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Experimental Validation of Crosstalk Minimization in Metallic Barriers with Simultaneous Ultrasonic Power and Data Transfer

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***Abstract*—For systems that require complete metallic enclosures, it is impossible to power and communicate with interior electronics using conventional electromagnetic techniques. Instead, pairs of ultrasonic transducers can be used to send and receive elastic waves through the enclosure, forming an equivalent electrical transmission line that bypasses the Faraday cage effect. These mechanical communication systems introduce the possibility for electromechanical crosstalk between channels on the same barrier, in which receivers output erroneous electrical signals due to ultrasonic guided waves generated by transmitters in adjacent communication channels. To minimize this crosstalk, this work investigates the use of a phononic crystal/metamaterial machined into the barrier via periodic grooving. Barriers with simultaneous ultrasonic power and data transfer are fabricated and tested to measure the effect of grooving on crosstalk between channels.**

***Index Terms*—Acoustic power transfer, acoustic data transfer, piezoelectric, guided waves, phononic crystal, metamaterial**

I. Introduction

Systems that require complete metal enclosures, such as containment buildings for nuclear reactors, prohibit the use of conventional electromagnetic techniques to power and communicate with interior sensors or equipment. In such cases, ultrasonic transducers can be placed on either side of the metal enclosure, sending and receiving ultrasonic waves to form an effective electrical transmission line that bypasses the Faraday cage effect [1]–[5]. Similar concepts have been explored to power biomedical implants [6].

As these ultrasonic power and communication systems become more mature, it is desirable to use multiple channels across the surface of the enclosure. This results in electromechanical crosstalk, in which ultrasonic channels output erroneous electrical signals due to guided waves propagating from channels elsewhere on the enclosure. This work experimentally investigates the use of periodically machined grooves to block guided wave propagation and hence minimize electromechanical crosstalk between channels.

II. Machined Phononic Crystal Characterization

Several 3 mm thick aluminum barriers were fabricated to represent the wall of the metal enclosure. From our previous work on this system, 5 designs were obtained for the periodic grooves to block wave propagation (and hence crosstalk) at 2.1 MHz. Two designs have grooves on one side of the barrier only (labeled G1.1 and G1.2), while three designs have

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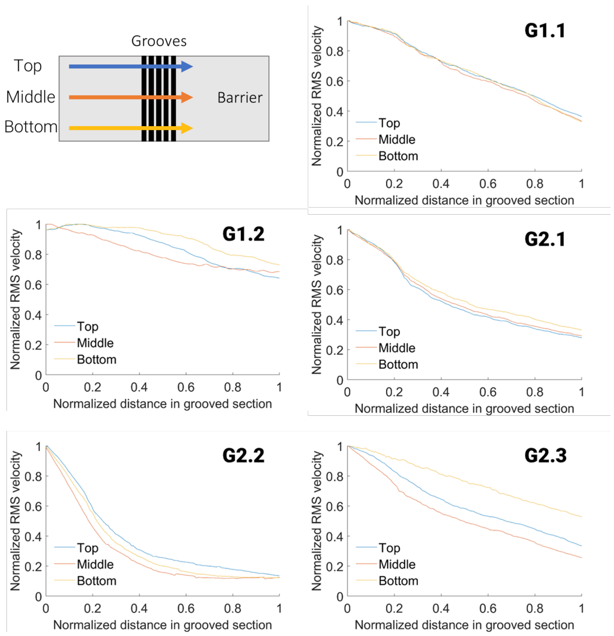

Fig. 1. Wave-blocking performance comparison for the 5 groove designs. The groove geometry and wave propagation direction are shown in the top left. The RMS wave velocity decreases across the grooved region of the barrier for each design, with little variation across the length of the grooves. Design G2.2 was the most effective at blocking wave propagation.

