Session 3aPLa

Plenary Lecture

Patricia K. Kuhl, Chair
University of Washington, Eagleson Hall 204, Box 354875, Seattle, Washington 98195

Chair's Introduction—8:00

8:05

3aPLa1. How listeners find the right words. Anne Cutler (MPI for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, The Netherlands)

Languages contain tens of thousands of words, but these are constructed from a tiny handful of phonetic elements. Consequently, words resemble one another, or can be embedded within one another, acoustics not withstanding. The past few years of psycholinguistic research have seen repeated confirmation that the process of spoken-word recognition by human listeners involves activation of multiple word candidates consistent with the input, and that these candidate words actively compete with one another. Current models of the word-recognition process are computationally explicit and can accurately reproduce the experimental results, as will be demonstrated by simulations with the SHORTLIST model, operating on a realistic vocabulary of 26 000 words. Activation and competition, however, do not exhaust the range of procedures which human listeners can call upon to find words in speech. My colleagues and I have recently established that listeners are sensitive, at an early, prelexical stage of speech processing, to constraints on what could potentially be a word of the language. Furthermore, cross-linguistic comparisons—of English, French, Japanese, and Sesotho—suggest that these constraints are not tailored to the characteristics of a particular vocabulary, but are universal.

Session 3aAAa

Architectural Acoustics and Noise: Structure-Borne Sound in Buildings: Measuring and Modeling Noise Flanking Transmission

Trevor R. T. Nightingale, Chair
National Research Council, Institute for Research in Construction, Building M-27, Montreal Road, Ottawa, ON K1A 0R6, Canada

Chair's Introduction—9:15

Invited Papers

9:20

3aAAa1. Sound transmission through permeable double-leaf membranes. Kimihiro Sakagami (Environ. Acoust. Lab., Faculty of Eng., Kobe Univ., Rokko, Nada, Kobe, 657 Japan), Masakazu Kiyama (Kobe Univ., Kobe, 657 Japan), Toru Uyama, and Masayuki Morimoto (Kobe Univ., Kobe, 657 Japan)

Double-leaf membranes with a permeable interior leaf are one of the typical constructions in membrane-structure buildings. A theory to predict the sound-pressure reflected by, and transmitted through, this type of double-leaf membrane was established by taking into account the coupled motion of the membranes and surrounding sound field [K. Sakagami, M. Kiyama, and M. Morimoto, J. Acoust. Soc. Am. **100**, 2735(A) (1996)]. In this same paper, the theory was experimentally validated. That work focused on absorption characteristics since the lack of absorption is one of the main acoustical problems in this type of building. The present paper investigates the sound transmission through a structure of this type in order to gain insight into its sound insulation performance which, in many cases, needs to be improved. The effects of the parameters of the double-leaf membrane on its transmissibility are demonstrated and discussed through numerical examples: The characteristics drastically change with the permeability of the interior leaf. The effect of the interior permeable leaf's mass is slight, whereas that of the exterior impermeable leaf is significant, particularly at mid-high frequencies. The effect of an absorbent layer in the cavity is also examined.

9:40

3aAAa2. Prediction of noise transmission through commercial profiled metal cladding systems. Y. W. Lam (Dept. of Acoust. Audio Eng., Univ. of Salford, Salford M5 4WT, UK)

Lightweight profiled metal cladding systems generally have poor acoustic insulation characteristics, and traditional theories for evaluating noise transmission through building elements are usually not applicable to double-skin profiled systems because of their orthotropic nature. Based on extensive experimental observations, a new method for predicting the sound reduction index (SRI) of commercial double-skin cladding systems is proposed. The method combines existing theory for orthotropic flat plates with finite element analysis to account for the pronounced ''dips'' in the SRI at midfrequencies, which are caused by the resonances of the profile geometry. The predicted SRI was shown to compare well with measurements on 15 cladding systems used in the experimental work. The method was further extended to cover commercial double-skin cladding constructions. Analytical equations were formulated to account for the orthotropic nature of the cladding sheets, the sound bridging through fixing supports, and the sound reduction through the in-fill insulation. Comparisons of predictions against sound reduction measurements were made on a wide range of commercial cladding products. Good agreement between predictions and measurements was found.

10:00

3aAAa3. European prediction models for building acoustics. Eddy Gerretsen (TNO Inst. of Appl. Phys., P.O. Box 155, NL-2600 AD Delft, The Netherlands, gerretsen@tpd.tno.nl)

About 8 years ago work started in the European standardization organization (CEN) to create prediction models for several acoustic aspects in building: airborne sound transmission, impact sound transmission, facade sound transmission, facade sound radiation, and the noise caused by technical equipment. The main aim is to provide the link between the acoustic performance of products and elements, as measured by standardized laboratory measurement methods, and the performance in the realized buildings. So far the prediction models for the first four aspects are (almost) finished. The work on the part concerning equipment noise has yet to start, handicapped as it is by a lack of available knowledge in this area. The chosen approach for the models on airborne and impact sound transmission applies separate independent transmission paths between rooms, which can be shown to be a first-order estimation of a SEA approach. For these models a new quantity has been introduced to characterize the structure-borne sound transmission at junctions of building elements. Further work is focusing on the description of measurement methods to determine this quantity and on verification of the models in order to indicate more precisely their reliability in predicting the acoustic performance of buildings.

10:20

3aAAa4. Structure-borne transmission in lightweight buildings. Robert J. M. Craik (Dept. of Bldg. Eng. and Surveying, Heriot-Watt Univ., Riccarton, Edinburgh EH14 4AS, UK)

The move away from mass as a means of reducing sound transmission in buildings has led to the development of lightweight buildings. High levels of sound insulation are achieved by introducing discontinuities while retaining structural integrity. This paper will examine structure-borne sound transmission in lightweight framed buildings. For sound transmission through a wall or floor it is the coupling between the frame and the lightweight panels which must be considered. The coupling can be classified as either a line connection or a point connection. Each of these cases will be examined and the theories for sound transmission compared with experimental results. Flanking transmission must also be considered and models for the coupling between the structural elements will also be examined. These models are different from traditional buildings as many of the elements behave as beams rather than as plates. The structure is therefore a collection of beams and plates rather than just plates. Some of the transmission paths for transmission between adjacent rooms will be examined both for the case where all walls and floors are lightweight constructions and for the case where there is a mixed construction with traditional walls but lightweight floors.

10:40

3aAAa5. Flanking paths between walls and lightweight wood frame floors using statistical energy analysis. T. R. T. Nightingale (Inst. for Res. in Construction, Natl. Res. Council Canada, Ottawa, ON K1A 0R6, Canada), and J. A. Steel (Heriot Watt Univ., Riccarton, Edingurgh EH14 4AS, Scotland)

Previous work has examined flanking paths from a floor/ceiling assembly to a load-bearing wall (where the floor joists were oriented normal to the supporting wall). It was shown that beams at the joint (plates and joist header) must be considered when predicting transmission at this type of joint. The dominant flanking path was from the floor deck to the supporting wall which reduced the apparent sound insulation from FSTC 59 to 53. The path from the upper to the lower wall was insignificant. This paper presents the results of a similar study that examined flanking paths from a nominally identical floor/ceiling assembly to a non-load-bearing wall (where the joists were parallel to the joint axis). Measured velocity level differences and apparent sound insulation are compared to the load-bearing wall configuration. Flanking paths involving a non-load-bearing wall are shown to have no appreciable impact. Joint models are presented using both standard wave methods and dynamic stiffness methods. The joint models are incorporated into a statistical energy analysis model of the system. Measured and predicted results for the two joint configurations are compared and show good agreement between 100–3150 Hz.

11:00

3aAAa6. The use of semianalytical calculation models to verify SEA predictions of flanking transmission in building structures. Ivan Bosmans and Gerrit Vermeir (Lab. of Bldg. Phys., Katholieke Univ. Leuven, Celestijnenlaan 131, B-3001 Heverlee, Belgium, ivan.bosmans@bwk.kuleuven.ac.be)

The prediction of structure-borne sound transmission between coupled plates represents a key aspect when studying sound transmission in buildings, since vibrational energy flow between walls and floors leads to the existence of flanking paths. The resulting flanking transmission can be assessed theoretically using statistical energy analysis (SEA). In this method, the coupling between plates is usually estimated based on the wave approach for the corresponding semi-infinite plates. For a specific type of junction, one might consider verifying the predictive performance of SEA experimentally on an isolated plate junction. However, possible discrepancies between measured and predicted data can result either from the failure of the calculation model for the semi-infinite plates, or by the violation of the basic SEA assumptions. In this paper, a semianalytical calculation model based on a modal summation approach for finite-sized plates is proposed to determine the source of the prediction error. For this purpose, calculations are performed for two ensembles of similar corner junctions with randomly distributed dimensions. The analysis emphasizes the influence of the model overlap factor on the accuracy of SEA. [Research funded by the Flemish Institute for the promotion of Scientific Technological Research in Industry (IWT).]

WEDNESDAY MORNING, 24 JUNE 1998 CASCADE BALLROOM II (W), 11:25 TO 12:55 P.M.

Session 3aAAb

Architectural Acoustics and Noise: Impact of Trains on Performance Halls

George P. Wilson, Chair
Wilson Ihrig and Associates, Inc., 5776 Broadway, Oakland, California 94618

Invited Papers

11:25

3aAAb1. Owner/builder perspective of the impact of trains on performance halls for Benaroya Hall, Seattle. Andrew Clapham, Project Manager (Seattle Symphony, 305 Harrison St., Seattle, WA 98109-4645)

The Seattle Symphony began planning for a new concert hall in early 1987 at a location near their existing venue, the Seattle Opera House. During funding negotiations with The City of Seattle in 1992, the City made it clear that they wished to have the new facility located in their downtown core area. They offered a site that had many added challenges. These included being in the flight path of Sea-Tac International Airport; being alongside the Metro transit tunnel which is to accommodate light rail; being located in the heart of a very active city; and finally being located directly above the twin track railroad tunnel that runs north to south through the city center. In order to achieve the desired acoustical quality for the 2 500-seat main auditorium and 540-seat recital hall, not only for performances, but also for digital recording, a number of innovative design and construction techniques were required. These ranged from a massive foundation slab above the tunnel, to construction of a vibration isolated building within a building, which is supported on natural rubber isolation bearings. The challenges of designing and constructing this unique building will be presented.

11:45

3aAAb2. Vibration isolation design for Benaroya Hall. George P. Wilson (Wilson, Ihrig & Assoc., Inc., 5776 Broadway, Oakland, CA 94618)

Location of the new Seattle Concert Hall, Benaroya Hall, directly over an existing Burlington Northern railroad tunnel required development of a very effective vibration and noise isolation system. The first step in the design was to measure the ground-borne vibration and noise levels from trains via boreholes at the site and in the basement levels of nearby buildings located over the tunnel. From the measured vibration, the expected sound level in the performance space was projected for comparison with the criterion established for acceptable level and inaudibility. This comparison determined the amount and frequency range for the reduction required. The degree of reduction of structure-borne noise required determined that the design required two parts, a massive foundation mat for coupling loss and an isolation system with 4-5 Hz effective natural frequency and full reduction over a wide frequency range. Achieving the needed attenuation required a structure with very high mechanical impedance and isolators which provide a low acoustical impedance over a broad frequency range, leading to the use of heavy concrete structure and natural rubber isolation bearings. Details of the design parameters and materials are presented along with results from measurements with the completed isolation system and partially completed hall.

12:05

3aAAb3. Structural design for vibration isolation at Benaroya Hall. Brian H. Glover (Skilling Ward Magnusson Barkshire, 1301 Fifth Ave., Ste. 3200, Seattle, WA 98101-2699)

Vibration and noise isolation criteria, together with an urban site for the Seattle Symphony Hall, created unusual constraints for its structural design. A massive concrete mat foundation bridges and isolates the railroad tunnel running diagonally under the site. Two garage levels and an isolation level further separate the Auditorium from the tunnel, while 30 ft of unexcavated soil remain between the Auditorium and an adjacent underground transit station. Heavy concrete construction is used extensively to add mass for isolation. Concrete topping was added to the Auditorium roof for isolation, and double concrete walls surround the Auditorium. Exterior precast concrete cladding adds further mass and isolation. To speed construction time, the Auditorium balconies, including the inner walls which were cast to odd geometric shapes, are precast concrete. The Auditorium structure is isolated from the surrounding structure by an uninterrupted, 7-in.-wide joint, creating a ''box within a box'' The only structural connections to the Auditorium inner box are two types of special, natural rubber isolation bearings at its base. One bearing type takes gravity loads. The other type, initially prestressed, takes lateral loads. The need for bearing access under the base of the Auditorium created unusually shaped transfer girders.

Contributed Papers

12:25

3aAAb4. Controlling subway noise in the LG Arts Center—Sangnam Hall. D. Stanton Korista and Ahmad Abdelrazaq (Skidmore, Owings & Merrill LLP, 224 South Michigan Ave., Ste. 1000, Chicago, IL 60604)

The LG Arts Center in Seoul, Korea is a multifunction facility including a Hall intended for a variety of performances including western drama and dance, chamber music, traditional Korean folklore plays, opera, oration, and digital recordings. The 1050 seat Hall is designed to guard against both airborne and groundborne noise. Airborne noise is controlled by enclosing the stage house and the audience chamber with 200-mm airspace double walls. Horizontal and vertical acoustical joints at the Hall structure interface with the main building and control groundborne noise generated by the subway trains in a tunnel adjacent to the site. The subway tunnel and the foundation structure of the building are in the same rock strata and the groundborne noise is transmitted as structure-borne noise to the Hall through the lower-level parking structures. Without isolation the noise from the subway would have intrusive effects on the multifunctional use of the performance hall and stage area. Vibration isolation rubber bearings are provided in the interface design to reduce the noise to acceptable levels in the noise critical space. The impact of the proposed isolation bearing pads on the building design and their acoustical benefits are discussed.

12:40

3aAAb5. Train and rail transit noise in cinemas and theaters: Case studies. M. Asselineau (Peutz & Assoc., 103 Bd Magenta, F75010 Paris, France)

Train and subway noise unfortunately often turns out to be part of the show in theaters and cinemas of large cities, as the history of rail lines construction, or simply the urban planning, brought them close together. This paper aims to submit and discuss a few case studies, involving both rehabilitation and new construction projects, that feature cinema and performance facilities located near underground and suburban lines, main lines, or even high-speed lines. Those case studies, which range from real success to total failure, outline the architectural and technical context of the situation and discuss the sound and vibration levels measurements, as well as the technical solutions that were applied to the construction. It turns out that in rehabilitation projects, while the client may be willing to improve the acoustics, structural limitations can often be encountered, while in new projects there often is a need to convince the client of the importance of vibration control.

WEDNESDAY MORNING, 24 JUNE 1998 VASHON ROOM (W), 9:15 A.M. TO 12:40 P.M.

Session 3aAB

Animal Bioacoustics: General Animal Bioacoustics

G. Pavan, Chair

Centro Interdisiplinaire di Bioacustica, e Ricerche Ambientali, Universita degli Studi di Pavia, Via Taramelli 24, 27100 Pavia, Italy

Invited Paper

9:15

3aAB1. Three-dimensional computer modeling of biosonar emission in the common dolphin. James L. Aroyan (Elo TouchSystems, Inc., 41752 Christy St., Fremont, CA)

Several delphinid species are known to possess a highly sophisticated and adaptable biosonar system, yet the exact acoustic mechanisms involved in signal generation, emission, and reception remain poorly understood. Recently, a novel computational approach was utilized in an investigation of the acoustical mechanisms of dolphin biosonar. Three-dimensional acoustic simulation techniques and a new method for mapping acoustic tissue properties from x-ray computed tomographic data were applied to models of the forehead and lower jaw tissues of the common dolphin, *Delphinus delphis.* This approach proved highly effective in studying the detailed processes of biosonar emission and reception in this animal. The results of the investigation which concern the emission

system of this dolphin will be presented. These results include: (1) the common dolphin's skull plays the predominant role in beam formation; (2) the melon contributes significantly to narrowing of the emitted beams; (3) the melon behaves as a waveguide and a lens in the biosonar signal emission process; (4) the results of both inverse simulation and forward extrapolation programs suggest that the biosonar signal source tissues lie within a small volume of the soft tissues of the right nasal passageway.

Contributed Papers

9:45

3aAB2. Acoustic pathways of hearing in the bottlenose dolphin, *Tursiops truncatus*. Whitlow W. L. Au (Hawaii Inst. of Marine Biol., P.O. Box 1106, Kailua, HI 96734), Bertel Mohl (Univ. of Aarhus, Aarhus, Denmark), Paul E. Nachtigall (Hawaii Inst. of Marine Biol., Kailua, HI 96734), Jeffrey L. Pawloski, and James L. Aroyan (Elo TouchSystems, Inc., Fremont, CA)

The acoustic pathways for the reception of sound in the Atlantic bottlenose dolphin were studied by measuring auditory brain-stem-evoked potential responses as a specially designed suction cup hydrophone was placed at different areas of the animal's head. The dolphin was trained to come out of the water and beach on a rubber mat. Evoked responses were recorded differentially with suction cup surface electrodes placed between the parietal (noninverting) just posterior to the blowhole and mastoid (inverting). A transient signal was used as the stimulus and the amplitude of the stimulus was lowered in fixed dB steps until the evoked response reached a specific level close to the threshold level. The results indicate that the most sensitive portion of the lower jaw is slightly forward of the pan-bone and about 3/4 of the way toward the front of the lower jaw and along certain spots on the bottom midline of the lower jaw. The relative sensitivity of different areas of the lower jaw was also determined. The measurement results will be compared with results from calculations based on numerically solving the three-dimensional wave equation for wave propagation into the lower jaw of the dolphin. [Work supported in part by ONR, Grant No. N0001496WX30364.]

10:05

3aAB3. Effect of low-frequency seismic exploration signals on the cetaceans of the Gulf of Mexico. Shannon Rankin and William E. Evans (Marine Acoust. Lab, Texas A&M Univ., 5007 Ave. U, Galveston, TX 77550)

The increasing use of seismic exploration has created a need to understand effects that intense low-frequency sounds have on the distribution, abundance, and behavior of cetaceans. The goal of this study is to determine possible effects of seismic exploration on cetaceans in the northern Gulf of Mexico. Low-frequency sounds originating from seismic exploration were compared with the presence/absence of cetaceans as determined by acoustic and visual methods of detection. The recordings were collected via a towed passive hydrophone array during seasonal GulfCet research cruises from 1992–1997. The study area consisted of 14 north–south transects ranging from the 100–2000 m isobath in the northern Gulf of Mexico. For odontocetes, with the exception of sperm whales, no relationship between presence of low- and medium-frequency seismic noise was found on a relatively large spatial scale of hundreds of kilometers. For mysticetes, results were inconclusive due to small sample size. These findings suggest that the repetitive signals generated by seismic exploration may not have a negative impact on the large-scale distribution or overall abundance of delphinids in the Gulf of Mexico. However, additional studies have indicated possible negative impacts on aspects of communication and orientation of behavior in sperm whales (*Physeter macrocephalus*).

10:25

3aAB4. An onboard acoustic data logger to record biosonar of free-ranging bottlenose dolphins. Douglas P. Nowacek, Peter L. Tyack (Dept. of Biol., Woods Hole Oceanogr. Inst., Woods Hole, MA 02543), Randall S. Wells (Chicago Zoological Society, c/o Mote Marine Lab., Sarasota, FL 34236), and Mark P. Johnson (Woods Hole Oceanogr. Inst., Woods Hole, MA 02543)

An acoustic data logger has been developed which utilizes a two-channel DAT recorder housed in aluminum and attached to the dorsal fin. The recorder has a flat frequency response from 10 Hz to 14 kHz, and each tape can store 120 min. The first suction-cup hydrophone (sensitivity −205 dB) was placed 10 cm posterior of the blowhole, and the second 20 cm below the lateral base of the dorsal fin. The anterior ''high-frequency'' hydrophone, designed to record echolocation signals, has unity gain and a one-pole 10-kHz high-pass filter. The ''ambient'' hydrophone located at the base of the dorsal fin has +18-dB gain and a one-pole 1-kHz high-pass filter. To obtain echolocation recordings the ''high-frequency'' hydrophone was filtered through a simple demodulator in one of the deployments. The package includes VHF radio transmitters for tracking the animal and recovering the package after it releases via corrosible magnesium links. The package was attached to temporarily restrained animals which, after release, were followed to record behavioral data while the recorder logged acoustic activity. During the two successful deployments to date the logger recorded animal vocalizations, surfacing events, the sounds of passing boats, and hydrodynamic sounds produced by the animal's fluke strokes. [Work supported by ONR, OVF, SeaGrant-WHOI.]

10:45–11:00 Break

11:00

3aAB5. Results of underwater ambient noise measurements in three large tank exhibits at the Monterey Bay Aquarium. Daniel M. O'Neal and Steven R. Baker (Phys. Dept., Naval Postgrad. School, Monterey, CA 93943-5000)

Measurements have been made of the underwater ambient noise in three large tank exhibits at the Monterey Bay Aquarium: the Kelp Forest Exhibit (335 000 gal), the Monterey Bay Habitats Exhibit (350 000 gal), and the Outer Bay Waters Exhibit (1.4 million gal). A single, calibrated, Navy-type DT-276 was used. The hydrophone output voltage was preamplified and recorded using a 16-bit digital audio tape recorder with a sampling rate of 48 kHz. Measurements were made with various mechanical equipment (motors, fans, pumps, sprinklers, wave machine) turned on and off. On one occasion, the noise was measured in the largest tank, the Outer Bay Waters Exhibit, during a power shutdown. For comparison, measurements were also made at several locations and depths in the inner Monterey Bay. The results of one-third octave band and narrow-band analyses will be presented. Comparisons will be made between the aquarium and bay results and standard deep water ambient noise spectral density curves.

11:20

3aAB6. Identification of dolphin schools by bioacoustical unique features. Konstantin Kebkal (State Oceanarium of Ukraine, 9, Epronovskaya, 335024 Sevastopol, Ukraine, kostia@hotmail.com; kostya@fb10.tu-berlin.d400.de), Rudolf Bannasch (Technische Universitat Berlin, FG Bionik & Evolutionstechnik, Ackerstr. 71-76, D-13355 Berlin, Germany), and Valeriy Kulagin (State Oceanarium of Ukraine, 9, Epronovskaya, 335024 Sevastopol, Ukraine)

Long-term acoustical observations conducted on bottle-nosed dolphins (Tursiups truncatus ponticus) in the State Oceanarium of Ukraine as well as in the open sea revealed the existence of school specific acoustic features. It was found that each dolphin school uses a unique set of whistle contours in conjunction with a preferable frequency band and certain time characteristics. If the latter two characteristics somewhat vary according to particular surrounding and behavioral situations, the composition of normalized whistle contours stays stable. Each single whistle can be described by a set of polynomial coefficients characterizing its shape. Referring to the whole set of whistles emitted, a diagram of signal preferences can be built. Several samples will be presented to demonstrate that such diagrams represent acoustical portraits unique for every dolphin school. Based on those analyses, the development of a system for passive auto-

matic monitoring of dolphin abundance and migration activity is in progress. The system should consist of radio-acoustical buoys placed in the sea to record signals and to transmit them to a coastal station and an automatic signal analyzer in conjunction with an expert-system capable of determining whether the respective signals belong to a school registered earlier, or a new one.

11:40

3aAB7. Matched-field processing of baleen whale vocalizations using calibrated environmental models. Aaron M. Thode, Gerald L. D'Spain, and William A. Kuperman (Marine Physical Lab., Scripps Inst. of Oceanogr., Univ. of California at San Diego, La Jolla, CA 92093-0205)

During the 1997 Marine Mammal Vocalization (MMV) experiment conducted by the Scripps Marine Physical Laboratory last September, J15 source tows were conducted in a highly range-dependent environment northwest of San Nicolas Island in the Southern California Bight region. The tows consisted of eight radial tracks ranging from 1 to 6 nautical miles from the research platform FLIP, along all cardinal directions. Among the signals broadcast were low-frequency combs (18–110 Hz), middle-frequency combs (50–200 Hz), FM downsweeps (900 to 50 Hz over 9 s), and an Eastern Pacific type A blue whale recorded during the 1996 MMV experiment. Multiple CTD casts were also taken, and a bathymetric database was obtained from the National Oceanographic Service. All these data are used to calibrate matched-field processing environmental models, which are subsequently applied to find the location in 3D space of a series of blue whale vocalizations. [Work sponsored by ONR.]

12:00

3aAB8. Feasibility of monitoring bowhead whales with a vertical line array. Kevin D. Heaney and Peter N. Mikhalevsky (Sci. Applications Intl. Corp., 10260 Campus Pt. Dr., San Diego, CA 92121)

As part of the ACOUS trans-Arctic acoustic propagation experiment, a vertical line array will be deployed off Pt. Barrow, Alaska in the summer of 1998. The array will be cabled to shore and will be capable of real-time recording of acoustic frequencies from 20 to 500 Hz. This array will provide scientists the opportunity to record bowhead whale songs in real time from hydrophones spanning the water column. Currently, the bowhead whale census is taken during the spring migration from the edge of ice leads. The feasibility of doing a Fall census, when the sea is relatively free of ice, will be presented. Recordings of bowhead whale songs, and simulations of localization using the vertical array will be presented. Using varying bathymetry and sono-buoys, to add to the horizontal resolution of the array, 3D localization of vocalizing whales should be possible.

12:20

3aAB9. Observations of the movements of humpback whales about an operating seismic survey vessel near Exmouth, Western Australia. Robert D. McCauley (Ctr. for Marine Sci. Technol., Curtin Univ. Technol., P.O. Box U 1987, Perth 6854, Western Australia), Micheline-Nicole Jenner, Curt Jenner (Ctr. for Whale Res., Broome 6725, Western Australia), and Douglas H. Cato (Defence Sci. Technol. Organisation, Prymont, NSW 2009, Australia)

As part of a project investigating the interaction of air-gun noise and marine animals, monitoring of migrating humpback whales traversing the track of a seismic vessel was conducted in October 1996. Four separate pods traveling SW in 100–120 m of water were followed as they approached a seismic vessel traveling on an east/west heading and operating a 2678 cui air-gun array every 8 s. The response of pods was to change course at 3–6 km from the vessel so as to pass in front of or behind it. In one instance a single animal was observed moving slowly at 4.2 km NNW of the vessel, then to suddenly accelerate to 10–12 kn on a SW course across the vessel's bow at a closest range of 1.5 km. It then swam S at 5–10 kn until it was 4 km from the vessel. During the period of rapid swimming the animal stayed close to the surface with the tail flukes often breaking the water, maintaining a 40-s blow interval. The animal then swam steadily SW, eventually stopping and commencing singing on encountering a pod of two animals at 15 km from the still operating seismic vessel. [Work supported by the Energy Research and Development Corporation, Australian Petroleum Production and Exploration Association, and WMC Petroleum.]

WEDNESDAY MORNING, 24 JUNE 1998 GRAND BALLROOM A (S), 8:30 TO 10:30 A.M.

Session 3aAO

Acoustical Oceanography and Underwater Acoustics: Acoustic Determination of Ocean Parameters

Jeffrey A. Nystuen, Chair
Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98105

Contributed Papers

8:30

3aAO1. Applications of two frequency insonification techniques to oceanic bubble sizing. Andy D. Phelps, Matt D. Simpson, and Timothy G. Leighton (Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton SO17 1BJ, UK, ap@isvr.soton.ac.uk)

This work presents the results from using a combination frequency acoustic technique to measure the near-surface bubble population in both the open sea and surf zone. The benefits of using a combination frequency technique are that the collected data are more accurate and less prone to ambiguities than linear backscatter measurements. The technique monitors the appearance of sum-and-difference signals generated by the nonlinear interaction of two sound fields: one high-frequency signal scattering geometrically from the bubble surface and the other used to excite the bubble into resonant pulsation. The work details the calibration of the apparatus necessary to relate the measured heights of the sum-and-difference terms to actual numbers of bubbles, and describes the experimental procedure for the collection of the oceanic data. The collected data are verified using simultaneous measurements of the dispersive sound speed and attenuation, which can be compared with estimates calculated from the measured bubble population. The results from a number of trials are presented, with both time-averaged and time-variant measures of the local population demonstrated. [Work supported by the Natural Environment Research Council.]

8:45

3aAO2. Possibilities for small-scale emission tomography of bubble plumes in shallow water. Ivan P. Smirnov, Alexander I. Khil'ko (Inst. of Appl. Phys., Nizhny Novgorod, 46, Ulianov, Str., 603600, Russia), Paul A. Elmore, and Jerald W. Caruthers (Naval Res. Lab., Stennis Space Center, MS 39529)

Bubble plumes, created at the sea surface by breaking waves, emit sound in a broad range of frequencies. Based on the spatial and temporal characteristics of the emitted sound, emission tomographic reconstruction of the noise source distribution and evolution may be possible. It is shown that the space/time variables needed for the reconstruction process can be estimated from the coherence function of the radiated noise. The effectiveness of the reconstruction procedure when noise is present is estimated theoretically by the following physical model: (1) the location and time of bubble creation is assumed to be random and statistically independent, (2) the spatial distribution of the noise in the cloud, the spatial structure of the cloud, and the coherence function of the noise are described by a Gaussian distribution, (3) the sizes of the sources are much smaller than the size of the acoustic fields, and (4) the observation distance is much greater than the size of the sources. The requirements for the reconstruction process and the possible limitations of the method are discussed.

9:00

3aAO3. Monitoring air–sea exchange using ambient sound. Jeffrey A. Nystuen (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, nystuen@apl.washington.edu)

Wave breaking and precipitation are important processes contributing to the exchange of momentum, heat, water, and gas at the air–sea interface. These processes are also principal generators of high-frequency (over 1 kHz) underwater ambient sound. Furthermore, the bubbles generated by the breaking waves and raindrop splashes can be stirred downward into the ocean mixed layer forming an effective sound absorption layer. When present this layer modifies the ambient sound field, and can thus be detected using passive acoustics. Using the passive sound field as the exploratory tool, more conventional measurements of salinity, temperature, bubbles, wind, and surface waves will be examined. Anomalies in near-surface salinity are explained by acoustically derived rainfall and wind-speed measurements. Acoustically derived rainfall measurements suggest that rain affects the surface wave field. Enhanced injection of bubbles into the mixed layer by rain in the presence of high wind is indicated by changes to the shape of the underwater sound spectrum. [Work supported by ONR Ocean Acoustics and NSF.]

