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Investigation on a method for suppression of grating lobe by controlling waveform of transmitted ultrasound
超音波送信波の制御によるグレーティングローブの抑圧法の検討

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1. Background

For determination of the specifications of an ultrasonic probe, it is necessary to consider the grating lobe characteristic. Generation of grating lobes depends on the element spacing of the transducer array and the ultrasonic wavelength. Therefore, methods for suppression of grating lobes are required. It is well known that grating lobes can be avoided by narrowing the element spacing. However, the lateral spatial resolution is degraded due to a decrease in the aperture size.

In the present study, the mechanism of generation of grating lobes was discussed and a method for suppression of grating lobes was examined with computer simulation.

2. Principles

2.1. Computer simulation

Ultrasonic field generated by an array transducer was simulated by FieldII which runs on MATLAB [1-3].

2.1.1. Specifications of simulated ultrasonic probe

The specifications of the simulated ultrasonic probe are shown in Table 1. In the present study, ultrasonic field generated by a phased array transducer was simulated. The transmit focal distance and steering angle were set at 70 mm and -30 degrees, respectively.

Table 1. Specifications of simulated probe

Number of physical elements	16
Height of element	5 mm
Width of element	0.49 mm
Kerf of element	0.01 mm
Speed of sound	1500 m/s
Transducer center frequency	3 MHz
Sampling frequency	100 MHz

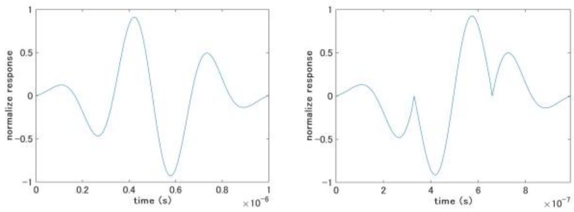
2.1.2. Transmitted wave

The conventional transmitted wave is a sinusoidal wave of 3 cycles. The proposed transmitted wave is also composed of 3 sinusoidal waves, each of which is a single sinusoidal wave, but the polarity of the second wave is reversed. The envelopes of the conventional and proposed transmitted waves were both a Gaussian function expressed as follows:

$$\omega(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right) \qquad (1)$$

where μ is the half length of the pulse and five different values of σ of 0.1, 0.15, 0.2, 0.25, and 0.3 μs were examined.

The rectangular and Tukey functions were used as transmit apodization. Figures 1(a) and 1(b) show the simulated transmitted waves used in conventional and proposed methods, respectively. In the subsequent experiments, σ was set at 0.2 μs.



(a) (b)

Fig. 1 Waveforms of transmitted ultrasound.
(a) Conventional. (b) Proposed.

2.1.3. Generation of Grating lobe

Suppression of grating lobes can be achieved by satisfying the condition described by Eq. (2). In contrast, when grating lobes are generated, the direction of the grating lobe is expressed by Eq. (3).

$$d < \frac{\lambda}{1 + |\sin\theta_m|}, \qquad (2)$$

$$\sin\theta_g = \sin\theta_m \pm \frac{\lambda}{d}, \qquad (3)$$

where λ is wavelength, d is element width, θ_m is the direction of the main lobe, and θ_g is the direction of the grating lobe [4]. Figure 2 illustrates how the grating lobe is generated when a plane wave is transmitted from an array transducer. In Fig. 2, the main lobe was steered at -30 degrees, and the grating lobe is generated at an angle of +30 degrees.

As illustrated in Fig. 2, the grating lobe is generated because the spherical waves at phase differences of $2\pi n$ $(n = 1, 2, \dots, N-1)$, where N is the number of cycles of the transmitted wave, interferes constructively when the conventional transmitted wave is used. The grating lobe consists of $(M + N - 1)$ cycles, where M is the number of elements in the transmit aperture.

On the other hand, using the proposed transmit waveform, the grating lobe is suppressed by destructive interference among such waves because the second sinusoidal wave in the transmitted waveform is inverted. However, such destructive interference is difficult to control in the 1st, 2nd, $(M+N-2)$-th, and $(M+N-1)$-th cycles of the grating lobe due to the limited number of cycles of the transmitted waveform.

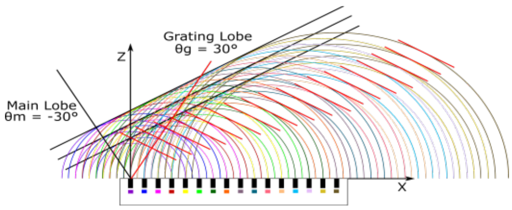


Fig. 2 Illustration of generation of wavefronts.

