Program of the Forty-Third Meeting of the Acoustical Society of America
Hotel Statler, New York, New York, May 8, 9, and 10, 1952

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Session A: Noise and Noise Control

Contributed Papers

A1. The Use of Binaural Tape Recording in Automotive Noise Problems. DAVID C. APPS, *General Motors Proving Ground, Milford, Michigan.*—For several months a binaural magnetic tape recorder has been used in automotive quieting tests. Various conditions are compared by playback of the recordings to a jury wearing binaural headphones. Because of the greatly improved realism obtained, smaller differences may be resolved than heretofore possible with a monaural system. A considerable part of the improved realism is due to the reduction of the bass emphasis usually observed when a monaural recording system is used for interior car noise. The equipment will be available for a demonstration of 2-channel *vs* 1-channel playback on typical recordings, using 2-phone headsets.

A2. Noise Characteristics from Axial Flow Compressors. OSMAN K. MAWARDI, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.**—The conventional methods of design of axial flow compressors usually consider the losses introduced by the generation of noise to be of negligible magnitudes and therefore ignore them entirely in a study of compressors. As a result, there is scant information on the relation between the noise level and the performance properties of compressors. In the present paper an attempt is made at working out the basis of a method of evaluation of the noise characteristics from compressors. The method makes considerable use of the experimental findings of Beranek and Rudmose† on noise due to airplane propellers. The analysis presented here considers the noise to be generated by a number of point sources of equal magnitudes but of random phase. The resultant intensity level of these point sources (presumed to be located at the tip of the compressor blades) is calculated on a statistical basis. The expected noise level is given as a function of blade tip speed, clearance between blades and stator case, number of blades and the power expended in driving the compressor.

* This research was supported in part by an ONR contract (N5ori-07861).
† L. L. Beranek and H. Wayne Rudmose, J. Acoust. Soc. Am. 19, 357 (1947).

A3. Aerodynamic Noise and the Estimation of Noise in Aircraft. O. R. ROGERS AND R. F. COOK, *Wright Air Development Center, Dayton, Ohio.*—Noise resulting from the flow of air over the fuselage of an airplane has been investigated and found to depend principally on approximately the fifth power of the indicated air speed. The resulting emperical relation of noise level to airspeed is found to be quite useful in estimating the noise in the frequency range above 600 cps, for airplanes varying widely in size, shape, and method of propulsion. From this relation a method has also been evolved for making rough estimates of the weight of acoustical insulation necessary to reduce the noise in airplanes to a predetermined level.

A4. Preliminary Estimate of a Hearing Damage Risk Criterion for Steady State Noise. HOWARD C. HARDY, *Armour Research Foundation of Illinois Institute of Technology, Chicago, Illinois.*—Much of the lack of correlation between noise level and hearing damage is because of unsatisfactory theories which express the effect of frequency. It is possible to get a simple damage risk criterion, if one makes the following assumptions: (1) that hearing damage for those who work in noisy environment is a progressive auditory fatigue phenomenon, (2) that the fatigue is the same function of the stimulus in the inner ear for all frequencies, and (3) the sensation level is a similar function of the stimulus in the inner ear for all frequencies. The damage is, on this hypothesis, simply a function of the sensation level and varies with frequency in the same manner. Fletcher's calculation of the energy levels in the fluid near the basilar membrane as a function of sound pressure and frequency[1] supports this theory. This analysis leads to the setting up of equal loudness contours for broad-band noise which correspond to hearing damage contours. Such curves explain for the first time the 4000 cps "notch" in the audiograms of industrial workers. Research data taken from a survey of industrial noise serve to establish two octave band curves which tentatively appear to bracket the region for damage risk for daily exposure over many years to a steady state noise environment. When the noise exceeds 100 sones in any octave band, long exposure definitely appears to be damaging. When the noise does not exceed 50 sones in any octave band, there appears to be very little danger of hearing damage even after many years of working day exposure. These conclusions are supported by the few data available in the literature. Evaluation of clinical data, which have not yet been disclosed by industrial audiologists and otologists, should make it possible to confirm and more sharply define the damage risk levels.

[1] H. Fletcher, J. Acoust. Soc. Am. 24, 129, (1952).

A5. Tentative Criteria for Noise Control Design. WALTER ROSENBLITH, LEO L. BERANEK, RICHARD H. BOLT, ROBERT B. NEWMAN, JORDAN J. BARUCH, AND SAMUEL LABATE, *Bolt Beranek and Newman, Cambridge, Massachusetts.*—Presented in this paper is a set of criteria that have been developed and applied on numerous noise control problems. A wide range of confirmatory evidence and experiences has led us to view these criteria with some confidence, although we recognize that they are subject to modification on the basis of additional data which are continuing to accumulate. An essential feature of the criteria is that they incorporate a specification of frequency dependence (usually expressed by octave bands) as well as overall sound pressure level. Tentative criterion curves are presented for: (a) risk of permanent damage to the hearing mechanism under habitual exposure to (i) continuous spectrum noises and (ii) single frequency components; (b) speech communication conditions in terms of percentage intelligibility, voice level, distance between talkers, and type of vocabulary; (c) risk of annoyance to residential areas as dependent on type and previous noise conditioning of the community, daytime *vs* nighttime exposure, and the time pattern of the exposure. Emphasis is laid on the importance of interpreting these criteria in the light of the inherent variability among individuals in their responses to noise stimuli.

