

## The Research of the DML Loudspeakers Properties

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### Introduction

The complex systems of loudspeakers and different algorithms of the audio signal processing are using for creating the optimum conditions for the listener independently of his position in the room. By traditional electrodynamics loudspeakers to create optimum diffusion acoustic field is sufficiently complicated. First of all, the directivity of the radiation of such loudspeakers depends on frequency, while the secondly, for the reproduction of full range of frequencies it is usually necessary to use low-, middle- and height frequency loudspeakers. Furthermore, these transformers have low effectiveness transformation of electrical signal into the acoustic signal.

There has been developed a new class of the loudspeakers, the principle of work of which is based the excitation of vibration in flat panel as a result of which they appear the standing waves [1]. For the production DML loudspeakers are used rigid, light materials with the small mechanical damping. The effectiveness of DML loudspeakers reaches 90 – 98 % [1].

The new method has been developed, called wave field synthesis (WFS) for reproduction of uniform sound field [2]. This method gives a possibility to generate an accurate representation of the original wave field in the entire listening space. In this method individual loudspeakers are replaced by loudspeaker arrays that generate wave fronts from true or virtual sources. Unlike all traditional methods, the loudspeakers arrays generate an accurate representation of the original wave field in the entire listening space. For creating the uniform acoustic field in the room by the method of WFS can be adapt the loudspeakers type DML [4].

### The distributed mode loudspeakers

A distributed-mode loudspeaker (DML) is operating on bending-wave principles. A randomly vibrating (not in-phase) stiff and light panel radiated sound across surface as

opposed to a small cone acting as a piston (in-phase). The emission of sound energy into air occurs then when for propagated in the solid plate surface waves are created specific ratios between the wave propagation velocities in the solid and air media and the angle, at which plane wave is emitted into the airspace. In the damping medium, such as is real panel, is formed the dispersion of phase speed. If thickness of panel is considerably less than the wavelength of bending vibrations, process acquires the resonance nature: on the flat panel is formed the system of the standing waves and the collection of volumetric components of waves will be attached to them in air. If a flat panel is excited in such a way, that to force its bending oscillating, then it will be to emit acoustic waves. But the structure of acoustic field can be strongly heterogeneous. Because of such flexural vibrations of the diffuser of conventional electrodynamics loudspeaker is especially harmful phenomenon. For obtaining the more uniform acoustic field, it is necessary to optimize the correlative parameters of flat panel. Such parameters include the geometry of panel, its physical properties, and properties of actuators, methods and place (places) of their fastening.

Bending waves propagate across the surface of a panel and undergo multiple edge reflections to form a dense modal distribution. This dense modality is closely linked to the surface wave velocity being proportional to the square root of frequency.

When the bending wavelength is longer than the wavelength in air, real sound power is radiated to air. The direction of radiation is related to the speed of sound in air,  $c_0$ : [5]

$$\sin(\vartheta_c) = \frac{\lambda_o}{\lambda_b} = \frac{c_o}{\sqrt{\omega}} \cdot \sqrt{\frac{\mu}{B}}, \quad (1)$$

where  $B$  – bending stiffness,  $\mu$  – panel density.

The frequency where the wavelength is the same for the bending wave and for the sound wave in air is:

$$f_c = \frac{c_o^2}{2 \cdot \pi} \cdot \sqrt{\frac{\mu}{B}}. \quad (2)$$

### Simulation of bending waves in flat panel

For the flat panels rigid sheets with small damping are used. A common model for viscous damping is Rayleigh damping, where the damping is assumed to be proportional to a linear combination of the stiffness and mass. For a system with a single degree of freedom, the following equation of motion describes the dynamics of such a system with viscous damping:

$$m \frac{d^2 u}{dt^2} + c \frac{du}{dt} + ku = f(t), \quad (3)$$

where  $m$  – mass,  $u$  – displacement,  $t$  – time,  $k$  – stiffness.

