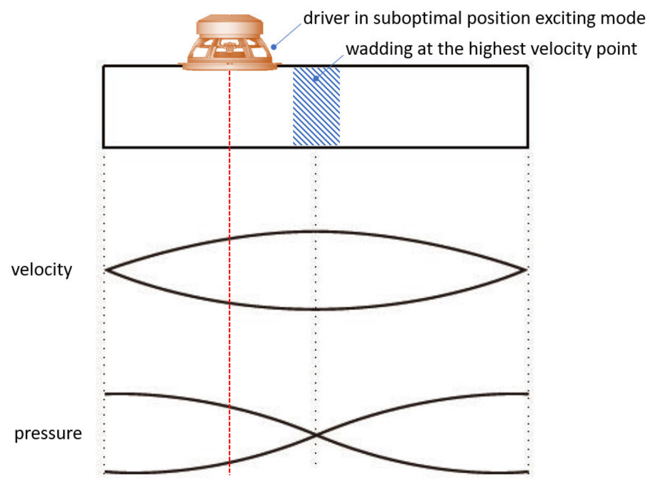


Figure 36. First standing wave mode shape in a long enclosure with closed ends

The arrangement and type of acoustic damping material inside the midrange and low frequency cavities of R Series with MAT has been re-optimised to dampen standing waves resulting in a perceivable sonic enhancement in the clarity of the upper bass and midrange.

Figure 37 shows measurements of the R11 Meta LF driver diaphragm velocity taken with a laser vibrometer with and without wadding inside the enclosure. The glitches observable in the response at ~250Hz and 490Hz correspond to the first two longitudinal standing waves and their disappearance is obvious when wadding is added at strategic points. The further improvement between R Series (2018) and R Series with MAT is shown as well.

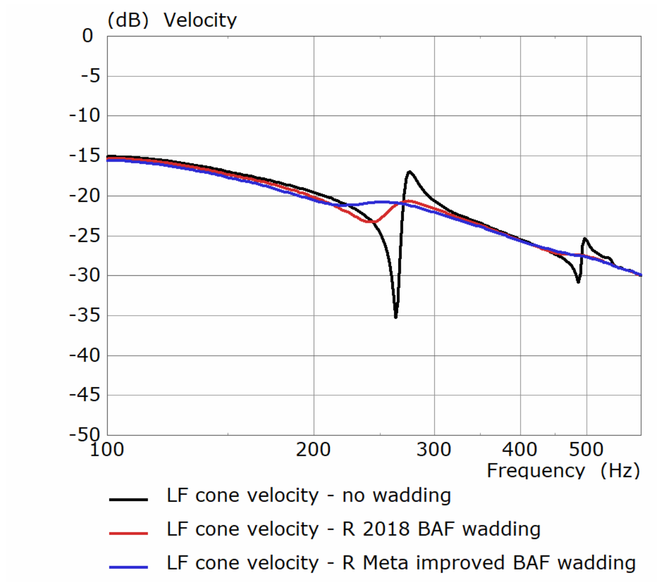


Figure 37. Measured LF cone velocity of R11 Meta showing the effect of standing waves and their improved damping

Figure 38 shows a similar comparison for the midrange driver for resonances occurring at 770Hz and 1.5kHz. For R Series with MAT the midrange acoustic damping has been changed from BAF wadding to high-density Ethylene-vinyl acetate (EVA) copolymer foam to further increase damping of the sharp resonance around 1.5kHz.

Even with a stiff, heavy, and well damped enclosure, the high acoustic pressure of standing waves inside the enclosure can press against the enclosure walls like a balloon and make them vibrate, creating a large radiating surface for the resonance to efficiently transduce into radiated sound.

Figure 39 shows a comparison of the velocity of the cabinet side wall of an R11 Meta outside the midrange enclosure when foam is added while Figure 40 shows the associated frequency response of the midrange (without crossover) where the successful treatment of the standing waves is observable and the loss in low-frequency response is minimal.

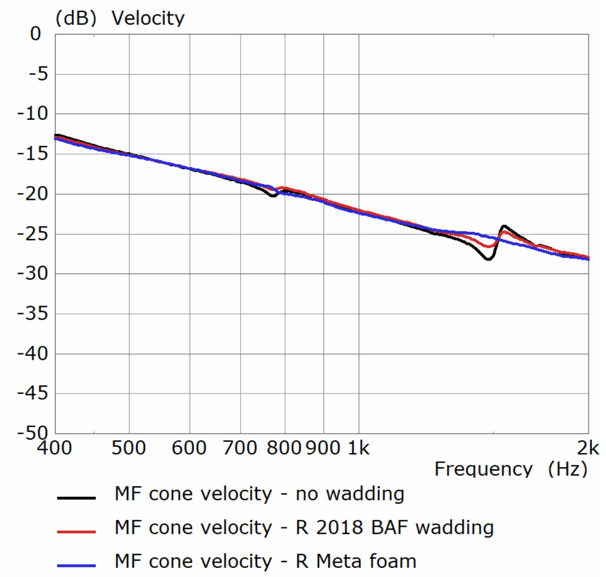


Figure 38. Measured midrange cone velocity of R11 Meta showing the effect of standing waves and their improved damping

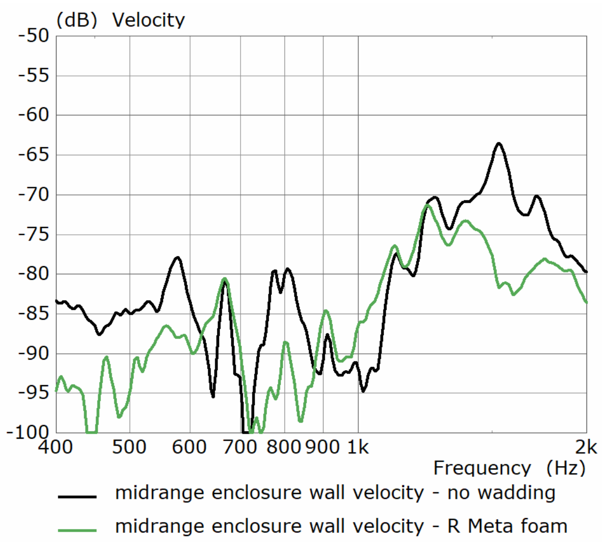


Figure 39. Measured surface velocity of cabinet wall outside midrange enclosure in R11 Meta comparing the standing wave leakage with and without acoustic damping

