Rethinking flat panel loudspeakers

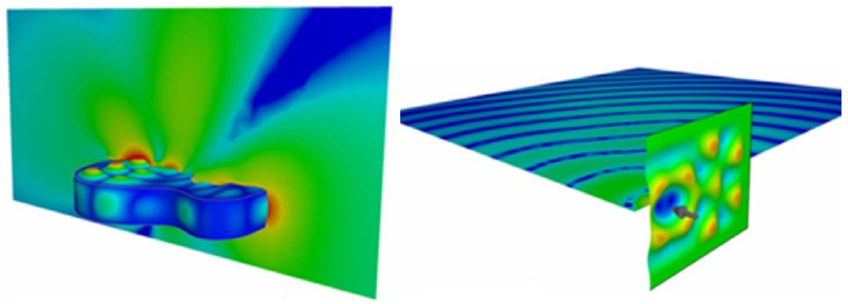
Acoustic improvements for invisible sound integration

Benjamin Zenker, from the Technical University of Dresden, and founder of ZEN Audio Engineering, has been developing loudspeakers for more than 15 years. During the last three years, he has developed simple and robust methods to improve the acoustic quality of flat panel loudspeakers by increasing the low-frequency output, extending the upper frequency limit, lowering the deviation of the frequency response, and optimising the directivity behaviour. His aim is to invisibly integrate sound within architecture and make flat panel loudspeakers an alternative to conventional speaker systems.

Sound is becoming a key part of interior design. It enriches the journey within hospitality environments with beautiful, therapeutic sound. Imagine a room full of warm sounds, suitably selected to cater to your mood, welcoming you. The sound is surrounding you, interacting with you and unwinding you. Isn't it delightful and magnetising? If you spot a loudspeaker, is the moment still so surprising and magnetising? Benjamin Zenker, from the Technical University of Dresden, and founder of ZEN Audio Engineering, would answer: not at all. Invisible loudspeakers are essential in creating a mindfulness sound experience. Once you spot the loudspeaker, the imagination disappears.

INVISIBLE LOUDSPEAKERS

Zenker's research is improving the acoustic quality of flat panel loudspeakers. Invisible loudspeakers, in the form of flat panel loudspeakers, distributed-mode loudspeakers, and bending wave loudspeaker, create sound by using one or more exciters to induce vibrations on a flat surface. Exciters vibrate the surface they are mounted to, creating an invisible speaker. The surface is being vibrated to produce the sound, so there is no need for openings in the surface. These speakers work like musical instruments, radiating sound through the vibration of the structure, so any surface in a room can be a loudspeaker – the door of a cupboard, a picture on the wall, or even the wall itself. The radiation principle is more complex and harder to optimise than conventional speakers, which obstructs companies from entering the market. Zenker has developed robust physical methods that can be adopted by the market and reduce the inhibition to produce flat panel loudspeakers.



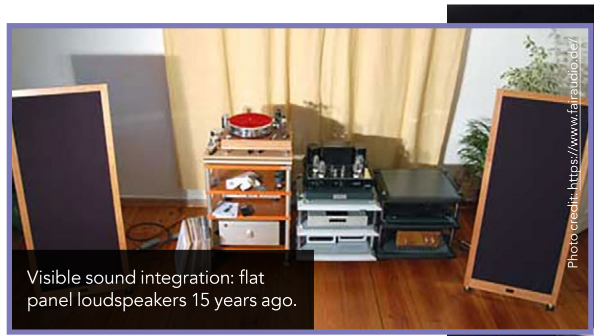
Flat panel loudspeakers work like musical instruments, radiating sound through structural vibrations.
Left: Sound radiation of a guitar. Right: Sound radiation of a flat panel loudspeaker.

Invisible loudspeakers are not new to the market. In 1995, the British company New Transducer Limited (NXT, founded as Verity Laboratories) started working with a small team of engineers to bring flat panel loudspeakers to a commercial realisation. NXT hedged this technology with 1,000 patent applications worldwide and licensed it to potential customers, but only a few managed to bring it to the market.

FLAT PANEL LOUDSPEAKERS AND TODAY'S MARKET

Zenker launched this research by examining why the market failed more than 25 years ago. Since then, the market has changed incredibly, and the advantages of flat panel loudspeakers suit today's customer needs. Considering this market change requires answers to two questions: how did you consume music in the 1990s? How many speakers did you use at home?

