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ECHOES

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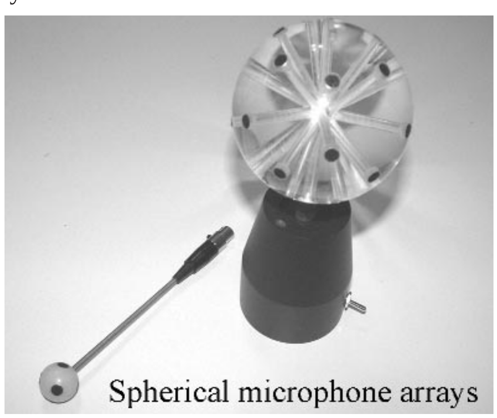
Electroacoustic Systems for 3-D Audio – A report from the Pittsburgh meeting

Gary W. Elko and Jens Meyer

Our binaural hearing systems are immediately exposed to spatial sound fields at birth (and arguably before birth). As we begin to process acoustic signals, we learn to use our binaural hearing to analyze the sound field to which we are exposed. Human hearing responds to sound pressure, which is a scalar field having three spatial dimensions. Thus, as we strive for better recording and reproduction of sound, it is reasonable that we move towards audio systems that address our natural binaural ability and build systems that recreate real three dimensional sound fields.

Stereo audio has been in existence for more than 70 years and is still the most common technique used for audio recording and playback. In the mid 1970's, with the advent of quadraphonic audio systems, there was an attempt to increase the number of playback channels to enhance the spatial aspects of the sound field. However, quadraphonic systems were not widely accepted and quickly disappeared. The explosive growth of DVD players for home theater systems that allow for 5.1 and 6.1 channel (and more) playback using Dolby ™ and DTS™ multichannel systems has led to a wider acceptance and appreciation for surround-sound audio. This short article describes some of the current research in this area with emphasis on the papers presented at a special session on 3-D audio at the ASA Pittsburgh meeting in June 2002.

One advance in the recording of sound-fields has its origins in work done in the early 1970's by Gerzon. A basic innovation in this work was to expand on the stereo microphone techniques invented by Blumlein. Gerzon proposed a tetrahedral arrangement of microphones, where the sound field is separated by appropriately combining 4 first-order differential microphones. The term "first-order differential" relates to the beamforming process where the beam pattern can be described by the combination of an omnidirectional term and a first-order difference between closely-spaced pressure microphones. The first-order term can be associated with the acoustic particle velocity due the Euler's equation that relates the acoustic particle velocity to the gradient of the pressure field. By combining the omnidirectional term along with the pressure gradient term, a general steerable first-order microphone can be formed. This microphone has been commercially produced as the Soundfield microphone. Although first-order sound field microphones are useful for recording of the spatial sound field, they are probably still too broad in their spatial response for more accurate playback systems.



Photograph of two spherical arrays. The smaller 6-element microphone has a radius of 0.75 cm and the larger 24 microphone has a radius of 3.75 cm.

At the Pittsburgh meeting, Meyer and Elko presented some new work on a spherical microphone array that further extends the previous work by allowing any desired steerable beamformer to be realized. This paper showed how to realize an efficient modal beamformer based on the orthonormal decomposition of the incident pressure sound field into spherical harmonics. Since this decomposition is similar in spirit to standard eigen-analysis techniques, the system was named: "eigenbeamformer" or Eigenmike™. By choosing to place pressure microphones on a rigid sphere, it was shown that the decomposition allows the recording of all desired spherical harmonic components in the desired passband, contrary to results that would be obtained had one used an open sphere (where the microphones are placed in free space). A spherical

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We hear that...

• On July 10, **Elaine Moran** received a 35-year award from the Acoustical Society of America. Congratulations, Elaine!

• At its May meeting, the Council of the National Academy of Engineering elected ASA Fellow **C. Dan Mote, Jr.** to a three-year term as councillor. Mote, President of the Universty of Maryland as well as Glenn Martin Institute Professor of Engineering, has been an Academy member since 1988.

