FLEXOUND
AUGMENTED AUDIO

FLEXOUND Augmented Audio™ technology white paper

The Surface Nearfield Speaker Solution for Uniquely Immersive Listening

Introduction

We rely on personalised audio content throughout our daily lives; to be entertained, to be informed and to be able to communicate remotely. The challenge has always been how to deliver content discreetly, without loss of impact or fidelity, retaining sufficient awareness of our environments, and maximizing comfort. Traditionally the challenge has been addressed with two approaches: using headphones for personal listening (in acoustic Nearfield) and using loudspeakers for shared audio reproduction in the acoustic Farfield.

Flexound proposes a new solution and new approach to personal sound by drawing from the best of both the traditional approaches. Sound reproduction with full impact and fidelity of loudspeakers without the need to wear headphones. This technology moves beyond the limits of Farfield and Nearfield listening. This approach, innovated and developed by FLEXOUND Augmented Audio™ in Finland, explores the multisensory, full frequency Surface Nearfield that enables soundwave vibration to be part of the experience.

This White Paper will introduce the design philosophy and unique aspects of Flexound's Surface Nearfield Speaker technology. It is intended to act as a starting point for further reading into multisensory listening, as well as Flexound's technical implementation in automotive and cinema contexts.

Table Of Contents

Origins and Innovation

Most transformative inventions are born in a moment of inspiration, and Flexound's Surface Nearfield technology is no different. Flexound's founder Jukka Linjama was challenged by his wife, (a professional and occupational therapist working with autistic children) to make a huggable cushion that would capture the buzz from a live music performance.

Mirja, Jukka's wife, had used soundwave vibration devices and music to help direct the attention of disabled children during therapy. But there was no single solution that would combine soundwave vibration feel with actual listening to sound content. Jukka was playing violin one day, when he was reminded that it wasn't just his ears doing the listening.

As he pulled the bow across the strings of his violin, Jukka could feel the vibrations in both arms, neck and chin while he heard the notes with his ears, deepening his connection to the violin and the piece of music. It was the combination of the two senses that made playing this acoustic instrument such an extraordinary experience for Jukka, and profoundly connected him to the emotional content of the music.

Understanding this is key to reproducing sound in an immersive fashion, because our skin is sensitive enough to be able to feel sound frequencies up to 500Hz – perhaps even as high as 1,000Hz for our fingertips. It's not just the lowest frequencies that move us, which surprises many people. (This is reflected in how hearing starts to develop before birth, as sounds from the outside world – and the mother's voice – are transmitted through amniotic fluid in the fetus.)

Taking inspiration from the soundboard of his violin, Jukka drew on his academic background – and work experience in haptics and acoustics – to develop his ideas into new augmented audio technology, which harnessed the Surface Nearfield.

Figure 1. TAIKOFON® FeelSound Player cushion product for therapy applications with its soft soundwave vibration and monophonic ambient soundscape.

This prompted the breakthrough that was used to create the Taikofon® therapy cushion, FLEXOUND Augmented Audio™'s first product (Fig. 1 below). Taikofon® creates an ambient soundscape around it, which felt like magic because it was also tangible. This breakthrough then forged a path to Flexound's technology eventually appearing in cinema and automotive applications.

This path required experimentation and led to discoveries that took the Flexound team to new horizons in tactile-audio reproduction. Taking the inspiration of the soundboard of the violin a step further, the team combined acoustic measurement and psychoacoustics with a methodical trial-and-error approach, in the manner of pioneering instrument makers.

Figure 2. HUMU® Augmented Audio Cushion™ with strong tactile bass and stereophonic personal soundscape.

Prototypes were initially handcrafted to experiment with the sound and vibration responses of different materials and designs. Progress was hard fought, and after the surprising spatial monophonic soundscape illusion of Taikofon®, another breakthrough was made in ambient acoustics with stereo and the HUMU® product, which created a compelling binaural illusion (Fig. 2 above).