Twenty-five years ago, high-quality loudspeakers were found in the living room – a symbol of status and optimised for high-quality music reproduction.



Visible sound integration: flat panel loudspeakers 15 years ago.

Invisible sound integration: flat panel loudspeakers today.

Flat panel loudspeakers can be integrated as part of the interior design.

Back then, it was difficult to exploit the advantages of flat panel loudspeakers. In today's smart homes, it's straightforward to run multiple speakers and listen to your favourite music throughout your home. Smaller loudspeakers are often distributed across all rooms, but where should they be placed and how can they be hidden? Customers want the comfort of technology, but they don't want to see it. Moreover, reducing the size of loudspeakers also reduces their acoustical quality. Zenker explains that to reach market acceptance, the acoustic quality needs to be improved.

> **Invisible loudspeakers are essential to creating a mindfulness sound experience. Once you spot the loudspeaker, the imagination disappears.**

FILLING THE ACOUSTIC GAP

These concerns led Zenker to investigate the acoustic gap between smart speakers (the consumed products) and high-quality speakers (state-of-the-art technology). Flat panel loudspeakers generally can't achieve the acoustic performance of conventional speakers of the same dimensions as they produce less output. They can, however, be integrated where they can't be seen. Furthermore, these locations offer large surface and volume, which can be used to reach higher sound pressure levels and lower bass than small smart speakers.

Zenker decided to compare different types of speakers to find out if a modern flat panel loudspeaker can fill the acoustic gap. Four categories of loudspeakers represented by a market-leading product were assessed: smart speaker, flat panel, soundbar, and studio monitor. After thorough analysis, he wasn't surprised to find that, in terms of acoustic parameters, the studio monitor performs best, followed by the soundbar and the flat panel. The smart speakers achieved the lowest scores. The lower frequency limit, comparable frequency response deviation, and an increased acoustic output, led to a higher preference rating of the flat panel loudspeaker compared to the smart speaker.

Evaluating the overall acoustic performance of the flat panel loudspeaker revealed that it is filling the gap of acoustic performance between the soundbar and the smart speaker. These results indicate that the image of the flat panel loudspeaker needs to be reconsidered since it outperforms the smart speakers that are so commonly used at home.

ACOUSTIC OPTIMISATION

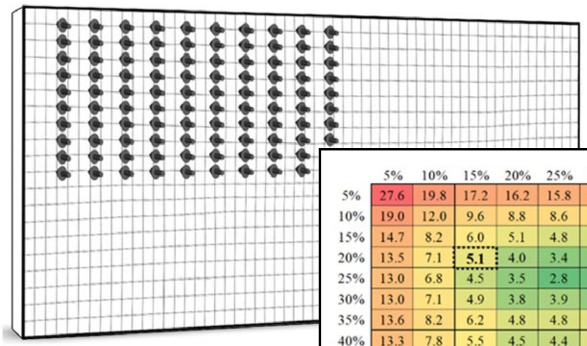
While customers are willing to integrate invisible speakers, they won't settle for inferior sound quality. It is, therefore, essential to improve the sound quality of flat panel loudspeakers and reach similar acoustical properties to conventional systems. Psychoacoustics research has shown that four parameters are essential for a positive loudspeaker preference rating: low-frequency deviation, the lower and upper frequency limit, the deviation and slope of the frequency response, and a homogeneous directivity pattern. Zenker has researched each parameter to optimise the technology to reach a higher acoustic preference rating.

OPTIMISED EXCITER POSITIONING

A crucial part of panel loudspeaker design is positioning the exciter. A flat panel loudspeaker's sound is generated by the excitation of plate-bending waves travelling across the panel's surface. The sound radiation is strongly influenced by the position of the exciter, as different combinations of bending modes are excited with each position. The perfect position depends on the size of the panel, the material properties, and the chosen frequency range of use. Zenker employed FE-simulation to develop an electro-mechanical-acoustical model to visualise the influence of the positioning and reduce the development time required. He demonstrates its use in finding the best excitation position for various panel sizes and aspect ratios.