In the Rayleigh damping model, the damping parameter  $c$  is expressed in terms of the mass  $m$  and the stiffness  $k$  as

$$c = \alpha_{dM} m + \beta_{dK} k, \quad (4)$$

where  $\alpha_{dM}$  and  $\beta_{dK}$  – the mass and stiffness damping parameters, respectively.

The problem with the Rayleigh damping model is getting good values for the damping parameters. A much more physical damping measure is the damping ratio—the ratio between actual and critical damping, often expressed as a damping factor in percentage of the critical damping. It is possible to transform damping factors to Rayleigh damping parameters. For a specified damping factor  $\xi$  at a frequency  $f$

$$\xi = \frac{1}{2} \left( \frac{\alpha_{dM}}{2\pi f} + \beta_{dK} 2\pi f \right). \quad (5)$$

The far-field response of any vibrating area in an infinite baffle is proportional to the velocity Wave number spectrum and can be calculated [5].

$$P_{(R,k_0,\theta,\varphi)} = jk_0 Z_0 \cdot \frac{e^{-jk_0 R}}{2\pi R} \cdot \mathbf{V}_{(k,\theta,\varphi)}, \quad R \rightarrow \infty; \quad (6)$$

where  $P_{(R,k_0,\theta,\varphi)}$  – sound pressure at frequency  $f = k \cdot c_0 / 2\pi$ , listening angle  $\theta$ ,  $\varphi$  and distance  $R$ ;  $Z_0$  – specific plane wave impedance  $Z = \rho_0 c_0$ ;  $\rho_0$  – air density;  $c_0$  – sound velocity of air;  $\mathbf{V}_{(k,\theta,\varphi)}$  – spatial Fourier-transform of panel velocity.

### Results of simulation

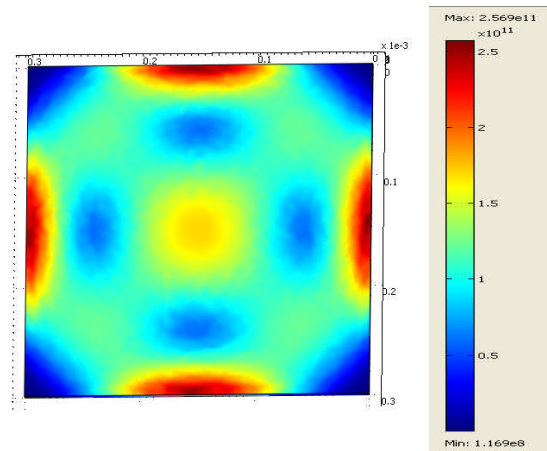
For the simulation of flexural vibrations in the flat panel the program COMSOL MULTIPHYSICS was adapted.

First case – glass panel, dimension: 300 x 300 x 5 mm, one edge is fixed, an excitation frequency from 50 to 2000 Hz.

Same simulation results are shown in Fig. 1 and 2.

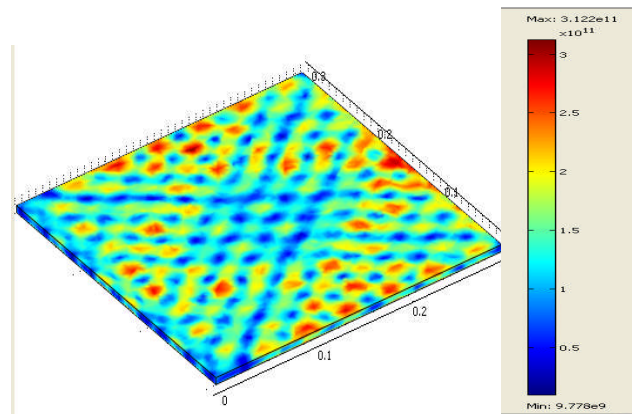
The second case – glass panel, dimension: 300 x 300 x 5 mm, alternate edges are fixed.

The thirty case – glass panel, dimension: 300 x 300 x 5 mm, all edges are fixed.



**Fig.1.** The panel bending waves consisted when the frequency of excitation was 537 Hz and are fixed all edges

The fourth case – polyimide panel, dimension: 300 x 300 x 5 mm, all edges are fixed.



