1Pa-58

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 131-132
6-8 December, 2010

Sub-aperture Decoding to Enhance Performance of Coded Excitation using Long Transmission Coding Wave
符号化送受信における口径分割を用いた符号伸張方法の検討

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1. Introduction

Coded excitation can improve the signal-to-noise-ratio (SNR) of ultrasound imaging, by allowing the use of a long transmission waves without compromising axial resolution. The SNR improvement of ultrasound imaging with coded excitation is approximately proportional to a square root of the code length. In a typical coded ultrasonic imaging, coded waves are transmitted, reflected waves are received, and the signal is decoded after receive beam forming[1].

In order to achieve a high lateral resolution, the beam forming is normally performed based on a low f-number and real-time dynamic focusing, which limits the maximum length of coded waves. If the code length exceeds the focal length, densities of delay curves are different depending on channel positions in a reception aperture. Because of this reason, coding waveforms are deformed depending on channel position, and pulse can't be compressed without detectable range sidelobe. Individual decoders before the beamformer can extend the duration of code exceeding the length of the focal zone determined by a low f-number dynamic focusing beamformer[2,3].

Barker codes and chirp codes are commonly used as code sequences[1,4]. Since the Barker code is very simple binary chip code, its implementation is very easy. Since a mismatched filter for a Barker code eliminates the range sidelobe level of decoded signal by optimizing filter shape. However, to achieve an acceptable rage sidelobe level, the length of mismatched filters needs to be about 40-100 times as large as length of the Barker code. This length is too large to construct a set of individual decoders at an acceptable cost.

In this study, the decoding beamformer structure suited to dynamic focusing and Barker codes was investigated, and computer simulations were used to demonstrate the approach.

2. Method

We investigated a sub-aperture decoding technique as shown in Fig.1. In this technique, the receiving aperture is divided into N_{app} sub-apertures, beamforming is performed in each sub-aperture, and each output of sub-aperture is decoded, delayed and summed together to complete beamforming in the whole aperture.

In this study, a point-spread function of transmitting was assumed to be an order of magnitude larger than that of receiving. Based on this assumption, only receive beamforming process was calculated. The receiving aperture had an f-number of 1 and no apodization. In this simulation, a 13 bit Barker code, whose coding period was 3λ/4, was used to drive each of the 256 channels of transducer elements with a pitch of λ/4, having a 60% fractional band width. Here, λ was defined by the center frequency. To suppress possible simulation errors caused by reasons other than the relation between the depth of field and the coding duration, a sufficiently small sampling period, λ/256, was used. In this condition, the duration of a coding signal is 1.25 times as long as the –3 dB depth of field determined by the whole aperture. A 67 tap mismatched filter, with which the range side lobe level of a decoded signal of –55 dB can be achieved, was used.

The results of two different ways of dividing the aperture into sub-apertures were compared. The first method was equal-width division, i.e. all sub-apertures have a constant width. The second method was equal-phase-difference division (Fresnel type division). The maximum phase difference in each sub-aperture was equalized and minimized at the same time.

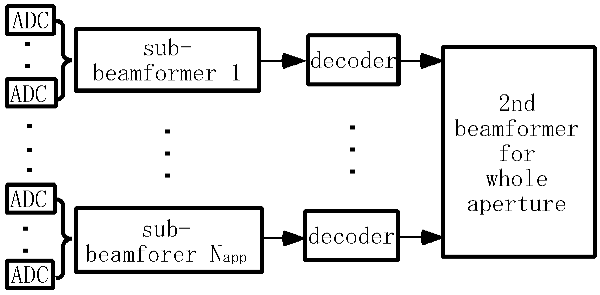

Fig. 1 Block diagram of sub-aperture decoding

3. Results and discussion

Figure 2 shows the decoding waveform. On the top of this figure the case of N_{app} = 1 is shown.

When N_{app} = 16, the cases of the equal-width division and the Fresnel type division are shown in the middle and bottom of this figure, respectively. In the center of the time axis in each figure, a waveform of compressed signal is seen, while artifacts are seen near the both ends of the time axis. Figure 3 illustrates the maximum rage sidelobes in dB obtained from simulation as functions of the number of sub-apertures. When the number of equal-divided sub-apertures is small, the improvement in the range sidelobe level was insufficient. In marked contrast to this, the range sidelobe level of the Fresnel type division was suppressed more effectively. The difference between two dividing ways was reduced as the number of sub-apertures increased.