9:15

3aAO4. Wave scattering and propagation in bubbly liquids. Zhen Ye (Dept. of Phys., Natl. Central Univ., Chung-li, Taiwan, ROC) and Alberto Alvarez (Natl. Central Univ., Chung-li, Taiwan, ROC)

Acoustic wave propagation through bubbly liquids can be modified significantly by its scattering by the bubbles. The effects may be conveniently studied either by diagram methods when the number of bubbles is large, or by numerical simulation when the number is not so large. In this paper, numerical simulation on the acoustic scattering and propagation in a bubbly mixture is reported, with comparison to the effective medium theories. The analysis shows possible Anderson localization of acoustics waves. It is found that collective modes in bubble clouds are possible when the bubble volume fraction reaches a certain value. [Work supported by NSC of ROC and Spanish Ministry of Education.]

9:30

3aAO5. Rough surfaces characterization using a time-reversal mirror. Philippe Roux, Mathias Fink (Lab. Ondes et Acoustique, ESPCI, 10 rue Vauquelin, 75005 Paris, France), and James H. Rose (Iowa State Univ., Ames, IA 50011)

A new method is described for determining the rms height and autocorrelation function of rough surfaces using measurements made with an acoustic time-reversal mirror (TRM). First, the TRM insonifies the surface and the backscattered wave is recorded and time-reversed. Second, the TRM is displaced parallel to the surface and, at each displacement the previously recorded time-reversal wave is rebroadcast. For zero displacement the time-reversed wave is matched to the surface and the original incident pulse is recovered (upon reflection of the rebroadcast wave). However, with increasing displacement the signal ceases to resemble the incident pulse. The decorrelation of the signal allows one to characterize the surface. Measurements are reported for a number of periodic and random rough surfaces.

9:45

3aAO6. The Aharonov–Bohm effect revisited by an acoustic time-reversal mirror. Philippe Roux, Julien De Rosny, and Mathias Fink (Lab. Ondes et Acoustique, ESPCI, 10 rue Vauquelin, 75005 Paris, France)

The violation of time-reversal invariance for acoustic waves to achieve a new way of characterizing a vorticity field with a double acoustic time-reversal mirror (TRM) is taken advantage of. In particular, it is shown experimentally that the double TRM works as a vorticity amplifier. In the case of a vorticity filament, the sound-vorticity interaction is interpreted as the acoustical analog of the Aharonov–Bohm effect. Numerical experiments simulate the acoustical Aharonov–Bohm effect by propagating a plane wave which is scattered by a heterogeneous motionless medium.

10:00

3aAO7. Real-time characterization of unstationary flows using a time-reversal mirror. Agnes Maurel, Julien De Rosny, Sebastien Manneville, Philippe Roux, and Mathias Fink (Lab. Ondes et Acoustique, ESPCI, 10 rue Vauquelin, 75005 Paris, France)

Violation of time-reversal invariance for acoustic waves is a new method for characterizing a vorticity field with a double acoustic time-reversal mirror (TRM). Experiments show that the double TRM works as a vorticity amplifier and, even in the case of small vorticity field, provides the characteristics of the flow. Moreover, the TRM works in real-time and allows one to measure the vorticity field at a 20-Hz frequency rate. The case of a Von Karman vortex street is studied experimentally.

10:15

3aAO8. Results from cross-correlation measurement of estuarine current velocity. Roger W. Bland and Daniel G. Neuman (Dept. of Phys. and Astron., San Francisco State Univ., San Francisco, CA 94132)

A technique for accurate measurement of the average water velocity in estuarine environments has been developed. The technique is based on measuring the travel time of 200-kHz ultrasonic signals. A high degree of precision has been obtained using a cross-correlation technique, and long, detailed time series have been recorded. However, in some geometries the precision is degraded by multipath interference. Measurements of current speed in California's Sacramento-San Joaquin River Delta system will be discussed, with particular reference to the effects of multipath interference. Data were collected throughout a large flood in Dec. 1996–Jan. 1997. An analysis of the variation of the strength of the ultrasonic signal has been carried out to determine the attenuation of the signal due to the load of suspended sediment, and the results will be presented. The current-velocity time series recorded in the San Francisco Bay also show wave trains from boat wakes. These wakes will be discussed.

Session 3aBV

Bioresponse to Vibration/Biomedical Ulttrasound: Ultrasound Assisted Drug Delivery I

Pierre D. Mourad, Chair
Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98105

Chair's Introduction—8:00

Invited Papers

8:05

3aBV1. Mechanisms for biological effects of ultrasound. Edwin L. Carstensen (Dept. of Elec. Eng. and Rochester Ctr. for Biomed. Ultrasound, Univ. of Rochester, Rochester, NY 14627)

At least three physical processes have the potential to produce therapeutic benefits through ultrasound exposure. These include heating, cavitation, and a related group of second-order mechanical effects that involve radiation forces and streaming on a macroscopic or microscopic scale. In most applications of ultrasound in physical therapy, deep heating is the postulated rationale for its use. Hyperthermia as an adjunct to cancer therapy requires sophisticated control of ultrasonic heating. At higher levels, ultrasound can be used to destroy precisely selected tissues obviating the need for surgical intervention. In this application, nonlinear propagation can be used to selectively increase the absorption parameters of the target tissues. At low amplitudes the response of bubbles is dominated by the acoustic pressure. At a critical acoustic pressure, however, the inertia of the surrounding medium becomes controlling. At this threshold acoustic pressure a 10% or 20% increase in acoustic pressure leads to an increase in the collapse pressure in the bubble by orders of magnitude. Radiation forces can be detected by auditory and tactile sensors. Macroscopic acoustic streaming may alter transport across biological membranes and microscopic streaming exerts stresses on the membranes and the cytoplasmic and nuclear contents of cells.

8:30

3aBV2. Toxin and gene transfer into cells by extracorporeal shock waves. M. Delius (Inst. for Surgical Res., Univ. of Munich, Klinikum Grosshadern, 81366 Munich, Germany) and U. Lauer (Univ. of Tübingen, 72076 Tübingen, Germany)

Shock wave application to cells *in vitro* causes a transient increase of the permeability of the cell membrane which does not lead to cell death. It was hypothesized that shock waves might be a new method of transferring therapeutic agents directly into cells. To test this, biological effects resulting from the acoustical transfer of proteins and nucleic acids into cells were examined. Protein transfer was examined with the ribosome inactivating proteins gelonin and saporin which inhibit the cellular protein synthesis. Dose response curves were established with three tumor cell lines in the presence and absence of shock waves. Compared to the controls, shock waves enhanced the action of gelonin and saporin from 300 to 40 000 fold. *In vivo* experiments with an animal tumor model established that acoustic transfer of these agents into cells also occurred *in vivo*. Gene transfer by shock waves was examined in a number of cell lines by plasmid vectors carrying standard reporter genes. Transfer succeeded in many cases yet the transduction efficiency was lower than with other established methods of gene transfer. In summary shock wave permeabilization is a new method for tumour therapy and gene transfer.

8:55

3aBV3. Ultrasound-induced transcutaneous transport for drug delivery and diagnostics. Joseph Kost (Dept. of Chemical Eng., Ben-Gurion Univ., Beer-Sheva, 84105, Israel, kost@mit.edu), Samir Mitragotri, and Robert Langer (MIT, Cambridge, MA 02139)

In spite of major research and development efforts in transdermal systems and the many advantages of the transdermal route, impermeability of the human skin is still a major problem that limits the usefulness of the transdermal drug delivery approach. Application of ultrasound induces temporary structural changes in the skin resulting in enhanced transdermal transport of molecules (sonophoresis). Experimental findings suggest that among all the ultrasound-related phenomena evaluated, cavitation plays the dominant role in sonophoresis, suggesting that application of low-frequency ultrasound should enhance transdermal transport more effectively. It was found that at the low ultrasound frequencies high molecular weight molecules including insulin, interferon, and erythropoietin can be transported through the skin. Recently it was shown that the enhanced skin permeability during sonophoresis also facilitates outward diffusion of glucose present in the interstitial fluids beneath the skin. The *in vitro* as well as *in vivo* experiments show that the amounts of glucose extracted by sonophoresis are proportional to the blood glucose concentrations. Furthermore, the amount of glucose extracted by ultrasound can be measured and used to predict temporal changes in the blood glucose levels. These results demonstrate the feasibility of developing a noninvasive method of drug delivery and diagnostics using ultrasound.

9:20–9:35 Break

Contributed Papers

9:35

3aBV4. Ultrasound for the mediation of a therapeutic agent through the blood–brain barrier. Leonard J. Bond (Univ. of Denver Res. Inst., 2050 E. Iliff Ave., Denver, CO 80208) and Lawrence Ng (Univ. of Colorado Health Sci. Ctr., Denver, CO 80262)

There is a critical need to develop safe, noninvasive, nonchemical methods to enhance the delivery of nonlipophilic neuropharmaceuticals to the brain. A novel method for mediating nonlipophilic drug transport across the blood–brain barrier (BBB) will be presented. Preliminary data were obtained using a unit operating at 1.6 MHz with ultrasound coupled through water and an attenuating layer onto an *in vitro* cell-culture model of the BBB. The effects of different intensities on permeation rate and cell integrity were investigated. Various microscopic techniques were used to determine cell condition and viability. At low intensities no effects were seen. At intermediate intensities enhanced permeation up to levels of a factor of 3 increase were measured. At the highest intensity substantial cell disruption was observed. Preliminary observations regarding the mechanism for the interaction of ultrasound with the BBB will be presented. Work is in progress to determine the conditions for effective trans-cranial delivery of ultrasound using phantoms constructed to model *in vivo* brain. By promoting transport of nonlipophilic drugs across the BBB, this approach has the potential to safely and effectively treat a wide range of brain and central nervous system disorders.

9:50

3aBV5. Mechanistic studies of ultrasonically enhanced transdermal drug delivery. J. M. Farrell (Harvard-MIT Div. for Health Sci. and Technol., Boston, MA 02139), S. Mitragotri, S. Theis, J. Kost, and R. Langer (MIT, Boston, MA 02139)

The transdermal route of drug delivery offers a noninvasive and painless alternative to more traditional routes such as injections. However, its applicability is limited to only a handful of drugs due to the low permeability of the skin. It has been demonstrated that low-frequency ultrasound significantly enhances transdermal transport of a variety of drugs (sonophoresis). There is strong experimental evidence to suggest that cavitation plays a key role in this enhancement, although it is not clear which cavitational effects are primarily responsible for the transport. Cavitation can affect transdermal transport in at least two ways: It can induce changes in skin structure, creating pathways or channels for molecules to diffuse across and/or it can induce convective transport across the skin. An experimental system has been developed to assess contributions due to each of these phenomena individually. Although the data are insufficient to eliminate a role for convective processes, these experiments clearly indicate that stuctural changes in the skin play an important, and probably primary, role in enhanced transport.

Invited Paper

10:05

3aBV6. Enhancement of ultrasound-mediated transfection with cavitation micronuclei. James F. Greenleaf (Dept. of Physiol. and Biophys., Mayo Clinic and Foundation, Rochester, MN 55905, jfg@mayo.edu) and Mark E. Bolander (Mayo Clinic and Foundation, Rochester, MN 55905)

Many methods are available for transferring foreign genes into mammalian cells (transfection). The advantages of ultrasound-mediated transfection are that it can be controlled in both space, by focusing, and time, by exposure. It was tested whether ultrasound-mediated gene transfection in cultured immortalized human chondrocytes would be enhanced using artificial cavitation nuclei in the form of Albunex®. Here 1.0 MHz ultrasound transmitted through the bottoms of six-well culture plates containing media with green fluorescent protein reporter gene plasmids at a concentration of 40 μg/ml and Albunex® at 50×10^6 bubbles/ml produced a peak transfection efficiency of about 50% of the living cells when exposure was 4×10^5 P spatial average peak pressure (SAPP) for 20 mins. Using these parameters, transfection efficiency increased linearly with ultrasound exposure pressure with a transfection threshold observed at a SAPP of 10^5 P. Adding fresh Albunex® at 50×10^6 bubbles/ml prior to sequential one second 3.2 or 4.0×10^5 P exposures increased transfection efficiency by 15% for each of three consecutive exposures. Efficient *in vitro* and perhaps *in vivo* transfection appears possible with ultrasound providing both temporal and spatial control over the transfection process.

Contributed Paper

10:30

3aBV7. Defects of bilayers generated by ultrasound. M. S. Malghani, Jie Yang, and Junru Wu (Dept. of Phys., Univ. of Vermont, Burlington, VT 05405)

Transdermal drug delivery is handicapped by the low skin permeability caused by highly ordered structure of lipid bilayers in the outer human skin layer. It has been reported that ultrasound can increase the permeability of human skin [S. Mitragotri, D. Blankschtein, and R. Langer, Science **269**, 850–853 (1995)]. The enhancement was attributed to acoustic cavitation but the underlying physical mechanism is not fully understood. As a model, dipalmitoylphosphatidylcholine (DPPC) lipid bilayers are insonicated by ultrasound of two submegahertz frequencies (168 and 707 kHz). The free-field spatial peak pressure amplitudes of both are measured to be 6×10^5 Pa. Bilayer defects, which have average diameters of tens to hundreds of nanometers and can be detected by an atomic force microscope, are generated within less than 0.5 min. The number of the defects grows with time. The defect growth rate at the 168-kHz frequency is about 3.5 times that at the 707-kHz frequency.

Session 3aEA

Engineering Acoustics: Electroacoustics and Standards

George S. K. Wong, Chair
Institute for National Measurement Standards, National Research Council, Montreal Road, Ottawa, ON K1A 0R6, Canada

Invited Papers

8:00

3aEA1. Selected topics in electroacoustical calibrations, measurements, and standards. Victor Nedzelnitsky (Natl. Inst. of Standards and Technol., Sound Bldg. 233, Rm. A147, Gaithersburg, MD 20899-0001, vnedzel@nist.gov)

Modern instruments including multichannel dynamic signal analyzers capable of FFT and other signal processing, as well as improved concepts for applying these instruments to particular electroacoustical measurement and standardization issues, are essential tools in modern electroacoustical metrology. The overall uncertainty of a measurement, and its suitability for its intended purpose, may involve components of uncertainty that are individually and collectively difficult to evaluate. In such instances, the capacity to perform the same measurement in different ways can be especially valuable. Different measurements exploiting differences in source signals, signal processing implementations, and apparatus can provide valuable insight and can support the validity of measurement results and interpretations. Examples selected from recent and ongoing work at NIST include calibration or characterization of microphones and microphone arrays in a free field, examination of imperfections in anechoic chambers, and measurement of effects of instabilities and nonlinearities in electroacoustical systems. Recent ANSI (American National Standards Institute) and IEC (International Electrotechnical Commission) standardization work involving the coherence function method for examining nonlinearities in the electroacoustical performance of hearing aids has elicited comments proposing an alternative method involving the Hilbert transform. Some significant advantages and disadvantages of these methods are discussed.

8:15

3aEA2. Progress in silicon microphones. Gerhard M. Sessler (Univ. of Technol., Merckstrasse 25, D-64283 Darmstadt, Germany, ses@uet.th-darmstadt.de)

Recently, several advances have been made in the design, technology, and performance of silicon microphones. New or significantly modified transducers are: (1) condenser microphones consisting of a single chip processed with sacrificial-layer technology to form the electrode-air gap system; (2) condenser microphones with small parasitic capacitance to decrease the load on the sensor output; (3) optical-waveguide microphones utilizing novel waveguide designs and operating with intensity modulation, which, to date, has not been used in acoustic silicon sensors. Also, attention has been given to various types of ultrasonic silicon microphones for airborne sound. Of importance in all implementations is the equivalent noise level, which is, in some microphone-preamplifier systems, sufficiently low for certain applications, but still higher than for conventional microphones. The present state of the art with respect to transducer design and performance will be discussed.

8:30

3aEA3. Design and properties of face to face couplers for microphone comparison calibration. Erling Frederiksen (Bruel and Kjaer, Skodsborgvej 307, 2850 Naerum, Denmark. erlingfred@bk.dk)

This paper describes the design and properties of microphone comparison calibration couplers. In 1988 Bruel and Kjaer introduced a sound level calibrator with a built-in reference microphone which, via a feed-back system, controls the sound pressure in its coupler cavity. This was a significant step in the direction of more stable calibrators. The same calibrator presented another new principle. The microphone to be calibrated and the reference are placed face to face in such a short distance that their diaphragms see essentially the same sound pressure which is produced by a rotational symmetrical source. This mounting was found to improve the accuracy and to increase the upper frequency limit of the new calibrator by more than five times in comparison with previous calibrator configurations. Today IEC-TC29 prepares an international standard for comparison calibration of working standard microphones. The method of this standard uses the special symmetrical mounting of the source and the microphones. The paper describes results obtained with some experimental couplers which are made in this connection in order to analyze the calibration accuracy and optimize the frequency range. The couplers are mainly intended for comparison of sensitivity magnitude but may also be used for comparison of phase response characteristics.

8:45

3aEA4. Controlled environment for reciprocity calibration of condenser microphones. George S. K. Wong and Lixue Wu (Acoust. Standards, Inst. for Natl. Measurement Standards, Natl. Res. Council, Ottawa, ON K1A 0R6, Canada)

For precision reciprocity calibration of condenser microphones it is necessary to operate the calibration apparatus under a controlled environment such that fluctuations in pressure, temperature, and relative humidity are reduced to a minimum. The design, implementation, and performance of a highly stable environmental chamber for calibration of microphones and instruments is discussed. For reciprocity microphone calibrations, the system enables resolution of better than 0.001 dB.

9:00

3aEA5. Procedures for the precision of sound power determination by S. I. scanning method. Hideki Tachibana (Inst. of Industrial Sci., Univ. of Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo, 106 Japan) and Hideo Suzuki (Ontec R&D Co., Ltd., Yokohama, 226 Japan)

As the third international standard of ISO 9614 series (Acoustics—Determination of sound power levels of noise sources using sound intensity), the precision method by scanning is now being drafted by ISO/TC43/SC1/WG25. It will be Part 3 (Precision method for measurement by scanning), following Part 1 (Measurement at discrete points: precision, engineering and survey classes) and Part 2 (Measurement by scanning: engineering and survey classes). In this paper, the outline of the draft and discussions are introduced by focusing on the measurement accuracy, the methods for checking the adequacy of the measurement sound field (field indicators), and practical procedures.

9:15

3aEA6. Experimental study on the accuracy of sound power determination of S. I. scanning method. Hiroo Yano (Chiba Inst. of Technol., 2-17-1 Tsudanuma, Narashino-shi, Chiba, 275 Japan), Hideki Tachibana (Univ. of Tokyo, Tokyo, 106 Japan), and Hideo Suzuki (Ontec R&D Co., Ltd., Yokohama, 226 Japan)

In ISO/TC43/SC1/WG25, the precision method of sound power determination by sound intensity scanning method is being drafted as the third standard of ISO 9614 series. For this drafting work, some experimental studies were performed on the measurement accuracy, the methods for checking the measurement sound field (field indicators), and practical procedures of signal processing during the scanning. The sound power determination was made for artificial sound sources (a reference source and a sound source system consisted of two loudspeakers) and actual noise sources (a vacuum cleaner and an air compressor) by changing such measurement conditions as the scanning density, the scanning speed, and the strength of the extraneous noise. From the experimental results, the validities of the specifications in the draft are examined.

9:30

3aEA7. Electroacoustics and standards. Gunnar Rasmussen (G.R.A.S. Sound & Vib. aps., Skelstedet 10B, 2950 Vedbæk, Denmark)

Standardization within electroacoustics has been of great importance for the development of sound measuring instrumentation. The sound level meters are used to build up a homogeneous database, which in turn is used as a foundation for the measurement standards. Based on the database, regulation and legislation of noise exposure, noise control, product labeling, etc., may take place. The development of standards for sound level meters, measurement microphones, and calibration techniques has led to big improvements. The development of standards for intensity instrumentation and measurements will hopefully lead to similar improvements in developing the instrumentation and practical use in the daily work of the practitioners. The revision of the standards is important. They should hopefully lead to improvements for the manufacturer and for the users. The revisions should take into account the technical development and the expanded use of instrumentation in the acoustical and mechanical field. The ability to measure small changes in emitted intensity by critical sources is important for research in noise control. The measurement of sound-pressure level in the outdoor environment is not well treated in the standards, although it is an area where the legislation is most restrictive regarding noise exposure, because it influences the largest parts of the population. Examples and proposals will be given.

9:45–10:00 Break

Contributed Papers

10:00

3aEA8. The study of long-term sensitivity changes in backplate electret type condenser microphones. Kenzo Miura (Matsushita Commun. Eng. Co., Ltd., 4-3-1 Tsunashimahigashi, Kohoku-ku, Yokohama, 223 Japan) and Yoshinobu Yasuno (Matsushita Commun. Industrial Co., Ltd., 600 Saedo-cho, Tsuzuki-ku, Yokohama, 224 Japan)

The estimation of the lifetime of a usual electret condenser microphone (ECM) using an electret foil as a diaphragm has already been reported by authors. On the other hand, backplate electret type condenser microphones (BECMs) used for mobile telephones, recently, and the backplate that is laminated with electret foil has been examined and studied concerning the estimation of sensitivity changes over a long time span. Heat acceleration tests for electret foil on the backplate were taken, and from the results, the surface charge decay of backplate electret was estimated. As the thickness of the diaphragm in a BECM is thinner than the usual ECM, sensitivity increasing because of looseness of diaphragm tension was expected to become larger than the usual ECM. Therefore, heat acceleration tests for the diaphragm only were taken and estimates of the levels of sensitivity increasing by the looseness of the results. The charge decay characteristics on the electret surface and the characteristics of tension looseness in the diaphragm had both results taken together. The long-term sensitivity changes of BECMs were estimated and compared with the sensitivity of BECM samples that were left for about 10 years at room temperature.

10:15

3aEA9. Measurement of microphone random-incidence and pressure-field responses and determination of their uncertainties. Johan Gramtorp and Erling Frederiksen (Bruel & Kjaer, 2850 Naerum, Denmark, jgramtorp@bk.dk)

For many applications it is important to know the frequency response of the measurement microphone. In an earlier paper the determination of the free-field response and the uncertainties of the responses based on actuator calibration for $\frac{1}{2}''$ microphones was discussed [J. Gramtorp and E. Frederiksen, J. Acoust. Soc. Am. **100**, 2672 (1996)]. This paper continues by discussing the determination of the pressure-field and random-incidence responses and the determination of their uncertainties. The pressure-field responses are based on estimated pressure-field corrections obtained using the pressure-field reciprocity technique and electrostatic actuator calibration. The random-incidence responses are based on a large number of free-field measurements with different angles of incidence increased in small steps, and calculated according to IEC 1183, combined with electrostatic actuator calibration. From most manufacturers no infor-

mation on the uncertainties is available, but a complete set of uncertainty values for pressure-field and random-incidence corrections and responses for the new Bruel & Kjaer Falcon Range microphones will be presented and discussed.

10:30

3aEA10. Measuring system for the derivation of thermal loudspeaker parameters. Gottfried K. Behler and Armin Bernhard (Inst. for Tech. Acoust., RWTH Aachen, Templergraben 55, D-52056 Aachen, Germany, gkb@akustik.rwth-aachen.de)

Loudspeakers used in high-power applications are stressed by mechanical and thermal load. Both can be the reason for damage and should be controlled. Whereas the mechanical situation can be derived from the input voltage and the total impedance, which can be measured easily, it is rather difficult to calculate for the actual voice coil (VC) temperature under working conditions. It is possible to derive the VC temperature from the input voltage using linear mathematics if the thermal equivalent circuitry of the loudspeaker including the cabinet is known. Former papers have discussed the thermal equivalent circuitry of the loudspeaker without taking the cabinet into account. In the presented paper an equivalent circuit is presented, which can be used for loudspeakers in different cabinets and a measuring method is shown, that enables long-term measurements on loudspeaker systems with constant input power using a PC-based regulator. The main problem is to calculate the voice coil temperature from the measured impedance data. The solution of this problem is presented. At least the thermal parameters of the equivalent circuit are calculated from the measured data using curve fitting. Different loudspeakers and setups have been tested. The results will be presented.

WEDNESDAY MORNING, 24 JUNE 1998 GRAND CRESCENT (W), 9:15 TO 12:25 P.M.

Session 3aMU

Musical Acoustics: Bowed String Instruments

Thomas D. Rossing, Cochair
Physics Department, Northern Illinois University, DeKalb, Illinois 60115

Carleen M. Hutchins, Cochair
Catgut Acoustical Society, 112 Essex Avenue, Montclair, New Jersey 07042

Invited Papers

9:15

3aMU1. Studies in bowing point friction in bowed strings. Robert. T. Schumacher (Dept. of Phys., Carnegie Mellon Univ., Pittsburgh, PA 15213)

By using force transducers at the terminations of a violin E string, one may reconstruct the force and velocity at the bowing point that produces those termination forces [R. T. Schumacher and S. Garoff, Institute of Acoustics, Proceedings, Vol. 19: Part 5, 43–48 (1997) (ISMA'97)]. That information, combined with examination of the ''friction track'' [R. T. Schumacher and S. Garoff, CAS J. **3**(2), 9–16 (1996)] allows the possibility of determining the frictional properties of the rosin-mediated bow–string interaction. The reconstruction of the force, $f(t)$, and velocity, $v(t)$, allows determination of the force–velocity relation $F(v)$. That reconstruction is a delicate operation requiring careful measurement of the reflection functions of the transverse waves at the terminations. Use of simulations aids in determining the limitations of the reconstructions. Knowledge of $F(v)$, combined with examination of the friction track, variation of the chemical constituents of the rosin, and chemical preparation of the string surface, as well as measurements of the rosin's physical properties, such as softening temperature and x-ray structural examination, will eventually establish the physical basis for the alternating adhesion–lubrication properties of the rosin that produce the slip-stick string oscillation.

9:40

3aMU2. Modal analysis of violins and cellos. Thomas D. Rossing, Mark Roberts, Eric Bynum, and Laura Nickerson (Phys. Dept., Northern Illinois Univ., DeKalb, IL 60115)

Normal modes of bowed string instruments are determined by the coupled motion of the top plate, back plate, enclosed air, ribs, neck, fingerboard, etc. Normal mode testing has traditionally been done using sinusoidal excitation, either mechanical or acoustical, although modal testing with impact excitation is a fast, convenient way to determine the normal modes of an instrument. Holographic interferometry provides the greatest detail about mode shapes, but the best understanding of the normal modes of an instrument results from application of more than one testing method. The normal modes in a cello are found to be quite similar to the corresponding modes of a violin, although they may appear in a different order in frequency. Modal frequencies in one cello were found to occur at 0.29 to 0.43 times the corresponding mode frequencies in a violin.

10:05

3aMU3. A normal-mode-based model of violin radiation. George Bissinger (Phys. Dept., E. Carolina Univ., Greenville, NC 27858, bissingerg@mail.ecu.edu)

A simple physical vibration–radiation model based entirely on experimental modal analysis can successfully predict the spatially averaged radiative properties of a bridge-excited violin measured with a rotating microphone array. The energy transfer from bridge excitation to acoustic radiation is modeled using (a) the measured transfer mobility $Y(\omega)$ to characterize energy transfer from the bridge to the corpus, and (b) the radiation efficiency R_{eff}, calculated from a boundary element program for each normal mode to characterize the energy transfer from the corpus to the air. This model provides string-specific radiation predictions and allows one to make quick estimates of the averaged acoustical effects of violin adjustments or modifications which would be expected to change $Y(\omega)$ but not R_{eff}, e.g., bridge trimming. Extensions of the model and future applications and directions for its application will be discussed.

10:30

3aMU4. Influence of the weight of mutes on tones of a violin family. Kenshi Kishi (Dept. of Electro-Commun., The Univ. of Electro-Commun., 1-5-1, Chofugaoka, Chofushi, Tokyo, 182 Japan, kkishi@peacock.ee.uec.ac.jp)

The phrase ''con sordino'' is used for the score of a violin family to indicate the use of a mute. The mute is used to reduce the volume of the violin tones and change their tone quality. This paper examines the influence of the weight of mutes on tones of a violin using the spectral envelopes of the violin tones. Violins with and without mutes were played by a skilled player in an anechoic chamber to produce tone samples which were then recorded on a DAT recorder. Using the tone samples, the time variances of the fundamentals and spectral envelopes obtained by FFT analyses were examined. The force transfer function of a cello bridge with mutes installed, which is used for convenience, was measured. From these examinations and analyses, we made the following observations: (1) the higher the order of harmonics, the lower their relative sound pressure levels compared with that of the fundamental and (2) the level differences between the peaks and dips of the spectral envelopes are reduced as the weight of a mute is increased.

10:55–11:05 Break

11:05

3aMU5. Anomalous low frequencies from a bowed violin string. Roger J. Hanson (Phys. Dept., Univ. of Northern Iowa, Cedar Falls, IA 50614, roger.hanson@uni.edu) and Frederick W. Halgedahl (Univ. of Northern Iowa, Cedar Falls, IA)

With a bow force greater than the Schelleng maximum and careful bow control, it is possible on a violin to produce sounds of definite pitch ranging from approximately a musical third to as much as two octaves below the normal pitch. [Hanson *et al.*, CAS J., **2**, Series II, 1–7 (1994)]. The pitch is in agreement with the fundamental frequency of the observed harmonic series. The fundamental itself is very weak if the sounds are produced on the open violin G string. These anomalous low frequencies (ALF) occur when the bow force is great enough to prevent the Helmholtz kink from triggering the normal release of the string from the bow hair. The bow serves as a quasitermination point of the string so that there are pronounced bow-nut and bow-bridge reflections yielding at the bow a very complex waveform, some portion of which triggers the slipping of the string. The ALF can also be produced on a bowed monochord where the motion at several points is detected optically, and the sound is generated from the resulting signal. Some musical applications of the effect will be discussed.

