DALI iO-12

WHITE PAPER

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1. INTRODUCTION

The recent history of high performance headphones is generally populated by models that inhabit one of two camps. There are wired headphones, intended to be driven by dedicated headphone amplifiers, that deliver high performance and sound quality through traditional passive electro-acoustics design and engineering. These are headphones intended for home-based critical listening and the intense personal enjoyment of favourite music.

Then there are headphones that prioritise convenience "on-the-go". These are active headphones that incorporate battery power, Bluetooth wireless connection and sometimes noise cancellation technology.

Wired or Wireless

Our aim however with the new IO-12 is simple – to produce a headphone model that covers both camps, wired or wireless, equally brilliantly. The IO-12 is among the highest performing conventional, passive analogue headphones available, yet it can also play the wireless, noise-cancellation, on-the-go convenience role to perfection.

The technical story of the DALI IO-12 headphones begins with the IO-4 and IO-6 of 2019. These two headphone models introduced the idea of DALI as a manufacturer of headphones and represented the initial steps of a new journey. The IO-12 is the next step, and it represents a giant stride. The IO-12 borrows elements of the unique design of those first DALI headphones, yet it is a product of far greater ambition that in particular incorporates completely new electro-acoustics and electronics, and a driver designed around our unique and patented SMC motor system material.

Through the application of electro-acoustic and electronic technologies, design know-how, and expertise developed over 40 years at DALI, the IO-12 offers inherent passive audio performance and sound quality that can be measured against the best headphones of any type. This means that when used in its passive analogue mode the IO-12 is among the best performing and finest sounding headphones available. With the IO-12 there's no longer any need to balance traditional, passive headphone sound quality against active wireless headphone convenience. The IO-12 has both basses covered at the highest level.

But the IO-12 also simultaneously offers state of the art Bluetooth wireless streaming, brilliantly effective and music optimised audiophile active noise cancellation, and remarkably generous battery life with all the important modern day convenience those features enable. In this white paper we will tell the story of the IO-12's design and development.

2. DALI IO-12 HEADPHONE BACKGROUND

Like the IO-4 and IO-6, the IO-12 is a product entirely of in-house DALI design created to the highest possible standards in terms of engineering, durability, comfort and functionality. The IO-12 is a closed-back, over-ear (circumaural) design that encloses the entire ear within ear cups that rest on the side of the head. The circumaural format offers the twin advantages of optimising comfort and reducing air-leak variation from user to user. This is hugely important to ensure that all users experience the same fantastic sound quality. The circumaural format also enables the integration of a large diameter driver for optimal sound quality. And combining the circumaural format with a closed-back headphone configuration offers the best possible passive noise isolation (PNI), and is a fundamental requirement for active noise cancellation (ANC).

3. DESIGNED FOR TRUE AUDIOPHILE PERFORMANCE

Moving-coil headphone and speaker drivers are conceptually similar, consequently the extraordinary technological advances in speaker driver design and performance made by DALI over the last 40 years also have great relevance to headphones. So IO-12 headphones are designed and engineered true to the same sound principles as our full-size loudspeakers.

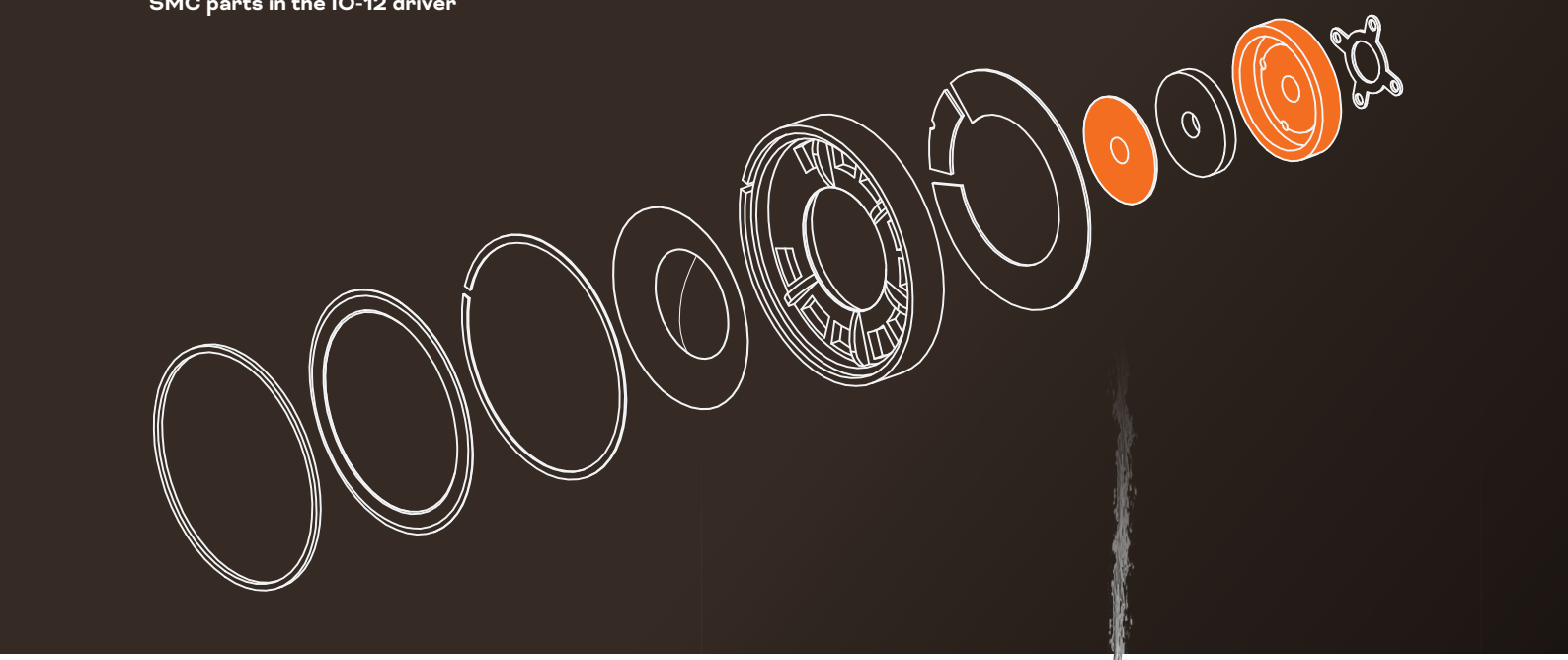
Featuring technologies such as our patented SMC magnet material, low-loss free-edge surround, rigid paper fibre cone and low resonance enclosures, the IO-12s deliver the same low-loss sound with ultimate clarity and dynamic capabilities that you would expect from any DALI speaker. Furthermore, DALI is unusual in designing and developing headphone drivers in-house rather than relying on standard, off-the-shelf items. The IO-12 is both unique in design, remarkable in performance and completely developed in-house.