• **Manfred Schroeder**, University of Goettingen and Bell Labs (ret.), gave the Audio Engineering Society's Heyser Memorial Lecture on "The Unreasonable Effectiveness of Mathematics in Audio." The lecture, postponed from September 2001, was given on 2 December at the Javits Center. Schroeder is a Fellow of ASA and also a Gold Medalist (1991).

• **Wesley L. Nyborg** was named Lauriston S. Taylor Lecturer for the National Council for Radiation Protection and Measurements. His lecture "Assuring the safety of medical diagnostic ultrasound" was published in the May issue of *Health Physics*. Nyborg is professor emeritus of physics at the University of Vermont and a Fellow of ASA.

• The ANSI Board of Standards Review has approved standard S12.60 on Classroom Acoustics. The standard should be available soon in printed and electronic copy, and it may be bundled with a copy of the ASA brochure on Classroom Acoustics supporting the technical details of the standard.

• First Honors in the student design competition sponsored by the ASA and the National Council of Acoustical Consultants at the Pittsburgh ASA meeting, with a cash prize of $1000, went to **William Chu** and **Dana Smith**, Rensselaer Polytechnic Institute. Four Commendations, with cash prizes of $500 each, were give to **Bridget Bednarczyk** (U. Florida), **Phillis Henderson** (U. Florida), **Kevin Kane** and **Iraklis Lampropoulos**, Rensselaer Polytechnic Institute, and **Rob Lee** and **Mike Oliva** (U. Kansas).

• The Acoustical Society presented **Leonid M. Brekhovskikh**, Honorary Fellow of ASA, with a certificate expressing congratulations on his 85th birthday. The presentation was made in Russia in May by William Kuperman.

ECHOES

Newsletter of the Acoustical Society of America

Provided as a benefit of membership to ASA members

The Acoustical Society of America was organized in 1929 to increase and diffuse the knowledge of acoustics and to promote its practical applications.

Echoes Editor .Thomas Rossing

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• **Lily Wang**, University of Nebraska, was awarded an NSF CAREER Award. The CAREER program recognizes and support the early career-development activities of teacher-scholars who are likely to become academic leaders.

• **Henry Cox**, chief scientis and senior vice president of Orincon Corporation International in Arlington, Virginia, was elected a member of the National Academy of Engineering.

Live on the Internet: Sounds of the Sea

James Mercer from the Applied Physics Laboratory, University of Washington and Christopher Fox from the Pacific Marine Environmental Laboratory have succeeded in placing a vertical hydrophone array atop the Pioneer Seamount at a depth of 1000 m. The array consists of four hydrophone elements suspended above the seafloor at a spacing of 30 m. The array is cabled to a shore station near Half Moon Bay, California, where the multiplexed acoustic channels along with temperature, tilt, and pressure data, are de-multiplexed and digitized. The continuous data stream is being transmitted on a commercial DSL data line to the Internet. The summed-channel data are available as a real-time spectrogram displaying the most recent six minutes of data, in an interactive form where digital data can be accessed. The web site is located at www.pmel.noaa.gov/vents/acoustics/pioneer.html.

A wide variety of acoustic signals have already been identified, including earthquakes, shipping noise, seismic air guns, and a variety of large marine mammals such as blue, fin, humpback, and sperm whales. Computers with an audio player (such as Real Player) can be used to listen directly to live signals. According to Mercer, there are always interesting sounds to be heard.

New ASA Fellows

New ASA Fellows (left to right): William Hartmann (ASA President), David Marsh, Janet Weisenberger (ASA Vice President), Asbjorn Krokstad, Rachel Clifton, Andzej Rakowski, Leon Sibul, Lynne Werner, Kerry Commander, Darlene Ketten, David Swanson, Patrick M. Hurdle, Brian Houston, Andrea Simmons.

