2P2-14
Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Low-frequency ultrasound imaging using pulse compressed parametric sound
パルス圧縮パラメトリック音源による低周波超音波イメージング

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1. Introduction

To improve the quality of ultrasound image, ultrasounds at high frequency are used for ultrasonography, since the high frequency sound indicates a short wavelength and a high directivity. However, the propagation of high-frequency ultrasound is confined to a relatively shallow region from a medium surface, because the ultrasound at high frequencies is much attenuated by the medium viscosity and the penetration depth is limited.

A parametric acoustic array[1,2] that is a directive sound source at low frequency is a possible solution to resolve this problem. Disadvantages of a parametric sound for measurements and imaging are low range resolution due to its long wavelength and a low signal level originating from a nonlinear phenomenon. To resolve such problems, we have applied a pulse compression technique to parametric sounds and attempted to measure the distance of a target. The results indicated that the duration time of parametric sound was decreased by the application of pulse compression[3], and the distances were accurately measured by the compressed parametric sound[4].

In this study, to realize a low-frequency ultrasound imaging with relatively high range resolution, we applied the pulse compressed parametric sound to a sound source for ultrasound imaging[5], and discussed features of the proposed method comparing with a usual high-frequency ultrasound imaging.

2. Theory

Parametric sounds are not directly radiated from a sound source and are generated from the nonlinear interaction of finite amplitude primary ultrasounds at neighboring high frequencies radiated form a sound source. A transmitting transducer is driven by a modulated signal to generate a chirp-modulated parametric sound for the pulse compression.

To compressed receiving parametric sound echo from targets, the operation of cross-correlation between the echo and reference (template) signals is performed. Chirp signals with constant amplitude similar to chirp-modulated parametric sound are used as the reference signals. The compressed echo signals indicate the distances of targets and the deference of acoustic impedance between the target material and a surrounding medium. The details of the pulse compression of parametric sound have been described in a previous paper[3].

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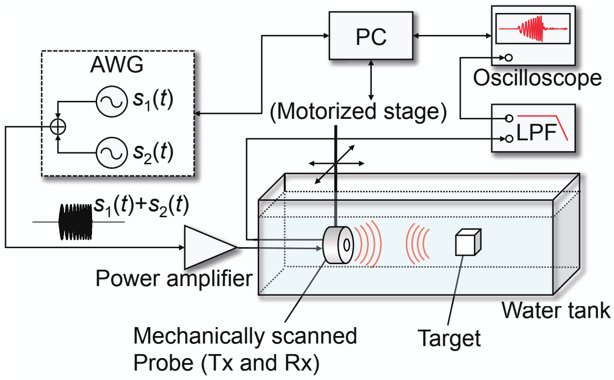


Fig. 1 Experimental setup for pulse compressed parametric sound imaging.

