Active control of acoustical beamforming with an electrode array on a piezoelectric rubber composite

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An "active" method of controlling acoustical beamforming with a linear array of electrodes configured on a composite piezoelectric rubber sheet is demonstrated. The active control is achieved by applying a dc bias on the electrode elements. The electroded regions of the piezorubber sheet exhibit piezoelectric activity proportional to the magnitude of the bias. By selectively biasing the electrodes, the corresponding locales of the array are forced to be active or inactive (piezoelectrically) for electroacoustic synergism. The ability to control the piezoelectric response of individually electroded regions provides a method to change the wave vector response of the electroacoustic transducer array. Tailored beamforming is therefore, made plausible with appropriate dc bias applied to selective electrodes. This "active" method could be useful in "smart" beamforming strategies and "active" control of vibrations. Test results on a prototype sample are presented as the proof of the concept.

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INTRODUCTION

Piezoelectric composite rubber has recently become a viable candidate material for surface sensor applications. For example, conductive rubber and piezoelectric polymer films have been deployed in tactile recognition[1] sensor technologies. Also, a recent application of piezoelectric composite rubber sheet specifies sensitive hydrophone designs,[2–4] and investigations concerning the identification of pertinent material parameters[2,3,5] of such piezorubbers are also pursued as current topics of research. This Letter presents results concerning the application of composite piezorubber (in sheet form) to realize a directional acoustic radiation detection (beamforming) using a single piece of piezorubber with two (or more) "actively" controlled sets of electrodes. This is achieved by controlling the piezoelectric activity under the regions of each set of the electrodes (approximating a linear array) on the piezorubber via dc bias applied to the electrode sets, selectively. To "turn off" the piezoelectric response between a given set of electrodes, the dc bias is increased such that the polarization of the material is driven into saturation, thus incapacitating the electroelastic electric activity.

The piezorubber material used is available commercially from NTK Technical Ceramics (under the designation PR-307) and consists of a dispersion of lead titanate particles embedded in a chloroprene polymer matrix. The resulting structure is termed as 0–3 composite, implying that the piezoelectric particulates have zero connectivity in the three coordinate axes and thus are completely isolated from one another in the matrix, while the polymeric host has connectivity in all three coordinate axes. The piezorubber is poled in a direction perpendicular to the sheet surface, so that it forms a thickness-drive piezoelectric vibrator.

I. EXPERIMENT

Measurements were performed in an anechoic chamber (at the Florida Atlantic University Center for Acoustics and Vibrations). The piezorubber element employed has dimensions $51\times51\times3$ mm. Electrodes were prepared by applying a thin layer of silver paint to form two sets of four opposing electrodes in an inter-digital configuration on each surface of the sample as depicted in Fig. 1. Each electrode is approximately 5 mm wide and adjacent electrodes are separated approximately by 1.5 mm. Wire leads were attached to each electrode for a coaxial output. A sound source consisting of an electrostatic acoustic driver insonified the piezorubber transducer with a 25-kHz sine wave from a distance of 91.4 cm.

The effects of applying a dc bias on the piezoelectric response of the sample was investigated by measuring the ac signal output across the back-to-back electrode pair on the piezorubber in response to an acoustical excitation. Variable dc bias was provided by a simple circuit shown in Fig. 2 across the back-to-back interdigital electrodes. The ac signals induced in response to acoustical excitation of the electrodes (isolated from the dc bias by blocking capacitors) were fed to into an HP 3561 A spectrum analyzer for recording.

II. RESULTS

Figure 3 depicts plots of the relative (electrical) response of the piezorubber test sample to a normal acoustic irradiation under the activation of both electrodes of the interdigital configuration with equal dc bias. It is distinctly observed that the measured electrical response is a function

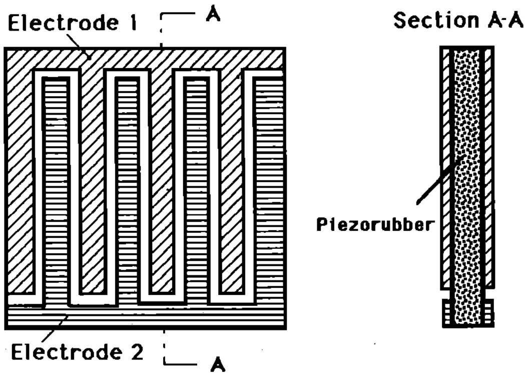

FIG. 1. Test array electrode configuration on the piezorubber sample.

of the bias (implicitly measured via I_e). And, at a specific value of dc bias, the detectable electroacoustic synergism due to piezoelectric activity ceases.

To extend this result to beamforming applications, the horizontal beampattern of the linear piezorubber array (Fig. 1) is estimated. To calculate the expected angular response, each array element is considered approximately as a point receiver since the element widths are about 5 mm each and the wavelength of excitation is 14 mm. Further, the incident acoustic waves are approximately plane inasmuch as a 10° phase shift over the width of the piezorubber sample occurs at a distance of 83 cm, resulting in a normalized beampattern[6] specified by

$$v^2(\theta)=\left(\frac{\sin(n\pi d\sin\theta/\lambda)}{n\sin(\pi d\sin\theta/\lambda)}\right)^2, \tag{1}$$

where n is the number of elements and d the element spacing. This ideal pattern is plotted in Fig. 4(a) for two cases, namely, both sets of the interdigitized electrodes ($n=8$, $d=6.5$ mm) and a single set of the interdigitized electrodes ($n=4$, $d=13$ mm) being active.

