

W H I T E P A P E R

TRIO11 BE



Context

The professional division of Focal, Focal Professional, has been constantly learning since its arrival on the monitor scene. Its ultimate goal? To offer high-performance work tools and an extreme level of precision, enabling all professionals and music production enthusiasts to have total confidence in what they are hearing. Totally transparent reproduction of the audio signal has been made possible by, among other aspects, the development of innovative technologies such as the 'W' composite sandwich cone, or the pure Beryllium inverted dome tweeter.

Over the years, these innovations have established the loudspeakers from the SM6 line as true references, in their category, on the professional audio market. However, while these high-end monitors guarantee the reproduction of each and every micro-detail, exceptional sound image precision and absolute neutrality, they remain primarily dedicated to nearfield. So how could Focal satisfy sound engineers who prefer working in the midfield? How could we meet the needs of the biggest, highest-volume studios searching for that coveted Focal sound signature? With Trio11 Be.

Here is the story behind the new reference monitor from Focal Professional, designed for both nearfield and midfield applications. Discover the latest technological innovations for music production, post-production or broadcast, offering an excellent SPL without compromising neutrality and acoustic transparency, so essential for studio work.



Objectives

There is no such thing as an ideal listening situation. Every sound engineer, musician, and producer has their own preferred way of working. Nearfield listening is more suited to studios in which the acoustics are not optimal; positioning yourself close to the loudspeakers allows you to listen at a lower volume and favours the direct sound. The effects of the room, such as reflections or resonance modes, are thereby minimised. However, working in the nearfield for a long time can be fatiguing.

Other sound engineers prefer to work in the midfield, further away from the loudspeakers. Moving away from the monitors allows you to listen at a higher volume, and therefore feel more the impact of the low frequencies in the upper part of the body. In addition, the difference in distance between the ears and each speaker driver is lesser than in the nearfield. This means that by moving away from the box, you are less subject to the positioning effects of the speaker drivers, as well as the diffraction effects of the box. If the room has good, controlled acoustics, it can then be very interesting if these acoustics contribute to the listening experience and therefore to the mastering, in order to be placed within a more realistic context of the end listener.

To best meet these differing expectations and to offer a great versatility of usage and configurations, we had to make sure we developed a high-power monitor. But increasing the power causes a higher level of distortion on the transducers, on the amplification and accentuates the "hiss" that comes from the tweeter between 1 and 12 kHz. Technological responses therefore needed to be developed in order to combine high-power amplifiers with speaker drivers boasting higher efficiency and power handling than the current transducers, while guaranteeing no noise.

The aim of this project was clear: to analyse the acoustic and electronic technologies and parameters that have an impact on perception and distortion, as well as the hisses on current systems, in order to minimise these effects as far as possible, while offering a significantly higher SPL.

Technological obstacles

Achieving Focal standards of quality while increasing performance and minimising associated problems was no easy task. The combination of highly-sensitive transducers with a high-power preamplifier/amplifier system with a high voltage gain is not consistent with a low hiss level, particularly at low volumes. The requirements at the level of this hiss proved to be very close to the performance of nearfield monitoring loudspeakers, whereas in the context of this type of project, the speaker drivers had to be more sensitive and the amplifiers more powerful, thereby generating more 'hiss'.

In addition to these difficulties, there was the compact nature of the electronics, which had to be compatible with the dimensions of a classic monitor, and the cooling, which could not be performed with a ventilation system that generated too much noise.

Record of work carried out

Our acoustic and electronic performance goals lay beyond what is offered by technologies accessible in this power range. So how could we exceed these limits? What steps would allow us to achieve these performance goals?

Firstly, from an acoustics point of view, improvements were made on the midrange and bass speaker drivers, primarily to increase their sensitivity while minimising their distortion.

To develop a woofer speaker driver with a low (F_s) resonance frequency, and thereby to achieve a good SPL in the sub-bass, a large mass on the woofer and a low compliance (inverse of the stiffness). However, this type of woofer will lack dynamics due to this heavy mass, which is difficult to move. A light woofer and a low compliance will allow good dynamics, but its F_s resonance frequency will be rather high. While developing the woofer for the Trio11 Be, we wanted to achieve very good dynamics, while retaining a low F_s and great excursion.

To do this, the mass of each part of the woofer was optimised. The 'W' composite cone allows a perfect combination of lightness, damping and rigidity, the three crucial parameters that define a quality cone. An aluminium flat wire was chosen for the coil, to limit the mass of the moving part as much as possible, as well as a thin surround and two highly-flexible spiders. The two symmetrically inverted spiders allow a perfectly symmetrical movement (figure 1). These guidance points on the former also serve to minimise any swing effect.

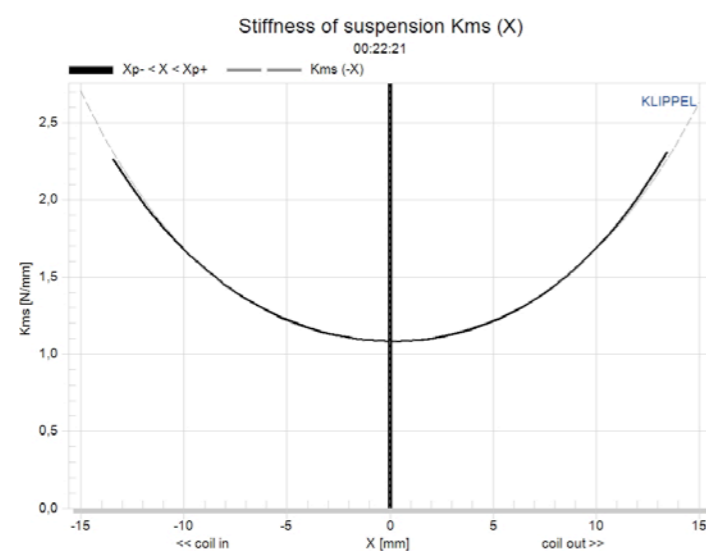


Figure 1: Surround rigidity and symmetry

The non-linear behaviour of a woofer primarily intervenes when it moves beyond maximum excursions X_{\max} . If the power of the magnetic system is too low, the speaker driver will then have to “force” its movements and this is where distortion comes into play. This is why, on this new 10” woofer, the magnetic power is extremely high, to allow it to remain in its “comfort zone”, and the perfect symmetry of the magnetic system guarantees linear behaviour. Figure 2 illustrates this stability of the magnetic system, with a B.I. Force Factor of 19 for an excursion of $\pm 11/16$ ” (17mm). Figure 3(a) shows the excursion according to the frequency and output voltage, and figure 3(b) illustrates this instant return to idle state for each frequency and each output voltage, producing excellent speaker driver dynamics.