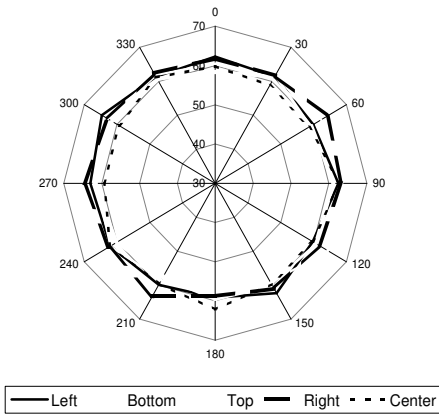
**Fig. 2.** The panel bending waves consisted when the frequency of excitation was 4816 Hz and are fixed all edges

### Results of experiments

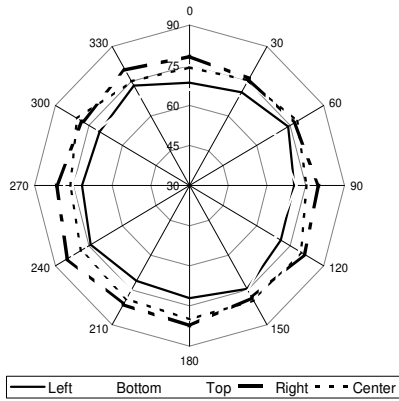
Instruments used for the experiment: magnetostrictive actuator FeONIC Soundbug; sound pressure level meter HiFish AC 2.0; generator of the low frequencies G3-112; oscilloscope C1-49; measuring microphone type A-67 and two models of distributed-mode loudspeaker: polystyrene panel 500x600x3 mm and glass panel 500x600x10 mm.

It was measured the sound pressure level at a distance of 1 m from the panel in the horizontal and vertical planes through every 30 deg. Panel was excited by magnetostrictive actuator. The place of fastening actuator was changed in the course of experiment: one actuator in the center, on the edges, in the angles; one in the center, the second on the ledge.

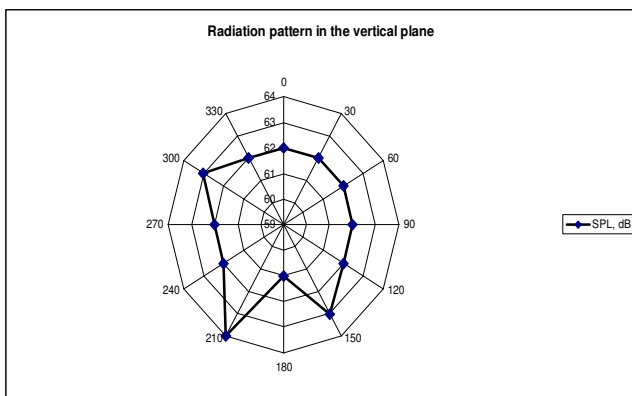
The results of measurement in horizontal plane on polystyrene panel are shown in Fig. 3, 4, 5 and 6.



**Fig. 3.** Radiation pattern for the cases of fastening actuator in the center, on it is left, to the right, in to the top, in to bottom. Frequency of the excitation was 1 kHz

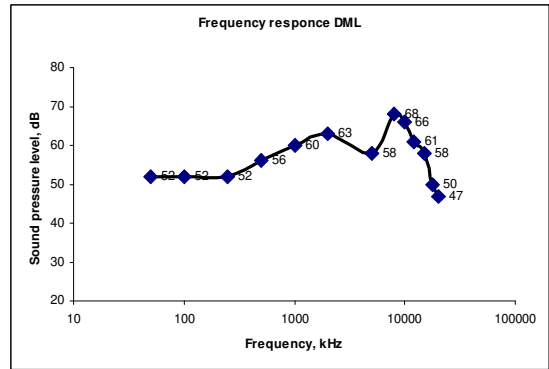


**Fig. 4.** Radiation pattern for the cases of fastening actuator in the center, on it is left, to the right, in to the top, in to bottom. Frequency of the excitation was 10 kHz



