3P-46

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 547-548
6-8 December, 2010

Parametric Sources Designed for Reducing Carrier Ultrasounds
キャリア超音波の低減を目的としたパラメトリック音源

Yoshiyuki Hara†, Yoshu Maekawa, Hideyuki Nomura, and Tomoo Kamakura
(Graduate School of Informatics and Engineering, The University of Electro-Communications)
原 祥之‡, 前川　陽州, 野村 英之, 鎌倉 友男 (電気通信大学 情報理工学研究科)

1. Introduction

Although primary ultrasound beams are intense, the pressure amplitudes of parametric sounds are generally much smaller than those of ultrasounds. Hence, the ultrasound signals are sometimes obstructive when only the parametric sound signal has to be detected accurately. In addition, the potentially harmful effects on biological materials of high-power ultrasound fields have attracted a great deal of attention. In order to address such problems, we propose a simple and effective solution, namely, a phase-inversion technique for reducing the amplitudes of primary waves to the greatest possible extent without significantly degrading the acoustic properties of the parametric array.

2. Numerical Examples

We now consider the problem of how to reduce the pressure amplitudes of primary waves more widely around the beam axis. According to the model proposed by Moffett *et al.*[1], the primary beam from an ultrasound projector starts out as a collimated plane wave with a cross-sectional area equal to that of the projector face up to a distance a^2/λ, where a is the dimension of the projector and λ is the wavelength of the primary wave. Beyond this distance, the beam spreads cylindrically and then spherically with propagation. If the dominant generation of parametric sounds is substantially finished or the parametric array is terminated at a distance of less than a^2/λ, the objective of reducing only the primary waves is successfully achieved through the use of the phase inversion technique because a parametric sound basically is generated due to the nonlinear interaction of two primary waves, which have the same amplitude whether the driving signal is in-phase or 180° out of phase. In contrast, the primary waves themselves are canceled out in the far field, especially on the beam axis of the source, when the phase inversion is selected. Inevitably, parts of the primary beams from the two neighboring projectors are mixed in the near-field region. As a result, the difference frequency components decrease 3 dB or more compared with the conventional uniform driving, as demonstrated in the previous reports[2]. Therefore, it is expected that reducing the pressure of the primary wave in a wide region by phase inversion crucially weakens the generation of the difference frequency wave.

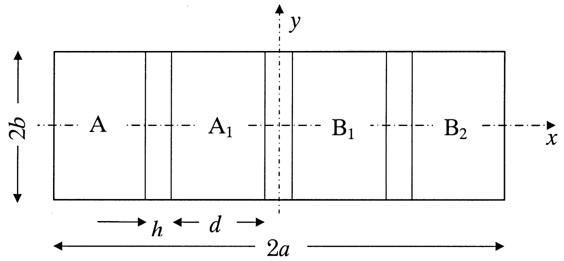

Figure 1　Source model for numerical simulation.

Figure 1 illustrates a simple theoretical model of the ultrasound source we propose. The source is composed of four planar projectors with rectangular apertures of the same area S ($=d\times 2b$). Based on the concept of the phase inversion technique, the neighboring projectors are driven by the phase shift of 180°, i.e., the signals that drive projectors A_2 and A_1 are out of phase, and the signals of projectors A_1 and B_1 are also out-of-phase, and so on. In addition, in order to reduce the mixing region of the primary waves from the neighboring projectors as much as possible in the near-field, the four projectors are separated by a distance of h.

Numerical examples of the pressure fields of the primary and secondary waves are presented in Fig. 2 using the Khokhlov-Zabolotskaya-Kuznetsov equation. In the simulation, the dimensions of the ultrasound source are assigned as follows: d=8 cm, h=2 cm, $2a$=38 cm, and $2b$=12.5 cm. The active area of the source is then $4S$=400 cm^2. In addition, the SPLs of the two primary waves of 26 and 28 kHz are both 130 dB at the source (P_1=P_2=89.4 Pa). Importantly, the pressures on the individual projectors are not allocated in the same amplitude. In order to make the source more responsive at the center than at the edge with negligibly small sidelobes for the difference frequency wave, the individual projectors are simply weighted in accordance with a binominal expansion of degree N-1, where N is the number of the projectors [3]. In the present source configuration, N=4. The relative coefficients in weighting then become (1,3,3,1) from projector A_2 to projector B_2 sequentially. In practice, the weighting factors are determined to be $(-\sqrt{1/2}, \sqrt{3/2}, -\sqrt{3/2}, \sqrt{1/2})$ from the based on the phase inversion and the following considerations: (i) the difference frequency component is essentially generated due to the multiplication process of the primary waves, and (ii) the total acoustic power radiated from the source is the same as a uniform pressure distribution source $4Sp_0^2$ (p_0=89.4 Pa). Additional beam patterns are shown in the figure when the source face over $2a \times 2b$ is vibrated uniformly with amplitude p_0' for comparison. The magnitude p_0' is determined by the condition that the acoustic power is equal to $4Sp_0^2$, i.e., $p_0'=p_0S/ab=0.918p_0=82.1$ Pa.