Electroacoustic Systems for 3-D Audio

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geometry also has the desirable quality that it is rotationally symmetric along any axis that goes through the center. Finally, it was also shown that the rigid sphere increases the signal-to-noise ratio by 3.5 dB at low frequencies due to the wave diffraction effects. One spherical microphone that was shown at the meeting had a radius of 3.75 cm with 24 microphones arranged somewhat equally on the surface. A beamformer design was shown for up to third-order spherical harmonics which sets the maximum directional gain at 12 dB. For comparison, the first order system described above allows a maximum gain of 6 dB. This enhanced gain is constant over frequency, but care must be taken at low frequencies for noise and spatial aliasing at frequencies where the average microphone spacing exceeds one-half of the wavelength. An interesting application discussed for the spherical array was in off-line processing. Finally, it was suggested that having a relatively complete decomposition of the spatial sound field would enable future sound editing advances as well as post-processing for forensic sound studies.

Along with the design of the sound field recording microphone array, is the corresponding playback system. Heinz Teutsch, a PhD student working with Professor Kellermann in the Telecom Lab at the University of Erlangen-Nurnberg, showed work sponsored by the European CARRUSSO project. This project is investigating multichannel input and output audio systems for spatially realistic teleconferencing applications. A playback system that Mr. Teutsch described, was the Wave-Field-Synthesis (WFS) system based on the work of Professor Berkhout and colleagues at Delft University. The basic idea is to implement a discrete solution to the interior Helmholtz-Huygens integral equation and then reproduce the sound field in an enclosed space by using appropriate sources (pressure and velocity) on the surface that defines the space. By using a variant of the wave solution, one can express the interior problem as a discrete Rayleigh integral equation and thereby use standard loudspeakers. Professor Berkhout's team at Delft has built arrays with more than 100 loudspeakers arranged around the listener at the same height. Although one can only generate an axial (two-dimensional) sound field with this array, it was claimed that good surround sound is generated with this system. There is also current work by Ward and Abhayapala on using spherical harmonics to investigate the spatial fidelity of these systems. It is clear that the linkage between the recording and playback arrays using spherical harmonics is a natural basis for further developments in this field and this work is ongoing.

Another scheme to obtain 3D audio, using a much more simplified approach, exploits the fact that human listeners respond to the acoustic pressure. (We will ignore the fact that head motion is integral in the perception of sound fields for the moment). Thus, if the acoustic pressure is controlled at both ears of a listener, it should be possible to give the impression of any desired sound field (even ones that are not physically possible!). One solution is to wear headphones, but this also sometimes introduces some artifacts such as acoustic images appearing to come from within the head. Using loudspeakers solves this problem, but introduces another problem of inter-channel cross-talk; where the right channel signal diffracts around the head and enters the left ear and similarly for the left-channel signal arriving at the right ear. A solution to the cross-talk problem was first given by Atal and Schroeder in 1966. The cross-talk canceler scheme uses knowledge of the geometry of the ears and loudspeaker positions to compute the components of the right speaker to the left ear and vice-versa. By adding a filtered version of the left channel signal to the right loudspeaker and a similar filtered version of the right channel to the left loudspeaker, one can obtain pressure signals at the two ears that are left and right signals only. Although this scheme worked, it was very sensitive to any head motion (even very small head motion). An advance to this solution came from Hamada and Nelson who reported on the stereo-dipole at the joint ASA/ASJ meeting in Hawaii in 1996. The stereo-dipole uses two closely-spaced loudspeakers in the Atal-Schroeder cross-talk cancellation scheme. An advantage of this scheme is that the control of the cross-talk now falls on the surface of a cone whose apex is at a point between the two loudspeakers. The Atal-Schroeder method only offers control at two discrete circles around the axis of the speakers. The stereo-dipole thus allows some freedom of motion of a listener toward and away from the loudspeakers. One existing problem, however, is that if the listeners rotate their heads, then the precedence effect can lead to conflicting spatial cues and the listener cues in on the real loudspeaker positions. Takeuchi and Nelson presented a paper at the Pittsburgh meeting that addresses these unwanted precedence cues. Their simple and elegant solution was to note that the precedence effect is significantly less if the incident signals from the cross-talk system arrive from above the listener. Thus, they have located the loudspeakers above the listener and claim to have removed this problem. The stereo-dipole also has problems related to high levels of signals that are sent in extraneous directions. Dr. Takeuchi discussed appropriate room treatment to handle this problem. Ward and Elko have suggested using more loudspeakers to ameliorate this problem by putting constraints on the sound field radiated in directions away from the listener.

