FINKTEAM

WM-4

WHITE PAPER

May 2017

The first WM-4 cabinets leave the cabinet shop.

Introduction

As a division of Europe's premier loudspeaker design consultancy, we at FINKTEAM are involved in the creation of many different speakers across a wide range of prices. Loudspeaker manufacturers hire us because of our expertise, experience and extremely well-equipped simulation and measurement facilities. But we are 'backroom boys' so much of our work is, in the nature of consultancy, confidential: only if the client elects to mention our involvement are we credited.

When we began work on designing a loudspeaker for ourselves, from the ground up and virtually without cost limitations, we envisaged it both as demonstration of our capabilities and as a very useful internal reference. There was no intention that it would go on sale. We are loudspeaker engineers, not loudspeaker manufacturers – at least, not normally.

But events took an unexpected turn when Marantz Europe's brand ambassador Ken Ishiwata heard an early and not very eye-pleasing prototype (it was known internally as 'the washing machine') and asked us to create a properly finished version which he could use to demonstrate his electronic designs. This speaker, the WM-3 – with industrial design by Kieron Dunk of IDA in England – we unveiled at the Munich High End show in 2016, and it was so well received that we were forced to rethink. Like a car maker who shows a concept car that wows press and public alike, we realised that there was unexpected demand for what we had created.

So we set about making it a 'real' product, a process which involved much more than creating a small-scale production line. We decided to enhance the design in key respects: by swapping the WM-3's nice, but not perfect bass driver for a design of our own, by improving the midrange driver chassis, and by selecting a different AMT (Air Motion Transformer) tweeter. Of course, all this required changes to the crossover and cabinet too.

The result of our efforts, the WM-4, is the best loudspeaker we currently know how to make: the distillation of our wide, deep experience of designing loudspeaker drive units and loudspeaker systems, and marrying them into something even greater than the sum of its parts.

We believe the combination of our design skills together with total control of manufacturing as we build in-house allows us to deliver a world-class loudspeaker system that is at home playing audiophile demo tracks as playing classic rock, jazz and orchestral music.

In summary, the WM-4 may be a technical tour-de-force but it is all for one single purpose: to maximise musical enjoyment.

Overview

FINKTEAM's WM-4 is a three-way, twin-cabinet design featuring a 15-inch bass driver, twin 5.5-inch flat-diaphragm midrange drivers and an AMT tweeter. The two midrange drivers and tweeter, arranged as an MTM (D'Appolito) array, are housed in the top cabinet which is faceted to reduce diffraction effects. The bass driver occupies the lower cabinet and is reflex loaded via a large forward-firing port.

The WM-4 combines wide bandwidth (30Hz-30kHz) with high sensitivity (90dB) but is easy to drive, with an average impedance of around 6 ohms and low impedance phase angles. To make the WM-4 better adapted to use with some valve amplifiers, an optional impedance smoother is provided which reduces the impedance variation and hence the frequency response errors that result from high amplifier output impedance.

Bass units

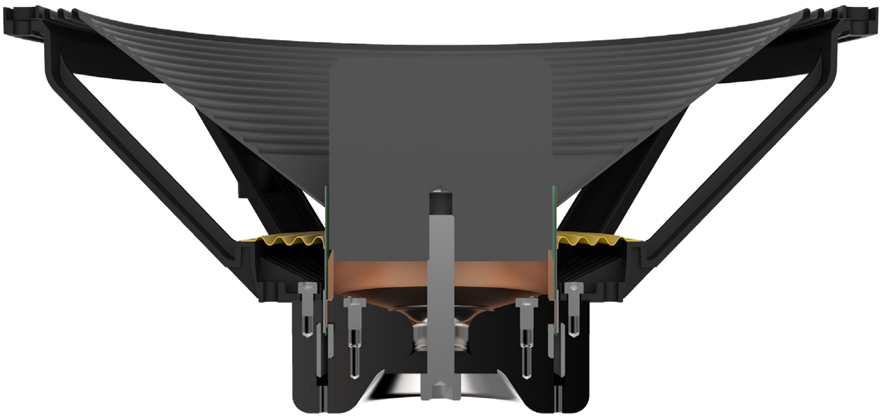


Figure 1. Cross-section of the bass driver

Concept

Fifteen-inch woofers have a long history. Before the days of transistor amplifiers, the limited electrical output power of tube amplifiers made it necessary to use drive units with high efficiency. The easiest way of increasing a driver's efficiency is to increase its radiating area, and the 15-inch driver proved to be a good compromise between size and efficiency. At the same time 15-inch woofers became a de facto standard for pro audio applications, whether in sound reinforcement systems or bass guitar amplifiers.

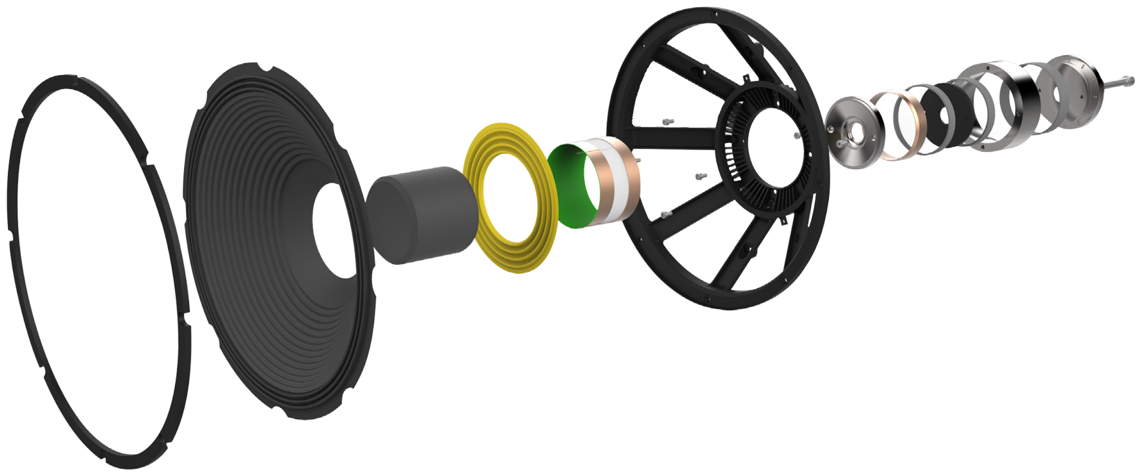
When transistor amplifiers eroded the need for large drivers, the 15-inch hi-fi-woofer fell out of fashion. It survived in the pro audio arena where 15-inch drivers still play an important role in numerous applications, but the requirements for this type of driver are somewhat different to those in the hi-fi-world. A typical pro audio 15-inch woofer provides high power handling, high excursion and is compatible with quite a small cabinet. It is optimised to run most of the time at 20 to 50 per cent of its rated power handling. On the hi-fi side, design priorities would be low distortion and low mechanical losses while cabinet size is not as restricted.

