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A planar loudspeaker for generating evanescent wave

エバネッセント波発生のための平板スピーカ

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1. Introduction

As the popularization of mobile devices increases, near field communication method has been developed, for example IC cards and two dimensional barcode systems. On the other hand, acoustic communication in air has recently received broad attention[1-3]. In particular, acoustic communication method for mobile devices has been studied[4, 5]. Therefore, we attempt to propose near field acoustic communication device for mobile devices. In this study, a planar loudspeaker for generating evanescent wave is proposed. We focused on evanescent wave that decays away with distance from sound source. This phenomenon can be useful for privacy protection and preventing production of noise since acoustic signal can only reach to the vicinity of the source. Evanescent wave generators which consist of planar array using a sheet of Polyvinylidene difluoride (PVDF) or a dipole loudspeaker and digital filter has been presented[6, 7]. However, sound generation systems using these arrays have nodes on sound field, which prevents receiving signal some position. Therefore, this study aims to generating uniform evanescent sound field by constructing a planar loudspeaker. We designed loudspeaker for generating evanescent wave, and simulated attenuation of sound pressure level with distance from the plate.

2. Evanescent wave generation from a plate

When bending wave propagates on a plate and its phase velocity is smaller than sound velocity in sound field, evanescent wave is generated in the region adjacent to the plate surface. In this situation, the sound pressure p decays exponentially with the increasing distance from the plate[8]. Bending vibration in a plate is expressed as beam vibration. Phase velocity of bending wave c_p is obtained by solving the following equation

$$c_{\mathrm{p}} = \left(\omega^2 \frac{ESK^2}{\mu}\right)^{\frac{1}{4}}. \qquad (1)$$

where ω, μ, E and S are angler frequency, line density, Young's modulus, and cross-section area of the beam, respectively. For a rectangular section beam of depth d, radius of gyration expressed as $K = d/\sqrt{12}$. Therefore, bending wave has velocity dispersion and c_p depends on driving frequency. When plate material is acrylic plastic, density of plate and Young's modulus is assumed respectively ρ = 1,160 kg/m^3, E = 3.39 GPa. **Figure 1** shows frequency characteristic of phase velocity and wavelength of bending wave of a plate, which is obtained by solving eq. (1) and d = 2 mm. According to Fig. 1, when sound velocity in air is 340 m/s, phase velocity of bending wave whose frequency is under 20 kHz is slower than sound velocity. Then sound does not propagate from infinite plate, and evanescent wave is locally generated in theory. In order to confirm generating evanescent wave, we measure sound pressure decaying with distance from the plate by numerical simulation.

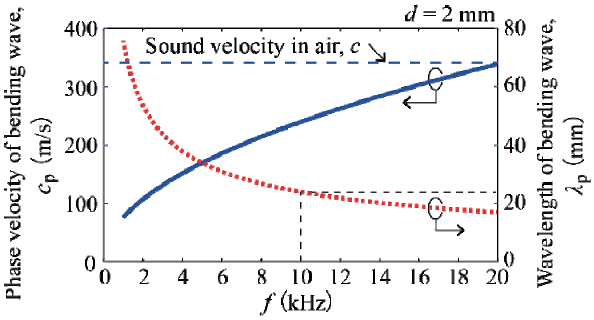

Fig. 1 Frequency characteristics of velocity and wavelength of bending wave when d = 2 mm

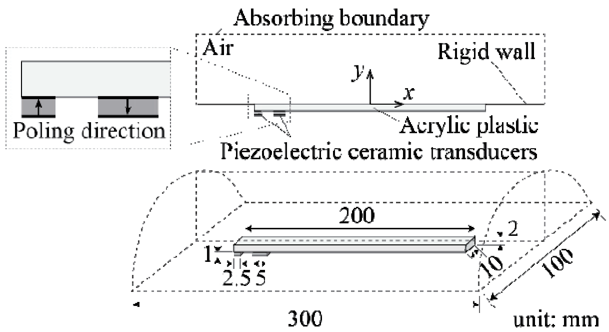

Fig. 2 Shape of a planar loudspeaker and boundary conditions in simulation

3. A planar loudspeaker for generating evanescent wave

3.1 Simulation procedure

A planer loudspeaker was designed for generating evanescent wave. **Figure 2** shows shape of a planar loudspeaker and boundary conditions in simulation. This speaker consists of acrylic plastic plate (vibration plate) and piezoelectric ceramic transducers (vibration source). Width and pitch of the piezoelectric ceramic transducers are 2.5 and 5 mm, which are 1/10 and 1/5 of wavelength of bending wave at 10 kHz frequency as shown in Fig. 1. The boundary of sound field was absorbing boundary condition, and the boundary which is placed at same height with surface of plate was rigid wall. Young's modulus and Poisson ratio of acrylic plastic are 3.39 GPa and 0.35 respectively. Elastic stiffness c, piezoelectric stress constant e and relative permittivity ε of piezoelectric ceramic transducers are assumed $\{c_{11}{}^{E}, c_{12}{}^{E}, c_{13}{}^{E}, c_{33}{}^{E}, c_{44}{}^{E}, c_{66}{}^{E}\}$ = {138.9, 77.8, 74.3, 115.4, 25.6, 30.6} (GPa), $\{e_{31}, e_{33}, e_{15}\}$ = {-5.2, 15.1, 12.7} (C/m^2), and $\{\varepsilon_{11}{}^{S}, \varepsilon_{33}{}^{S}\}$ = {762.5, 664.2}. A frequency response of bending wave on a plate and generating sound field were simulated in three dimensional space using simulation software (COMSOL Multiphysics 4.2) based on the finite element method. Input voltage is 10 V. Elastic wave field was coupled with sound field through boundary surface. The boundary surface interchanges particle velocity and sound pressure between elastic wave field and sound field.