In conclusion, the use of new loudspeaker and microphone array designs along with commensurate signal processing is opening new areas of research for the acoustics community. With the current acceptance of surround-sound audio by consumers, there has been a wide appreciation of higher spatial fidelity of sound fields. There are still many unsolved problems that need to be addressed before we find ubiquitous use of psychoacoustically accurate spatial audio recording and playback systems, but the future configurations of these systems are starting to take shape.

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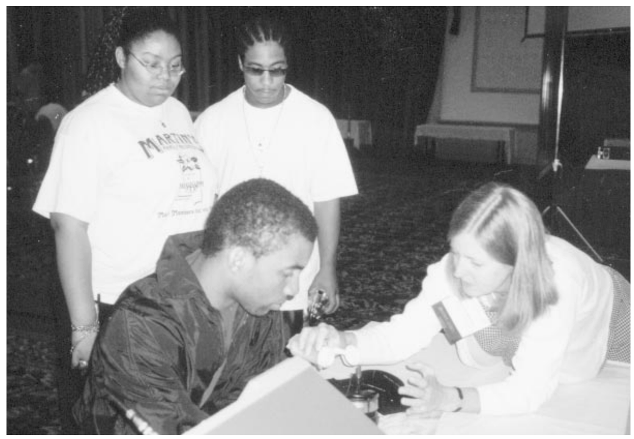
Echoes from Pittsburgh

Robert Apfel receives ASA Gold Medal from President William Hartmann

Ira Hirsh, Vice President Janet Weisenberger, and Shirley Hirsh at the dinner honoring Ira.

Gold Medalist Tony Embleton, and President William Hartmann.



Christy Holland demonstrates vibrations to visiting high school students.

Pittsburgh attendees enjoyed a buffet social on a riverboat.

ASA Awards to Science Writers

Barb Sotirin

Did you know that high-intensity sound waves could soon be used for acoustic surgery? Or that hairy, miniature ears could be floating around in your body listening for disease?

To encourage the communication of acoustical science and engineering to the general public, the Acoustical Society of America (ASA) sponsors two annual awards for outstanding popular works on acoustics. One award is for a popular piece on acoustics composed by a journalist or group of journalists and the other is for a popular piece on acoustics composed by an acoustics professional or group of professionals. Each award includes a $1000 prize and an award certificate.

This year's winners deserve our congratulations for fascinating and accessible articles on acoustics. Bennett Daviss won the journalist award for his *New Scientist* (July 2001) article "Snap, crackle and pop." He described a revolutionary technology developed by a team of scientists and engineers at the Jet Propulsion Laboratory to miniaturize and sensitize acoustic microphones initially meant to provide a robotic interplanetary probe with super-sensitive hearing. Another application could be to listen to the "movement of flagella and cilia, and even cell division and respiration." By injecting sensors into the bloodstream, "the nano-ears could be used to eavesdrop on the body's metabolism like miniature stethoscopes, spotting diseased or cancerous cells before they get a chance to spread." The design mimics the human ear by simulating stereocilia with carbon nanotubes – a cylindrical form of the buckyball structure that are several nanometers in diameter and up to 60 micrometers long. This translates into much greater sensitivity than the human ear cilia that have a diameter of around 100 nanometers and are one or two micrometers long.