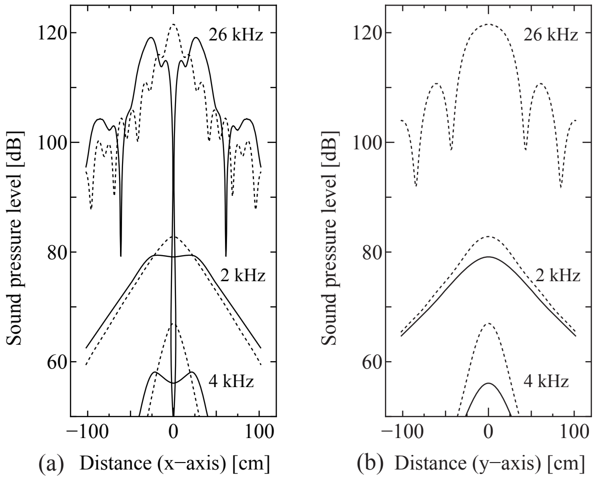

Figure 2 Simulated beam patterns along the x-axis (a) and along the y-axis of the 26-kHz primary and 2-kHz difference frequency waves at a distance of 4 m from the source. Solid lines denote the patterns when the pressure amplitudes on the four projectors are weighted.

Figure 2 simulates that the pressure levels of the primary wave result in an 8-dB reduction by means of the pressure-weighted and phase-inverted method within the relatively wide region of $|x| \leqq$ 20 cm. Unfortunately, the pressure levels of the difference frequency beams are still 3-dB lower and are slightly broader in the mainlobe than those of the usual driving mode with uniform pressure distribution under the condition that the source apertures and radiated acoustic powers are the same. The former and latter beam patterns are indicated by the solid and dotted lines, respectively. As before, the second harmonic components of 4 kHz are considerably decreased by the proposed driving mode.

Figure 3 illustrates the pressure distribution maps in the x-y plane at z=4 m. The source conditions are the same as those in Fig. 2. Figure 3(b) shows that the zonal region of a relatively low pressure exists along the y-axis while maintaining a width of -20 cm$\leqq x \leqq$20 cm, in which the primary wave attains the highest pressure for the uniform driving mode, as shown in Fig. 2(a). The pressure levels of the 2-kHz difference frequency beam exhibit an almost circular contours when the phase inversion mode is combined with a weighing technique, although the source aperture is actually elongated in the y-direction.

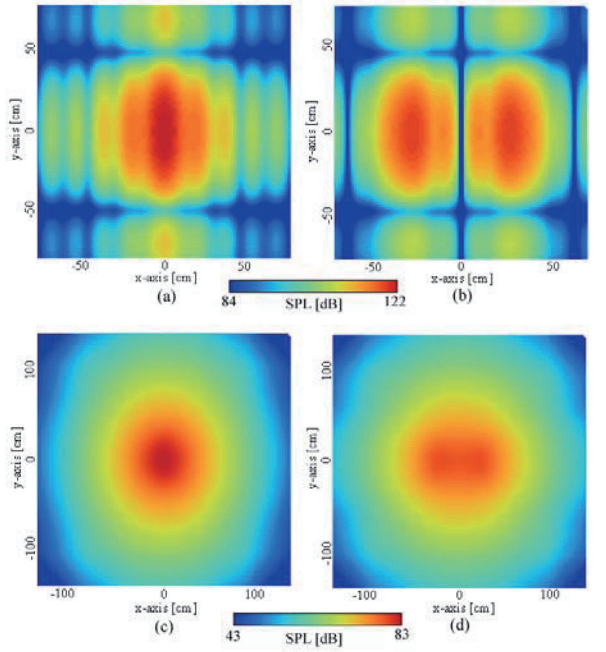

Figure 3 Pressure distributions in the x-y planes at z=4 m. The source conditions are the same as in Fig. 2. (a) and (b) 26-kHz primary wave, (c) and (d) 2-kHz secondary wave, (a) and (c) uniform driving, (b) and (d) pressure-weighted.

3. Conclusions

Numerical simulations are executed for reducing ultrasound pressure levels without significantly degrading the acoustic properties of the parametric array. Appropriate experiments are needed to verify the usefulness of the present idea and technique.

This study was supported in part by a Grant-in-Aid for Scientific Research(B) No. 22360094 from the Japan Society for the Promotion of Science.

References

1. M. Moffett, R. Mellen, and W. Konrad: JASA. **63** (1978) 1326.
2. Y. Hara, Y. Maekawa, H. Nomura, and T. Kamakura: IEICE Technical Report **US2010-1** (2010-4).
3. J. Caruthers: *Fundamentals of Marine Acoustics* (Elsevier, NY, 1977) p. 59-60.