Having screened the market for possible candidates for the WM-4 it became apparent to us that none of the 15-inch pro audio woofers is suitable for a home hi-fi application, so a new 15-inch woofer had to be developed from scratch. The woofer we designed features a stiff corrugated straight-sided cone made from glassfibre-reinforced non-pressed paper pulp with a thickness of 3mm to prevent sound leaking through it from inside the cabinet. The cone is rather deep to make it as stiff as possible, with the result that the first cone breakup mode occurs at a high 1kHz, well outside the woofer's operating range.

Hi-fi woofers generally use half-roll rubber surrounds but the WM-4's is a triple-roll fabric type which, with the paper cone, gives it the appearance of a pro woofer. The difference is that we have co-optimised the stiffness of the surround and spider (suspension) to achieve the linearity of a half-roll surround but without its high hysteresis. Subjectively this ensures 'quick', 'snappy' bass.

The motor uses a neodymium magnet within the 102mm diameter voice coil. Its excursion capability was determined by the requirements of normal listening levels. It was modelled on the premise of loud hi-fi use rather than for use as a PA system. Thus the voice coil's winding height is 20mm, combined with a 10mm magnet gap height. Within the motor system multiple aluminium demodulation rings compensate for voice-coil-induced eddy currents, while a copper shield on the pole piece reduces voice coil inductance. Together these measures assure extraordinary low distortion figures across the whole woofer passband, and together with the low inductance change with excursion.

When we first built the driver with a dust cap, a cavity resonance in the air volume trapped beneath it caused a severe artefact in the frequency response. This was subsequently eliminated by replacing the dust cap with a phase plug (Figure 2). This also further reduced mechanical losses caused by non-laminar airflow in the magnet gap and through the magnet's vent hole.

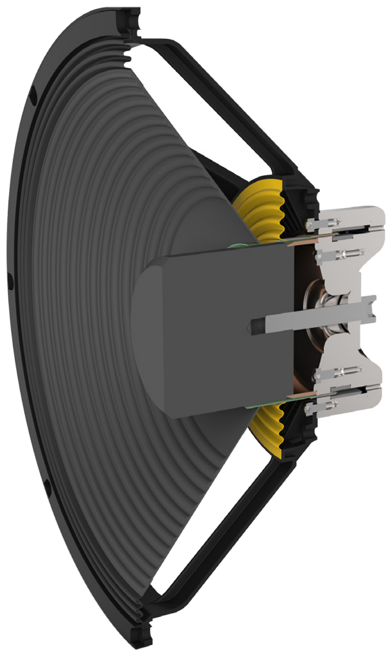


Basket
The die-cast aluminium basket features precision-milled functional dimensions (*eg* at the spider and surround gluing areas).

Cone
A corrugated straight-sided cone, supplied by Dr Kurt Mueller in the UK is used made from glassfibre-reinforced non-pressed paper pulp. The cone thickness is 3mm to help prevent sound migrating from inside the cabinet.

Spider
The spider and surround geometries have been optimised to match the force versus excursion (*Bl(x)*) characteristic of the motor. Spider and surround have nearly identical compliance values, so the woofer in effect features a double-suspension system which prevents instability and cone rocking at high excursions. The spider is made from pure Nomex fabric which guarantees low mechanical losses and minimal degradation due to ageing.

Surround
Unlike a typical single-roll foam or rubber surround, the triple-roll poly-cotton surround generates a stiffness versus excursion (*Kms(x)*) characteristic comparable to that of the spider.



Phase plug

The woofer has a phase plug to avoid cavity resonance underneath a conventional dust cap. In Figure 2 this cavity can be seen resonating at a little over 300Hz; with the dust cap replaced by a phase plug, the artefact disappears.

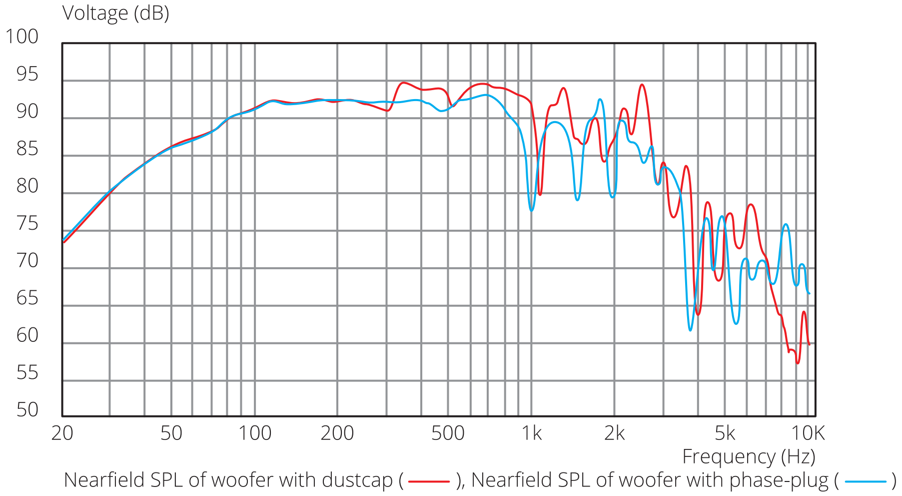


Figure 2. Effect on near-field frequency response of replacing the woofer dust cap with a phase plug

Motor

The motor system features a neodymium magnet located inside the voice coil. Multiple aluminium demodulation rings inside and outside the magnet gap help to reduce the variation of inductance with excursion, while a copper-cap on the inner pole piece reduces overall inductance. These measures assure low distortion figures.