Highly Advanced Driver

As with any other loudspeaker, the heart of the headphone is the driver, and in order to achieve a natural and undistorted sound, a high performance unit is essential. Being a loudspeaker company we fully understand the importance of a high performance driver. So the IO-12 employs a very highly advanced, DALI designed unit with a large 50 mm diaphragm optimised to offer low loss, low distortion, minimal colouration and accurate dynamics throughout the entire frequency range. The larger than usual driver diameter ensures linear operation with minimum compression and aids low frequency performance and means less equalisation is required for brilliant bass - in either passive of active mode. This, together with the optimised mechanical vibrational characteristics of the driver's paper fibre diaphragm, means that even the most delicate musical details are rendered crystal-clear. It also means that the sound never gets tiring, even after hours of listening.

The IO-12 driver also incorporates some DALI speaker driver techniques. It's voice-coil, for example. Rather than employing a self-supporting, former-less construction (typical of headphone drivers) the IO-12 uses a voice-coil former, with the same shape and style as in a normal DALI speaker driver. The result is lower distortion though improved voice-coil structural integrity.

SMC parts in the IO-12 driver



SMC Headphone Drivers

The IO-12 headphone drivers incorporate the same DALI SMC material employed to great effect in our EPICON high-end audiophile speaker range and this constitutes a hugely significant advance in headphone driver technology, performance and sound quality.

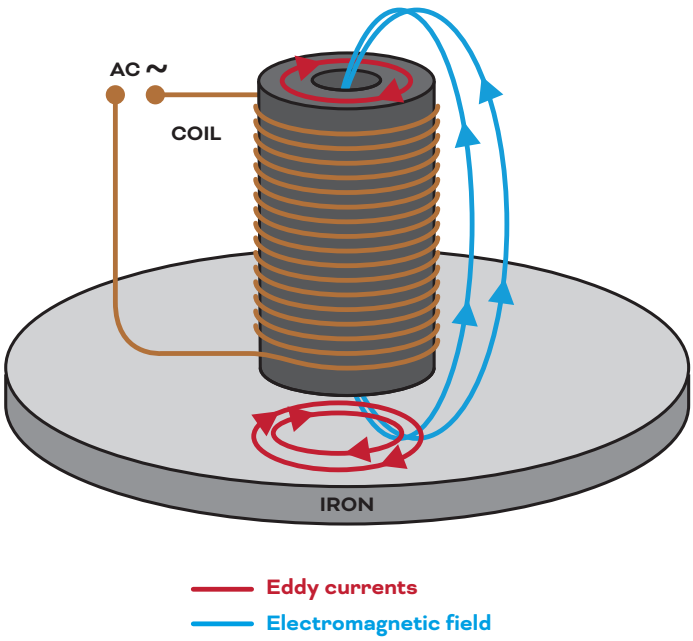
One of DALI's most significant speaker driver developments over the past decade has been the development and application of SMC – Soft Magnetic Composite. SMC is a granular material that can be moulded under heat and pressure to create motor system components used in the heart of speaker and headphone drivers. This application for SMC is the subject of DALI patents so is unique.

The IO-12 driver however doesn't employ SMC only in localised regions of its motor system; every component, other than the neodymium-iron-boron magnet, is manufactured fully from SMC: top plate, pole-piece and back-plate. The full SMC motor system of the IO-12 driver is made possible partly by its relatively modest dimensions, however it still marks a very significant achievement and milestone in the narrative of DALI driver design.

