Audio Engineering Society

Convention Express Paper 65

Presented at the 154th Convention

2023 May 13-15, Espoo, Helsinki, Finland

Surface nearfield source (SNS) approach compared to flat panel speaker implementations

Jukka Linjama

Flexound Systems, Tietäjäntie 12, FI-02130 ESPOO, Finland

Correspondence should be addressed to Author (jukka.linjama@flexound.com)

ABSTRACT

Surface nearfield source (SNS) approach for sound reproduction which is categorized between headphones and loudspeakers was introduced in [1]. The SNS can be embedded for example in the headrest as a personal sound system, providing also a natural audio-tactile augmentation to the listening experience. This paper focuses on the implementation of SNS speaker solution and how it relates to conventional flat panel speakers and structural vibration exciter solutions. Operation principle of panel type speakers is discussed, and low frequency vibration behavior of SNS solution integrated into a seat is illustrated using a lumped parameter model.

1 Introduction

The idea of the first flat-panel loudspeaker was born already in 1920s and has since evolved to include products used in the fields of home theater, public address systems, and telecommunications [2]. Their main benefit in addition to their flat form factor is the (almost) full frequency range operation compared to conventional multi-way loudspeakers with cones drivers that have limited operational frequency range.

This paper aims at clarifying specific features of the new sound reproduction approach called Surface Nearfield Source (SNS) [1] by comparing it to related existing solutions. For this purpose, panel speakers are treated as two categories, shown in Table 1: electrostatic panel speakers and distributed mode (DML) panels, including structural exciter "vibration speakers". Panels with distributed drivers like electrostatic panels operate with planar distributed force acting on a suspended foil, providing a narrow radiation pattern (pistonic plate dipole) to farfield. DML panels operate with point driven bending wave panels or structural exciters mounted on any surface. They create wide, non-directive diffuse radiation pattern. The surface nearfield source (SNS) based sound reproduction in Table 1 differs from all other loudspeaker solutions in that it is primarily intended for the use in the nearfield and audio-tactile listening experience in contact with the speaker.

This paper begins with a brief analysis of the operation principles of the speaker categories listed in Table 1.

Table 1. Comparison of the operation and use of panel-type loudspeakers

Solution type/ Feature	Electrostatic panel	DML panel	Surface nearfield source (SNS)
Drive Principle	Planar distributed force acting on suspended foil	Inertial point force acting on resonating bending wave field panel	Inertial point force acting on elastic panel and porous layers
Primary use	Room farfield	Room farfield	Personal nearfield + tactile contact
Radiation pattern	Narrow, pistonic plate dipole	Wide, diffuse field	Surface nearfield

Then the implementation of the SNS approach with Elastic Vibrating Element EVE [1] is described more in detail and its dynamic behaviour at low frequencies is illustrated using a lumped parameter vibration model.

2 Panel speaker categories

2.1 Electrostatic membrane loudspeakers

Electrostatic speakers operate with a lightweight electrically conductive suspended foil or membrane that is actuated by a distributed electrostatic force between the driving stator electrodes that are sound transparent (rigid porous or grid structure), also called as plane wave transducers [3]. This type of speakers act as pistonic, plane wave type of (plate dipole) sound source, and are therefore very directive in the farfield. Fig. 1. illustrates the operation principle of this category of speakers.

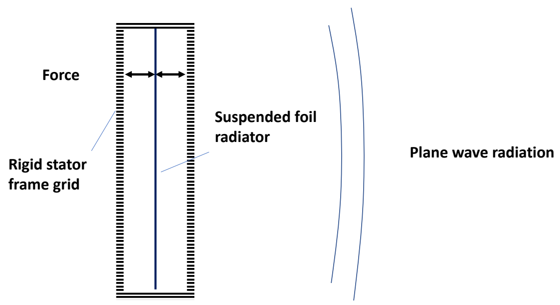

Figure 1. Illustration of the operation principle of an Electrostatic loudspeaker.

Due to their open structure (acoustic short circuit at low frequencies), electrostatic speaker panels usually require a very large surface and/or additional subwoofer to provide the low frequencies to farfield listening position.