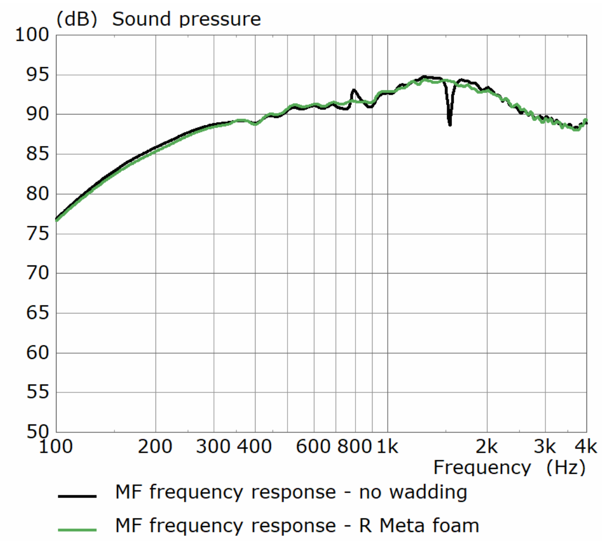


Figure 40. Measured frequency response of the midrange in R11 Meta (no crossover) comparing the standing wave leakage with and without acoustic damping (at 1m distance)

Bass-reflex ports

Bass-reflex ports are very useful in passive loudspeakers. At low frequency they are tuned to work in tandem with the LF drivers and the enclosure's acoustic volume to further extend the system's bass response and reduce driver displacement and thus distortion.

However, ports add complications to a system, two of which are air turbulence noise and leakage of enclosure standing waves at higher frequency.
The noise from air turbulence is greatly reduced by optimising the profile of the inner and outer port opening flares through a Computer Fluid Dynamics (CFD) numerical simulation (Figure 41).

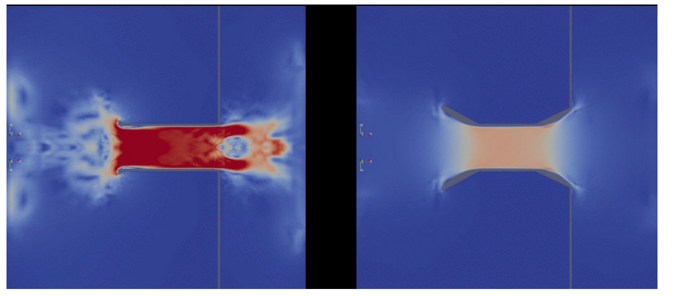


Figure 41. CFD model showing the effect of the computer-optimised port flare geometry on air turbulence

In R Series, the ports are located on the back of the enclosure so that their internal opening can be freely positioned in locations that minimise the leakage of internal acoustic resonances (Figure 42) (see Damping of Standing Wave Resonances).

Another challenge seldom discussed with ports are their inherent tube-like resonances. These resonances are naturally related to the size of the port acting like a small organ pipe and at high frequencies, typically around midrange, ports produce their own distinctive sound that colours that of the drivers.

Since the introduction of LS50, and improved during the development of the Reference Series, a mechanism has been devised in which the wall of the tubular port section is made from a flexible rubber that allows the wall to expand with the acoustic pressure of the port resonances. Since rubber has high internal damping, it dissipates energy away from these resonances. This results in a reduced acoustic output of the port resonances, while the low-frequency behaviour of the port remains unaffected. Figure 43 shows the mechanism of resonance damping through port flexible walls.

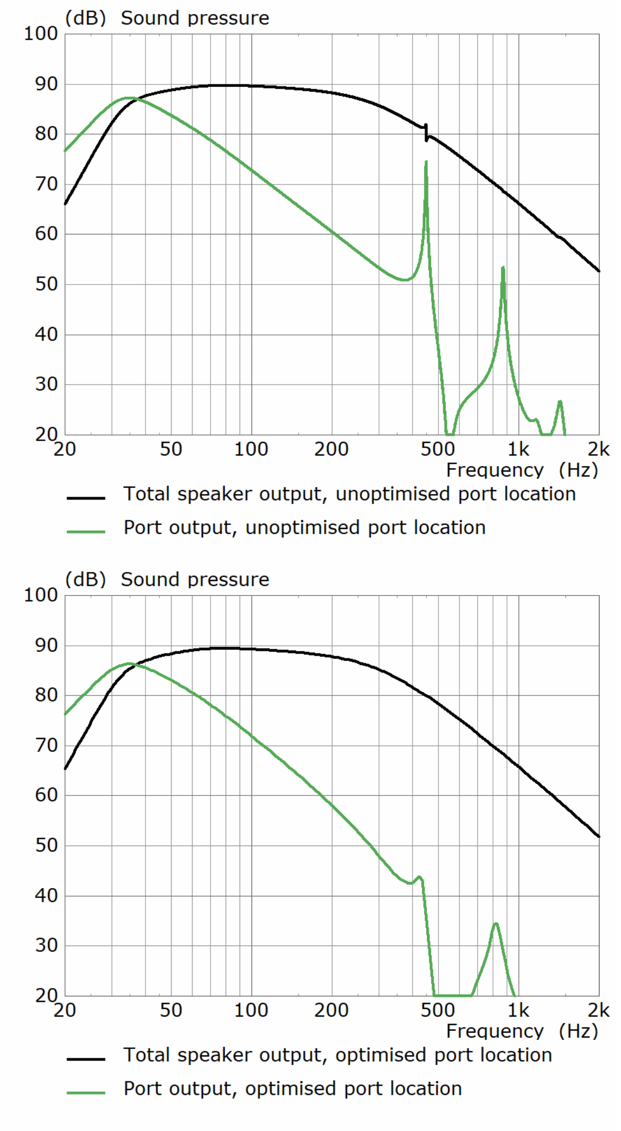


Figure 42. System output simulation showing the effect of optimised port location on standing wave leakage

Figure 43. Pressure of the first resonance in a port with rigid walls (top) and flexible walls (bottom)

Crossover

The primary role of a crossover filter network is to combine the output of the different drivers in a speaker such that the transition between them is smooth in magnitude and phase and that they work in their intended frequency range away from damage and distortion.

However, to maximise the communication of spatial cues in a recording that enhances the realistic perception of the stereo image by the listener, a speaker's frequency response must be designed to be smooth on-axis as well as off-axis, both vertically and horizontally. This is so that the room's early reflected sound has a tonal balance that is not abruptly dissimilar to the speaker's direct sound.

