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Electrical method for crosstalk cancellation in transducer arrays

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ABSTRACT

In this paper, we report a new and simple electrical method to cancel crosstalk in the acoustical arrays. This solution has several advantages compared with that proposed in a previous paper (Bybi et al 2013) [17] where adapted electrical voltages were applied to each neighboring element of the active element in order to reduce the displacement field on their active surface. Firstly, it allows obtaining accurate correction electrical voltages, since it requires average electrical measurements (impedance and current measurements) instead of the displacement measurement in each point at the surface of the radiated element. In addition to this, the method does not need a laser vibrometer which is expensive in terms of time and difficult to use accurately for displacement measurement in water. To demonstrate the ability of the proposed solution an array composed of seven-elements, similar to those used in medical imaging and NDT applications, made of a conventional piezo-ceramic material PZT-27 is fabricated. Then an electrical method based on electromechanical equivalent circuits for piezoelectric materials and motional current measurements is applied. The experimental and numerical results obtained demonstrate the ability of the proposed technique to reduce crosstalk as well as its robustness and ease of implementation.
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1. Introduction

Since the late 1980s, ultrasound phased array systems have been successfully used in most medical fields and have already become the preferred imaging method in a variety of clinical situations. Research in this domain currently focuses on very high frequency imaging with the aim of improving the clinical diagnosis. These efforts include the use of new transducer materials. For example, single crystal materials like lithium niobate ($LiNbO_3$) have been utilized to reach frequencies superior to 100 MHz [1] and piezo-composite materials [2–5] have been proposed for applications needing operating frequencies superior or equal to 30 MHz. Similarly, silicon micro-machined transducers [6–8] have been developed to replace conventional piezo-ceramic arrays and electronic devices could thus be integrated on the same substrate.

Nevertheless, crosstalk, which is associated with acoustic wave propagation between successive array elements, is a problem for all these kinds of arrays as it is responsible for anomalous behavior in the directivity of the array. Many researchers have investigated this phenomenon over the years. Assaad et al. [9] developed a numerical method to calculate the pressure radiated from linear arrays, including acoustical and mechanical interactions. The far-field directivity pattern of part of the array was computed using dipolar dampers and an extrapolation algorithm previously described in Ref. [10]. This part consisted of an active elementary transducer (electrically driven) mounted between 2Q passive (electrically grounded) neighboring transducers. Then, the resultant pressure of a finite phased and focused array could be obtained by summing up the far-field directivity patterns of the 2Q+1 transducer sets weighted by the classical term which takes into account the geometrical and electrical phase shifts. This numerical method has been widely cited and used by other researchers working in the domain [11] and [12].

Different solutions have been proposed to reduce crosstalk. A first approach [13–15] was to have a numerical model of the acoustic array in order to study the effect of design modification on crosstalk. These studies investigated more particularly the geometry and dimensions of the kerf filling material (width and depth of kerfs, minor and major kerfs, attenuator polymeric wall placed between array elements etc.) because it is known to be the main component of the transducer which affects crosstalk most significantly. Another promising solution consisted in developing a systematic method for active cancellation of crosstalk. In a similar manner, previous studies [16,17] provided a Finite Elements (FE) algorithm to adapt harmonic electrical voltages on each neighboring element of the active element in order to reduce the displacement field on their active surface. This method required displacement measurements using a laser vibrometer but accurate results were difficult to obtain over the entire array surface. In addition to this, the use of the numerical results in the experiment

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was not straightforward since the method was very sensitive to the characteristics of the array (material properties and geometry). Zhou et al. [18] developed another method using the transfer function matrix relating input voltages V_i to output pressures P_i in the case of transient excitations [19]. In this case, the measurement precision of the elements' transfer function using a hydrophone, or other methods such as direct receive transfer measurement or pulse echo technique [20], was limited. Therefore the method was based on the transfer function calculated by FE, which was not perfectly matched to the real physical device.

The aim of this paper is to offer a new and simple electrical method to cancel crosstalk in acoustic arrays using the analogy between the motional current and normal displacement. The advantage of this electrical method compared to the previous ones is that it requires average measurements (impedance and current measurements) instead of individual measurements. Furthermore, the method also offsets fabrication problems when the array is not optimal as an example due to imperfections in terms of symmetry.

In order to simplify the study, we first and foremost choose to check the validity of the proposed correction method in a simple case where only one element of the transducer array is driven (central element). It is clear that in the case of the transducer array used in acoustical imaging this method should be tested on each element of the transducer array in the purpose to see its efficiency during the focus and the deflection of the acoustic beam. This will be the main objective of our future works, where we will tend to also take into account the presence of an acoustic lens in front of the transducer array.