4. Summary

We proposed sub-aperture decoding technique to achieve a high SNR without sacrificing high spatial resolution due to a low F-number with an acceptable size of hardware. Equal-phase-difference division (Fresnel type division) showed better performance at a small number of sub-apertures compared to the equal-width division. When the transmission waveform was encoded by the 13-chip Barker code, received with an aperture with an f-number of 1, and decoded with a mismatched filter, the proposed technique, with the number of sub-apertures of 16, lowered the range sidelobe level from -25 dB to -45 dB.

This approach will make a long code sequence usable and expand the possibility of coding design such as a coding for simultaneous multiple transmissions and receiving.

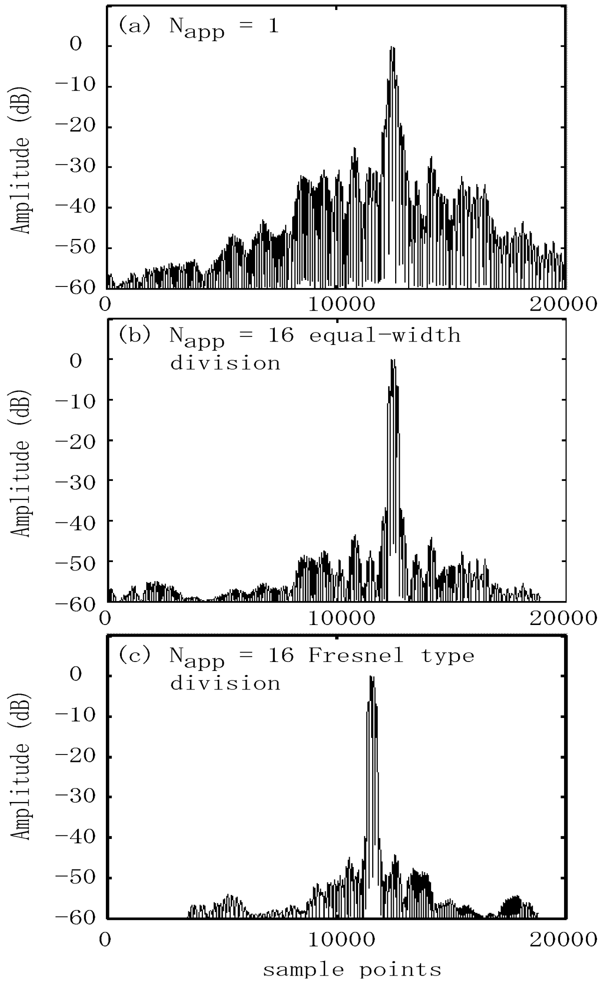

Fig.2 Decoding waveform of whole aperture (a), equal-width division, Napp = 16 (b) and Fresnel type division, Napp = 16 (c)

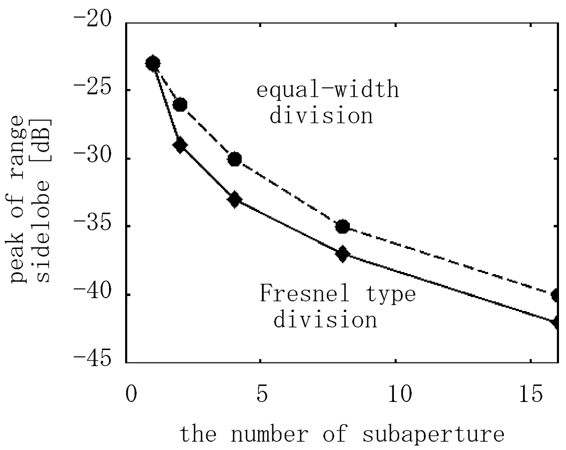

Fig.3 Maximum values of range sidelobe vs the number of subaperture. Dashed line shows results of equal-width division and solid line shows results of Fresnel type division.

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