Therefore, a secondary but equally important function of the crossover is to help ensure this smooth transition occurs in all directions, not only on the speaker's frontal axis.

To design such a crossover, it is necessary to simulate it first through a virtual computer model of the crossover network and feed it with measurements of the impedance and anechoic frequency response of the LF, MF and HF sections playing individually.

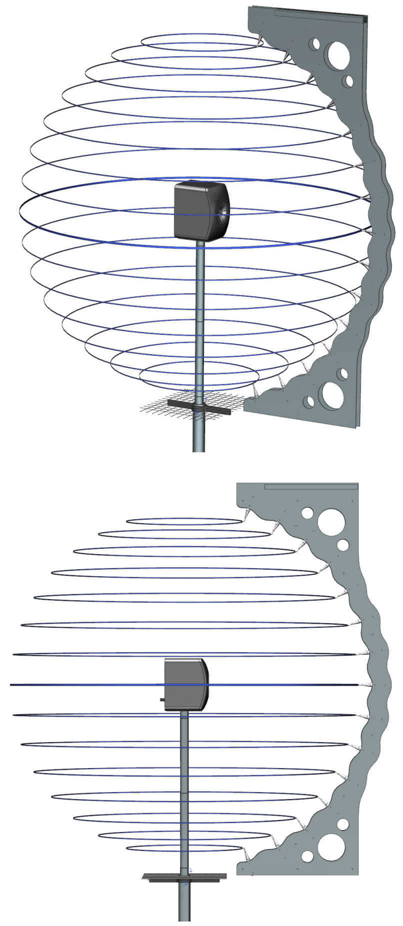


Figure 44. Representation of the measurement data acquisition system in KEF's anechoic chamber

Figure 44 shows a 3D representation of the measurement data acquisition system used in KEF's anechoic chamber. An array of omnidirectional microphones captures the anechoic frequency response of the speaker at various vertical angles. The speaker is then rotated on a turntable and the measurement is repeated every few degrees. This results in a sphere of frequency response data that can be fed into the computer model and post-processed to produce relevant acoustic metrics. These metrics then inform the crossover design in terms of how the speaker's individual driver outputs are combined.

Figure 45 shows the crossover topology used across the series consisting of a three-way network, except for R8 Meta which uses a different 2-way topology optimised for Dolby Atmos®.

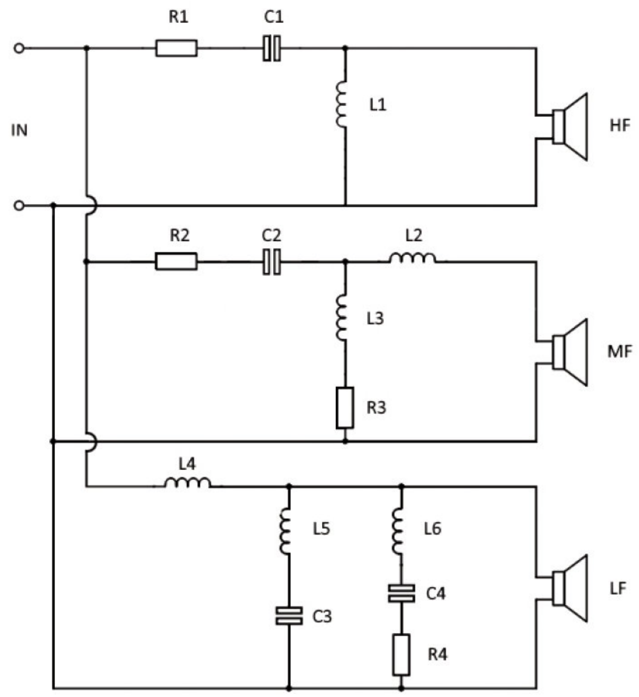


Figure 45. Main crossover topology for R Series with MAT (3-way models)

The new topology simplifies the tweeter filter to improve the system's directivity, uses a single series capacitor C2 in the MF branch, and only uses C3 in the LF branch in some models to help tailor their directivity across LF to MF.

The tweeter series capacitor (C1) has been upgraded to a better design Polypropylene film one with a thicker film, lower resistance contact layer (schoopage), lower resistance terminals and a thicker outer damping layer. Where possible, air core inductors have been used and all cored inductors have a laminated steel core of a specially selected grade to reduce THD.

In R Series with MAT the overall frequency response and directivity smoothness have been further improved. To improve directivity, priority has been assigned to obtaining a smoother acoustic power average and smoother vertical and horizontal directivity averages. These curves are special averages of the speaker's off-axis response. As an example, Figures 46 and 47 show a comparison of the balance between R3 (2018) and R3 Meta, where a smoother result has been achieved.

The R3 Meta is a special case within the range as the LF section does not form a symmetrical arrangement around the Uni-Q, since it has only one LF driver. For this reason, the Uni-Q is mounted close to the top edge of the enclosure, and this results in a dip in its acoustic power directivity index just above 2kHz. Designing a crossover considering only the axial response smoothness would result in a corresponding bump in the acoustic power average. The studied approach, however, allows a dip in the axial response, prioritising a smooth power average. This represents the approach refined during the development of Reference Meta [8] as well as extensive listening tests in different rooms.

System THD Performance

The aggregate outcome of the improvements outlined in the previous sections can be somewhat summarised in the system's total harmonic distortion. Figure 48 shows a comparison of THD (%) at 90dB SPL matched at 500Hz at 1m distance between R11 (2018) and R11 Meta. The full audible frequency band is shown to highlight the results from the multiple improvements in the system.

The measurements show the reduced harmonic distortion across the high frequency band covered by the tweeter, the very low distortion across the midrange passband (~0.1%), the disappearance of the glitch at 950Hz associated with the MF suspension resonance, the suppression of the bump around 250Hz due to the lower distortion midrange motor and a broad improvement to the LF section mainly due to the crossover design.

Summary

The R Series was originally introduced as a more affordable option to the Reference Series while directly benefitting from the research conducted during the development of KEF's highest performance ranges.