11:30

3aMU6. Acoustical aspects of chamber music for strings. Juergen Meyer (Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany, juergen.meyer@ptb.de)

Playing string quartet music under different room acoustics conditions demands adaptation of the playing technique, particularly of the articulation. If not damped by the bow, violin tones have a 60-dB decay time of about 0.5 s in the highest part of the range, increasing to about 1 s for the lowest tones; in the lower stringed instruments, decay times are as much as 3 s. When damped by the bow, the decay times can be shortened to about 0.1 s. Attack times of staccato violin tones are of the order of 30–50 ms; smoothed attacks may be prolonged up to 200 ms. The temporal structure of a fast staccato tone sequence (14 tones per second) is mainly characterized by breaks in the overtones of the order of 25 ms, whereas the fundamentals seem to be blended together or slurred. These values correspond with typical acoustical criteria of historical and contemporary chamber music halls. To determine the reaction of musicians to the boundary conditions as well as the listeners' impressions, a test was performed by playing the same programs of short and different music examples during only 3 h in three halls having different room acoustic properties.

Contributed Papers

11:55

3aMU7. Radiation mechanisms of a violin with known modal characteristics. Lily M. Wang and Courtney B. Burroughs (Grad. Prog. in Acoust., Penn State Univ., P.O. Box 30, State College, PA 16804)

Multiplanar near-field acoustic holography (NAH) involves reconstructing the surrounding radiated sound field from measurements of the complex pressure on at least four intersecting planes enclosing a source [L. M. Wang and C. B. Burroughs, J. Acoust. Soc. Am. **100**, 2654(A) (1996)]. After a brief review of the multiplanar NAH technique, results from applying the algorithm to a bowed violin (Hutchins' SUS295) are shown for each open string. An open-frame mechanical bowing apparatus, which has been previously described, is used to excite the violin [L. M. Wang and C. B. Burroughs, J. Acoust. Soc. Am. **99**, 2502(A) (1996)]. Areas of significant radiation on the violin structure are identified. Measurements are also compared to results from modal analyses previously performed on the same instrument. [Work supported by NSF Graduate Fellowship, Bell Laboratories GRPW Grant, and AAUW Selected Professions Dissertation Fellowship.]

12:10

3aMU8. Behavior of real violin strings, mechanically bowed. Norman C. Pickering and Michael P. Kerr (J. D'Addario and Co., Inc., Farmingdale, NY)

Traditional methods of evaluating various types of strings for bowed instruments have relied almost exclusively on subjective impressions of expert players. In the real world, busy professionals rarely have enough time or objectivity to provide string designers and manufacturers with precise information. Furthermore, such opinions are affected by factors unrelated to the stings themselves, and are subject to change in ways that are often difficult to relate to the design details of the product being tested. The use of a well-designed bowing machine makes it possible to amass quantities of data on specific strings, enabling string makers to discover the characteristics that are favored by professional artists. Data is obtained for strings having cores of gut, synthetic polymers, monofilament, and stranded steel. By varying bow force, velocity, and distance from the bridge an envelope of usable combinations is accurately determined. Time for development of Helmholtz waveform partial by partial, average frequency variation as well as cycle-by-cycle period variation, and overall spectral distribution can all be determined with good repeatability. Driving strings magnetically instead of by bowing permits frequency determination of individual partials, an indication of string flexibility or lack of it. This work has led to new string designs, incorporating new materials and manufacturing processes.

WEDNESDAY MORNING, 24 JUNE 1998

CASCADE BALLROOM I, SECTION A (W), 9:15 TO 11:10 A.M.

Session 3aNSa

Noise and Architectural Acoustics: Low-Frequency Noise

Louis C. Sutherland, Chair
27803 Longhill Drive, Rancho Palos Verdes, California 90275-3908

Chair's Introduction—9:15

Invited Papers

9:20

3aNSa1. A new way of reducing self-sustained flow noise. Reni A. Henry, Anas Sakout, Alex L. Coiret (Lab. L.E.P.T.A.B., La Rochelle Univ., avenue Marillac, 17042 La Rochelle Cedex 1, France), and Aziz Hamdouni (Poitiers Univ., 86960 Futuroscope Cedex, France)

Vortex shedding from shear layers may be driven by the resulting acoustical field. In order to achieve noise reduction, the feedback loop is broken down with the help of auxiliary secondary flows that are created by means of minor geometrical modifications. Experiments have been conducted on a flow through two close orifice plates in a cylindrical duct: they have brought forward the possibility of reaching stable paths of flow bifurcations where an important noise reduction is obtained in a large range of flow rates. By creating a suitable interaction between the main shear layer of the confined jet and thin auxiliary shear layers, noise reduction takes place in a range of 20–40 dB. The latest result is the following: due to the stability of the flow bifurcation path that can be reached, such a level of noise reduction is maintained in a large range of flow conditions. Moreover, by choosing an adequate path, noise reduction takes place for flow conditions where intense tones would be present if these flow conditions were to be reached through conventional means. It may be emphasized that such methods are costless, compared to some sophisticated active control methods.

9:50

3aNSa2. A new approach to low-frequency room noise criteria. Robert D. Hellweg, Jr. and Hsien-sheng (Jason) Pei (Digital Equipment Corp., PKO2-1/J60, 129 Parker St., Maynard, MA 01754, hellweg@mail.dec.com)

There are three different and conflicting room criteria methods that are widely used by consultants today: room criterion (RC), balanced noise criterion (NCB), and noise criteria (NC). The RC procedure is documented in ANSI S12.2-1995 ''Criteria for evaluating room noise'' and the ''1995 ASHRAE Applications Handbook;'' the NCB procedure in ANSI S12.2; and the NC ''tangency'' method in the ''1991 ASHRAE Applications Handbook.'' There are significant differences in the three criteria, especially for low frequencies, which can impact the costs both of new designs and of remedial actions to existing facilities. In order to promote a resolution to these differences, NOISE-CON96 and NOISE-CON97 held special technical sessions on room noise criteria. Based on our analysis of published research and on experiences dealing with other noise sources, the authors suggest an approach to resolve the low-frequency differences: (1) establish basic room criterion curves for noises without abnormal temporal or spectral characteristics, and (2) apply correction factors to the measured data to account for abnormal features before comparison to the basic criterion. This paper presents details of the suggested approach, the status of revisions to ANSI S12.2 and to the ASHRAE handbook, and other ongoing research.

10:20

3aNSa3. Parameters involved in low-frequency noise annoyance. Ulf Landstrom (Natl. Inst. for Working Life, Box 7654, S-907 12 Sweden)

Noise annoyance and related adverse responses evoked during exposures in low-frequency environments are effected by a number of separate and interacting parameters. Laboratory as well as field studies have shown that in most cases the correlations between annoyance and noise levels or linear values are very weak. For descriptions of the fundamental correlations between low-frequency noise exposure, annoyance, and related adverse effects, deeper knowledge about the different interacting factors is needed. One consequence of this deficient knowledge of the critical factors for low-frequency noise annoyance is that well-founded methods for the evaluation of annoyance and related adverse effects are still missing. Noise control, building and rebuilding of new acceptable environments, or other types of measures against the low-frequency noise problems cannot be based only on evaluations of the dBA or other simple rating alternatives. For adequate evaluations and measures, deeper knowledge about interacting factors, e.g., tones, frequency character, bandwidth, exposure time, fluctuations, perception, masking and type of work, is needed. The present paper is a summary of the results and conclusions that could be drawn from studies directed upon some of the most important parameters involved in low-frequency noise annoyance.

Contributed Paper

10:50

3aNSa4. The effects of age on annoyance caused by low-frequency noise. Rukhsana Adams and Bridget M. Shield (School of Eng. Systems and Design, South Bank Univ., London SE1 0AA, UK, shieldbm@sbu.ac.uk)

A laboratory study into the response of subjects to noises of varying intensity and frequency content has been carried out. Eighty subjects ranging in age from approximately 20 to 70 yr were asked to rate sounds according to annoyance. The hearing levels of the subjects were tested using pure-tone audiometry. The annoyance ratings have been analyzed to investigate relationships between annoyance and spectral shape, and also to determine whether the annoyance responses are related to age or hearing acuity. Preliminary results suggest that there is a strong relationship between age and response to low-frequency sound, subjects over the age of 45 finding sounds with high levels of noise below 200 Hz significantly more annoying than younger subjects. However, the annoyance ratings of the older subjects do not appear to be related to hearing levels, suggesting that the response may be due to some other factor such as the association of the noise.

WEDNESDAY MORNING, 24 JUNE 1998

CASCADE BALLROOM I, SECTION B (W), 9:15 TO 11:40 A.M.

Session 3aNSb

Noise: Tire Noise

Paul R. Donavan, Chair

Noise and Vibration, MC 483-324-101, GM Proving Ground, Building 24, Milford, Michigan 48380

Chair's Introduction—9:15

Invited Papers

9:20

3aNSb1. The investigation of a towed trailer test for passenger tire coast-by noise measurement. James K. Thompson (Automated Anal. Corp., 2805 South Industrial, Ste. 100, Ann Arbor, MI 48104, jthompso@autoa.com) and Thomas A. Williams (Hankook Tire, 3535 Forest Lake Dr., Uniontown, OH 44685)

It is difficult to quantify the portion of coasting vehicle noise that is due to tire-pavement interaction alone. There are often contributions from aerodynamic noise of the vehicle, transmission whine, noise from suspension components, and other miscellaneous sources. The towed-trailer method used in the revised SAE J-57 standard has been shown to be an effective means of isolating tire-pavement noise for truck tires. This paper reports the results of a test program conducted by SAE Tire Noise Standards Committee to evaluate the feasibility of towed-trailer coast-by testing of passenger and light truck tires. The results of tests conducted in April 1996 at the Ohio Transportation Research Center are described and they indicate that accurate measurements are possible for towed-trailer testing of passenger tires. It is shown that a key aspect of performing such a test is reducing the noise of the tow vehicle and that sufficient reduction is possible even for quiet test tires. During the period of this work, the ISO/TC 31/WG 3 working group developed a draft trailer test method for evaluating tire noise. This test procedure was also evaluated. The results show the proposed test method to be highly accurate for tire noise evaluation.

9:40

3aNSb2. Assessment of tire/pavement interaction noise under vehicle passby test conditions using sound intensity measurement methods. Paul R. Donavan, Richard F. Schumacher, and Jeffrey R. Stott (Noise and Vib. Ctr., 483-324-101, General Motors Proving Ground, Milford, MI 48380)

Over the past several years, sound intensity measurement methods have become an increasing valuable tool in isolating tire/pavement interaction noise when a vehicle is tested under full throttle acceleration conditions such as the ISO 362 R15 procedure. Several investigations have been conducted and reported which demonstrate the relationship between ''on-board'' sound intensity measured close to a tire contact patch and the sound pressure level measured by a stationary microphone 7.5 m away from the line of travel of the vehicle. Using these relationships, the contribution of tire/pavement noise can be assessed relative to other noise sources associated with a vehicle under acceleration as measured at 7.5 m. In this application, it has been determined that some tires can produce significantly higher noise levels under the torque of acceleration than under cruise conditions. Sound intensity has also been used to separate sound propagation from sound generation effects in the assessment of test surfaces such as those specified by SAE and ISO. This paper reviews the various applications of sound intensity in the assessment of tire/pavement interaction noise issues related to vehicle passby noise, the implication of recent findings on noise reduction strategies, and the potential for standardization of sound intensity techniques.

10:00

3aNSb3. The influence of belt and tread band stiffness on the tire noise generation mechanisms. Wolfgang Kropp, Krister Larsson, and Stephane Barrelet (Dept. of Appl. Acoust., Chalmers Univ. of Technol., S-41296 Gothenburg, Sweden, wk@Ta.chalmers.se)

A brief introduction to a theoretical model is presented which describes a smooth tire rolling on a rough road surface. The model is limited to a two-dimensional contact between tire and road. It includes the vibration properties of the tire, the nonlinear contact, and the sound radiation. It is also taking into account the influence of the acoustic properties of the road surface. The model is applied to determine the sound radiated due to the tire vibrations and the local deformations of the tread band. A parameter study is presented which shows the influence of the bending stiffness of the belt and the stiffness of the tread band on the noise generation and radiation mechanisms. The study also considers the influence of the surface roughness of the road. In this way it is possible to quantify which part of the roughness spectrum is leading to sound generation via tire vibration and which part of the roughness spectrum is involved in the local deformation of the tread band.

10:20

3aNSb4. Identification of sources of tire/pavement interaction noise. Richard J. Ruhala and Courtney B. Burroughs (Grad. Prog. in Acoust., Penn State Univ., State College, PA 16804)

Although most highway noise is due to radiation from rolling tires, the dominant sources of tire/pavement interaction noise remain largely unknown. In this study, near-field acoustical holography (NAH) is used to visualize the acoustic field of a rolling tire on outdoor pavement surfaces. Since NAH measurements are conducted in the near field, areas of maximum radiation from the tire may be localized with a much finer resolution than with conventional measurements. Planar NAH is used to scan planes along the side, front, and rear planes of the tire. A scanning mechanism will be attached to an automobile trailer for measurements of tire noise under realistic conditions and procedure as developed in earlier results [R. J. Ruhala and C. B. Burroughs, SAE 972047 (1997)]. Several types of tires are evaluated, including blank tire, tire with even spaced transverse grooves, tire with only circumferential grooves, and a production passenger car tire. The tires are tested on both smooth and rough pavements, and at several speeds. The results will provide further insight into the sources and mechanisms of tire/pavement interaction noise. [Work supported by Goodyear, DOT, and GM.]

Contributed Papers

10:40

3aNSb5. Effects of the acoustical characteristics of road pavements on long-range sound propagation. Michel C. Bérengier (L.C.P.C. - Ctr. de Nantes, BP 19, 44340 Bouguenais, France), Jean-François Hamet (I.N.R.E.T.S. 25, 69675 Bron cedex, France), and Yves Pichaud (L.C.P.C.-Ctr. de Nantes, 44340 Bouguenais, France)

For many people in industrial countries, traffic noise is considered as one of the most important elements of discomfort. In the past 15 years, the only protections for the neighboring populations against road traffic noise were road barriers. For a short time, the modification of the road pavement can partly contribute to decrease this nuisance. Recent research on the acoustical performances of road pavements have been carried out, and, a first ranking in the close proximity of the road has been established using a standardized method. From these first results, it is possible to predict the road traffic noise far from the road taking into account the acoustical characteristics of various pavements. This prediction procedure requires the theoretical knowledge of all the physical phenomena occurring along the propagation path. This is the reason why the model used for calculation integrates ground effects over mixed surfaces and atmospherical parameters such as vertical sound-speed gradients. The pavement effect is introduced in the model through the sound power spectrum of the tire/road noise source located a few centimeters above the road surface. The predicted results are advantageously compared to *in-situ* measurements carried out over some hundred meters.

10:55

3aNSb6. Acoustic modeling of road vehicles for traffic noise prediction: Determination of the sources heights. Jean-François Hamet, Marie-Agnès Pallas (I.N.R.E.T.S. 25, av. François Mitterand, case 24, 69675 Bron cedex, France), David Gaulin, and Michel C. Bérengier (L.C.P.C.-Ctr. de Nantes, 44340 Bouguenais, France)

For traffic noise predictions road vehicles can be modeled by point sources. When dealing with the evaluation of noise barrier's efficiency or of far-field noise, the knowledge of the sources heights is of primary importance. Their determination can be obtained from two different methods. The first one deals with an inverse fitting procedure performed on experimental excess attenuation results between two receivers 7.50 m apart. Knowing the noise frequency spectrum at the reference microphone and the pavement and close ground impedances, it becomes possible to adjust the source height by minimizing the prediction/measurement differ-

ence. By this procedure, the equivalent noise source is found very close to the surface. Otherwise, sources heights can be obtained directly using microphone arrays. These measuring techniques are now commonly used to localize sound sources of railway vehicles. Their application to road vehicles appears to be more recent. For the present case dealing with the determination of the source height only, a simple vertical array can be implemented. Preliminary measurements made on a light vehicle confirm that the acoustic radiation due to the various sources (including engine noise) comes practically entirely from the car underbody, i.e., from a zone close to the ground.

11:10

3aNSb7. Modeling of tangential contact forces. Krister Larsson, Stephane Barrelet, and Wolfgang Kropp (Dept. of Appl. Acoust., Chalmers Univ. of Technol., S-412 96 Gothenburg, Sweden, kl@ta.chalmers.se)

The main noise source from vehicles at speeds greater than 50 km/h is the tires. To reduce traffic noise it is therefore necessary to understand the noise generation mechanisms in the contact between tire and road. The paper presents an improvement of an earlier developed acoustic rolling model concerning a smooth tire rolling on a rough surface. This model consists of three steps. First, the radial contact forces between road and tire are calculated. These forces give the vibrations of the tire, which finally give the sound radiation from the tire. A method to include the tangential forces into the rolling model is the topic of this paper. To do this, the influence of the tread blocks on the force transmission from the road to the belt of the tire has to be known. A FEM-model of one tread block is made in order to determine its dynamical properties. A simplified model of the block is established, by only taking into account the two lowest modes in the frequency range of interest (i.e., up to 3 kHz). This simplified model is included in the existing contact model to give the response of the tire due to tangential or radial excitations.

11:25

3aNSb8. Computational and subjective procedures for the assessment of sounds with weak tonal components. Wolfgang Ellermeier (Inst. of Psychol., Univ. of Regensburg, Regensburg, Germany) and Matthias Vormann (C.v.O Univ., Oldenburg, Germany)

A discrete tone is defined as ''prominent'' if the level of the tone exceeds the level of the noise contained in its critical band by 6 dB. Tonal or narrow-band noise components of tire sounds often fall short of this level, but are nevertheless rated as prominent by test drivers. Tonality is closely related to the sensation of pitch strength, which depends upon the sensation level, bandwidth, duration, and frequency of the tonal components present. In order to compare a number of computational procedures for calculating the tonality of sounds, a broad range of tire noises, synthesized tire sounds, and artificial tone–noise mixtures in which the level and bandwidth of the tonal components was varied, were subjectively assessed using (a) a paired-comparison technique, and (b) categorical judgments collected from about 60 listeners. They were objectively assessed by tone-to-noise and prominence-ratio measurements, and by a new method based on a model of pitch sensation which accounts for the temporal and frequency resolution as well as for masking properties of the human ear. The advantages and limits of the different methods will be compared and discussed. Especially for weak narrow-band components, the pitch model seems to be superior to the other methods used to quantify the degree of tonality.

WEDNESDAY MORNING, 24 JUNE 1998

CASCADE BALLROOM I, SECTION C (W), 9:15 A.M. TO 12:05 P.M.

Session 3aNSc

Noise and Engineering Acoustics: Occupational Noise Exposure Monitoring: Instrumentation, Methods, and Histories

John P. Seiler, Chair

Mine Safety and Health Administration, Cochran Mill Road, Building 028, P.O. Box 18233, Pittsburgh, Pennsylvania 15236

Chair's Introduction—9:15

Invited Papers

9:20

3aNSc1. Instrumentation for the measurement of occupational noise exposure: Past, present, and future. Theodore J. Kuemmel (Quest Technologies, Inc., 510 S. Worthington St., Oconomowoc, WI 53066)

The instruments used to measure occupational noise exposure have all evolved from the basic sound level meter. Variation of the sound fields and the dynamics of the measurement environment raised questions about the validity and accuracy of occupational noise exposure measurements. Measurement practice and instrumentation have evolved significantly to overcome the limitations inherent in the measurement of sound levels. Modern microprocessor based instruments which automatically compute noise exposures have dramatically improved the validity and accuracy of occupational noise exposure measurements. Today many of the measurements of occupational noise exposure can be reliably replicated. This paper addresses the challenges faced when attempting to assess occupational noise exposure, and their influence on the development of occupational noise exposure measurement instrumentation. The influence of technology, regulation, and standards on instrument development is also addressed.

9:35

3aNSc2. Occupational noise measurement standard: ANSI S12-19. Richard Goodwin (Acoust. Systems, Inc., P.O. Box 146, Vandalia, OH 45377, asi898-3198@worldnet.att.net)

This standard provides procedures for the measurement of occupational noise exposure from all types of noise; e.g., continuous, fluctuating, intermittent, and/or impulse/impact. Measurements may be reported as sound level with corresponding duration, time-weighted average sound level, and/or noise dose. This standard provides for the measurement of the noise exposure of individuals and can be extended to represent groups performing similar activities. It can also be used to measure the noise exposure from a given job or activity. This standard does not provide procedures for the measurement of occupational noise exposures attributable to the rise of earphones or telephone receivers. This standard presents recommended practices for utilizing instrumentation such as a sound level meter, noise dosimeter, integrating sound level meter, and acoustical calibrators. Guidelines are provided for measurement conditions such as the acoustical environment, measurement activities, and operational variations. The parameters surrounding the noise and its impact on the selection of instrumentation is presented. Specific guidelines for using a sound level meter, a noise dosimeter, and an integrating sound level meter are presented. Guidelines for documentation and reporting of the measurement of occupational noise exposure are specified.

9:50

3aNSc3. What are we still doing wrong in assessing occupational noise exposure? Daniel L. Johnson (Larson-Davis, Inc., 1681 West 820 North, Provo, Utah 84601)

Sound level meters/dosimeters and measurement/prediction procedures have improved greatly over the last 20 years. Instrumentation nowadays can be expected to assess the energy of impulsive noise properly, provide a time history of the noise exposure, and have a sufficient dynamic range. Nevertheless, some improvements are still needed. These improvements are to (1) rework the SLM standards so the measurement envelope for all instruments, regardless of type, can be specified to be the same; (2) provide better methodology for determining when infrasound and ultrasound need to be measured; (3) provide a mechanism for properly assessing intermittent exposures, including the inclusion of effective quiet; and (4) finally, as a visionary dream, provide long-term measurement of occupational/nonoccupational noise exposure coupled with environmental factors as well as health factors such as blood pressure and hearing threshold levels. The need for and the details of each of these improvements will be discussed.

10:05

3aNSc4. Types and frequencies of abnormal sound levels when using noise dosimeters to establish worker TWAs. Larry H. Royster (Dept. of Mech. Eng., North Carolina State Univ., Raleigh, NC 27695-7910) and Julia D. Royster (Environ. Noise Consultants, Inc., Raleigh, NC 27622-0698, effective_hcps@compuserve.com)

The potential contamination of noise dosimetry noise exposure findings as impacted by the following types of artifacts was investigated: thumping of the microphone, moving the microphone around during the sample, hollering directly into the microphone, effects of body reflections, and blowing directly at the microphone. The findings from this investigation support the assumption that contamination of noise dosimetry daily noise exposure results is not of significant concern, at least when using a 5-dB exchange rate (OSHA). In addition, the detailed histogram records obtained from conducting noise dosimetry noise exposure surveys at five large industrial facilities were reviewed. Of the over 28 000 histogram samples reviewed, less than 14 samples indicated potential contamination from unusual noise sources. In summary, the results of this study confirm what the authors have observed over many years of conducting industrial noise exposure studies using noise dosimetry: contamination of noise dosimetry findings is not a significant issue (at least when a 5-dB exchange rate is utilized).

10:20

3aNSc5. Sound exposure profiling: A noise exposure assessment alternative. Lee D. Hager (James, Anderson & Assoc., Inc., P.O. Box 23113, Lansing, MI 48909, lee_hager@compuserve.com)

Assessment of worker sound exposure based on incremental task sound levels has a history dating back to the earliest days of recognition of noise as a hearing hazard. Sound exposure profiling (SEP) uses current technology to compile task-based sound measurements to model long-term risk of exposure to hazardous noise. SEP is an alternative to full-shift dosimeter techniques for sound exposure assessment. The methodology offers the advantage of providing additional information about noise sources and how worker interaction with noise sources results in long-term risk of exposure. SEP has been adopted by several major corporations as their corporate strategy for assessment of worker noise exposure, and is supported in ANSI S12.19-1996, ''Measurement of Occupational Noise Exposure.'' This paper will described SEP and its application in industry.

10:35

3aNSc6. Unusual jobs require unusual methods for noise exposure measurement. John P. Barry (U.S. Dept. of Labor—OSHA, 3535 Market St., Philadelphia, PA 19104, john.barry@internetmci.com)

With the diversity of the American workplace, the one size fits all approach cannot accommodate every occupational noise exposure measurement challenge. This is precisely why ANSI Standard S12.19-1996, ''Measurement of Occupational Noise Exposure,'' permits different measurement criteria and a variety of instrumentation and methodologies. The Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) use employee-worn noise dosimeters almost exclusively to document alleged violations of the occupational noise standards. However, employers and consultants may use any method that properly identifies those employees who need to be included in a hearing conservation program and that relates the noise exposure with the risk of occupational hearing loss and the effectiveness of hearing protection devices. Some environmental and

operational hearing loss and the effectiveness of hearing protection devices. Some environmental and operational problems that affect occupational noise measurement are temperature, humidity, rain, wind, radio, magnetic and microwave interference, intrinsic safety, and the presence of hazardous materials. To illustrate effective handling of these measurement problems, the methodologies used in the occupational noise exposure assessment of operating municipal departments will be discussed.

10:50–11:05 Break

Contributed Papers

11:05

3aNSc7. Investigation of intermittency in the noise exposure pattern of longwall coal miners. J. Alton Burks and Roy C. Bartholomae (Pittsburgh Res. Lab., Nat. Inst. for Occupational Safety and Health, P.O. Box 18070, Pittsburgh, PA 15236, aib5@cdc.gov)

It is generally recognized that intermittent exposures to noise are less hazardous than continuous exposures with the same energy. This effect has been accounted for in the USA with the use of a 5-dB exchange rate, instead of the 3-dB rate associated with the equal energy principle. However, the appropriateness of the 5-dB exchange rate for assessing the risk of noise exposures in mining has never been examined closely. The authors have previously reported the results of a worker noise exposure survey conducted at six longwall coal mines [R. C. Bartholomae and J. A. Burks, Proceedings: NOISE-CON '94, 1017–1022 (1994)]; the time-resolved dosimeter data from that study were reanalyzed to determine if the noise exposure pattern of longwall miners can be categorized as intermittent. For this purpose *effective quiet* is defined to be a period of time in which the sound level is less than 75 dBA [W. Melnick, J. Acoust. Soc. Am. **90**, 147–154 (1991)] for 10 s or longer [K. D. Kryter, *The Effects of Noise of Man* (1985), p. 273]. It is found that the miners experience an average of 125 periods of effective quiet and an average total quiet time of 1.7 h on a daily basis.

11:20

3aNSc8. Hearing hazard evaluation and hearing conservation in a very reverberant indoor firing range. Felix Z. Sachs (U.S. Army Ctr. for Health Promotion and Preventive Medicine, 5158 Blackhawk Rd., APG, MD 21010-5422, felix_sachs@chppm-ccmail.apgea.army.mil)

OSHA and Army regulations differentiate steady from impulse noise exposure, but the boundary is fuzzy. A 300-m research indoor firing range produced 10-s reverberation times resulting in noise exposures straddling this boundary. Worker exposure was assessed as both steady and impulsive under both OSHA and Army criteria. The highest peak level was 164.9 dBP, the maximum ''slow'' level was 133 dBA. Hearing protector calculations for steady noise used the NIOSH ''assumed protection values'' method. Army noise criteria use 3-dB exchange between level and time. Any parallel filter analyzer could measure the time-averaged octave band levels. OSHA uses 5-dB exchange rate, a rare feature on parallel filter analyzers. Administrative controls were most stringent for the Army steady noise method and least restrictive for the MIL-STD-1474 impulse noise method. For OSHA steady noise, allowable rounds per day depended on the number of shots fired per burst due to the 5-dB exchange rate. [The opinions or assertions contained herein are the views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.]

11:35

3aNSc9. Noise from sandblasting. Tonnes Ognedal and Rune Harbak (Sinus AS, Sandvigaa 24, N-4007 Stavanger, Norway)

With respect to the increased focus on the working environment, a project has been carried out in order to investigate the noise exposure for personnel working with sandblasting and UHP-water blasting. For sandblasting, three different aspects that influence the noise exposure have been evaluated: (a) Noise from the nozzle and the blasting object, (b) noise generated by the air supply in the masks/helmets, and (c) sound attenuation of the masks and helmets. Normal A-weighted noise levels outside the protective gear are between 110 and 120 dB while sandblasting. The noise level inside the mask and the inner hood will vary from 95–105 dB from the sandblasting. The noise generated by the air supply can be as high 90–100 dB inside the inner hood. Thus the total average noise exposure for the personnel (without earplugs) is 97–107 dB with today's most common equipment in Norway. Noise from UHP-water blasting can also reach levels up to 110–120 dB, depending on the blasting object and the acoustic environment. Normal working gear gives less protection to the ear than the sandblasting gear. Both the sandblasting and the UHP water blasting may create loss of hearing to the workers.

11:50

3aNSc10. Occupational noise and solvent exposure in the printing industry. Rande Ferris and Beno Groothoff (DTIR, Queensland Govt., Brisbane, Australia 4030, rande.ferris@dtir.qld.gov.au)

The study examined the effects on hearing from occupational noise and solvent exposure in the printing industry and was conducted by measuring a selection of workers' daily noise dose, sampling personal solvent exposures and audiometric testing before and after shifts for the detection of a hearing threshold shift. Audiometric test results were inconclusive due to the inadequate testing areas provided at each workplace. Personal monitoring confirmed that where solvent exposure occurs, high noise levels are usually also present. Fifty-three percent of the noise dose level measurements exceeded the statutory limit $L_{\mathrm{Aeq,8h}}$ of 85 dB and a further 9% exceeded the limit of 140 dB (L_{in}). Twenty-two percent of the analyzed solvent exposure samples revealed benzene, with 5% exceeding the worksafe exposure standard of 16 mg/m^3. The lack of essential information contained in Material Safety Data Sheets (MSDSs) for substances used in the printing industry was highlighted. Accurate MSDSs are required to assist employers in discharging their obligation to provide correct information about hazardous substances to employees under the Workplace Health and Safety Act of 1995, as well as the hazards associated with those substances. Better information is required in an MSDS, from manufacturers and suppliers, as to the specific properties and health hazards of a hazardous substance.

