IMAGING WITH A 2 MHz SPARSE BROADBAND PLANAR ARRAY

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Abstract- A portable high-resolution sonar has been under development to provide Navy Divers with an acoustic imaging systems for mine reconnaissance. The first phase of development was completed in 2000 with the demonstration of a broadband, 6% sparse line array, imaging a simple target in the NUWC Acoustic Test Facility (ATF). Element locations for this array were computed based on a grid point optimization technique[1] which minimized close-in sidelobes. The center frequency was 2 MHz with a 667 kHz bandwidth. A new sparse planar array, consisting of 121 1 mm x 1 mm 2 MHz elements, has been fabricated, to provide 3-D acoustic images of underwater targets. This array was also designed using the grid point optimization technique.[1] The first phase of testing with simple targets will be completed in 2001 for the planar sparse array.

I. INTRODUCTION

For undersea acoustic minefield reconnaissance and mine hunting by divers, a handheld, low cost sonar system is needed. To achieve these goals, a high-resolution, three-dimensional sonar imaging system based on a large-area electronically steerable two-dimensional sparse array is being designed and built by Teratech Corporation of Burlington, MA. The system will provide continuous real-time scanned images throughout a 20° field of view. The processing requirements are to provide image updates at a rate of four frames per second. The resolution of an imaging sonar in azimuth and elevation is directly proportional to its aperture in wavelengths. The overall goal of this effort is to develop an acoustic system capable of imaging with 2 cm^3 resolution at a range of 3 meters.

II. PROTOTYPE ONE DIMENSIONAL ARRAY

A 20 cm. one dimensional sparse array was designed using the approach in Kay (2). It was fabricated by Tetrad Corp, Englewood, CO and tested in the NUWC Acoustic Test Facility. The array was 264 elements across, with a pitch of .781 mm. From this array, 32 elements were active.
Fig. 1 shows the predicted receive response for a 2 MHz array, designed for a 667 kHz FM slide waveform. Fig. 2 shows the measured near-field beampattern for a source at 3 meters for the prototype array as obtained in the NUWC Acoustic Test Facility. The transmit pulse was the FM slide with a 50 microsecond pulse width. The free-field voltage sensitivities of the individual active elements were measured at approximately –250 dB //V/ µPa over the frequencies of interest. The first sidelobes were typically 18 dB down. The average source level over the bandwidth of the fm slide was 192 dB // µPa.

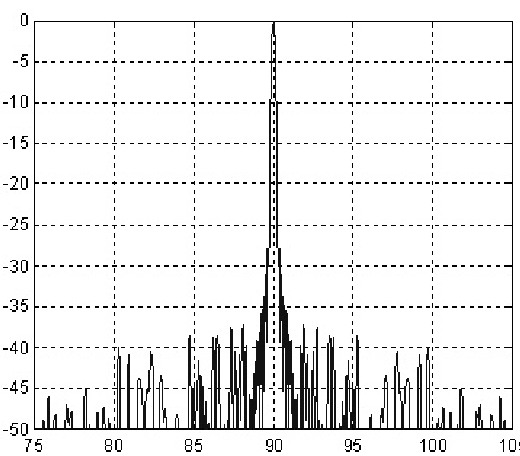

Fig. 1. Predicted beampattern for 20 cm. one dimensional array.

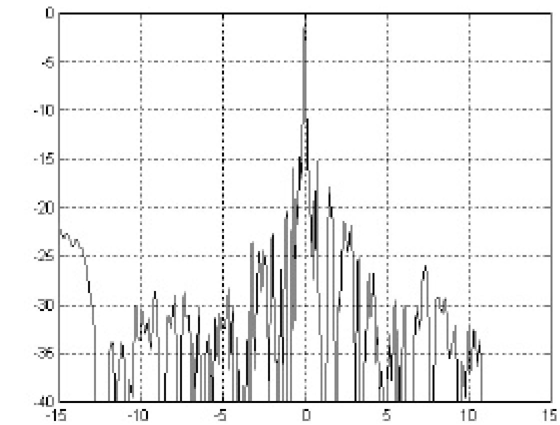

Fig. 2. Measured beampattern for prototype one dimensional array.

