

## Proper Bandwidth for Frequency Averaging in Medical Ultrasound Imaging Using Frequency Domain Interferometry

### 周波数領域干渉計法を用いた超音波イメージング法における適切な周波数平均幅

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### 1. Introduction

For the early detection of artery stenosis and atherosclerosis it is important to improve the range resolution in ultrasonography (US). We have reported that frequency domain interferometry (FDI) with the Capon method has the potential to acquire vascular ultrasound images with high range resolution. The FDI method with the Capon method requires that the echoes returned from different target are not correlated with each other; however, in US temporal averaging has little potential to suppress the correlation between the echoes. Therefore, we have employed frequency averaging to suppress the correlation between echoes from different targets [1]. In this study, we investigate the proper bandwidth utilized in frequency averaging.

### 2. Frequency Averaging for Decorrelation between Echoes

The FDI imaging method with the Capon method utilizes a covariance matrix of a received signal. In US frequency averaging should be applied to the covariance matrix for the decorrelation between echoes returned from different targets. The covariance matrix of a received signal after frequency averaging is

$$\mathbf{R}_A = \frac{1}{M} \sum_{m=1}^M \mathbf{R}_m \quad (1)$$

$$R_{mij} = X_{H(i+m-1)} X_{H(j+m-1)}^* \quad (2)$$

where  $\mathbf{R}_m$  is a sub-matrix of the covariance full-matrix,  $R_{mij}$  is the  $(i, j)$  element of a  $m$ -th sub-matrix  $\mathbf{R}_m$ ,  $X_{Hk}$  is the  $k$ -th frequency components of the RF data after whitening,  $[\ ]^*$  denotes the complex conjugate, and  $M$  is the number of sub-matrices used in frequency averaging. Each sub-matrix  $\mathbf{R}_m$  is extracted from the same covariance full-matrix to construct  $\mathbf{R}_A$ , as shown in Fig. 1.

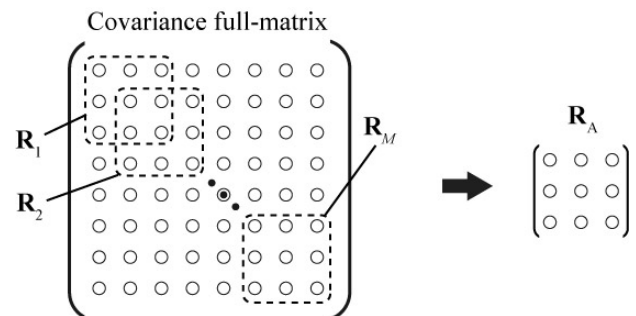


Fig. 1 Schema of frequency averaging applied to a covariance full-matrix.

The employment of a large averaging number  $M$  powerfully suppresses the correlation between echoes from different targets and the computational load, at the cost of the decrease of the effective bandwidth utilized for range beamforming. This means that there is a trade-off between decorrelation between echoes and an effective bandwidth. Therefore, it is important to find the optimum  $M$  to acquire a high range resolution ultrasound images.

### 3. Influence of Frequency Averaging on Range Resolution of FDI Imaging Method

To investigate the influence of frequency averaging on the range resolution of the FDI imaging method with the Capon method, we simulate that a single target and a couple of targets exist in a region of interest. We assume the worst scenario in which the same echo waveforms are received from the two targets. Fig. 2 shows the echo waveforms used in this study, where the target intervals of the target couples are 0.1, 0.2, 0.3, 0.4 and 0.5mm. In the simulation study we utilize the echo of RF data returned from the horizontal boundary between 20% gelatin and 4% agar as the echo returned from each target. The  $-6$  dB bandwidth of the echo from the boundary is 2.4 MHz. The echo of RF data was acquired by a commercial US device with a 7.5 MHz linear array probe, and its sampling frequency is 30 MHz. We

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employ 134 frequency components from 5 to 9 MHz, where the sampling interval in the frequency domain is 30 kHz.

We examine the range resolution of the FDI imaging method when  $M = 33, 67$  and  $100$ . The employment of  $M = 33, 67$  and  $100$  means that the bandwidths utilized for frequency averaging are 1, 2 and 3 MHz and the effective bandwidths for range beamforming are 3, 2 and 1 MHz, respectively. When  $M$  of 33 and 67 are employed, the proposed method succeeded to estimate all the target locations correctly. The proposed method employing  $M$  of 100 failed to estimate the target locations when the target interval was 0.1 mm. This result implies that the depiction of two targets 0.1 mm apart requires the effective bandwidth of 2 MHz or more.