The R Series with MAT carries on this legacy by integrating numerous acoustic innovations, resulting in objectively better performance in the laboratory and a

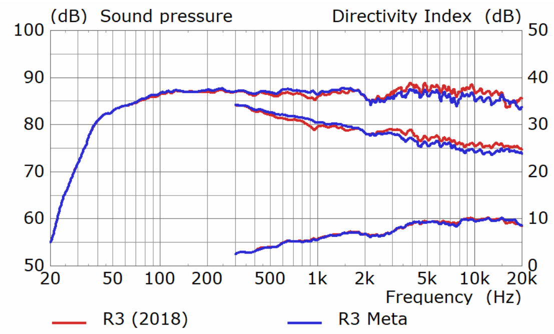


Figure 46. Axial frequency response, acoustic power average and acoustic power average directivity index of R3 (2018) (red) vs. R3 Meta (blue)

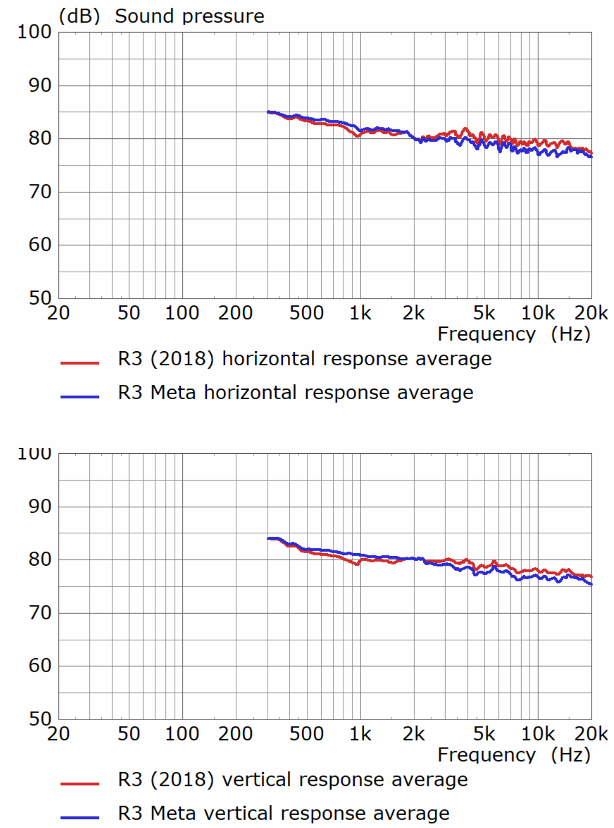


Figure 47. Horizontal (top) and vertical (bottom) response average of R3 (2018) (red) vs. R3 Meta (blue)

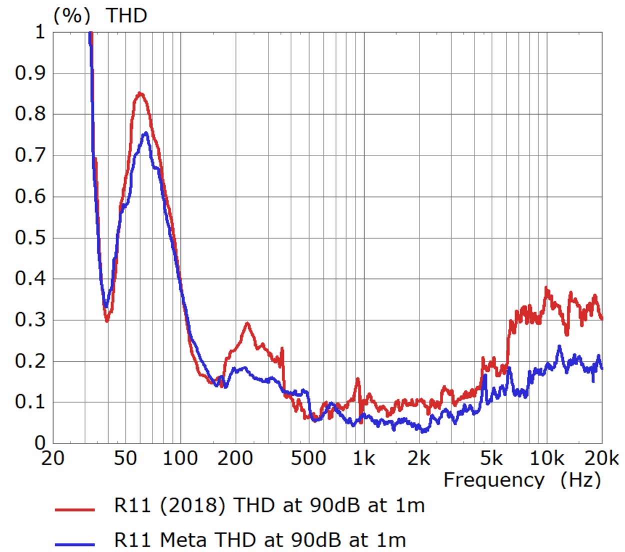


Figure 48. Comparison of THD (%) between R11 (2018) (red) and R11 Meta (blue) at 90dB SPL matched at 500Hz at 1m

more realistic and engaging musical reproduction experience in the listening room.

This paper aims to provide insight into the development process of these innovations by explaining their engineering and supporting its arguments with results from computer simulations and laboratory measurements.

The tweeter metamaterial absorber, innovative drivers, enclosure acoustical behaviour, and new crossover filter networks together combine to result in a loudspeaker range with a much higher capability for faithful and engaging musical reproduction.

References

[1] "The Reference (White Paper)." KEF R&D, Apr. 2014. [Online]

[2] "R Series 2018 (White Paper)." KEF R&D, Oct. 2018. [Online]

[3] M. Dodd and J. Oclee-Brown, "A New Methodology for the Acoustic Design of Compression Driver Phase Plugs with Radial Channels", 125th Audio Eng. Soc. Convention, 2008

[4] S. Degraeve and J. Oclee-Brown, "Metamaterial Absorber for Loudspeaker Enclosures", 148th Audio Eng. Soc. Convention 2020

[5] "LS50 Collection (White Paper)." KEF R&D, Sep. 2020 [Online]

[6] M. Dodd, "Optimum Diaphragm and Waveguide Geometry for Coincident source Drive Units", 121st Audio Eng. Soc. Convention 2006

[7] "Blade/The Reference with MAT (White Paper)." KEF R&D, Feb. 2022. [Online]

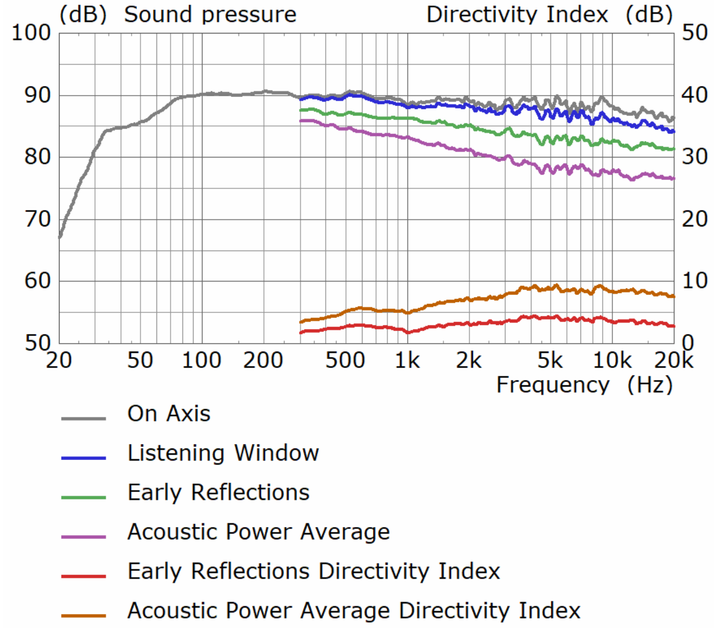
[8] "LS50 (White Paper)." KEF R&D, Sep. 2011. [Online]