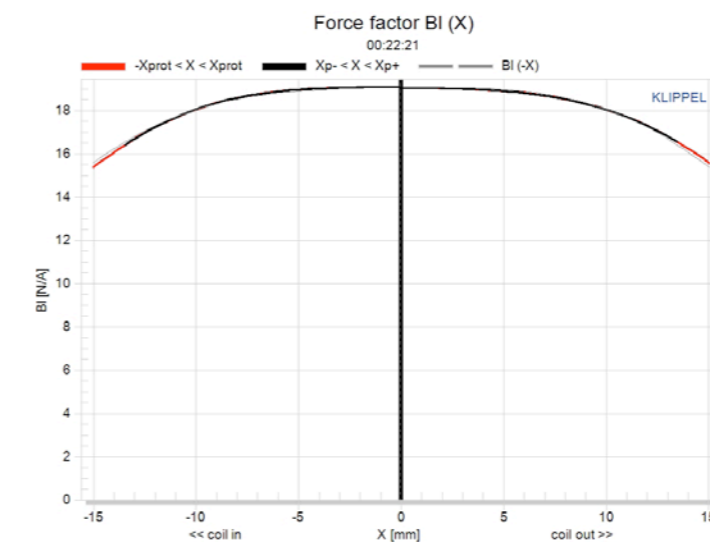
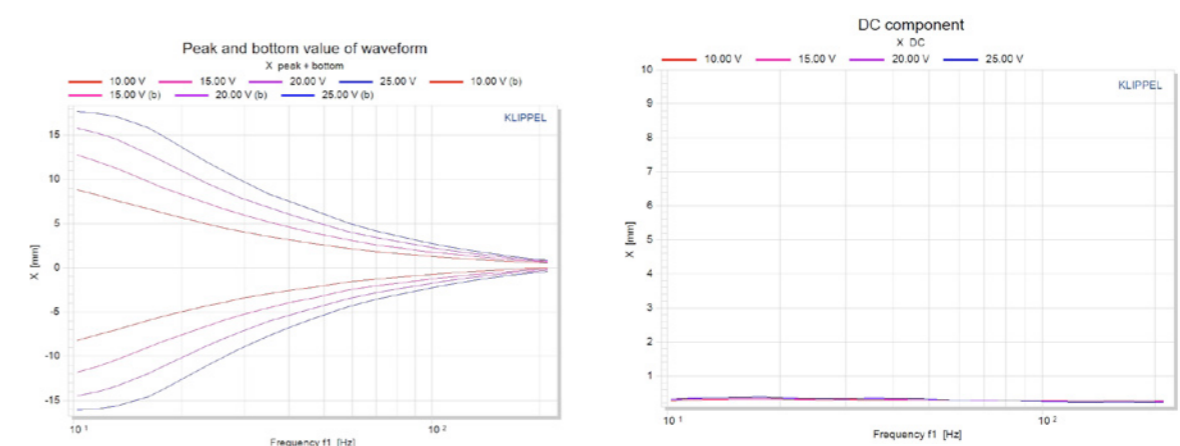


Figure 2: Magnetic power of the 10” woofer and coil movement



Figures 3: (a) Excursion according to frequency and output level: $X(f, V_{out})$ and (b) return to idle state: $Offset(f, V_{out})$

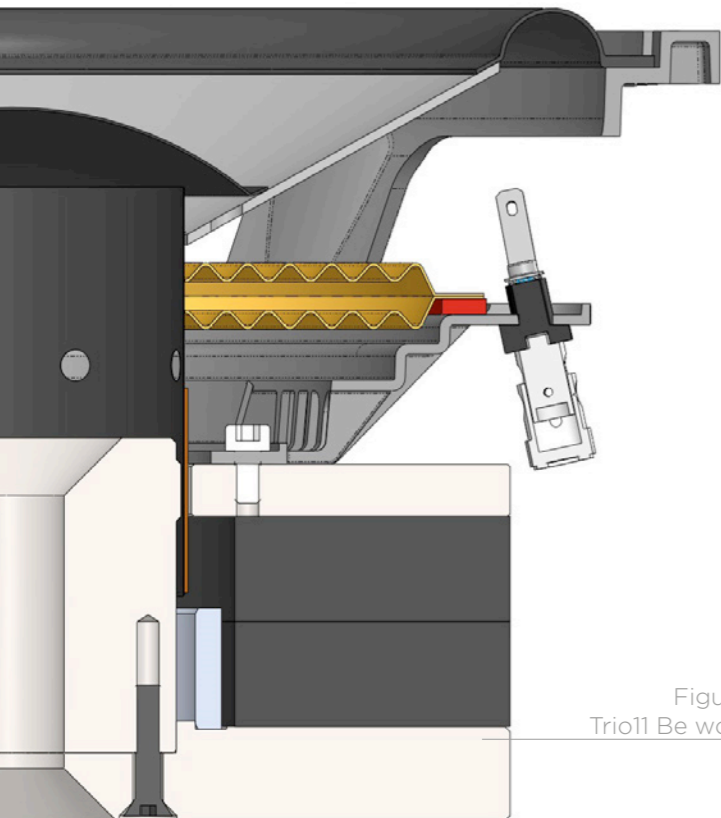


Figure 4:
Trio11 Be woofer

Thanks to the high compliance of the surround (flexibility of spiders, thin surround), the Trio11 Be woofer achieves a very low resonance frequency, for an effective and well-defined reproduction in the sub-bass region. The optimised masses of the cone, surround, coil and spiders, as well as the high power of the magnetic flux have enabled us to preserve the maximum acceleration of the speaker driver. This means that the Trio11 Be woofer has all the qualities needed to deliver excellent dynamics and great excursion whilst preserving a low F_s resonance frequency.

The woofer (figure 4) also benefits from one of the technological advances Focal has developed over recent years, the NIC (see Appendices), which acts as a Faraday cage around the coil and improves the stability of the magnetic flux while reducing distortion and intermodulations across low and midrange frequencies.