A6. Propagation of Sound in a Water Spray Muffler. OSMAN MAWARDI AND CONRAD HEMOND, *Bolt Beranek and Newman, Cambridge, Massachusetts.*—In many jet engine testing facilities, water sprays are installed in the exhaust piping to cool the exhaust gases to temperatures which will not damage the walls of the pipe. The water sprays appreciably alter the character of the sound propagation through the piping. The present paper discusses the dependence of the attenuation of sound on such characteristic parameters of the water-spray muffler as its geometry, the amount of air circulated, the quantity of water sprayed, and the average sizes of the water droplets in the air stream. The attenuation of sound in the muffler is found to be due mainly to viscous losses in the boundary layer between water droplets and air. The theory discussed demonstrates that in order to achieve maximum sound attenuation through such a muffler there are optimum conditions as to quantity of water used and the method of its injection into the air stream. The relative velocity of the air stream to that of the injected water must lie within a critical range in order to fix the average size of the water droplets.

A7. Some Data on the Performance of Sound Attenuating Treatments. SAMUEL LABATE, *Bolt Beranek and Newman,* Cambridge, Massachusetts.*—An attempt has been made to obtain reliable information on the intrinsic performance of sound attenuating treatments used in the air flow passages (stacks, ducts, tunnels) of test cells and other aircraft engine test facilities. The apparent performance in a particular installation may be influenced by flanking transmission through the surrounding structure, by standing waves within the cell, by reflections at the ends of the treated section, by the radiation pattern at the exit, and by the spectral characteristics of the noise source for the measurements. These effects must be assessed separately if one is to obtain valid data on the attenuation value of the treatment itself. One can then correlate measurements from many installations and from laboratory experiments to yield generalized performance characteristics. Some results so obtained are given for (a) uniformly spaced absorptive baffles within and parallel to the air stream over a range of baffle thicknesses and separations, (b) absorptively lined sections of ducts, and (c) right-angle bends with absorptive lining facing the incident sound. Illustrative of the generalization, the data on bends are fitted to a single curve plotted against the ratio of duct width to wavelength with good agreement where the absorptive lining satisfies certain scaling restrictions.

* The work reported here was performed collaboratively by Richard H. Bolt, Leo L. Beranek, Robert B. Newman, Jordan J. Baruch, Samuel Labate, Wilson Nolle, Henry Lang, and Adone C. Pietrasanta.

A8. Noise Control for Eight- by Six-Foot Supersonic Wind Tunnel. L. L. BERANEK, S. LABATE, R. H. BOLT, R. B. NEWMAN, AND U. INGARD, *Bolt Beranek and Newman, Cambridge, Massachusetts,* AND E. T. MARSH, H. R. MULL, AND J. C. EVVARD, *National Advisory Committee for Aeronautics, Cleveland, Ohio.*—The noise produced by a large experimental supersonic windtunnel in which a shock wave was employed to produce high wind velocities and in which a jet engine was operating was sufficient to disturb residents of Cleveland within five miles during after-midnight operations early in 1950. The disturbing noise extended from 5 cps to 8000 cps. Components between 4 and 20 cps were reduced by a series of resonators. Components between 20 and 700 cps were reduced by a set of six parallel lined ducts properly chosen in size and lined according to charts of P. M. Morse. Above 700 cps, the reduction was provided by a series of parallel absorbent baffles and two lined bends. The resultant acoustic muffler renders the noise unobjectionable even in nearby office buildings, without affecting significantly the aerodynamic performance of the windtunnel.

Session B. Psycho Acoustics and Hearing

Contributed Papers

B1. The Space-Time Patterns of the Cochlear Microphonic in Guinea Pig. I. TASAKI, H. DAVIS, AND J.-P. LEGOUIX, *Central Institute for the Deaf,* St. Louis, Missouri.*—Two or three pairs of nichrome steel electrodes (20μ) are inserted into each of two or three turns of the cochlea of guinea pig. One electrode of each pair is in scala tympani, one is scala vestibuli. Such "differential" leads record nearly pure cochlear microphonics from segments of the cochlear partition only about 1 mm long. Low tones evoke microphonics from all four turns; but as the frequency is increased (holding the response from the basal turn constant by adjusting the intensity of sound), the microphonic ceases, first at the apical turn, then at the third turn, and finally at the second turn. The normal *space pattern* for each frequency as revealed by its cochlear microphonic is a long plateau rising slowly from the basal end but with a much more abrupt fall toward the apex. The locus of this abrupt fall is characteristic for each frequency. The *space-time* pattern of an acoustic signal is a decelerating traveling wave moving from base toward apex. The velocity of a 500-cycle wave falls from about 70 m/sec in the basal turn to about 2 m/sec near the helicotrema. These electrical patterns are in general agreement with the mechanical patterns described by Békésy.

The space and space-time patterns remain normal even when large sections have been removed from the bony shell of the second turn, over both scala vestibuli and scala tympani. The traveling wave still originates in the basal turn even when the cochlea is stimulated by sound transmitted through the fluid in a small pipette that enters scala vestibuli of the third turn through a hole in the bony shell.

* Work done under contract N6onr-272 with the ONR.