Voice coil

102mm copper clad aluminium wire (CCAW) voice coil wound on a GRP (glassfibre) former.

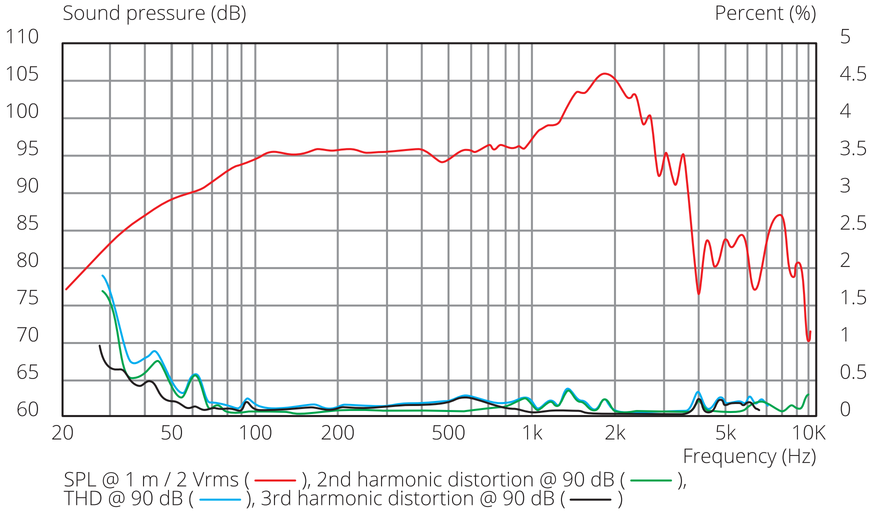


Figure 3. Bass driver on-axis frequency response and second and third harmonic distortion, measured at 1m, 95dB SPL

Midrange driver

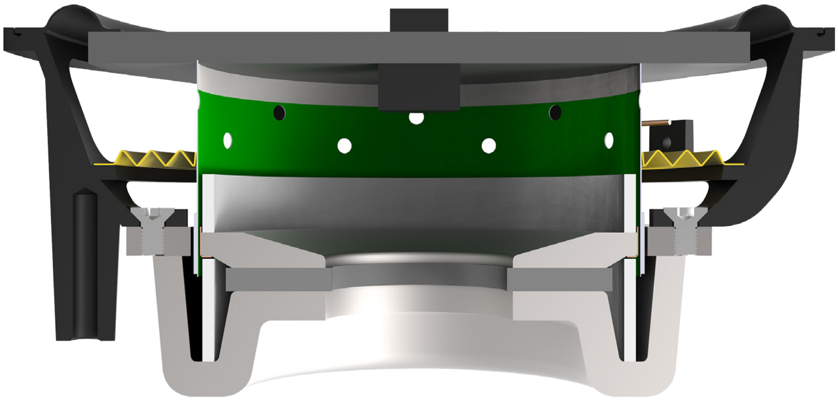


Figure 4. Cross-section of the midrange driver

Concept

We had three principal objectives in designing the midrange driver: wide bandwidth, freedom from 'cavity effect' and low distortion.

We've achieved this by using our made in house FMWD (Flat Membrane Wide Dispersion) units, optimised for high-performance applications, designed by and exclusive to FINKTEAM. These operate pistonically on-axis but exploit bending resonances at 2, 6, 12 and 18kHz to bolster off-axis output. These resonances are controlled by two damping pads mounted either side of the flat diaphragm to ensure a wide, flat on-axis frequency response and smoothly decaying power response (Figure 5). The wide bandwidth allows optimum choice of crossover frequencies and simplifies crossover design.

Because the diaphragm is planar, the driver does not cause the diffraction effects that result when grazing radiation (sound travelling close to the baffle surface) encounters the cavity formed by a conventional cone diaphragm. This removes a distinctive colouration.

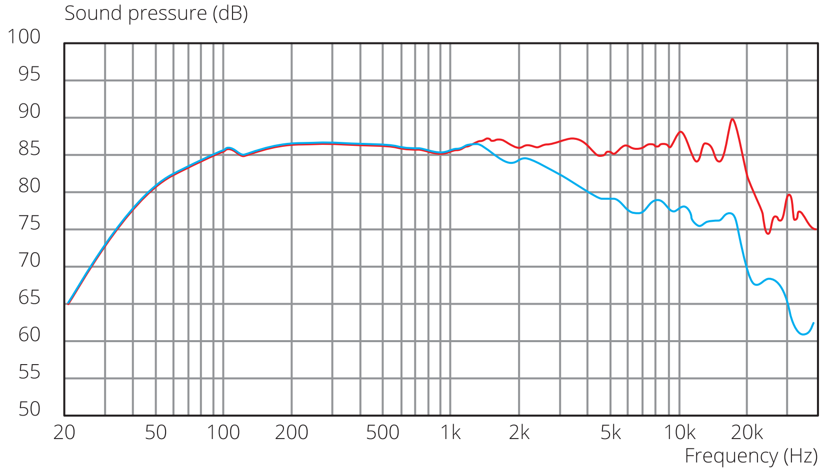


Figure 5. Midrange driver on-axis pressure response (——) and power response (——)

The third objective was achieved in significant part by minimizing back-EMF induced currents in the motor system. Two aluminium tubes below and above the magnet gap and a copper shield on the inner pole-piece keep third harmonic distortion low, which is otherwise generated by eddy currents travelling in the motor's metal structure.