Session 3aPAa

Physical Acoustics: Sonochemistry and Sonoluminescence: SC I

Kenneth S. Suslick, Cochair
Department of Chemistry, University of Illinois, 601 South Goodwin Street, Urbana, Illinois 61801

Jacques L. Reisse, Cochair
Université Libre de Bruxelles, Chimie Organique, CP 165, Avenue F. D. Roosevelt 50, 1050 Brussels, Belgium

Chair's Introduction—7:55

Invited Papers

8:00

3aPAa1. Under which conditions is sonochemistry able to give information about the so-called extreme conditions prevailing inside the collapsing bubbles? Jacques Reisse, Kristin Bartik, and Nicolas Segebarth (Univ. Libre de Bruxelles, Chimie Organique, CP 165, 50, ave. F. D. Roosevelt, 1050 Bruxelles, Belgium)

Sonochemistry is able to give information about the extreme conditions prevailing inside collapsing bubbles. However, this information is obtained only when the experimental data correspond to primary chemical steps taking place in the gas phase inside the bubbles. This is unfortunately often not the case: The experimental data correspond, in the majority of cases, to secondary reactions taking place either in a shell around the collapsing bubble or in the bulk liquid. The short introductory talk to the sonochemistry session will be devoted to trying to answer the following questions: How must reactions, able to give relevant information about the so-called extreme conditions inside the bubbles, be selected? What is the actual reaction zone inside the bubble and what are the temperature limits for this zone? Is it certain that the ''active zone'' for sonochemistry is always the same as the ''active zone'' for sonoluminescence? Why does sonochemistry involve radicals instead of ions?

8:20

3aPAa2. Sonochemical preparation of protein microspheres. Kenneth S. Suslick, Kenneth J. Kolbeck, Gregory S. Kufner, and Gregory W. Szewczyk (Dept. of Chemistry, Univ. of Illinois, 601 S. Goodwin Ave., Urbana, IL 61801)

Aqueous suspensions of protein microspheres with Gaussian-like size distributions in the micron size range can be produced with high-intensity ultrasound by the sonochemical oxidation of cysteines to form interprotein disulfide cross links. The microspheres can be synthesized containing a core of aqueous or organic liquids (i.e., microcapsules) or air (i.e., microbubbles such as Albunex). The micron sized spheres are contained by a 60-nm layer of protein (approximately ten protein molecules.) The small diameter (less than 5 μm) of the microspheres permits the microspheres to circulate through the bloodstream, while sonochemically linking native protein to form microspheres prevents the expected *l* immune response. To date, we have synthesized microspheres that can be monitored with *in vivo* imaging techniques (MRI and x-ray) as well as microscopy. The distribution and circulation lifetime in the bloodstream has been altered by modifying the properties of the microsphere. These microspheres have many potential biomedical applications such as drug delivery vehicles, blood substitutes, and radiological imaging agents.

8:40

3aPAa3. Sonochemistry of aqueous solutions: EPR and spin trapping studies of radical intermediates. Peter Riesz and Vladimir Misik (Natl. Cancer Inst., NIH, Bethesda, MD 20892-1002)

The primary free radical species produced in the sonolysis of aqueous argon-saturated solutions (i.e., H, OH, and O_2-) and in N_2-containing aqueous solutions (H, OH, O_2-, NO) can be identified by electron paramagnetic resonance (EPR) combined with spin trapping. The EPR experiments using cadmium(2+) ions as hydrated electron scavengers show that no detectable level of hydrated electrons is formed in the sonolysis of argon-saturated water at neutral *p*H. The temperature dependence of the semi-classical treatment of the kinetic isotope effect for H and D formation by O–H and O–D bond scission in 1:1 H_2O–D_2O mixtures was used to estimate the effective temperatures (2000–4000 K using phenyl *t*-butyl nitrone spin traps) in collapsing cavitation bubbles. At low concentrations of nonvolatile solutes (e.g., acetate ions, amino acids, and sugars) only radicals formed by H-abstraction were observed. At high concentrations, pyrolysis radicals such as methyl radicals from acetate, amino acids, and sugars could also be spin trapped. For volatile organic solutes, the effect of the vapor pressure of the solute on the effective value of gamma (the ratio of C_p/C_v) in the cavitation bubble is the major determinant of radical yields.

9:00

3aPAa4. Sonoluminescence and sonochemistry in aqueous solutions containing surface active solutes. Franz Grieser, Muthupandian Ashokkumar, and Katrina Barbour (AMPC, School of Chemistry, Univ. of Melbourne, Parkville, 3052 Australia)

The ultrasound induced reduction of gold chloride in aqueous alcohol solutions has been measured and compared with the extent of sonoluminescence (SL) quenching observed in the same solutions, as a function of alcohol concentration. Both ultrasound initiated phenomena were found to be directly related to the Gibbs surface excess concentration of the alcohol at the gas/water interface. The SL quenching occurs in two distinct surface excess regimes. The first region accounts for about 90% quenching of the SL signal. The second quenching region extends over a broader surface excess range and the profile matches the extent of enhancement in the reduction of gold chloride. When the nonvolatile surfactant sodium dodecylsulfate (SDS) was used instead of alcohol, the trends in the SL signal and in the sonochemical reduction process were quite different. At low concentrations (<2 mM) of SDS, the SL signal was enhanced over that obtained from water without surfactant. At higher SDS concentrations, the SL signal declined and leveled off to about 80% of the water signal at about 10 mM. In contrast, the reduction of gold chloride increased to about 8 mM SDS and then remained constant above this value. Possible mechanisms that explain the results will be presented.

9:20–9:40 Break

9:40

3aPAa5. Sonochemical reactor optimization using computational acoustics techniques. Jean-Louis Y. Migeot (LMS Numerical Technologies, 70 Interleuvenlaan, 3001 Leuven, Belgium)

The designer of a sonochemical reactor is confronted by a complex problem characterized by a large number of design parameters: reactor shape and dimensions, number, positions and power of ultrasound sources, frequency, solvant, temperature, etc.? A wide parametric study cannot be conducted experimentally due to time and cost constraints and a numerical model seems the only viable approach. Such a model must reflect the inherent complexity of the system and at the same time be simple enough to provide relevant results in a reasonable amount of time. This paper proposes an iterative modeling methodology based on the following steps: (1) a finite-element model of the fluid in the reactor, (2) a relationship between local acoustic pressure and gas fraction released by cavitation, and (3) equivalent acoustic properties for the cavitating medium. After a few iterations, this model leads to two main results: (1) the pressure field in the reactor and (2) the cavitation zone and the distribution of gas fraction in this cavitation zone. One can further postprocess the pressure field to predict the streaming forces on the fluid and therefore predict the flow pattern using classical CFD techniques.

10:00

3aPAa6. Sonochemistry—A demonstration lecture. Timothy J. Mason (Sonochemistry Ctr., School of NES, Coventry Univ., Coventry CV1 5FB, UK)

The potential uses of sonochemistry for the processing and chemical industries of the future have been established already in the chemical laboratory. The driving force for this technology is acoustic cavitation and a deeper understanding of this phenomenon will be required to help sonochemistry achieve more widespread acceptance and implementation in industry. For this reason a coordinated research effort is needed involving not only chemists but engineers, physicists, and mathematicians. In the past interaction between these disciplines has been limited due to the different scientific circles in which they move, but a few conferences, including this one, have sought to bring such disciplines together to promote cooperation. This presentation incorporates a series of demonstrations which illustrate the types of physical and chemical effects of cavitation and ultrasound which interest the chemist. These will include degassing, the generation of free radicals, the effects of cavitation near a surface, the dispersion of solids, emulsification, and particle manipulation in an acoustic field. Hopefully these will serve not only as an introduction to sonochemistry for those whose main discipline is not chemistry, but also as a focus for the powerful effects of cavitation which need deeper coordinated exploration.

Contributed Papers

10:20

3aPAa7. The effects of organic compound doping in single-bubble sonoluminescence. Muthupandian Ashokkumar, Franz Grieser (AMPC, School of Chemistry, Univ. of Melbourne, Vic 3052, Australia), William B. McNamara, Kenneth S. Suslick (Univ. of Illinois—Urbana, IL 61801), Thomas J. Matula, C. Allen Frensley, and Lawrence A. Crum (Univ. of Washington, Seattle, WA 98105)

Controlled experiments have been conducted to ascertain the effects of doping with organic compounds on single-bubble sonoluminescence (SBSL) in water. Previous experiments with multi-bubble sonoluminescence (MBSL) indicate that millimolar additions of alcohols quench the sonoluminescence intensity [Ashokkumar *et al.*, J. Phys. Chem. (in press)]. For a given concentration of alcohol, the degree of quenching apparently depends on the hydrophobicity of the alcohols. Similar results are observed in SBSL, using Ethanol, 1-Propanol, and 1-Butanol [intensity quenching measurements of 1-Butanol agrees with those of Weninger *et al.*, J. Phys. Chem. **99** (1995)]. Spectra and radius-time measurements are obtained for these systems. Further experiments with weak organic acids and bases, which change their neutrality with *p*H, are also being conducted. The results and possible interpretations will be discussed. [This research supported by DOE, NSF, and the ARC.]

10:35

3aPAa8. An interpretation of the MBSL temperatures deduced from metal atom emission. Lawrence S. Bernstein (Spectral Sci., Inc., 99 South Bedford St., Burlington, MA 01803, larry@spectral.com)

Recent MBSL observations [McNamara *et al.*, Univ. of Illinois (private communication)] of metal atom emission from a variety of metal carbonyls seeded into Ar display similar peak emission temperatures of approximately 5000 K. Additionally, metal ion emission lines have not been detected. These observations can be interpreted to mean that the peak emission temperature is also the peak collapse temperature. The same conclusion was previously reported based on the same 5000 K temperature observed for C2 MBSL. However, it was argued [Bernstein *et al.*, J. Phys. Chem. **100**, 6612 (1996)] that the chemistry giving rise to C2 emission

turns on and off in a narrow temperature window around 5000 K. Thus it was concluded that C2 emission is not a useful thermometer for higher collapse temperatures which may be attained in MBSL. It is argued that a similar situation exists for the metal atom emission chemistry. Detailed calculations based on a coupled chemical–hydrodynamic collapse model support this hypothesis. The lack of observed metal atom ion lines is attributed to the absence of sufficiently strong lines in the observational spectral window of the experiments.

Session 3aPAb

Physical Acoustics: Nonlinear Acoustics I: 1. History; 2. Solids; Rocks; 3. Surface Waves, Part 1

Lev A. Ostrovsky, Cochair
NOAA/ERL/ETL, 325 Broadway, R/E/ET-1, Boulder, Colorado 80303

Mack A. Breazeale, Cochair
National Center for Physical Acoustics, Coliseum Drive, University, Mississippi 38677

Invited Papers

7:45

3aPAb1. Development of solid state nonlinearity. M. A. Breazeale (Natl. Ctr. for Physical Acoust., Univ. of Mississippi, University, MS 38677)

The nonlinear acoustics of solids developed from the nonlinear acoustics of fluids. Originally, the problem was to undo correctly the Hooke's Law assumption without losing nonlinear terms. At present, one problem is to find a use for nonlinear acoustics of solids. The first problem has been solved; the second one is an ongoing one. It is the reason for special sessions. To develop geological exploration based on nonlinear acoustics, at first it was thought that nonlinear acoustics of crystalline solids would do. Now it is known that other nonlinearities must be considered. The purpose of the present paper is to show how solid state nonlinear acoustics developed, how nonlinear acoustics of crystals requires only one nonlinear term, and to give evidence of the fact that the subject needs to be expanded.

8:05

3aPAb2. Acoustic nonlinearities in earth solids. Lev A. Ostrovsky (Univ. of Colorado, CIRES/NOAA Environ. Technol. Lab., 325 Broadway, R/E/ET1, Boulder, CO 80303, lostrovsky@etl.noaa.gov) and Paul Johnson (Los Alamos Natl. Lab., Los Alamos, NM 87545)

Nonlinear elastic response in earth solids is a robust and representative physical characteristic. In this lecture the evidence leading to this conclusion is presented by providing an overview of theoretical and experimental developments in the domain. Illustrated measurements include those of nonlinear response in rock from a variety of dynamical wave experiments. The evidence leads to a pattern of unifying behavior. Nonlinear elasticity in earth solids is large relative to most materials; hysteresis and ''discrete'' memory play an important role in nonlinear properties of earth solids; nonlinear response is evident over a large frequency interval (dc to several MHz at least); and nonlinear response is significant, as is commonly appreciated, at large static and dynamic strain levels, but also at small strains where this behavior and the manifestations of this behavior are commonly disregarded. Recently, the methodology for extracting the nonlinear coefficients for a material have been proposed. Some theoretical models of structural nonlinearity of solid media and of wave propagation in such media are also described.

8:25

3aPAb3. Model equations for nonlinear surface waves. M. F. Hamilton (Dept. of Mech. Eng., Univ. of Texas, Austin, TX 78712-1063), Yu. A. Il'inskii, and E. A. Zabolotskaya (MacroSonix Corp., Richmond, VA 23228)

The theoretical framework developed originally for modeling nonlinear Rayleigh waves in isotropic elastic half-spaces [Zabolotskaya, J. Acoust. Soc. Am. **91**, 2569 (1992); see also Knight *et al.*, *ibid.* **102**, 1402 (1997)] has been extended to encompass a broad class of nonlinear surface wave problems. The theory is based on Hamiltonian mechanics, in which spatial Fourier amplitudes are used as generalized coordinates, and coupled spectral equations are obtained for the harmonic amplitudes in the wave. The nonlinearity coefficient matrices are expressed explicitly in terms of the second- and third-order elastic moduli of the materials. Solutions of the equations describe harmonic generation, waveform distortion, and shock formation not only at the interface but also in the interior of the solid. Cylindrical spreading and beam diffraction may be taken into account, as can transient effects in pulses. Model equations, and simulations of nonlinear surface waves in real materials, shall be presented for Rayleigh, Stoneley, Scholte, and Lamb waves, and surface waves in crystals and piezoelectric materials. The validity of the theory has been demonstrated via quantitative agreement with measurements of laser-generated Rayleigh wave pulses with shocks in fused quartz [Lomonosov *et al.*, J. Acoust. Soc. Am. **101**, 3080(A) (1997)]. [Work supported by NSF and ONR.]

8:45

3aPAb4. Principles and applications of nonlinear acoustic nondestructive testing. Alexander M. Sutin and Dimitri M. Donskoy (Stevens Inst. of Technol., Davidson Lab., 711 Hudson St., Hoboken, NJ 07030)

Nonlinear acoustic techniques have recently been introduced as a new tool for nondestructive inspection and evaluation of fatigued, defective, and fractured materials. Various defects such as cracks, debonding, fatigue, etc., lead to anomalously high levels of nonlinearity as compared with flawless structures. One of the acoustic manifestations of such nonlinearity is the modulation of ultrasound by vibration. This effect is explained by using a model of the defect as contact between two rough surfaces. The vibration varies the contact area modulating the ultrasonic probing wave passing through the defect. A theoretical model considering interaction of different modes of vibrations and probing waves is discussed. Two methods employing the nonlinear interaction of ultrasound and vibration were developed, namely vibro-modulation (VM) and impact-modulation (IM) methods. The VM method employs forced harmonic vibration of the tested structure, while the IM method uses impact excitation of the structures natural modes of vibration. The crack detection tests were carried out for different objects made out of steel, plastic, glass, concrete, and carbon. These nonlinear techniques demonstrated certain advantages as compared with the conventional linear acoustic technique, specifically high sensitivity and applicability to highly inhomogeneous structures. [First author was supported in part by RFBR, Grant No. 96-05-64459.]

Contributed Papers

9:05

3aPAb5. Measurements of surface-wave harmonic generation in nonpiezoelectric materials. Donna C. Hurley (Natl. Inst. of Standards and Technol., Div. 853, 325 Broadway, Boulder, CO 80303, hurley@boulder.nist.gov)

Methods for exciting surface waves suitable for harmonic generation experiments in nonpiezoelectric materials have been investigated. Such methods are needed for improved characterization of engineered surfaces. Unlike conventional ultrasonic techniques, nonlinear experiments require the ability to produce finite-amplitude, spectrally pure surface waves. Comb structures were selected from the methods evaluated, because they appear to offer the greatest potential for harmonic generation experiments on arbitrary substrates. The out-of-plane component of the surface waves was measured using a Michelson interferometer. The apparatus enabled direct measurement of absolute displacements with a spatial resolution of approximately 50 μm. Using this combination of excitation and detection techniques, the evolution of narrowband surface waves in the 1–10 MHz range was studied. Displacement amplitudes as large as 35 nm at a fundamental frequency of 10 MHz were observed. The spatial behavior of the fundamental and second-harmonic displacements indicated that, for correct interpretation, it was necessary to account for diffraction and other geometrical effects. Quantitative results will be presented for a variety of experimental configurations, including different substrates and comb shapes. Experimental results will also be compared to predictions of available theories for nonlinear surface wave propagation.

9:20–9:30 Break

9:30

3aPAb6. Pulsed nonlinear surface acoustic waves in crystals. R. E. Kumon, M. F. Hamilton (Dept. of Mech. Eng., The Univ. of Texas at Austin, Austin, TX 78712-1063), Yu. A. Il'inskii, E. A. Zabolotskaya (MacroSonix Corp., Richmond, VA 23228), P. Hess (Inst. of Physical Chemistry, Univ. of Heidelberg, 69120 Heidelberg, Germany), A. M. Lomonosov, and V. G. Mikhalevich (General Phys. Inst., Russian Acad. of Sci., 117942 Moscow, Russia)

A theoretical model developed recently for the propagation of nonlinear surface acoustic waves in crystals [Hamilton *et al.*, *Nonlinear Acoustics in Perspective*, edited by R. J. Wei (Nanjing U.P., Nanjing, 1996), pp. 64–69] is used to investigate transient effects associated with pulses. The present work extends an earlier theoretical investigation of pulsed nonlinear Rayleigh waves in isotropic solids [Knight *et al.*, J. Acoust. Soc. Am. **96**, 3322(A) (1994)]. The latter was verified via comparison with measurements of laser-generated nonlinear Rayleigh waves with shocks in fused quartz [Lomonosov *et al.*, J. Acoust. Soc. Am. **101**, 3080(A) (1997)]. Here simulations of waveform distortion and shock formation are presented for pulses in real crystals, including Si, KCl, and Ni, and for a variety of surface cuts and propagation directions. The second- and third-order elastic moduli in the nonlinearity matrix are taken from measurements reported in the literature. Attention is focused on waveforms corresponding to recent measurements of laser-generated nonlinear surface waves propagating in Si along the $\langle 112 \rangle$ direction in the (111) plane [Lomonosov and Hess, *Nonlinear Acoustics in Perspective* (Nanjing U.P., Nanjing, 1996), pp. 106–111]. Preliminary comparisons of theory with measurements obtained in related experiments are in good agreement. [Work supported by ONR and the RFBR Foundation.]

9:45

3aPAb7. Rayleigh wave solitons in layered media. Robert I. Odom (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105)

The problem of weakly dispersive long waves in a thin nonlinear solid layer over a linear isotropic solid half-space is formulated as a nonlinear thin plate problem with one free surface and one surface bonded to the underlying linear isotropic half-space. If terms cubic in the displacement gradient are retained in the nonsymmetric Piola–Kirchoff stress tensor, a multiple-scale perturbation analysis of the equations of motion leads to the Benjamin–Ono equation $u_t + \alpha u u_x + \beta \mathscr{H}[u_{xx}] = 0$, where u is a particle displacement, $\mathscr{H}[\cdot]$ indicates the Hilbert transform, and α and β are constants that depend on the material properties of the layer and half-space. The Benjamin–Ono equation admits soliton solutions, and can be solved by the inverse scattering transform. This work may provide a mathematical model for small amplitude nonlinear seismic waves propagating in a thin sediment layer over a much harder basement. It may also have application to surface acoustic wave (SAW) device physics.

10:00

3aPAb8. Nondestructive flaw detection in a solid medium using nonlinear acoustic effects. C. M. Song, K. I. Jung, and S. W. Yoon (Acoust. Res. Lab., Dept. of Phys., Sung Kyun Kwan Univ., Suwon, 440-746, Rep. of Korea, swyoon@yurim.skku.ac.kr)

In a solid material it is very difficult to find tiny defects or cracks with the conventional linear acoustic techniques as nondestructive evaluation methods. When defects exist in a material, nonlinear acoustic responses become dominant in a propagating medium and can make it possible to detect such defects. As an application of such nonlinear acoustics, a nonlinear acoustic modulation technique for nondestructive flaw detection described in previous work [Kim *et al.*, J. Acoust. Soc. Am. **101**, 3029 (1997)] was applied to several different sample materials to confirm its

feasibility. The second harmonic measurements can easily indicate existence of tiny defects or cracks in the samples. The time-delay measurements of the modulated sum and difference frequency signals can accurately locate defects in aluminum, steel, and brass solid rods, respectively.

10:15

3aPAb9. Slow nonlinear dynamics in rock. R. A. Guyer (Dept. of Phys. and Astron., Univ. of Massachusetts, Amherst, MA 01003), K. R. McCall (Univ. of Nevada, Reno, NV 89557), and K. E-A. Van Den Abeele (Los Alamos Natl. Lab., Los Alamos, NM 87545)

Recent experiments on the elastic response of Berea sandstone show that nonlinear excitation of a resonant bar is accompanied by a slow dynamics, a dynamics involving time scales many orders of magnitude longer than the excitation period, $2\pi/\omega$. A lumped-element description of a resonant bar is developed. A complementary phenomenological theory of slow nonlinear dynamics is postulated. This phenomenological theory is used in the lumped-element description to explain the experiments. The results illustrate the possibility of experimental exploration of slow nonlinear dynamics using the acoustic analogue of a NMR experiment. [Work partially supported by OBES, Engineering and Geosciences Grant No. W7405-ENG-36, the National Science Foundation Grant No. EAR-9528965, and the Institute of Geophysics and Planetary Physics at Los Alamos National Laboratory.]

10:30

3aPAb10. Nonlinear behavior in rock: Experiments show two distinct behaviors. James A. TenCate, Koen E. A. VanDenAbeele,[a] and Thomas J. Shankland[b] (Los Alamos Natl. Lab., Los Alamos, NM 87545)

The compliant features of rocks—cracks, pores, and the fluids filling them—give rise to a variety of nonlinear elastic effects. As a means of achieving large dynamic strains, longitudinal resonance experiments on thin bars of sandstones were performed. Resonance curves were obtained by measuring acceleration at the end of the bar while sweeping frequency at a fixed drive level. As drive levels increased, resonance curves showed peak bending toward lower frequencies (softening modulus). Two very distinct nonlinear behaviors were observed for several different rock samples. At moderate strain amplitudes ($\approx 10^{-6}$), the effects of nonlinearity became quite pronounced: rapid peak shifting and resonance curve shape changes were accompanied by slow dynamics—shapes of the nonlinear resonance curves depend on sweep direction and rate [Geophys. Res. Lett. **23**, 3019–3022]. However, even at lower strain amplitudes, nonlinearity remains. Small frequency shifts are observed, even down to the measurement noise of our apparatus. The exact nature of the transition between the two nonlinear behaviors (e.g., effects of temperature or composition) and an explanation for the nonlinearity at very low strain levels are being pursued. [Work supported through the Office of Basic Energy Sciences—Geosciences of the Department of Energy.] [a]Currently at Laboratorium Bouwfysica, K.U. Leuven, Belgium. [b]Currently at Bayerisches Geoinstitut, Bayreuth, Germany.

WEDNESDAY MORNING, 24 JUNE 1998 FIFTH AVENUE ROOM (W), 9:15 TO 11:40 A.M.

3a WED. AM

Session 3aPP

Psychological and Physiological Acoustics: Auditory Attention I

Donna L. Neff, Cochair
Boys Town National Research Hospital, 555 North 30th Street, Omaha, Nebraska 68131

Ervin R. Hafter, Cochair
Department of Psychology, University of California, 3210 Tolman Hall, #1650, Berkeley, California 94720

Chair's Introduction—9:15

Invited Papers

9:20

3aPP1. Shared attention to simultaneous stimulation. Ervin R. Hafter, Anne-Marie Bonnel, and Erick Gallun (Dept. of Psych., Univ. of California, Berkeley, CA 94720, hafter@socrates.berkeley.edu)

Shared attention is studied using a dual task, where observers respond independently to two simultaneously presented signals. Cost is defined by a loss in performance relative to one signal tested alone. Standard stimuli are followed by signals that can be either incremental or decremental changes in level, frequency, or spatial location, relative to the standard. In a ''detection'' paradigm, the subject says ''change'' for signals of either polarity, but in an ''identification'' paradigm where all trials present signals, the subject responds with the polarities. Comparing results with fixed standards to those with a standard that roves from trial to trial shows that a major determinant of the cost of shared attention is the type of memory used in the task. Fixed standards, which show reliance on absolute memory, yield relatively high performance, but there is a cost of shared attention. Conversely, with roved standards, where absolute memory cannot be used, performance is relatively low and there is no cost. Thus a dissociation is found in which the additional process used in the context-coding mode is costly for attention but not performance. [Research supported by the Natl. Inst. of Health (NIDCD 07787), USA, Univ. of California, USA, and CNRS, France.]

9:45

3aPP2. Cross-modal links between auditory and visual attention. Charles Spence (Dept. of Psych., Oxford Univ., South Parks Rd., Oxford OX1 3UD, England, charles.spence@psy.ox.ac.uk) and Jon Driver (Univ. College London, London WC1E 6BT, England)

Using the orthogonal spatial-cuing paradigm, it has been shown that people make elevation discriminations concerning target sounds more rapidly and accurately when auditory targets are presented at covertly attended azimuths location [C. Spence and J. Driver, J. Exp. Psychol. Hum. Percept. Perform. **20**, 555–574 (1994)]. These shifts of auditory spatial attention could either be elicited endogenously, by informative cues that predicted the likely target location, or exogenously by peripherally presenting spatially uninformative auditory cues. More recently, extensive cross-modal links between audition and vision in the control of both exogenous and endogenous orienting have been reported, such that, for example, a shift of auditory attention typically leads to a shift of visual attention to the same location [C. Spence and J. Driver, J. Exp. Psychol. Hum. Percept. Perform. **22**, 1005–1030 (1996)]. Participants in all previous behavioral studies of crossmodal attention had their eyes and head in spatial alignment. New data is reported showing a partial remapping of audiovisual space when the eyes and head are misaligned (i.e., when people look out of the corner of their eyes). This remapping ensures that attention is oriented to the correct distal location, irrespective of receptor misalignment. [Work supported by MRC (UK).]

10:10

3aPP3. Auditory objects of attention. C. J. Darwin and R. W. Hukin (Exp. Psych., Univ. of Sussex, Brighton BN1 9QG, UK, cjd@biols.susx.ac.uk)

Although interaural time differences (ITDs) are the dominant cue for the lateralization of complex sounds, they are remarkably weak at grouping together simultaneous sounds. Experiments are reviewed which explore the relationship between this observation and auditory attention. A small difference in ITD between two sentences spoken in the same voice is sufficient to allow a listener to say which of two target words occurred in the attended sentence, even when the two sentences are resynthesised to have the same fundamental frequency. By contrast, a large difference in ITD does not allow a listener to exclude a single harmonic from a target steady-state vowel within an attended sentence. The results can be explained by assuming that listeners are not able to attend directly to frequency components that share a common ITD. Rather, listeners attend to the direction of auditory objects, whose frequency composition is determined by grouping cues such as onset time and harmonicity, and whose lateral position is determined from the lateralization cues of the component frequencies. [Work supported by UK MRC.]

10:35–10:50 Break

10:50

3aPP4. Perceiving talking faces: Insights into attention. Dominic W. Massaro (Dept. of Psych., Univ. of California, Santa Cruz, CA 95064)

Perceivers naturally integrate auditory and visual information in the perception of speech and emotion. Although both modalities contribute to perception, instructions and intention appear to modulate the impact of these modalities. Although there is some influence of the to-be-ignored modality, perceivers can attenuate its influence so that some degree of control is possible. The fuzzy logical model of perception provides a good account of performance under the different instruction conditions. For the estimation of the free parameters corresponding to the parameters that correspond to the evaluation of the auditory and visual sources, the FLMP assumed different parameter values in the different instruction conditions. Different parameter values were sufficient to capture the results. Intention can thus be accounted for in terms of information with no qualitative changes in information processing. Within the framework of the FLMP, the fundamental pattern recognition algorithm does not change. Bearing out this assumption, intention can enhance or attenuate the information contribution of sources that are available, but intention does not seem capable of enforcing another type of pattern recognition algorithm. Future research using expanded factorial designs should be able to provide a more definitive understanding of the role of intention and attentional set in pattern recognition. [Work supported by NIDCD.]

11:15

3aPP5. Electrophysiological studies of auditory spatial attention. Steven A. Hillyard and Wolfgang A. Teder-Salejarvi (Dept. of Neurosci., U.C. San Diego, La Jolla, CA 92093, shillyard@ucsd.edu)

Recordings of event-related potentials (ERPs) from the scalp can track the processing of auditory signals through the afferent pathways from brainstem to cortex. ERP components elicited in auditory cortex during the time range 50–200 ms are highly sensitive to selective attention, with attended sounds eliciting greater amplitudes than unattended sounds. Using combined ERP and behavioral measures, the allocation of auditory attention was studied in a free-field array of seven or eight speakers. Brief noise bursts were presented in a random, fast-paced sequence from all the speakers, and subjects were required to attend to the sounds at one location while ignoring the others. Both behavioral detection responses and ERP amplitudes were highest for stimuli at the attended location, with a progressive falloff for responses to increasingly distant sound sources. These data revealed the shape of spatial tuning curves for auditory attention in free-field and support gradient models of attentional allocation. An analysis of ERP waveforms indicated that spatial selectivity is established by consecutive stages of progressive fine-tuning over the time range 50–350 ms poststimulus. [Work supported by Grants from NIMH and ONR.]

