Abstract No: PO-25

Designing a high-performance parametric speaker system: simulation and optimization

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The parametric speaker is designed to direct omnidirectional sound waves towards a specific target. Over the past two decades, numerous research studies have been conducted to optimize parametric speaker systems, with a focus on enhancing audio quality and extending the range of sound propagation. The objectives of this research include the enhancement of the audio quality, the reduction of total harmonic distortion through modulation techniques, and the amplification of the modulated output to increase the effective hearing distance. These goals were pursued alongside the development of a properly designed ultrasonic transducer array circuit, a critical component of a parametric speaker system. Prior to the conception of the novel parametric speaker system, a comprehensive simulation study was conducted using the commercially available COMSOL Multiphysics software. For this study, the Pressure Acoustics, Frequency Domain (acpr) interface, the Solid Mechanics (solid) interface, and the Electrostatics interface were utilized. The principal aim of this simulation study was to analyse the minimal electric potential required for an ultrasonic transducer element to generate a directional sound wave capable of propagating over a one-metre distance. To achieve this, a PZT-5H piezoelectric element with a stacked aluminium metal diaphragm was constructed. The electric potential across the piezoelectric plate was step by step varied from 5 V to 100 V. Polar plots illustrating the sound pressure level of ultrasound propagation in the air domain at a distance of one-thousand-four-hundred millimetres from the source were generated for each simulation. The simulation model of the piezoelectric element was meticulously constructed after a thorough examination of a cross-sectional cut of an ultrasonic transducer and the arrangement of layers within the metal cover. This model adopted a two-dimensional (2D) axially symmetric space dimension. This approach leveraged the rotational symmetry of the elements to simulate in 3D, thereby reducing simulation complexity. The analysis revealed that when the electric potential was below 10 V, the sound pressure remained below 60 dB. However, upon increasing the electric potential to above 60 V, although the expected directionality was achieved, distortions adversely affected the output signal. Such sound propagation characteristics were deemed unsuitable for a parametric speaker system. Upon analysing the polar graphs generated for a 30 V electric potential, it was evident that directionalized sound pressure levels in the air were achieved with minimal distortions compared to other simulated systems. Consequently, a 30 V electric potential was selected as the amplified signal voltage peak-to-peak for application to the designed ultrasound speaker. This approach was undertaken to ensure optimal performance and minimize distortion in the parametric speaker system.

Keywords: Parametric Speaker, Ultrasonic Transducer, piezoelectric, total harmonic distortion, COMSOL Multiphysics

Acknowledgment
This research will be supported by the Accelerating Higher Education Expansion and Development (AHEAD) Operation of the Ministry of Higher Education of Sri Lanka, funded by the World Bank.