2.2 Bending wave panel loudspeakers

This category of speaker solutions consists of point force driven radiator panel structures, usually called DML panel speakers, and related (more or less DIY) structural vibration exciter speakers. Loosely related to this group of speakers are also bass shakers that are intended to primarily support bass with tactile vibration but do not provide wider frequency range audio.

2.2.1 Distributed mode loudspeakers

DML speakers are suspended lightweight panels with diffuse (high modal density) bending wave field that radiates a diffuse sound field. See Fig. 2.

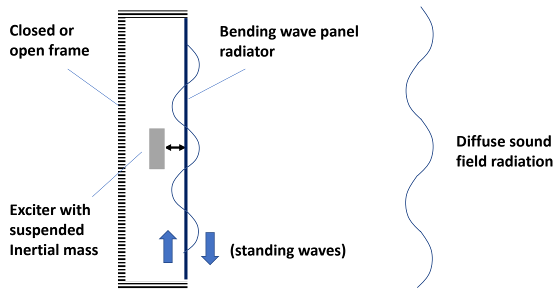

Figure 2. Operation principle of a DML panel speaker schematically.

The basic concept of DML panels is simple—to radiate sound by exciting the bending vibrations of a panel using one or more small force actuators mounted to the panel surface. However, in comparison to cone-radiator loudspeakers, flat-panel loudspeakers have not achieved widespread commercial acceptance due to deficiencies in their sound quality. Fundamentally, the design challenges of flat-panel speakers arise from the intrinsically large number of mechanical degrees of freedom of a panel radiator [2].

A number of methods have been explored to compensate for the acoustical shortcomings of flat-panel speakers [4], and carefully designed flat-panel loudspeakers have been rated in blind listening tests as competitive with some prosumer-grade conventional loudspeakers. [5].

A major challenge for bending wave panel-based solutions is the low frequencies where the modal overlap of distinct panel resonances (denoted as standing waves inf Fig. 2) is not sufficient and this inevitably results to coloration of sound.

2.2.2 *Structural exciter speakers*

This group of loudspeakers in based on the idea of DML applied to any (panel type of) rigid surface like wall, table etc. Solutions can be intended to provide a wide frequency range, or just bass subwoofer or pure tactile shaker to enhance low frequency perception in parallel with loudspeakers (or headphones).

Advantages of the exciter-technology include the possibility of integrated “invisible“ loudspeaker with protection against environmental influences (weather, water, cleaning agents) and vandalism, and possibilities for high quality sound output and a wide sound dispersion angle. Disadvantages include lower efficiency factor compared to standard loudspeakers and that devices that are able to touch the excited surface can cause disturbing noise. In addition to this, acoustic performance is strongly dependent on material, dimensions and shape of the excited plate [6].

Related to exciters are also the heavy-duty "bass shakers" intended on substituting subwoofers with low-frequency bass vibrations [e.g. 7].

2.3 The SNS approach

In the context of this paper, SNS can be considered as a combination of structural exciter, bass shaker and DML panel operation. The key differentiating factor is that a soft poro-elastic cushion is part of the vibration and sound transmission. The operational principle is illustrated in Fig. 3. Soft layered construction enables the listener to be ultimately close to the speaker surface or touching it. Thus, the name, surface nearfield source, that is free from farfield speaker room interaction challenges (reflections, challenges with directivity etc.)

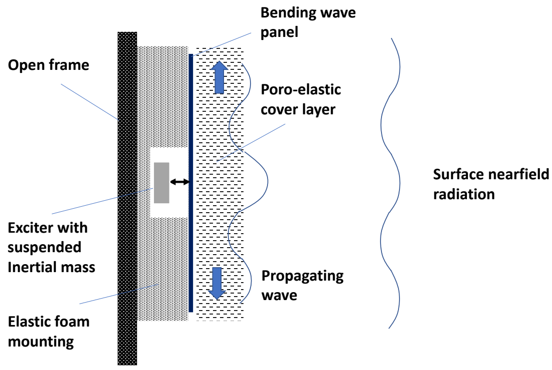

Figure 3. Illustration of the operation principle of an SNS speaker.