The suspension system has been designed to generate symmetric reaction forces in the operating range and to match the motor's force versus displacement (*Bl(x)*) characteristic.

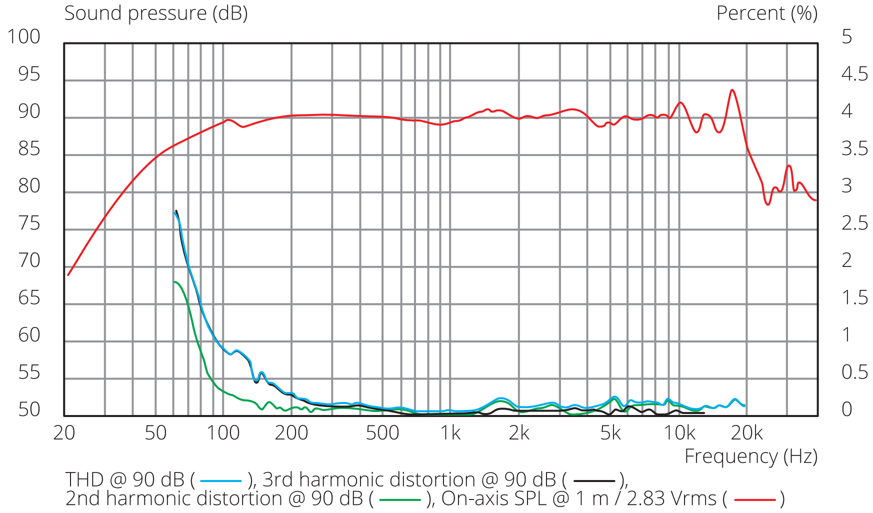
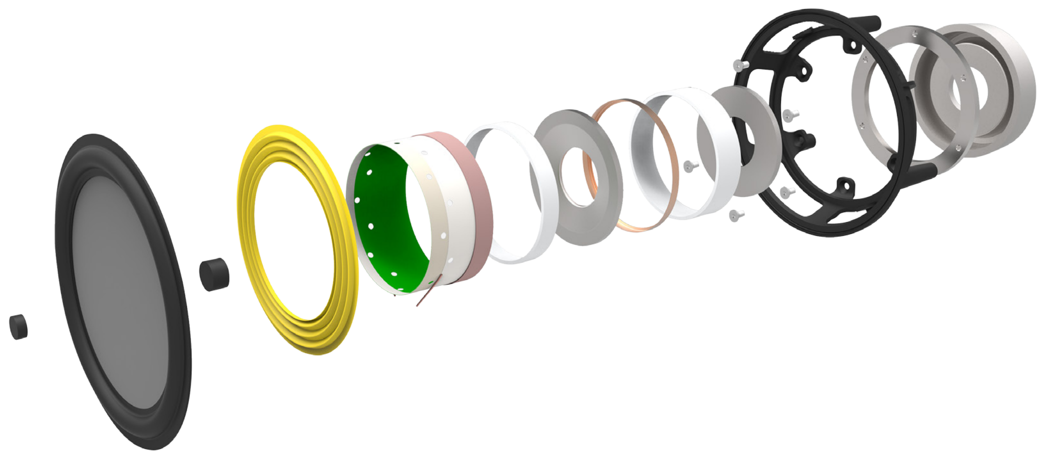


Figure 6. Midrange driver second and third harmonic distortion measured at 1m, 90dB SPL



Basket
Die-cast aluminium chassis featuring three threaded holes for rear mounting.

Cone
5mm thick paper honeycomb panel for minimum mass and carefully dimensioned bending stiffness.

Motor
The motor system features a neodymium magnet located inside the voice coil. Two aluminium demodulation rings inside and outside the magnet gap minimise inductance variations with cone excursion, while a copper cap on the inner pole piece reduces overall inductance. Both measures assure low distortion.

Voice coil
75mm diameter copper clad aluminium wire (CCAW) voice coil wound on a GRP (glassfibre) former.

Tweeter

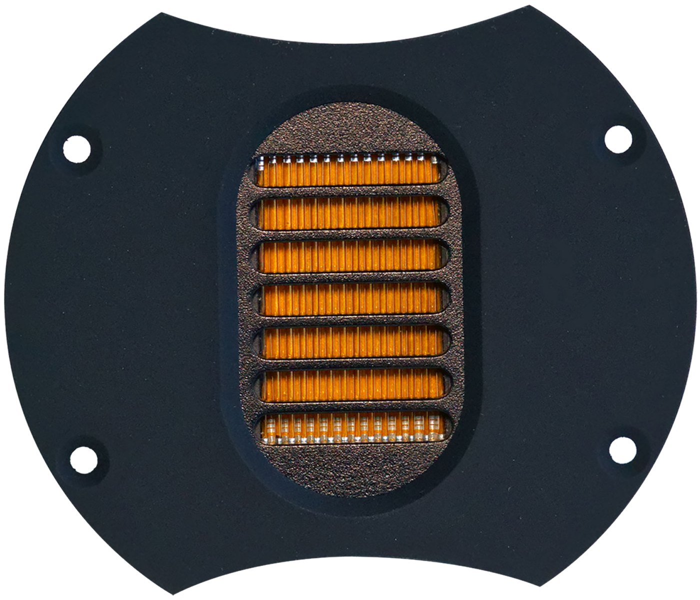


Figure 7. The WM-4's Air Motion Transformer tweeter

Concept
The tweeter is an Air Motion Transformer (AMT) operating according to the principles established by its inventor Oskar Heil. Developed by Mundorf together with FinkTeam and manufactured specifically for FinkTeam by Mundorf, the AMT has a strong, 25µm-thick pleated Kapton diaphragm with 50µm aluminium strips. This material has extremely good internal damping, resulting in particularly low distortion. A special etching process was developed to produce it and the diaphragm configuration optimized through a large number of tests.

Since the diaphragm dimensions are comparable to those of a 25mm dome tweeter, dispersion is also similar. Frequency response reaches up to 30kHz while distortion is very low and mainly second harmonic. The AMT's almost constant impedance also facilitates simplified crossover design.