R Series Meta

Model Information, Specifications and Measurements

R11 Meta

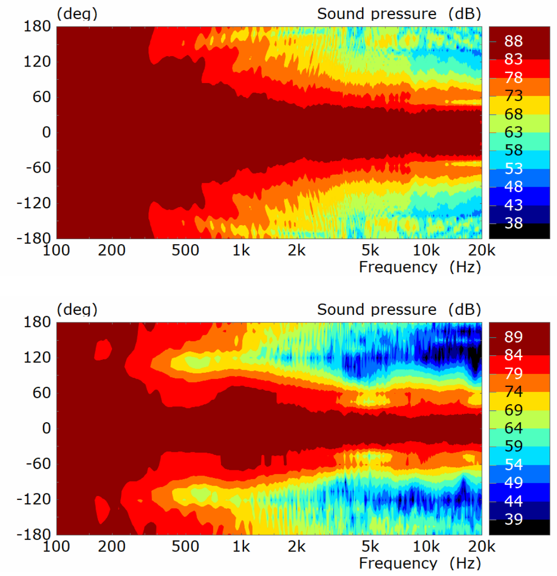
Three-way Floorstanding Loudspeaker

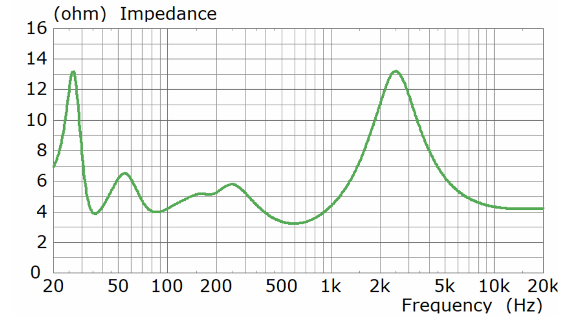


R11 Meta Spinorama

Technical Specifications

System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Drivers: LF: 4 x 165mm (6.5 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	30Hz - 50kHz
Typical in-room bass response (-6dB)	26Hz
Frequency response (±3dB)	46Hz - 28kHz
Crossover frequencies	330Hz, 2.5kHz
Recommended amplifier power	15-300W
Sensitivity (2.83V/1m)	90dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 33Hz and above <0.5% 80Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	113dB
Impedance	4 Ω (min. 3.2 Ω
Weight	36.5kg (80.5 lbs)
Dimensions with plinth (H x W x D)	1296 x 311 x 384 mm (51.0 x 12.2 x 15.1 in.)

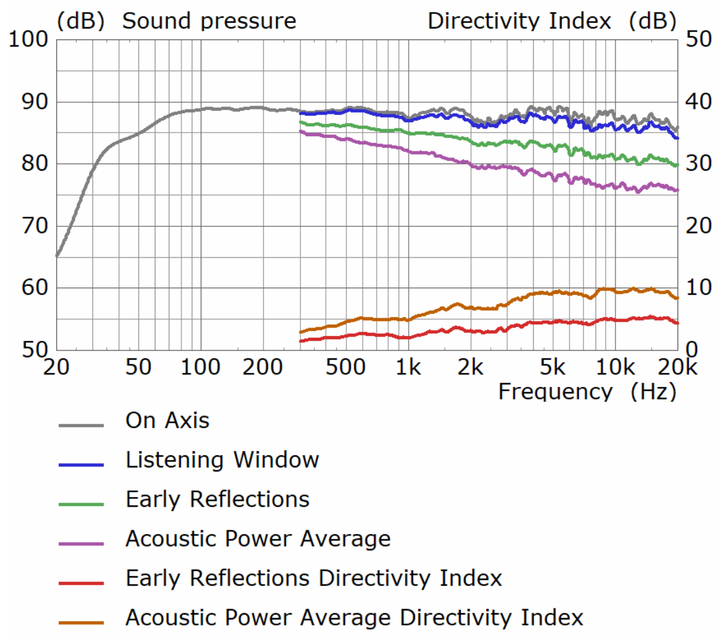




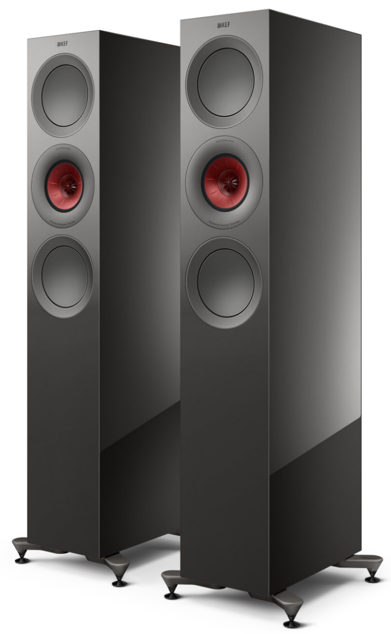
R11 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R7 Meta