The midrange speaker driver (figure 5) has also benefited from these advances with the addition of the TMD (see Appendices) comprising masses arranged at specific points of the surround in order to optimise piston movement, dampening certain resonances and reducing distortion. Many simulations and listening sessions have been conducted in order to determine the ideal position for the TMD, as simulations aren't always self-sufficient. Thanks to the 'W' composite cone, the 'break up' frequency is located well beyond the range of use, and therefore maintains a piston action across its entire frequency range. Wide openings on the chassis, coil and under the spider minimise the reflection and resonance effects, maximising air movement in order to reduce distortion and thereby produce better acoustic transparency. Likewise, the neodymium motor enables a combination of high power and compactness in the magnetic system, similarly to minimise reflections.

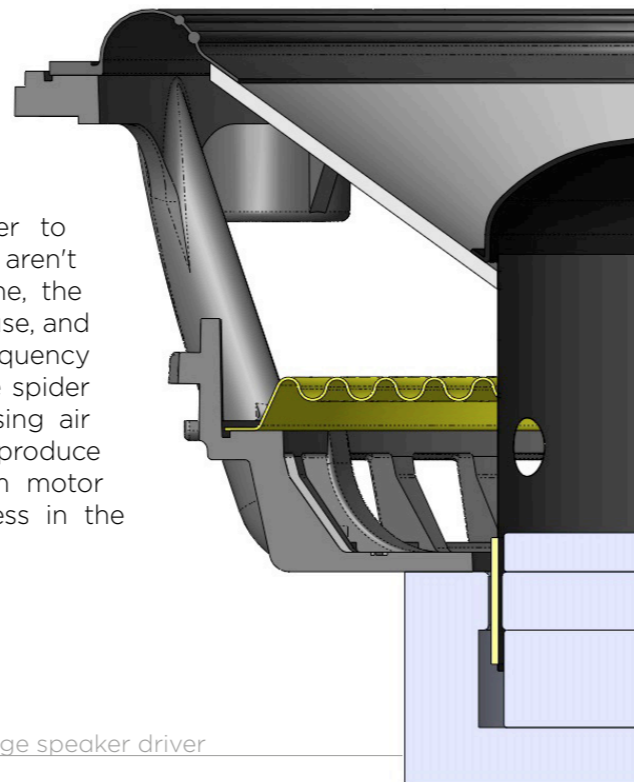


Figure 5:
Trio11 Be midrange speaker driver

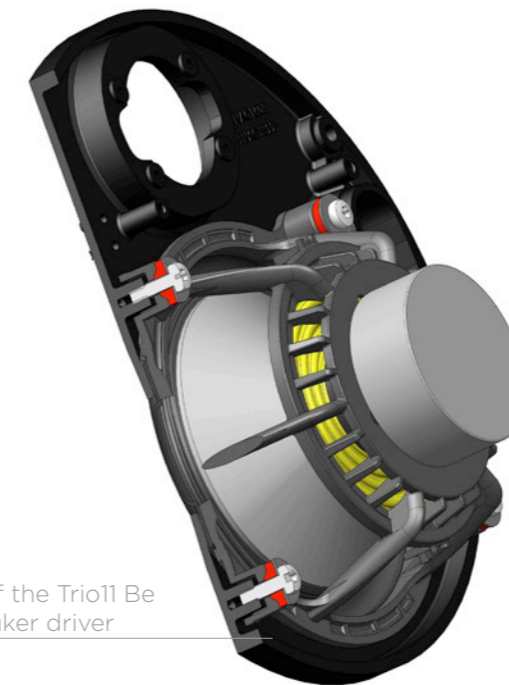


Figure 6:
Silent blocks of the Trio11 Be
midrange speaker driver

A rubber ring between the chassis of the speaker driver and the plate prevents vibrations from being transmitted to the cone. However, in our quest for the ultimate sound reproduction, we observed that light vibrations were still being carried through the screws. The development of silent blocks (in red on figure 6) has therefore enabled us to completely decouple the chassis from the cabinet to eliminate any transmission of vibration or resonance.



Figure 7:
Trio11 Be tweeter

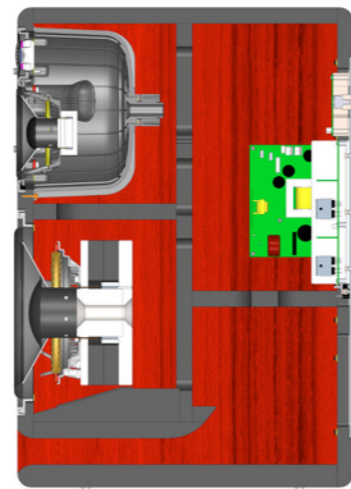
The 1" tweeter with pure Beryllium inverted dome (figure 7), a Focal signature, presents (as with Trio6 Be) a perfectly linear frequency response, excellent dynamics and a large dispersion. The protective grille has been developed and optimised to be as acoustically transparent as possible. The tweeter's tonal balance has been done with the grille.

Just like Trio6 Be, Trio11 Be has two monitors in one thanks to FOCUS mode: the control pedal lets you switch between a 3-way monitor and a 2-way monitor. The 2-way monitor has a reduced frequency response (90Hz - 20kHz) to check the transfer quality of mixes on systems with limited bass frequency response such as, for example, televisions, radios, computers, etc. And since balancing the register of the midrange is so critical, FOCUS mode also makes it possible to control the mix with a harder driven midrange speaker driver as it also becomes the speaker driver for the low frequencies in 2-way mode.

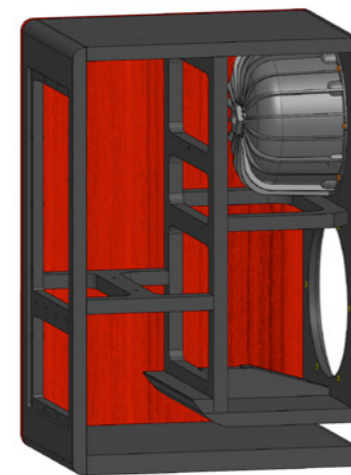
To handle the large volumes of air generated by this powerful woofer, special attention has been paid to the vent (figure 8 (a) and (b)). Firstly, the opening surface at the front has been enlarged as far as possible, with no obstacle in the way, thereby making it possible to maintain a constant tonal balance, even at high SPLs, and to reduce compression phenomena to keep the bass ranges controlled and dynamic. The flare of the vent has been optimised to minimise turbulence. Finally, to reduce vibrations, the wall is $1\frac{3}{16}$ " (30mm) thick.