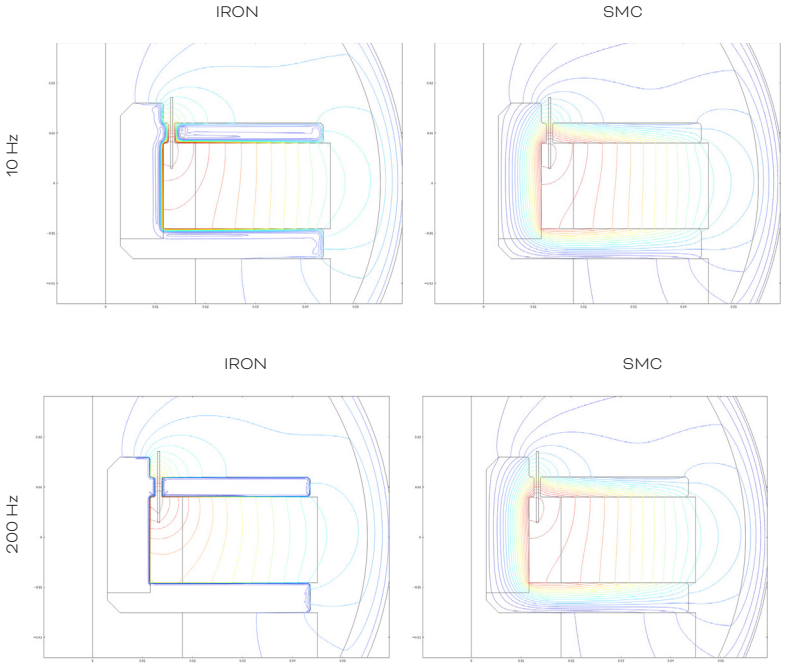
The great benefit that SMC brings to the IO-12 drivers is that while the material has high magnetic conductivity it is also, in contrast to iron based materials, electrically non-conductive. Being electrically non-conductive, SMC comprehensively recasts the dynamic performance of a headphone driver through nullifying distortion and loss-causing phenomena inherent to drivers that incorporate electrically conductive iron magnet system components – a category that includes almost every other headphone drivers. DALI has long embraced and espoused the philosophy that minimising signal loss in audio transducers is the route to improved sound quality and the application of SMC to the IO-12 headphone drivers is the latest radical and unique expression of that philosophy.

Eddy Currents

When a driver voice-coil moves in response to the music signal through the magnet gap of a motor system that uses an iron based pole-piece, the movement causes localised electrical currents to flow in the pole-piece. These eddy currents will cause distortion through modulation of the audio signal, and introduce a braking effect that reduces the driver's ability to follow the dynamics of the music signal. With a pole-piece made of non-conducting SMC however eddy currents cannot arise so the distortion and loss they cause is neutralised.

