PRACTICAL RECOMMENDATIONS FOR USING SOUND TRANSDUCERS WITH GLASS MEMBERANE AS AUDITORY DISPLAY BASED ON MEASUREMENTS AND SIMULATIONS

György Wersényi
Széchenyi István University,
Department of Telecommunications,
H-9026, Győr, Egyetem t. 1, Hungary
wersenyi@sze.hu

József Répás
Széchenyi István University,
Department of Telecommunications,
H-9026, Győr, Egyetem t. 1, Hungary
repas@sze.hu

ABSTRACT

Newly designed vibrating transducers can be used coupled directly to solid surfaces such as wood or glass as plane wave short-distance loudspeakers. Our former analysis evaluated the *SolidDrive* transducer glued on to glass surfaces of different sizes and forms. Further investigations concluded that these parameters do not influence the transmission and quality of the coupled system significantly. The second part of this investigation included only one size and geometry for further numerical simulations using COMSOL FEM, as well as for acoustic measurements of the transfer function at selected frequencies. Examination of different wall-fixing and mounting methods were also included. Concluding results show that the overall sound quality is inferior to regular loudspeakers, however, using a supplementary subwoofer results in enjoyable music transmission for a short distance. Furthermore, placement of the transducer in the middle of the membrane and having mounting points at the corners are recommended in practical applications.

1. INTRODUCTION

In auditory display design we usually incorporate with headphones and/or loudspeakers. Both methods have their advantages and disadvantages. In case of a loudspeaker setup, one of the main disadvantages is to have quite large boxes and usually they are fixed or hard to transport.

Besides the classical electromagnetic dynamic loudspeakers there exist different types of alternative loudspeakers. They have generally reduced size, different shape and layout, however, usually also a decreased bandwidth, sensitivity and a higher price. Nevertheless, some special applications may focus on this technology to replace classical loudspeaker setups, including auditory displays.

As an example, a Distributed Mode Loudspeaker (DML) is a flat panel loudspeaker technology, developed by NXT, in which sound is produced by inducing uniformly distributed vibration modes in the panel through a special electro-acoustic exciter. Transducers for distributed mode loudspeakers include moving coil and piezoelectric devices, and they are placed to correspond to the natural resonant model of the panel. The “SurfaceSound” is a traditional flat-panel application with a frequency range up to 18 kHz, size-independent directivity, but with low sensitivity for lower frequencies and insufficient stereophonic image. The applicability of DML panels for wave field synthesis (WFS)-based sound reproduction has been also investigated, where large number of closely spaced loudspeakers is necessary. It has been incorporated into a number of novel products such as school equipment, portable folding speakers etc. [1].

Recently, a new group of loudspeakers has been introduced: the so called “invisible audio” [2-4]. Manufacturers ship the vibrating transducer only about a size of a beer can that can be mounted on any glass or wooden surface such as windows, doors, tables etc. In this way the vibrating surface becomes the membrane, radiating almost plane waves. According to the manufacturers the sound quality is “good”, but brochures and commercial materials do not contain reliable measurement data. Because these systems could be an alternative also for auditory displays, for narrative applications (installations, museums), for personal use etc., we analyzed the possibilities of one of them.

Our investigation included numerical simulations using Finite-Element-Methods (FEM) with the COMSOL software package, as well as acoustic and vibration measurements for comparison [5-8]. Our goal was to determine the technical parameters, overall sound quality and application areas depending on the material of the vibrating surface, size and geometry, placement of the transducers and mounting methods [9]. Figure 1 and 2 show pictures of the transducers. Because they cannot be disassembled and the inside construction is classified, we also X-rayed the SolidDrive for an inside look.

Figure 1: Left the SolidDrive, right the Feonic Transducer [2, 4].

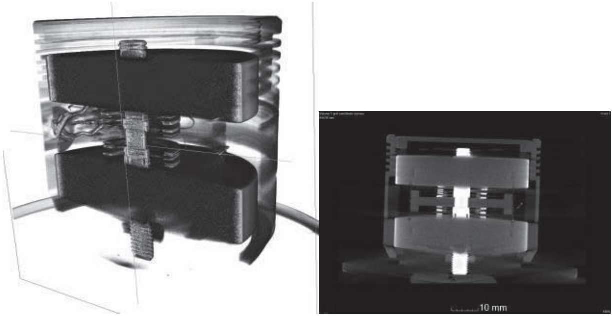

Figure 2: Revealing some secrets: X-Ray images from the SolidDrive. They function based on the electromagnetic principle.