B2. Effect of Different Types of Electrodes in Electrophonic Hearing. GORDON FLOTTORP, *Psycho-Acoustic Laboratory, Harvard University, Cambridge, Massachusetts* (Research Fellow of Norwegian Council for Research, Oslo University, Norway).—What Stevens[1] has called the electrophonic effect, i.e., the sensation of hearing due to an electric current passed through the head, was first observed by Volta in 1800, and for many years it was thought to be a single phenomenon having a single cause. Jones, Stevens, and Lurie[2] showed that at least three different kinds of sensation, involving three separate mechanisms, may result from electric currents applied to the head, but it now appears that electrophonic hearing is even more complicated than they supposed. Depending upon the kind of electrode system employed, a sinusoidal electric current gives rise to at least five phenomena. (1) Electrode immersed in salt solution in the ear (the most common method). The subject hears a complex tone, containing mostly second harmonic, suggesting the action of a square-law transducer. (2) Electrode in contact with the epidermis of the meatus. The subject hears the first harmonic, and at low frequencies he may also hear a noise. (3) Electrode on the mucous tissue inside the middle ear (with the eardrum removed). The subject hears the first harmonic and/or a noise. (4) Large-area electrode on the skin, any place on the head. Provided the skin is dry the subject hears the second harmonic; if it is wet, he hears nothing. (5) Moving electrode on the skin or on the roof of the mouth (fricative effect). This gives the strongest sensation of hearing. The subject hears either the first harmonic or the first and second harmonics, or the second harmonic alone, depending upon the applied voltage and upon the placement and the properties of the electrode. The experimental results seem to indicate that the hearing of a tone under any of these five conditions is probably due to vibrations set up outside the cochlea, although there appears to be at least four different transducing mechanisms. Contrary to earlier hypotheses the tympanic membrane is apparently not involved in the conversion of the electrical energy into mechanical vibration.

[1] S. S. Stevens, J. Acoust. Soc. Am. 8, 191–195 (1937).
[2] Jones, Stevens, and Lurie, J. Acoust. Soc. Am. 12, 281–290 (1940).

B3. Antibiotics and the Cochlea. JOSEPH E. HAWKINS, JR., *Merck Institute for Therapeutic Research, Rahway, New Jersey.*—Electrophysiological study of the ototoxic effects of streptomycin in the cat has shown that prolonged treatment with large doses of the antibiotic may cause varying degrees of depression of the microphonic response of the cochlea, with or without comparable reduction in the amplitude of the response of the auditory nerve. Hydroxystreptomycin exhibits this specific toxicity in a much higher degree, while certain preparations of neomycin cause rapid and complete loss of the functions of both the microphonic mechanism and of the nerve. Commercial dihydrostreptomycin, on the other hand, usually causes an enhancement of the microphonic response and, at the same time, depression and splintering of the action potential patterns of the nerve. The nature of the ototoxic action and its significance for the study of auditory physiology are discussed.

B4. New Types of Ear Wardens. J. ZWISLOCKI, *Psycho-Acoustic Laboratory, Harvard University, Cambridge, Massachusetts.* (Research Fellow).—On the basis of experience with previous models, new ear wardens have been developed in an effort to improve the intelligibility of speech heard through the wardens and the protection of the hearing of the wearer, and to provide him with maximum comfort. One of these wardens attenuates the whole frequency range important for hearing, one serves as a low pass filter. The choice between them depends upon the characteristics of the noise encountered and the activity of the wearer. Experiments have been carried out to assess the protection afforded under a variety of conditions in both industrial and military situations.

B5. Recent Advances in Hearing Aids. L. GRANT HECTOR, HARRY A. PEARSON, NEAL J. DEAN, AND RICHARD W. CARLISLE, *Sonotone Corporation, Elmsford, New York.*—The experience gained in fitting a large number of impaired persons with hearing aids is presented, showing illustrative ranges of impairment between 30 and 100 decibels fitted with three progressively powered hearing aids. General features of each hearing aid are discussed, showing the circuits and arrangements for peak clipping and automatic gain control. The microphone, air and bone receivers are described, considering features developed for providing optimum reliability in service, such as moistureproofing and design arrangements providing miniaturization concomitant with ruggedness.

B6. Noise Audiometry. JUERGEN TONNDORF AND F. A. BROGAN, *USAF School of Aviation Medicine, Randolph Field, Texas.*—Audiometric tests (pure tones and speech) were conducted on deafened ears in quiet and at several levels of calibrated white noise. The cases were classed into six groups based upon results of their threshold audiograms. "Recession" describes the gradual approach toward normal levels with increasing noise of masking curves obtained from such ears. In cases displaying recruitment recession was relatively rapid, although not complete in some cases. A pure tone-to-speech perception ratio was established between the three audiometer frequencies within the speech range and the level of the 50 percent spondee score. Corrections were applied for (1) the type of loss and (2) the subject's unfamiliarity with the quietness of audiometric test rooms. This ratio is expected to differentiate speech losses as to their auditory or extra-auditory origin. From the results of speech tests, the "Social Adequacy Index for Hearing" in noise was evaluated in the same manner customarily used under quiet conditions. Adjustment of the test results was necessitated because of the narrowing of the "Useful Auditory Area" induced by noise. The SAI frequently increased but in some cases decreased with noise, indicating the relative hearing efficiency in noise of deafened subjects.