**Fig. 5.** Radiation pattern in the vertical plane for the case of fastening actuator in the center. Frequency of the excitation was 10 kHz

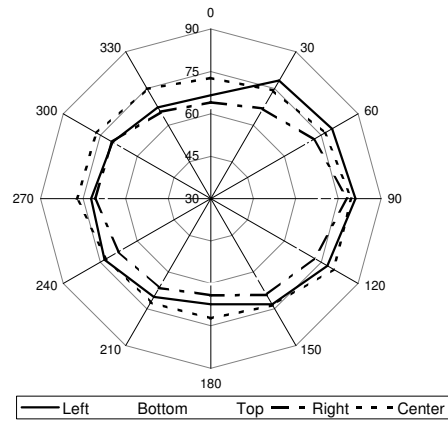
According to the results of measurement the deviation of sound pressure level on frequency of 10 kHz was  $\pm 2.22$  dB in the horizontal plane and  $\pm 0.8$  dB in the vertical plane for case of fastening actuator in the center.



**Fig. 6.** The sound pressure level at the different frequencies, actuator are fastened in the center of polystyrene panel

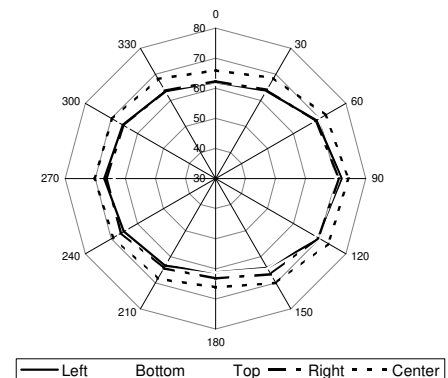
The obtained results show that the radiation pattern and the pressure level of sound remains comparatively constant in wide range of frequencies.

The results of measurement on glass panel are shown in fig. 7, 8, and 9.

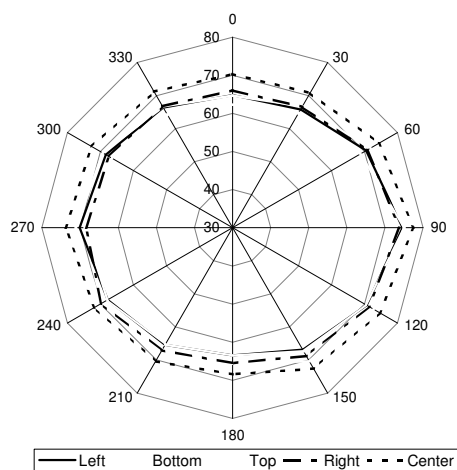


**Fig. 7.** Radiation pattern for the cases of fastening actuator in the center, on it is left, to the right, in to the top, in to bottom. Frequency of the excitation was 2 kHz

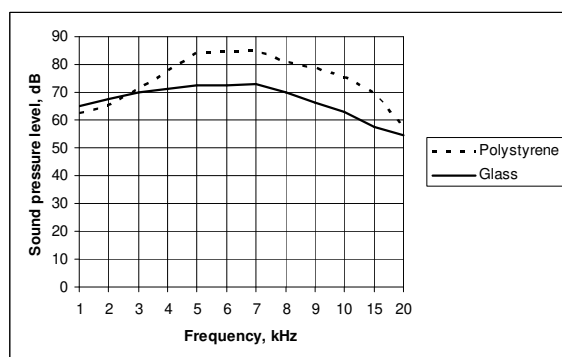
From the comparison of the results of measurement on polystyrene and glass panels, in the case of glass panel is observed more expressed the directivity of radiation. But the sound pressure level is lesser, that there can be related with insufficient power of actuator.



**Fig. 8.** Radiation pattern for the cases of fastening one actuator on the ledge, second in the center, on it is left, to the right, in to the top, in to bottom. The excitation frequency was 2 kHz



**Fig. 9.** Radiation pattern for the cases of fastening one actuator on the ledge, second in the center, on it is left, to the right, in to the top, in to bottom. The excitation frequency 5 kHz



**Fig. 10.** The sound pressure level at the different frequencies, actuator are fastened in the center of polystyrene and glass panel

The obtained results of measurement on the experimental models of loudspeakers in practice are not distinguished from the results of obtained other researchers on the commercial models DML loudspeakers [4].