Prioritising the listening experience has since allowed Flexound to uncover the physical mechanisms behind its deeply immersive, multisensory experience. It has defined new qualities and benchmarks for audio-tactile performance, and gained the deep knowledge required to integrate this technology into any audio system.

Multisensory Listening

FLEXOUND Augmented Audio™ has worked extensively to develop the technology around multisensory listening. This is because humans are hardwired to use all sensory channels at the same time, synthesising various cues from the outside world to build up our own personal interpretation of it. Sensory information is constantly received by the central nervous system, while the brain divides attention and nervous activity between different senses. This is known as sensory integration.

As with our sense of vision – in which rapid, involuntary movements of the eye continuously scan the field of view – our sense of touch is based on sensory-motor cooperation between the movement of our bodies, and tactile receptors.[1]

So, when it comes to listening and sound, we are talking about more than just 'hearing'. Listening is an intentional activity in which our attention is focused on features in the sound environment, from music to distracting background noise. Because listening is situational, we can now say that sound reproduction takes place in a listening context.

Feeling Sound

Our sense of hearing always adapts to the listening context we are in. For example, auditory cues in our environment can support directional vision, while motor skills and our sense of touch support hearing, in many respects. For instance, accurate directional hearing is not possible without the dynamic cues provided by slight head movements.[2]

Both our skin and our eardrums sense sound in the same way – through mechanical vibrations – either via sound waves in the air, or through direct contact with vibrating surfaces. To be truly immersive, a listening experience should use both our sense of hearing and our sense of touch, thereby becoming audio-tactile. This brings many advantages because we already know that the information conveyed by two sensory channels is more than the sum of separate sensory channels.[3]

Music Moves You

As well as being more efficient at conveying information, the emotional content of audio – in particular, music – is greatly amplified through multisensory listening. We know that music profoundly affects our moods, while it unconsciously directs attention and evokes memories connected to specific songs or passages. Depending on the type of music, it can either relax or energise, helping us to concentrate, relax and meditate, or to motivate exercise.[4]

In fact, multisensory listening has been used in vibroacoustic therapy for more than thirty years to deliver music therapy, physiotherapy, and rehabilitation. The science shows that using low-frequency sound vibrations (30–120Hz) to massage the body, combined with music listening and therapeutic interaction, has a clinical healing effect on the body and mind.[5]

Now, FLEXOUND Augmented Audio™ has made a breakthrough in creating Surface Nearfield technology, which delivers full range audio to our senses of touch and hearing, but also synchronises and balances the vibration 'feelscape' with the audible soundscape.

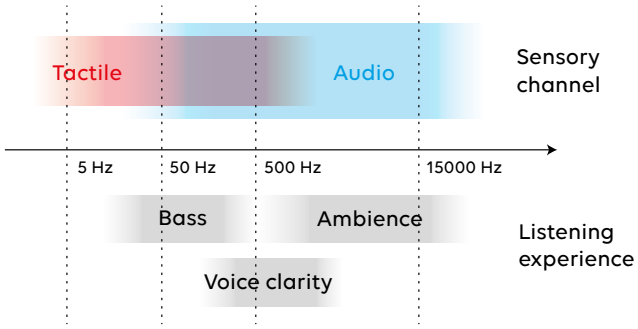

Figure 3. The useful frequency ranges of Tactile and Auditory sensory channels, and their relation to Bass, Ambience and Voice Clarity enhancements in FLEXOUND Augmented Audio™.

This is achieved through a new kind of speaker, the single, full range Surface Nearfield solution, which is in contact with the body, and delivers an immersive audio-tactile experience, shown in Fig. 3.

Those low frequency sound vibrations can be said to be in the 'tactile frequency range'. Air is a poor conductor for these frequencies so more force (typically turning up the volume) is needed to feel them, but other materials conduct them with ease. This means that FLEXOUND Augmented Audio™'s solution allows for a personally powerful low frequency experience that does not disturb people nearby, but still boosts the effect of Flexound's tactile frequency reproduction, sending vibrations into the furniture backrest. These tactile vibrations support the auditory signal for greater immersion within the sound experience.