The rigidity of the cabinet has been optimised using several braces around the tweeter-midrange horn, around the woofer and the electronics. These braces have been precisely positioned to reduce vibrations of the cabinet as much as possible and to dampen any resonance.

Frequency response measurements quickly offer a good indication of the quantity of foam necessary to dampen internal resonances, but only listening really allows optimal positions and quantities to be achieved (figure 9). The foams have been specifically selected for the midrange speaker driver or for the woofer.



a.



b.

Figures 8:
(a) Section of Trio11 Be showing vent,
(b) Internal 3D view

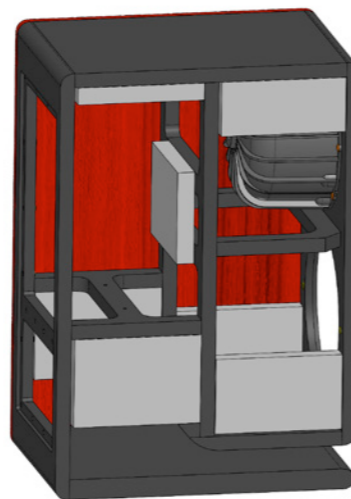


Figure 9:
Trio11 Be
internal foam

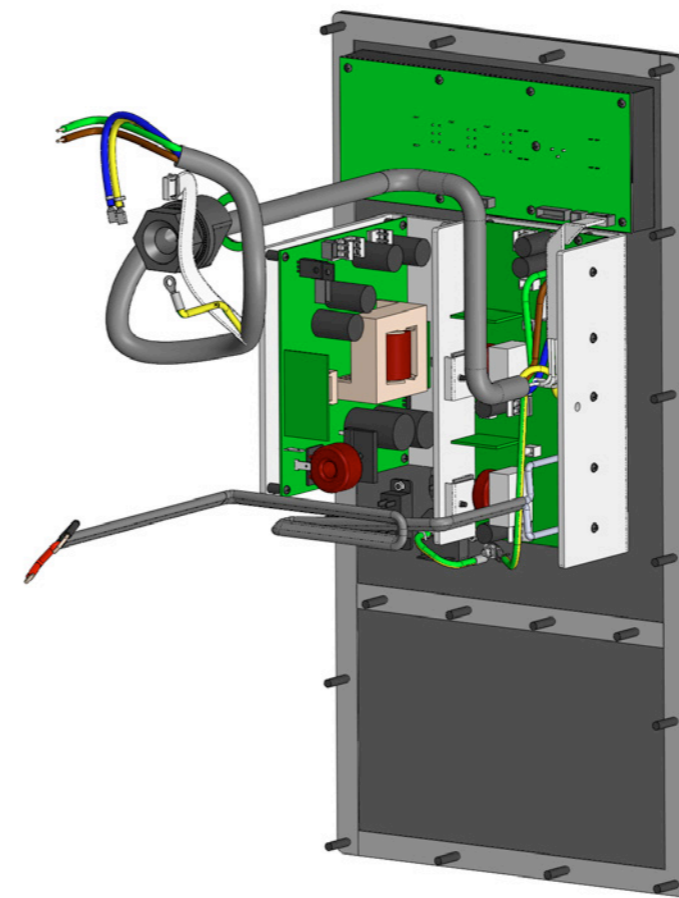


Figure 10:
Electronics inside Trio11 Be

Developing the ideal amplification for a monitor to offer high power, necessary for the midfield, and no noise, essential in the nearfield, required very careful attention to be paid to each parameter (figure 10). Firstly, the midrange and bass speaker are amplified by a class G amplification using BASH technology. This technology combines the best of classes AB and D by offering the quality of an class AB amplifier and the efficacy of a class D.

Secondly, we have opted for an assembly of discrete components. This design is more complicated to develop but enables us to optimise all criteria as far as possible, namely noise, bandwidth, distortion and power. The graph in figure 11 shows a measurement of total harmonic distortion and of extremely low noise. The measurement also shows the effect of the compressor at high volumes. Even at high volume, the signal remains clean.

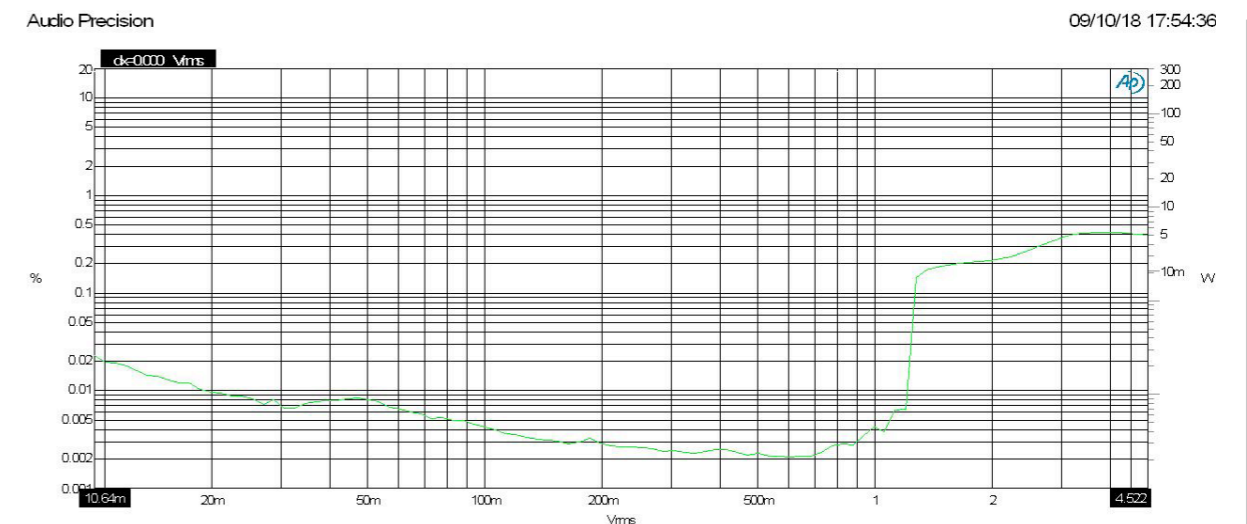


Figure 11:
Total harmonic distortion
and noise measurement (THD + Noise)



Results

In designing Trio11 Be, the aim was to achieve both more power and less noise: and Focal succeeded. Trio11 Be can be used for nearfield and midfield listening, offering greater versatility in terms of usage and installation configurations. Thanks to the latest technologies in acoustics (new speaker drivers, TMD, NIC) and electronics (BASH), Trio11 Be reveals the tiniest micro-details of the sound signal, while guaranteeing an exceptional stereo image and no distortion. Like Trio6 Be, Trio11 Be makes it possible to check the mix transfer sound quality thanks to FOCUS mode, letting you switch between a 3-way system and a 2-way system.