2. MEASUREMENT AND SIMULATION

Based on the operation manual of the SolidDrive transducer, acoustic parameters are listed as follow:

- broadband, 70 Hz – 15000 Hz (depending on the vibrating surface),
- impedance 8 Ohm,
- mass 0,5 kg,
- recommended amplifier power 10-100 W,
- sensitivity: N.A.,
- vibrating membrane: glass or wood,
- exciter: high-power neodymium magnet, two symmetrical motors,
- achieved STI (Speech Transmission Index) is “excellent”: 0,75 points.

For the measurements we applied both vibration measurements (accelerometers) and acoustic installations (microphones). For numerical simulations COMSOL Multiphysics was used. We focused on the following parameters: sensitivity, frequency range and directional characteristics. In case of the membrane, we used only glass surfaces of different geometries (size, thickness and shape), different placement of the transducer and different mounting methods (screws or frame). Some of the results are based on real measurements, some only based on simulation and some using both methods.

Simulations and measurements of the 50x50x0,6 cm glass plate were conducted to determine the most appropriate fixing and mounting methods, both for the transducer on the plate as well as the for the plate on the wall. These included:

- transducer glued in the middle of the plate and no wall fixing,
- transducer glued randomly on the plate (avoiding any symmetry-axis or resonant nodes) and no wall fixing,
- transducer glued almost in the corner of the plate and no wall fixing,
- transducer glued in the middle of the plate and plate fixed on the four corners,
- transducer glued randomly on the plate and plate fixed on the four corners,
- transducer glued in the middle of the plate and plate fixed in a frame,
- transducer glued randomly on the plate and plate fixed in a frame.

At the first five setups both measurement and simulation were carried out, at the last two, only simulation results exist.

3. RESULTS

Figure 3 and 4 show simulated and measured data of the frequency response. The simulation was in good correlation with measurement data showing a frequency range up to only 10 kHz. The goal has been also to test the simulation method, whether it is capable of replacing acoustic and vibroacoustic measurements.

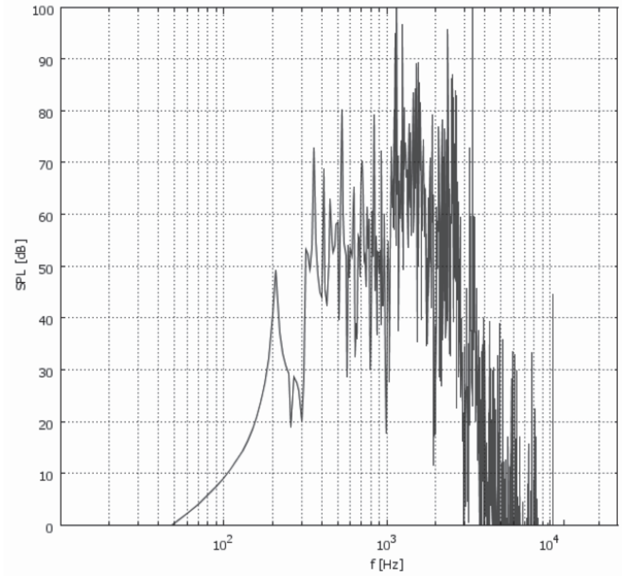

Figure 3: Simulated transfer function of the 50x50x0,6 cm glass membrane. Using different sizes and geometries, simulated transfer functions appeared to be very similar.

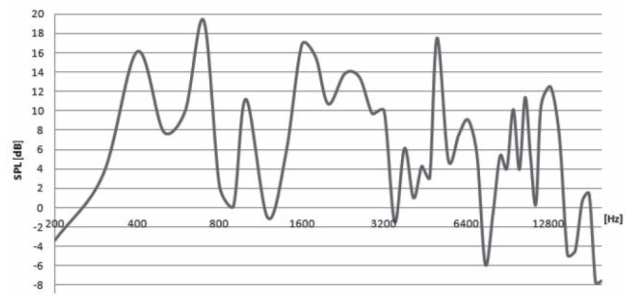

Figure 4: Measured transfer function of the 50x50x0,6 cm glass membrane.