By augmenting hearing with feeling in the Surface Nearfield solution, we enable the three benefits mapped to tactile, audio-tactile and auditory perception frequency ranges, which are depicted in Fig. 3 (above):

a) Tactile 'Bass': low frequency extension that goes well below 50Hz, where tactile perception dominates hearing.
b) Audio-tactile 'Clarity' in the midrange: clarity of voice supported by audio and tactile sensory channels up to 500Hz.
c) 'Ambience' of the Surface Nearfield at mid and high frequencies above 500Hz where binaural directional hearing primarily operates.

Because the human voice, and voiced instruments, such as guitars and violins operate predominantly in the mid-range frequencies, it is those that are the most relevant when we talk about clarity. Indeed, our auditory attention naturally gravitates to these frequencies, as it is an evolutionary advantage [6], so the mid-range is arguably the most critical frequency range in audio reproduction.

FLEXOUND Augmented Audio's™ solution capitalises on the ability of our skin to detect mid frequencies through touch, and our ears to detect them through air. This brings two senses to bear and increases clarity. Not only does this make spoken dialogue and other mid-range signals clearer and more enjoyable for everyone, but it also makes them much more accessible for the hearing impaired.

Due to this dynamic, Flexound's Surface Nearfield solution creates an immersive, holistic listening experience that can help you to seek specific moods, and energise or focus your mind. As Fig. 4 (below) shows, the solution allows it to synchronise both the audible soundscape and the skin-contact vibration 'feelscape' into a single holistic experience, connecting the body and mind, and evoking emotions. This embodied sound experience can also help you to relax, or to practise meditation, which has been shown to counter chronic stress and anxiety, and promote mental wellness.[7]

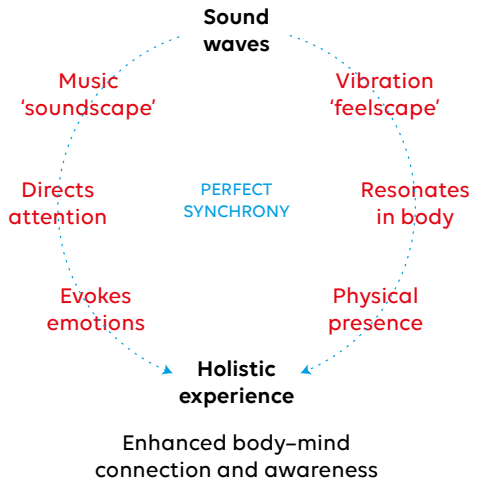

Figure 4. Immersive listening becomes a holistic experience when the sound wave vibration 'feelscape' is in synchrony with the audible soundscape.

Traditional Listening Contexts: Farfield vs Nearfield

FLEXOUND Augmented Audio™ has made a breakthrough in Surface Nearfield listening, but to understand what that means, it's necessary to distinguish between the two listening modes: Farfield and Nearfield.

Traditionally, we have either listened in the Farfield some distance away from loudspeakers, or in the Nearfield, such as with headphones that are placed very close to the ears. Farfield loudspeakers create an audio image, which consists of the direct sound, as well as reflections from hard surfaces, which they create by interacting with the space around them.

If you're close enough to loudspeakers then they can also be in the Nearfield, where room reflections are weak. In effect, speaker placement (and listener location) are critical to getting the desired sound reproduction. Questions such as 'at what point do we move out of the Nearfield and into the Farfield', are extremely dependent on the specific set-up. Past a certain critical distance, direct sound waves are overcome by sound reflections in the room, with delay and sound level defined by the room reverberation time.[8] This is illustrated in Fig 5, where the room farfield is indicated as an area where the direct sound becomes too quiet to be clearly perceived. This may be due to the reverberant sound, or alternatively, the ambient noise level.

