Mechanics/Machinery

Micro-Horn Arrays for Ultrasonic Impedance Matching

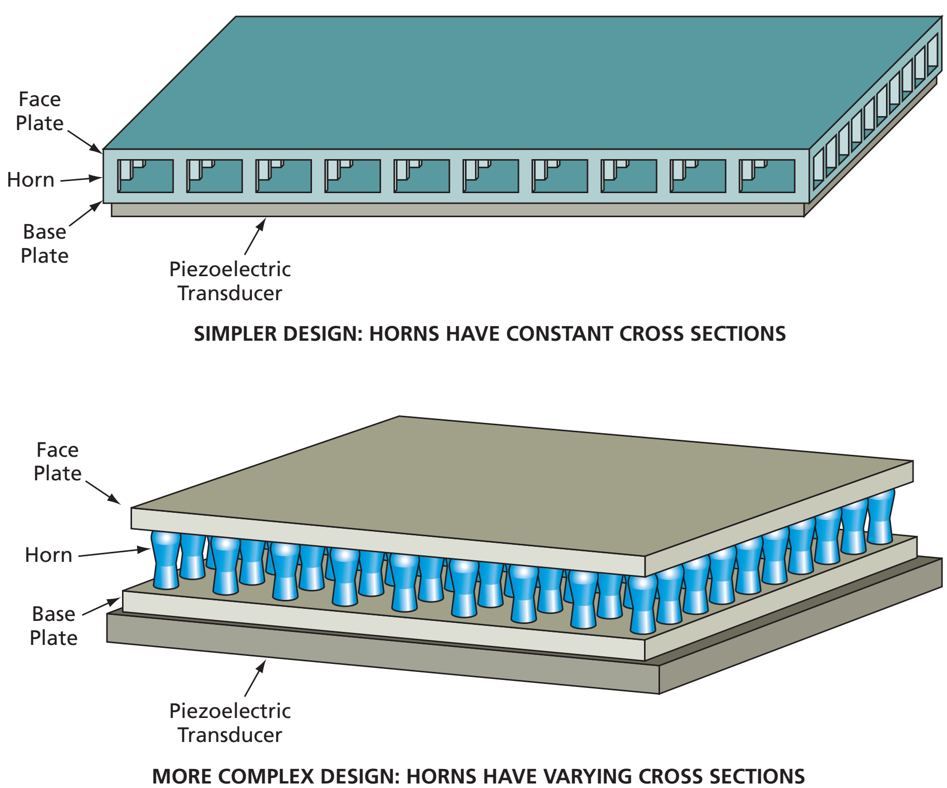
Horn impedance matching is extended from lower frequencies into the ultrasonic range.

NASA's Jet Propulsion Laboratory, Pasadena, California

Thin-layered structures containing arrays of micromachined horns, denoted solid micro-horn arrays (SMIHAs), have been conceived as improved means of matching acoustic impedances between ultrasonic transducers and the media with which the transducers are required to exchange acoustic energy. Typically, ultrasonic transducers (e.g., those used in medical imaging) are piezoelectric or similar devices, which produce small displacements at large stresses. However, larger displacements at smaller stresses are required in the target media (e.g., human tissues) with which acoustic energy is to be exchanged. Heretofore, efficiencies in transmission of acoustic energy between ultrasonic transducers and target media have been severely limited because substantial mismatches of acoustic impedances have remained, even when coupling material layers have been interposed between the transducers and the target media. In contrast, SMIHAs can, in principle, be designed to effect more nearly complete acoustic impedance matching, leading to power-transmission efficiencies of 90 percent or even greater.

The SMIHA concept is based on extension, into the higher-frequency/lower-wavelength ultrasonic range, of the use of horns to match acoustic impedances in the audible and lower-frequency ultrasonic ranges. In matching acoustic impedance in transmission from a higher-impedance acoustic source (e.g., a piezoelectric transducer) and a lower-impedance target medium (e.g., air or human tissue), a horn acts as a mechanical amplifier. The shape and size of the horn can be optimized for matching acoustic impedance in a specified frequency range.

A typical SMIHA would consist of a base plate, a face plate, and an array of horns that would constitute pillars that connect the two plates (see figure). In use, the base plate would be connected to an ultrasonic transducer and the face plate would be placed in contact with the target medium. As at lower frequencies, the sizes and shapes of the pillars could be tailored for impedance matching in a specified ultrasonic frequency range. In a design that would be simplest to implement by micromachining, the



Small Horns in a Planar Array would be sized and shaped for matching acoustic impedance between an ultrasonic transducer and a medium in contact with the face plate. The horns could be fabricated by micromachining.

horns would have constant cross-sectional areas as shown in the upper part of the figure. In this case, the dimensions of the horns could be chosen on the basis of a Mason equivalent-circuit model (a simplified model, well-known in the piezoelectric-transducer art, in which the electrical and mechanical dynamics, including electromechanical couplings, are expressed as electrical circuit elements that can include inductors, capacitors, and lumped-parameter complex impedances.) In a more complex, more nearly optimum design, the cross-sectional area of each horn would be either stepped or made to vary as a continuous function of through-the-thickness position, as shown in the lower part of the figure.