Three-way Floorstanding Loudspeaker

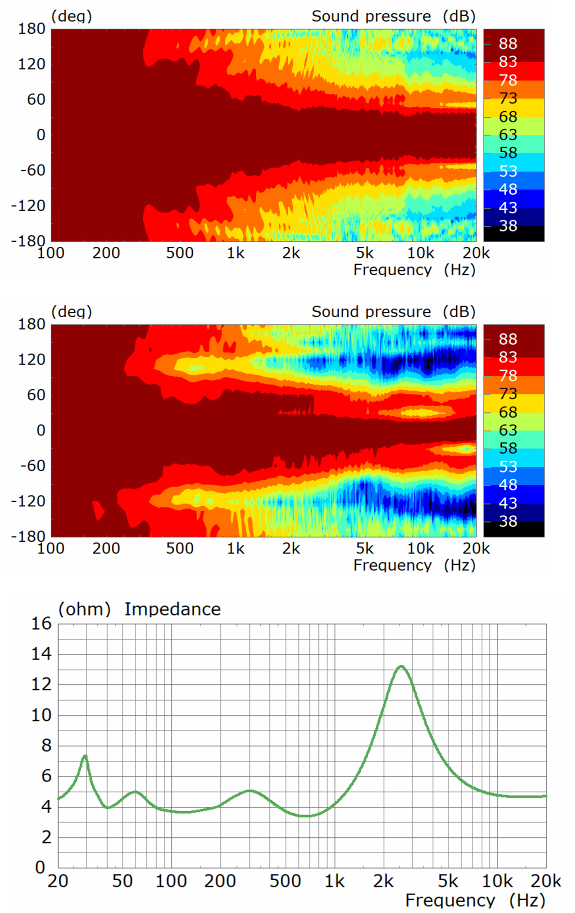


R7 Meta Spinorama



Technical Specifications

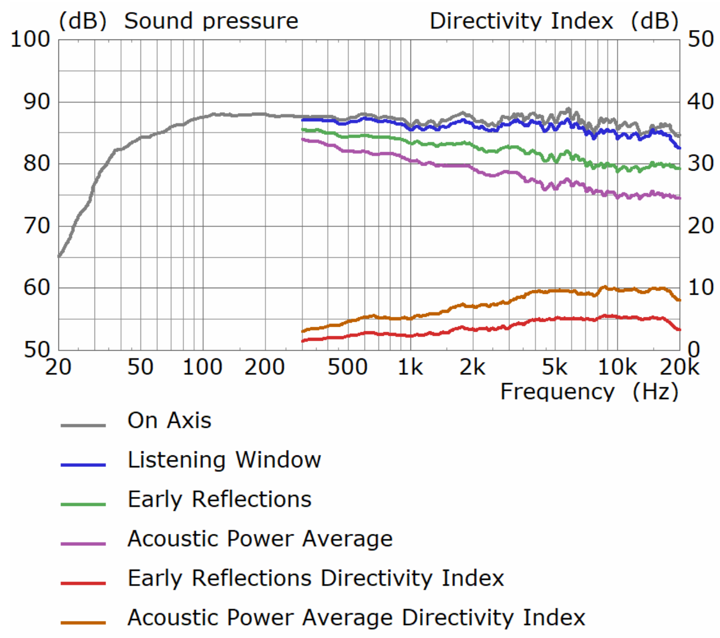
System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Drivers: LF: 2 x 165mm (6.5 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	33Hz - 50kHz
Typical in-room bass response (-6dB)	27Hz
Frequency response (±3dB)	48Hz - 28kHz
Crossover frequencies	400Hz, 2.4kHz
Recommended amplifier power	15-250W
Sensitivity (2.83V/1m)	88dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 76Hz and above <0.5% 110Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	111dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	29.3kg (64.6 lbs)
Dimensions with plinth (H x W x D)	1109 x 311 x 384 mm (43.7 x 12.2 x 15.1 in.)



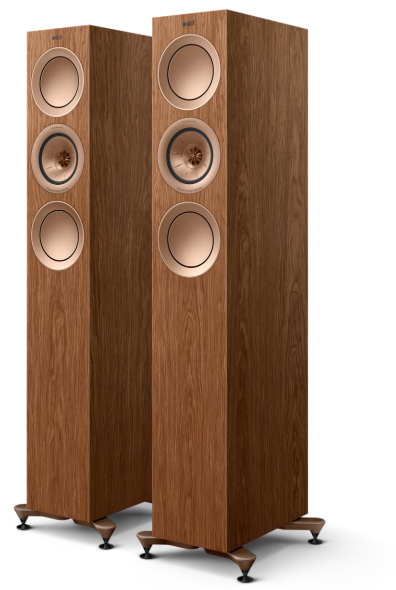
R7 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R5 Meta

Three-way Floorstanding Loudspeaker

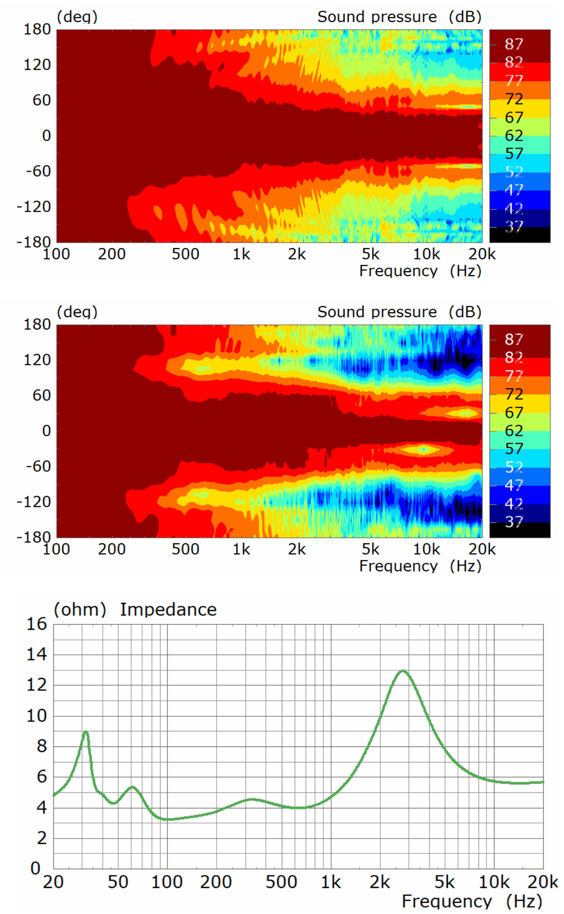


R5 Meta Spinorama



Technical Specifications

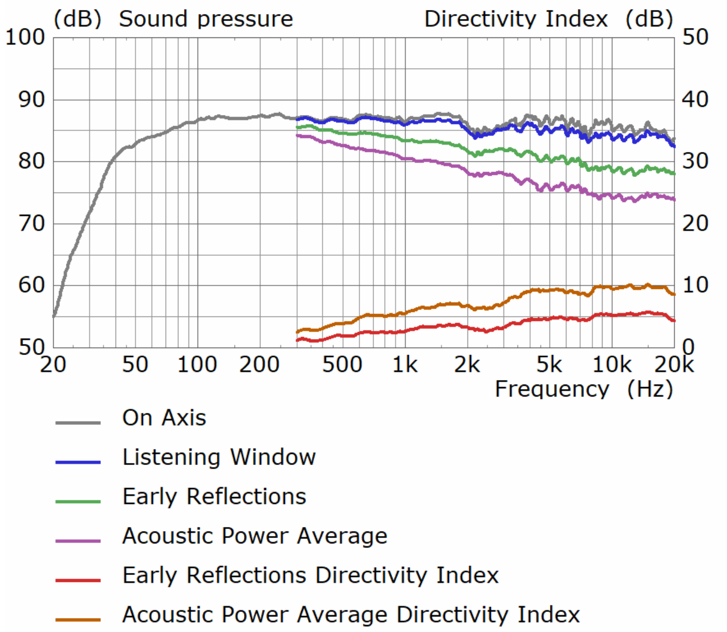
System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Drivers: LF: 2 x 130mm (5.25 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	38Hz - 50kHz
Typical in-room bass response (-6dB)	29Hz
Frequency response (±3dB)	52Hz - 28kHz
Crossover frequencies	400Hz, 2.7kHz
Recommended amplifier power	15-200W
Sensitivity (2.83V/1m)	87dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 75Hz and above <0.5% 110Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	110dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	24.5kg (54.0 lbs)
Dimensions with plinth (H x W x D)	1025 x 272 x 344 mm (42.2 x 10.7 x 13.5 in.)