In the first section of this paper, the crosstalk cancellation method proposed and the models used to determine the electrical voltages needed are described. The second section presents the transducer array fabricated and the numerical directivity pattern results obtained before and after crosstalk cancellation. The last section is dedicated to the application of the correction method to the device fabricated. All the calculations were carried out at low frequency in order to compare them with the experimental results, thus facilitating the fabrication of the transducer array.

2. Crosstalk cancellation method

2.1. Electrical equivalent circuit

Fig. 1(a) shows a piezoelectric material polarized in the direction perpendicular to its thickness and driven by an electrical voltage V at the thickness resonance frequency. Fig. 1(b) represents the equivalent electromechanical circuit at the mechanical resonance frequency [21]. This circuit is composed of an electrical part (R_0, C_0) and a mechanical part (R, L and C) corresponding to the damping, mass and inverse stiffness respectively. The two parts are coupled through an ideal transformer of turn ratio N. It can be easily demonstrated that this representation is similar to the circuit in Fig. 1(c), which is composed of the same electrical part (R_0, C_0), and a mechanical part with motional components C_m, L_m and R_m. This circuit will be used in the following work.

The relationship between the normal displacement on each element and the motional current is given by [22]

$$N = \frac{I^M}{\dot{U}}, \tag{1}$$

where I^M is the motional current and $\dot{U}$ is the vibration velocity associated with the displacement. In the case of harmonic excitation at the angular frequency ω_0, the relationship (1) can be

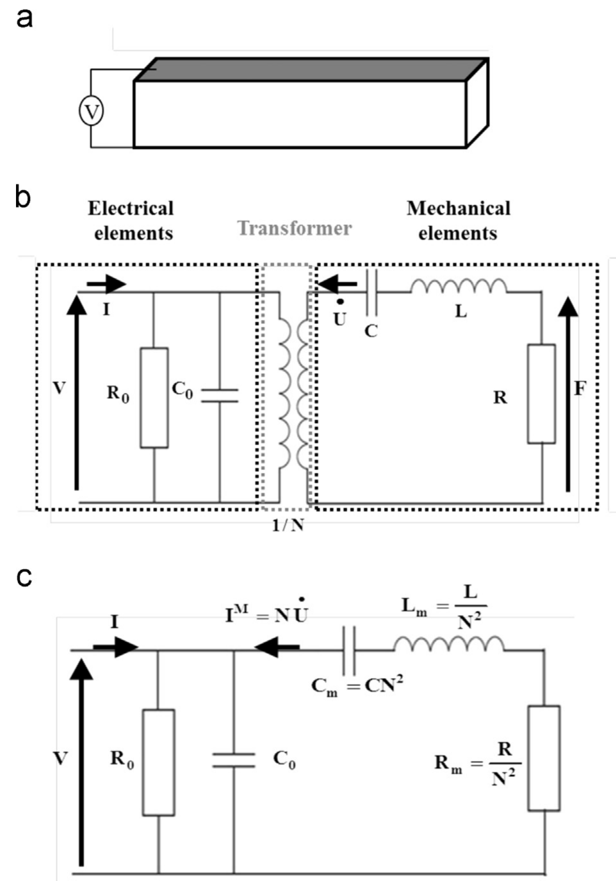

Fig. 1. Electromechanical equivalent circuit of a transducer: (a) piezoelectric material polarized in the direction perpendicular to its thickness; (b) equivalent electromechanical representation at the resonance frequency with transformer; and (c) equivalent electromechanical representation at the resonance frequency without transformer.

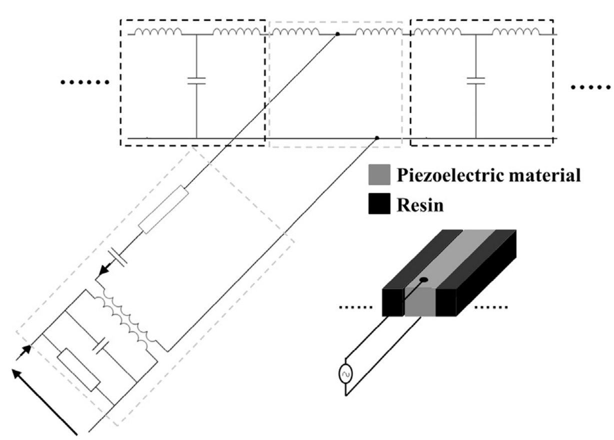

Fig. 2. Electromechanical equivalent circuit of an elementary cell of a transducer array composed of $2n+1$ elements bound by resin.

rewritten as

$$I^M = -jN\omega_0 U. \tag{2}$$

For $2n+1$ piezoelectric elements bound to each other by a non-conductive resin, the previous circuit can be chosen for each piezoelectric element, while the resin can be represented by a transmission line without losses [23] (two similar inductors and one capacitance). The periodic equivalent circuit is illustrated in Fig. 2 by one elementary cell.

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