DEVIATION OF THE FREQUENCY RESPONSE

Even if the exciter is well positioned, the deviation of the frequency response in a flat panel loudspeaker is higher than a conventional speaker. Frequency response describes how well all the audible frequencies are reproduced. Fluctuations can be irritating, and we tend to notice upward deviation more than



	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	27.6	19.8	17.2	16.2	15.8	15.4	15.1	14.6	14.1	14.0
10%	19.0	12.0	9.6	8.8	8.6	8.5	8.4	7.9	7.4	7.2
15%	14.7	8.2	6.0	5.1	4.8	4.8	5.3	5.0	4.5	4.5
20%	13.5	7.1	5.1	4.0	3.4	3.5	3.9	3.8	3.3	3.5
25%	13.0	6.8	4.5	3.5	2.8	2.9	3.3	3.3	2.8	2.7
30%	13.0	7.1	4.9	3.8	3.9	3.6	3.3	3.7	4.0	3.9
35%	13.6	8.2	6.2	4.8	4.8	4.9	4.6	5.2	6.5	7.7
40%	13.3	7.8	5.5	4.5	4.4	4.9	5.6	5.5	6.6	8.2
45%	12.9	7.2	4.9	4.4	4.7	5.2	6.6	6.2	5.4	5.1
50%	12.7	7.1	4.8	4.6	5.4	5.6	6.9	6.8	5.2	5.1

Quarter 1 | Quarter 3 | Quarter 4

Zenker set up a simulation model to predict the best excitation position by simulating 100 different positions per panel.

downward deviation. Zenker presents an alternative to minimise the impact of specific modes to compensate for high deviations. He uses a small air gap behind the panel to suppress selected vibrations, resulting in lower deviations of the frequency response. This stiffening is known from bracing in music instruments, but adding mass reduces the output. By using air pressure as stiffening, only the deviation is minimised, without affecting the overall output.

LOW-FREQUENCY PERFORMANCE

Low-frequency performance is a physical problem for flat panel loudspeakers resulting in less output and higher deviations in the frequency response. Zenker reinvestigated a hybrid woofer-driven design to improve the low-frequency behaviour of flat panel loudspeakers. The woofer is part of a speaker system designed to reproduce low-frequency sound signals – the bass. The hidden woofer excites the whole panel uniformly and offers huge improvements when compared to an exciter-driven panel. It is a simple and robust construction, which can be mass produced. The panelled woofer design produces a low-frequency bass response similar to that of a large conventional system.

UPPER FREQUENCY LIMIT

While monitoring the behaviour of different types of exciters attached to the same loudspeaker panel, Zenker noticed significant deviations of the upper frequency. These differences were not explainable with the panel properties and the regular Thiele/Small loudspeaker parameters. He visualised the cause using wave6 simulation software and Klippel measurement equipment. The rigidity of the panel can cause additional bending in the exciter. This bending is called break-up and is the upper frequency limit. Zenker introduces new methods to measure and predict the upper frequency limit. He also created a prototype with reinforced structure to increase the resonance frequency and extend the frequency range of the loudspeaker panel.

DIRECTIVITY RESPONSE

The next step was to improve the directivity response of an existing panel. Loudspeaker directivity describes the extent to which the sound is focused in a particular direction rather than broadcasting it in all directions around the room. Zenker improves directivity by changing the resulting vibration pattern using edge damping. Damping is preventing vibration, or just allowing the object to return to rest for the shortest time. Flat panel loudspeakers tend to a wide radiation, but too much energy can be transmitted to the side angles, producing unnatural sounds. Zenker simulated the mechanical and acoustic relationships. His analysis revealed that the directivity response of the damped panel was more homogeneous, with a higher mean value and lower standard deviation. Additional damping produces similar sensitivity but improved directivity. Optimising the directivity index without any losses requires more complex methods, eg, the use of several exciters, with higher production costs. This method of edge damping, however, is a simple, robust, inexpensive, and effective approach for improving the directivity of flat panel loudspeakers.

AN INNOVATIVE LOUDSPEAKER SYSTEM

Zenker believes that developing technology and new possibilities will make more people want to take advantage of invisible speakers. The low visual profile offers opportunities to integrate larger and more powerful devices with higher acoustic quality than smart speakers. He concludes that flat panel speakers are an alternative for customers who want higher acoustical quality and more power than smart speakers provide, without requiring space for larger devices.