TMD suspension or our midrange obsession...

In continuation of the work done for the woofer-midrange driver of the Diablo Utopia, and with hindsight and experience gained through the manufacture of thousands of drive units revealing the high criticality of the cone-suspension assembly, we realized that the multitude of parameters involved made it illusory to suppose we could develop a solution empirically. We had instead to develop a computer simulation model that represents this complex mechanical connection well enough, first to correlate the results observed from many prototypes, and second to develop a non-empirical, reliable solution. Today, computing power is enabling the finite element

method to calculate the dynamic response of complex objects and thus to predict the behaviour of virtual prototypes. And consequently to devise accurate and relevant solutions.

Standard measures such as frequency response, distortion, even laser interferometry, highlight the problem but as a snapshot, a still photograph. What we need is a 'movie' to reveal the motion, understand the phenomenon as a whole and thus devise effective solutions. 'Patch' correction of static defects linearizing the response curve can be devastating to dynamic behaviour. The midrange is undoubtedly the most complex area and

the most demanding musically; it is a key element of the sound signature of Focal, and spoiling its resolution is simply not an option!

With a numerical model that correlated closely with classical acoustic measurements on numerous prototypes (over a hundred have been tested!), we could at last consider a remedy. The computer model is used to accurately assess the addition of mass or stiffness to the suspension, the added masses acting as a dynamic vibration absorber. The technique, which is well known, is termed a "tuned mass" or "harmonic" damper.

It was used with great success in the suspension of the Renault R25 F1 car in 2005 – and was quickly banned because it was considered anti-competitive by the FIA! It is also the basic principle of antiseismic systems for modern skyscrapers. (fig A)

This principle applied to a drive unit surround consists of two small circular rings, acting as additional masses, which oscillate in opposition to the resonance frequency of the surround. (fig B)

This device offers major advantages. We are able to:

- Use an exponential cone profile that extends the bandwidth to more than 5kHz and thus achieve better transient response;

- Choose a very light surround, eliminating the resonance that is even stronger when the mass is low;

- Damp resonance in the direction of the sound radiation (the radial plane) whereas competitors' devices damp circumferential resonances of the suspension. (fig C et D)

Thus we can combine benefits which were previously irreconcilable: low mass, optimum damping and extension of the frequency response. (fig E)

This leads to several benefits at the listening level: improved transient response coupled with a flat frequency response and reduced distortion, of the order of more than 50 per cent in an area where the ear is

highly sensitive around 2kHz. This results in more accurate timbre, improved definition and better stereo imaging. To clarify the last point, the resonance of a conventional surround blurs the soundstage, especially when the resonance is marked. TMD suspension eliminates the problem at source. (fig F)

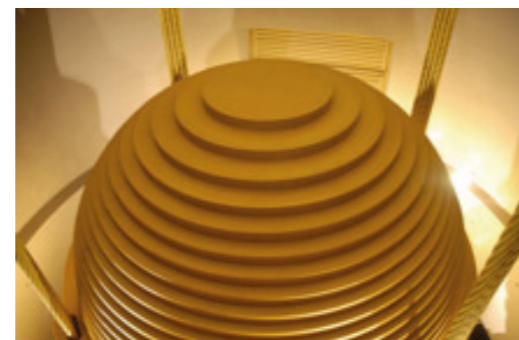
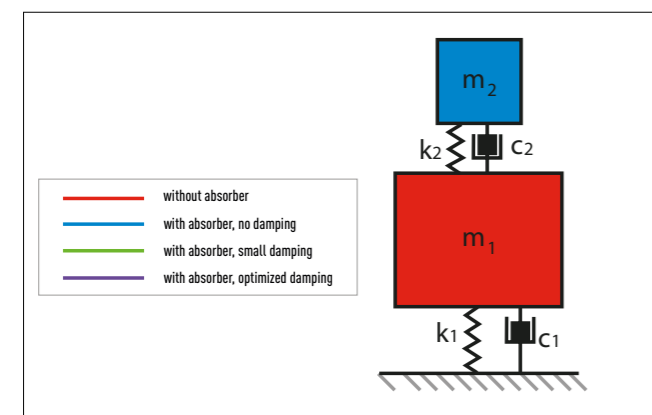
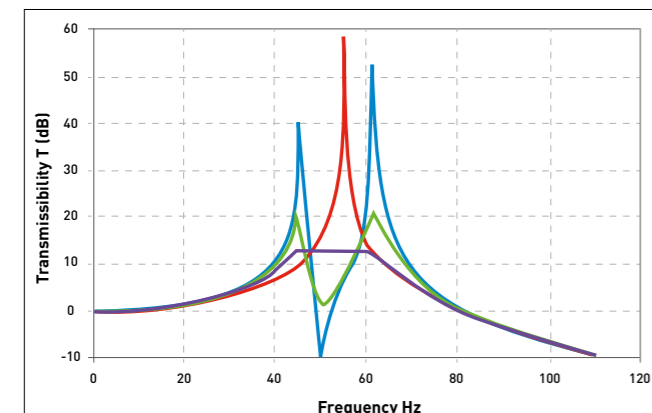


Fig A: The principle of the tuned harmonic damper (TMD) is shown in the graph, above. A system comprising a single mass m_1 and spring k_1 has a marked resonance (red trace). Addition of a second mass-spring system, m_2/k_2 as shown in the diagram, results in two resonance peaks (pink trace in the graph). If the anti-resonance dip is aligned with the resonance of m_1/k_1 we obtain the green curve and finally, with careful application of damping, the black curve – the resonance has virtually disappeared! Photo down shows the TMD ($m_2 = 660$ tonnes) used in the skyscraper Taipei 101.