3. Experiment results

Figures 3-5 show the sound fields (a) and the grating lobe components (b) obtained with the conventional waveform and rectangular apodization, with the proposed waveform and rectangular apodization, and with the proposed waveform with Tukey apodization, respectively. Figures 3-5(b) show the wavefronts of the grating lobes near the focal distance at a steering angle of +30 degrees. Figure 6 shows the lateral pressure profiles at the focal distance, which superimposes three profiles obtained under different experimental conditions. Figure 7 shows the full widths at half maxima (FWHM) obtained under respective experimental conditions with corresponding σ values.

As shown in Figs. 3-5, the grating lobe levels around an angle of +30 degrees obtained with the proposed waveform are lower than that obtained with the conventional waveform. Moreover, the grating lobe level could be more suppressed using the proposed waveform with Tukey apodization.

With respect to the main lobe, the lateral beam widths obtained with the proposed waveform (Figs. 4 and 5) are broader than that obtained with the conventional waveform (Fig. 3). FWHMs were evaluated as 4.94 degrees (Fig. 3(a)), 9.75 degrees (Fig. 4(a)), and 10.06 degrees (Fig. 5(a)). The lateral width of the main lobe is hardly influenced by transmit apodization.

4. Conclusion

In the present study, a waveform of transmitted ultrasound, which is similar to that used in the coded excitation was examined for suppression of the grating lobe. The obtained results show that the proposed method can suppress grating lobes but the directivity of main lobe degrades. In future work, the spatial resolution of an ultrasonic image obtained with the proposed transmit waveform will be evaluated.

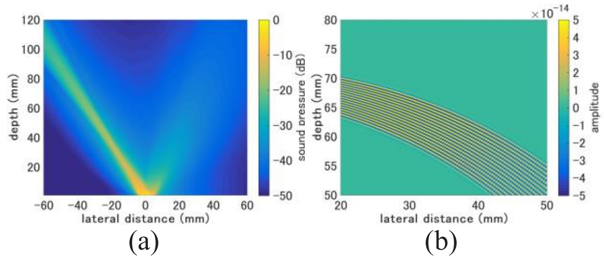


Fig. 3 (a) Sound pressure field and (b) grating lobe component obtained with conventional waveform (rectangular apodization).

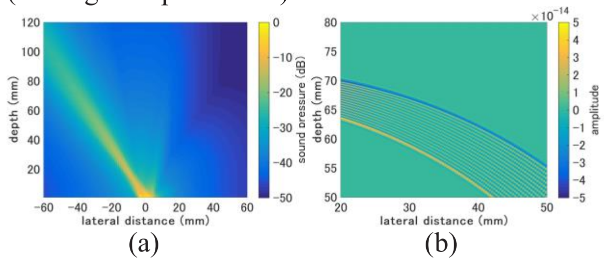


Fig. 4 (a) Sound pressure field and (b) grating lobe component obtained with proposed waveform (rectangular apodization).

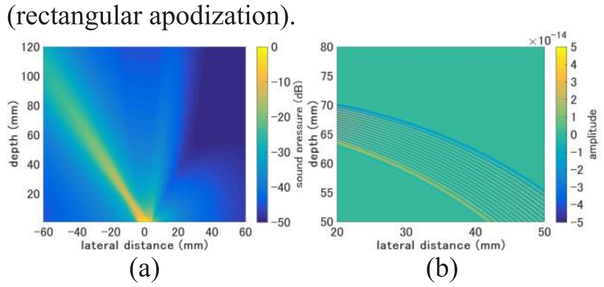


Fig. 5 (a) Sound pressure field and (b) Grating lobe component obtained with proposed waveform (Tukey apodization).

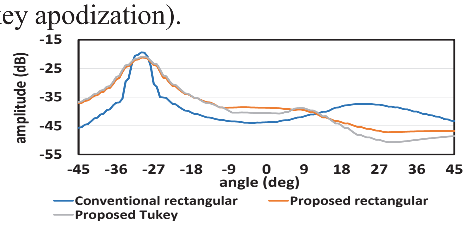


Fig. 6 Lateral pressure profiles at focal distance.

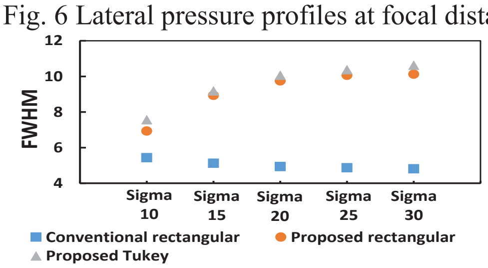


Fig. 7 FWHMs for σ values under three conditions.

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