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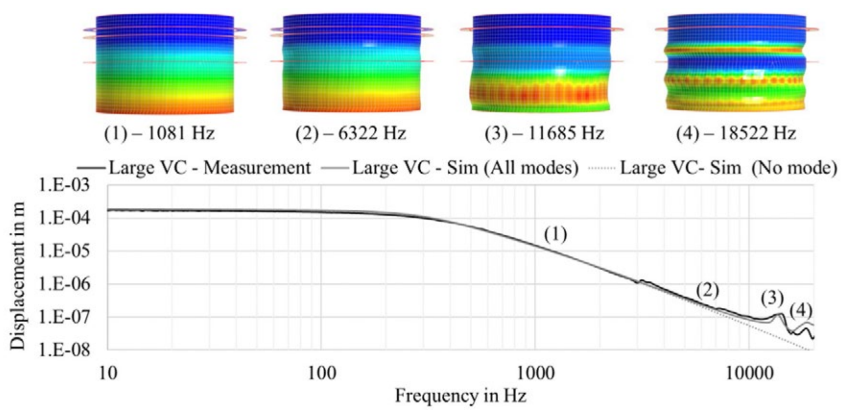

Visualisation of the voice-coil break-up mode at highest frequencies.

Behind the Research

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Research Objectives

Benjamin Zenker has improved the acoustic quality of flat panel loudspeakers.

Detail

Bio

Benjamin Zenker has been developing loudspeakers for more than 15 years. He developed his own loudspeaker series with his dad and won awards in a German-wide young researchers' competition. Benjamin studied mechanical engineering and acoustics at TU Dresden, and gained experience working as an intern in the field of modal analysis with Audi AG and the acoustic simulation company wave6. He is now in the final stages of his PhD, after learning precision craftsmanship with a furniture manufacturer. He is R&D Engineer at Klippel GmbH and founded his own audio consultancy, ZEN Audio Engineering.

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References

Zenker, B, (2019) Rethinking Flat Panel Loudspeakers – an Objective Acoustic Comparison of Different Speaker Categories. *AES E-Library*. www.aes.org/e-lib/browse.cfm?elib=20616

Zenker, B, (2020) Upper Frequency Limit of Flat Panel Loudspeakers – Evaluation of the Voice Coil Break-Up Modes. *AES E-Library*. www.aes.org/e-lib/browse.cfm?elib=20741

Zenker, B, (2020) Low-Frequency Performance of a Woofer-Driven Flat-Panel Loudspeaker (Part 1: Numerical System Analysis and Small Signal Measurement). *AES E-Library*. www.aes.org/e-lib/browse.cfm?elib=20928

Zenker, B, (2020) Low-Frequency Performance of a Woofer-Driven Flat-Panel Loudspeaker (Part 2: Numerical System Optimization and Large Signal Analysis). *AES E-Library*. www.aes.org/e-lib/browse.cfm?elib=20980

Zenker, B, (2019) Low Deviation and High Sensitivity – Optimized Exciter Positioning for Flat-Panel Loudspeakers by Considering Averaged Sound Pressure Equalization. *AES E-Library*. www.aes.org/e-lib/browse.cfm?elib=20619

Zenker, B, (2021) Improved Directivity of Flat-Panel Loudspeakers by Minimizing the Off-Axis Radiation below Coincidence. *Appl Sci*, 11, 7001. doi.org/10.3390/app11157001

Zenker, B, (2020) Improved Sound Radiation of Flat-Panel Loudspeakers Using the Local Air Spring Effect. *Appl Sci*,10, 8926. doi.org/10.3390/app10248926

Personal Response

What's the next step in development of the flat-panel loudspeaker before bringing it to the market?

" It is important to create market acceptance for flat panel loudspeakers. This requires adjusted acoustic standards, updated development tools, open-minded designers with new ideas of sound integration, and courageous companies developing new products. It is essential to remove the fear of developing flat panel loudspeakers. With my research, I have shared simple and robust methods that improve the acoustic quality of flat panel loudspeakers; it is important to me that they are considered as an alternative to conventional systems, as they offer the cleanest solution to integrate sound in every environment. Be creative and rethink flat panel loudspeakers. "