A medical technique, known as acoustic haemostasis, offers a non-invasive treatment for internal bleeding and might have saved the life of Britian's Princess Diana "had paramedics been able to treat her hidden wounds at the scene of the accident." Your colleagues Shahram Vaezy, Roy W. Martin and Lawrence A. Crum discuss the results of their research to tightly focus high-power ultrasound for medical applications. The "intensity at the focal point is typically 1000-10 000 watts per centimeter squared, some four to five orders of magnitude greater than the intensities of diagnostic ultrasound. The waves can be focused using a concave transducer that emits ultrasound waves that converge to a region the size and shape of a grain of rice" generating a pressure wave as high as 1 million pascals at the focal point. Read all about it in their article "Acoustic surgery" published in *Physics World* (August 2001) which was selected as the winner of the award for acoustics professionals.

These articles were chosen by a panel of ASA members as having best met the criteria of accessibility by the general public, relevance to acoustics, accuracy, and quality of the entry. The Science Writers Award panel is a sub-group of the ASA's Public Relations Committee. My thanks to panel members Suzanne Boyce, Bill Cavanaugh, E. Carr Everbach, Joanne Miller, Tom Rossing, Bill Siegmann, and Jim Yu for their participation as this year's judges.

The basic criteria for entries are accessibility of the piece by the general public, relevance to acoustics, accuracy, and the quality of the entry. Entries may be from a variety of media, including video, major Internet sites, books, newspapers, magazines, audio tapes, audio broadcasts, etc.

Entries for the next competition should have been published, issued, or broadcast between January 1, 2002 and December 31, 2002. Submissions of entries need not be made by the author. Multiple entries by a single author are accepted.

To enter next year's competition, please send 4 copies of each entry (legible photocopies are OK if originals are not available) making sure that it includes author name, publication name, and publication date, publisher's address, and author's complete contact information (including email address) by April 15, 2003 to:

Elaine Moran
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Suite 1NO1, 2 Huntington Quadrangle
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For more information, please contact:

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Barb Sotirin is Chair of the Science Writers

(Acoustics in the News, continued from page 8)

• The "hum" is back, this time in Kokomo, Indiana, according to a story in the June 17 issue of the *New York Times*. The symptoms are pretty much the same as the Taos Hum (ECHOES, Autumn 1995) and the Copenhagen Hum (ECHOES, Fall 1997). Various residents describe a sound "like butter crackling in a skillet" or the buzz of a busy highway. Many blame the hum, which began in 1999, for health problems including headaches, nausea, diarrhea, fatigue and joint pain. The city has appropriated $100,000 to study the problem, and is seeking proposals from "qualified acoustical engineering consultants." One engineer, sent there by Fox TV to do a survey, noted a fairly strong component of infrasound around 10 Hz, which is inaudible to most people, but can be sensed by others. Studies made in connection with the Copenhagen Hum (see ECHOES, Fall 1997) found that the ability to hear the hum appears to be hereditary, because of the number of sisters, mothers, and daughters who can hear it. There were not so many brothers, sons, and fathers who heard it, however. Using directional finding equipment, the low frequency noise in the homes of the Danish hum hearers was traced to various industrial plants.

Scanning the Journals

Thomas D. Rossing

• The April issue of *Acoustics Australia* is a special issue on **Ocean Acoustics** edited by L. J. Hamilton. Included in it are papers on "Scattering in the ocean," "Australian research in ambient sea noise," "An introduction to ship radiated noise," and "Seafloor data for operational predictions of transmission loss in shallow ocean areas."

• "The power of hearing" is the title of an interesting article on **hearing and cochlear mechanics** by Thomas Duke in the May issue of *Physics World*. He credits cosmologist Tommy Gold with first suggesting (in 1948) that the ear employs an active process that adds energy at the frequency that it is trying to detect, rather like the regenerative radio receiver. This active process counteracts friction in the cochlea, so that sharp frequency tuning and high gain can both be achieved. The wisdom of Gold's suggestion was underlined in 1971 when William Rhode used the Mössbauer effect to measure the velocity of the basilar membrane and show that the frequency tuning was far sharper than in the dead cochleae that von Békésy studied in his celebrated research.