In the work are not studied the frequency response of actuator. Therefore a comparatively large non-uniformity of the frequency response of experimental flat panel can be determined by the parameters of actuator.

In the measurements of the arrangement of flexural vibrations on the experimental panel the microphone type A-67 was adapted. The results of measuring the arrangement flexural vibration on the experimental panel, taking into account the non-identity of the material experimental panel and model, it does not contradict the results of simulation.

## Conclusions

1. DNL loudspeakers emit acoustic waves with practically equal sound pressure level in the entire hemisphere.
2. The application of two actuators for the excitation of panel increases the emission of sound energy into the forepart hemisphere.
3. Radiation pattern of the investigated flat panels slightly depend from the exciting frequency.
4. Non-uniformity of response in the range of frequencies from 50 Hz to 20 kHz was  $\pm 6.4$  dB
5. The strongest sound pressure level was developed at frequencies from 5 kHz to 7 kHz.

## References

1. **Harris N. J., Hawksford M. O.** Introduction to distributed mode loudspeakers (DML) with first-order behavioral modeling // IEE Proc. Circuits Devices. – 2000. – Vol. 147, No 3. – P. 153–157.
2. **Berkhout A. J., de Vries D., Vogel P.** Acoustic Control by Wave Field Synthesis // J. Acoust. Soc. Am. – 1993. – Vol. 93. – P. 2764–2778.
3. **Morse P., Ingard U.** Theoretical Acoustics. – McGraw Hill, 1968.
4. On the Applicability of Distributed Mode Loudspeaker Panels for Wave Field Synthesis based Sound Reproduction. Accessed at: [http://www.soundcontrol.tudelft.nl/Personnel/Rinus%20Boone\\_files/RB\\_AES2000.pdf](http://www.soundcontrol.tudelft.nl/Personnel/Rinus%20Boone_files/RB_AES2000.pdf)
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6. Comsol Multiphysics. Structural Mechanics Module. User's Guide. Accessed at: <http://www-bsac.eecs.berkeley.edu/~jvclark/msms/COMSOL/smeug.pdf>.

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**A. Dumčius, L. Bernatavičius. The Research of the of DML Loudspeakers Properties // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 8(88). – P. 47–50.**

Some properties of the flat loudspeakers are examined, the principle of work of which is based on the excitation of the standing waves in the flat rigid panel. These devices are called distributed mode loudspeakers (DML). The frequency range of response and sound pressure level in range was measured. The results are given of simulation and measurement for polystyrene and glass panel. In this paper Ill. 10, bibl. 6 (In English; summaries in English, Russian and Lithuanian).

**A. Думчюс, Л. Бернатовичюс. Исследование параметров ДМЛ громкоговорителей // Электроника и электротехника. – Каунас: Технологія, 2008. – № 8(88). – С. 47–50.**

Рассматриваются некоторые свойства плоских громкоговорителей, принцип работы которых основан на возбуждении стоящих волн в плоской жесткой панели. Это так называемые громкоговорители распределенной моды (ДМЛ). Измерялся диапазон воспроизводимых частот и уровень давления звука. Приведены результаты моделирования и измерений для панелей из двух материалов. Ил. 10, библи. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

**A. Dumčius, L. Bernatavičius. Plokščiųjų garsiakalbių savybių tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 8(88). – P. 47–50.**

Nagrinėjamos paskirstytosios modos garsiakalbių (PMG) savybės. Garsiakalbių veikimas pagrįstas stovinčiųjų bangų standžioje plokštėje sužadiniu. Tirtas atkuriamų dažnių ruožas ir garso slėgio lygis. Pateikti polistireno ir stiklo plokščių modeliavimo ir matavimų rezultatai. Il. 10, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).