B7. Perception of Speech by Deafened Listeners and Its Relation to the Design of Hearing Aids. HARVEY FLETCHER, *Columbia University, New York, New York.*—This paper describes a method of calculating the articulation scores which a talker-listener pair will obtain in terms of the response of the hearing aid, the audiogram (both bone and air) of the listener, and talking level of the talker, and the proficiency factor of the talker-listener pair. This method was used to calculate the articulation scores for all the talker-listener pairs and the six kinds of hearing aids used in the test at Harvard made by Davis and his associates. The calculated and observed results agree within the experimental error. The philosophy underlying the method of calculation is used to predict the ideal type of response to be used by a deafened listener. It leads to the following simple rule. The ideal response R in db gain at any frequency is given by $R=\beta_A-\frac{2}{3}\beta_B+\alpha_I$, where β_A is the hearing loss by air conduction, β_B is hearing loss by bone conduction, and α_I is the over-all gain (same for all frequencies) to bring the speech level at the listener's ear to its optimum value. If the values of $\beta_A-\frac{2}{3}\beta_B$ at the three frequencies 500, 1000, and 2000 chs are examined and the average of the two highest values called β_2, then the maximum value of α_I is given by $\alpha_I(\max)=52-\beta_2$. The optimum gain α_I is, in general, less than $\alpha_I(\max)$, and so a means of lowering the gain in the set must be provided. When $\alpha_I(\max)$ calculates to be negative, then the optimum gain α_I is equal to $\alpha_I(\max)$. These gains are all with reference to a speaker 100 cm from the listener, and speaking so that his average level at the listener's ear is 66 db. If the speaker moves farther away or talks softer, then it is counted a negative gain or a loss. If he moves closer or talks louder it is counted as a gain.

B8. Signal Detection in Hearing. C. W. SHERWIN, *Control Systems Laboratory, University of Illinois, Urbana, Illinois.*—A question is raised regarding the operation of the two time constants in hearing. The short-time constant of about 15 milliseconds, due presumably to the cochlear filter system, is a "signal amplitude integrator." The long-time constant of about 0.5 second, due presumably to the central nervous system, is a "signal power integrator." Under some conditions not yet understood, the short-time constant can be directly observed by signal duration experiments without interference from the long-time constant. Some experiments were performed on the detection of pure tones in white noise in which both "signal detections" and "false alarms" were recorded. It was found that the listener does not treat errors of the "signal miss" type in the same manner as he treats errors of the "false alarm" type. For signal detectabilities ranging from 30 to 90 percent a typical observer will have an almost imperceptable false alarm probability, usually much less than 1 percent. This result will be discussed in the light of the theoretical behavior of the two integration mechanisms mentioned above.

B9. In Search of the Missing 6 Db. W. A. MUNSON AND FRANCIS M. WIENER, *Bell Telephone Laboratories, Murray Hill, New Jersey.*—The unexplained difference in sound pressure in the ear canal which appears to exist when equally loud low frequency tones are presented alternately from an earphone and from a loudspeaker has bedeviled acousticians for many years and, unfortunately, still continues to do so. There are presented here the results of some of the measurements carried out at the Bell Telephone Laboratories which show the magnitude of the effect and various attempts at explaining it. While no satisfactory explanation has been found, it is hoped that publication of these results will stimulate interest in the problem.

B10. A Case of Tonal Uniaural Diplacusis. W. D. WARD, *Psycho-Acoustic Laboratory, Harvard University, Cambridge, Massachusetts.*—During a current investigation of ears with chronic high frequency tonal gaps, it was found that some sort of uniaural diplacusis is usually associated with this type of hearing abnormality. Generally this uniaural diplacusis takes the form of a "rough" or "noisy" sensation within certain frequency ranges. In one subject, however, the distortion is definitely tonal in character; in particular, frequencies from 2700 to 3300 and from 3900 to 4500 cps are heard as two or more separate tones. Extensive tests show that when an objective frequency F (within the above ranges and below 60 db SPL) is presented, one or more of the following tones is heard in addition to F: $2F$-3600, 2(3600)-F, $3F$-2(3600), 3(3600)-$2F$. (These tones represent the difference tones heard in a normal ear when F and an objective tone of 3600 cps are presented simultaneously.) Also, rough beats are heard at threshold for frequencies from 3500 to 3700, with a null point at 3600 cps. Finally, when the acoustic stimulation consists of alternate one-second tones and silence, the silent period is filled with a 3600-cps "after-clang." These results suggest some basic instability of this ear at 3600 cps. There is, however, no persistent tinnitus. The similarity of the observed effects to the "personal tone" reported by Flottorp[1] and to the "tinnitus beats" of Wegel[2] is discussed.

[1] G. Flottorp, Fra Fysikkens Verden 2, 49–65 (1950).
[2] R. L. Wegel, Arch. Otolaryng. 14, 158–165 (1931).

B11. Ultrasonic Attenuation in Human Skull Bone.* T. F. HUETER, H. T. BALLANTINE, JR., AND D. KYRAZIS, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*—Some measurements have been made on attenuation in bone in order to provide basic information needed in certain medical applications of ultrasonics. Valid data are difficult to obtain because of inherent variability in bone thickness and structure, and because adequately fresh bone samples are not easy to obtain. A special "bone gun" was used to obtain disks from cadaver skulls, and measurements were made on some 35 of these disks within a few hours after death. Attenuation coefficients (in db/cm) were determined by measuring the insertion loss of samples of different thickness. The attenuation increases by more than 60 db/cm over the range from 0.26 to 3.5 megacycles, but the function is not linear. A possible mechanism for the nonlinear behavior is suggested.

* This investigation was supported by a research grant from the National Cancer Institute of the National Institutes of Health, Public Health Service.

Session C. Noise and Noise Control

Panel Discussion—Unsolved Noise Problems

C1. Unsolved Problems Relating to Hearing Loss in Industry. DR. GORDON D. HOOPLE.

C2. Unsolved Military Noise Problems. DR. LEO BERANEK.

C3. Unsolved Noise Problems in the Aircraft Industry. DR. ROBERT O. FEHR.

C4. Unsolved Problems in Architectural Acoustics. DR. RICHARD K. COOK.

C5. Unsolved Basic Physical Research Problems in the Field of Noise. DR. HOWARD C. HARDY.