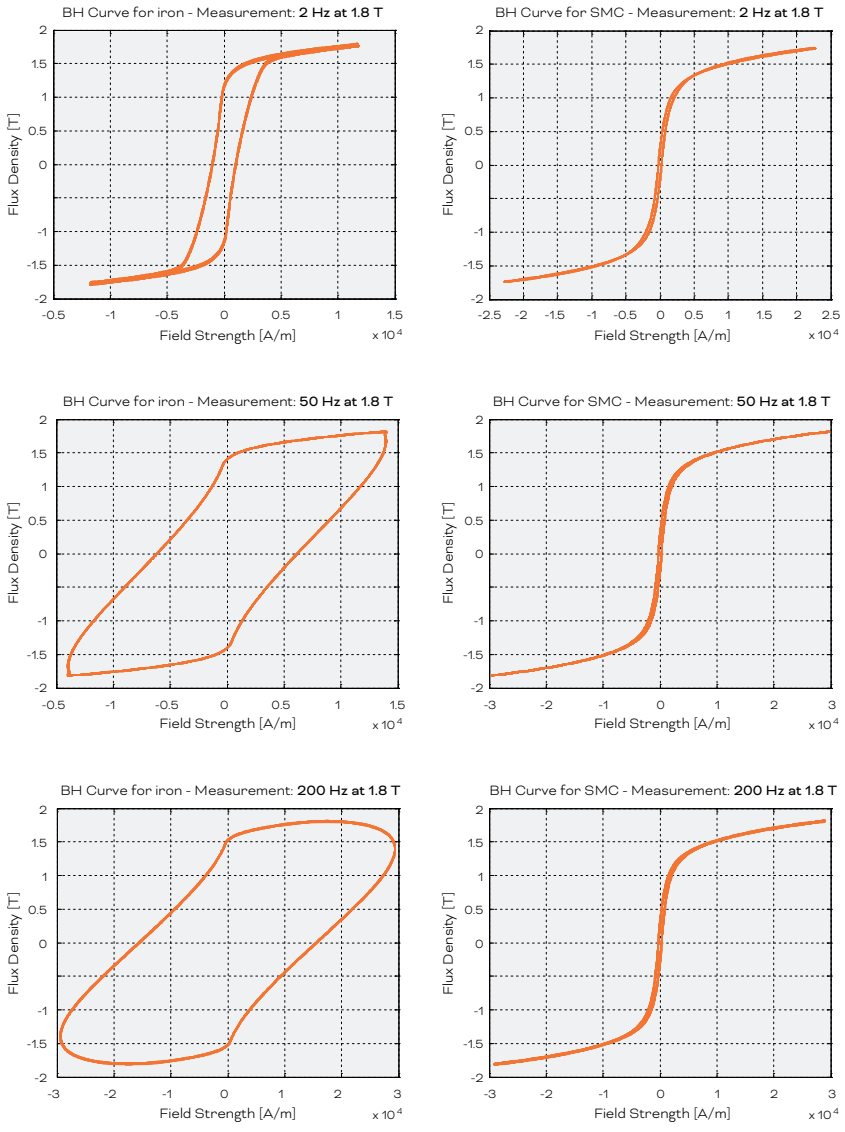


V SMC Motor System Flux Lines



Flux Modulation
In addition to creating eddy currents in an iron-based pole piece, movement of the voice-coil will also modulate the magnetic flux in the voice-coil gap. Electrically conductive iron based components in the motor system magnify this effect and result in measurable and audible distortion. Changing to non-conducting components removes the magnification effect and in turn significantly reduces distortion.

V Hysteresis



Magnetic Hysteresis
Hysteresis is a phenomenon common to many dynamic systems in which an aspect of their behaviour differs with direction. A spring, for example, might display slightly different force characteristics in tension and compression. Hysteresis occurs in iron based driver magnet systems as they magnetise and demagnetise at different rates in response to the audio signal, and it results in non-linear behaviour that is expressed as distortion. Replacing iron based components in the magnet system with non-conductive SMC reduces the magnetisation hysteresis effect and makes the dynamic behaviour of the system more linear.

Note

These graphs are for illustrative purposes to highlight the features of SMC in a speaker driver. Measured values are not specific for the IO-12 driver.

Minimised Harmonic Distortion

While the development of SMC in order to eliminate driver distortion mechanisms was originally focused on speaker drivers, it is equally applicable to headphone drivers. This is particularly significant as headphone listening is finely sensitive to distortion. Levels of distortion that are barely audible with speakers are more significant when headphone listening because the overall noise floor is naturally lower.

The exceptional distortion performance of the IO-12 driver is illustrated in the frequency response graph. It illustrates the reduction in third harmonic distortion delivered by the IO-12 driver in comparison to a similar, non-SMC equipped driver. The graphs demonstrate that IO-12 third harmonic distortion remains below 0.01%, above approximately 1 kHz, this represents a reduction up to ten times in comparison to the conventional, non-SMC driver.

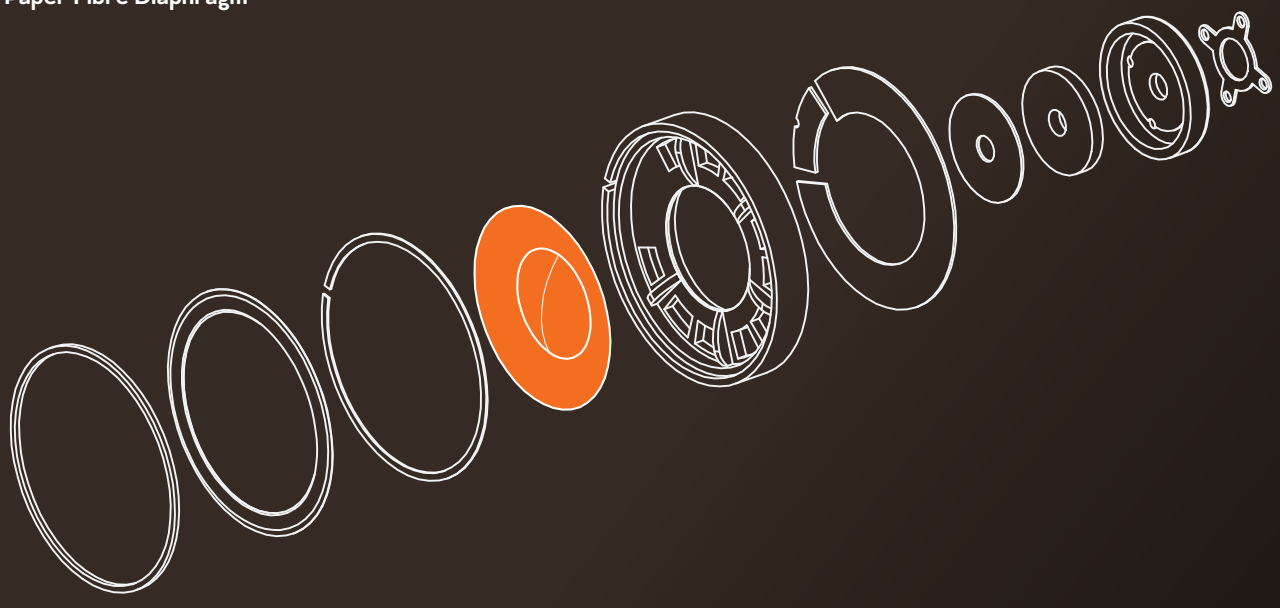
In subjective terms, the reduction in distortion that results from SMC technology in the IO-12 driver results in a significant increase in clarity and detail, and a marked reduction in the potential for fatigue over long listening sessions.