This work was done by Stewart Sherrit, Xiaoqi Bao, and Yoseph Bar-Cohen of Caltech for NASA's Jet Propulsion Laboratory. For more information contact iaoffice@jpl.nasa.gov.
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Improved Controller for a Three-Axis Piezoelectric Stage

Advantages over a prior controller include compactness, greater adaptability, and higher resolution.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved closed-loop controller has been built for a three-axis piezoelectric positioning stage. The stage can be any of a number of commercially available or custom-made units that are used for precise three-axis positioning of optics in astronomical instruments and could be used for precise positioning in diverse fields of endeavor that include adaptive optics, fabrication of semiconductors, and nanotechnology.

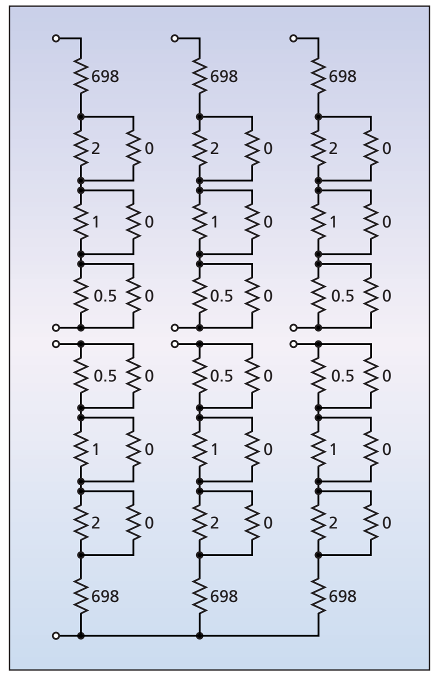
In a typical application, the stage is used to move an optic through a small distance with a required resolution of the order of a nanometer or a fraction of a nanometer. Typically, the piezoelectric actuator for each axis can be made to expand through a maximum stroke ≤12 μm by applying a potential ≤120 V to it. To provide position feedback for closed-loop control of the potential applied to the piezoelectric actuator for each axis, the expansion of the actuator is sensed by means of a strain gauge bonded to the side of the actuator. The resistance of the strain gauge changes from about 700 to 701 Ω as the actuator expands through its maximum stroke. The strain gauge is part of a Wheatstone bridge, so that the small change in resistance from a nominal value can be converted to a Wheatstone-bridge output voltage. To close the control loop, the Wheatstone-bridge output voltage is amplified and compared with a voltage representing an actuator set point specified by an external control computer or other external source. The difference between these voltages constitutes a servo error signal, which is amplified for application to the affected piezoelectric actuator.

The improved controller supplants a prior controller that resided in a 19-in. (≈48-cm) rack. The most expensive part of the improved controller consists of servocontroller circuitry on a 4.25-by-7.5-in. (≈11-by-19-cm) printed-circuit board, denoted the main board. The strain gauges are connected into Wheatstone-bridge circuits that include relatively inexpensive, interchangeable resistor bridge circuits (see figure) on a 2.5-by-3.5-in. (approximately 6-by-9-cm) satellite printed-circuit board. The satellite board can readily be replaced by another with different circuitry tailored for a different actuator/strain-gauge combination.

The three Wheatstone bridges are driven by a precision voltage reference on the satellite board, powered by a cable from the main board. The voltages representing the actuator set points are generated by three 18-bit, self-calibrating, digital-to-analog converters on the main board. The amplification of the Wheatstone-bridge output voltages is effected by two-stage, low-noise instrumentation amplifiers on the main board.

The servo error signal for each axis is further amplified and filtered. The filter circuitry can be built to have either 2-Hz bandwidth (resulting in spatial resolution of 0.1 nm) or 200-Hz bandwidth (resulting in spatial resolution of 1 nm). The amplified, filtered signal is fed to a final high-voltage amplifier, the output of which is applied to the piezoelectric actuator. By means of a CMOS input on a control connector, some of the servocontroller circuitry can be bypassed, causing the actuators to operate in a rapid-motion, open-loop control mode.

One of the greatest advantages of improved controller over the prior controller arises from a low-noise design. The dominant component of noise is now Johnson noise from the strain gauges; the input-referred noise from all other components is lower by design. The lower-noise design makes it possible to refine spatial resolution from a prior limit of 1 nm to the present limit of 0.1 nm.



These **Resistor Bridge Circuits** are parts of Wheatstone bridges that include strain gauges. Resistance values are in ohms. The zero-ohm resistors are jumpers that can be removed to trim the bridges.

This work was done by Shanti Rao and Dean Palmer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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