Session D. Psycho Acoustics and Speech Communication

Contributed Papers

D1. A Method for Studying Speech Communication Systems. E. L. R. CORLISS, *National Bureau of Standards, Washington, D. C.*—Because of the statistical nature of speech sounds, time-exposure photographs of the display on a Panoramic Analyzer can be used as high speed acoustic spectrograms of impulsive sounds. For speech systems, the analyzer is modified to sweep at the syllable articulation rate. The photographs can be interpreted to show quantitatively a number of characteristics of speech communication systems. So far, this process has been applied to the study of the characteristics of speech recordings and in the calibration of speech audiometers.

D2. The Information of Elementary Auditory Displays. IRWIN POLLACK, *Human Resources Research Laboratories, Bolling Air Force Base, Washington, D. C.*—Whereas the ear's sensitivity for detecting a difference in frequency between two tones is remarkably acute, the ability of listeners to identify (and name) tones presented in isolation is relatively poor. When the frequency of a single tone (in the frequency range 100–8000 cps) is varied in equal logarithmic steps (and when the sound level is arbitrarily varied to reduce loudness cues), the amount of information transferred is about 2.3 bits. (The equivalent proficiency of response for an informational transfer of 2.3 bits is perfect identification among only 5 tones.) The amount of information that can be transferred is, within rather wide limits, independent of the number of tones and the range of frequencies employed.

D3. Pitch Discrimination Data from Two Psychophysical Methods.* W. A. ROSENBLITH AND K. N. STEVENS, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*—Pitch discrimination data for pure tones have been obtained for two trained subjects at frequencies of 250, 1000, and 4000 cps. Two psychophysical procedures were used: In one method (Munson and Gardner's[1] ABX procedure) the subject votes whether the third in a series of three tones sounds more like the first or the second of the series. In the second method (used extensively by Harris[2]) the subject is presented with a standard tone followed by a test tone, and he judges whether the test tone is higher or lower than the standard. The difference limens measured by the second method are for both subjects smaller (by a factor of two or more) than those found by the ABX procedure. This fact gains in significance since one subject has small DLs while the other has rather large ones. Judgmental data obtained from a limited choice situation can provide at best an upper bound for so-called ultimate sensory capacity. Practically speaking, the second method not only yields smaller DLs, but is also easier on the subjects, who can form the discrimination relatively quickly.

* This work was supported in part by U. S. Air Force Contract W19 122ac-14.
[1] W. A. Munson and M. B. Gardner, J. Acoust. Soc. Am. 22, 189 (1950).
[2] J. B. Harris and S. E. Stuntz, Am. Psychologist 5, 269 (1950).

D4. The Perception of Vowel Formants.* K. N. Stevens, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*—Synthetic vowel sounds, formed by electrical excitation of resonant circuits by a regular series of impulses, have been used as stimuli in a group of psychophysical experiments. The experiments include measurements of just noticeable differences (JNDs) in formant frequency and in band width for the synthetic sounds with one and two resonances, and with resonance band widths comparable to those found in measured vowel spectra. Average JNDs in formant frequency and band width at 1000 cps are 17 cps and 25 cps, respectively. The results are used to establish a frequency scale for the representation of vowel formants. Equal distances on this scale correspond to an equal number of JNDs in formant frequency. The proposed scale is approximated more closely by a linear frequency scale than by a mel scale. The approximate number of JNDs between pairs of vowels (arranged on a scale from front to back vowels) is evaluated, and is in the range 15–20 on the average. In general, the data indicate that frequency analysis of vowels using a filter band width as narrow as 45 cps provides more information than the perceptual processes can resolve.

* This research was supported under U. S. Air Force Contract W19 122ac-14.

D5. The Masking of Tones by White Noise as a Function of the Interaural Time Displacement of the Noise. Lloyd A. Jeffress, Hugh C. Blodgett, and Bruce H. Deatherage, *Defense Research Laboratory, The University of Texas, Austin, Texas.**—In a recent paper, the present authors described the effects upon masking of varying the interaural phase positions of a 500~ tone and of the 500~ masking component of a white noise. The present paper extends this work by displacing the masking noise in time. This is accomplished by moving one head of a binaural tape reproducer. The results are in agreement with those previously published on the masking of tones by noise, and support the idea of a "critical" band. They also furnish additional evidence of the importance for masking level difference, of the interaural noise correlation.

* Resulting from research done under Bureau of Ships Research and Development Contract NObsr-52267.

D6. A High Intelligibility Interphone System for Use in Military Aircraft.* A. H. Kettler, L. J. Flodman, D. W. Martin,† and M. L. Graham, *Special Devices Engineering Section, RCA Victor Division, Camden, New Jersey.*—At the end of World War II the introduction of a wide variety of extremely noisy aircraft flying very long missions at high altitudes had placed demands on interphone communications that the old system could not meet. Beginning in 1947 an entirely new system was developed with the close and active cooperation of the Air Materiel Command (now Wright Air Development Center). The criterion of performance is the word articulation of the entire system. New microphones, headsets, loudspeakers, amplifiers, control panels, and power supplies were developed. The resulting system has a frequency range of 200–6000 cps. It is very flexible, extremely comfortable, and provides high word articulation scores in 120-db sound fields at altitudes up to 35,000 feet.

* This paper reports work performed under Air Force Contract W-33-038-ac-18181.
† Now with the Baldwin Company, Cincinnati, Ohio.

D7. A New Automatic Screening Audiometer. Aram Glorig and Robert R. Wilke, *Walter Reed Army Hospital.*—A screening audiometer has been developed, which functions automatically. It has the following salient features: The subjects are required to make simple numerical choices as indicated by visual instructions. A single numerical choice for each frequency serves to evaluate the two ears separately. The stimuli consist of interrupted tones of pre-set levels. The operation of this instrument and the results of the field tests are presented.