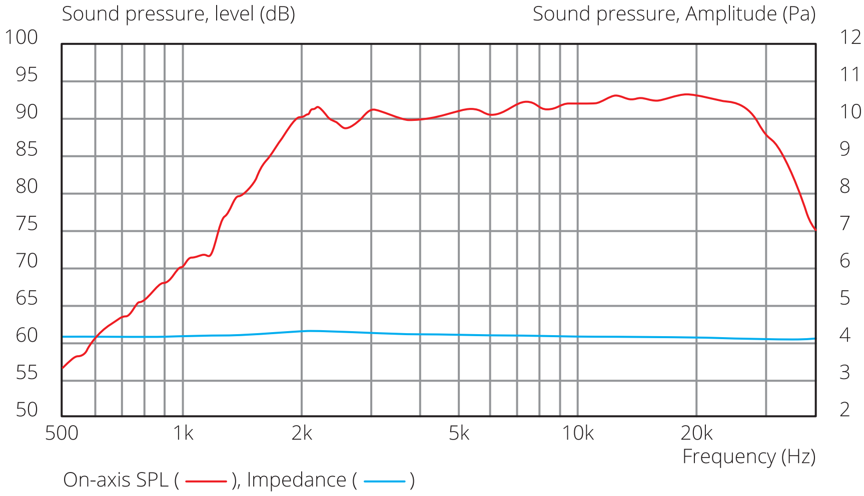


Figure 8. Tweeter on-axis frequency response and impedance

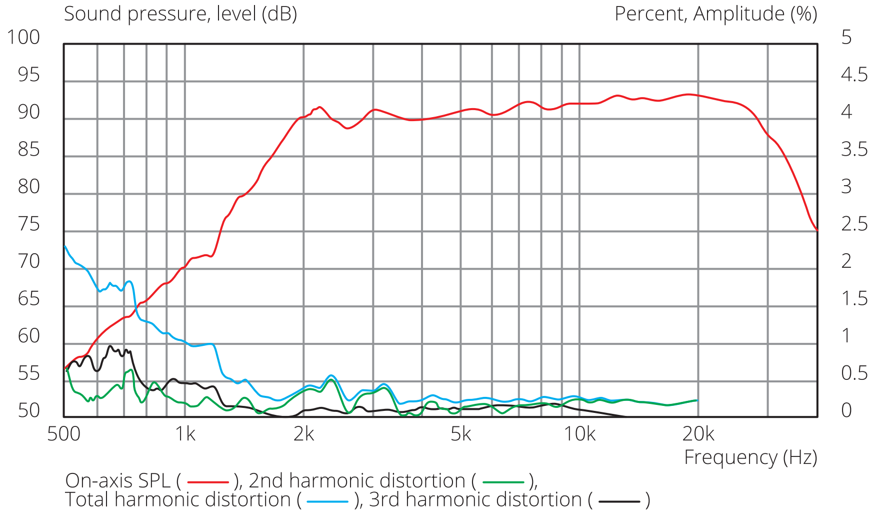


Figure 9. Tweeter second and third harmonic distortion measured at 1m, 90dB SPL

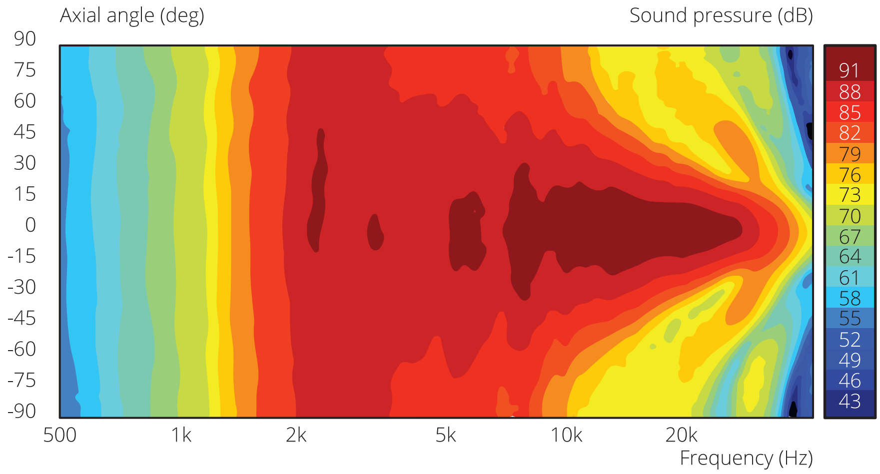


Figure 10. Tweeter horizontal dispersion

Crossover

Concept

Crossover design in the WM-4 is straightforward because the drivers have essentially flat frequency responses, eliminating the need for any large compensation.

The basic topology is fourth-order Linkwitz-Riley. This refers, of course, to the acoustic behaviour, not the electrical filtering. Drive units have their own inherent roll-offs which the electrical filter must account for to achieve the desired acoustic filter response.

A fourth-order Linkwitz-Riley alignment allows us to connect all the drive units with the same acoustic polarity, achieve an essentially flat on-axis frequency response, and ensure predictable results off-axis.