Low Loss Paper Fibre Diaphragms

A driver diaphragm, whether it be a speaker or headphone component, marks the border where audio leaves the transducer and enters the world of sound, so the diaphragm's mechanical properties; mass, rigidity, damping and vibrational behaviour, are of critical significance. And due primarily to the lower volume levels required of headphones compared to speakers, headphones can cover the entire audio band with one driver, so it is even more critical to optimise the diaphragm's mechanical properties.

Optimising headphone driver diaphragms through expertise in material selection and physical profile dovetails perfectly with DALI know-how. Four decades of speaker driver diaphragm design leaves DALI perfectly placed to transfer all that accrued skill and expertise to headphone diaphragms. So perhaps it is no surprise that the IO-12 driver diaphragm borrows from DALI's proprietary paper fibre diaphragm material. DALI paper fibre material offers a unique combination of mass, rigidity and damping that's perfectly tailored to wide-band reproduction with minimal distortion and energy storage. Employed in the IO-12, in combination with its SMC motor system, the result is a headphone driver with performance and inherent sound quality unlike any other.

Paper Fibre Diaphragm



Enclosure Engineering

With the IO-12 Being a closed back headphone design, the driver is mounted in an enclosure like a miniature loudspeaker cabinet. With loudspeakers, the main purpose of the cabinet is to isolate the front and rear surfaces of the diaphragm from one another, in order to create low frequency output. The speaker cabinet simply prevents the air pressure on the front of the diaphragm from being cancelled by the reverse phase air pressure from the rear of the diaphragm.

With headphones, on the other hand, the front and rear side of the diaphragms are isolated by the ear pad, so there is no need for the driver to sit in a sealed enclosure to create bass. However, if there is no enclosure behind the headphone driver, the only barrier between the ear and the ambient noise will be the thin diaphragm of the driver, and that offers very minimal acoustic isolation. Furthermore, the driver plays as loud on the rear surface as on the front, so with no enclosure the music heard by the headphone user will be equally as audible to everyone else.

Although the main purpose of the enclosure is different for headphones compared to loudspeakers, the principles and requirements for good enclosure design are the same. It is well appreciated among hi-fi enthusiasts and audiophiles that the vibrational rigidity and damping of speaker cabinets is of critical importance to sound quality. But to a very significant extent the same is also true of the ear cup enclosures that house the drivers in closed back (circumaural) headphones such as the DALI IO-12. There would be little point in developing a headphone driver with the performance of the IO-12 unit and then degrading its performance by installing it in a resonant enclosure that imprints its own character on the sound. But that is not the only concern when designing a headphone enclosure. Another, very important thing to consider is passive noise isolation. The headphone's ability to dampen outside noise without the use of ANC.

In development we discovered that if the enclosure resonates at a certain frequency, then at that frequency, the passive noise isolation is significantly reduced. Which means that it is very important that the headphone enclosure is resonance free and inert at all frequencies in the audible range. So, the IO-12 headphone ear cups are specifically engineered with an outer shell combining inherent rigidity with internal bracing to ensure that they are vibrationally inert. This, combined with specially designed internal damping material gives the IO-12 excellent passive noise isolation as well as low distortion from the enclosures, at all frequencies.

Within the ear cup enclosures a mixed material damping strategy is implemented: a rubber pad positioned between the driver magnet and ear cup enclosure wall handles mechanical damping, and located around the driver, a natural felt ring that absorbs the rearward radiation of the diaphragm. The felt pad is manufactured from the same material used for a similar purpose in the DALI KORE EVO-K Hybrid Tweeter. The result is an ear cup enclosure that, in contrast to countless less thoroughly engineered headphones, adds nothing of its own signature to the music.

IO-12 Sound Quality.

In addition to the focus on inherent audio performance and sound quality through advanced passive electro-acoustics, DALI IO-12 headphones are also packed with digital signal processing (DSP) and advanced amplification technologies dedicated towards optimisation of their active performance. Despite the availability of remarkable DSP power however, passive IO-12 audio performance is of paramount importance. This is because, firstly, extraordinary passive performance enables outstanding sound quality when the headphones are used in passive mode (switched off) - connected perhaps to a high-end audiophile headphone amplifier. Furthermore, when used in passive mode, the IO-12 uses a sophisticated