In the 1980s researchers identified bundles of hair cells as being responsible for the active amplification. It was found that outer hair cells are electromotile; when a voltage is applied, the cell body contracts longitudinally. Each of the bundles appears to be capable of generating oscillations at a particular frequency. When one of these nonlinear dynamical systems is on the verge of vibrating, it is especially sensitive to periodic disturbances at frequencies close to its characteristic frequency. The onset of spontaneous oscillations, corresponding to what is known as a "Hopf bifurcation," may be the source of otoacoustic emissions in our ears.

• A detailed investigation of phonon modes in DNA macromolecules is presented in the May issue of *Physical Review E* (volume 65, paper 051903). Experimental evidence confirms the presence of multiple dielectric resonances in the submillimeter-wave spectra (0.01 to 10 Thz). A direct comparison of spectra between different DNA samples reveals a large number of modes and a reasonable level of sequence-specific uniqueness.

• Surface waves play an important role in the exchange of mass, momentum and energy between the atmosphere and the ocean. **Wave breaking** supports air-sea fluxes of heat and gas, which have a profound effect on weather and climate, but wave breaking is poorly quantified and understood, according to a paper "Distribution of breaking waves at the ocean surface" in the 2 May issue of *Nature*. Using aerial imaging and analysis it was found that the distribution of the length of breaking fronts per unit area of sea surface is proportional to the cube of the wind speed and that, within the measured range of the speed of the wave fronts, the length of breaking fronts per unit area is an exponential function of the speed of the front. Furthermore, the fraction of the ocean surface mixed by breaking waves, which is important for air-sea exchange, is dominated by wave breaking at low velocities and short wavelengths.

• The June issue of *Sound and Vibration*, guest edited by Malcolm Crocker, features 3 articles on the **Vibroacoustics Environment** of Spacecraft during launch and flight. Terry Scharton writes about "Vibration and acoustic testing of spacecraft;" William Hughes and Mark McNelis write about "Recent advances in vibroacoustics;" and Rabi Margasahayam and Raoul Caimi discuss "Launch pad vibroacoustics research at the Kennedy Space Center." As Crocker reminds us in his opening editorial, the noise from spacecraft rocket engines on launch pads is very intense and causes vibration not only of the spacecraft vehicle but of the launch tower and related support facilities as well. In some cases the vibration can be of sufficient magnitude to cause fatigue and eventual failure of some parts.

• The March issue of *Acoustical Science and Technology* includes a tutorial paper on "**Neural mechanisms of binaural hearing**." Two of the three cues used to localize sound are binaural, involving a comparison of the level and/or timing of the sound at each ear. The third cue depends on sensitivity to the elevation-dependent pattern of spectral peaks and troughs that result from multiple sound waves interfering at the tympanic membrane. Different physiological mechanisms process these different localization cues. Neurons in the dorsal cochlear nucleus are selectively sensitive to the spectral notches that result from interference between sound waves at the ear. Interaural level differences are initially processed in the lateral superior olive by neurons receiving inhibition from one ear and excitation from the other. Interaural time differences are converted into discharge rate by neurons in the medial superior olive with excitatory inputs from both ears and that only fire when their inputs are coincident. The contribution of such coincidence detectors to sound-source localization is discussed in the light of recent observations.

• The **perception of reverberation time in small listening rooms** is discussed in a paper in the May issue of the *Journal of the Audio Engineering Society*. Small rooms are characterized by short reverberation times and strong resonances. However, most of the parameters used to describe the acoustics of small rooms were derived from studies in large diffuse rooms with long reverberation times. The aim of this study was to determine the difference limen for midfrequency reverberation times shorter than 0.6 s, which are usually encountered in small rooms. The difference limen was found to be 0.042±0.015 s.

• A paper in the August issue of *Applied Acoustics* assesses the tuning and damping of the **historical carillon bells** in Perpignan, France and their changes through restoration. The modal frequencies and decay rates were estimated by means of the matrix pencil algorithm, a parametric signal processing method. Tuning was found to be accurate except for the highest notes. On average, the bells ring 15% longer after the restoration, which included sanding their oxide layer. Damping rates are also more consistent throughout the range of the instrument.