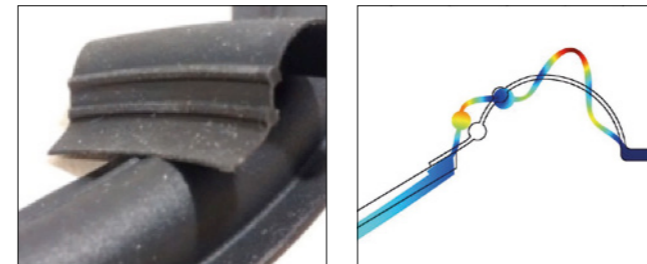


Fig B: Two moulded circular beads in the surround form our tuned harmonic damper. While this appears to be a simple solution, over a hundred different configurations were tested to optimize the result.

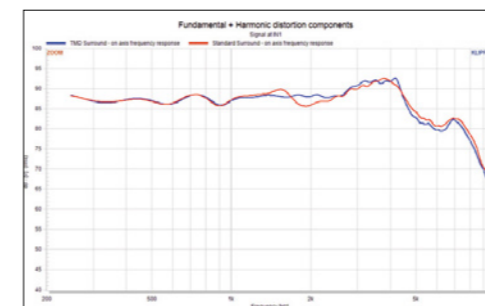


Fig C: Effect of the harmonic damper on linearizing the frequency response between 1.5 and 2kHz (blue trace with TMD, red trace without, all other parameters the same).

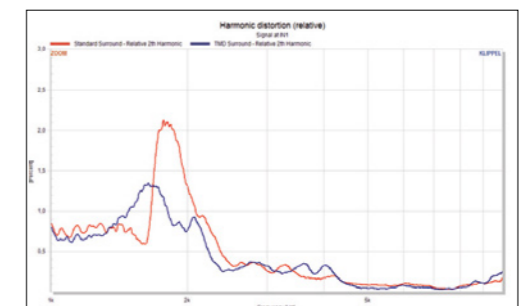


Fig D: Effect of the harmonic damper on nonlinear distortion, which is halved between 1.5 and 2kHz (blue trace with TMD, red trace without, all other parameters the same).

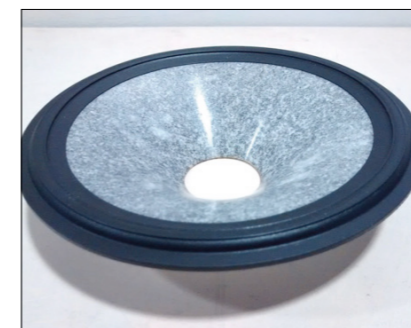


Fig E: Optimum parameters combined: very low moving mass for high definition, exponential profile for extended frequency response, and optimum surround damping for linear response and low distortion.

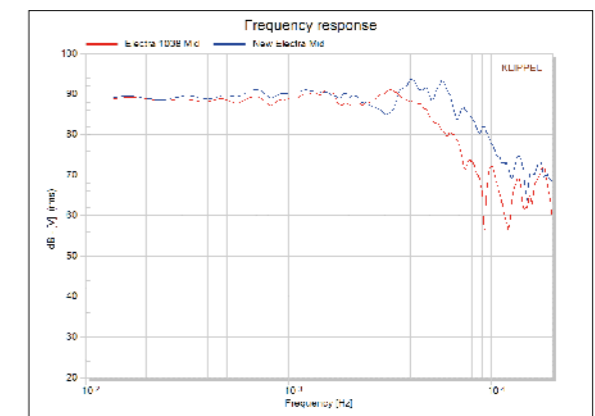


Fig F: Frequency response of our latest midrange driver (blue trace) compared to the previous-generation W-cone midrange, representing prior state-of-the-art performance (red trace). Note the improved response linearity between 1 and 2kHz and the frequency extension provided by the exponential cone profile. Improvements to the magnetic circuit also contribute (see next section). NB: The dip at 3kHz in the blue trace is due to the tested driver not being fitted with a dust cap.

Refining the magnetic circuits

In recent decades our work on the magnetic circuit primarily comprised optimizing the magnetic field strength and therefore the force factor, a key criterion in terms of acceleration and thus expressive musical rendering.

Also we have:

- Developed motors equipped with advanced magnetic materials for the Utopia III and the Be tweeter, and field coil woofers with our EM technology;
- Reduced magnetic losses by optimizing the geometry of the pole piece, sizing of the plate-core (T-Yoke) and flatness of field plates, as in

the multiferrite Power Flower midrange unit. Further research work on a concept speaker with its voicecoil around the circumference of a flat diaphragm (US Patent 2013/0064413) was very informative.

To improve performance further is an extremely complex problem because this is a dynamic electromagnetic system with multiple interrelated factors. As the coil moves in the gap it modulates the magnetic field (Lenz's law), in different ways depending on its position. And as the voice coil current varies depending on the music signal, it induces Eddy currents in

the magnetic circuit which have the effect of slowing the movement of the coil.

Both these phenomena vary according to a third factor, which is the frequency. Ideally we would like to eliminate these effects but they are very complex and only sophisticated numerical modelling could help us progress. This work, undertaken over three years of research, has delivered important improvements, similar in significance to that achieved mechanically with the "Gamma structure" used in our cabinets to provide an inert, neutral foundation for the drive units.

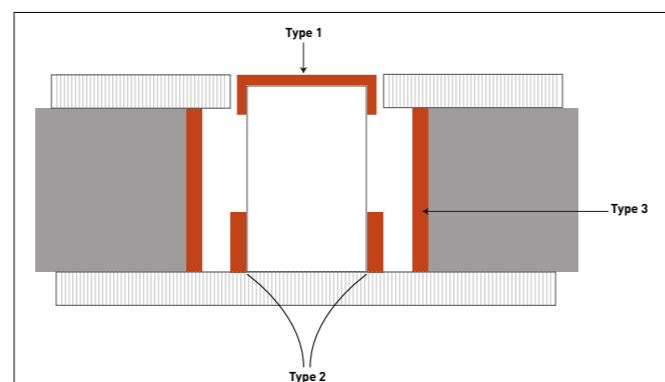


Fig G: Three types of Faraday ring that can be fitted to limit the effect of Eddy currents. As types 1 and 2 have the undesirable side-effect of reducing the force factor (BL), we used type 3.

The need for a simulation tool

Many attempts have been made in the last 70 years to avoid the effect of Eddy currents. Use of a Faraday ring of copper or aluminium is common but unsatisfactory since it embodies no overall vision of the phenomenon. It was not until the late '90s with the development of the Klippel Analyzer that we finally had a tool to reveal their dynamic behaviour. Moreover, these devices can have a detrimental impact on the field strength and therefore the force factor (BL), which for Focal is not an option.