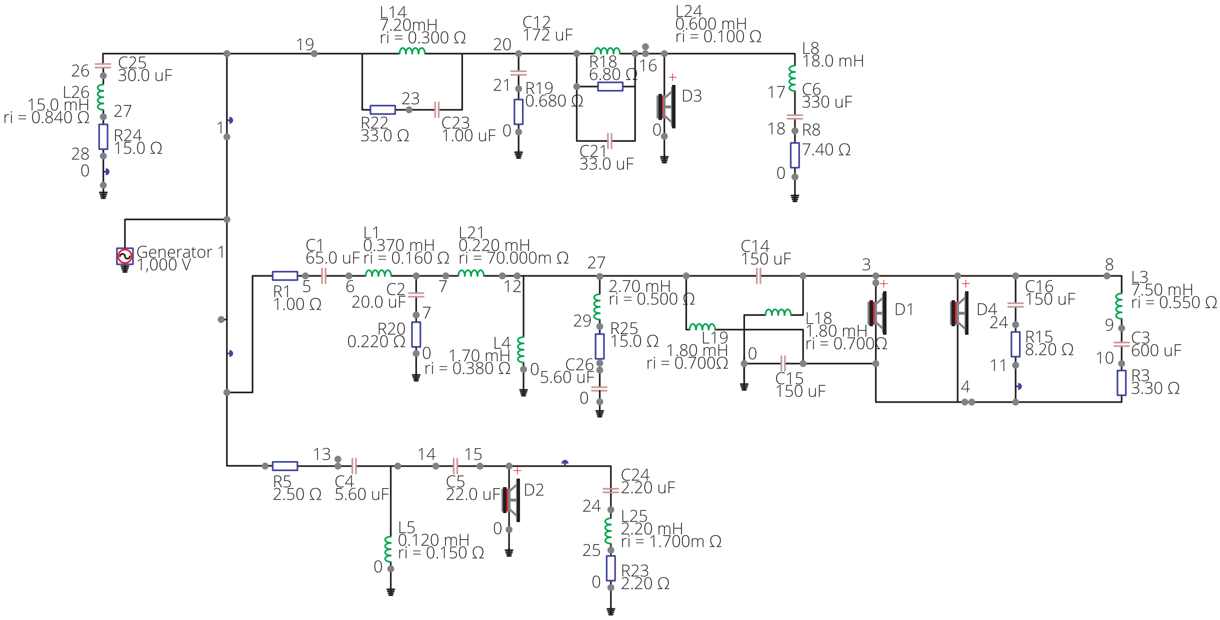


Figure 11. Schematic of the WM-4 crossover network

Figure 12. The huge main inductor in the bass network, which is air-cored and uses 3mm diameter wire

Woofer network

This can be divided into three parts. The first is a second-order filter comprising a large inductor and parallel capacitor, in series with a resistor. This main inductor (Figure 12) is air-cored, to prevent the addition of distortion that would occur with even the best laminated steel core. Experiments with ferromagnetic cores, often used even in very expensive speakers, showed increased distortion in combination with the woofer, so there was no alternative. Wire diameter of 3mm was required to ensure sufficiently low inductor resistance. The capacitor is a Mundorf EVO polypropylene.

The series LCR compensation that follows is there to smooth out the response above 500Hz. Even though the compensation barely shows in the graphs its effect can be heard. Another air-cored inductor and Mundorf EVO capacitor makes sure that no extra 'character' is added. The additional RC combination, which bypasses the large inductor, reduces the output above 1kHz.

An LCR network in parallel with the woofer – the third part – compensates for an impedance peak created by the ported bass alignment. Without it this large peak at 100Hz would not only be present in the speaker's overall impedance trace but the impedance would drop in the 200Hz region to around 2 ohms. The large 18mH inductor has a high-power laminated steel core and is combined with multiple paralleled capacitors and a high-power resistor.

Midrange network

The midrange filter can also be divided into three parts. The first is a bandpass filter with a second-order high-pass slope and third-order low-pass slope. All the inductors are air-cored and the capacitors a mix of Mundorf EVO and Mundorf Supreme. An additional LCR correction filter tames a small peak between 1 and 2kHz – the correction is tiny but necessary to avoid a small coloration.

The second section of the midrange filter is an all-pass phase adjusting network. Marrying a 15-inch woofer to two 5.5-inch midrange drivers is not easy because only if their outputs are in phase at the crossover point is their integration perfect. Otherwise the speaker will sound thin in the lower-midband, as many three-ways do. Again, distortion-free air-cored inductors and Mundorf EVO capacitors are used.

The third section stabilises the impedance of the midrange unit. The LCR combination corrects for the effect of the fundamental resonance, while the RC combination compensates for the very little inductance the midrange driver has. The level-setting resistor is an Isabellenhütte Maganin type.

Tweeter network

Here we have just two sections. The first is a third-order high-pass filter, again with air-cored inductors and a combination of Mundorf Evo and Supreme capacitors together with an Isabellenhütte resistor. The second section compensates for the fundamental resonance of the AMT.

Crossover components

All parts in the WM-4 crossover are made in Germany and around 90 per cent sourced from our friends at Mundorf locally in Cologne. We wanted maximum control over quality, with direct contact to the manufacturer.

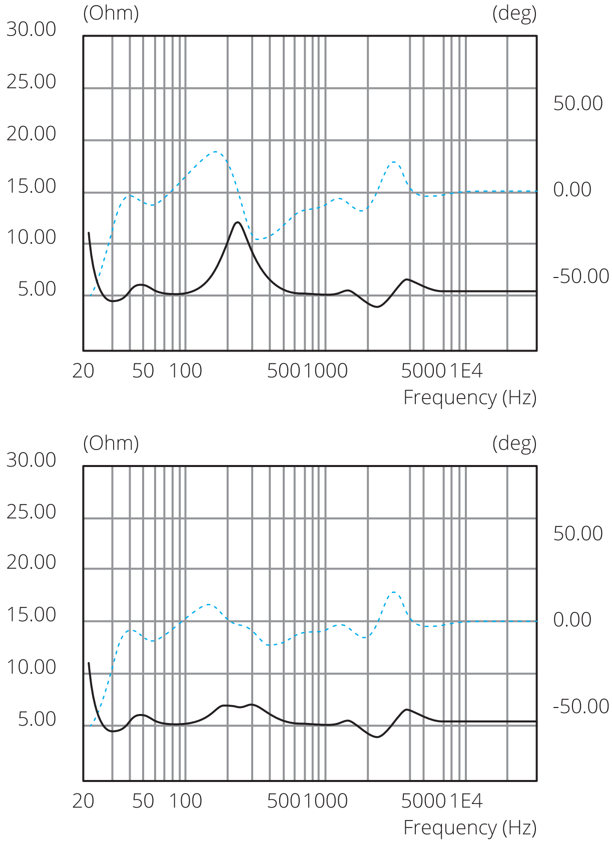
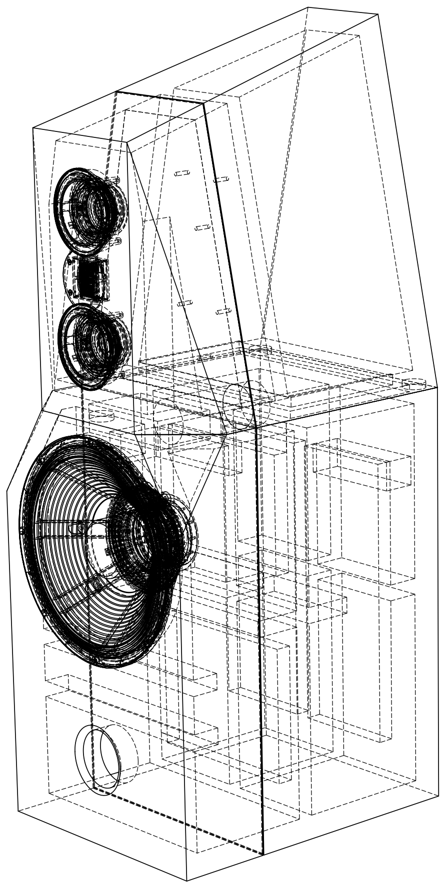