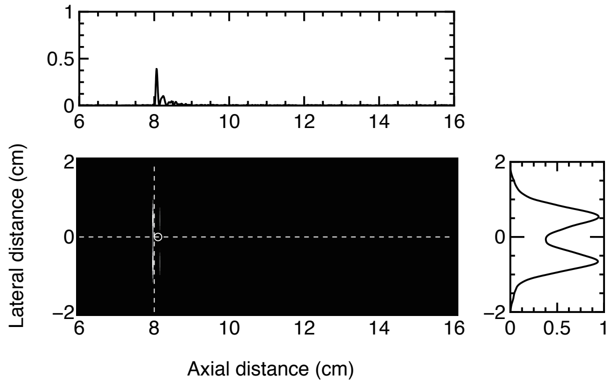
3. Experiment

3.1 Method

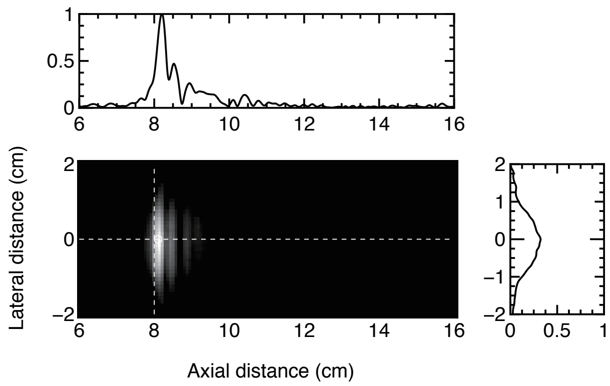
To verify the realization of the proposed ultrasound imaging, fundamental experiments were carried out using a target in water. **Figure 1** shows the experimental setup. The probe is composed of a ring type transmitting transducer with a center hole and outer and inner diameters of 25.4 and 4 mm, respectively. To receive parametric sound echoes, a hydrophone with a diameter of 4 mm and with a flat response below 600 kHz. The hydrophone is inserted to the hole of the ring type transducer.

To generate chirp-modulated parametric sound, the transmitter was driven by modulated signal. The center frequency f_0 of the driving signal was set to be 2.8 MHz. The lower and upper frequencies of chirp-modulated parametric sound were set to be 100 and 500 kHz, respectively, so that the chirp bandwidth was 400 kHz. The sweep time was 33.3 µs which corresponds to ten cycles of chirp signal.

As a target, we used a brass rod placed perpendicular the beam axis of the transmitter. The brass rod had a diameter of 2 mm, and the distance between the transmitting surface and the near



(a) High-frequency short pulse.



(b) Compressed parametric sound.

Fig. 2 Ultrasound image of a brass rod with diameter of 2 mm at distance of 8 cm from the transmitting surface. Top and right curves of each image are A scopes along the dotted lines.

surface of rod to the transmitter was set to 8 cm.

To obtain a B mode image of target, the imaging probe is mechanically scanned by motorized stages, which are controller by a computer, in a horizontal direction perpendicular to the transmitted beam axis with step size of 1 mm. Chirp-modulated parametric sound echoes form the target were received by the hydrophone, and applied by cross-correlation between the echo signals and the reference.

3.2 Results and discussion

Figure 2 shows B mode images of a brass rod. As a reference, an image obtained from high-frequency short pulses of a center frequency of 2.8 MHz, which is generated from a pulser/receiver, is also shown together. Echoes of high frequency short pulse and cross-correlation functions of parametric sound echoes are normalized by each of the maximum amplitude, and the images are presented by linear scale. Axial distance is converted form the flight time of echo multiplied by the sound speed in water. The cross points of dotted lines indicate the near the surface of the target to the transmitter.

The image obtained from the compressed parametric sound indicates accurately the target position, although the spread of image in the rage direction is wider that that obtained form the high-frequency short pulse.

It is noted that the image obtained from the compressed parametric sound indicates only one peak, although that obtained from the high-frequency ultrasound indicates two peaks. These peaks are artifacts caused by the complicated near filed of high frequency ultrasound.

Although we show only the image of a brass rod with diameter of 2 mm at distance of 8 cm, we attempted to obtain images of brass rods with diameter from 2 to 8 mm at distance from 1 to 32 cm using the compressed parametric sound. For each the target, the application of pulse compression on the ultrasound imaging is useful and the range resolution is improved.

From these results, it is suggests that the range resolution of low-frequency ultrasound imaging is improved by the application of compressed parametric sound. In addition, the proposed method is useful in near field imaging.

4. Conclusions

In this study, we applied the pulse compressed parametric sound to ultrasound imaging. The obtained images reveal the feasibility of low-frequency ultrasound imaging with relatively high range resolution, in particular, the method is useful in near field imaging.

For future works, it is necessary to evaluate the resolutions and the available depth of imaging of the proposed method.

Acknowledgments

This work was supported by JSPS Grants-in-Aid for Scientific Research (2534062) and the Regional Innovation Strategy Support Program, MEXT, Japan.

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