Session 3aSA

Structural Acoustics and Vibration: Damping and Absorption

Jean R. Nicolas, Chair
Department Genie Mecanique, Universite de Sherbrooke, Uds 2500 Boulevard de l'Université, Sherbrooke, QC J1K 2R1, Canada

Contributed Papers

8:00

3aSA1. An algorithm for calculation of material loss factors using single degree of freedom method and digital data measured by FFT analyzer. Toshiyuki Maeda (Dept. of Mech. Eng., Nishinippon Inst. of Technol., 1633, Aratsu, Kanda, Miyako, Fukuoka, 800-03 Japan, t.maeda@nishitech,ac,ip)

The half-power band-width method that is conventionally used to calculate material loss factors cooperated with one single degree of freedom method using data of each resonance response of a material bring out estimation errors caused by approximation of resonance frequency due to discrete frequency when data are measured with FFT analyzer. The proposed new algorithm is able to determine the actual resonance frequency, and its amplitude directly from digital data and loss factors without approximation.

8:15

3aSA2. Dynamic and acoustic properties of beams of composite material. Shiva Sander Tavallaey (MWL, Dept. of Vehicle Eng., KTH, 100 44 Stockholm, Sweden)

Modern engineering techniques require the use of more sophisticated and optimized structural design. One way towards this aim is the use of materials which in some way optimize their inherent properties. A concept which suits this purpose very well is composite/sandwich material. Sandwich/composite materials find numerous applications where high strength and low weight are important criteria. The dynamic behavior of a sandwich beam with different boundary conditions has been investigated. Measurements have been carried out. Free-free and clamped-clamped boundary conditions were included. Modal analysis has been used to estimate resonance frequencies and modal parameters. Further, acoustical parameters of a composite plate are measured. An analytical model for prediction of wave propagation constants in sandwich/composite structure is presented. Measured and predicted results are compared.

8:30

3aSA3. Full-spectrum-based acoustic spectroscopy for determining elastic and damping constants in forced-free bars. Qiushuang Guo and David A. Brown (Dept. of Elec. and Comput. Eng., and Ctr. for Marine Sci. and Technol., Univ. of Massachusetts—Dartmouth, N. Dartmouth, MA 02747)

Elastic moduli and damping have been previously determined by measuring the resonant frequencies and quality factor of a virtually free–free bar. The development of a complete analytical solution to the longitudinal wave equation including damping effects for a bar freely supported, driven at one end, and under the influence of transducer mass and stiffness at both ends was previously reported on [Qiushuang Guo and David Brown, ''Effects of transducer mass on resonance frequency and quality factor of free-free bar,'' J. Acoust. Soc. Am. **101**, 3062 (1997)]. The analytical solution to the torsional and flexural waves in a bar including damping effects will be reported on here. When the entire spectrum of data is used, a more accurate determination of elastic moduli and internal damping coefficient is obtained. [Work supported by the University of Massachusetts—Dartmouth.]

8:45

3aSA4. Numerical method using filter banks for vibroacoustic analysis in the medium frequency domain. Sylvie Gorog and Philippe Micheau (Université de Sherbrooke, Sherbrooke, QC J1K 2R1, Canada)

Efficient numerical tools are needed to predict the vibroacoustic response of a viscoelastic structure in the medium frequency range. The presented method is formulated within the framework of nonuniform modulated filter banks, a signal processing tool. The structure is described using a variational approach. The method consists of dividing the frequency domain of interest into several subdomains and hence solving a time domain equation of motion for each subdomain. The complete displacement field is then reconstructed from the different time domain solutions. This time-frequency computations rely on the design of analysis and synthesis filter banks. Flexural vibrations of plates *in vacuo* are studied to illustrate the numerical efficiency of the method. According to the variational approach that is used, results show that the proposed method allows the computation of the solution in frequency domains where classical modal methods and direct methods are limited from a numerical point of view. This numerical tool is of great interest for the study of structures having frequency-dependent properties.

9:00

3aSA5. Improvement of damping via analysis of viscoelastic composites. Ibrahima Sow, Jean Nicolas, and Toan Vu-Khanh (Dept. Genie Mecanique, Universite de Sherbrooke, UdS 2500 Blvd. de l'Universite Sherbrooke, QC J1K 2R1, Canada)

High damping materials allow vibration and noise to be suppressed or at least reduced. Unfortunately, materials with high loss tangents also exhibit low modulus of elasticity. A new composite damping material is investigated, which consists of specially designed fibers embedded in a viscoelastic matrix. This new approach not only enhances damping through improvement of matrix loss tangent by the addition of elastomer, but also through selection of adequate ply orientation, ply stacking, geometry of fibers, and fraction of fibers. Theoretical analysis of the viscoelastic properties of this composite is presented in order to identify the optimum material with high stiffness and high loss tangent according to all parameters. To address validation theoretical developments are compared to experimental results.

9:15

3aSA6. Characteristics for vibration damping of the concrete included secondary subject. Noboru Ishikawa and Hidemaro Shimoda (Inst. of Technol., Shimizu Corp., 3-4-17 Etchujima Koto-ku, Tokyo, 135 Japan)

A concrete structural material with damping performance for vibration has been investigated. It is proposed that in order to reduce the sound propagation in the solid material, the concrete material disperses many

small cells in which many easy moving particles are included. It is expected that the vibration energy which is applied to the material is absorbed by the impaction and friction of the particles alternatively and between particles and cell's wall. The preliminary experiment to confirm the capability of the high damping material on the basis of this concept has been carried out. It was shown that damping performance of the specimen depended on the size, the density, and the volume fraction of the particles by the impact vibration testing for the coupon-sized test specimen. The effect of the easy moving particles for reduction of the sound propagation in the solid was confirmed by the sound propagation testing for the middle-sized panel specimen.

9:30

3aSA7. Finite-element modeling of the vibroacoustic behavior of poroelastic materials. Hamid Bouhioui and Murray Hodgson (UBC, Dept. of Mech. Eng., 2324 Main mall, Vancouver, BC V6T 1Z4, Canada, bouhioui@mech.ubc.ca)

Porous materials are widely used nowadays as part of the insulation systems in the automotive industry or as effective sound absorbers in other areas, such as architecture. Their complex dynamic behavior is due to the various interaction phenomena within the elastic porous material. Such materials have been effectively modeled thanks to the original work of Biot. In the work reported here, the classical Biot theory for elastic porous materials is used for the development of a new three-dimensional finite element. While the finite-element development remains classical, a new numerical implementation is proposed. This new approach allows very fast computation times compared to the approaches existing in the literature. The finite element developed is general and suitable for any type of finite-size, extended-reaction porous material, with any boundary conditions. Comparisons are made using solutions found in the literature, along with a fine analysis of different aspects of the vibroacoustic behavior of porous materials.

9:45

3aSA8. Modeling of porous material added damping on a vibrating plate. Nicolas Dauchez, Sohbi Sahraoui (Laboratoire d'acoustique, Université du Maine, UMR CNRS 6613, Av O. Messiaen, 72085 Le Mans Cedex 9, France, dauchez@laum.univ-lemans.fr), and Noureddine Atalla (Université de Sherbrooke, Sherbrooke, QC J1K 2R1, Canada)

Porous materials like plastic foam are well known for their ability to absorb sound. When bonded onto a vibrating structure they may add damping. Their damping performance is investigated here. The generic configuration is a free aluminum plate (28 cm$\times$22 cm$\times$1 mm) mechanically excited (20–500 Hz), damped by a 1- to 5-cm-thick foam layer. The analysis of porous material behavior, based on Biot–Allard theory [J.-F. Allard (Chapman and Hall, 1993)] shows that damping is mainly related to the frame viscoelasticity. A formulation of an equivalent plate, substituting the porous layer by a monophasic viscoelastic material, is presented. This formulation gives behavior indicators, like amount of added stiffness and damping. It also accelerates the computation of the structure vibration, compared with a 3-D finite element code, including poroviscoelastic elements [R. Panneton and N. Atalla, J. Acoust. Soc. Am. **100**, 346–354 (1996)]. Good agreement is found with both the complete discretized formulation and experimental results. Maximum damping available from biphasic phenomena, like air flow induced by the layer flexure, is also evaluated and compared with structural damping. This shows that more sophisticated mounting conditions should be used to take advantage of the biphasic property.

10:00

3aSA9. On the use of assumed spatial distributions for the vibration analysis of built-up plate structures. Ross A. Fulford and Bjorn A. T. Petersson (Loughborough Univ., Loughborough, Leicestershire LE11 3TU, UK)

For the vibratory analysis of built-up structures, traditional pointlike connections cannot be applied where the interface is large and the wavelength small. Instead, the spatially distributed wave field has to be accounted for whereby the interface has to be considered as either a surface or, for a one-dimensional contact, a line. To analyze such, the traditional approach is to rely upon numerical methods such as the finite element method. These approaches are often cumbersome, however, in that they reveal little about the physics of the systems. As an alternative, this paper considers the development of a method whereby the spatially distributed properties of a line contact can, with the salient physics retained, be included in simplified mathematical models. The basis of the method is to describe the spatial properties with respect to Fourier components and hypothesize that the first order, i.e., uniform, component is most influential. Via an assumed uniform force distribution, the approach is applied, with some promise, to the problem of predicting the vibratory power transmission between a box and a plate.

10:15

3aSA10. Statistical analysis of boundary sound absorption in a panel-cavity system. K. S. Sum and J. Pan (Dept. of Mech. and Mater. Eng., Univ. of Western Australia, Nedlands, Western Australia 6907)

Sound absorption due to acoustic-structural coupling has a significant effect on the acoustical behavior of an enclosed sound field in vibroacoustic systems. In the high-frequency range, this absorption is related to the average behavior of acoustic and structural modes and a statistical description (e.g., statistical energy analysis) of the coupling and its effect on the sound field response is well known. In both the low- and medium-frequency ranges, acoustic-structural coupling of low-order modes tends to dominate and there are large variations in acoustical behavior between acoustic modes. Therefore accurate modal description of the sound field boundary conditions is now important. However, in the medium-frequency range, the complicated boundary conditions are difficult to describe due to the presence of a large number of dominant acoustic and/or structural modes. Thus acoustic-structural coupling is not well understood and the physical interpretation of sound absorption in this frequency range is not clear. The aim of this paper is to obtain some physical insights in the behavior of sound absorption due to acoustic-structural coupling at medium frequencies. The coupling is statistically analyzed for a panel-cavity system and its physical relationship to the boundary sound absorption is illustrated.

10:30

3aSA11. Sound transmission through multilayer structures with isotropic elastic porous materials. Noureddine Atalla, Raymond Panneton, Michel Tournour, and Celse K. Amedin (G.A.U.S., Dépt. Génie Mécanique, Univ. de Sherbrooke, Sherbrooke, QC, Canada)

This paper discusses the prediction of transmission loss through multilayer structures with porous materials. First, a brief review of recent formulations for multilayer structures with poroelastic materials is presented. Second, the transmission loss problem is described and formulated using a coupled finite element and boundary element procedure. Issues such as poroelastic-elastic coupling, poroelastic-fluid coupling, and radiation from a poroelastic material will be addressed. The developed model is validated through numerical examples. Its advantages and limitations are discussed. Finally, typical results showing the vibroacoustic effects of several parameters such as the multilayer configuration, the types of porous materials, and the mounting conditions are presented. [Work supported by Bombardier, Inc., Canadair and N.S.E.R.C.]

Session 3aSC

Speech Communication: Language Specific Influences During Infancy

Peter W. Jusczyk, Chair
Psychology Department, Johns Hopkins University, Ames Hall, Charles Street at 34th, Baltimore, Maryland 21218-2686

Chair's Introduction—9:15

Invited Papers

9:20

3aSC1. Bilingual exposure and some consequences on native-language recognition processes at four months. Laura Bosch (Dept. Psicologia Basica, Universitat de Barcelona, Passeig de la Vall d'Hebron, 171, 08035 Barcelona, Spain)

Evidence of language-specific influences on infants' speech perception presupposes the existence of a basic level of native-language representation. Findings from a language discrimination task, indicating that two-month-old infants perform successfully only when one of the two languages is the native one, but not when both are unfamiliar languages, have been interpreted as evidence that a primary representation of the structure of the native language has been reached, and is probably based on the prosodic/rhythmic properties of the input language (Mehler *et al.*, 1996). The capacity to discriminate languages seems also to be dependent on their prosodic distance. Recent research in this laboratory has addressed the issue of language discrimination for a prosodically close pair of Romance languages, i.e., Spanish and Catalan. While four-month-old infants from monolingual environments seem able to recognize their native language, either Spanish or Catalan, infants from bilingual families did not show a preference for either language. In a second series of experiments, infants from bilingual environments were tested with the same procedure, this time selecting one of their familiar languages to be contrasted with a completely unfamiliar one (English and also Italian). When compared to infants from monolingual families, they showed slower orientation latencies toward the familiar language.

9:45

3aSC2. Effects of language experience on speech perception. Patricia K. Kuhl (Dept. of Speech and Hearing Sci., Univ. of Washington, Seattle, WA 98195)

Language experience during the first year of life has a dramatic effect on infants' perception and production of speech. In this presentation, (a) studies of cross-language effects of language experience on consonant and vowel perception, (b) studies of the effects of speech experience on infants' vowel production, and (c) infant Mismatched Negativity (MMN) responses for speech will be used to show that language experience causes infants to ignore physical differences between speech stimuli that are irrelevant in their native language. A theory is offered to explain how early language experience alters speech perception. The theory holds that listening to native-language speech causes infants to develop ''perceptual maps'' of the incoming speech information. These maps functionally alter the perceived distances between physical stimuli. [Work supported by NIH.]

10:10

3aSC3. The development of phonetic perception in the first year of life. Linda Polka (School of Commun. Sci. and Disord., McGill Univ., Montreal, QC H3G 1A8, Canada, cztg@musica.mcgill.ca)

There is considerable evidence that language-specific influences on speech perception begin early in life with attunement to different aspects of language structure emerging at different ages in the first year. With respect to segmental units, cross-language research has focused on the perception of syllables differing in a single consonant. This talk will focus on research investigating developmental patterns in cross-language vowel perception in the first year of life. A series of experiments exploring vowel perception in English-learning and German-learning infants as well as English-speaking and German-speaking adults will be presented. The results provide further insights into the emergence of language-specific influences and also reveal language-universal perceptual biases that infants bring to the task of vowel perception. Implications of these findings with respect to the early development of phonetic perception and vocal production will be addressed. [Work supported by NSERC.]

10:35–10:45 Break

10:45

3aSC4. Developing sensitivity to native language sound patterns. Peter W. Jusczyk (Depts. of Psych. and Cognit. Sci., Johns Hopkins Univ., Baltimore, MD 21218, jusczyk@jhu.edu)

During the second half of their first year, English-learning infants begin to show sensitivity to the structure and organization of native language sound patterns. In particular, they give evidence of recognizing the phonetic, phonotactic, and prosodic characteristics of native language words. Moreover, their sensitivity to these features of native language sound organization appears to play a critical role in infants' ability to segment words from fluent speech. Evidence for the use of this language-specific information in word

segmentation by infants will be presented. In particular, we will focus on changes in the development of word segmentation abilities between 7.5 and 10.5 months of age. In addition, findings will be considered that suggest infants' representations of the sound patterns of words are detailed both in terms of the phonetic properties and indexical features that they include. [Work supported by NICHD and NIMH.]

11:10

3aSC5. Updates on becoming a native listener. Janet F. Werker, Judith E. Pegg, Rushen Shi, and Christine Stager (Dept. of Psych., Univ. of British Columbia, 2136 West Mall, Vancouver, BC V6T 1Z4, Canada)

Infants' sensitivity to the sound structure of the native language becomes finely honed during the first year. New studies confirm and extend this fact in the domains of phonetic, metrical, and grammatical processing. First, infants were tested on their ability to discriminate phonetic, but nonmeaningful differences in the native language. Although most 6- to 8-month olds discriminated [d] versus [t], 10- to 12-month olds did not. Thus, by 10–12 months, infants listen to only those phonetic differences that distinguish acceptable native-language syllabic shapes. Next, English-learning infants' discrimination of single syllable words such as ''clone'' from their WS counterparts, e.g., ''cologne'' was examined. Testing infants from the newborn period through the first year of life revealed that this ability is not robustly evident until around 10 months. Finally, the authors asked whether infants are sensitive to the acoustic and phonological cues distinguishing content from function words. Using lists of content versus function words excised from infant-directed utterances, it was found that both neonates and 6-month olds distinguished these broad grammatical categories. These studies confirm and extend our understanding of initial biases and listening experiences on infant speech processing. A critical question the authors are now addressing is how these changes in speech perception prepare the child for language learning.

11:35

3aSC6. Rapid gains in the speed and efficiency of word recognition by infants in the second year. Anne Fernald, John P. Pinto, and Daniel Swingley (Dept. of Psych., Stanford Univ., Stanford, CA 94305-2031)

Toward the end of the second year, during the period of rapid development in productive vocabulary known as the ''vocabulary explosion,'' infants also make dramatic gains in the speed and efficiency with which they are able to recognize familiar words in fluent speech. Here several studies using an on-line measure of speech processing by infants from 15 to 24 months of age are presented. In this research, an auditory-visual matching procedure, in which infants looked at two familiar pictures while hearing a target word that matched one of the pictures, was used. Monitoring infants' eye movements from the onset of the target word, word recognition was assessed by measuring infants' latency to look to the matching picture in response to the spoken word. These studies show that by the end of the second year, children are progressing toward the highly efficient performance of adults, using incomplete acoustic information to make rapid and accurate decisions about the identity of spoken words. [Work supported by NIMH.]

12:00–12:10 Discussion

WEDNESDAY MORNING, 24 JUNE 1998 METROPOLITAN BALLROOM (S), 7:45 TO 10:45 A.M.

Session 3aUW

Underwater Acoustics and Acoustical Oceanography: Bottom Geoacoustic Characterization and Inversion I (Précis Poster Session)

Subramaniam D. Rajan, Chair
Scientific Solutions, 5907 106th Avenue, NE, Kirkland, Washington 98033

In this session, an oral summary of each paper will be presented followed by a poster session. All posters will be on display, and all contributors will be at their posters, from 9:30 a.m. to 10:45 a.m.

Chair's Introduction—7:45

Invited Paper

7:50

3aUW1. Measuring parameters that control acoustic propagation in granular sediments near the seafloor. Robert D. Stoll (Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY 10964, stoll@ldeo.columbia.edu)

Propagation of acoustic waves in granular sediments near the water-sediment interface is controlled by a number of parameters such as fluid and grain compressibility, permeability, and the compressibility and shear stiffness of the skeletal frame in a water environment. A new experimental technique for evaluating several of these properties is described wherein a cylindrical, water-saturated sample is subjected to vertical, steady-state fluid flow. By controlling the hydraulic gradient, any desired vertical, effective

stress may be generated and acoustic measurements then made across the diameter. When the effective stress is reduced to zero, acoustic measurements yield the compressibility of the grains, whereas at nonzero effective stress levels, it is possible to assess the effects of depth of embedment which causes changes in the compressibility and stiffness of the frame. Finally, by measuring the flow rate at each gradient, a direct evaluation of permeability is made. Preliminary measurements agree with most historical evaluations of these parameters suggesting that some recent work which challenges the traditional values is in error. [Work supported by ONR, code 321OA.]

Contributed Papers

8:10

3aUW2. Matched-field inversion using the down hill simplex algorithm. Martin Musil (School of Earth and Ocean Sci., Univ. of Victoria, Victoria, BC V8W 2Y2, Canada), John M. Ozard (Defence Res. Establishment Atlantic, Victoria, BC V9A 7N2, Canada), and Michael J. Wilmut (Royal Military College, Kingston, ON K7K 7B4, Canada)

In recent years inversion techniques have been proposed to effectively and efficiently determine geophysical parameters. The focus of this matched-field inversion (MFI) study is to determine the geoacoustic and geometric parameters for a North-East Pacific shallow water data set. MFI correlates modeled data, called replicas, with the measured data and uses a search algorithm to find model values which maximize the correlation function. In our MFI the parabolic equation (PE) is used to compute the replicas to account for mode coupling in the range-dependent environment. The first stage of the optimization algorithm employs a random search to determine $N+1$ parameter sets with the best correlations, where N is the number of parameters being determined. Next the $N+1$ sets are the input to the downhill simplex algorithm. The algorithm is shown to perform well for simulated vertical line array data for search parameter ranges representative of the environment in the shallow North-East Pacific Ocean. The inversion technique was then applied to measured data obtained in the North-East Pacific on the continental shelf using towed CW and broadband sources and a vertical array of hydrophones. The geometric parameters of the experiment and dominant geoacoustic parameters were successfully recovered.

8:14

3aUW3. Numerical analysis on inversed bottom geoacoustic models for predicting a shallow-water acoustic field. Guoliang Jin and Renhe Zhang (Shanghai Acoust. Lab., Academia Sinica, Shanghai 200032, PROC)

The bottom reflection coefficient as a function of the grazing angle is calculated for a liquid bottom with depth-dependent sound velocity, density, and attenuation. The bottom geoacoustic parameters of a simplified model, which describes only the depth dependence of sound velocity and treats the density and attenuation as the depth independent, are derived from the bottom reflection coefficients by the least-squares fit. The inversion accuracy in reproducing an acoustic field in the water column is tested by the performance of matched field processing, the sound propagation losses, modal group velocities, and modal eigenvalues for numerical examples. In general, the test results are good for single frequencies, but degrade for broader frequency bands. The possible distortion of the depth dependence of sound velocity from the inversion under the simplified model is discussed.

8:18

3aUW4. A multifrequency inversion method for geoacoustic parameters. Renhe Zhang, Fenghua Li, and Wenyu Luo (Natl. Lab. of Acoust., Inst. of Acoust., Chinese Acad. of Sci., Beijing 100080, PROC, zrh@public.east.cn.net)

The effects of the bottom parameters on the sound field are discussed theoretically and two characteristic angles relevant with geoacoustic parameters are put forward. Based on the theoretical analysis of the characteristic angles, a multifrequency inversion scheme is given as follows: High-frequency and far-field data are used to invert the upper bottom parameters first, and then low-frequency and near-field data are used to invert the lower bottom parameters. Simulated geoacoustic inversions based on simulated annealing method and the beam-displacement ray-mode (BDRM) sound propagation model are applied to the test cases from the 1997 Geoacoustic Inversion Workshop. The simulated inversions show that the inversion results of multi-frequency inversions are more accurate and reliable than those of the single-frequency inversions. The multi-frequency inversion scheme is also applied to the experimental data from '96 China–US Far Yellow Sea Experiment. [Work supported by NSF of China and ONR of USA.]

8:22

3aUW5. Geoacoustic parameter inversion from waveform structure. Fenghua Li and Renhe Zhang (Natl. Lab. of Acoust., Inst. of Acoust., Chinese Acad. of Sci., Beijing 100080, PROC, zrh@public.east.cn.net)

Based on the beam-displacement ray-mode (BDRM) sound propagation model, the effect of the bottom reflection coefficient on the pulsed waveform structure in shallow water with a thermocline is discussed. Simulated numerical calculations show that in shallow water with a thermocline, the bottom reflection amplitude and the bottom reflection phase can be inverted by the envelope of the pulsed waveform and the pulsed waveform structure, respectively, when the source and/or the receiver are above the thermocline. Using the experimental data from '96 China–US Far Yellow Sea Experiment, inversions for bottom reflection amplitude and reflection phase are performed. The waveform correlation between the experimental waveform and the inversion waveform is about 0.88 while the envelope correlation between them is about 0.95. The inversion of the experimental data shows that the inversion for the bottom reflection coefficient is effective and the inversion results are stable when the source and/or the receiver are above the thermocline. [Work supported by NSF of China and ONR of USA.]

8:26

3aUW6. Geophysical measurements on sediment cores and geoacoustic modeling. Philip P. Thomson, John I. Dunlop (Dept. of Appl. Phys., UNSW, Sydney 2052, Australia), and Frank Neissen (Alfred Wegner Inst., Bremerhaven, D-27568, Germany)

Geophysical measurements on marine sediments cores have considerable interest and importance in underwater acoustics and marine geophysics. A series of studies on geoacoustic properties of marine sediments have been conducted and modeled on the samples from Australian continental shelves by the technique developed by UNSW. More works were carried out on cores from North Atlantic ocean basins at the Alfred Wegner Institute in Germany by using a multisensor core logger (MSCL). MSCL is a logging device which enables a number of geophysical measurements such as p-wave velocity, gamma ray attenuation, and magnet susceptibility on marine sediment cores encased in cylindrical plastic core liners. A pair of compressional wave transducers at 250 kHz is used to measure dilatational velocity and a gamma ray source and detector are used to measure attenuation in the cores. A comparative study of physical properties measured by a MSCL system and UNSW technique has been applied to a wide range of frequencies and modeled with modified Biot–Stoll theory.

8:30

3aUW7. Building an acoustic library for categorizing bottom substrate type. John Hedgepeth, Colleen Sullivan (BioSonics, Inc., 4027 Leary Way NW, Seattle, WA 98107, jhedgepeth@biosonicsinc.com), Robert Sullivan (Parametrix, Inc., Seattle, WA), and Patrick Schneider (Instituto de Ciencias del Mar, Barcelona, Spain)

A hypothesis to categorize bottom substrate type is that information about the bottom sediments is encoded in the echo signal. Bottom typing means that to decode this information, however, for data verification, the user of automated typing programs should establish libraries where data acquisition of acoustic data is accompanied by physical core samples of the bottom. Separate verification should be done for different types of bottoms (e.g., %rocks, %sand, %silt, and %clay). Data from 126 observations of sediments in the vicinity of Commencement Bay near Tacoma, WA was used to establish libraries and to test the capability of the Visual Bottom Typer software to categorize correctly. Four different algorithms were used: division of the first bottom echo, ratio of the first and second bottom echo, cumulative intensity of the first bottom echo, and fractal dimension of the first bottom echo. The echo signal parameters depended not only on the type of bottom sampled but also on the equipment parameters. Two different frequencies and two different beam widths were compared. Verification results were valid for particular combinations of equipment parameters.

8:34

3aUW8. A measuring method for shear wave velocity of marine sediment using radiation impedance. Masao Kimura (Dept. of Ocean Eng., Tokai Univ., 3-20-1 Orido, Shimizu, Shizuoka, 424 Japan, mkimura@scc.u-tokai.ac.jp)

Radiation impedance of a circular vibrating plate on the surface of viscoelastic medium such as marine sediment varies with the viscoelastic properties of the medium. Therefore it is possible to predict the viscoelastic properties using the characteristics of the radiation impedance. It was demonstrated that the shear wave velocity of viscoelastic media can be determined using the value of the frequency at which the imaginary part of radiation impedance becomes zero, and the measured results of shear wave velocities for dry and wet sands were shown. In this study, the radiation impedance is measured for some kinds of marine sediment models. Then, the values of shear wave velocities obtained from the measurements of the radiation impedance, and the measured values using a bimorph type piezoelectic transducer, are compared. Moreover, the effect of the size of the radius of the circular vibrating plate on the measured values of shear wave velocities are considered.

8:38

3aUW9. Measurements of high-frequency acoustic scattering from seabed vegetation. Anthony P. Lyons and Eric Pouliquen (SACLANT Undersea Res. Ctr., APO AE 09613-5000, lyons@saclantc.nato.int)

Knowledge of the acoustic properties of seabed vegetation is required for accurate seafloor characterization in many shallow-water sites. As the study and modeling of acoustic scattering from seabed vegetation have been very limited to date, characteristics such as the dependence of scattering strength on grazing angle or frequency are still largely unknown. In order to quantify these properties, acoustic scattering experiments were conducted in beds of *Posidonia Oceanica* at several sites near the islands of Elba and Sardinia, Italy and in Saros Bay, Turkey with side-scan, single beam, and parametric transducers. Normal incidence broadband measurements were made at both the primary (40 kHz) and secondary (8 kHz) frequencies of a parametric sonar. Oblique incidence measurements were made with linear sources at frequencies from 29 to 385 kHz and with coverage over a large range of grazing angles. Results of these measurements are presented in terms of scattering strength versus grazing angle as well as scattered amplitude statistics. The mean scattering strength of the posidonia beds was found to be quite high (≈ -22 dB) and also to be fairly constant over most of the range of grazing angles, indicative of a volume scattering mechanism. Ultimately this effort will aid in the development of theoretical models of acoustic backscatter in seagrass covered sites.

8:42

3aUW10. Use of Scholte waves to determine the shear wave velocity structure in marine sediments. Sayuri Kawashima and Masao Kimura (Dept. of Ocean Eng., Tokai Univ., 3-20-1 Orido, Shimizu, Shizuoka, 424 Japan, 60oid001@scc.u-tokai.ac.jp)

Scholte waves propagating in marine sediments exhibit velocity dispersion, if the shear wave velocity of the sediment under the seabed surface depends on the depth. Therefore, it is possible to obtain the shear wave velocity profile of marine sediment, using velocity dispersion characteristics of Scholte waves. In this study, *in situ* experiments of Scholte waves in marine sediments are conducted off the coast of Shizuoka. A weight-drop system, lifting a weight and releasing it, was used as the source. Propagated signals are detected by gimbaled geophones. Group velocity dispersion characteristics are obtained from the recorded signals using the multiple filter method. Next, the depth dependence of shear wave velocity is obtained from the group velocity dispersion curves of Scholte waves using an inversion method. Furthermore, the estimated depth dependence of shear wave velocity is investigated.

8:46

3aUW11. Simplex simulated annealing: A hybrid approach to geoacoustic inversion. Mark R. Fallat and Stan E. Dosso (School of Ocean Sci., Univ. of Victoria, Victoria, BC V8W 3P6, Canada)

The problem of matched-field inversion of acoustic fields for ocean-bottom geoacoustic properties has received considerable attention in recent years. In order to avoid the large number of local minima typical of multidimensional geoacoustic parameter spaces, many inversions apply global optimization methods, such as simulated annealing (SA), to minimize the mismatch between measured and modeled fields. However, the random manner in which SA searches the parameter space can be quite inefficient, particularly near convergence and/or in cases where the minima represent narrow valleys not aligned with the parameter axes. In addition, standard SA has no memory, so a good solution may be discarded at the early stages and never revisited. In order to improve the efficiency and effectiveness of SA, a local inversion component based on the downhill simplex method within a global approach to geoacoustic inversion has been incorporated. The simplex method is sensitive to local gradients, and provides efficient perturbations at all stages which are independent of the coordinate axes. Also, the simplex of models carried through the inversion retains good models and provides a memory for the algorithm. The hybrid approach of simplex simulated annealing will be described and illustrated for geoacoustic inversion. [For Underwater Acoustics Best Student Paper Award.]