Figure 13. WM-4 impedance without (top graph) and with optional compensation (solid line, modulus; broken line, phase)

Impedance compensation

To adapt the WM-4 for use with tube amplifiers which have a high output impedance, it is supplied with an optional impedance compensation network. As Figure 13 shows, this truncates an impedance peak at about 230Hz, thereby reducing its effect on frequency response when the WM-4 is driven from a high-impedance source.

Cabinet



Typical loudspeaker cabinets have pronounced structural resonances which are very audible and reduce the speaker's 'signal-to-noise ratio'. At FINKTEAM we take this aspect of loudspeaker performance very seriously because we know that a quiet cabinet allows the reproduction of low-level detail in a recording which is otherwise swamped by spurious cabinet output. Coloration and time smear are reduced, stereo image focus is improved and listener fatigue postponed.

The lower and upper cabinets of WM-4 are designed differently according to the frequency range of the vibrations to which they are subjected by their respective drive units. Compliant spacers position the upper cabinet precisely on the lower one while ensuring effective vibration isolation between the two.

With the bass cabinet the design emphasis is on making the cabinet as stiff as possible, to force panel resonances above the crossover frequency to the midrange drivers. This is achieved using internal bracing, the positioning of which was optimised using finite element analysis and confirmed with laser interferometry measurements. It is important that braces add stiffness only where needed, otherwise they can transfer energy to other parts of the cabinet, making the control of cabinet vibration harder.

With the midrange/tweeter cabinet the design emphasis is on panel damping. It is impossible to force all the panel bending resonances above the passband so instead they are damped to reduce their amplitude to below audibility. This is achieved using a multilayer construction that combines multi-thickness MDF panels with a damping layer whose internal friction converts vibration into heat. FINKTEAM-developed algorithms help specify ideal material thicknesses to achieve the best results, but the ultimate determination is made by subjective assessment.

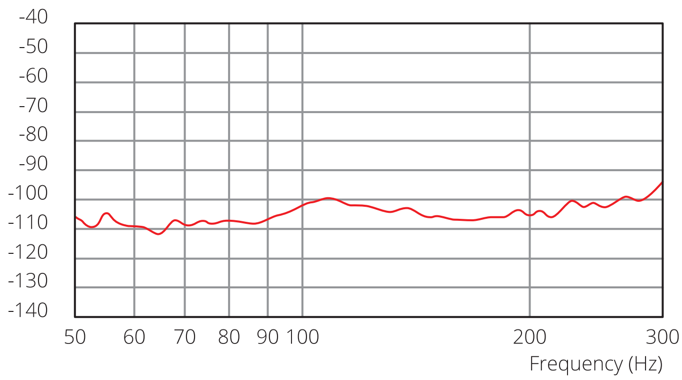


Figure 14. Bass cabinet surface velocity

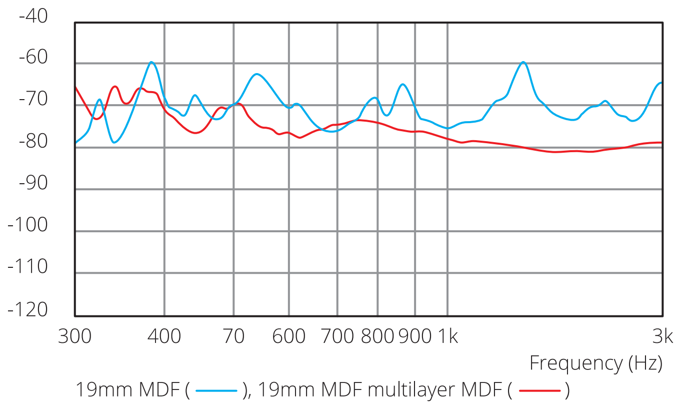
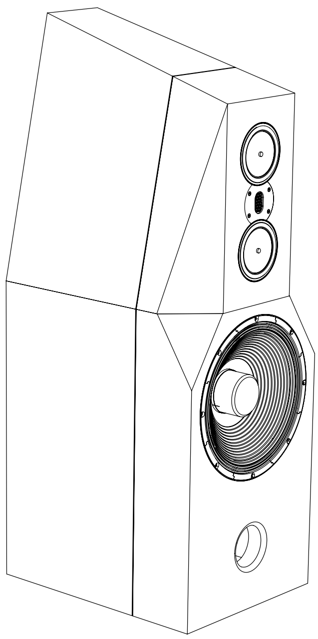


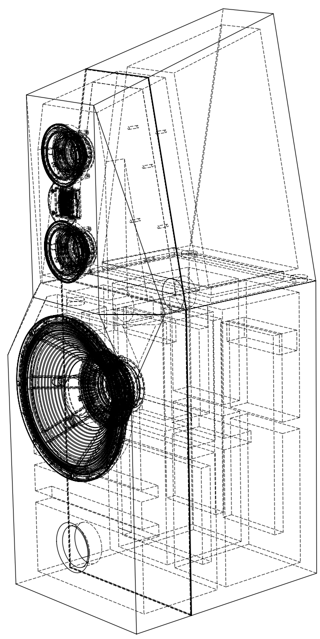
Figure 15. Top cabinet surface velocity

Structural resonances are not the only ones we need to control: there are also standing waves within the enclosed volume of air. These impose forces on the enclosure walls and can also escape the cabinet either by passing through the diaphragm of the drive unit or, in the case of a vented speaker like the WM-4, through the reflex port.