In contrast, the proposed method employing  $M$  of 33 estimated the echo intensity returned from targets at 12, 6.8, 3.8, 1.9 and 0.85dB lower than the true echo intensity when the target interval were 0.1, 0.2, 0.3, 0.4 and 0.5mm, respectively. The proposed method employing  $M$  of 67 estimated the echo intensity returned from targets at 6.7, 1.9, 0.25, 0.041 and 0.17dB lower than the true echo intensity when the target interval were from 0.1 to 0.5 mm. This results indicates that we should employ the bandwidth of 2 MHz or more for frequency averaging to estimate the echo intensity with a sufficient accuracy when the interval of a couple of targets is 0.2 mm or more.

### Acknowledgment

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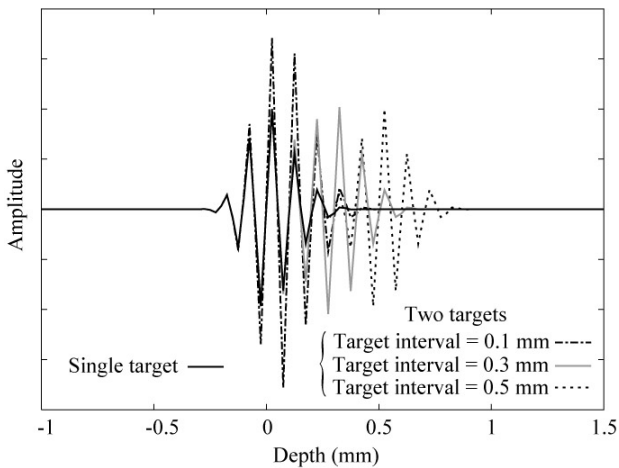
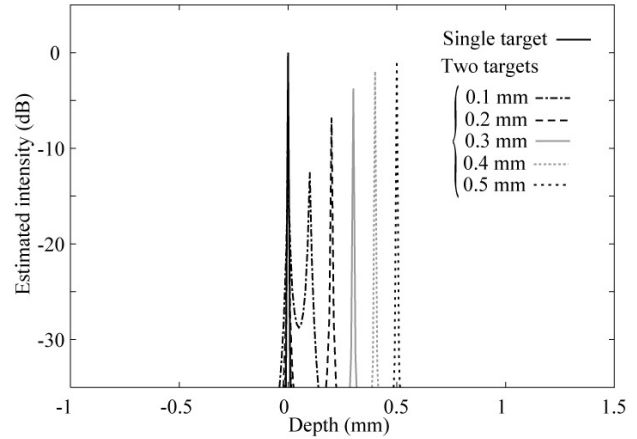


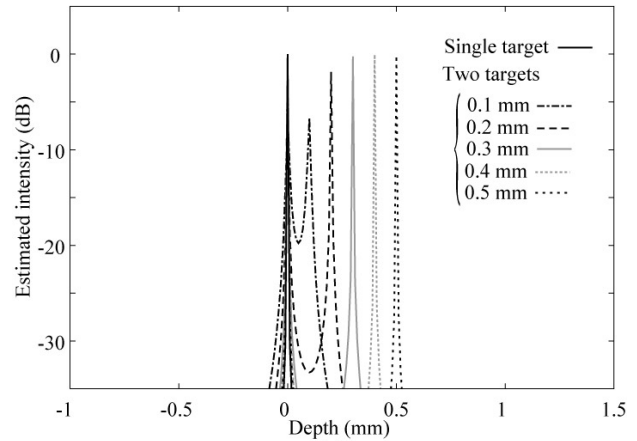
Fig. 2 Echo waveforms returned from a single target and a couple of targets, where the target intervals of the target couples are 0.1, 0.3 and 0.5 mm.

### References

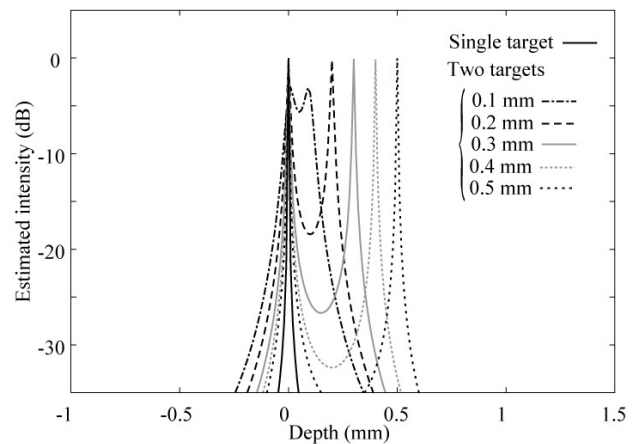
1. H. Taki, K. Taki, T. Sakamoto, M. Yamakawa, T. Shiina and T. Sato: Proc. IEEE EMBS (2010) 5298.



(a)



(b)



(c)

Fig. 3 Estimated intensity using the proposed FDI imaging method, where the bandwidths utilized for frequency averaging are (a) 1, (b) 2 and (c) 3 MHz. A single target and a couple of targets exist in the ROI, and the target intervals of the target couples are 0.1, 0.2, 0.3, 0.4 and 0.5 mm.