Beampattern measurements were conducted with the test piezorubber linear array sample for (i) both sets of the interdigitized electrodes under "on" condition (with a bias specified by $I_e=10$ μA), and (ii) with one electrode set switched "on" and the other electrode set being "off" ($I_e=5$ mA). Beampatterns were also measured for both sets of electrodes not being connected to the controlling circuitry. The normalized results are presented in Fig. 4(b). These measured (controlled) patterns are seen to correlate with the theoretical patterns of Fig. 4(a) pertaining to an ideal array approximation [Eq. (1)]. Deviation from the ideal response of Fig. 4(a) as indicated by the power leakage out of the main beam in Fig. 4(b) is attributed primarily to the presence of the electroded areas along the top and bottom of the piezorubber sample (Fig. 1) that provide common electrical potentials for each set of interdigital electrode fingers. The ideal linear array assumes that each array element is a point source, and thus omnidirectional, however, the presence of the interdigital common electrode areas will reduce the phase discrimination between array elements since the ac signals from the electrode common areas are inherently summed with those of the individual electrode array elements. Additionally, it is observed in Fig. 4(b) that the measured beampatterns exhibit response degradation as end fire ($\theta=90°$) is approached. This effect was caused by acoustic wave absorption in the porous foam mounting which was flush with the surface of the piezorubber array and effectively blocked the end-fire radiation.

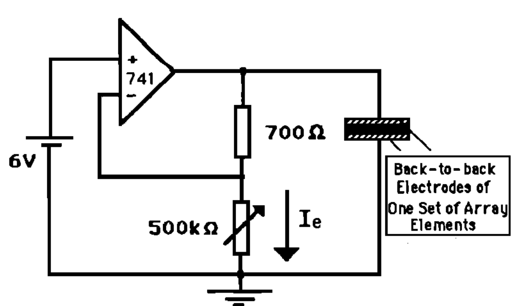

FIG. 2. Circuit diagram for dc charging of the electrodes on the piezorubber.

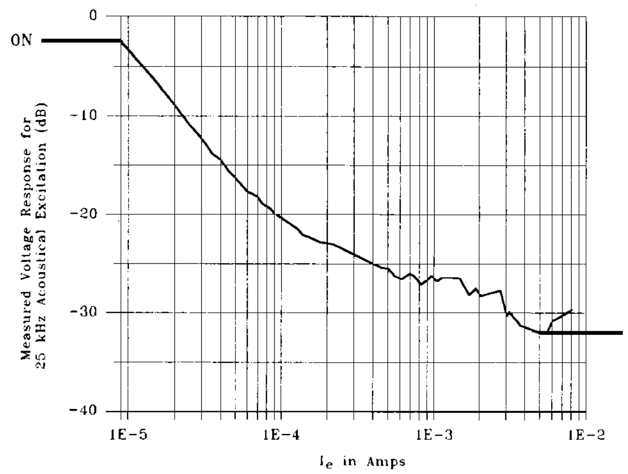

FIG. 3. Measured (relative) voltage response of the piezorubber sample (with a single pair of electrodes subjected to normal acoustic sine wave irradiation at 25 kHz) versus applied dc charging current.

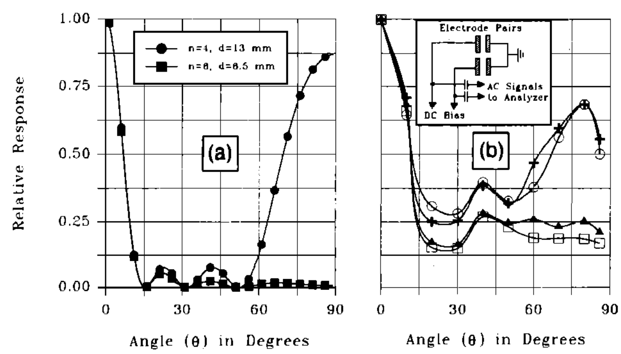

FIG. 4. (a) Calculated beampatterns at 25-kHz excitation of an ideal linear array [as per Eq. (1)]. (b) Measured (normalized) beampatterns of the piezorubber test array with and without dc bias conditions. □ Output of both electrode pairs in parallel and no dc bias. ○ Output of one electrode pair with no dc bias (the other pair floating). ▲ Output of both electrode pairs in parallel and dc biased to be "ON." + Output of both electrode pairs in parallel, one pair dc biased "ON," the other pair "OFF."

III. CONCLUSION

Active control of acoustical beamforming using a piezorubber composite sheet is demonstrated by selectively "switching off" the piezoelectric response at the electrodes with a dc bias of sufficient magnitude. The mechanism that renders the piezoelectric response inactive with the application of dc bias at the electrodes is depolarization of the piezoelectric domains. The method of inerting the piezoelectric response selectively at the desired locales is extended presently to modulate the spatial response of the acoustical array configured on a continuous piece of piezorubber sheet. This technique leads to an alternative beamforming strategy without resorting to the conventional phase-shift or time delay circuitry. Such "active" control method(s) of acoustical beamforming could be profitably used in "smart sensor" applications[7] and/or "active" control of vibrations.[8]

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