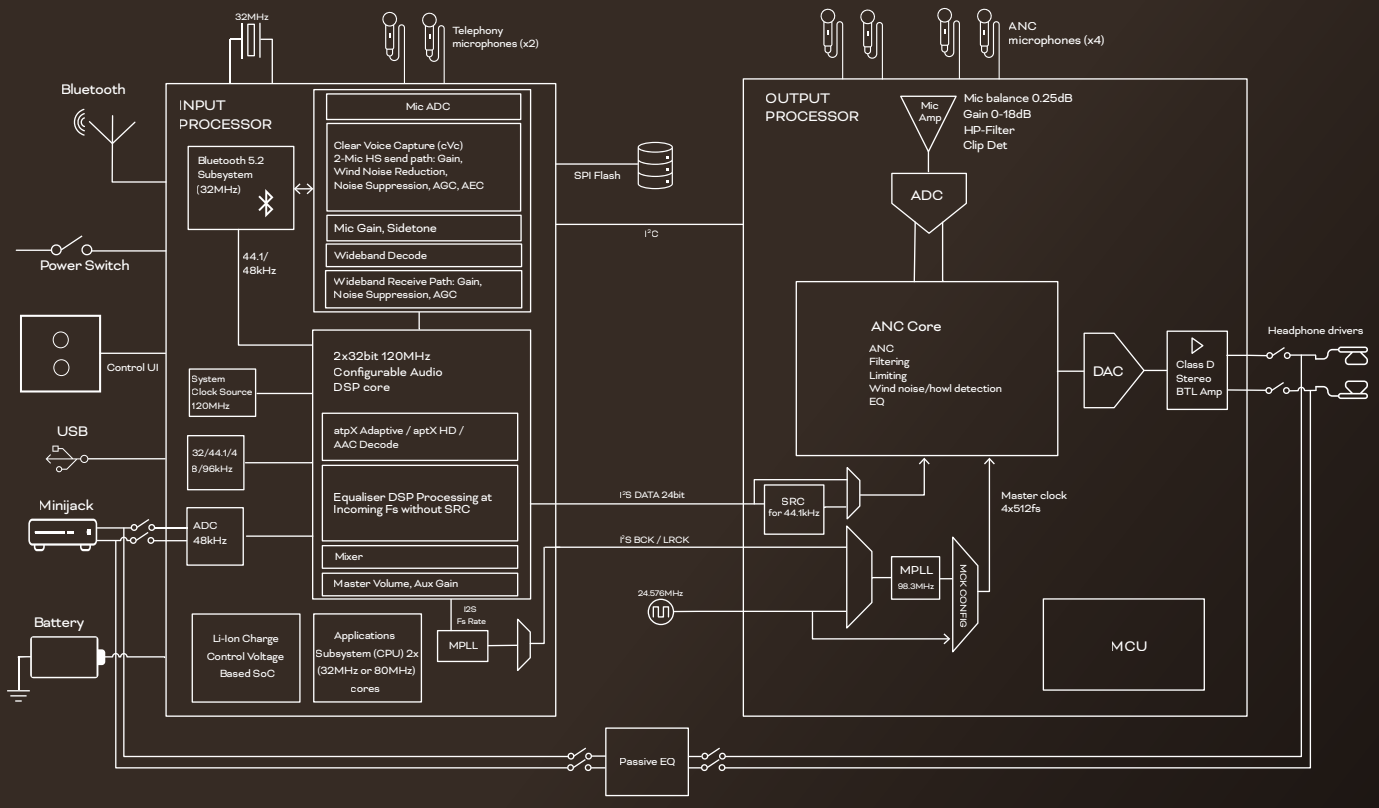
internal passive filter, ensuring the same sound quality and performance, as when using the DSP based filtering used in active mode.

And secondly, the higher the level of passive performance, the less DSP power must be dedicated to its optimisation. IO-12 headphones gain immense sound quality through outstandingly accomplished passive electro-acoustics, and then magnify its value through the application of smart, targeted and sympathetic DSP. In terms of optimising sound quality however, DSP can offer capabilities far beyond the scope of even active analogue electronics. With DSP, finely targeted equalisation of a driver's inherent frequency domain characteristics can be made in order to add that final finesse of realism and clarity. In many headphones, DSP is simply used to enable streaming and noise cancellation technologies, but in the DALI IO-12, DSP is inherent also to its active mode sound quality.

Fully Bridged Amplifier

IO-12 active sound quality is also optimised through its use of advanced electronic components sourced from world leading manufacturers such as Qualcomm and Sony. And rather than employ a conventional half-bridge amplifier topology, the IO-12 amplifier employs a fully bridged topology - effectively two amplifiers working together. The benefits are increased efficiency (typically greater than 90%), which helps with headphone battery life, and reduced distortion in the audio band, which of course also contributes to improved sound quality.

IO-12 Block Diagramme



4. IO-12 HEADPHONE ARCHITECTURE

While the headline technologies of the IO-12 headphones are primarily to be found in its passive mode performance, SMC electro-acoustics, digital signal processing, wireless streaming and active noise cancellation, the experience of the IO-12 for every user will begin with how they look, how they feel to the touch, and how comfortable they are to wear. So to reflect this, it is perhaps appropriate to describe their industrial design and how they came to look and feel the way they do.