D8. Performance Characteristics under Water of Plane Arrays of Barium Titanate Transducers. Leon Camp, *Bendix Aviation Corporation.*—Plane arrays of barium titanate transducers are described. Their polar intensity patterns are shown with the results of calibration tests. The quantity of data presented is offered as proof that these are unquestionably excellent instruments.

Session E. General Acoustics and Transducers

Contributed Papers

E1. The Acoustics Design of the Large Council Chambers, Permanent Headquarters of the United Nations, New York. Robert B. Newman, *Bolt Beranek and Newman,* Cambridge, Massachusetts.*—The design of large parliamentary chambers for conferences conducted in many languages presents a number of new acoustics design problems. Not only must the acoustic environment be "comfortable," but it must be possible to hear clearly a person speaking in any part of the delegates area, either directly or as simultaneously translated into any of four or five languages. The design and isolation of the many booths for translators, radio, and press surrounding these rooms was the subject of much study. The general isolation of noise from surrounding service areas and outdoor sources, such as traffic on the East River and in the air, were also considered. Special attention was given to the coordination of the sound reinforcing system with the acoustic design of the chambers. Preliminary articulation tests have been conducted in these rooms and the results are presented.

* The work reported here was performed collaboratively by Richard H. Bolt, Leo L. Beranek, Robert B. Newman, Vern O. Knudsen, Samuel Labate, and William Lang.

E2. The Reflection from Irregular Surfaces. F. MANSFIELD YOUNG, *Acoustics Laboratory, Massachusetts Institute of Technology.*—The problem of the reflection of acoustical waves from an infinite wall, having prescribed irregularities or a prescribed distribution of acoustical material upon it, is formulated in terms of an integral equation. By taking the Fourier transform of the equation it can be reduced to a form easily handled by numerical techniques. Expressions for scattering and absorption cross sections can be obtained without actually solving the equation. Much information of a qualitative nature can be obtained from inspection of the equation. An "index of diffusion" is introduced which is a measure of the effectiveness of a given surface in breaking up the reflected wave. The application of the above methods to simple scattering surfaces (e.g., strips and pillars) will be discussed.

E3. The Transmission of Sound through Thin Cylindrical Pipe Walls.* R. H. BOLT, J. E. YOUNG, AND H. C. LANG, *Bolt Beranek and Newman, Consultants in Acoustics, Cambridge, Massachusetts.*—Measurements have been made on the transmission of sound through the walls (1/16 in. thick) of cylindrical steel pipes (9- and 15-in. diameter). Two source arrangements were used: (a) an approximately uniform distribution of small speakers along the axis, and (b) a speaker in one end, radiating into the pipe, with a ρc termination at the opposite end. The results from the two methods are qualitatively similar but exhibit significant differences in magnitude. The transmission loss (TL) behavior of thin-walled cylinders can be related to two principal resonances at $f_1 \simeq (5400/d)$ cps and $f_2 \simeq 1.65 \times 10^3 (t/d^2)$ cps; d=diam, ft; t=wall thickness, in. At f_1 the walls stretch in a radial, axially symmetric mode of vibration. At f_2 the walls bend in a mode of vibration that is symmetrical about a diameter. Above f_1 the TL approaches that predicted by a "mass law," rising with increasing frequency at about 6 db/octave. Below f_2 the TL approaches that predicted by a "stiffness law," rising with decreasing frequency at about 6 db/octave. At f_1 and f_2 the TL reaches minimum values that are controlled by internal resistance. Between f_1 and f_2 the TL rises to a broad maximum. These properties are illustrated by approximate agreement between the experiment and a first-order theory. The results are also compared with field measurements on pipes up to 10-ft diameter carrying high level broad-band noise.

* This work is an extension of studies commenced by K. Uno Ingård and A. W. Nolle.

E4. Measurements of the Tonal Characteristics of Carillon Bells. FRANK H. SLAYMAKER AND WILLARD F. MEEKER,* *Stromberg-Carlson Company, Rochester, New York.*—High quality magnetic tape recordings were made of individual bells at the carillon location, including bells cast by Meneely and Company, Watervliet, New York; Van Aerschodt, Louvain, Belgium; John Taylor and Company, Loughborough, England; Franz Schilling Söhne, Apolda, Germany. Measurements made on the tapes with a sound analyzer, Stroboconn, and an automatic level recorder gave the relative tuning, the relative amplitudes at the microphone position, and the decay rates of the various components in the bell tone. The hum tone, strike tone, minor third, perfect fifth, octave of the strike tone, octave plus a major third and octave plus a perfect fifth, as well as other higher components, will be demonstrated audibly with the aid of a sound analyzer.

* Now with Radio Corporation of America, Camden, New Jersey.

E5. Compound Direct Radiator Loudspeaker. HARRY F. OLSON, JOHN PRESTON, AND EVERETT G. MAY, *RCA Laboratories, Princeton, New Jersey.*—The closed cabinet, with or without a port, has become the standard mounting arrangement for a direct radiator loudspeaker mechanism for high fidelity sound reproducing systems. One of the objections to the cabinet for these systems is the large size required to obtain adequate low frequency response. The effective volume of a small cabinet may be increased by the use of an auxiliary loudspeaker mechanism which drives the radiating loudspeaker mechanism. This system has been termed a compound direct radiator loudspeaker. The use of the compound direct radiator loudspeaker makes it possible to obtain low frequency response comparable to that of the conventional wide range system but in a cabinet having only a fraction of the volume of the cabinet in the conventional system.