This approach helps in solving a major challenge of DML panel speakers: the low frequency end where the individual panel resonances dominate [2]. Inherent mechanical dissipation (or semi-conductive transmission of acoustic energy) in SNS solution evens out the distinct resonances and renders them equalizable with DSP. This is illustrated in Fig. 3 with propagating wave behaviour instead of resonant standing waves. In addition to this, in comparison to electrostatic or DML panels, the effect of acoustic short circuit is negligible in the immediate nearfield, which results to a very energy efficient bass extension.

Tactile bass shaker aspect is involved in SNS implementation, as sound is perceived both as SNS extreme nearfield soundscape and as vibrotactile “feelscape” when in contact with human skin and body.

3 SNS speaker implementation with the Elastic Vibrating Element EVE

The core of the SNS-based audio implementation is the Elastic Vibrating Element, EVE, which provides full frequency range audio, together with tactile vibration from a single source [1].

EVE is conceptually a “speaker element” but is more than that as EVE serves as a distributed audio-tactile source together with the structures surrounding it. EVE consists of a vibrating panel with an electromagnetic inertial driver inside soft, porous layers and a material cover, depicted in Fig. 3. The use of soft material distinguishes it from conventional flat panel speakers that are based on a directly radiating planar plate (or foil) into farfield.

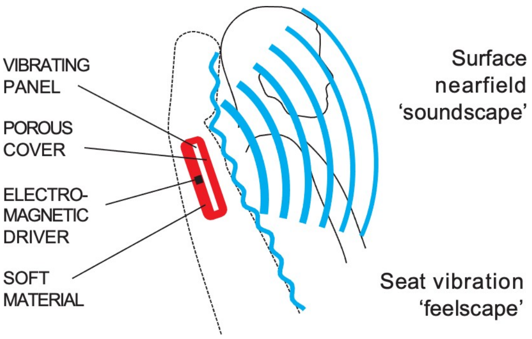

Figure 3. Audio-tactile SNS speaker implementation in a seat with embedded Elastic Vibrating Element, EVE [1].

4 EVE integration to seats and audio systems

This EVE implementation of the SNS can be applied in small scale cushion type of personal listening devices, where the EVE transmits the vibrations and the full frequency range audio while being comfortably in contact with the listener. This type of cushion SNS implementation works best for personal sound reproduction without headphones. Strong bass is perceived with low SPL, and this is beneficial for e.g. relaxing sound massage, or wellness and therapy applications. Challenge for cushion implementations may be excessive vibration when listening loud, especially if the cushion is very compact and not soft enough.

Alternatively, EVE may be integrated into a larger structure such as seat backrest. This implementation has further benefits compared to the separate cushion case, especially in bass reproduction. These aspects will be discussed next.

4.1 Low frequency vibration behavior

Several factors influence the low frequency performance of the seat: exciter dynamics, EVE properties and its mounting to the seat, and seat resonances. These are analyzed next with lumped parameter vibration models, also used in [8] for DML panels.

The low frequency performance of an electrodynamic exciter is limited by its cut-off frequency, known as the mounted resonance f_0 of the exciter

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{1}$$

where k denotes the dynamic stiffness of the exciter magnet suspension and m is magnet mass. As the exciter is mounted to a lightweight panel instead of rigid ground, the actual cut-off frequency of the system will be higher, depicted with a lumped parameter model in Fig 4. In this case the magnet mass m_i will be replaced with the effective (reduced) mass m_{eff} seen by the excitation force. The lighter the panel, the higher the cut-off frequency of the system.

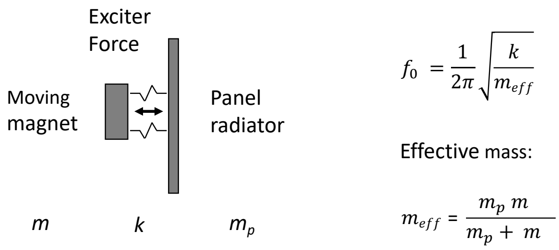

Figure 4. Natural frequency of the exciter – panel system.

EVE construction has porous foam layers on top of the panel. This layer provides losses and additional mass to the system which are beneficial for the low frequency behavior. Losses are presented with damping coefficient of the foam c_f in Fig. 5 illustrating the EVE dynamics at low frequencies with lumped parameters.