Three configurations of Faraday ring are commonly encountered (fig G); only the one disposed within the motor near the magnet does not affect the force factor.

The difficulty resides in the sizing of this ring. Our tests have shown that low frequency performance is very sensitive to the thickness of the ring, whereas turn-to-turn distance in the voice coil is very important at high frequencies. With our simulation tool, we were able to work effectively to optimize both our woofers and our midrange drivers.

The first step in our research was to focus on evaluating the change in inductance of the voice coil as it moves within the magnet gap, as a function of frequency. Ideally the inductance should remain constant but does not. Mathematical tools developed in-house with reference to measurements made on numerous physical prototypes have led to the development of simulation software that finally allows us to work effectively. (fig H)

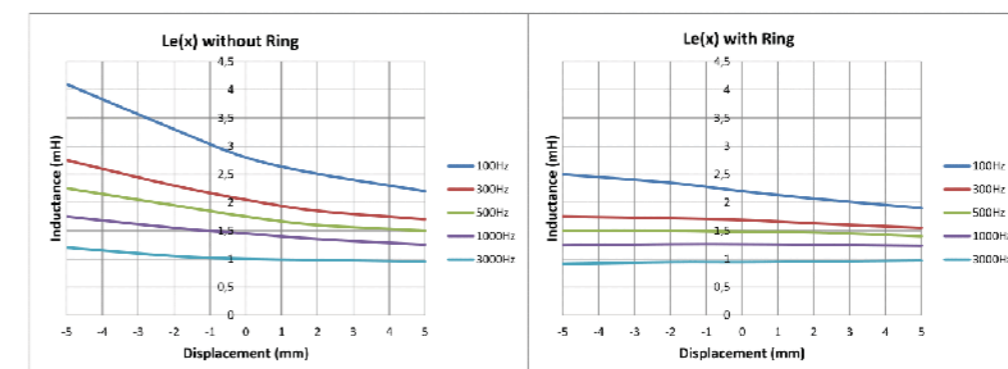


Fig H: The power of our simulation tool brings new insights and above allows us optimize magnetic circuits that were previously unthinkable. In this example we model the variation in voice coil inductance with position in the magnet gap at five different frequencies without Faraday ring (left) and with ring (right)

New woofer magnetic circuit

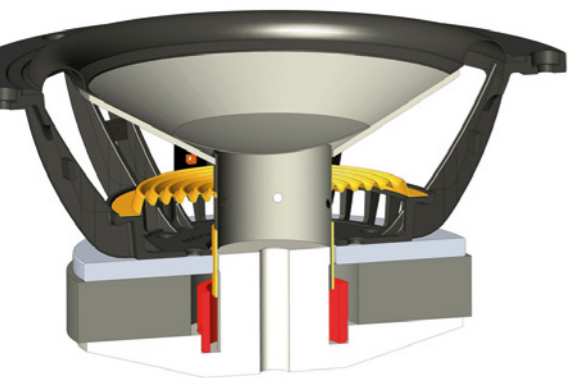


Fig I: Ideal positioning of the Faraday ring for a woofer motor obtained through our simulation tool.

The best results were obtained with a concentric Faraday ring placed at the base of the pole piece, 3mm to 20mm high, having no direct contact with either the pole piece or the magnet. Measurements made using the Klippel Analy-

zer reveal the precision of our mathematical model and its power to optimize a magnetic circuit. What might seem irreconcilable is now possible: to have inductance that is independent of the position of the voice coil, the current in the voice coil, and signal frequency. Distortion (harmonic and intermodulation) is reduced by 70 per cent! (fig J)

New midrange driver magnetic circuit

Our historical obsession with the midrange encouraged us to go further, as this is an area of the spectrum where the ear is extremely sensitive. As mentioned previously, in 2009 we developed a concept loudspeaker that uses no pole piece (US Patent 2013/ 0064413) where

the voice coil is immersed in the direct field of an annular neodymium magnet. Because this magnetic circuit lacks any ferromagnetic element, it is notable for being insensitive to Eddy currents induced by the current flowing through the voice coil, which changes in relation to the music signal. It has behaviour close to that of air, resulting in a magnetic field that remains stable up to more than 5kHz - ideal for a midrange driver. (fig K)



Fig K: Magnetic circuit without a pole piece. Focal patent US 2013/0064413

The main reason that this concept has not yet found application (in addition to the manufacturing issues) lies in the amount of Neodymium needed to achieve high sensitivity in a 6-inch midrange driver. Nevertheless it was a useful reference we have named NIC (Neutral Inductance Concept)

when envisaging the magnetic circuit of an economically viable midrange unit.

Our simulation tool was very helpful in developing an optimal structure with performance closer to our NIC reference. A central Neodymium magnet is topped with a ferro-

magnetic pole piece brought to saturation ($> 1.5T$) by a second Neodymium pellet above it (fig L). The field is looped by a ferromagnetic circuit dimensioned to avoid saturation. Finally a Faraday ring is carefully positioned further to reduce distortion below 1kHz. (fig M)

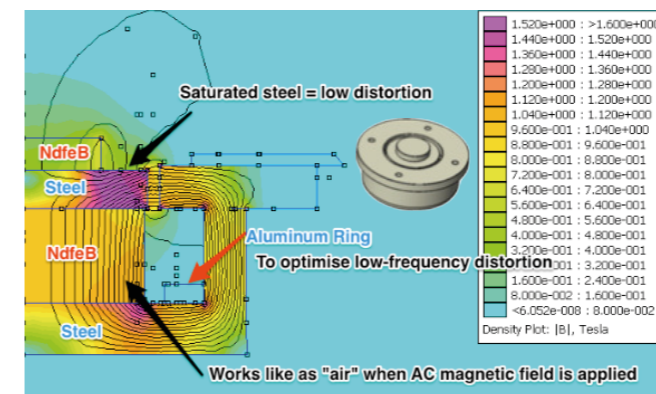


Fig L: Our simulation tool has led us to this optimized «NIC» magnetic circuit for the midrange driver. It reconciles efficiency with linearity of the voice coil inductance as a function of both the position of the coil and the current flowing through it, across the frequency range.