E6. A Corner Loudspeaker-Enclosure Combination. J. J. BARUCH AND H. C. LANG, *M.I.T., Cambridge, Massachusetts.*—A corner loudspeaker-enclosure combination is described which embodies a modification of the acoustic phase inverter. The design incorporates an array of perforations to provide the inductance. Control of the Q is achieved by varying the size and shape of the array. An electrical analog has been built and tests indicate good agreement between the analog response and the measured response of the loudspeaker. The loudspeaker to be demonstrated has a response flat to within ±4 db from 45 cps to 13,000 cps and occupies a volume slightly larger than one-half cubic foot.

E7. Mechanical Sound Sources for Obstacle Perception by Audition. VIC TWERSKY, *New York University.*—Two simple devices of the type mentioned in the title will be discussed. Each consists essentially of a cup-sized parabaloidal plastic reflector with a vibrator in the focal plane. The first type, similar to one developed by D. R. Griffin at Cornell, employs a dented flat steel spring and produces loud broad-band high frequency clicks when triggered. The second employs a miniature reed whistle and produces several different high frequency squeaks (depending on how a rubber bulb built into the horn is manipulated). Preliminary tests with four subjects indicate the following: The first type produces sufficient sound for distinct echoes to be returned from distant objects outdoors but is too loud for indoor use; the second type is useful indoors up to a far point of 5–20 feet (depending on ambient noise), giving rise to essentially the same sort of cues obtained with the continuous wave electronic models employed previously.[1]

[1] V. Twersky, Am. J. Psych. LXIV, 409 (1951).

E8. Acoustic Instrumentation for High Intensities.* R. W. LEONARD AND I. RUDNICK, *Physics Department, University of California, Los Angeles, California.*—This paper will describe a 100-kilowatt audiofrequency siren and associated measuring equipment. Plane waves are produced in a 10-inch diameter tube at pressure levels in excess of 180 db. The condenser microphone used in these measurements operates at temperatures of the order of 170°F and in air stream velocities of the order of 200 miles per hour.

* Part of this work was performed under ONR contract N8onr-70502 with Soundrive Engine Company, Los Angeles, California, under the authors' technical direction.

E9. Duality in Mechanics. P. LE CORBEILLER AND YING-WA YEUNG, *Harvard University, Cambridge, Massachusetts.*—Given an electric network E_e which has M meshes and P node-pairs, its electric dual E_i will have P meshes and M node-pairs and its classical mechanical analog M_f will have $M+1$ nodes, M independent node-pairs and P independent node cycles. A second mechanical system M_v, the classical analog of E_i, will have M cycles and P node-pairs. If, for example, $M=2$, $P=3$, the system E_e and M_v, analogs in the Firestone or "mobility" method, will be governed by two mesh equations, expressing that the algebraic sum of the voltages or velocities around any loop is zero; the systems E_i

and M_f, also Firestone analogs, will satisfy two node equations, expressing that the algebraic sum of the currents or forces leaving any node is zero. These four sets of equations are identical, interchanging symbols suitably. The consideration of the four systems, E_e, E_i, M_v, M_f, forming a complete set, shows the advantages of the Firestone over the classical system of analogies and suggests a systematic use of duality in mechanical as well as in electrical systems.

Session F. Instrumentation

Contributed Papers

F1. Analytical Comparison of Square-Law and Correlation Detectors.* ROBERT HILLS, JR., AND JAMES J. FARAN, JR., *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—A mathematical analysis has been made of two methods of using a two-element array for the reception of random signals. In the first method, the signals from the two elements are added and the resultant "sum" signal is measured with a square-law rectifier and an averager; in the second, the instantaneous product of the signals is formed and averaged. A point source of random noise in an isotropic noise background is postulated as providing the input signal to the systems. With the exception of constant terms in the average output of the square-law detector, the "directivity patterns" of the two systems are the same and are simple functions of the autocorrelation function of the signal. With any practical (finite-time) averaging device, unwanted fluctuations (noise) will appear along with the signal in the output of both systems. For small input signal-to-noise ratios, it is found that the output dc-signal-to-ac-noise ratio is never less for the correlator than for the square-law detector, but can be as much as 3 db greater for the correlator, provided the element spacing is sufficiently wide.

* This research has been aided by funds made available under a contract with the ONR.

F2. Experimental Comparison of Square-Law and Correlation Detectors.* JAMES J. FARAN, JR., AND ROBERT HILLS, JR., *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—A semicircular array, 30 ft in diameter, of 41 five-inch loudspeakers has been built in the Harvard anechoic chamber to provide a two-dimensional isotropic noise background. A separate gas-tube noise generator powers each speaker. Signals can be superposed on the noise applied to any speaker. With this array it is possible to study methods of detecting and locating signals in such a background. Included in the instrumentation is circuitry for the measurement of the signal-to-fluctuation-noise ratio at the detector output. Preliminary experiments using a two-element array and a square-law or correlation detector have been carried out. The measured patterns and signal-to-noise ratios are in good agreement with theory.

* This research has been aided by funds made available under a contract with the ONR.