• A paper in the May issue of the *Journal of the Audio Engineering Society* describes a **model of loudness** applicable to time-varying sounds. The stages of the model include: (a) a finite impulse response filter representing transfer through the outer and middle ear; (b) Calculation of the short-term spectrum using the fast Fourier transform; (c) Calculation of an excitation pattern from the physical spectrum; (d) Transformation of the excitation pattern to a specific loudness pattern; (e) Determination of the area under the specific loudness pattern. This gives a value for the instantaneous loudness, from which the short-term perceived loudness can be calculated using an averaging mechanism similar to an automatic gain control system, with attack and release times. Finally, the overall loudness impression is calculated from the short-term loudness using an averaging mechanism with longer attack and release times.

• "**Reverberation in rectangular long enclosures** with diffusely reflecting boundaries" is discussed in the January/February issue of *Acta Acustica*. A computer model divides every boundary into a number of patches and replaces patches and receivers with nodes in a network. For a number of hypothetical long enclosures, the model shows that with the increase of source-receiving distance the RT30 increases continuously and the early decay time increases rapidly until it reaches a maximum and then decreases slowly. Decay curves are concave in the near field and then become convex. For diffusely as opposed to geometrically reflecting boundaries, the sound attenuation along the length is notably greater, and air absorption is more effective with regard to both reverberation and sound attenuation.

• "A study of timing in two Louis Armstrong solos" is the title of one of the papers in a special collection of papers on **timing and rhythm in jazz** in the Spring issue of *Music Perception*. Precise timing analysis of two mid-tempo solos focused on stop-time sections. Two key elements of swing were analyzed: placement of the downbeats and the swing or triplet ratio. For these solos, Armstrong played fairly close to the beat with a swing ratio of about 1.6 to 1.

• **Using acoustics to study surface roughness** in agricultural surfaces is the subject of a paper in the July issue of *Applied Acoustics*. Sound propagating parallel to a smooth porous ground attenuates more rapidly than in a free space due to absorption in the air filled pores. Furthermore, additional attenuation occurs for propagation over a rough surface, and these additional attenuation mechanisms can be used to quantify the surface roughness, even on a porous surface. Modeling results are discussed for a variety of surfaces ranging from impermeable to loosely packed soil. Data on steep wedges yielded a roughness length scale twice that of previous studies on gravel.

• "**Localization of virtual sound** as a function of head-related impulse response duration" is the title of a paper in the January/February issue of the *Journal of the Audio Engineering Society*. The accuracy with which three participants could localize virtual and free-field sound was measured using an absolute localization paradigm incorporating 354 possible sound-source locations. Whereas some previous studies have suggested that the localization of virtual sound is affected only by extreme smoothing of head-related transfer functions, this study indicates that localization can be subtly disrupted by modes smoothing. The localization performance for virtual sound generated from 10.24- and 20.48-ms head-related impulse responses was as good as that for free-field sound.

• **Tunneling of acoustic waves** through the forbidden transmission of acoustic band gap array is the subject of an interesting pedagogical paper in the July issue of *American Journal of Physics*. The acoustic band gap is created in a waveguide with a periodically spaced series of dangling side branches. Using an impulse response method, the transmission properties of the array are characterized and the regions of forbidden transmission identified. Tunneling pulses, whose frequency content lies completely within the forbidden transmission region, are used to explore the concepts of tunneling time and group velocity. The group velocity of the tunneling pulse is considerably larger than the speed of sound. The analogous experiments are well known for electromagnetic waves but not acoustic waves.

• "Estimation of the **underwater explosion depth** from the modified cepstral analysis of sea reverberation" is the title of a paper in the May/June issue of *Acoustical Physics*. A mathematical model of the signal produced by an underwater explosion is used to obtain the dependence of the explosion depth on the argument at which the cepstrum of the signal reaches its maximum.