8:50

3aUW12. Frequency dependence of acoustic response due to randomness and uncertainties in physical properties of porous media. Yongke Mu, Mohsen Badiey, and Alexander H.-D. Cheng (Univ. of Delaware, Newark, DE 19716)

Models of acoustic waves in porous media are complicated because of the multiple physical parameters involved. The physical structure of these parameters can be random, and the accuracy toward their direct measurement or indirect estimate is generally uncertain. In order to better understand the extent by which different parameters can affect the interaction between the acoustic waves and the porous media, these randomness and uncertainty issues need to be addressed. In this paper, the investigation is based on the Biot model. First, the model is improved based on effects arising from the statistical distribution of pore/grain size. Next, effects of

randomness in sediment stratigraphy are examined. Also, we take into consideration the uncertainty resulting from data scarcity. Numerical tools used include propagator matrix, PE, and Monte Carlo simulation. From the variation of different parameters a different result is found. But frequency is found to always play an important role. For example, at lower frequencies the effects of pore/grain size can be neglected, but at higher frequencies they have significant impact. The material frequency response for the microscopic and macroscopic randomness is examined here. The results offer a better understanding of the interaction between the acoustic waves and the porous media.

8:54

3aUW13. Inversion of explosive shallow-water transmission loss data to obtain acoustic seabed models. Marshall V. Hall (DSTO Maritime Operations Div., P.O. Box 44, Pyrmont, NSW 2009, Australia, marshall.hall@dsto.defence.gov.au)

Acoustic transmission losses (TL) measured with explosive charges along a track in shallow water have been analyzed at frequencies in octave steps starting from 16 Hz. The results have been inverted to obtain the acoustic properties of the seabed, which is modeled as a uniform half-space. There are five unknown parameters: sound and shear speeds (C_p and C_s), sound and shear absorption coefficients (A_p and A_s), and density. The number of unknowns is reduced to three by using a regression equation for density in terms of C_p, while A_s is set to its maximum physical value. By holding C_s fixed for subsets of the process, the number of unknowns is reduced to two (C_p and A_p). For a given seabed, the theoretical TL is computed as a function of range using TL models valid for stratified media. The rms residual between the measured and theoretical TL is computed over rectangles in the C_p–A_p plane. The position at which the rms residual is a minimum is noted, and expressed as a function of C_s. Criteria for selecting the optimum result are discussed. The half-space properties contain useful information, but since they vary with frequency, they do not describe the actual seabed.

8:58

3aUW14. The development of the multibeam echosounder: An historical account. Ståle Vilming (Norwegian Univ. of Sci. and Tech., Fac. of Elec. Eng. and Telecom., Trondheim, N-7034, Norway, vilming@tele.ntnu.no)

The first paper on narrow-beam echosounding was published in 1960. Since then, the advantages of the principle of multibeam swath bathymetry for seabed mapping has been recognized by many institutions working in the field of area mapping underwater. We intend to review the development the multibeam echosounder has undergone from the ''beginning'' until the present in order to better understand the challenges facing the field today. It can safely be said that the field of area mapping has diversified into many directions since the 1960s. At that time most of the development was related to the mechanical and electronic system components, whereas present research focuses on: better algorithms for more precise mapping, seabed classification, image processing, acoustical modeling of the backscattering process from seafloor and volume, and high-resolution methods for direction finding of plane waves. Multibeam echosounding thus encompasses many scientific disciplines, and we consider it important to summarize the state of the art in these disciplines as far as they are related to seabed characterization. This could help scientists to better understand the requirements for further research.

9:02

3aUW15. A comparison of Hankel transform algorithms' performance in shallow-water waveguides and their effect on the determination of seabottom plane-wave reflection coefficients. Ben Cox and Phillip Joseph (Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton SO17 1BJ, UK, btc@isvr.soton.ac.uk)

Complex acoustic pressure data as a function of range may be decomposed into its constituent wave-number components by taking the Hankel transform. This paper investigates the accuracy of a number of discrete Hankel transform algorithms applied to computer simulated pressure data in a shallow water channel for a variety of seabed bottom types. The results are compared against the exact solution and the most accurate algorithm identified for shallow-water applications. The differing behavior of these algorithms is illustrated by their use in the Hankel transform method proposed by Frisk *et al.* [J. Acoust. Soc. Am. **68**, 602–612 (1980)] for the determination of seabottom plane-wave reflection coefficients. The results from computer simulations and scale model tank experiments are compared.

9:06

3aUW16. Comparison of the performance of global optimization methods with perturbative methods in the estimation of ocean bottom properties from multifrequency data. Subramaniam D. Rajan (Sci. Solutions, Inc., 18 Clinton Dr., Hollis, NH 03049)

During 1988 a series of acoustic propagation experiments was conducted in the Hudson Canyon area off the coast of New Jersey. It included synthetic aperture experiments in which a source transmitting multiple tones was towed toward/away from a vertical array of receivers. By this means, a two-dimensional structure of the acoustic field was obtained at eight different frequencies. This data set is used to estimate the bottom acoustic properties using global optimization approaches such as simulated annealing and genetic algorithm and to compare their performance with that of perturbative methods, which because of their simplicity have some advantages over the global methods.

9:10

3aUW17. Performance evaluation of horizontal and vertical vector sensor arrays in shallow water environments. Peter Gerstoft (Marine Physical Lab., UCSD, La Jolla, CA 92093-0704) and Joo Thiam Goh (DSO Natl. Labs., 118230 Singapore)

In planning an experiment it is essential to have as diverse information as possible in order to obtain a good estimate of the relevant parameters. Traditionally, the inversion for waveguide parameters as well as the source location is done exclusively using pressure measurements. Recently, it has been suggested by Nehorai and Paldi [IEEE Trans. Signal Process. **42**, 2481–2491 (1994)] that arrays of vector sensors (sensors that measure both pressure and velocities) could be used. Experiments have also been conducted in deep water by D'Spain *et al.* [IEEE Oceans (1992)]. In a realistic shallow-water environment the use of either vector or pressure sensors on a linear horizontal/vertical array with amplitude-only or complex-valued data at a number of discrete frequencies are discussed. Based on developed maximum-likelihood functions, the performance for the above type of data will be classified using either a global or a deterministic approach. For the deterministic approach, the Cramer Rao lower bound (CRLB), based on derivatives of the likelihood function, is used. For the global approach the *a posteriori* distributions are examined. These are based on Monte Carlo integration of the likelihood function. [Work supported by DSO National Laboratories, Singapore.]

9:14

3aUW18. Range-dependent environmental mismatch in matched-field tomography (MFT). Ronald T. Kessel (School of Earth and Ocean Sci., Univ. of Victoria, P.O. Box 3055, Victoria, BC V8W 3P6, Canada)

The goal of MFT is to determine unknown geoacoustic properties of the ocean by fitting a model to data recorded when the source–receiver configuration is known. The best-fit model presumably gives the best estimate of the actual geoacoustic properties along the propagation path. But the best-fit model, like the family of trials from which it is drawn, is necessarily constrained and idealistic. For simplicity, the horizontal variation of the sediments and bathymetry might have been ignored, and all trials might have had the same number of sediment layers, fixed arbitrarily perhaps, with each trial simply assigning different geoacoustic properties to those layers. If the best-fit model does not match the actual environment in these and other respects, then in what way does its properties represent those of the actual environment? When is the best-fit narrowly functional, fitting one data set well enough, but failing given other source–receiver configurations or frequency bands? These fundamental questions are addressed using the adiabatic theory of mode propagation, following a general perturbative approach to mismatch in any geoacoustic parameter in weakly range-dependent environments. Systematic and random mismatch are considered, and the implications for MFT are explored.

9:18

3aUW19. Application of coordinate rotation to inversion for sediment parameters. John S. Perkins, Michael D. Collins, and Laurie T. Fialkowski (Naval Res. Lab., Washington, DC 20375)

A global optimization technique (e.g., simulated annealing), combined with an accurate acoustic simulation capability, provides the means to invert measured acoustic data for unknown environmental parameters (e.g., sediment properties). Two problems are often encountered: (1) Which parameters are actually important to the solution? and (2) What are the parameter couplings? These problems can be regarded as difficulties in navigating through a multidimensional landscape to find the global minimum of the cost function (the error between the measured data and the simulated acoustic field corresponding to a given set of parameter values). A coordinate rotation technique based on the eigenvectors of the covariance matrix of the gradient of the cost function has been developed [M. D. Collins and L. Fishman, J. Acoust. Soc. Am. **98**, 1637–1644 (1995)]. In applying this technique to low-frequency (<200 Hz) SWellEX-96 data involving a drifting source of known position and a 32-element vertical receiver, a 12-parameter representation of the sediment structure and properties leads to a frequency-dependent parameter hierarchy and parameter couplings. The resulting environmental inversions are compared with previous characterizations and are used in matched-field processing to locate the source at other times during the experiment. [Work supported by ONR.]

9:22

3aUW20. Offshore geoacoustic inversions using sounds from land vehicle activity. Gerald L. D'Spain, William A. Kuperman, LeRoy M. Dorman, Lewis P. Berger, and William S. Hodgkiss (Marine Physical Lab., Scripps Inst. of Oceanogr., La Jolla, CA 92093-0704)

Land-based vehicle activity can be clearly detected and tracked by underwater acoustic sensors located outside the surf zone. This capability has been demonstrated with nearshore seismoacoustic data collected during the Marine Physical Lab's Adaptive Beach Monitoring (ABM) program. The purpose of this paper is to demonstrate how the sounds from these land vehicles can be used to perform inversions for the offshore geoacoustic properties, somewhat akin to the use of Vibroseis in geophysical exploration. The event of interest here is where four tracked vehicles traveled down the beach at a speed of 10 m/s, creating signal beam levels that exceeded background levels by 35 dB in the 30- to 70-Hz band. The signal-to-background noise ratio in single element spectra also is sufficiently high that these vehicles can be used as sources of opportunity. The datum for the inversions is the strong frequency dependence of the phase velocity of the arrivals in this frequency band. Forward modeling is performed with a parabolic equation (PE) code written by Mike Collins. Results are compared to those obtained from the offshore arrivals of broadband detonations conducted on the beach. [Work supported by ONR, Code 32.]

9:26

3aUW21. The multiple scattering interactions of cobbles and pebbles lying on the ocean floor. C. Feuillade and R. W. Meredith (Naval Res. Lab., Stennis Space Center, MS 39529-5004)

A new model for predicting the sonar target strengths of ensembles of rocks lying on the ocean floor has recently been presented. The model represents rocks by either rigid movable spheres or elastic spheres of variable size, density, and numerical/geometrical configuration. When the rocks are densely packed, and therefore in close proximity to each other, it is important to consider the contribution that multiple scattering interactions make to the collective scattering response. To investigate this question, a T-supermatrix formalism, a self-consistent procedure which includes all orders of multiple scattering [see Lim and Hackman, J. Acoust. Soc. Am. **91**, 613–638 (1992)], has been developed to describe the radiatively coupled ensemble. The method allows the coherently summed scattered pressure field in any direction to be determined, as well as the total power scattered by the system. Application to rocks of cobble and pebble size classes indicates that the effect of multiple interactions is dependent upon the acoustic frequency, the rock spacing relative to the radius, and the grazing angle. The results obtained provide a basis for estimating the relative importance of these interactions in determining target strength. [This work was supported by ONR/NRL.]

Session 3aPLb

Plenary Lecture

Terry Ewart, Chair
Applied Physics Laboratory, University of Washington, MS HW-10, Seattle, Washington 98105

Chair's Introduction—11:00

Invited Paper

11:05

3aPLb1. Stochastic effects in ocean acoustics. Advances in theory and experiment. Barry J. Uscinski (Dept. of Appl. Mathematics and Theoretical Phys., Univ. of Cambridge, Cambridge, UK)

As the need to operate in the kilohertz range increased in the 1960s, existing approaches to ocean acoustics, based on sound-speed profiles and ray-tracing, became quite inadequate. The raggedness of acoustic transmissions, previously regarded simply as noise, was so pronounced at the higher frequencies that the stochastic properties themselves became an urgent area of research. Several major ocean transmission trials were carried out to obtain fluctuation data. The trial at Cobb Seamount produced results that could not be explained by existing random-wave propagation theory. The research that followed led to significant advances in several areas. New propagation theory emerged based on the parabolic equations for the acoustic field moments. In particular it was the construction of analytical solutions of the equation for the fourth moment that provided the first satisfactory explanation of the Cobb intensity fluctuation spectra. Advances in numerical simulation methods and capability have allowed pictures of the full stochastic acoustic field in an ocean transmission trial to be produced. These have not only confirmed experimental variances and cross correlations but have also revealed the spatial structure of the field, including interesing features such as the elongated sound ribbons that arise in some cases.

Meeting of Accredited Standards Committee S2 on Mechanical Vibration and Shock

to be held jointly with the

U.S. Technical Advisory Group (TAG) Meeting for ISO/TC 108 Mechanical Vibration and Shock (and Subcommittees ISO/TC 108/SC1, SC2, SC3, SC5, and SC6)

D. J. Evans, Chair S2 and Chair of the U.S. Technical Advisory Group (TAG) for ISO/TC 108, Mechanical Vibration and Shock
National Institute of Standards and Technology (NIST), Acoustics, Mass and Vibrations Group, Building 233, Room A147, Gaithersburg, Maryland 20899

Accredited Standards Committee S2 on Mechanical Vibration and Shock. Working group chairs will present reports of their recent progress on writing and processing various shock and vibration standards. There will be a report on the interface of S2 activities with those of ISO/TC 108 (the Technical Advisory Group for ISO/TC 108 consists of members of S2, S3, and other persons not necessarily members of those committees), including plans for 1998 meetings of ISO/TC 108 and/or its Subcommittees.

SCOPE OF S2: Standards, specifications, methods of measurement and test, and terminology in the fields of mechanical vibration and shock, and condition monitoring and diagnostics of machines, but excluding those aspects which pertain to biological safety, tolerance and comfort.

Session 3pPL

Plenary Lecture

Whitlow W. L. Au, Chair
Hawaii Institute of Marine Biology, P.O. Box 1106, Kailua, Hawaii 96734

Chair's Introduction—1:00

1:05

3pPL1. Marine mammal ears: An anatomical perspective on underwater hearing. Darlene R. Ketten (Biol. Dept., WHOI, Woods Hole, MA 02543 and Dept. of Otolaryngol., Harvard Med. School, Boston, MA 02114, dketten@whoi.edu)

Analyzing structure and function in specialized ears can produce new insights into fundamental hearing mechanisms and lead to technological advances. Research into dolphin echolocation is a classic example. Recently, however, concerns over anthropogenic sounds in the oceans pushed us to develop a broader knowledge of marine mammal hearing, and, in the last five years, hearing research on marine mammals expanded considerably. The resulting data on their hearing, ear anatomy, and vocalizations suggest that marine mammal ears are more diverse and complex than previously expected, with acoustic capabilities spanning infra to ultrasonic ranges. Seals are amphibious hearers with middle and inner ears similar to land carnivores, while the ears of whales are strikingly different and are adapted exclusively to hearing underwater. Consistent with high sound speeds in water, specialized fats, not air-filled canals, conduct sound to the ear, and both middle and inner ears are located well outside the skull. Vestibular components are reduced, consistent with cervical fusion related to hydrodynamic body shapes; but their cochlear components, particularly the auditory fibers, are hypertrophied. Neural hypertrophy may be adaptive for high background noise, but may also be related to exceptional signal processing mechanisms in both infra and ultrasonic whales.

Session 3pAA

Architectural Acoustics: The Technical Committee on Architectural Acoustics Vern O. Knudsen Distinguished Lecture

A. Harold Marshall, Chair
Marshall Day Associates, Wellesley Street, P.O. Box 5811, Auckland 01, New Zealand

Chair's Introduction—2:15

Invited Paper

2:20

3pAA1. Concert hall research: Balancing complexity and practicality. John Bradley (Inst. for Res. in Construction, Natl. Res. Council, Montreal Rd., Ottawa, ON K1A 0R6, Canada)

An approach that has carefully balanced complexity and practicality has led to several new developments in concert hall research. These new developments are reviewed and their practical implications are explored. The two separate dimensions of spatial impression, apparent source width and listener envelopment, are each related to different physical parameters. The relationship between these acoustical parameters and the design of halls will be explored. For example, listener envelopment is related to the relatively late arriving lateral sound energy. Measurements in a number of halls will be used to explore how this and other acoustical measures of spatial impression are related to hall design. This same new understanding of spatial impression can also further enhance our understanding of sound fields under balconies and help us to design improved electroacoustic enhancement systems. Spatial impression is also influenced by sound level and especially by lower frequency levels. The importance of levels and the balance between high- and low-frequency levels has often been neglected. New work relating the perception of bass and treble sound to different factors will be reviewed. Previous studies and new analyses will be used to explore how hall design can influence perceptions of tonal balance in concert halls.

Session 3pAO

Acoustical Oceanography and Animal Bioacoustics: Acoustics of Fisheries and Plankton I

Christopher Feuillade, Chair
Naval Research Laboratory, Stennis Space Center, Mississippi 39529-5004

Invited Paper

1:30

3pAO1. An intermediate-range sonar for fish detection. David Farmer, Mark Trevorrow (Inst. of Ocean Sci., 9860 W. Saanich Rd., Sidney, BC V8L 4B2, Canada, dmf@ios.bc.ca), and Bjarke Pederson (LIC Eng., D-2900 Hellerup, Denmark)

A primary challenge in acoustic fish stock assessment is the limited sampling volume of vertically oriented sonars. While long-range imaging with powerful shore-based systems has demonstrated interesting possibilities, practical and environmental constraints motivate an intermediate technology with the goal of mapping fish distributions to ranges of a few km. This work describes a 40-element 12-kHz array deployed both for subsurface towing and also for mounting on the sea floor with motor drive allowing azimuthal rotation. Field tests in the towed configuration have been carried out in the Strait of Georgia, with the array maintained on the sound channel axis at a depth of 40 m. While there was some sensitivity to towing depth, fish could be detected out to the 7-km sampling limit at the same time as fishing activity showed the presence of migrating sockeye salmon. Sea floor deployment in a shallow coastal area demonstrated the sonar's ability to track herring and provides experience in the use of a rotating mount for sector imaging of fish schools. Based on experience gained with this implementation, both the potential applications and limitations of this approach for intermediate range fish detection are identified.

Contributed Papers

1:50

3pAO2. Shallow-water salmon and herring detection using 100-kHz sidescan sonars. Mark V. Trevorrow, David M. Farmer (Inst. of Ocean Sci., 9860 W. Saanich Rd., Sidney, BC V8L 4B2, Canada), and Bjarke Pedersen (LIC Eng. A/S, Hellerup, Denmark)

Acoustic results of fish detection using fixed 100-kHz sidescan sonar installations in the Fraser River (British Columbia) and in the Oresund (near Copenhagen, Denmark) are reviewed. Looking transverse to the river flow, echo traces due to migratory salmon were observed at ranges up to 250 m in water 6 to 13 m deep. The salmon trajectories were readily identified and counted against the background of reverberation from the river surface and bottom sediments. Similarly in the Oresund, long-term monitoring detected migrating herring schools above background reverberation at ranges up to 500 m in water 10 to 13 m deep. In both cases, occasional strong backscatter interference from vessel wakes and wind-induced surface bubble layers was observed. In the Oresund, changes in acoustic propagation conditions due to bottom inflow of more saline oceanic water drastically reduced fish detectability. For salmon in the river, acoustic multipaths due to boundary reflections were distinguishable from direct echoes at ranges up to 150 m. The general problems of shallow-water boundary reverberation and multipath reflection focusing will be reviewed, with discussion on how to compensate for these waveguide effects.

2:05

3pAO3. Multibeam sonar image processing and three-dimensional analysis of fish schools. Chafiaa Hamitouche, Valerie Fracasso, and Carla Scalabrin (ENST-Bretagne, Technopole de Brest-Iroise, B.P. 832, 29285, Brest Cedex, France)

Digital data from a high-resolution multibeam sonar were processed to provide 3-D fish school descriptors. The multibeam sonar operates at a carrier frequency of 455 kHz, with 60 beams of 1.5° each, allowing an observation angle of 90°. The envelope of the signal is sampled every 5 cm. The usual operating range is 100 m with a ping rate of 7 pings/s. This huge amount of data provides larger biovolume samples with higher data resolution than standard fisheries research vertical echosounders used until now to describe fish school structure [C. Scalabrin *et al.*, ICES J. Mar. Sci. **53**, 181–188 (1996)]. Furthermore, the use of a multibeam sonar allows construction of 3-D images of fish schools. Data were processed by specially designed image algorithms in order to account for anisotropy in the range and vessel movement direction planes. Three-dimensional analyses such as smoothing, segmentation, visualization of the segmented volume, and its quantification were performed. Three-dimensional patterns description tools (invariant with respect to translation, rotation, and scaling) were studied. These tools might lead to the classification of the detected structures using pattern recognition methods.

2:20

3pAO4. Near-resonance scattering from schooling fish. R. W. Nero, C. H. Thompson, C. Feuillade, and R. H. Love (Naval Res. Lab., Stennis Space Center, MS 39529-5004)

Most fish have air-filled swimbladders which provide some buoyancy to aid in swimming. These swimbladders resonate like damped air bubbles and are very efficient scatterers. A mathematical formalism has recently been developed to describe near-resonance backscattering from schooling fish. [C. Feuillade, R. W. Nero, and R. H. Love, J. Acoust. Soc. Am. **99**, 196–208 (1996)]. This model predicts that coupled resonance and interference effects will occur when fish are closely spaced. These effects cause the frequency response of a tightly packed school to differ significantly from that of a single fish. As fish spacings increase beyond several body lengths, these effects rapidly diminish. When this model was developed, only one small set of data was available for comparison to model predictions; these data gave indications that the model was valid [Holliday, J. Acoust. Soc. Am. **51**, 1322–1332 (1972)]. Experiments off the west coast of the United States and in the Gulf of Mexico have recently been conducted on several different species of schooling fish in order to confirm the validity of the model and determine its robustness. Measurements on numerous schools confirm that scattering from schooling fish is accurately represented by the model. [Work supported by ONR/NRL.]

2:35

3pAO5. Sound scattering from a few scatterers: Application to swimbladder fish. Zhen Ye and Alberto Alvarez (Dept. of Phys., Natl. Central Univ., Chung-li, Taiwan, ROC)

This paper presents a general method for describing sound scattering by an ensemble of a few scatterers. A scheme is developed for calculating the effective scattering function of such an ensemble, including all orders of multiple scattering between targets. The method is then applied to low-frequency sound scattering by small fish schools. It is shown that in the backscattering, certain regular patterns in scattering appear as a result of interference rather than multiple scattering, when the fish form an ordered structure. The interference peaks are due to in-phase scattering, and can be explained by the Bragg reflection mechanism. Such regular interference patterns are gradually degraded, as the random deviation in each individual fish location from its mean position increases. For a completely random distribution of fish, the model recovers the results from the random-phase approximation. For the forward-scattering case, it lacks either the regular or the noisy interference. The scattering strength seems rather smooth, and may be well approximated by the incoherent summation of forward-scattering function of each individual fish. The scattering by partially or perfectly ordered fish schools is hardly distinguishable from that by totally random distributions of fish in the forward direction. [Work supported by the National Science Council and the Spanish Ministry of Education.]

WEDNESDAY AFTERNOON, 24 JUNE 1998 EAST BALLROOM B (S), 1:00 TO 2:55 P.M.

Session 3pBV

Bioresponse to Vibration/Biomedical Ultrasound: Ultrasound Assisted Drug Delivery II

Pierre D. Mourad, Chair

Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98105

Invited Papers

1:00

3pBV1. Chemopotential by low-level ultrasound. George H. Harrison and Elizabeth K. Balcer-Kubiczek (Radiation Res. Div., Univ. of Maryland, 655 W. Baltimore St., 6-015BRB, Baltimore, MD 21201, gharriso@umabnet.ab.umd.edu)

Recent laboratory studies have identified a new approach to cancer therapy: the potential of drug action by ultrasound. Both standard chemotherapeutic cytotoxins and relatively nontoxic compounds related to those used in photodynamic tumor therapy are being investigated. Common to most reported investigations has been the use of continuous wave ultrasound at spatial peak, temporal average intensities exceeding 0.5 W/cm^2, implying the likelihood of temperature elevation in insonated tissue, and usually involving cytotoxicity from the action of ultrasound alone. On the other hand, for potentiation of chemotherapy using tone-burst or pulsed ultrasound at spatial average, time average intensities less than 0.3 W/cm^2 has been demonstrated [G. H. Harrison, E. K. Balcer-Kubiczek, and P. L. Gutierrez, Ultrasound Med. Biol. **22**, 355–362 (1996)]. Chemopotentiation data will be presented for several biological test systems with emphasis on human prostate tumor cell lines. Mechanistic evidence will be analyzed; fluid streaming and shear stress are likely important determinants of chemopotentiation and the cell membrane can be expected to be an important site in this process. Ultrasound-induced modification of drug resistance may have important apoptotic links. These factors suggest the importance of treatment-induced differential expression of membrane-related genes.

1:25

3pBV2. Sonochemistry of sonodynamic therapy. Peter Riesz and Vladimir Misik (Radiation Biol. Branch, Natl. Cancer Inst., N.I.H., Bethesda, MD 20892)

Sonodynamic therapy is a promising modality for cancer treatment based on the synergistic effect of cell killing by a combination of drugs (sonosensitizers) and ultrasound. The effectiveness of sonodynamic therapy was demonstrated in cell studies and in tumor-bearing animals. The mechanism of drug-dependent sonosensitization is unknown, but it seems likely that various mechanisms operate for different classes of sonosensitizers. Ultrasound-mediated sonodynamic activation of porphyrins is particularly poorly understood and hypotheses ranging from singlet oxygen production to peroxyl radical formation have been advanced. Evidence has been obtained against some of the arguments which were proposed in favor of the singlet oxygen hypothesis and the requirement of extracellular localization of gallium porphyrin ATX-70 molecules for sonosensitization in HL-525 cells has been established. Short-lived toxic intermediates produced from sonosensitizers by ultrasound are implicated in the mechanism of sonodynamic activation of some sensitizers. EPR spectroscopy was used to identify proposed intermediates in the activation of certain sonosensitizers (e.g., *N*,*N*-dimethylformamide, DMSO) by ultrasound. Certain water-soluble azo compounds, which are stable at hyperthermia temperatures and can be decomposed by ultrasound to give peroxyl radicals capable of initiating peroxidation of lipids and damaging other cellular sites, appear to be promising sonosensitizers.

1:50

3pBV3. Gene activation and gene delivery with ultrasound. Evan C. Unger (Dept. of Radiol., The Univ. of Arizona, Tucson, AZ 85724-5067, eunger@vms.ccit.arizona.edu), Thomas McCreery, Robert Sweitzer, DeKang Shen, GuanLi Wu, and Veronica Caldwell (ImaRx Pharmaceutical Corp., Tucson, AZ 85719)

Transfection experiments were performed *in vitro* in cell culture and *in vivo* in fish and mice using cationic liposomes with several different reporter genes. The effect of continuous-wave 1-MHz ultrasound on cell viability, cell permeability, and gene expression was assessed. RT-PCR was used to monitor gene expression of cell repair genes in insonated cells. Acoustically active halocarbon-containing liposomes were prepared for gene delivery. Ultrasound increased cell permeability and gene expression following liposomal transfection. RT-PCR showed upregulation of repair of a number of cell repair genes after ultrasound exposure. The acoustically active gene delivery vehicles provided highly efficient transfection both with and without ultrasound *in vitro* and *in vivo*. Following IV administration of halocarbon-containing liposomes/gene complexes, preferential gene expression was observed in the insonated tissue. Ultrasound has potentially useful applications for targeting and enhancing gene therapy.

2:15

3pBV4. Ultrasound activation of new drugs for killing cancer cells. Katsuro Tachibana and Toshiki Uchida (First Dept. of Internal Medicine, Fukuoka Univ. School of Medicine, 7-45-1 Nanakuma, Jonan, Fukuoka, 814-80 Japan)

The study of the destructive action of ultrasound in conjunction with drugs upon cancer has become an exciting area. New substances that are chemically activated by low level ultrasound energy have recently been discovered [Tachibana *et al.*, Lancet **349**, 325 (1997)]. Three nontoxic red stains frequently used for cosmetics and food, Rose Bengal, Eosin Y, and Erythrosine B were evaluated if cytotoxic effects can be induced by ultrasound energy *in vitro*. Gastric and leukemic cancer cell line suspensions were exposed to ultrasound (1 MHz) with or without the drugs. The survival rate of the cells was measured immediately after treatment. The temperature increase was less than 2 °C. Treatment with ultrasound plus drugs resulted in a significant reduction of the survival rate compared to ultrasound alone. Whereas the drug alone showed no change in survival rate. Although the mechanism is unclear, it is postulated that ultrasound energy, possibly cavitation, activated these drugs. Further experiments should be carried out to evaluate its use in the clinical situation. The three stains could be applied as new booster agents for treatment of cancer by ultrasound.

Contributed Paper

2:40

3pBV5. Control of ultrasound-mediated reversible membrane permeabilization for targeted drug delivery. Mark R. Prausnitz, Keyvan Keyhani, Aimee Parsons (School of Chemical Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0100), and Thomas N. Lewis (Georgia Inst. of Technol., Atlanta, GA 30332-0405)

Ultrasound-mediated permeabilization of cell membranes is a potentially useful method to noninvasively enhance delivery of therapeutic compounds into targeted cells. Unlike previous studies concerned only with cell death, in this study the effects of ultrasound exposure parameters on reversible membrane permeabilization of prostate cancer cells were determined. Cells were suspended in a solution containing a membrane-impermeant marker (calcein) and exposed to 24-kHz ultrasound. Viability and molecular uptake were quantified using flow cytometry. Average uptake increased with incident ultrasound pressure above a threshold and reached a plateau (20%–25% of external calcein concentration); increased with total exposure time; was weakly dependent on pulse length (3.3 ms to 1.0 s) with a small maximum at 10–33 ms and a sharp decline at 1.0 ms; and was independent of duty cycle (0.5%–50%). The fraction of viable cells decreased continuously with increasing pressure, decreased as uptake increased for most other examined condition was approximately 25% for maximum uptake under optimal conditions. Uptake decreased approximately exponentially with the time at which calcein was added to the cell suspension after exposure, with a time constant of about 1 min. The membrane disruptions allows uptake of albumin (MW=66 000) but not R-phycoerythrin (MW=240 000).