As with its DALI headphone predecessors, the IO-12 benefits from hundreds of hours of research into headphone fit, use and mechanical durability, and as a result they major on comfort and ease of real life use. What for example, would be the point of the IO-12's thirty-five hour battery life, if they were heavy or uncomfortable? So the IO-12 borrows much of the extensively researched, carefully developed, Danish designed, and much admired IO-4 and IO-6 architecture and ergonomics. Memory foam ear pads, for example, that prioritise long term comfort, and numerous choices made in the design process that minimise headphone weight so that long periods of use aren't, literally, a pain in the neck. Durability is also a vital element of the IO-12 story. If a headphone are to be used when out and about, they have to take the knocks of everyday life in their stride without failing on the job. The IO-12 is as robust as they come.

A few things have changed for the IO-12 however; some apparently minor and some more obviously significant.

Material Luxury and Perfect Fit

The most obvious industrial design enhancements for the IO-12 concern materials. The IO-12 headband and ear pads are finished in luxurious, high quality real leather, and the ear pads themselves are larger and rectangular in form with a new and more generous 3D profile. The new ear pad profile distributes pressure over a greater area and provides an improved acoustic seal over a wider range of head shapes. The latter change significantly benefits both low frequency audio performance and passive noise isolation. And while the use of natural leather is most obviously apparent in appearance, its use, especially on the IO-12 ear pads markedly enhances comfort and tactile feel. And similarly following the leather theme, also new for the IO-12 is a luxurious leather carry case.

Intuitive Control with No App Required

Less obvious changes in the design of the IO-12 include improved hardware control, with traditional buttons, rather than a combination of slide switch and buttons, used for power, sound mode and ANC control. And a new, radial brushed and anodised finish to the ear cup external surfaces. And the IO-12 is unusual in not relying on an app for configuration or control. Apps, we think, tend to add complexity, and often frustration, when the DALI philosophy is all about easier access to high quality music. There's no app required

Admire and Adopt

While the IO-12 features design enhancements over its predecessors it simultaneously adopts many of their much admired features: the rotating ear cups that enable the headphones to be packed flat in tight spaces, and the intuitive user interface with playback, telephony and volume control buttons located in the right ear cup logo plate for example. The logo plate is the multi-function button for controlling Play, Pause, Next, Previous, Take Call and End Call. The upper and lower part of the ear cup outer ring, which surrounds the logo plate, control Volume Up and Down respectively.

- Play / pause / skip track / take call: press the Logo
- Volume up: press upper part of outer ring
- Volume down: press lower part of outer ring

The remaining IO-12 buttons; Power / BT pair and "ANC", are placed more conventionally, but are still easy to locate.

To support the user experience still further, the IO-12 produces voice prompts that report the state of operation, connectivity, battery level and ANC mode. But rather than use a generic, chip generated voice, we chose to use prompts spoken by film, TV and voice actor Linford Brown. The voice prompts were recorded and mixed in-house at DALI. Pairing and Battery Level are additionally indicated visually by multicolour LED indicators on the right ear cup.

The IO-12 is designed for intuitive ease, convenience of use and especially, resilience. During IO-12 development we worked with one of Europe's largest consumer audio service organisations to identify potential headphone failure modes and to engineer resilience into their design.

5. CONNECTIONS, WIRELESS STREAMING, NOISE CANCELLATION AND SOUND MODES

IO-12 Analogue Connections

The IO-12 is first and foremost a very high-performance passive headphone design and is in its element when used in passive mode with high quality analogue amplification. The headphones incorporate a wired analogue jack connection socket located on the left ear cup. The jack socket enables connection to analogue amplification devices such as specialist high-end headphone amplifiers and in-flight entertainment systems and works when the headphones are switched either on (active mode) or off (passive mode). Connecting IO-12 headphones in analogue passive mode also enables their continued use with an exhausted battery.

However, in scenarios that involve traditional high-end signal-chains, IO-12 passive analogue connections offer performance and sound quality that speaks of traditional values of warmth and a more relaxed presentation, while sacrificing nothing in terms of inherent sound quality or the portrayal of musical detail. Passive analogue IO-12 connection is also ideal for gaming use because it results in zero latency.

When IO-12 headphones are used in passive mode, none of their DSP based features (ANC, driver equalisation or sound modes) or control functions will operate, and volume control will be defined by the source headphone amplifier.

But in addition to use in passive analogue mode, the IO-12 can also be used in active mode with a traditional analogue input. It's a best of both worlds mode where the DSP of the IO-12 enables active noise cancellation, local volume control, sound modes and active equalisation, while at the same time it retains the simplicity of a wired analogue connection. Perhaps you're listening in passive mode at home with IO-12s connected to an audiophile headphone amp and suddenly the background noise of a busy home intrudes. Simply switch to active mode, engage ANC and the problem is fixed.

IO-12 Digital Connections

Wireless Formats:
For digital sources the IO-12 headphones are designed with wireless Bluetooth use primarily in mind. They support all the latest high performance Bluetooth audio codecs: AptX, AptX HD, AptX Adaptive and Apple AAC for wireless music streaming and their wireless performance is state of the art as a result.

USB Connection:
IO-12 headphones are also specifically designed to produce exceptional sound quality when connected to a USB audio source. USB connection in particular, thanks to its potential to access high resolution audio and the lack of any need for wireless signal processing or sample rate conversion, offers truly stunning sound quality that, if the source material is of commensurate quality, is competitive with the very best headphones of any type. The IO-12 also supports up to 96kHz sample rate over USB, with no downsampling applied for ultimate sound quality.

