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1.5-D ULTRASOUND TRANSDUCER ARRAY CHARACTERIZATION

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Abstract—The objective of this work was twofold. The first was to investigate theoretically and experimentally the acoustical and electrical parameters of 1.5-D ultrasound transducer arrays for 3-D imaging applications. Modeling and simulations of arrays of various geometry, center frequencies, and materials were performed, analyzed and optimized. The optimization criteria was the best achievable lateral and elevation imaging resolution. The second objective was to fabricate several optimally designed prototypes of 1.5-D arrays, measure their acoustic fields in three dimensions, and characterize their performance. Investigated were such vitally important performance issues such as spatial resolution, acoustical and electrical crosstalk, matching techniques, electrical impedance and element size, pulse-echo bandwidth and sensitivity. In this paper results of the study on transducer dispersion and impedance is reported. It is shown that ceramic pillars of the correct aspect ratio must be used to define the active 1.5-D array elements.

INTRODUCTION

The "1.5-D array" notation is commonly given to small two-dimensional arrays with a limited number of elements along the elevation dimension, as illustrated in Fig. 1. The 1.5-D array is useful for several technological reasons.

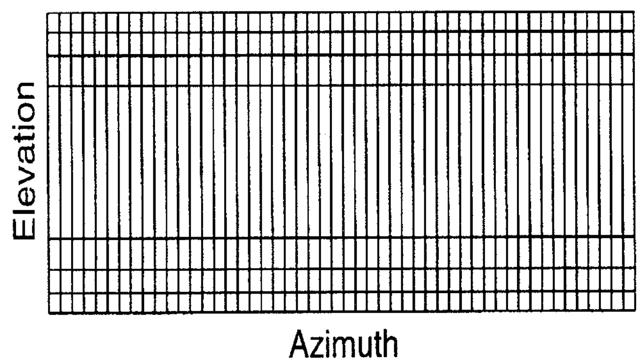

Figure 1: 1.5-D array, illustrating small number of elements along the elevation dimension relative to the azimuth.

The conventional 1-D imaging modality creates an azimuthal plane image representative of a tomographic"slice" through the region of interest. However, since only a weak, fixed-range mechanical focus is employed in the elevation direction, the image slice thickness, i.e. elevation resolution, is extremely poor (typically several millimeters). Furthermore, the elevation resolution is non-uniform throughout the field-of-view (depth) of the image. Consequently, image detail representing valuable diagnostic information is obscured or irretrievably lost.

In contrast, 1.5-D and 2-D transducer arrays allow dynamic control of the elevation beamwidth via apodization and electronic focusing. 2-D arrays could provide the ultrasound industry with long awaited 3-D imaging capabilities, characterized by symmetrical spatial resolution throughout the imaging field and superior imaging quality. Unfortunately, several factors have limited development of 2-D array technology, including the large number of elements, small size, electrical interconnect, and demanding system requirements, among others [1].

These aspects have caused 1-D array technology to dominate almost exclusively. However, the 1.5-D approach provides an important link between conventional 1-D ultrasonic arrays and 2-D arrays due to significant cost and implementation advantages. While several studies have focused on 2-D transducer arrays, *e.g.* [1], a suprisingly small body of published work exists on 1.5-D arrays, *e.g.* [2], yet significant issues remain to be addressed and resolved to bring the technology to a mature state of development. It is the objective of this work to theoretically and experimentally characterize 1.5-D arrays to optimize their design. One goal is to find the necessary balance between cost and performance. Long-range plans call for a development of a series of optimized 1.5-D linear and phased arrays tailored for different diagnostic applications and integrated with electronics in a mechanically driven compact 2-D scanhead. Small, hand-held 2-D scanheads become feasible and affordable, thus creating an opportunity for a portable 3-D scanner, with improved image quality.

This paper describes the results of the research effort devoted to study the dispersion associated with 1.5-D array element size, as well as to investigate their electrical impedance. This allows extraction of material parameters for simulation purposes, and analysis of system front-end requirements including electrical matching and signal to noise ratio issues.

METHODS

The dispersion (vibrational characteristics versus element size and frequency) in 1.5-D transducer arrays was analyzed. This analysis is important because typically the elements in 1-D arrays may be assumed to vibrate in a quasi-one-dimensional mode. Length resonances are removed in frequency due to the fact that the elevation height (length of the PZT element) is much greater than the width or thickness of the element [3]. However, a 1.5-D array will typically have its elevation height diced into a variety of sub-lengths. These parallelpipeds may have length resonances close to the thickness mode resonance if the aspect ratio is not controlled properly. Such coupled resonances and dispersive effects could decrease the pulse-echo sensitivity as well as cause different sections of the array to have different frequency responses (bandwidths and center frequency). The result of the transducer analysis is a well-characterized element response that can be used as input to acoustic field calculations.

Plates of PZT-5A (Vernitron) were diced into pillars of various aspect ratios. Ratios studied were kept at a constant width to thickness aspect ratio of 2:1, which is used in medical transducer arrays to maintain a thickness-mode vibration. Elements of each plate were electrically wired in parallel to reduce the electrical impedance for higher accuracy measurements. The PZT plates possessed a thickness of 1.5 mm for accuracy and ease of fabrication. Since all results can be normalized, generality was not compromised. Electrical impedance was measured on a network analyzer (Hewlett-Packard 8751A/87511A) and stored on a PC for further analysis.

