RESOLUTION-IMPROVED OPTICAL BEAMFORMER WITH A MULTIPLE LINE ARRAY SENSOR STRUCTURE FOR THE DIRECTION DETECTION OF LOW FREQUENCY ACOUSTIC WAVE

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Abstract- To find the origin of acoustic signal, an array type of sensors is necessary, but this array structure accompanies spatial aliasing problem by the finite and discrete number of sensors. This problem can be overcome by using acousto-optic beamforming. For low frequency (< 1 kHz) application, conventional one-dimensional beamforming needs a long beam path. In this paper, two-dimensional beamforming using a multiple line array structure is proposed to improve direction resolution in low frequency range. Its resolution performance is compared through simulation with that of one-dimensional beamforming.

Keywords- Two-dimensional beamforming, Acousto-optic sensing,

I. INTRODUCTION

Finding the direction of acoustic signal is possible by simultaneously detecting the signals from multiple sensors placed at different locations which are called as an array of sensors. The correlation among the outputs of each sensor determines the signal direction but the direction resolution is mainly influenced by the spatial aliasing caused by the limited space such as the finite number and spacing of sensors [1]. Also, this aliasing restricts largely the applicable operating frequency range in beamforming. To overcome this problem, the beamforming method using acousto-optic effect was proposed [2]. This method uses a beam of light travelling between Laser Doppler Vibrometer (LDV) and static mirror. When the beam propagates and meets the acoustic signal, then the phase is continuously changed [3]-[5]. Therefore, the acousto-optic beamformer can be considered as continuously distributed acoustic sensors, i.e., an infinite number of sensors with zero spacing. Only, to enhance the resolution in low frequency application like infrasound, the array with longer length is necessary.

In this paper, we propose a sandglass array structure composed of multiple mirrors to improve the resolution and compare with conventional one-dimensional acousto-optic beamforming through simulation.

II. TWO-DIMENSIONAL BEAMFORMING

Figure 1 shows conventional and the proposed two-dimensional beamformers. In one-dimensional beamformer, the beam only experiences phase change on the x-axis and show a main and side lobes in beam pattern. To expect the narrow main lobe, we proposed the structure of Fig. 1(b) by adding two diagonal beam paths. In the proposed structure, the beamforming output is maximized at θ=0° and the phase change of LDV- mirror B should be equal to that of mirror A and C at the frequency of the acoustic signal. Here, two diagonal straight lines of LDV - mirror A and mirror B - C can be regarded as the Ø-tilted line array beamformer. Thus, it constructs side lobes at ±Ø together with the main mode. Then, they can contribute to the narrow width by arranging phase condition. These beam paths form side lobes at the small angle of Ø and has an effect to narrow the main lobe formed by two horizontal lines at the specific frequency.

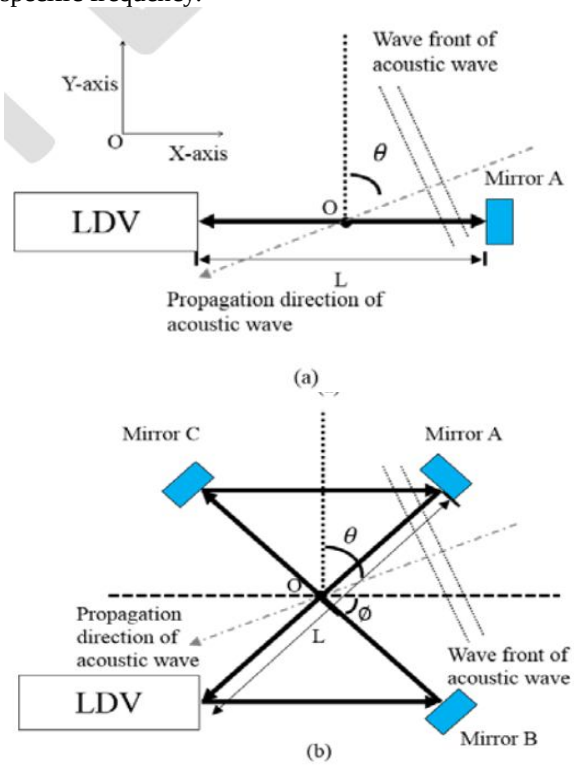


Fig. 1 (a) One-dimensional acousto-optic beamformer, (b) The proposed acousto-optic beamformer with multiple line arrays. (Bold line: optical beam path, O: array center, θθ: incident direction of acoustic signal, L: maximum length of straight line, Ø: angle between the path BC and x-axis)