IO-12 Battery Charging and Connectivity

For battery charging and the most reliable USB connection IO-12 headphones employ a USB-C connector. Use of a USB-C connector avoids a failure mode that is common with micro-USB connectors resulting from their incorrect insertion. One great benefit of revisiting the DSP design in the IO-12 headphones is that doing so has resulted in signal path and processing revisions that have significantly reduced battery power consumption. So now, despite its feature set being broadly equivalent to the IO-6, the 1100 mAh Li-ion battery of the IO-12 offers operational life that is 50% greater – typically thirty-five hours. You could potentially fly to the other side of the world and back, with active noise cancellation engaged all the way, and still not need to charge your IO-12 headphones.

IO-12 Audiophile Active Noise Cancellation

The optional active noise cancellation technology of the IO-12 is based on that conceived for the IO-6, however, through the development of completely new noise cancellation algorithms, its performance is significantly enhanced. In particular, IO-12 noise cancellation has been specifically tuned by DALI to ensure that its operation doesn't result in artefacts that degrade the headphones' musical performance - it's noise cancellation for audiophiles. It's all too easy, when configuring noise cancellation technology, to emphasise noise reduction and not notice that the music has paid a price. The IO-12 resolutely puts the music first.

The larger and more generously padded ear cups of the IO-12 also play a significant role through both their increased inherent passive noise isolation and providing an improved acoustic seal. With IO-12 ANC, environmental noise, be it the sounds of a street, the random chatter of people, or the constant drone of a flight, is equally effectively suppressed. As well as enhancing the experience of using headphones in the real world, improved noise cancellation also effectively benefits headphone sound quality by lowering the noise floor and rendering subtle musical details more audible. It also means headphone listening doesn't require high, and possibly harmful, volume levels to be used.

The IO-12 ANC transparency feature, which enables external sounds to be passed through the headphones, effectively making them one way (out to in) acoustically transparent, is also significantly enhanced and more effective. And the IO-12s revised Clear Voice Capture technology microphones also contribute to enhanced intelligibility and communication when the headphones are used for wireless telephone calls.

IO-12 Sound Modes

In addition to DSP based ANC, IO-12 headphones incorporate two sound mode options; Hi-Fi and Bass. Sound modes are selected from the Sound Mode button on the IO-12 right ear cup that enables quick and intuitive selection. In Hi-Fi mode, IO-12 sound quality will accurately reflect the frequency balance of the incoming audio signal. In Bass mode, IO-12 sound quality is boosted at low frequencies to emphasise lower range musical elements and to offer a slightly more traditional and comfortable, loudness feel to the sound. As well as providing the low frequency enhancement that can sometimes lift a piece of music to new heights, Bass mode is also useful for those who wear glasses as it can compensate for the slight bass drop that might be result from glasses interfering with the headphone ear cup seal.

6. IO-12 USER INTERFACE

The DALI IO-12 headphones borrow much of their predecessors' user interface and they're just as intuitive and convenient in use as a result. Other wireless headphones sometimes appear to have been designed without real-world use properly considered. Randomly located buttons are often too small, and playback or volume control control is unclear and far from intuitive. But with the IO-12, there's no need to read a manual or download and install an app. Just switch the headphones on, connect a source and start enjoying your music.

Creating an intuitive and convenient real world user interface was always part of the DALI IO design brief, and the IO-12 fully expresses that philosophy. The most often used functions; volume, playback and telephony, are accessed through buttons elegantly integrated into the logo plate and outer ring of the right ear cup. The logo plate is a multi-function button for controlling Play, Pause, Next, Previous, Take Call and End Call, while upper and lower segments of the ear cup ring, which surrounds the logo plate, control Volume Up and Down. And the use of tactile buttons to control the IO-12 means that, in contrast to many other active headphones, they can be operated while wearing gloves and will actually withstand use in cold weather.

To support the user interface, the IO-12 headphones feature voice prompts that report the operational state, connectivity and battery level. And power status, pairing and battery level are also indicated visually by multi colour indicators on the right ear cup.

Furthermore, we at DALI are all headphone users and appreciate just how important it is that a pair of headphones works in the real world - on the bus, on a flight, grabbed and thrown into a bag, or lent to a teenager to be returned in one piece. The DALI IO-12 will take all of this in its stride and still play your music, both relaxing at home and on the go better than you've ever heard it before.

7. THE DALI AUDIOPHILE FAMILY

The IO-4 and IO-6 began the headphone journey for DALI, and now the IO-12 explores exciting new territory. It joins the DALI family at an exhilarating time. The DALI KORE has cemented DALI's position as manufacturer of one of the world's finest audiophile speakers, and now the same Danish engineering and design team, employing the same tools and philosophies, has created the IO-12. The IO-12 brings DALI values of sound quality and musical communication to audiophile headphone listening. And it does so with the convenience of faultless wireless streaming, the benefit of effective noise cancellation and the ease of flawless comfort.

The DALI IO-12 may well be the only headphones you will ever need.