which is composed of an amplifier for each intensity level and a signal generator. A Franz diffusion cell setup in combination with a spectrophotometer is used for experimental testing of nail permeability by measuring the amount of drug delivered through the membrane. Animal nails are used as a human nail model, and both drug-mimicking dye and Penlac (a topical prescription drug) are used for testing.

THURSDAY MORNING, 22 APRIL 2010 LAUREL A/B, 8:00 TO 11:45 A.M.

Session 4aEA

Engineering Acoustics: Sound Projection and Transduction

Stephen C. Thompson, Chair
Pennsylvania State Univ., Applied Research Lab., P.O. Box 30, State College, PA 16804

Chair's Introduction—8:00

Contributed Papers

8:05

4aEA1. On the concept of transient directivity: Pipes and horns. Daniel Tengelsen, Brian E. Anderson, and Timothy W. Leishman (Dept. of Phys. and Astron., Acoust. Res. Group, Brigham Young Univ., Provo, UT 84602)

Directivity is a convenient way to represent how sound radiates from some arbitrary object in steady-state. The steady-state condition is implied when time harmonicity is assumed. Because all physical systems do not begin in steady-state, this directivity measurement is only valid after the transient portion of the solution has decayed. Transient directivity—a measure of sound radiation versus angle at a given instant in time and before the system has reached steady-state—is presented. Understanding an object's transient and steady-state radiation characteristics may be important in understanding the sound radiation from sources that are transient in nature. Results of transient directivity will be presented for pipes and horns from both numerical models and experimental measurements.

8:20

4aEA2. Modeling of transducer arrays for direct digital-to-analog conversion of signals. Jose Amado, Nikita Tkachov, and Charles Thompson (Dept. of Elec. and Comput. Eng., Univ. of Massachusetts Lowell, 1 University Ave., Lowell, MA 01854, jose_amado@student.uml.edu)

A binary weighted array of speakers will be used to reconstruct a decomposed sequence of delta functions. The idea of directly converting digital signals to an analog acoustic output was first proposed by J. L. Flanagan in 1979, in which he designed, fabricated, and tested digital transducers for 4-, 5-, and 6-bit PCM signals. Flanagan found that at 6-bit resolution, the system fell short of good quality, and that condenser transducers had a limited output sound level of about 85 dB. Simulations will be used to investigate experimentally developed models for transducers and apply the direct digital-to-analog approach.

8:35

4aEA3. A new loudspeaker design for the enhancemenet of sound image localization on flat display panels. Gabriel Pablo Nava, Keiji Hirata, and Yoshinari Shirai (NTT Commun. Sci. Labs., NTT Co., Hikaridai 2–4, Seika-cho, Kyoto 619-0237, Japan, pablo@cslab.kecl.ntt.co.jp)

In most audio-visual multimedia applications, conventional stereo loudspeakers have been used to implement auditory displays. However, a fundamental problem with this kind of displays is that only the listeners situated at the sweet spot and over the symmetrical axis of the loudspeaker array are able to accurately localize the sound images. Although a number of audio signal processing algorithms have been proposed to expand the listening area, relatively less study on new loudspeaker configurations has been explored. This paper introduces a simple, yet effective, loudspeaker design to enhance the localization of sound images over the surface of flat display panels. In contrast to previous approaches, expansion of the listening space is achieved by attachment of rigid barriers which physically modify the sound radiation pattern of the loudspeakers. Moreover, numerical simulations, experimental sound measurements, and subjective tests have been preformed to validate a prototype of the proposed loudspeaker design using a display panel of an immersive teleconferencing system. Finally, an example of an interactive application was implemented involving real-time speaker tracking with a microphone and video cameras.

8:50

4aEA4. Head-tracking interface using a Wii remote. Megha Sunny, Ayse Kalkan-Savoy, and Charles Thompson (Dept. of Elec. and Comput. Eng., Univ. of Massachusetts Lowell, 1 University Ave., Lowell, MA 01854, megha_sunny@student.uml.edu)

In this work, we will examine the problem of detecting the angular motion of head in effort to build a head-tracking system to control sound. The head motion occurs in X, Y, and Z linear directions and three rotation angles, namely pitch, roll, and yaw. In the past, we had difficulties to detect the rotation angles, especially yaw. Our current work focuses on the detection of rotation angles using a software interface program. The distance between sound source and head, and angular rotation data is collected by the Wii-remote's built-in optical sensor and three-axis accelerometer. These real-time data will be used as input to our software interface. Results will be used in conjunction with head related transfer function to create the three dimensional sound source effects.