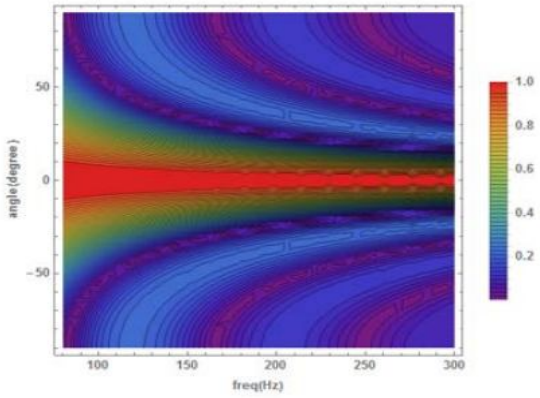
$$\text{Amplitude}(\theta) = \left| \lim_{d\to 0} \lim_{M\to\infty} \frac{1}{M} \sum_{m=0}^{M-1} s(t - (\vec{\alpha} \cdot \overrightarrow{l_m})) \right|,$$

where $\alpha\vec{\alpha}$ is the slowness vector of the acoustic signal and $llmm$is the location vector of mth sensor which has reference point (O) in Fig.1. Therefore, the output of the beamformer can be optimized by adjusting length (L) and angle (Ø). In this paper, we considered the same length limitation of L to compare the resolution performance of two-dimensional beamforming with that of one-dimensional beamforming, assuming the same maximum space.

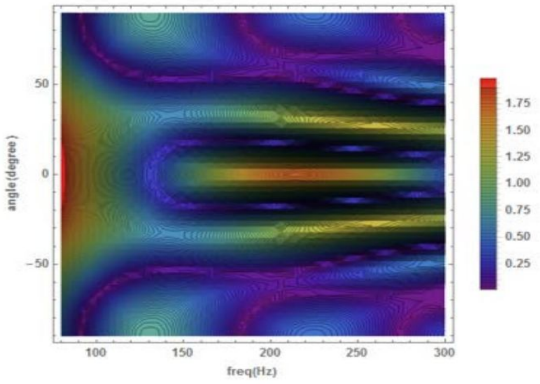
III. RESULTS AND DISCUSSION

3.1. Beamforming pattern in low frequency range

The simulation was run for 4m Length (L) and at the optimizedØ of 25°, and focus on the frequency range of 180 - 280 Hz, which corresponds to the non-detectable frequency range of typical electronic devices. Fig.2 (a) shows the beam pattern of one-dimensional acousto-optic beamformer, covering all frequency range. On the other hand, Fig.2 (b) shows the beam pattern only around 230 Hz . However, it can be seen that the resolution of the proposed beamformer was enhanced compared with that of the conventional one.



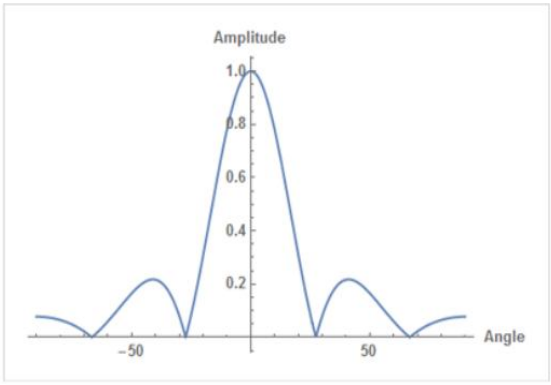
(a) Conventional beamforming output
Length 'L' : 4m