The advantage of Nearfield listening (either with studio monitor speakers or headphones) is in the accuracy and clarity of direct sound, unaffected by the room. While some amount of added reverberation sounds natural, in the Farfield the echoes and reverberation in the room heavily affect the speech clarity, frequency response and the sound image.

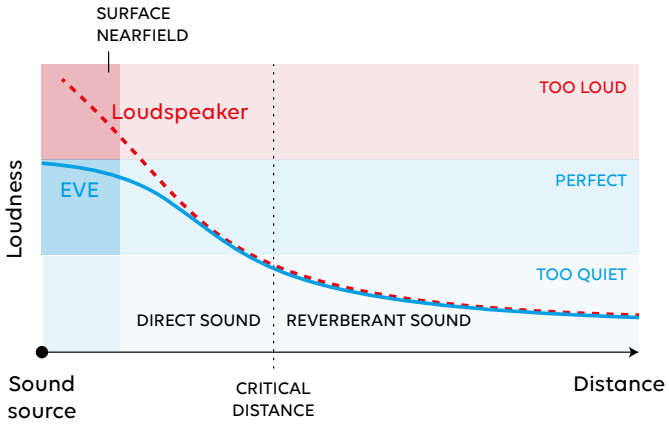

Figure 5. Loudness versus listening distance in Farfield and Nearfield regions of a compact sound source in a room. EVE is a distributed surface sound source, which enables close listening in its Surface Nearfield.

However, there is one challenge in using loudspeakers in the Nearfield. If the sound source is compact (as with treble elements in loudspeakers) the sound image in the Nearfield is very dependent on the distance to each ear: sound may be localised at the source and be overly loud if the ear is moved close to the source.

Moving Beyond the Nearfield – the FLEXOUND Augmented Audio™ Solution

During the technology development, FLEXOUND asked whether it was possible to create a Nearfield audio solution that minimised the localisation of sound to the source? This creates a sound image that better tolerates various head positions, and maintains traditional stereo listening performance, despite producing sound from a backrest or neck cushion. The experience is more analogous to 'being in the band' (or playing the instrument) than 'being in the audience'.

More and more, people are using mobile phones and tablet speakers to hear audio content, pushing the envelope of Nearfield listening. Improved hands-free speakers on these devices have prompted people to watch movies or conduct remote meetings without headphones.

Reacting to this trend, some companies have created wearable accessory speakers such as neck bands, or sound pillows with small speakers (or headphones) placed inside. Unfortunately, these do not fully solve the problem of disturbing others nearby, and their low frequency response has been generally lacking.

A response to this lack of low-end is offered by those products with separate vibrating devices for personal bass sound reproduction, either installed in a seat, or as wearables. In practice, none of these solutions for Nearfield listening are able to provide full frequency range audio without combining loudspeakers with separate vibration devices, and sometimes headphones. This is where Flexound has broken through the convention and created a new solution.

FLEXOUND Augmented Audio™'s technology is based on listening in the ultimate Nearfield: the Surface Nearfield[9] (see Fig. 5). This multisensory, full range solution uses a simple but effective combination of components to create a new kind of sound reproduction that achieves the following:

1. **A fully immersive listening experience that delivers new clarity to the low and mid frequencies, giving them greater impact and also making them more accessible.**

2. **Freedom from headphones, while enjoying a precise and powerful bass sound that does not bleed out too much into the room.**

3. **An ambient stereo soundscape, despite the sound source being behind the head.**

The core of the solution is the Elastic Vibrating Element (EVE), a layered porous plate structure that serves as the primary sound source, which can be listened to very closely without the sound being heavily localised. Its patented construction creates an audio image that spreads around the head.

Building the EVE

Flexound's Elastic Vibrating Element (EVE) consists of a vibrating soundboard inside soft, porous layers and a material cover (Fig. 6, below), which distinguishes it from conventional speakers and flat panel speakers. This gives it two major advantages:

1. The EVE can transmit both vibrations and full range audio while being in comfortable contact with the listener – a world first in audio technology.
2. The EVE can be integrated into a larger structure (such as a seat backrest) to transmit vibrations to a wider surface area, for a strong Nearfield bass sound that does not radiate into the Farfield (due to its dipole radiation characteristics).