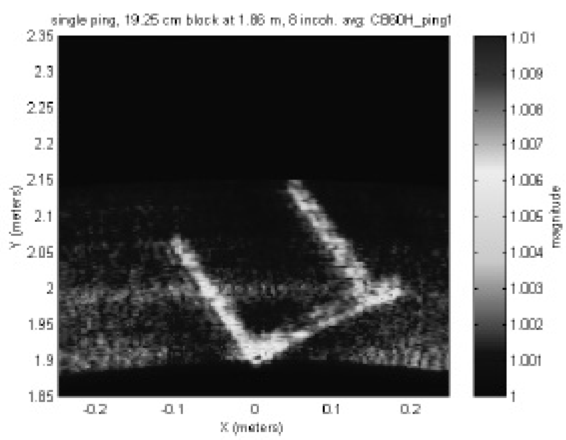

Fig.3. Acoustic image of cinder block suspended vertically in the Acoustic Test Facility. The array is at the bottom looking up along the y axis .

Experiments were conducted in the NUWC ATF to image various targets with the 32 element sparse line array. The targets were illuminated with a bistatic projector mounted 25 cm below the center of the array, perpendicular to the line of the array with a source level of 192 db *//mPa* at a range of 1.86 meters. Simple targets consisted of a 10 cm. stainless steel sphere and a 23 x 36 x 0.6 cm aluminum plate. A 19 x 19 x 40 cm. cinder block was submerged to provide an interesting and more complex target. The dynamic range of the peak target highlights was approximately 40dB. This was observed when comparing the level of the peak specular highlight from the aluminum plate at broadside with that of the plate rotated 45 degrees. Fig. 3 show an example image from the cinder block at a 60 degree orientation, with optimized shading. The image dimensions are 0.5 m. x 0.5 m. The projector is located at bottom looking up. In this visual, three sides of the block appear to be imaged. The two solid cinder block walls are the thicker parallel sides. The voids are ported on the remaining face and allow the far wall to be imaged.
The experimental setup is shown in Fig. 4.

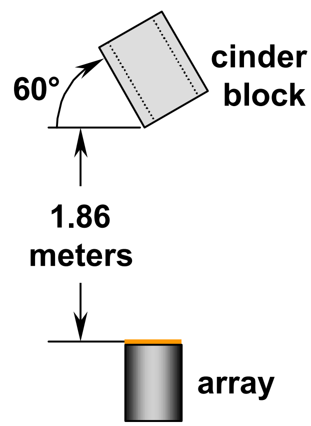

Fig. 4. Physical arrangement of sparse linear array and cinder block target.

III. MATCHED FILTERED PROCESSING
The response of the array was computed as the square of the matched filtered output as derived by Kay (2). The target was illuminated with an FM slide of bandwidth W = 667 kHz and center frequency F_0 = 2 MHz. The power at the beamformer /matched filter output for a signal arriving from an angle q_x, q_y is therefore

$$\mathrm{B}(q_x, q_y) = \left(\frac{1}{M^2} \sum_{i=0}^{M^2-1} w_i \cos(2pF_o t_i) \frac{\sin(pt_i W)}{pt_i W} \right)^2$$

(1)

where τ_i is the time delay to the ith sensor, w_i is the weight applied to the *ith* element and M is the number of sensors in each dimension. The ith sensor is located at $r_i = (x_i, y_i)$, u is the unit vector in the direction of propagation and c is the speed of sound.

$$t_i = \frac{\mathbf{u}^T \mathbf{r}_i}{c} = -\frac{1}{c}(x_i \cos\theta_x + y_i \cos\theta_y) \tag{2}$$

IV. PLANAR ARRAY

A second generation of transducer elements was designed for the planar array. These elements were constructed in bricks of 3 x 3 and 3 x 6 elements, different from the first generation array where the entire array was formed from only three bricks. The element size was also increased to 1 mm x 1 mm to improve producibility of the devices. A new 2D composite structure was developed with improved sensitivity and bandwidth as compared to the first generation elements developed for the sparse line array. The challenge was to build a 2D structure with wavelength size elements that radiated with wide bandwidth without a strong coupling to adjacent elements. Typically, medical arrays have only one dimension at wavelength size. With both the x and y dimensions being of the same order of magnitude as the wavelength, the structure supported more undesirable modes which degraded the overall device performance. Two matching layers with the ceramic were required to achieve 50% bandwidth and isolation cuts were made between all elements to reduce coupling. Finite element analysis (FEA) was used to guide the changes for the design of the second generation elements. The FEA modeled a 3 x 3 grid of elements; each element consisted of a 2 x 2 grid of columns. A partial array was fabricated with 9 second generation elements. The free-field voltage sensitivities of the individual active elements were measured at approximately -220 dB //V/ µPa with a 50% bandwidth.