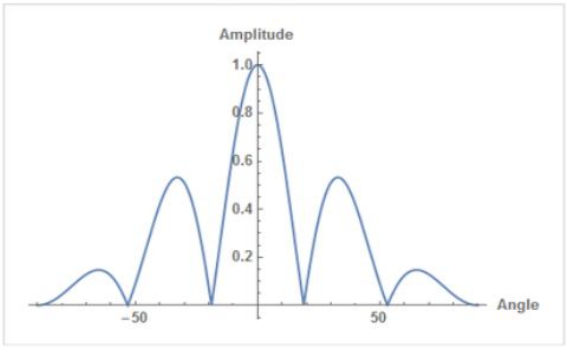
(b) Proposed beamforming output
Length 'L' : 4m
Angle 'Ø' : 25°

Fig. 2 Beam patterns of (a) conventional and (b) the proposed beamformers in the frequency range of 80 - 300 Hz.

3.2. Lobe characteristics at the center and edge of frequencies. To confirm the lobe characteristic of the beam patterns, simulation at the edge frequency of 180 Hz and the center frequency of 230 Hz was executed.



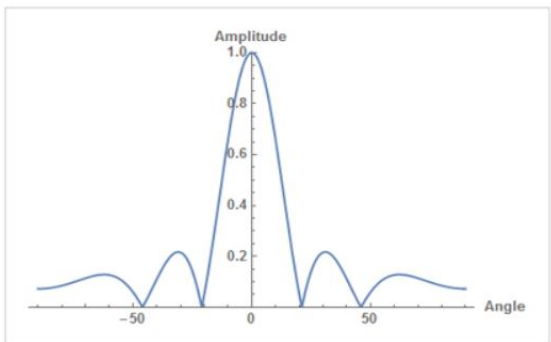
(a) Conventional lobe characteristic
Length 'L' : 4m
Frequency : 180 Hz



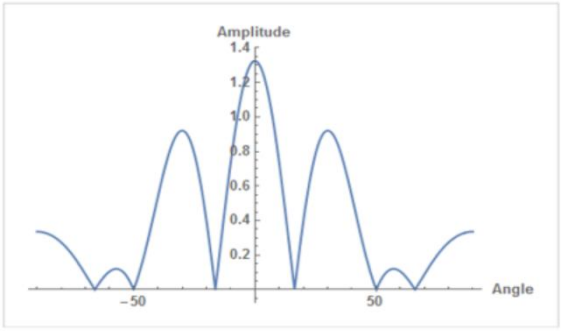
(b) Proposed lobe characteristic
Length 'L' : 4m
Angle 'Ø' : 25°
Frequency : 180 Hz

Fig. 3 : Lobe characteristics of (a) conventional beamformer and (b) proposed beamformer in fixed frequency 180 Hz.

Fig.3 shows the lobe characteristic at the fixed frequency of 180 Hz. The width of main lobe in conventional beamformer was 55° but the width of main lobe in the proposed beamformer was reduced to 40°.



(a) Conventional lobe characteristic
Length 'L' : 4m
Frequency : 230 Hz



(b) Proposed lobe characteristic
Length 'L' : 4m
Angle 'Ø' : 25°
Frequency : 230 Hz

Fig. 4 Lobe characteristics of (a) conventional beamformer and (b) proposed beamformer in fixed frequency 230 Hz

Fig.4 shows the lobe characteristic at the center frequency. The width of main lobe in conventional beamformer was 40° but the width of main lobe in the proposed beamformer was 30°. These results show that the proposed beamformer can improve direction resolution even though the application can be limited to small frequency range.

CONCLUSIONS

An acousto-optic beamformer composed of multiple straight lines was proposed and showed that it can enhance the resolution of the beamformer in the frequency range of 180 – 280 Hz. It is confirmed that multiple straight lines, especially, diagonal lines contributed to resolution improvement.

ACKNOWLEDGMENTS

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