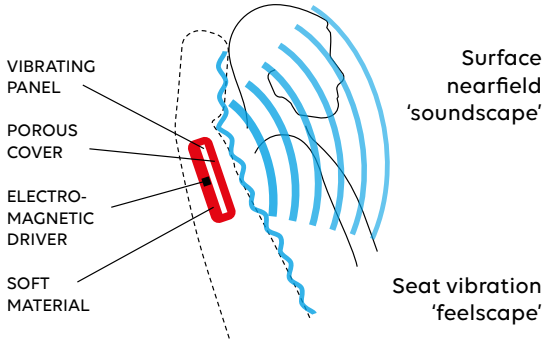

Figure 6. The Elastic Vibrating Element (EVE), audio-tactile Surface Nearfield Source implementation in a seat.

An interesting paradox lies at the heart of the EVE's success in creating a balanced audio image, because part of the acoustic and mechanical signal from the vibrating soundboard panel is lost as it passes through the soft, porous material layers. In fact, this paradox is the very essence of the innovation behind Flexound's Surface nearfield implementation: this kind of 'acoustic semiconductor' structure actually works in favour of the listening experience, because it evens out the spatial and frequency response characteristics of the Surface nearfield, without compromising the treble signal clarity.

EVE acts as a spatially distributed, surface sound source that is very natural. Despite the element being behind the neck, the listening experience resembles that of stereo headphones, or loudspeakers in a room.

In fact, the way that the audio image wraps around creates a compelling binaural illusion of the surrounding acoustic space. This may be a fortunate side-effect of the inaccuracy of human directional hearing, when distinguishing between sound coming from the front or the back (known as front-back confusion,[2] see Fig. 7 below).

Lateral (left-right) sound is easier to pinpoint, and the stereo EVE configuration provides this information so that it's perceived effortlessly. Front-back information, however, is more fuzzy, and brains tend to adapt and interpret auditory sensation the most meaningful way to fit to the listening context. This is another paradox with Surface Nearfield implementation: despite having a sound signal coming from the back, in most listening contexts this does not present a problem for audio clarity or enjoyment.

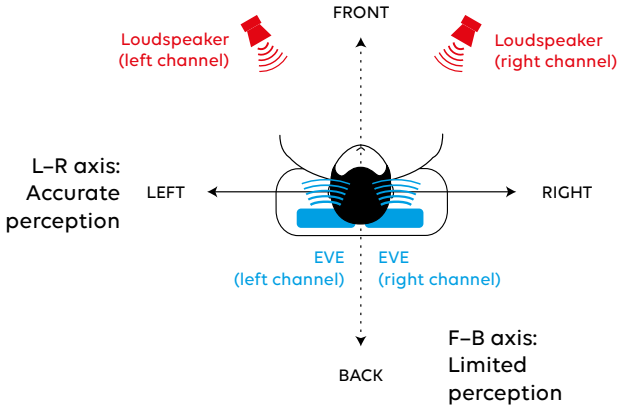

Figure 7. Spatial hearing in stereo sound reproduction. Stereo sound information is in lateral (left-right) direction where hearing is accurate, and not in front-back or up-down directions where also hearing is less accurate.

Integrating the Surface Nearfield into Audio Systems

Functionally, Flexound's EVE is a low sensitivity, full range speaker. Seats and devices using Flexound technology perform best when included in the design phase. All the seat attributes - stiffness, dimensions and materials contribute to how the seat will function as a speaker. Flexound has the knowledge to work with the seat design team to balance audio performance, seat design and achieving the needed certification and specifications. After the seat is designed, audio signal processing is used to fine-tune the acoustic frequency response, and manage the vibration volume so that the tactile feel is experienced at a comfortable level with all playback volume levels. Dedicated signal processing is also needed for seamless integration of FLEXOUND Augmented Audio™ to supplement existing audio systems, for example in cinema or car audio. In addition to industry standard multi-channel mixing and equalisation, Flexound has innovated dedicated signal processing for audio system integration, in order to maximise the effectiveness of the tactile sensation. Flexound technology includes 'Feelness Control' or the ability to increase or decrease the amount of vibration played on each seat. Adjusting the amount of vibration isn't affected by the other audio settings like Volume or balance. This 'Feelness Control' of audio signals is useful because the perceivable dynamic range of vibration is not as wide as with hearing, and people have individual preferences for vibration levels, which may vary again, depending on the listening situation.