Figures 5 and 6 show color plots from the simulation software. Values of simulated acceleration are according to the color bar on the right. The small black circle represents the transducer glued on to the plate.

Because numerical simulations are based on ideal models, calculated results show high symmetries and mathematical approximations (vibrating modes). However, conducting a multichannel vibration measurement showed that these approximations are in good correlation with measured data [9].

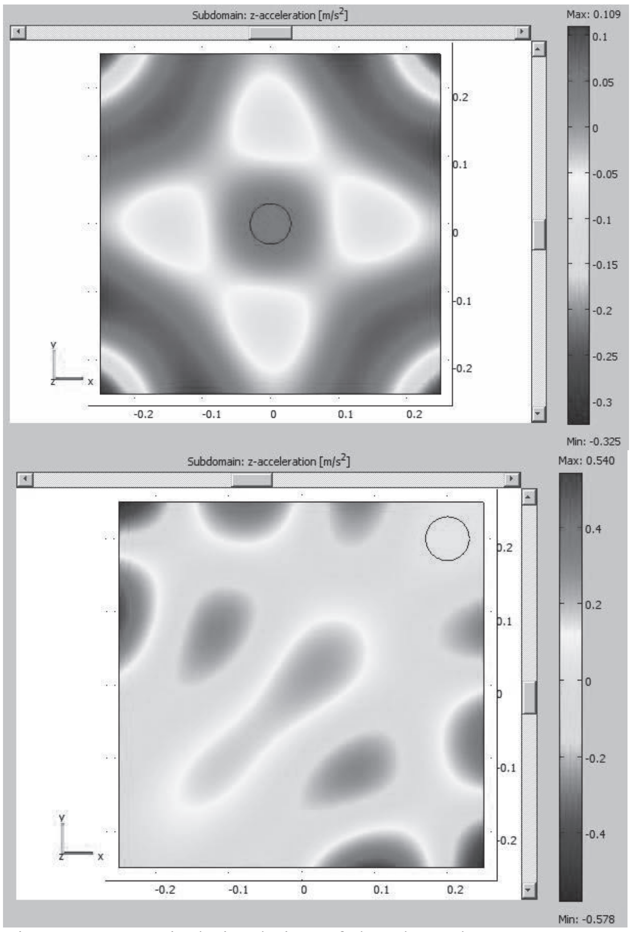

Figure 5: Numerical simulation of the glass plate at 1000 Hz, without fixings, and having the transducer in the center (top) and in the corner (bottom).

4. DISCUSSION

Because measurements using different vibrating surfaces can be difficult, time and cost expensive, we decided to rely also on numerical simulations. These kinds of simulations have enormous computational load, but if results are in good correlation with measurement data, predictions can be made based on the numerical methods.

Based on all of our results, the following recommendations could be a good summary, guideline for auditory display solutions:

- Transmission between 200 Hz and 10 kHz can be maintained almost independently of the material of the vibrating surface (glass or wood). However, frequency response is far from being linear.
- The geometry of the same size (rectangle or circular), and thickness of the vibrating surface is not significantly relevant.
- Sensitivity and reproduced SPL is relatively low, however, directional characteristics show almost plane wave propagation.
- Due to plane wave propagation, localization of reproduced sound sources may differ from results obtained with point-source propagation. Similarly to the DML system, stereophonic sound image and directional information of sound sources are insufficient.
- The use of a supplementary subwoofer system is recommended in case of musical reproduction even if one-channel reproduction is used.

After selecting the most user friendly and appropriate size in our analysis, further investigations were made with the 50x50x0,6 rectangle glass membrane. Using this, the possible placement of the transducer on the plate as well as the wall-fixing methods were simulated and measured. Based on these, we concluded that:

- A fixed (wall-mounted) plate does not differ significantly from a “free”, dismounted plate. The fixing method using the four corners with screws is recommended in contrast to fixing the glass in a frame, however, this version is also acceptable.
- Placing the transducer on the plate is not a critical issue, neither frequency response nor directivity are influenced significantly. A symmetrical placement (e.g. in the center of the plate) is recommended.