• Subjective experiments on **human phase perception** are discussed in a paper entitled "The effect of group delay spectrum on timbre" in the January issue of *Acoustical Science and Technology*. The stimuli in the experiments reported had a flat amplitude spectrum and a group delay spectrum with a single Gaussian peak. The first experiment used stimuli with different peak values having center frequencies fixed at 1 kHz and 4 kHz. When the peak values of the stimuli were between -1 ms and 2 ms, they are perceived to be zero phase regardless of their center frequencies and bandwidths. When the peak values are less than -8 ms or more than 10 ms and the bandwidths are less than one equivalent rectangular bandwidth, they are perceived to be similar.

ERRATA: The work on "Manatees, Bioacoustics and Boats" (first item in Scanning the Journals in the Spring 2002 issue) was done at Florida Atlantic University, not Florida State University, as reported.

Acoustics in the News

• From scientific investigations dating back nearly a century, it is known that whips make loud sounds when their tips attain supersonic speeds and send shock waves through the air. New calculations by applied mathematicians Alain Goriely and Tyler McMillen at the University of Arizona shed new light on the phenomenon, according to the 1 June issue of *Science News*. These calculations, soon to appear in *Physical Review Letters*, indicate that a loop rolling down the whip's length also goes supersonic when it's near the tip and begins to uncoil. This creates the whip's signature cracking sound, they say. Goriely and McMillen developed equations that account for a loop's curvature, tension, and speed as it zips along an extended, elastic rod. By feeding their equations into a computer, they determined that the leading edge of the loop would break the sound barrier while still slightly curled. Even though the tip's speed is also supersonic, the tip at that moment remains in the leading edge's wake and can't create shock waves.

Peter Krehl of the Ernst Mach Institute in Freiburg, Germany, who examined a cracking whip with a photographic method that shows shock waves, points out, however, that the tip of a whip must play a role since a whip won't crack without one. Nathan Myhrvold of Intellectual Ventures in Bellevue, Washington agrees that the new analysis is inconclusive because it neglects the cracker. Myhrvold's computer simulations indicate that some big dinosaurs could have created sonic booms with their whip-like tails, possibly for communication.

• On *Weekend Edition, National Public Radio,* Saturday, June 1, host Scott Simon also interviewed Alain Goriely, mathematics professor at the University of Arizona, about the sound of a cracking whip. Goriely pointed out that the sound you hear is a mini sonic boom, not unlike the sound that you hear when somebody shoots a gun or an airplane goes supersonic. The equation that describes whips is not too difficult to write, but good solutions are difficult to come up with, he said. The wave starts with pretty low velocity but reaches about twice or maybe three times the speed of sound for some part of the whip.

• A front-page story in the June 10 edition of the Pittsburgh *Post-Gazette* picks up on the acoustics of a cat's meow, as presented in paper 3aABb2 by Nicholas Nicastro at the Pittsburgh ASA meeting. Cats do communicate with people, but that doesn't mean they communicate like people. Nicastro hypothesizes that cats, which were domesticated more than 5000 years ago, have learned to use and shape their meows in ways that appeal to, or at least engage, humans. The meow is unusual in that cats rarely use it with each other; hissing, spitting, and purring seem to suffice for their peers. Cats seem to reserve their meows largely for humans and over the course of more than 5000 years of domestication have learned to tailor their meows for the human ear. The shorter the meows, the more pleasant and less urgent they seemed to humans. The longer meows seemed more urgent and less pleasant.

• To achieve true surround sound from all directions requires at least five loudspeakers placed carefully around a room. Now, according to a "Physics in action" story in the May issue of *Physics World*, a British company has developed a single loudspeaker panel that promises surround sound. The device is based on the same phased-array technology that is used in radio telescopes and underwater sonar applications. It uses 254 tiny magnetic transducers to produce a three-dimensional sonic interference pattern that changes in size and shape as the relative phase between the signals is adjusted. In this way, sound waves can be directed toward the walls and the ceiling of the listening room, where they are reflected to produce surround sound. Moreover, viewers can modify the overall effect by remote control rather than having to rearrange the furniture. To compute the phase and timing of the signals requires 12 gigaflops of computing power. Such processing power would have been unthinkable a few years ago, but now the powerful processor in the sound projector costs only $30.

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