9:05

4aEA5. The influence of matching layer material loss on radiation impedance conversion in ultrasonic transducers. Minoru Toda (Measurement Specialties Inc., 135 Gedney Rd., Lawrenceville, NJ 08648, minoru.toda@measspec.com)

PZT based thickness mode ultrasonic transducers for both air and water /tissue typically have a quarter wavelength front matching layer with impedance Zm. It is widely known that the lower acoustic impedance Z_R of the propagation medium is converted to a higher impedance at the PZT surface by the relation $Z\max = Zm^2/Z_R$ (quarter wavelength conditions). In this work, the converted impedance was accurately calculated using a transmission line model incorporating the mechanical quality factor Qm of the matching layer material. In a medical transducer, it was found that the peak value is 20% or 28% lower than $Z\max = Zm^2/Z_R$ for $Qm = 15$ or 10, respectively. For air transducers, the peak value is one to two orders lower than $Z\max$ for the same range of Qm. These Qm values are typically ob-

served for the filled epoxy matching layer materials used in medical transducers and also for porous or air entrained materials used for air acoustic transducers. A simple impedance conversion equation for an air transducer has been proposed, making the design of air impedance matching layers easier and suggesting that neglecting material loss leads to serious errors.

9:20

4aEA6. Transitory response of an acoustic levitator. Sahir Shakir and Charles Thompson (Dept. of Elec. and Comput. Eng., Univ. of Massachusetts Lowell, 1 University Ave., Lowell, MA 01854, sahir_shakir@student.uml.edu)

This work will examine the transitory response of an acoustic levitator. Simulations will be used to ascertain the relationship between viscous and inertial forces on the vertical conveyance of a solid projectile. The objective is to use standing waves of strong intensity in a cavity to elevate a solid projectile. The projectile is suspended by nonlinear acoustic forces, and by rate of change in the frequency, amplitude, or cavity length, the transitory response will be determined.

9:35

4aEA7. Two driving constructions of loudspeakers for low-frequency range by piezoelectric ultrasonic motors. Juro Ohga (Ohga's Acoust. Lab., 2-24-3, Tamanawa, Kamakura, 247-0071, Japan), Takehiko Adachi, Hiroki Saito, Ryosuke Suzuki, Gen Takeda, Hajime Kubota (Chiba Inst. of Technol., Narashino 275-0016, Japan), Hirokazu Negishi (MIX Acous. Lab., Shiba, Minato-ku, Tokyo 105-0014, Japan), Kazuaki Maeda (TOA Corp., Takarazuka 665-0043, Japan), and Ikuo Oohira (Oohira's Lab., Aobadai, Aoba-ku, Yokohama 227-0062, Japan)

The loudspeaker driven by piezoelectric ultrasonic motors is characterized by a precise very-low-frequency reproduction due to its high-driving mechanical impedance. It has a lot of merits comparing to the conventional electrodynamic loudspeakers. One of the reason will be that this loudspeaker is a power flow modulator, not a transducer. In this presentation, two sorts of ultrasonic motors are compared as driver elements of the loudspeakers. One is an ordinary revolution-type motor and the other is a reciprocal linear motion type actuator. The authors constructed and improved practical low-frequency-range loudspeakers by using continuous revolution of ultrasonic motors. Its final model uses combination of two motors with same axis, which drive two cone radiators moving oppositely. This model shows a satisfactorily large output sound pressure and stable reproduction. However, its complicated elements for connection of the motors and the cone radiators cause a mechanical weakness. The authors, therefore, propose another new, completely different construction to avoid this defect. It applies linear motion of two ultrasonic actuators. A moving piece driven by piezoelectric ultrasonic vibrators is connected directly to a cone radiator. Comparison at various viewpoints and practical performance of these two constructions are presented at the meeting.

9:50

4aEA8. An ultrasonic vibrator constructed from laminated Galfenol steel. Scott P. Porter, Stephen C. Thompson, and Richard J. Meyer, Jr. (Appl. Res. Lab., The Penn State Univ., P.O. Box 30, State College, PA, 16804)

An ultrasonic vibrator has been developed to serve as the drive mechanism for an electroacoustic transducer. This design explores the unique characteristics of Galfenol, a recently invented giant magnetostrictive material. In addition to possessing competitive strain capabilities, strong mechanical properties, and a high-magnetic permeability, Galfenol does not require a prestress mechanism and can be laminated to effectively mitigate eddy current losses. Designing the vibrator required the authors to carefully engineer the magnetic circuit so that proper bias fields could be established using a permanent magnet. This step will be demonstrated with one- and two-dimensional models. Drive coil considerations will also be discussed and the fabrication and assembly of the vibrator will be shown along with in-air measurements.