A sparse planar array with 121 elements has since been fabricated and is currently in testing. Horizontal and vertical nearfield beampatterns are being measured for the 121-element array and plans are to image the cinder block and a simulated manta mine at various orientation angles. Element data is being collected at a sample rate of 5 MHz. Simulation results for sparse array beampattern for data acquired at 5 MHz is shown in Fig. 5.

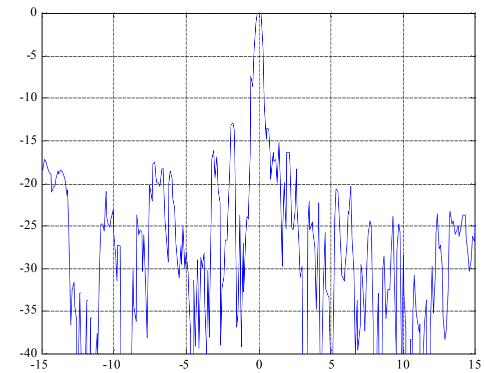

Fig. 5. Simulated azimuth beampattern, at 5 MHz sampling rate, for sparse planar array.

In comparison, first measurements of these data are shown in Fig. 6. For both cases, the array response is computed from –15 to + 15 degrees in increments of 0.1 degrees. The vertical axis range is 0 to –40 dB.

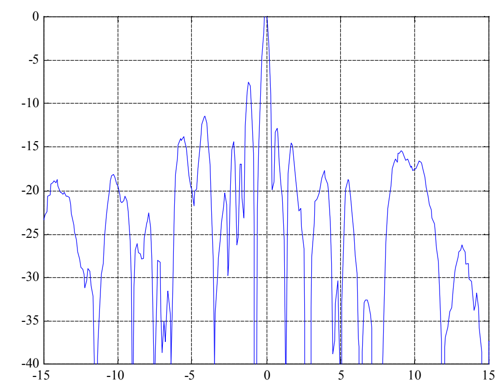

Fig. 6. Measured azimuth beampattern for sparse planar array in ATF at 5 MHz sampling rate.

The cinder block imaged with the 1D array was also imaged with the sparse planar array. The physical arrangement of the array and block is shown in Fig. 7. The computed image of the block is shown in Fig. 8.

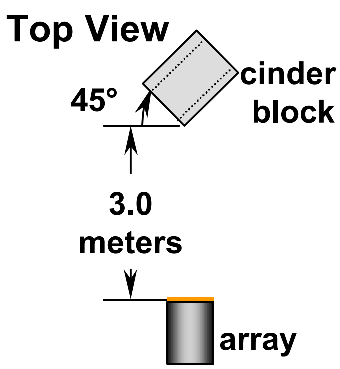

Fig. 7. Physical arrangement of sparse planar array and cinder block target.

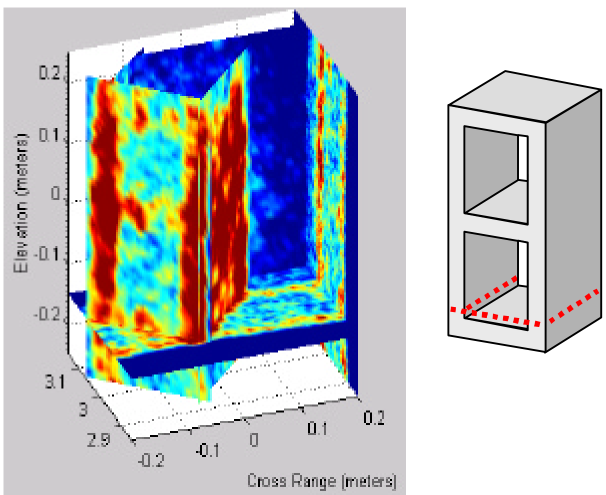

Fig. 8. Computed image of the cinder block.

The volume imaged is 0.5 m in elevation, 0.4 m. in azimuth and 0.3 m. in depth. For these data, 0.5 cm^3 voxels were computed to form the image. The transmit pulse was the FM slide with a 50 microsecond pulse width.

V. RESULTS AND CONCLUSION

The results shown in Fig. 8 are the first results obtained for this array and hardware configuration. A large variance was observed in the element to element sensitivity and the problem is carefully being investigated. Improved performance is expected once these problems are resolved and shading the array will be investigated. Progress will be reported at the conference later this year. Overall, the results obtain with a 0.1% sparse planar array are encouraging.

Acknowledgments

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