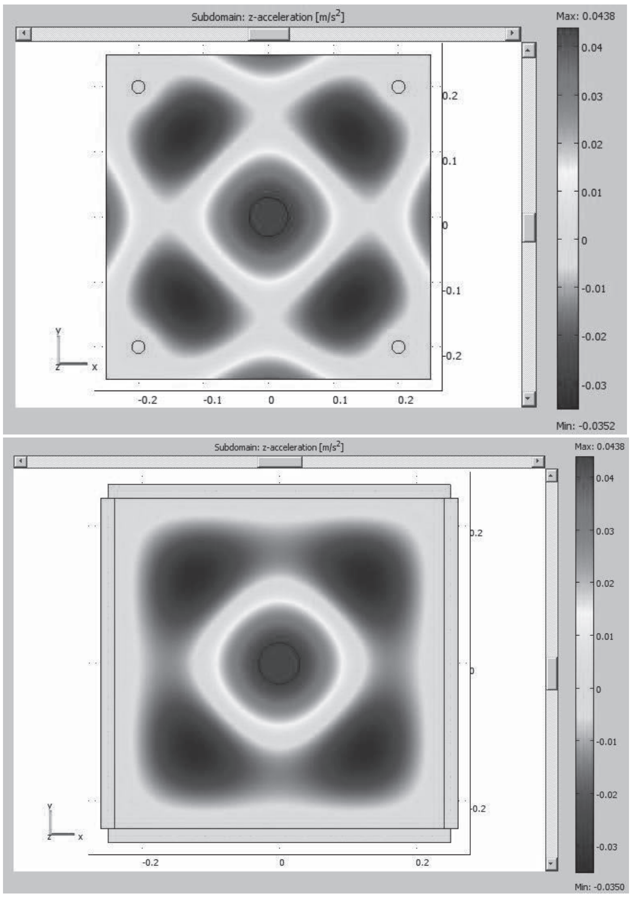

Figure 6: Numerical simulation of the glass plate at 1000 Hz having the transducer in the center and with screw fixings at the corners (top) and using a frame (bottom). Small circles in the top image show simulated wall-fixing points where displacement of the plate is zero.

5. SUMMARY

The SolidDrive SD1g resonator with vibrating plates of different size, geometry and material were measured and analyzed based on FEM models and acoustic measurement. The simulation focused mainly on glass membranes, but both acoustical and vibration measurements supported the conclusions. The goal was to determine the possibility of applications in auditory display techniques as well as giving recommendations for fixing and mounting methods. A frequency response from 200 Hz – 10 kHz was measured with almost plane wave propagation. Due to the relatively low SPL (sensitivity), applications using vibrating plates near the listener are recommended (windows, tables etc.).

These systems are not able to replace conventional loudspeakers if high audio quality is needed. On the other hand, “invisible audio” solutions, designer applications with acceptable quality of musical and speech transmission can benefit from this technology. Virtual audio displays can also realized if superior audio quality and proper directional information are not required, and loudspeaker installations should be replaced by other techniques (mobility issues). Future works include listening tests to verify the STI and subjective evaluation of sound quality.

6. REFERENCES

[1] M. M. Boone, W. P. J. de Bruijn, “On the Applicability of Distributed Mode Loudspeaker Panels for Wave Field Synthesis-Based Sound Reproduction,” AES Convention Paper 5162, AES 108th Convention, Paris, France, 2000.

[2] http://www.feonic.com/

[3] http://www.powerview.com/GlassResonator.html

[4] http://www.soliddrive.com/

[5] http://www.comsol.com/

[6] A. A. Piacsek, and R. T. Muehleisen, “Using COMSOL multiphysics software to investigate advanced acoustic problems,” *J. Acoust. Soc. Am.*, vol. 130, no. 4, pp. 2363-2363, 2011.

[7] C.-F. Liu, and Y.-T. Lee, “Finite Element Analysis of Three-Dimensional Vibrations of thick circular and annular Plates,” *Journal of Sound and Vibration*, vol. 233, no. 1, pp. 63-80, May 2000.

[8] A-M. Bruneau, “Amplitude and Phase Measurements of Vibrations of Radiating Surfaces in Order to Determine the Emitted Sound Field,” *J.Audio Eng. Soc.,* vol. 31, no. 12, pp. 907-913, 1983.

[9] Gy. Wersényi, „Evaluation of Vibrating Sound Transducers with Glass Membrane Based on Measurements and Numerical Simulations,” AES Convention Paper 8675, AES 132nd Convention, Budapest, Hungary, 2012.