WEDNESDAY AFTERNOON, 24 JUNE 1998 EAST BALLROOM A (S), 1:00 TO 3:00 P.M.

Session 3pEA

Engineering Acoustics: Advanced Transduction Materials

Elizabeth A. McLaughlin, Chair
Naval Undersea Warfare Center, Code 2131, 1176 Howell Street, B1170, Newport, Rhode Island 02841-1708

Contributed Papers

1:00

3pEA1. Efficiency and electromechanical resonance in magnetostrictive transducers. Frederick Calkins and Alison Flatau (Iowa State Univ., Dept. of Aerosp. Eng. and Eng. Mech., 2019 Black Eng., Ames, IA 50011)

Analysis of the transduction phenomenon of a Tonpilz Terfenol-D magnetostrictive transducer is presented. Transducer efficiency is discussed from electroacoustic and scalar energy perspectives. Equations are presented for identifying the frequency of most efficient transducer operation based on electroacoustic theory [F. V. Hunt, in *Electroacoustics: The Analysis of Transduction, and Its Historical Background* (Acoustical Society of America, New York, 1982)]. Experimental results are presented that show this analysis to be accurate. However, two nonintuitive results are observed: most efficient transducer operation occurs at a frequency above mechanical resonance; and changes in operating conditions which result in an increase in transducer efficiency cause the frequency of highest efficiency to increase even further above the frequency of mechanical

resonance. This motivated a comparison with a scalar energy analysis for development of a better, or at least more intuitive, understanding of the mechanisms which might explain this result. Energy analysis aids in recognizing the distinction between the transducer's mechanical and electromechanical resonances and that the magnitude of achievable efficiency will be enhanced by separation of electromechanical and mechanical resonances. Coupling the energy and electroacoustic analyses, one arrives at persuasive arguments for explaining the experimental observations regarding magnetostrictive transducer efficiency.

1:15

3pEA2. A study of 1-3 piezocomposites high drive limits. Thomas R. Howarth (Naval Res. Lab., Washington, DC, howarth@nrl.navy.mil), David Van Tol, Charles Allen, and Jack Hughes (Penn State Univ., State College, PA)

A preliminary study of the electrical drive limits of 1-3 piezocomposites has been completed. Two injection molded 1-3 piezocomposite samples were designed, fabricated, and procured from Material Systems, Inc. of Littleton, MA. Each of the composites had a 25% volume fraction of piezoceramic, a hard epoxylike matrix, a silver epoxy electrode pattern, 6-mm thickness, 100×100-mm total cross-sectional area with an active cross-section of 20×20 mm. One of the samples featured type II (PZT-5H) piezoceramic while the other featured type I (PZT-4). Each of the transducers was fitted with thermocouples to monitor temperature effects. Transducer efficiency, voltage response (TVR), current response (TCR), and power responses (TPR) were measured over the frequency range of 25 Hz–500 kHz in 200-Hz steps where the transducer thickness resonance frequency was approximately 240 kHz. This presentation shall outline the sample fabrication, the tests, and the final results. Photographs will be shown on the units upon failure. A comparison between the 1-3 piezocomposite materials limits shall be made with traditional piezoceramics. [Work supported by Dr. Kam Ng of ONR 334.]

1:30

3pEA3. The development of affordable constant beamwidth transducers using injection molded 1-3 piezoelectric composite. Kim C. Benjamin, A. L. Van Buren, and Sheridan Petrie (Naval Undersea Warfare Ctr., Newport, RI 02481)

The design, fabrication, and acoustic calibration results for a new class of constant beamwidth transducers (CBTs) is presented. This experimental study extends previously reported work by Van Buren *et al.* [J. Acoust. Soc. Am. **73** (1983)] in which a CBT was constructed using hundreds of individual end-capped PZT ceramic cylinders. Each ceramic element assembly was wrapped in corprene to provide mechanical isolation from the massive metal housing and to provide a pressure release boundary condition. This presentation describes a new design approach which employs injection molded piezocomposite which is curved to form a spherical cap. Design equations will be presented which allow one to dimension the active spherical section for a given application. Of key importance to a successful CBT design is the proper implementation of velocity amplitude shading. The current approach uses an area shading technique that is achieved through selective electroplating of copper. The design, construction, and measured results for three different geometries, including a 0.76-m (30″) diameter unit will be discussed.

1:45

3pEA4. Lamb wave generation in composite plates with a thin linear array of piezoelectric elements. Thierry Demol, Pierrick Blanquet, Emmanuel Moulin, and Christophe Delebarre (I.E.M.N. (UMR CNRS 9929), Dept. O.A.E., U.V.H.C., Le Mont Houy, B.P. 311, 59304 Valenciennes Cedex, France, demol@univ-valenciennes.fr)

Since Lamb waves are very efficient in the nondestructive testing of composite plates, new transducers are developed nowadays. They may be movable, stuck onto the surface, or integrated into the plates (''smart structures''). In order to detect defaults with few transducers, a multi-element linear array transducer has been developed to generate single-mode Lamb waves able to propagate over long distances. Movable prototypes were designed in order to evaluate their ability to generate the appropriate waves. Then, composite plates have been equipped with the same kind of transducers consisting of several thin PZT plates. High response levels have been obtained using a unidirectional composite with propagation along the fiber direction. Results for cross-ply laminates were inferior but still acceptable. The main result obtained during this experimental work was the understanding of the generation process for this kind of transducer. Unlike comb transducers, each element generates a separate wave and suitable time delays or spacing between the elements can improve the global response in accordance with linear rules. Furthermore, the delays are easily determined from the responses of each element. This behavior is very interesting as default detection is possible using the properties of the generation process.

2:00

3pEA5. Built-in transducer design for Lamb wave generation in composite structures. Pierrick Blanquet, Thierry Demol, Emmanuel Moulin, and Christophe Delebarre (I.E.M.N. (UMR CNRS 9929), Dept. O.A.E., U.V.H.C., Le Mont Houy, B.P. 311, 59304 Valenciennes Cedex, France, lamb@univ-valenciennes.fr)

Conventional ultrasonic inspection of large composite structures is very time consuming due to the necessity of surface scanning. Because they can propagate over long distances, Lamb waves are an attractive solution to this problem. Two methods are available for the generation of Lamb waves in composite plates. The first method, and the most useful one, consists of using bonded transducers. The second solution is to use a built-in transducer. In both cases, the transducers must be designed to generate efficiently the signal and choose the mode of propagation. In the following, a method to design a built-in transducer will be discussed. First, the case of a unidirectional composite plate is considered. An analytical method is developed, then the results are compared with those obtained using finite element analysis. In the case of a square element transducer embedded in the composite plate, the computed results are compared with experimental data. Then, the method is extended to the case of a multilayered plate. An analysis is performed to determine the optimal design of a built-in multi-element transducer.

2:15

3pEA6. Optimization of the piezoelectric circular bimorph. Andrzej Dobrucki (Wroclaw Inst. of Technol., Inst. of Telecom. and Acoust., Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland)

The combined finite-element and boundary-integral method was applied for modeling of vibration and sound radiation of piezoelectric circular bimorphs. The bimorph consists of two circular piezoelectric disks, which are separated by a metal plate. When an electric voltage is supplied to the bimorph, a bending moment develops which actuates the transducer to transversal deflection. During the design process of the transducer the following limitations must be taken into account: (1) piezoelectric material and thickness of the disks are usually predetermined, (2) the outer diameter of the transducer, i.e., of the metal plate is given. The influence of the metal plate material and its thickness on the frequency response of the transducer is discussed. Young's modulus, Poisson's ratio, density, and the loss factor characterize the properties of the materials. The influence of the ratio of a piezoelectric disk's diameter to metal plate diameter is also discussed. Another important property which was considered during the

optimization process, is the mounting of the transducer, i.e., applied boundary conditions. As an example, the design of a small transducer is presented. The results of calculations are in good accordance with the result of the measurement of realized construction.

2:30

3pEA7. Research on inhomogeneous 1-3 PZT/polymer composite transducer. DaLun Xu (Dept. of Modern Appl. Phys., TsingHua Univ. Beijing, 100084, PROC) and TieYing Zhou (TsingHua Univ., Beijing, 100084, PROC)

An improved equal stress physical model [W. A. Smith and A. Shaulov, Ultrasonics Symposium, 642–647 (1985)] for the inhomogeneous 1-3 PZT/polymer composite material is presented. This model calculates the properties that determine the thickness-mode oscillations in thin plates. Based on this model, together with the constitutive relations for polymer and PZT, expressions are derived for the effective material parameters such as electromechanical coupling constant, acoustic impedance, etc., in terms of the properties of constituents. A relation between the vibration amplitude of the transducer's surface and the volume fraction of the piezoceramic is also deduced. The distribution of the vibration of the transducer's surface, hence the distribution of the acoustic field, can be precisely controlled by adjusting the distribution of the volume fraction of the PZT phase in the transducer. To test our model experimentally, a number of special transducers were made. The measurements of the acoustic field that is produced by the transducers are in good agreement with the theory. The research provides guidelines for the transducer engineer to design inhomogeneous 1-3 PZT/polymer composite transducer, such as transducers of Gauss type, Bessel type, or other special types.

2:45

3pEA8. The ring-type all-fiber Fabry–Perot interferometer hydrophone system. Donglin Li (Harbin Eng. Univ., Dept. of Underwater Acoust. Eng., Harbin 15001, PROC)

In the paper the theory of the ring-type all-fiber Fabry–Perot interferometer hydrophone is given. Such a hydrophone system has been constructed. Experimental results have shown the system has a free-field open-circuit voltage sensitivity level of about -130 dB *re*: 1 V/μPa.

WEDNESDAY AFTERNOON, 24 JUNE 1998 GRAND CRESCENT (W), 2:15 TO 3:00 P.M.

Session 3pED

Education in Acoustics: Undergraduate Research Poster Session

Murray S. Korman, Chair
Department of Physics, U. S. Naval Academy, Annapolis, Maryland 21402

Contributed Papers

All posters will be on display, and all contributors will be at their posters, from 2:15 p.m. to 3:15 p.m.

3pED1. Nonlinear effects in the paraxial region of diffracting sound beams radiated by cylindrical sources. Svetlana V. Babenkova, Vera A. Khokhlova (Dept. of Acoust., Phys. Faculty, Moscow State Univ., Moscow 119899, Russia, vera@na.phys.msu.su), and Steven G. Kargl (Univ. of Washington, Seattle, WA 98105)

Intense cylindrical sources are widely used in underwater acoustics and medical ultrasound; however, nonlinear-diffraction phenomena in acoustic fields of this geometry are not studied yet as well as the fields produced by unfocused and weakly focused circular piston sources. The present work is based on a special analytical method that has been developed recently [M. F. Hamilton, V. A. Khokhlova, and O. V. Rudenko, J. Acoust. Soc. Am. **101**, 1298–1308 (1997)] to model nonlinear and diffraction effects near the axis of an acoustic beam radiated by apodized circular source. This method combines the advantages of the parabolic approximation with nonlinear geometrical acoustics, and it permits an exact solution of the nonlinear problem. The approach is extended to acoustic waves radiated by a finite-length cylinder. A system of nonlinear coupled equations describing waveform distortion in the paraxial region of the beam is derived from the modified KZ equation. Analytical solutions are obtained in the time and frequency domains for an initially sinusoidal wave radiated by the cylinder with Gaussian shading of the amplitude along the axis. Nonlinear waveform distortion, shock formation distance, harmonic propagation curves, directivity pattern, and effect of steering are investigated for various parameters of the source. [Work supported by ONR, RFBR, and CRDF.]

3pED2. Sentential prosodic contour facilitates adults' short-term memory for nonsense syllable strings. Diana L. Schenck (Dept. of Psych., and Cornell Phonet. Lab., Dept. of Modern Lang., Cornell Univ., Ithaca, NY 14853, dls14@cornell.edu)

Recent linguistic theories propose that prosodic contour functions to facilitate encoding, processing, and storing of information in the speech signal. To date, most evidence for these theories comes from studies of infant perception and processing of prosodic speech. The present study employed a short-term memory CV nonsense syllable recall task in order to attempt to replicate with adults the findings for infants that have supported these theories. Ten adult subjects listened to nonsense CVs in two sets, one presented with sentential prosodic contour, the other presented in list form, and recalled as many syllables, in order, from each string as they could. Results were significant at the $p<0.05$ level and supported the hypothesis that subjects would better recall those syllable strings presented in prosodic contour, as the number of errors was fewer for the prosodic set than for the list set. Small familiarity/order of presentation effects and individual differences were found for all subjects. These results suggest that (1) adults use processing and coding strategies similar to those employed by infants in response to linguistic stimuli; and (2) sentential prosody does, in fact, facilitate short-term memory for these stimuli, possibly by enhancing the perceptual saliency of the linguistic input.

3pED3. Design and development of PC-IMAT: Teaching strategies for acoustical oceanography, part II. Lee Anne Hurley, Kevin M. Thomas, Murray S. Korman (Dept. of Phys., U.S. Naval Acad., Annapolis, MD 21402), John W. Schuler (Navy Personnel Res. and Development Ctr., Brooks AFB, TX 78235), and Eleanor Holmes (Integrated Performance Decisions, Arlington, VA 22202)

The PC-IMAT (Personalized Curriculum for Interactive Multisensor Analysis Training) project is proving to be a flexible and effectively evolving computer-based training/educational platform needed to help tackle ASW and other tasks which require extensive analysis, classification, and interpretational skills. Midshipman taking SP411 (Underwater Acoustics and Sonar) are currently using PC-IMAT [J. Acoust. Soc. Am. **101**, 3096A (1997)] to help investigate effective instructional strategies which convey understanding of a complex multivariate domain (like ray trace or propagation loss models). Classroom demonstration lectures and out-of-class projects allow students to successfully interact with experimental apparatus and make actual measurements (e.g., Fourier analysis, detection theory, beam pattern functions, sound speed versus temperature, computer ray tracing, reflection and transmission at an interface, and target strength versus angle of a scale model sub). However, a link between textbook theories, the actual physics experiments, and the real world setting of tactical sonar has been missing. Usage of PC-IMAT on actual submarine training exercises shows the limitations and enhancements of tactical maneuvering when sonar systems are subject to complex surroundings. The research and development of ''scientific visualization'' on PC-IMAT should ultimately incorporate a strong link between both learning environments. [Work supported by ONR.]

3pED4. Sonic gas analyzers. Matthew V. Golden, Robert M. Keolian, and Steven L. Garrett (Grad. Prog. in Acoust., Penn State Univ., P.O. Box 30, State College, PA 16804, golden@sabine.acs.psu.edu)

Whistles were used to determine the presence of hydrogen and/or methane in mines before 1900 in Germany. Since early in the 20th century, the measurement of gas thermal conductivity using a hot wire technique has been the method of choice for nonspecific detection of ''contaminating'' gases in air. At that time, the choice of thermal conductivity detectors was motivated by the popularity of the Wheatstone Bridge circuit for precision measurement [P. E. Palmer and E. R. Weaver, ''Thermal-conductivity method for the analysis of gases,'' Tech. Papers of the Bureau of Standards, No. 249, Vol. 18, Jan. 7 (1924)]. At the present time, the precision-to-cost ratio for frequency/time measurements exceeds that for voltage/current measurement by more than an order of magnitude. This presentation will examine the advantages which an electronic measurement of sound speed using inexpensive components and novel resonator geometries can bring to the detection of gaseous contaminants in air. Prototype sensor/electronics results will be presented. A discussion of temperature compensation techniques as well as the sensitivity to changes in pressure and humidity will be included. [Work supported by ONR.]

3pED5. Use of pseudo-random codes in pulse compression. Paul Shoning and Antal Sarkady (Dept. of Elec. Eng., U.S. Naval Acad., Annapolis, MD 21402)

Pseudo-random, or pseudo-noise (PN), codes are numeric sequences which appear random to the uninitiated observer yet are easily predictable to those who know the generation algorithm. Traditionally, PN codes have been generated by a hand wired sequence of binary shift registers, but are now created using programmable logic chips wired from user defined netlists. A properly implemented logic chip can generate PN codes of maximum length $L=2^n-1$ where n is the number of shift register segments. The code's period is limited only by the number of shift registers available. Bipolar PN codes have a normalized autocorrelation function that is unity at zero shift and $1/L$ at all other shifts. Thus PN codes can be used to amplitude modulate (AM) the ''main bang'' of an active RADAR or SONAR system. This modulation produces compression which vastly improves the range resolution and the sensitivity of the system. The properties of PN codes and their use in a simulated active SONAR system will be demonstrated using MATLAB programs.

WEDNESDAY AFTERNOON, 24 JUNE 1998

CASCADE BALLROOM I, SECTION A (W), 2:15 TO 3:15 P.M.

Session 3pNS

Noise and Architectural Acoustics: Progress Report and Discussion on the Continuing Activity on ASA's Role in Noise and Its Control

David Lubman, Cochair
14301 Middletown Lane, Westminster, California 92683

T. James duBois, Cochair
9424 Crystal View Drive, Tujunga, California 91042

Chair's Introduction—2:15

A meeting is being sponsored by the Technical Committees on Noise and Architectural Acoustics to review current progress and invite further discussion on activity to increase the role of the ASA in noise, noise control and related architectural acoustics issues. This outreach effort has included activity on increasing public awareness about noise and noise control, on public hearing screening testing and development of self-testing techniques, on seminars on industrial noise, on meeting room acoustic environments and, currently of special interest, on classroom acoustics. Discussions about these and/or new related activity, including encouraging joint activity in these areas with other professional organizations will be encouraged.

Session 3pPAa

Physical Acoustics: Sonochemistry and Sonoluminescence: SC II

Jacques L. Reisse, Cochair
Universite Libre de Bruxelles, Chimie Organique, CP 165, 50 avenue F. D. Roosevelt, 1050 Bruxelles, Belgium

Kenneth S. Suslick, Cochair
University of Illinois, A420 CLS Laboratory, Box 15-6, 601 South Goodwin, Urbana, Illinois 61801

Chair's Introduction—12:55

Contributed Papers

1:00

3pPAa1. Hydrodynamical perturbation effects in multiple-bubble sonoluminescence. Alex Robinson, David W. Kuhns, Anatol M. Brodsky, and Lloyd W. Burgess (Dept. of Chemistry, Univ. of Washington, Seattle, WA 98195-1700)

This presentation will describe the observation of new dynamical effects in multibubble sonoluminescence (MBSL). The experiments show a specific time-dependent nonmonotonic response of MBSL in aqueous and organic solutions to hydrodynamical perturbations caused by sudden pressure changes. Through a fast pressure jump, the bubble field is forced into an excited metastable state, subsequently relaxing over a period of seconds to minutes. The period and intensity of the system excitation is highly dependent upon physical parameters and small concentrations of surface active species. By monitoring the system via sonoluminescence intensity, low level quantitation of alcohols and earth metals in water as well as percent concentrations of water in alcohols has been performed. [Work supported by the Center for Process Analytical Chemistry.]

1:15

3pPAa2. Dependence of multibubble sonoluminescence intensity on the sound field in a sonochemical reactor. Hideto Mitome, Teruyuki Kozuka, Toru Tuziuti (Natl. Industrial Res. Inst. of Nagoya, AIST, 1 Hitare-cho, Kita-ku, Nagoya, 462 Japan, mitome@nirin.go.jp), and Liming Wang (Japan Small Business Corp., Tokyo, 105 Japan)

Since sonochemical reaction is related to the generation of acoustic cavitation bubbles, sonoluminescence induced by the collapse of bubbles can be a measure to specify the reaction field. The present paper discusses dependence of multibubble sonoluminescence intensity on the sound field in a sonochemical reactor to specify the cavitation field quantitatively. Deionized and distilled water was filled in a square reactor cell $50\times50\times140$ mm, which was settled in a temperature-controlled water bath, and was irradiated by cw ultrasound changing the frequency from 20 to 250 kHz for various values of water depth and temperature. The intensity of sonoluminescence was measured by a photomultiplier tube with a converging lens ensuring all the sonoluminescing position was detectable. The experimental results show that the luminescence intensity is very sensitive to the water depth. A change as small as 1 mm alters the vibration mode in the cell. The intensity is also strongly dependent on the amount of dissolved air and temperature. Correlation between the luminescence intensity and the harmonics in the ultrasonic waveform generated by nonlinear vibration of bubbles is shown. [Work supported by Japan Small Business Corporation.]

1:30

3pPAa3. Problems of ultrasonic energy transferring into liquid-phase load. Oleg V. Abramov, Vladimir O. Abramov, Vitaly N. Bulgakov, and Oleg M. Gradov (Lab. of Ultrasound, N. S. Kurnakov Inst., Leninsky prosp. 31, Moscow 117907, Russia, abramov@ionchran.msk.ru)

The rational circuits of construction and modes of operations for a system: electric generator, electroacoustic transducer, sonotrode system, irradiator, and liquid phase are considered from the point of view of transferring vibrations of maximum power into the load. The analysis has shown that for realization of vibration transfer of the greatest possible acoustic power created by the electroacoustic transducer, it is necessary to use the sonotrode system with developed surface. It can be realized by using an irradiator of the tubular form, in which the longitudinal fluctuations are transformed into radial ones. Calculations of tubular type sonotrode systems, based on use of the analytical approaches and of computer modeling, are conducted. A number of sonotrode systems that transform longitudinal vibrations into ones, extending in a radial direction in relation to axes' tubular irradiator, is made and tested. For improving the technological efficiency of the device, the tubular irradiator form was optimized to increase the number of the cavitational bubbles beneficially worked in the liquid and intensity of hydroacoustic streaming. So, for increasing the number of the cavitational bubbles on the external surface of the tubular irradiator at the high-amplitude zones for the longitudinal vibrations, the cross lugs are formed. The stand for valuation of acoustic capacity, entered in liquid load, is assembled, and experimental research at the choice of optimum modes of ultrasonic processing of liquids with various physical properties (viscosity, surface tension, density) is conducted.

1:45

3pPAa4. Enhancement of ultrasonic cavitation yield by a bifrequency irradiation and its frequency effect. Ruo Feng, Channgping Zhu, Huamao Li, and Zhouhua Chen (State Key Lab. of Modern Acoust., Nanjing Univ., Nanjing, 210093, PROC)

The ultrasonic cavitation yield given by a combining orthogonal irradiation at frequencies of 28 kHz and around 1 MHz is studied experimentally by using electric detection method. It is shown that the cavitation yield produced by the bifrequency irradiation is much larger than the sum of the yields produced separately by the two irradiations. For instance, when the intensity of 28-kHz ultrasound is fixed but that of 0.87-MHz ultrasound changes in the range of 4–7 w/cm^2, the cavitation yield of the combining irradiation is equal to 1.9–3.4 times of the sum of the yields given separately by the two irradiations. The ultrasound beams of 28 kHz combined separately with 1.0 and 1.7 MHz are also used. The results show that the enhancement of cavitation yield by bifrequency irradiation is notably dependent on the used frequencies. When the intensity of 0.87-, 1.0-, and 1.7-MHz ultrasound is taken 6.5 w/cm^2, the combining irradiation

gives 4.4, 3.2, and 1.8 times the cavitation yield of 28-kHz irradiation, respectively, which is similar to that obtained previously by using single-frequency ultrasound irradiation. The authors would like to acknowledge Professor T. J. Mason for his valuable suggestion.

2:00

3pPAa5. Two-phase theory of acoustic wave propagation in magnetic liquids. Tomasz Hornowski (Inst. of Acoust., Adam Mickiewicz Univ., Matejki 48/49, 60-769 Poznań, Poland, hornaku@phys.amu.edu.pl), Mariusz Kaczmarek (Inst. of Fundamental Technolog. Res., Mielżyńskiego 27/29, 61-725 Poznań, Poland), Mikołaj Łabowski, and Andrzej Skumiel (Inst. of Acoust., Adam Mickiewicz Univ., Matejki 48/49, 60-769 Poznań, Poland)

A new theoretical approach to ultrasonic wave propagation in magnetic liquids is proposed on the basis of a two-phase model in which the solid phase (magnetic particles coagulating to clusters forming a rigid skeleton) and the liquid phase (carrier liquid) are described by separate sets of equations for the balance of mass, momentum, and angular momentum. Interaction between clusters is described by components of the stress and strain tensors in the solid phase whereas interaction between the clusters and the liquid is accounted for as Stokes, Basset, and added mass forces and the respective angular momenta. Expressions are derived for the velocity and attenuation as functions of the wave frequency and the angle between the propagation direction of the ultrasonic wave and the magnetic field. Moreover, the expressions obtained are checked experimentally for several ultrasonic wave frequencies *versus* the strength and direction of the magnetic field under various conditions. [Work supported by KBN Research Grant No. 2PO3B 07912.]

2:15

3pPAa6. Sonofluorescence image in an analogous sonochemical reactor. Huamao Li, Andong Xie, Fan Zhong, Huijun Wan, Lijun Liu (Sci. Res. Managerial Office, Ji'an Teachers' College, Ji'an, 343009, PROC), and Ruo Feng (Nanjing Univ., 210093, PROC)

According to the sonofluorescence principle of ultrasonic cavitation oxidation suggested by the authors [Huamao Li *et al.*, Acta Acust. **22** (1997)], the cavitation field distribution images in both analogous symmetrical and nonsymmetrical sonochemical reactors filled with aqueous Luminol–KOH alkaline solution have been taken when using an ultrasound with an operating frequency of 1.45 MHz and an ultrasonic electric power of 25 W. The images seem to show that the ultrasonic cavitation field in the analogous symmetrical sonochemical reactor appear symmetrical with uniform distribution, and the ultrasonic cavitation fields in the analogous nonsymmetrical sonochemical reactors appear nonsymmetrical with nonuniform distribution, but the nonsymmetrical cavitation field distribution can be guided along some curved way. The authors think that the sonofluorescence image method can be available for use in a sonochemical reactor designed for getting uniform or positioning cavitation field. [Work supported by the Natural Science Foundation of Jiangxi province and the Science Foundation of Ji'an Teachers' College.]

WEDNESDAY AFTERNOON, 24 JUNE 1998 CEDAR ROOM (S), 1:00 TO 2:15 P.M.

Session 3pPAb

Physical Acoustics: Nonlinear Acoustics I: 1. History; 2. Solids; Rocks; 3. Surface Waves, Part 2

Akira Nakamura, Cochair
3-6-1 Gakuen, Fukui Institute of Technology, Fukui, 910 Japan

Mack A. Breazeale, Cochair
National Center for Physical Acoustics, Coliseum Drive, University, Mississippi 38677

Contributed Papers

1:00

3pPAb1. Interaction of counterpropagating acoustic waves in materials with nonlinear dissipation and in hysteretic media. Hélène Bailliet, Vitalyi Gusev, Pierrick Lotton, and Michel Bruneau (Lab. d'Acoustique, IAM–UMR 6613, Univ. du Maine, av. O. Messiaen, 72085 Le Mans Cedex, France, helene@laum.univ-lemans.fr)

Current interest in the interaction of sound waves traveling in opposite directions is due to progress in thermoacoustics (where the acoustic resonator is a part of the refrigerator) and achievements in diagnostics of solids via the evaluation of standing waves in rods. In the present analysis, the second-order nonlinear processes are described by the equation $\partial^2 V_+/\partial t^2 - c_0^2(\partial^2 V_+/\partial x^2) = -(\partial/\partial t)\{(\partial/\partial x)[(\epsilon-1)V_-^2+V_+^2] + RV_+|V_+| - h[V_-^A+V_-\mathrm{sgn}(\partial V_-/\partial t)](\partial V_-/\partial x)\}$. Here $V_\pm = v_+(\mu x, t-x/c_0) \pm v_-(\mu x, t+x/c_0)$, $\mu \ll 1$, $v_\pm$ are particles velocities, and superscript A denotes amplitude of a periodic wave. Elastic nonlinearity [the first group of terms on the right-hand side (rhs)] does not provide effective interaction of ''±'' waves. Nonlinear dissipation (the term proportional to R on the rhs) is responsible for the additional attenuation of the ''−'' wave induced by the ''+'' wave. The chosen form of dissipative nonlinearity is typical of gas-filled porous structures used in thermoacoustics. Hysteretic nonlinearity typical of micro-inhomogeneous materials (the last group of terms on the rhs) leads to amplification of the weak ''−'' wave in the field of the strong ''+'' wave. Predicted stimulated backscattering of sound in hysteretic media can influence the operation of parametric underground antennas. [Work supported by DGA.]

1:15

3pPAb2. Pseudo-Rayleigh and pseudo-Scholte surface acoustic solitons. Vitalyi Gusev (Lab. d'Acoustique, Univ. du Maine, av. O. Messiaen, 72085 Le Mans, France), Christ Glorieux, and Jan Thoen (Lab. Akoest. Therm. Fys., Katholieke Univ., Leuven, Celestijnenlaan 200D, B 3001 Leuven, Belgium)

Soliton solutions for the equation $s^2(\partial v/\partial x) = \alpha(\partial/\partial\tau)v^2 + \beta(\partial/\partial\tau) \times (H[v])^2 - D(\partial^2/\partial\tau^2)H[v]$, describing wave propagation on a fluid–solid interface covered by elastically linear film, have been found analytically. In this equation x is a ''slow'' spatial coordinate, τ is a ''fast'' time, α and β are nondimensional nonlinear parameters, S is the wave velocity in the absence of a film, and H denotes the Hilbert transform with respect to τ. This equation generalizes the recently proposed model for nonlinear Rayleigh waves [J. K. Hunter, Contemporary Math. **100**, 185–202 (1989)] and the equation derived for Scholte waves [Gusev *et al.*, IEEE UFFC (1998)], where $D=0$, by accounting for linear variation of the wave velocity with frequency $D \equiv \partial s_p/\partial\omega(\omega=0+0)$. Velocity dispersion $s_p = s_p(\omega)$ $[s \equiv s_p(0)]$ is due to interface loading by an acoustically thin

film and described by the last term in the right-hand side of the equation. The problem of the nonlinear surface/interface wave amplitude distribution in the interior of the medium is also addressed.