The traditional solution is to fill the space with a fibrous tangle such as long-hair wool or BAF, or a flexible or rigid open-cell foam material. These subject internal air movement to frictional losses which damp the resonances. But they apply these losses at all frequencies, not just the resonance frequencies, and this can have a negative effect on sound quality. Dynamics and precision both suffer.

We've used a very different solution in the WM-4. Tuned quarter-wave resonators, mounted within the cabinet, act to equalise the pressure differential between the extremities and centre of the air space which occurs at the fundamental internal resonance. This virtually removes the resonance without the need for large amounts of cabinet stuffing.

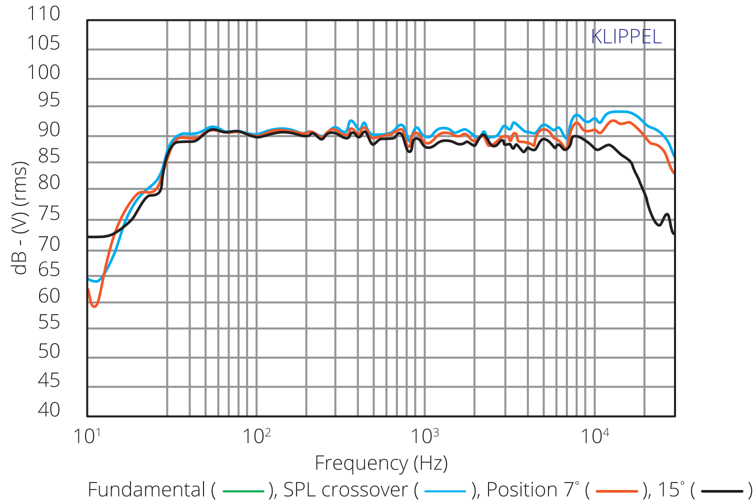




Specifications

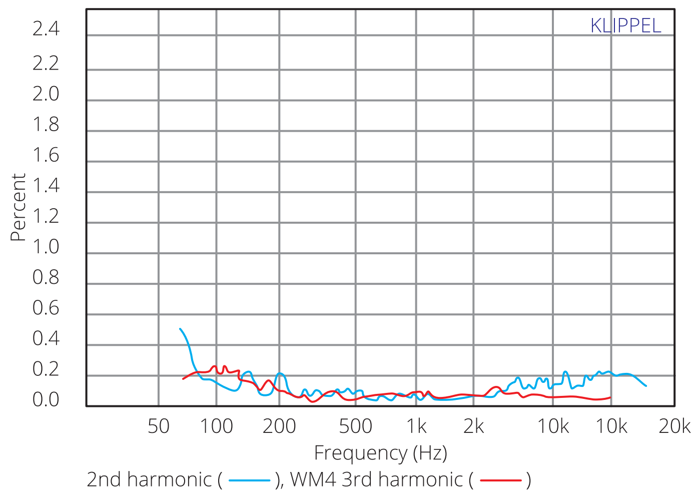
Frequency response		30Hz – 30kHz, − 6dB
Average impedance		6.5 ohms (6.2 ohms with optional impedance smoother)
Minimum impedance		4.1 ohms
Sensitivity		90dB SPL at 1m for 2.83Vrms input
Distortion		<0.2% THD at 90dB SPL
Drivers	Bass:	bespoke 15-inch, designed and manufactured by FINKTEAM
	Midrange:	twin 5.5-inch FMWD, designed by manufactured by FINKTEAM
	Tweeter:	1260mm^2 AMT (Mundorf)
Terminals		Mundorf silver-plated pure copper
Dimensions		1420 × 450 × 580mm (HWD)
Weight		135kg each
Finish		Choice of standard finishes or any finish to special order

WM-4 system response



WM-4 frequency response (blue trace, on axis; orange trace, 7 degrees off-axis horizontal; black trace, 15 degrees off-axis horizontal)

WM-4 system distortion



WM-4 harmonic distortion versus frequency at 90dB SPL

FinkTeam

Karl-Heinz Fink
The boss, the main man. Chief listener and master of the crossover.

Norbert Theisges
Norbert does most of our acoustic measurements and is our specialist for everything made with wood. Works on quality cabinet construction.

Walter Fuchs
Acoustical engineering, analogue electronics, measurement specialist and serious listener. Knows everything about red wine and turntables.

Markus Strunk
Our vibration specialist and master of the laser scanner. Markus makes cabinet improvements and runs a research program for better construction of future cabinets.

Lampos Ferekidis
Drive unit engineering and production, the man who does most of the number crunching.

Has nearly as many computers running in his office as NASA has for the Space Shuttle launch.

Kieron Dunk
Industrial designer extraordinaire. Always guaranteed to make something look smaller than it is and to capture the design of tomorrow today.

Steve Harris
Hi-fi, music and boys' toys enthusiast. Marketing and communication specialist.

With additional assistance from:
Henry Loch
Drive unit development. He glues all our drivers together and has more than 20 years' experience in building speaker units.

Hans-Bernhard Röckert
Hans-Bernhard has many years' experience in working with wood to cabinet maker level.

FINKTEAM