RESULTS AND DISCUSSION

Electrical impedance magnitude plots of the dispersion study are shown in Fig. 2. These figures show the tall, length expander bar (1:1 aspect ratio) yields a uni-modal (efficient) vibrational response. This fact is characterized by the presence of a single dominant mode, and lack of spurious adjacent modes. The aspect ratios of 2:1, 3:1, and 4:1 exhibit mode coupling effects, which are reduced as the ratio increases. Therefore, short elevation height elements should be subdiced.

The 1:1 aspect ratio element was further characterized by extracting one-dimensional equivalent parameters such as the speed of sound, dielectric constant, and mechanical and dielectric loss tangents from the transducer's impedance measurements. Table 1 lists the extracted constants.

Fig. 3 illustrates a comparison the measured data and extracted data used in a 1-D model (Mason model) simulation. These constants can be used to characterize a 1.5-D array element which is sub-divided into minors to assure a 1-D vibrational mode.

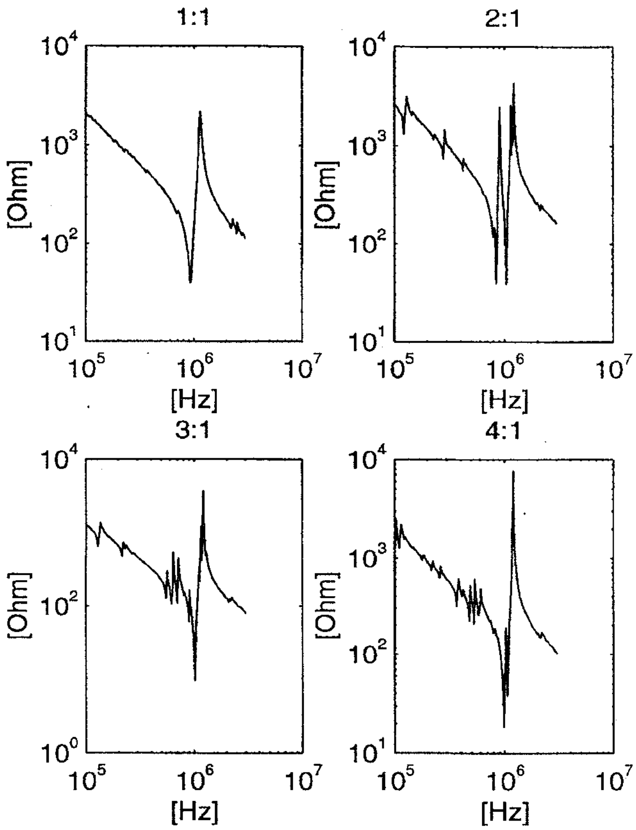

Figure 2: Electrical impedance magnitude of parallelpipeds of elevation height to width aspect ratios of 1:1 to 4:1. The thickness to width aspect ratio in each case is 2:1.

CONCLUSION

The purpose of this work was to investigate theoretically and experimentally the acoustical and electrical parameters of 1.5-D ultrasound transducer arrays for 3-D imaging applications. Modeling, simulations, and measurements of arrays of various designs were undertaken to optimize their performance. In this paper results of the study on transducer dispersion and impedance is reported. It is shown that ceramic pillars of the correct aspect ratio must be used to define the active 1.5-D array elements.

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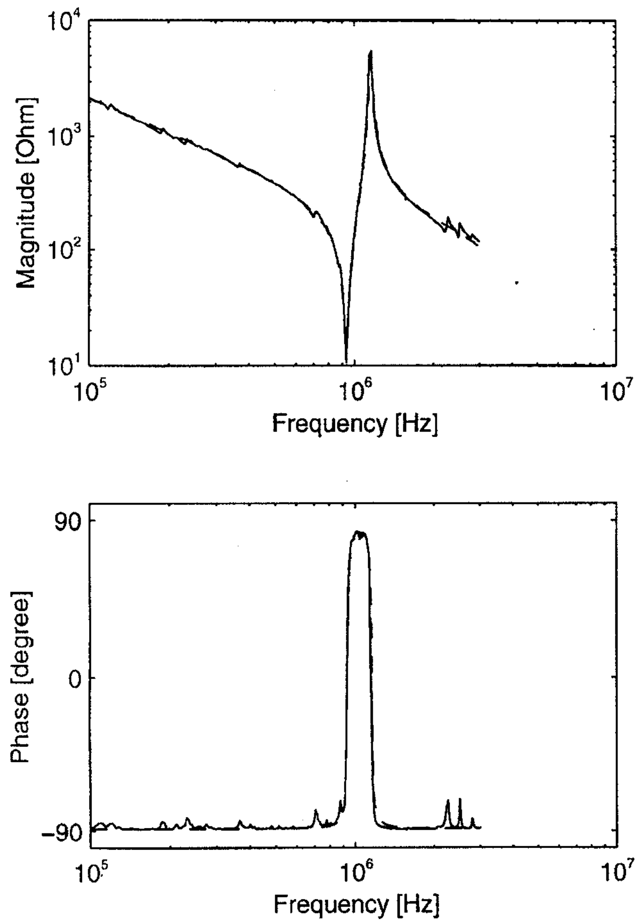

Figure 3: Simulated (–) and measured (-.) electrical impedance of the 1:1 by 2 thick aspect ratio PZT-5A pillar, using extracted constants.

Table 1: Extracted material constants for 1.5-D array subelement of 1:1 height to width aspect ratio by 2 thickness, PZT-5A.

Effective Velocity	3476 [m/s]
Resonance Frequency Constant	1401 [Hz*m]
Dielectric Constant	920
Free Dielectric Constant	1727
Mechanical Loss Tangent	0.0159
Dielectric Loss Tangent	0.0243
Effective Coupling Factor	0.6310
Mass Density	7750 [kg/m^3]

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