R5 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R3 Meta

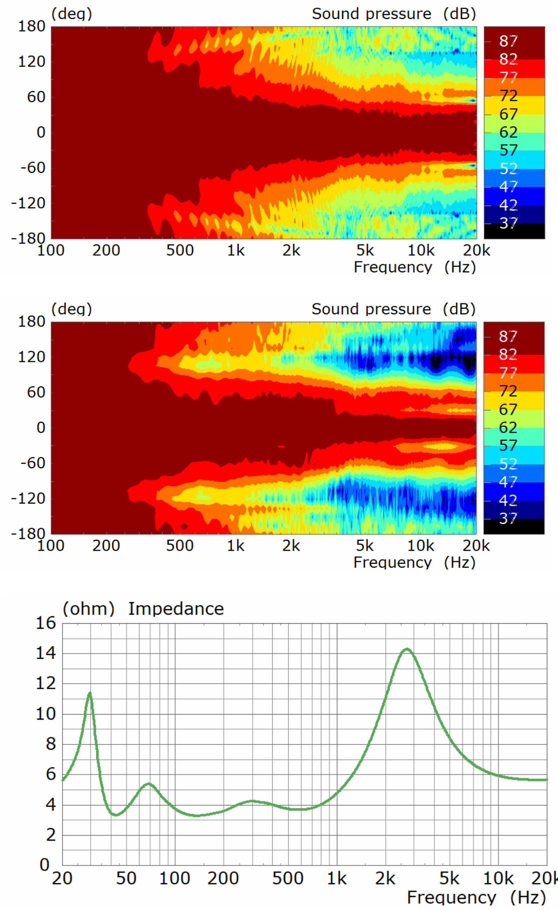
Three-way Bookshelf Loudspeaker



R3 Meta Spinorama

Technical Specifications

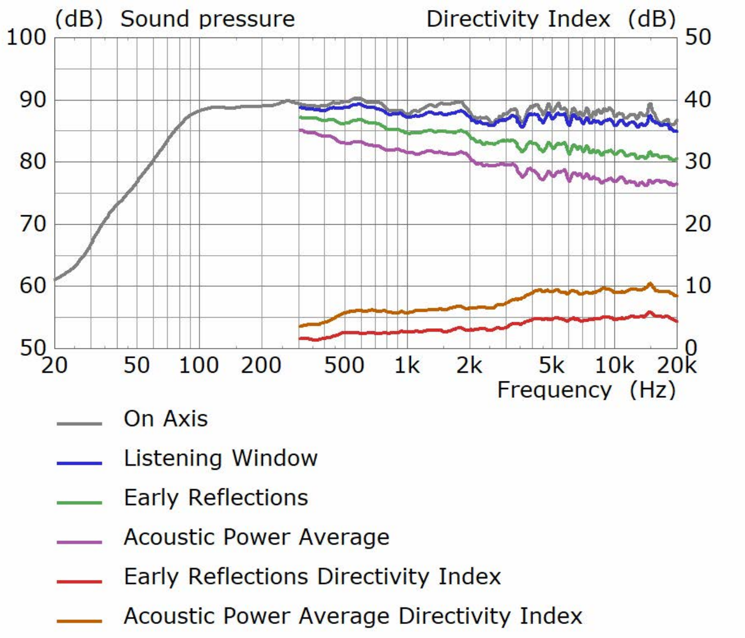
System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Driver: LF: 165mm (6.5 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	38Hz - 50kHz
Typical in-room bass response (-6dB)	30Hz
Frequency response (±3dB)	58Hz - 28kHz
Crossover frequencies	420Hz, 2.3kHz
Recommended amplifier power	15-180W
Sensitivity (2.83V/1m)	87dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 73Hz and above <0.5% 90Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	110dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	12.4kg (27.3 lbs)
Dimensions with plinth (H x W x D)	422 x 200 x 336 mm (16.6 x 7.9 x 13.2 in.)