10:05—10:15 Break

10:15

4aEA9. A preliminary analog circuit model of a balanced-armature transducer utilized for energy harvesting. Holly A. Smith and Stephen C. Thompson (Grad. Prog. in Acoust., Penn State Univ., 201 Appl. Sci. Bldg., University Park, PA 16802, has202@psu.edu)

This research investigates a balanced-armature transducer's potential to harvest ambient vibrational energy into electrical energy that could then be used to power small devices or recharge batteries. Such a device is desirable due to its compact size and environmentally friendly operation. An analog circuit model of a balanced-armature transducer was created in a version of SPICE. To ensure the model's accuracy, the electrical impedance predicted by SPICE was compared to experimental measurements. The model was then adjusted for energy harvesting. [Work supported in part by the Office of Naval Research.]

10:30

4aEA10. Modified single crystals for high-power, broadband underwater projectors. Nevin P. Sherlock and Richard J. Meyer, Jr. (Appl. Res. Lab., P.O. Box 30, State College, PA 16804)

When operating high-power electromechanical devices, the performance is often limited by self-heating within the active material. This is especially true in high-power, broadband underwater projectors using the piezoelectric single crystal $Pb(Mg_{1/3}Nb_{2/3}O_3–PbTiO_3$ (PMN-PT). Although PMN-PT crystals show an excellent piezoelectric response ($d_{33} > 1500$ pC/N) and high-coupling coefficient ($k_{33} > 0.90$), device performance is limited by the high-mechanical losses ($Q_M < 100$) and low-temperature phase transformation ($T_{RT} = 95$ °C). This work describes the material property enhancements of two compositional modifications and compares the performance of these crystals in high-power, broadband transducers. One such modification is the addition of $Pb(In_{1/2}Nb_{1/2}O_3$ (PIN) or $PbZrO_3$ (PZ) to the binary PMN-PT composition. The greater thermal stability of ternary PIN-PMN-PT and PZ-PMN-PT crystals is shown by comparing the dielectric permittivity, piezoelectric coefficient, and coupling coefficient to unmodified PMN-PT as a function of temperature. Additionally, the mechanical losses of PMN-PT have been decreased by doping with $Mn^{3,4+}$ ions. Using a laser Doppler velocimeter, the losses are evaluated under increasing ac electric drive. Using these data, high-power, broadband projectors were constructed from these modified crystals, and the results are compared to a projector using unmodified PMN-PT. [Funded by ONR under N00014-07-1-0336.]

10:45

4aEA11. Modeling thermal mitigation and nonlinear behavior in high-power single crystal 1-3 composite transducers. Tara L. Tubbs and Richard J. Meyer, Jr. (Appl. Res. Lab., State College, PA 16804)

The desire for high-precision sonar systems has forced 1-3 composite transducers to the forefront of sonar design. Single crystal, which has improved mechanical and dielectric properties over PZT, provides a variety of advantages, and their implementation into a 1-3 composite design makes them a great candidate for sonar transducers. Driving these transducers at high levels, we can get a broad bandwidth and high-power in a smaller device. However, high power introduces overheating and nonlinear behavior in the material properties. Using finite element software GID/ATILA from ISEN along with COMSOL MULTIPHYSICS, it is possible to incorporate these phenomena and solve thermal mitigation problems. This allows for improved high-power single crystal 1-3 composite transducers.

11:00

4aEA12. Use of compressively stressed zinc oxide to increase microspeaker response. Lukas Baumgartel (Dept. of Phys., USC MEMS Res. Group, 3737 Watt Way, PHE 621, Los Angeles, CA 90089, lbaumgar@usc.edu) and Eun Sok Kim (USC MEMS Res. Group, Los Angeles, CA 90089)

A micromachined piezoelectric speaker was fabricated on a 5×5-mm^2, 1-μm-thick silicon nitride diaphragm. A 4×4-mm^2 zinc oxide (ZnO) piezoelectric transducer sits in the middle of the diaphragm, providing

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actuation. Two variations were fabricated: one with the compressively stressed ZnO covering the region between the transducer and diaphragm perimeter—causing wrinkling—and another with the ZnO removed in this region. In both variations, the stress gradient causes curvature in the active area, raising the resonant frequency to above 4 kHz. The displacement response is therefore approximately flat from 40 Hz to 4 kHz. The speakers are driven with a sinusoidal voltage, and the response is measured with a laser interferometer. The wrinkled device exhibits 11 times larger response and can be actuated by much smaller voltage, achieving lower THD while still having a larger deflection. The wrinkled device is driven at 2 $V_{0.t.p.}$ from 40 Hz to 4 kHz, demonstrating a response of 55 nm/$V_{0.t.p.}$ and an average THD of 5.1%. The unwrinkled device is driven at 15 $V_{0.t.p.}$ over the same range, yielding a response of 5 nm/$V_{0.t.p.}$ and an average THD of 8.6%. Measured sound output and displacement spectra match each other well.