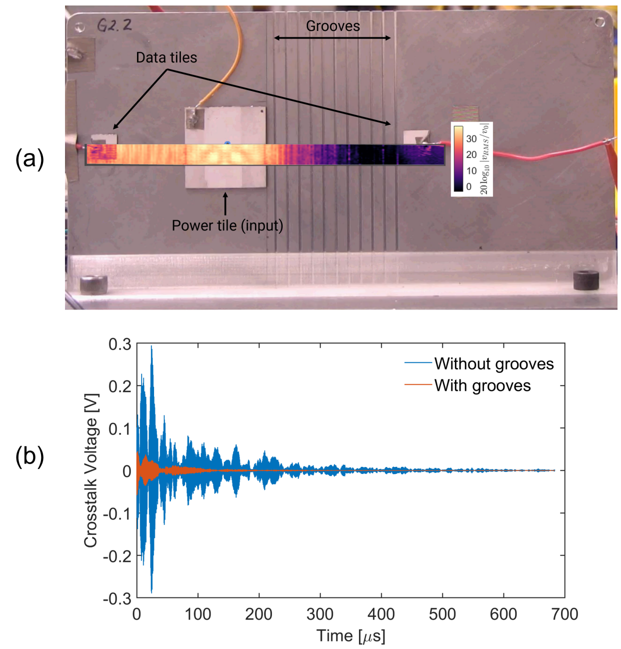

Fig. 2. (a) Image of the barrier with power and data transfer piezoelectric transducers. The right data transfer tile is protected from the power transfer tile by the periodic grooves. The inset heatmap shows the RMS surface velocity measured by the SLDV. (b) Comparison of the crosstalk voltage received by the two data transfer tiles.

grooves alternating on both sides of the barrier (labeled G2.1-G2.3). All grooves were kept at 1 mm wide to simplify the machining process. Grooves were machined perpendicular to the expected direction of wave propagation, i.e. parallel to the edge of the tile generating guided waves.

Each grooved barrier was characterized using an ultrasonic wedge transducer (7-cycle Gaussian burst at 2.1 MHz) and scanning laser Doppler vibrometer (SLDV). The SLDV enables measurement of the full surface velocity wavefield $v(x,t)$ generated by the wedge transducer. In this way, the wave-blocking capability of each groove design was measured experimentally. Each grooved barrier was tested at several vertical positions to investigate any variation in performance along the groove length. These results are summarized in Fig. 1. Design G2.2 was selected for further investigation since it performed the best of all of the designs.

III. Crosstalk Reduction Performance

The best-performing grooved barrier was instrumented with a representative set of piezoelectric transducers. One large tile ($3\,\text{cm} \times 3\,\text{cm} \times 1$ mm, resonant frequency 2.1 MHz) represented an ultrasonic power transfer tile, while two smaller tiles (1 cm × 1 cm × 0.4 mm) represented ultrasonic data transfer tiles. Both data transfer tiles were placed near the power transfer tile, with one tile separated from the power transfer tile by the periodic grooves. Thus, the voltage output of the data transfer tiles due to actuation of the power transfer tile can be directly compared to measure the reduction in actual received crosstalk. At the same time, the SLDV was used to measure the surface velocity of the barrier. These results are shown in Fig. 2.

The reduction in guided wave propagation is evident in Fig. 2a. The RMS surface velocity near the data tile on the right is nearly two orders of magnitude less than the surface velocity near the tile on the left. This aligns with the measurement of crosstalk voltage shown in Fig. 2b, which shows that the tile protected by grooves has a significantly reduced level of crosstalk voltage (85% reduction in RMS).

IV. Conclusions

We present the experimental characterization of machined phononic crystals designed to prevent electromechanical crosstalk in metallic ultrasonic communication systems with simultaneous data and power transfer. An ultrasonic wedge transducer and scanning laser Doppler vibrometer (SLDV) were used to characterize the wave-blocking performance of several groove designs. The best-performing design was further tested using piezoelectric transducers and SLDV. This design was able to reduce the received crosstalk voltage by 85% over the baseline, validating the use of periodic machined grooves to isolate ultrasonic communication channels.

Acknowledgment

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