R3 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R6 Meta

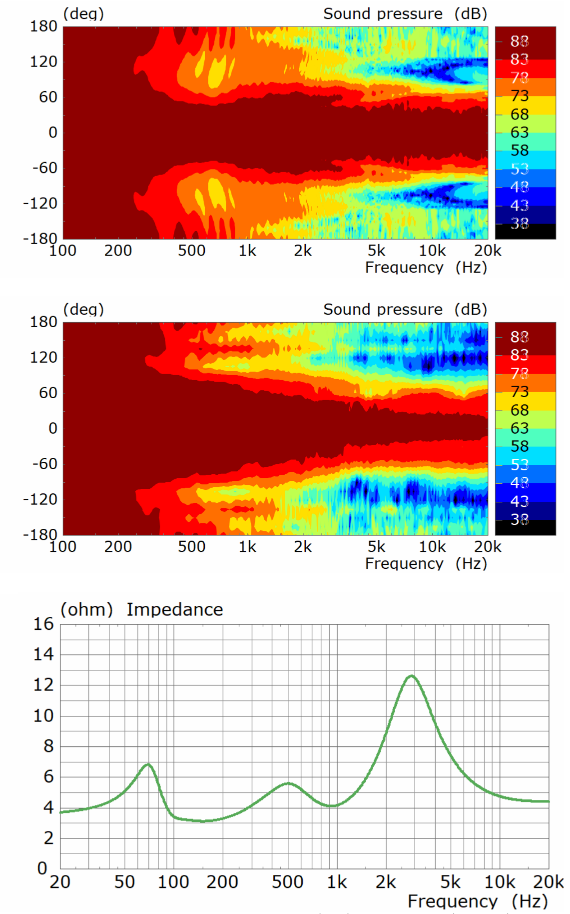
Three-way Centre Loudspeaker



R6 Meta Spinorama

Technical Specifications

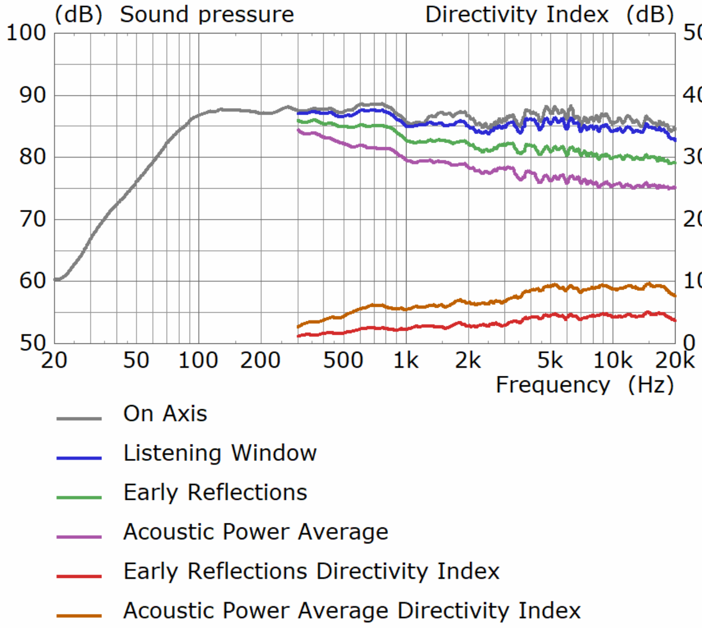
System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Drivers: LF: 2 x 165mm (6.5 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	55Hz - 50kHz
Typical in-room bass response (-6dB)	40Hz
Frequency response (±3dB)	65Hz - 28kHz
Crossover frequencies	550Hz, 2.4kHz
Recommended amplifier power	15-250W
Sensitivity (2.83V/1m)	88dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 65Hz and above <0.5% 93Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	111dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	17.8kg (39.2 lbs)
Dimensions with plinth (H x W x D)	200 x 625 x 339 mm (7.9 x 24.6 x 13.3 in.)



R6 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R2 Meta

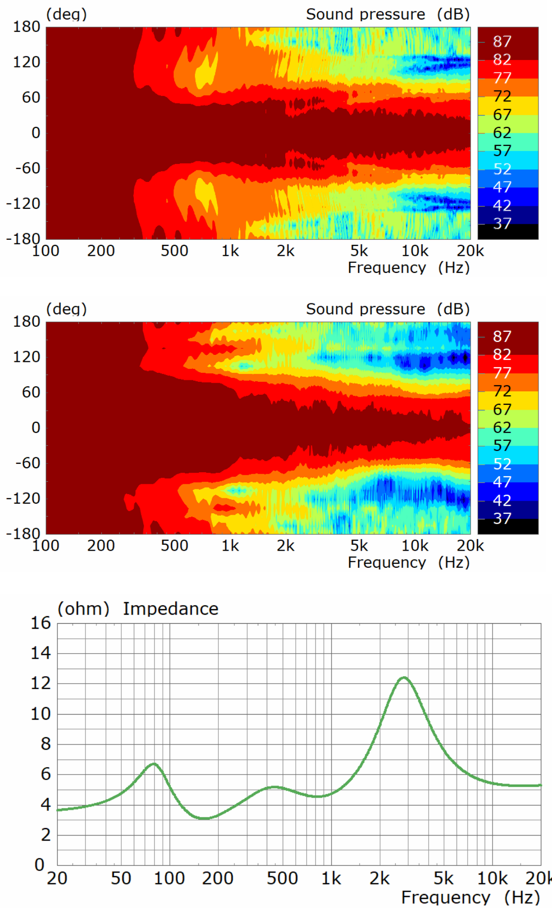
Three-way Centre Loudspeaker



R2 Meta Spinorama

Technical Specifications

System	Three-way bass reflex
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF: 125 mm (5 in.) aluminium cone Bass Drivers: LF: 2 x 130mm (5.,25 in.) hybrid aluminium cone
Frequency range free-field (-6dB)	58Hz - 50kHz
Typical in-room bass response (-6dB)	43Hz
Frequency response (±3dB)	67Hz - 28kHz
Crossover frequencies	560Hz, 2.5kHz
Recommended amplifier power	15-200W
Sensitivity (2.83V/1m)	87dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 84Hz and above <0.5% 95Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	110dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	15.4kg (34.0 lbs)
Dimensions with plinth (H x W x D)	175 x 550 x 309 mm (6.9 x 21.7 x 12.2 in.)



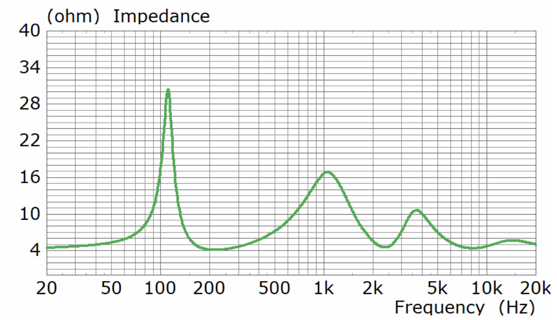
R2 Meta directivity contours - horizontal (top) and vertical (middle) - and impedance (bottom)

R8 Meta

Two-way surround/Dolby Atmos Loudspeaker

Technical Specifications

System	Two-way closed box
Drive units	Uni-Q Driver Array: HF: 25 mm (1 in.) aluminium dome with MAT MF/LF: 130 mm (5.25 in.) aluminium cone
Frequency range free-field (-6dB)	88Hz - 19.5kHz
Typical in-room bass response (-6dB)	-
Frequency response (±3dB)	97Hz - 17.5kHz
Crossover frequencies	2.6kHz
Recommended amplifier power	25-150W
Sensitivity (2.83V/1m)	85dB
Harmonic distortion 2nd & 3rd harmonics (90dB, 1m)	<1% 220Hz and above <0.5% 320Hz - 20kHz
Maximum output (Peak sound pressure level at 1m with pink noise)	106dB
Impedance	4 Ω (min. 3.2 Ω)
Weight	4.5kg (9.9 lbs)
Dimensions with plinth (H x W x D)	174 x 175 x 259 mm (6.9 x 6.9 x 10,2 in.)



R8 Meta impedance