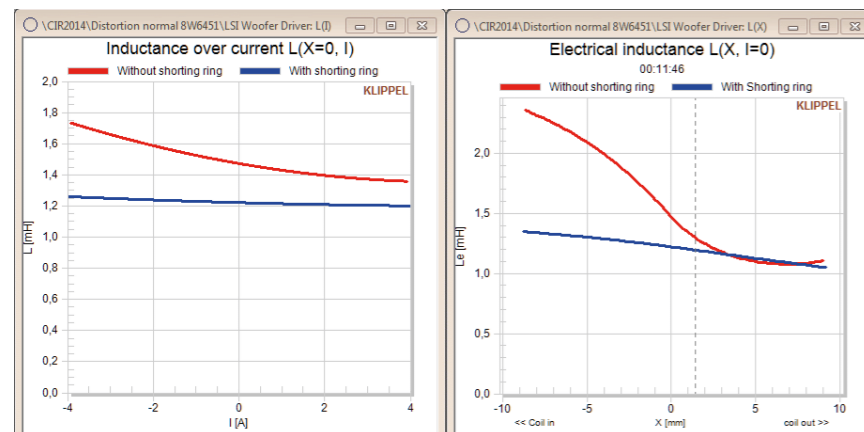


Fig J: Measurements made using a Klippel Analyzer on an 8-inch woofer without a Faraday ring (red trace) and with a Faraday ring optimized through our simulation tool (blue trace).

Left: Inductance variation as a function of the current through the voice coil, which is signal-dependent. Total stability.

Right: Inductance variation as a function of the position of the voice coil in the magnet gap. The improvement here is spectacular, especially as the coil moves into the driver.

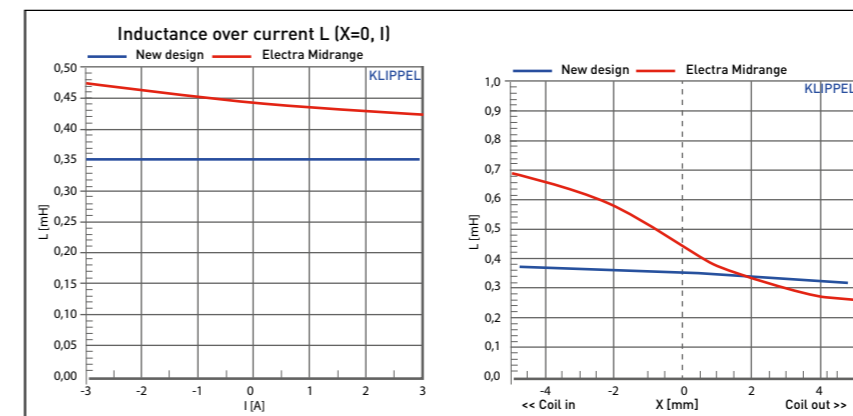


Fig M: Measurements made using a Klippel Analyzer on a 6-inch midrange driver with the new «NIC» magnetic circuit (blue trace) and a 6-inch midrange unit with a conventional ferrite motor (red trace).

Left: Inductance variation as a function of the current through the voice coil, which is signal-dependent. Total stability with «NIC».

Right: Inductance variation as a function of the position of the voice coil in the magnet gap. The «NIC» improvement is spectacular.

Two large plusses ...

We have now applied two major developments to our up-market midrange driver: our harmonic damper suspension "TMD" and our new magnetic circuit "NIC". It is interesting to see the combined effect of these two innovations on overall performance.

The results show: extended frequency response for better transient performance and thus better definition; high linearity in the critical region 1-3kHz for improved timbral accuracy; drastic reduction of resonance in the surround and nonlinearities in the magnetic circuit which are responsible for blurring the stereo image (fig N).

As for the woofers, distortion is reduced by about 70 per cent! This spectacular value shows that, above all, the focus of the Focal brand remains on its core business: the transducers. They are designed to enhance Focal's reputation for expressiveness of musical rendering!

Let us add that these performance figures are meaningless if taken out of their global context of providing the richest possible listening experience, emotional and sensory, with minimal coloration and the highest definition. This remains our crusade...

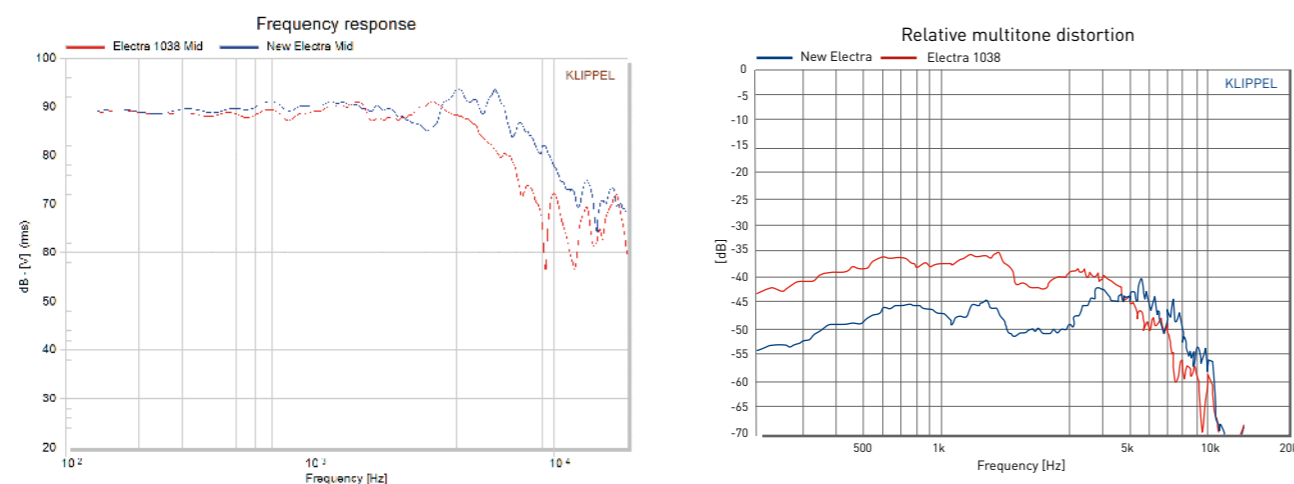


Fig N: Left, frequency response of our latest-generation midrange driver (blue trace) compared to the previous-generation W midrange (red trace). The extension of the frequency range, resulting from all the improvements but particularly the exponential cone profile, is important as it promises improved transient response. NB: The dip at 3kHz in the blue trace is due to the tested driver not being fitted with a dust cap. Right, distortion analysis using the Klippel multi-tone test signal which gives an overview of nonlinear distortion performance (harmonic and intermodulation). The lowering of distortion by about 10dB is a reduction of almost 70 per cent.



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