Ultra Broadband Ultrasonic Imaging using Nonlinear Acoustics

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Abstract
We have developed a new ultrasonic imaging method that can provide high-resolution and high-quality images to clinical diagnosis by extracting from echoes high-order harmonics generated when ultrasonic wave propagates in the living tissue and by forming images from relevant high-order harmonic components. In the recent research, in order to efficiently receive high harmonics generated in the propagation process inside the living body over a wide frequency band range, a special-purpose ultrasonic probe was trially produced with transmission PZT transducer and reception PVDF transducer affixed in a form of double-layer structure.

1. Introduction
The authors have been positively involved in developing an ultra-wideband ultrasonic imaging system as an advanced ultrasonic diagnostic equipment of the next generation. For the image quality and resolution in ultrasonic imaging, it is important to be a wideband, but currently, it is restricted by the bandwidth of transmission transducer. Thus the authors focused attention on higher harmonics generated when ultrasonic waves propagate through the human tissues, and even if the bandwidth of transmission transducer is narrow but if high-order harmonics that are generated in the propagation process could be received, a wideband imaging system could be equivalently achieved. Therefore, in order to receive high-order harmonics highly efficiently, a technique for using devices specialized for transmission and reception was adopted using PVDF of high-molecular piezoelectric film as reception transducer. Recently, a probe with bi-layer structure with PVDF affixed to the front surface of PZT, which was a transmission transducer, was produced as a prototype. The authors investigated generation of high harmonics using the present probe and reception of echoes by the probe, and the results will be reported in this paper.

2. Transmission and Reception Divided Type Probe of Bi-layer Structure
The transmission and reception divided type probe of bi-layer structure recently produced has the PVDF film (available from Toray Engineering Co., Ltd.) affixed to the vibration surface of circular recessed surface type transducer (available from Nihon Dempa Kogyo Co., Ltd.; center frequency: 2 MHz, focal length: 70 mm, diameter: 20 mm) of PZT. The center frequency of PVDF is 7.0 MHz, focal length 70 mm, and diameter 20 mm. Fig. 1 shows the general view.

Fig.1 The prototype probe.

3. Experiments

3.1. Under Water Experiments
Fig. 2 shows the receiving waveform measured with silica glass located at the focal length. Since the transmission PZT is of a comparatively narrow band, it has greater wavenumber.
than general pulses of commercially available ultrasonic diagnostic equipment.

Fig. 4 Spectrum of the echo from the phantom.

3.2. Phantom Experiments

The phantom with graphite powders suspended in agar gel is used for the experiments. Fig. 3 and 4 show echo waveforms and its spectrum, respectively. Fig. 3 indicates that the echo is considerably deformed by higher harmonics generated while the echo propagates in water. In addition, in the spectrum, it is possible to observe up to the tenth harmonic image, but the spectrum contains considerable noises. The authors consider that practically effective higher order harmonics are up to the fourth order harmonic image.

Fig. 5 shows the fundamental image and the harmonic images of the phantom. It is observed that speckle pattern of the image is different each other. In addition, as the order of harmonic increases, speckle noises are more reduced. It indicates that speckle noises can be reduced by summation of these images and then the image quality could be improved.[1] Fig. 6 shows the results of coherent summation.

It is observed that less speckle images of phantom by summation up to fourth harmonic images.

Fig. 6 Coherent summed images of the phantom as shown in figure5. Fundamental image (upper left), summation up to second harmonic image (upper right), summation up to third harmonic image (lower left) and summation up to forth harmonic image.
The fundamental image and the harmonic images for images of the agar gel phantom with a hole. In the images made from the fundamental component in the echoes, it is difficult to confirm the hole. On the other hand, the hole can be confirmed with higher harmonic images. For this phantom, coherent summation is carried out to reduce speckle noises. The resultant images are shown in Fig. 8.

**3.4. Needle Tip**

A needle was immersed in water and located at the focal point, and the echo was obtained. Fig. 11 shows the echo waveform and its spectrum. It is observed that the echoes from needle tip comprise from fundamental component up to tenth order harmonic. Then, the probe was mechanically scanned and the image was formed. Fig. 12 shows the harmonic image.

**3.3. Human Arm**

Fig. 9 shows harmonic images produced from echoes obtained by immersing a human arm and transmitting and receiving ultrasonic waves from the water surface. Since the reflection at the skin surface are considerably large, it is difficult to receives the echoes from inside farther penetrated region, so that the lower area of the image is relatively low intensity as shown in fig.9. Fig. 10 shows incoherent summed images. It is observed that the area on the skin surface is displayed as the smoothed curve due to the effects of the speckle reduction.
4. Conclusions

A transmission-reception divided type probe with bi-layer structure of transmission PZT and reception PVDF was produced as a prototype. In this paper higher order harmonic images were formed by using the probe and its applications were studied. In the underwater and the phantom experiments, up to tenth order harmonic components could be confirmed in the echo. The authors think that up to fourth order harmonic image would be practical because of frequency dependent attenuation in the biological tissues.

5. References