Once the seat design is complete and the digital signal control is in place, the integration focuses on content. Flexound Augmented Audio™ implementation doesn't require changes in the audio track but it's at this point that Flexound is different from conventional speakers. In cinema terms, Flexound seats are not center, left/right, rear, surround nor subwoofer channels. The audio tracks are down mixed to provide the sounds from all the typical channels. In this way, they are truly primary speakers that are then mixed in for timing to work with the other speakers in the system. The spatial effect is enhanced with a Flexound EVE and audio objects are faithfully reproduced.

In system integration, thorough co-development is needed in implementing both the mechanical integration of EVE to seats and selecting the parameters in audio signal processing software. This know-how and development service to licensees of Flexound Augmented Audio™ solution will enable optimum value-add to the listening experience and fast time-to-market.

Conclusion

FLEXOUND Augmented Audio™ has developed a new kind of Surface Nearfield speaker solution, to bring more clarity, deeper immersion and additional wellness benefits to personal audio, by also experiencing sound through body contact. The core of the solution is Flexound's Elastic Vibrating Element (EVE), which provides multisensory, full frequency range audio, together with vibration from a single source.

Together with associated audio signal processing, EVE can be integrated to seats or cushions to deliver an embedded, immersive loudspeaker system. Adaptable to a host of listening contexts, this Surface Nearfield speaker solution excels in automotive and cinema applications.

The audio-tactile listening experience delivered by FLEXOUND Augmented Audio™ combines two sensory signals to form an audio image greater than the sum of its separate parts, enabling a richer experience in which emotions are explored and expressed.

References

1. Bundy, A. Lane, S., Murray, E. Sensory Integration: Theory and Practice. F.A. Davis, 2nd edition 2002.
2. Pulkki, V. & Karjalainen, M. Communication Acoustics. Wiley 2015.
3. Strohmeier, & Jumisko-Pyykkö. Audiovisual interaction. In: Sensory Evaluation of Sound. Zackharov N. (ed.). CRC Press 2019
4. Bood, RJ et al. The power of auditory-motor synchronization in sports: enhancing running performance by coupling cadence with the right beats. PLoS One. 2013 Aug 7;8(8).
5. 2012 Punkanen, M. & Ala-Ruona, E. Contemporary vibroacoustic therapy: Perspectives on clinical practice, research, and training. Journal of Music and Medicine 4.3 (2012): 123-135.
6. Aboitiz, F. A Brain for Speech. Evolutionary Continuity in Primate and Human Auditory-Vocal Processing. Front. Neurosci., 27 March 2018
7. Kornjaca, D. et al, The Effects of Vibroacoustically Induced Microvibrations on Arterial Blood Pressure and Oxidative Stress in Rats. Serb. J. Exp. Clin. Res 15(2):83-88, 2014.
8. Howard, D & Angus, J. Acoustics and psychoacoustics. 5th edition, Routledge 2017.
9. Linjama, J. & Välimäki, V., Immersive personal sound using a surface nearfield source. Audio Engineering Society convention 153, Express paper 129, Oct 2022.

FLEXOUND™
AUGMENTED AUDIO

www.flexound.com
Tel: +358 10 5671 770
info@flexound.com

Tietäjäntie 2, FI-02130
Espoo, Finland

Pumpgatan 1 (Uni3 by Geely)
41755 Gothenburg, Sweden

Business Reg No.: FI25436353