11:15

4aEA13. Analysis and design of a MEMS (microelectromechanical system) directional microphone diaphragm with active Q control. Ronald N. Miles, Quang T. Su, Weili Cui, Dorel Homentcovschi (Dept. of Mech. Eng., Binghamton Univ., Binghamton, NY 13902-6000, miles@binghamton.edu), and N. Eva Wu (Binghamton Univ., Binghamton, NY 13902-6000)

The analysis and design of a MEMS directional microphone are described that incorporates electronic feedback to achieve active Q control. The microphone diaphragm consists of a 1 × 2-mm stiffened plate fabricated out of polycrystalline silicon that is supported on a central hinge. The sound pressure gradient incident on the diaphragm produces a rocking motion about the central hinge. Interdigitated comb fingers at each end of the diaphragm enable both capacitive sensing and electrostatic actuation. The diaphragm has been designed to have its dominant resonant mode have a frequency of approximately 1 kHz. By minimizing sources of passive damping, the thermal noise of the microphone has been shown to be lower than the noise floor of existing two-microphone systems used in directional hearing aids [Miles *et al.*, J. Acoust. Soc. Am. **125** (2009)]. However, this low-passive damping also results in an undesirable resonance within the audible frequency range. To minimize the adverse effects of this resonance, a simple analog electronic feedback system is designed that can result in acceptable performance in both the frequency and time domains. [Work funded by NIH Grant R01 DC009429.]

11:30

4aEA14. Response of a MEMS (microelectromechanical systems) directional microphone diaphragm with active Q control. Quang T. Su, Ronald N. Miles, Weili Cui (Dept. of Mech. Eng., Binghamton Univ., Binghamton, NY 13902-6000, quang.su@binghamton.edu), Mihir Shetye (Solteras, City of Industry, CA 91748), and N. Eva Wu (Binghamton Univ., Binghamton, NY 13902-6000)

Measured results are presented that demonstrate the use of proportional and derivative electronic feedback to improve the performance of a directional microphone. The microphone diaphragm consists of a 1 × 2 mm stiffened plate fabricated out of polycrystalline silicon that is supported on a central hinge. The sound pressure gradient incident on the diaphragm produces a rocking motion about the central hinge. Interdigitated comb fingers at each end of the diaphragm enable both capacitive sensing and electrostatic actuation. The sound pressure gradient near the diaphragm has been measured by numerically differentiating the pressure measured by a probe microphone at locations around the diaphragm. The sound-induced motion of the diaphragm was measured using a laser vibrometer. From these measurements, estimates of the mechanical parameters of the diaphragm were obtained. By applying a known quasi-static voltage across the interdigitated fingers and measuring the resulting diaphragm deflection, an estimate for the derivative of the capacitance with respect to the displacement is obtained for the comb fingers of the diaphragm. Using these experimentally determined parameters and a linearized dynamic model of the system, the measured response of the microphone system with feedback is accurately predicted. [Work funded by NIH Grant R01 DC009429.]

THURSDAY MORNING, 22 APRIL 2010 — DOVER C, 8:40 A.M. TO 12:00 NOON

Session 4aED

Education in Acoustics and ASA Committee on Diversity: Diversity Issues in Education in Acoustics

Juan I. Arvelo, Cochair
Johns Hopkins Univ., Applied Physics Lab., 11100 Johns Hopkins Rd., Laurel, MD 20723-6099

Preston S. Wilson, Cochair
Univ. of Texas at Austin, Dept. of Mechanical Engineering, 1 University Station, Austin, TX 78712-0292

Chair's Introduction—8:40

Invited Papers

8:45

4aED1. "Future faces of physics" and other initiatives to broaden participation in science. Catherine O'Riordan and Kendra Rand (American Inst. of Physics, One Physics Ellipse, College Park, MD 20740, coriorda@aip.org)

Together, Hispanic-Americans and African-Americans make up over 25% of the US population, but they earn only 7% of physics bachelor's degrees. In order to help broaden the participation of underrepresented groups in STEM fields, the American Institute of Physics has several programs to work with students as well as to reach the general public. To engage physics undergraduates on the challenging subject of diversity, the Society of Physics Students (SPS), a society of over 4000 undergraduate physics students that is part