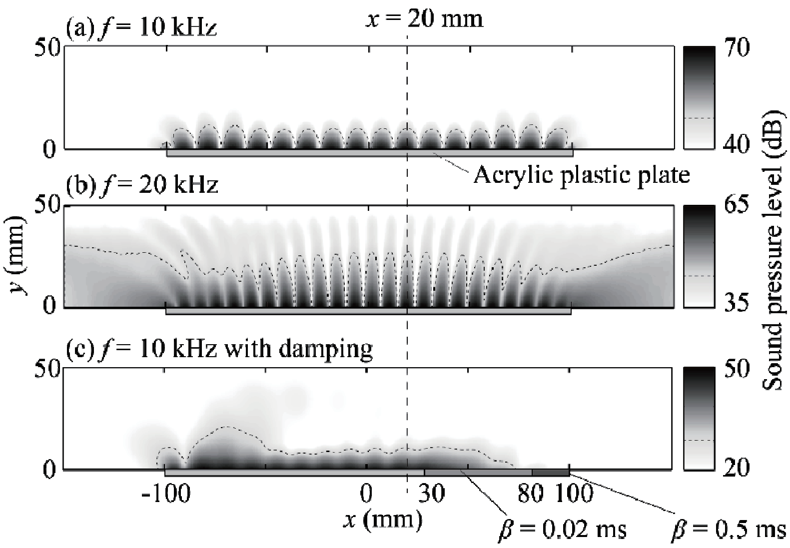

Fig. 4 Sound pressure level of the sound field on *x*-*y* plane in simulation: (a) f = 10 kHz, (b) f = 20 kHz, (c) f = 10 kHz with damping

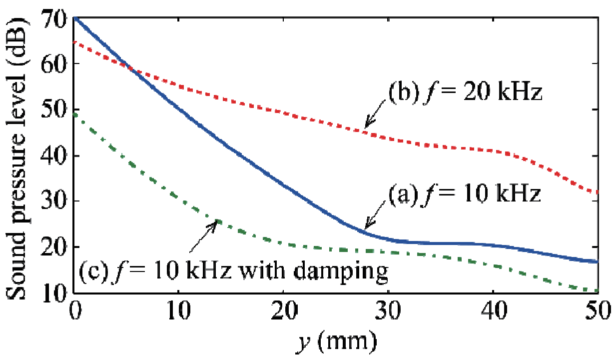

Fig. 5 Sound pressure level at x = 20 mm: (a) f = 10 kHz, (b) f = 20 kHz, (c) f = 10 kHz with damping

3.2 Results and discussion

Figure 4 shows sound pressure level of the sound field on *x*-*y* plane in simulation, and dotted line indicates the level 20 dB below from maximum level. Figures 4 (a) and 4 (b) show the results of driving frequency f = 10, 30 (kHz). Figure 4 (c) shows the result in case that f = 10 kHz and damping was introduced. Although vibration is attenuated by damping material in fact, Rayleigh damping was introduced for convenience, and stiffness damping coefficient β is shown. When input voltage was 10 V, maximum sound pressure level was 70, 65 and 50 (dB) in case of f = 10, 30 (kHz), and f = 10 kHz with damping respectively. These results are enough to receive by microphones of mobile devices. It is apparent that sound pressure level was attenuated 20 dB at y = 10 mm in Fig. 4 (a), 4 (c). On the other hands, sound pressure level was attenuated 20 dB at y = 40 mm in Fig. 4 (b). Distance attenuation was small since phase velocity of bending wave was close to sound velocity in the air when f = 20 kHz. Sound pressure level at x = 20 mm is shown in **Fig. 5**. In all cases, it is confirmed that the proposed loudspeaker can generate evanescent wave because amplitude of sound pressure was attenuated exponentially as shown in Fig. 5. According to Fig. 4 (a) and (b), it can be seen that standing wave was caused by reflecting bending wave at edge of the plate. However, in the case that damping was introduced, an evanescent sound field was generated without nodes as shown in Fig. 4 (c). From these results, it is suggested that the proposed loudspeaker provides quasi uniform evanescent sound field. The loudspeaker expects to be utilized for near field acoustic communication with privacy protection and preventing production of noise.

4. Conclusion

In this study, we focused on a planar loudspeaker using an acrylic plastic plate for generating evanescent wave. We measured decaying sound pressure level with distance from the plate by simulation. Generation of evanescent wave was confirmed by the result. When Rayleigh damping was introduced in order to prevent standing wave, evanescent sound field was generated quasi uniformly without nodes. As further study, more detailed investigation by experiment is planned.

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