1:30

3pPAb3. Nonlinear acoustics of solids: History and modern trends. Vladimir A. Krasilnikov (Dept. of Phys., Moscow State Univ., Moscow, 119899 Russia, snk@snk.phys.msu.su)

The author had the pleasure to be involved in the pioneering experiments on the nonlinear acoustic wave propagation in crystals and metals (1960). It was found that even for small wave amplitudes acoustic harmonics generation took place for longitudinal waves. The results obtained were interpreted from the point of view of Hooke's law nonlinearity due to nonparabolic interaction potential taking into account accumulation effects in nondispersive media. Besides that, transversal acoustic waves under some external effects like pressure, heating, etc., also demonstrated nonlinear behavior despite that it was forbidden in a framework of crystal lattice theory. It was accounted for by the development of structural disturbations in a material and seemed to be the first attempt to demonstrate the importance of acoustic nonlinear nondestructive testing of different materials. It was shown later that some construction materials and rocks have much higher nonlinear parameter values than those for crystals and metals. The paper will also present an historical review of recent developments in other areas of nonlinear acoustics in solids: measurements of nonlinear acoustic parameters, surface acoustic waves nonlinearity, ''clapping'' nonlinearity, defective solids and rocks, etc.

1:45

3pPAb4. Measurement of third-order elasticity in isotropic solids. Z. W. Qian (Natl. Lab. of Acoust., Inst. of Acoust., Acad. Sinica, Beijing 100080, PROC, qzw@canna.ioa.ac.cn) and Wenhua Jiang (Nanjing Univ., Nanjing 210093, PROC)

The responsibility of second-order harmonics to the SV incidence was investigated in an isotropic solid such as aluminum, and each sample to be measured was designed as a semicircular disk of which the cross section is a semicircular polygon in order to provide many incidental angles for measuring. The displacements of both the linear and second-order waves were observed in the area near the center of the semicircle, where the surface is stress free. According to the theory proposed by one of the authors (Qian), the third-order elastic constants can be obtained acoustically by the inverse techniques.

2:00

3pPAb5. Nonlinear acoustics of zero-volume nonbonds and cracks. Igor Yu. Solodov (Dept. of Phys., Moscow State Univ., Moscow, 119899 Russia, snk@snk.phys.msu.su)

The results of experimental investigation of nonlinear acoustic phenomena for surface (SAW) and bulk waves (BAW) in materials with nonbonded interfaces and closed cracks are reported. Several mechanisms of acoustic nonlinearity specific for such materials were found and analyzed. In a propagation mode SAW harmonics generation and wave interaction effects revealed two to three orders of magnitude increase in nonlinear parameter values for a nonbonded interface. Unconventional higher harmonics ratio was measured and manifested in a distinctive nonlinear SAW waveform distortion. Efficient generation of harmonics forbidden in homogeneous isotropic solids was observed for shear BAW in the presence of nonbonds and cracks. Peculiar rectification effects were found for SAW propagation and BAW reflection at an interface and shown to result in both acoustic broadening and creeping of a nonbonded area. Extremely high efficiency was measured for nonlinear BAW–SAW transformations accompanying combined three-wave interactions at a nonbonded interface. In a reflection mode such an interface demonstrated a unique feature of nonlinear reflection with inverse spectral distribution of the harmonic amplitudes. Some prospective applications of the effects observed were demonstrated in signal processing, tribology, and nonlinear NDE of zero-volume nonbonds and closed cracks.

WEDNESDAY AFTERNOON, 24 JUNE 1998 DOUGLAS ROOM (S), 12:25 TO 3:00 P.M.

Session 3pPAc

Physical Acoustics: Memorial Session for Isadore Rudnick

Richard Stern, Cochair
Applied Research Laboratory, Pennsylvania State University, P.O. Box 30, State College, Pennsylvania 16804-0030

Robert M. Keolian, Cochair
Applied Research Laboratory, Pennsylvania State University, P.O. Box 30, State College, Pennsylvania 16804-0030

Isadore Rudnick was born on May 8, 1917 and passed away in Los Angeles on August 22, 1997. He was considered America's foremost acoustical physicist during the second half of the twentieth century, having made seminal contributions to both classical and quantum acoustics and having trained scores of graduate students and several postdoctoral fellows. He received his Ph.D. in Physics at the University of California, Los Angeles (UCLA) and, after work at Duke University and Penn State, he returned to UCLA where he was a professor of Physics for the past 39 years. He held visiting academic appointments in Paris, Haifa, Rome, Tokyo, Copenhagen, and Nanjing. Professor Rudnick was a member of the National Academy of Science and the Governing Board of the American Institute of Physics and received the prestigious Fritz London Award for his research in Low Temperature Physics from the International Union of Pure and Applied Physics. He was a recipient of the Acoustical Society's Biennial Award (1948), its first Silver Medal in Physical Acoustics (1975), and the Gold Medal (1982). He served as the Society's vice president (1962) and president (1969).

Friends, family, colleagues and former students will present reminisces, photos, video clips, and jokes that we hope will remind attendees at this special session of how fortunate we all were to have benefited from the life of this great and wise gentleman and scientist. Attendees will have the opportunity to make informal comments at the conclusion of the scheduled presentations.

Chair's Introduction—12:25

Invited Papers

12:30

3pPAc1. Isadore Rudnick's contributions to nonlinear acoustics. Robert T. Beyer (Dept. of Physics, Brown Univ., Providence, RI 02912)

12:45

3pPAc2. Izzy Rudnick's educational demonstrations and videos. Robert M. Keolian (Applied Res. Lab. and Grad. Prog. in Acoust., Penn State Univ., P.O. Box 30, State College, PA 16804-0030)

1:00

3pPAc3. Metals, superconductors, phase transitions and Izzy. Moises Levy (MJL Assoc., Monaco Beach Club 807, Naples, FL 34103)

1:15

3pPAc4. Dr. Mudnick, rough-on-rates Rudnick, etc. Steven L. Garrett (Grad. Prog. in Acoust. and Appl. Res. Lab., Penn State Univ., P.O. Box 30, State College, PA 16804)

1:30

3pPAc5. My happy years with my mentor—Professor Isadore Rudnick. Junru Wu (Dept. of Physics, Univ. of Vermont, Burlington, VT 05405)

1:45

3pPAc6. Isadore Rudnick: Making waves in superfluid helium. J. D. Maynard (Dept. of Physics, Penn State Univ., University Park, PA 16802)

2:00

3pPAc7. Isadore Rudnick: Making waves in liquid helium. Seth J. Putterman (Physics Dept., Univ. of California, Los Angeles, CA 90095)

2:15

3pPAc8. Twelve-year study on hydrodynamic forced standing soliton of Faraday wave experiment—In memory of the late Isadore Rudnick. Rongjue Wei (Inst. of Acoust., Nanjing Univ., Nanjing, China)

2:30–3:00 Open Microphone

WEDNESDAY AFTERNOON, 24 JUNE 1998 WEST BALLROOM B (S), 1:00 TO 3:00 P.M.

Session 3pSA

Structural Acoustics and Vibration: Nonlinear Dynamics and Chaos

David Feit, Chair

Carderock Division, Naval Surface Warfare Center, 9500 MacArthur Boulevard, West Bethesda, Maryland 20817-5000

Contributed Papers

1:00

3pSA1. Vector fields and quadratic maps. Huw G. Davies and Konstantinos Karagiosis (Dept. of Mech. Eng., Univ. of New Brunswick, Fredericton, NB E3B 5A3, Canada)

Vector fields describing responses of nonlinear systems are often investigated by sampling on a suitable Poincaré section. For example, period-1 limit cycles yield one fixed point, period-2 two points, and so on. More information could be obtained if the full return map on the section rather than just the fixed points were known. Such a map can be obtained numerically from transient analysis of the system. Instead, an analytic approximation of the map is discussed here, in the general quadratic form $x_i(t)=a_{ij}(t)x_j(0)+b_{ijk}(t)x_j(0)x_k(0)$. $x_i(t)$ are perturbations away from the limit cycle, $t=0$ being chosen on the Poincaré section. This equation with $t=T$, the fundamental period, is the required map. $a_{ij}(T)$ is the Floquet monodromy matrix. Differential equations for a_{ij} and b_{ijk} are obtained from a Taylor expansion of the system equations and solved recursively. The three-dimensional Rössler attractor which is known to yield a smooth, one-dimensional unimodal map is used as an example. [Work supported by NSERC.]

1:20

3pSA2. Experimental and theoretical analysis of the nonlinear dynamics and acoustics of a rattling plate. Karen J. Fegelman and Karl Grosh (Dept. of Mech. Eng. and Appl. Mech., Univ. of Michigan, 2350 Hayward St., Ann Arbor, MI 48109-2125)

Rattle has become an important issue in the motive and aerospace industries. Design for the prevention and reduction of rattle noise requires that the underlying mechanisms be understood and powerful, flexible numerical tools be developed. In this paper, the focus is on the former, developing a basic theoretical and experimental foundation for determining the vibroacoustic behavior arising from the nonlinear dynamics associated with the rattle process. In order to understand the fundamental mechanics of rattle, a model problem was formulated involving a hinged plate rattling against a stiff contact point excited by base motion. The plate was modeled as a flexible beam and the resulting equations of motion were solved explicitly. It was found that the calculated accelerations at the tip of the beam quantitatively agree with those measured from an experimental test stand. In addition, the predicted and measured sound pressure levels (SPL) at various points were found to agree qualitatively. Finally, the closed form flexible body solutions were analyzed with regard to stability to predict transitions from periodic to chaotic rattling behavior. In particular, the sensitivity of the transition region to chaos on the base motion amplitude and frequency are investigated experimentally and theoretically.

1:40

3pSA3. Effects of disorder and nonlinearity on the propagation of classical waves. Olivier Richoux, Claude Depollier, Jean Hardy, and Abderrahmane Brezini (Inst. d'Acoustique Mécanique, UMR CNRS 6613, Univ. du Maine, 72085 Le Mans Cedex 9, France, bal@laum.univ.-lemans.fr)

The interplay between the effects of disorder and nonlinearity on the propagation of classical waves is examined by means of an analytical model and numerical simulations. A quasi-one-dimensional string is loaded by N masses, each one fixed to a spring. Disorder is introduced onto the system by considering masses and/or lattice spacing as random variables. Nonlinearity is assumed to arise from the dynamical potential associated to each spring. The wave propagation is formulated in terms of the transfer matrix. The Lyapunov exponent is computed for various system size, yielding the spectrum and the localization length. The numerical simulations have been performed for the linear ordered case which serves as support. The purely disorder linear system offers a direct realization for the observation of the classical Anderson localization. Disorder in mass perturbs the allowed band from the upper edge in contrast to the disorder in position from both edges, the latter appears more efficient in inducing the Anderson localization. The nonlinear system in presence of both order and disorder exhibits bandwidths greater than their respective similar linear case. These findings suggests strongly that nonlinear waves are robust enough to propagate through the system even in the presence of disorder.

2:00

3pSA4. Nonlinear vibroacoustical free oscillation method for crack detection and evaluation. Leonid M. Gelman and Sergey V. Gorpinich (Dept. of Nondestructive Testing, Natl. Tech. Univ. of Ukraine, 37, Peremogy pr, Kiev, 252056, Ukraine, ania@gelman.pp.kiev.ua)

For detection and evaluation of cracks, the vibroacoustical method of free oscillations, based on nonlinear dynamics of a tested object, is widely used. However, in spite of wide practical application, the theoretical basis of this method is insufficiently investigated. The theoretical research of the decrement of the damped nonlinear free oscillations is given in the presence of a crack in a tested object. New generalizations of the decrement for nonlinear oscillations are proposed and investigated. New analytical expressions between the decrement and relative size of a crack, factors of damping, and the natural frequency of a tested object without a crack are received, on the basis of which a new testing feature is proposed and investigated. The cases of small and large damping are considered. The results obtained allow one to explain the phenomena that appeared at the method usage. [Work supported in part by the John D. and Catherine T. MacArthur Foundation.]

2:20

3pSA5. Nonlinear dynamic behavior of a piezoelectric 1-3 composite. Thomas J. Royston (Dept. of Mech. Eng., Univ. of Illinois, Chicago, IL 60607-7022, troyston@uic.edu) and Brian H. Houston (Naval Res. Lab., Washington, DC 20375-5000)

The nonlinear vibratory behavior of a smart material component, a 1-3 piezoceramic composite, is characterized theoretically and experimentally. The developed theoretical model for the electroelastic behavior of the 1-3 composite follows conventional assumptions made by prior investigators but includes higher-order electrical, mechanical, and electromechanical terms in the constitutive equations for the embedded PZT-5 phase. Dynamic experimental measurements of the 1-3's mechanical response to harmonic electrical excitation over a range of excitation frequencies and mechanical loading conditions quantify the level of higher harmonic content (harmonic distortion) in the device and illustrate the dependence of this on the mechanical coupling conditions of the component to its surrounding. While this study focuses on a particular piezoelectric device, the techniques developed are applicable to the wide range of smart materials and structures which exhibit significant nonlinearity, including those based on piezoelectric, electrostrictive, magnetostrictive, and electrorheological technologies, to name a few. [Work supported by ASEE/NRL Summer Faculty Program.]

2:40

3pSA6. Theoretical bases of the vibroacoustical nonlinear forced oscillation diagnostics method. Nadezhda I. Bouraou (Dept. of Orientation and Navigation, Natl. Tech. Univ. of Ukraine, 37, Peremogy pr., Kiev, 252056, Ukraine), Leonid M. Gelman, and Nataliya Yu. Ossokina (Natl. Tech. Univ. of Ukraine, Kiev, 252056, Ukraine)

A new passive vibroacoustical forced oscillation diagnostics method, based on nonlinear dynamics of tested objects, is considered. The method uses nonstationary vibration excitation with changed frequency. For the first time, theoretical research of the nonlinear oscillation system is given with mentioned excitation and the presence of the crack in the tested object. New analytical expressions between the estimates of spectral density of signals, radiated at tested object forced oscillations, and the relative size of the crack, duration of diagnostics, and speed of frequency excitation changing are received. On the basis of mentioned expressions, testing data are proposed and investigated. Comparison with the case of stationary excitation is given.

Session 3pSP

Signal Processing in Acoustics: General Topics

Edmund J. Sullivan, Chair
Naval Undersea Warfare Center, Code 82101, Newport, Rhode Island 02841

Contributed Papers

1:00

3pSP1. Using acoustic impulses to detect buried objects. Charles G. Don, David E. Lawrence, and Andrew J. Rogers (Dept. of Phys., Monash Univ., Vic 3168, Australia)

A detector of nonmetallic buried objects, such as land mines, has been developed using acoustic impulses with a peak energy around 1 kHz. The initial proposal was to compare the difference in signals from two microphones spaced equally on either side of the sound source held a few centimeters above the ground. Ideally, over a uniform surface the difference signal is zero, however, when one microphone is over an object an additional reflected pulse remains after subtraction. In practice, this pulse is small and often obscured by noise. Better results have been obtained if data from a single microphone is subtracted from a ''reference'' waveform. Some problems which have to be overcome are optimizing the alignment of the two pulse trains and deciding whether or not to normalize the signals prior to subtraction. If care is not exercised, either process may distort or mask the required object reflection. This small reflected signal can be further enhanced, compared to the background noise, by correlating with an appropriate known waveform. Mention will also be made of the effects of different media and surface contours.

1:20

3pSP2. Automatic noise source recognition. Didier Dufournet, Philippe Jouenne, and Adam Rozwadowski (01dB, Inc., 1583 E. Genesee Street, P.O. Box 796, Skaneateles, NY 13152)

MADRAS is an acoustic monitoring system that features the automatic recognition of noise sources. It is based on a tree classifier able to use different classification techniques like signal processing, morphology, fractional analysis, and neural networking. A very high accuracy of recognition is achieved due to the optimization of the choice of real-time technique applied and to the intrinsic performance of each algorithm. MADRAS can learn the characteristics of new sources and also use a database of previously processed cases and typical events. The paper presents the results of multiple source recognition in a complex acoustic environment. Implemented on a real time PC-based measuring analyzer called Symphonie, MADRAS has been able to distinguish all noise sources. Acquired data may then be processed to obtain the energy contribution of each source and a list of the frequency of each appearance. Simulations may be viewed and modified.

1:40

3pSP3. A novel octave graphic equalizer. Marija F. Hribsek and Dejan V. Tosic (Faculty of Elec. Eng., Bul. Revolucije 73, 11000 Belgrade, Yugoslavia)

An octave constant Q graphic equalizer using a new class of active bandpass filters is presented. It covers all 11 standard octaves in a frequency range from 16 Hz to 20 kHz. The level in each octave can be changed within ± 20 dB with respect to the reference level which corresponds to the zero dB gain of the equalizer. The advantages of the proposed bandpass biquads are the use of only one operational amplifier per octave, a very small resistors spread ratio, and equal values of the resistors in all octaves. The computer simulation has been used to verify the design of the novel circuit. The new design has been compared to the existing solutions reported in the literature. The comparison shows excellent agreement with the published results. The effects of the finite gain and bandwidth of the real operational amplifier have also been investigated. The proposed new equalizer shows to be robust against these amplifier imperfections.

2:00

3pSP4. Tomographic scanning acoustic microscope system. Daesik Ko, Daekun Song, and Kyesuk Jun (24, mok-dong, chung-ku, Taejon, 301-729, South Korea)

In this paper, a new type of acoustic microscope system using the tomographic image processing technique of STAM (scanning tomographic acoustic microscope) and operation principles of the transmission-mode and detection technique of SAM (scanning acoustic microscope system) is proposed. Since SAM and scanning laser acoustic microscope system (SLAM) used in the past were operated at the reflection mode, these systems could not obtain high-resolution tomographic images. Although STAM could process tomographic images, due to the detection-using laser, problems such as complex detection hardware, alignment, and low S/N ratio occur. If the tomographic image processing technique is used for ultrasonic microscope systems, the axial resolution can be enhanced and it can help and work together with the existing systems to detect cracks that are difficult to find in the reflection mode. These experimental results will be used for various ultrasonic microscope tomographic image processing and ultrasonic measurements.

2:20

3pSP5. Motion compensated high-frequency synthetic aperture sonar. James T. Christoff (Coastal Systems Station, Dahlgren Div. Naval Surface Warfare Ctr., Code R21, Panama City, FL 32407-7001, christoff_jim@ccmail.ncsc.navy.mil)

The Coastal Systems Station has recently completed a set of sea tests using a high-frequency synthetic aperture sonar (HFSAS) mounted on a towed underwater vehicle. The processed results from these tests demonstrate that 2.5-cm resolution can be achieved in shallow water from a small physical array. This system had a Doppler unit to control the ping rate, but had no inertial navigation system and depended entirely upon acoustic backscatter from the seabed to correct for vehicle deviations in the line of sight. In these sea tests the dual overlapped phase center technique [Sheriff, Symposium on Autonomous Underwater Vehicle Technology, pp. 236–245, 1992] was used as the motion compensation algorithm. The tests were conducted over a target field in the Gulf of Mexico that contained a variety of targets, both small sphere and minelike targets. This paper will present results from the HFSAS in the form of a point response function and an acoustic image. The HFSAS achieved between 2.5- and 3-cm resolution on the smallest sphere and produced excellent images of the remaining targets out to a range of approximately 70 m. [Work supported by ONR.]

2:40

3pSP6. A study of extracting characteristic parameters of a tubular target. Renqian Wang and Yingchun Li (Dept. of Electron., Peking Univ., Beijing 100871, PROC)

An inverse problem of sound scattered by a tubular target is studied for extracting its characteristic parameters. A geometrical acoustic method is used to describe the scattered field of the tubular target. A physical model is suggested: the backscattering of a tube shell is simplified into reflection of a plane wave on layered media under conditions: $ka \gg 1$, $c/c2 \gg h/b$, here a, b, and h are outer radius, inner radius, and thickness of the tube shell, respectively, and c and $c2$ are sound velocity of the external medium of the tube shell and (longitudinal wave) sound velocity of the tube shell. Reconstruction formulas of the characteristic parameters of the tubular target are given. The characteristic parameters of an elastic tube shell, such as a metallic tube shell, a metallic tube covered with sound-absorbing materials, a bone tube of a pig, and soft tube shell such as a blood vessel, and a trachea of a pig, are reconstructed by using computer simulation and experiments. The theoretical results obtained by this method are supported by experiments.

WEDNESDAY AFTERNOON, 24 JUNE 1998 METROPOLITAN BALLROOM (S), 1:00 TO 3:00 P.M.

Session 3pUW

Underwater Acoustics and Acoustical Oceanography: Bottom Geoacoustic Characterization and Inversion II (Précis Poster Session)

Subramaniam D. Rajan, Chair
Scientific Solutions, 5907 106th Avenue, Northeast, Kirkland, Washington 98033

In this session, an oral summary of each paper will be presented followed by a poster session. All posters will be on display, and all contributors will be at their posters, from 2:00 p.m. to 3:00 p.m. To allow for extended viewing, posters will remain on display until 5:30 p.m.

Chair's Introduction—1:00

Contributed Papers

1:05

3pUW1. Head wave data inversion for geoacoustic parameters of the ocean bottom off Vancouver Island. Mark C. A. Laidlaw, Oleg A. Godin, and N. Ross Chapman (SEOS, Univ. of Victoria, P.O. Box 1700, Victoria, BC V8W 2Y2, Canada)

As a part of the Pacific Shelf-93 experiment, small explosive charges were used as underwater sound sources on the continental shelf off Vancouver Island. Broadband acoustic signals received by a vertical line array show the rich structure of precursors arriving prior to the direct water wave. Kinematic properties of the precursors are found to be consistent with those of head waves with different numbers of reflections at the ocean surface and bottom. Power spectra of the precursors reveal complicated interference structure, including deep nulls at relatively low frequencies. Positions of the nulls in the frequency domain and their depth dependence are shown to be sensitive to the variation of compressional wave speed in the bottom. A combination of beamforming, spectral analysis, and travel-time considerations is applied to separate and identify individual head wave arrivals in the sequence of precursor signals. Range- and depth-dependence of the travel times for individual head waves are inverted to determine compressional wave speeds in two distinct subbottom layers and to estimate the thickness of the sediment layers. The frequency- and range-dependence of the head waves amplitudes are analyzed to estimate the compressional wave attenuation. [Work supported by NSERC.]

1:12

3pUW2. Acoustic propagation in gassy sediments. Michael D. Richardson, Warren T. Wood (Marine Geosciences Div., Naval Res. Lab., Stennis Space Center, MS 39529, mike.richardson@nrlssc.navy.mil), Aubrey L. Anderson (Texas A&M Univ., College Station, TX 77843), and Roy H. Wilkens (Hawaii Inst. of Geophys. and Planetology, Univ. of Hawaii at Manoa, Honolulu, HI 96822)

Measurements of values of sediment physical properties, bubble volume, and bubble size distribution are used to predict sound speed and attenuation in the fine-grained, gassy sediments of Eckernförde Bay, Baltic Sea. The predicted results are compared to *in situ* and laboratory measurements of sound speed and attenuation over the frequency range of 5–400 kHz. Dispersion of sound speed is used to determine the upper limit of methane bubble resonance near 20 kHz. These data combined with bubble size distribution measured using CT scans of sediments held under ambient conditions yield an estimate of effective bubble size of 0.3–5.0-mm equivalent radii. Histograms of bubble size distribution are then used to predict frequency-dependent sound speed and attenuation based on the model of Anderson and Hampton [J. Acoust. Soc. Am. **67**, 1865–1903 (1980)]. Given the highly variable spatial distribution of bubble volume and size, the agreement between theory and measurement is remarkably good.

1:19

3pUW3. An optimization technique applied to the recovery of acoustic impedance profiles. Marcelo Magalhaes and Roberto Tenenbaum (Acoust. and Vib. Lab., Federal Univ. of Rio de Janeiro, Rio de Janeiro, Brazil)

A method based on a global optimization technique is used to solve the inverse (identification) problem of one-dimensional wave propagation in transversely infinite inhomogenous media. The scheme consists of minimizing a cost function given by the square distance (according to the Euclidean norm) between a measured and a synthetic signal, the latter produced by an arbitrary impedance profile. This cost function imposes several difficulties, since the model for the synthetic signal causes it to be polynomial whose degree is at least equal to the number of layers in which the profile is discretized. The optimization method used is a secant one, which, instead of making use of information about the second derivatives of the cost function, which is too time consuming, generates sucessive approximations of its Hessian matrix, based on information gathered as the procedure progresses. Moreover, in order to guarantee that the method follows a descent direction, that is, the cost function is always reduced, a BFGS (Broyden–Fletcher–Goldfarb–Shanno) updating rule is used, together with a Wolfe line search procedure. Results are shown for some continuous as well as stratified media, showing that the method works well with both smooth and nonsmooth profiles.

1:26

3pUW4. Sequential versus iterative methods for recovering acoustical impedance profiles of inhomogeneous media. Roberto Tenenbaum and Marcelo Magalhaes (Acoust. and Vib. Lab., Federal Univ. of Rio de Janeiro, Rio de Janeiro, Brazil)

Optimization methods for identification of nonhomogeneous media are known to be very time consuming. On the other hand, sequential methods (layer stripping methods) are computationally very efficient and rather unstable under noisy data. In this work, some recent optimization techniques are applied to recover the impedance profile from the reflected data. A careful approach has to be used though, since the cost function is highly nonlinear and its evaluation is quite costly in a computational point of view. The optimization method chosen is a secant one, which, instead of using information about the second derivatives of the cost function, generates successive approximations of its Hessian matrix, based on information gathered as the procedure progresses. The sequential method lies in a new algorithm for computing the reflection response of a truly layered media for an arbitrary input, which can easily be inverted. The results of both methods are compared for some synthetic echoes. The behavior of the methods for random and zero-average noise added to the response is studied. The advantage of using each of the methods as a function of the signal-to-noise ratio is then discussed.

1:33

3pUW5. An experiment on inversion of sound profile through ray modeling. Yuanliang Ma, Xiaoquan Jiang, Yuanhai Sheng (Inst. of Acoust. Eng., Northwestern Polytechnical Univ., Xi'an 710072, PROC, ylma@nwpu.edu.cn), Shixing Yang, and Qingzuo Cheng (CSSC, PROC)

An experiment was conducted in a lake of 150-m depth. A very short hydrophone array (3-m long or 1/50 of the water depth) was used for data acqisition, which consists of 13 hydrophones with 25-cm spacing. Receiving signals are modeled as sums of eigenrays determined mainly by the sound profile, while the sound profile is expressed by six measured samples at different depths in addition to a known sound speed at the bottom. The inversion is based on a simulated annealing algorithm off-line using a 486/100 microcomputer and completed within 2 min. The resultant rms error of sound profile is about 1.6 m/s in comparison with the measured data. An important feature of this approach is that instead of matching the measured to the modeled data vector, arriving structure expressed by the DOA angles and relative time delays are matched for the inversion. To estimate the arriving structure, high-resolution spectrum analysis techniques such as OWSF and MUSIC are adopted. The experiment has shown that inversion of the sound profile can be successfully achieved through ray modeling and using a very short vertical array.

1:40

3pUW6. Waveguide characterization estimation in shallow water using a vertical array. Dejun Jiang (Inst. of Acoust., Academia Sinica, Beijing 100080, PROC)

Waveguide characterization estimation in shallow water using the complex mode approximation of an acoustic field is presented. The advantages of the method are that (1) the dependence on the environmental parameters will obviously decrease. (2) The waveguide characterization parameters (k_m, β_m) can be obtained at the same time, even when the fine structure in the bottom medium, such as the number and thickness of layers, the velocity of compressive and shear wave, and attenuation, is less known or unknown. (3) It can extract the bottom reflection coefficient $V(k)$. Numerical examples illustrate that (1) the accuracy of k_m is at least 10^{-5}, the related error of β_m is mostly less than 20%, and the smaller the mode number, the smaller the related error is. (2) The reflection coefficient in the bottom at low grazing angle can be obtained using a vertical array where the total number of samples is $N=18$ and the length $L=90$ m. The experimental data of 500 Hz are emphatically discussed here. The results for an $f=500$-Hz-wide impulse acoustic signal source which is located at $z_s=11$ m and $r_s=21$ km show that the extracted accuracy of k_m is between 10^{-4} and 10^{-5} and the related error of β_m is between 9% and 26%.

1:47

3pUW7. The error analysis of inverse algorithms for reconstructing the acoustical parameter profile of layered media. Jun-xuan Lin and Qing-hua Bao (Dept. of Phys., Ocean Univ. of Qingdao, Qingdao 266003, PROC)

Reconstructing the parameter profile of layered media is studied with the telemeter of tiny structure in hydrology, oil exploration, and the position selection of petroleum platform in the ocean. It is a much studied topic in the field of ocean acoustics. An inverse scattering experiment of thermocline was completed by us in 1992. The inverse results by the sample iteration algorithm and DC algorithm agreed well with the data measuring by the CTD instrument. It is still an open question. Further discussion in the aspect of reliability is presented in this paper. Generally speaking, inverse errors are caused by: (1) the inverse algorithm itself, (2) signal processing for the stability of computation, and (3) the improper problem. The result of a model inverse experiment shows that the errors caused by the algorithm itself and signal processings are not so critical if the improper problem was not paying enough attention.

ASA Medals and Awards Plenary Session

Lawrence A. Crum, Chair
President, Acoustical Society of America

Presentation of Certificates to New Fellows

Presentation of Awards

R. Bruce Lindsay Award to Robert L. Clark

Honorary Fellowship to Carleen M. Hutchins

Helmholtz-Rayleigh Interdisciplinary Silver Medal to David E. Weston

Gold Medal to Floyd Dunn