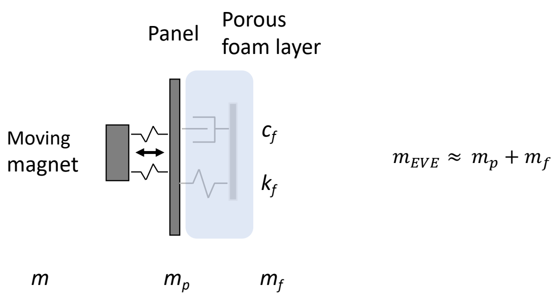

Figure 5. Low frequency vibration model the EVE with the poro-elastic foam layer highlighted.

When mounted elastically to a seat structure, EVE dynamics are coupled to the dynamic behaviour of the entire seat. Seat mechanical resonances enhance the vibration (and sound output) in the low frequency end. With proper design, these resonances can be utilized to distribute the energy to entire seat. This is illustrated in Fig. 6 where the dynamic behavior of the seat is simplified to a one degree-of-freedom resonance, and elastic mounting of the EVE is represented as stiffness k_{EVE} that in practice will possess damping properties as well.

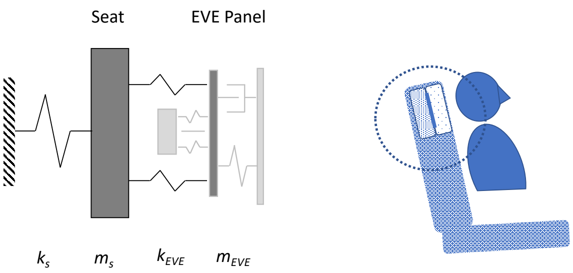

Figure 6. Simplified model of the EVE and the seat as a coupled dynamic system.

4.2 Audio system integration

SNS approach has been commercialized as Flexound Augmented Audio, first in cushions, and later seat integrated versions to cinema and automotive seats, an example shown in Fig 7. Audio system integration includes also dedicated audio processing and amplifiers that take care of seat specific multi-channel mixing, delay control and dynamics processing.

Figure 7. Cinema hall with Flexound Augmented Audio seat system. Each seat has a stereo EVE integrated into the backrest, acting in sync with the cinema loudspeaker system.[1]

5 Conclusions

Unique features of the SNS speaker implementation were described and characterized by comparing it to related panel-type sound reproduction solutions. Panel-type speakers can provide a natural-sounding soundscape in room farfield but with limited bass performance. Structural exciter solutions mounted on large surfaces or furniture structures are capable of performing as subwoofer, but high frequency performance is not well controlled. SNS approach attempts to combine the DML panel and vibration exciter approaches to an efficient full frequency range sound reproduction that operates on the immediate nearfield or contact to the listener.

[1] Flexound Systems. https://www.flexound.com/

References

[1] Linjama, J. & Välimäki, V., “Immersive personal sound using a surface nearfield source,” Audio Engineering Society convention 153, Express paper 129, Oct 2022.

[2] Heilemann, M. C., Anderson, D. A., Roessner, S., and Bocko, M. F., “The evolution and design of flat-panel loudspeakers for audio reproduction,” J. Audio Eng. Soc., 69(1/2), pp. 27–39, Jan./Feb. 2021.

[3] Kelloniemi, A. and Mettälä, K. "A Plane Wave Transducer: Technology and Applications," AES Paper 6945, (2006 October.).

[4] Bank, G. and Harris, N. "The Distributed Mode Loudspeaker-Theory and Practice," Paper MAL-18, (1998 March.). UK 13th Conference: Microphones & Loudspeakers (March 1998)

[5] Zenker, B., Merchel, S. and Altinsoy, M. "Rethinking Flat Panel Loudspeakers—An Objective Acoustic Comparison of Different Speaker Categories," AES Paper 10243, (2019 October.).

[6] Visaton. https://www.visaton.de/downloads/pdf/visaton_exciter_principles.pdf (accessed 2023-02-01)

[7] Dayton Audio Inc. https://www.daytonaudio.com/topic/excitersbuyerguide#how (accessed 2023-02-08)

[8] Anderson, D., Heilemann, C. and. Bocko, M., "Flat-Panel Loudspeaker Simulation Model with Electromagnetic Inertial Exciters and Enclosures," J. Audio Eng. Soc., vol. 65, no. 9, pp. 722-732, (2017 September.).