F3. A Simple Electronic Correlator.* JAMES J. FARAN, JR., *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—Attention has been drawn in the literature to the possible utility of correlation techniques in the reception of acoustic signals. In applying such techniques, it is often necessary to find the average of the instantaneous product of two electrical signals; the black box which performs this function, which is that of a generalized detector, may be called a correlator. By use of the quarter-squares method of multiplication $[AB=\frac{1}{4}(A+B)^2-\frac{1}{4}(A-B)^2]$, correlators can be constructed using common triodes as the square-law devices. In practice, however, such multiplier-averagers depend strongly upon the vacuum tube characteristics which in turn require, for stability, regulated plate and heater supplies and frequent balance adjustments. If the square-law vacuum tubes in the circuit mentioned above are replaced by linear rectifiers, as many have suggested, it is shown that the resulting circuit is similar in action to a correlator. The output of this "linear rectifier correlator" is a somewhat distorted replica of the unnormalized cross-correlation function of the input signals, but the output signal-to-noise ratio for small input signal-to-noise ratios is not appreciably less than that for a multiplier-averager. The linear rectifier correlator has the practical advantage of being completely independent of power supplies, if contact rectifiers are used, and requires no balance adjustments if care is used in its construction.

* This research has been aided by funds made available under a contract with the ONR.

F4. The Effect of Tube Noise on the Equivalent Noise Pressure of Transducer Systems. FRANCIS X. BYRNES, *Navy Electronics Laboratory, San Diego 52, California.*—In determining the equivalent noise pressure of transducer systems, the tube noise in the preamplifier is an important factor. Although adequate information on tube noise exists for the ultrasonic and higher audiofrequency range, it was found that there is very little quantitative data available on tube noise in the lower audio and infrasonic region. An experimental program to obtain quantitative data on tube noise in this frequency region down to 0.04 cps has been carried out. The usual increase in the tube noise spectrum level as the frequency went into the lower audio range, resulting from flicker effect, was observed. In addition, it was found that as the frequency was lowered into the infrasonic region, the slope of the noise spectrum became much steeper. Noise spectrums for a number of modern tubes will be presented.

F5. Method for Measuring Normal and Tangential Forces and Accelerations with Barium Titanate Ceramics. W. P. MASON, *Bell Telephone Laboratories, Murray Hill, New Jersey.*—Small pieces of barium titanate ceramic have been used in measuring normal and tangential forces and accelerations in telephone equipment. When these are poled in a direction normal to the electrodes these ceramics respond to normal forces, while if they are poled parallel to the electrode surfaces they respond to tangential forces along the direction of poling. Normal force responding ceramics have been used to measure forces in relays and accelerations in other systems. Tangential force responding ceramics have been used to investigate frictional forces and slide in mechanical systems and to measure tangential accelerations in various mechanical systems. These units are about 50 times as sensitive as quartz, the only other piezoelectric material with sufficient mechanical strength to be used in force measurements. Small ceramics pieces working into vacuum tubes with very high input resistances can measure forces and accelerations varying in time from 0.1 second to 1 microsecond. The voltage response for a given force and the stability with reversed voltages and time depend on the time and temperature of baking and on the effect of introduced additants. The response of the normal force responding ceramic depends on the distribution of stress over the surface, whereas the response of the tangential force responding ceramic is independent of the stress distribution.

F6. A Compact, Versatile Filter-Type Sound Analyzer. D. VON RECKLINGHAUSEN AND H. H. SCOTT, *Hermon Hosmer Scott, Inc., Cambridge, Massachusetts.*—The advent several years ago of a pocket-size Sound Level Meter meeting all ASA standards created an immediate demand for a complementary instrument to analyze sound. Such a unit is now available, based upon the Dynamic Noise Suppressor circuits. The resulting unit is contained in a small leather case, similar in appearance and weight to a home-type motion picture camera, and is provided with a shoulder strap which allows the instrument to be used while the operator is walking about. This greatly facilitates analytical noise surveys, since no cumbersome equipment is involved which has to be placed upon a table or on the floor. The Analyzer meets all proposed ASA standards and, in addition, has an adjustable band width varying from one-half octave upward in steps of one-half octave. One control switches the pass-band but the high and the low frequency cutoffs may also be adjusted separately. The frequency range exceeds proposed ASA requirements by one octave at both low and high frequency limits. In addition, the instrument includes a calibrated attenuator giving, with the indicating meter, a range of 66 db. The indicating meter meets the ASA ballistic requirements, and an output circuit is provided so that the instrument may be used as a general-purpose filter. While designed particularly for use with the Type 410-B pocket-size Sound Level Meter, the Analyzer may be used with practically any other Sound Level Meter or suitable signal source. The filters may also be cut out of the circuit entirely so that the instrument may function as a general-purpose amplifier or audiofrequency voltmeter with a calibrated attenuator. The range of the amplifier exceeds 20 to 20,000 cycles.

F7. A Simplified Audiospectrometer.* R. W. BENSON AND I. J. HIRSH, *Central Institute for the Deaf, St. Louis, Missouri.*—A relatively small array of equipment is described that permits the measurement of the power spectrum of irregular or discontinuous sounds, including speech. A sample of speech, or any other sound, is recorded on a loop of magnetic tape that can be played back over and over again. Repetitions of the sample are independent of the variability of the talker. The output of the tape playback is fed through a system of cascaded, variable electronic filters; the output of the filters is fed to a square-law integrator circuit, which has been adapted from Rudmose *et al.*[1]; and the output pulses of the integrator activate an electronic scaler. Scaler counts are proportional to the energy and an absolute value of energy is obtained from a calibration in counts per second. Flexibility is enhanced by the fact that the number and the width of frequency bands measured may be determined or changed at will. From an apparatus point of view it is shown that spectral analysis of speech need not require special components, which must be purchased for that purpose alone, but rather mostly employs equipment that is standard in most experimental laboratories. Increase in the time required for measurement is offset by a reduction in the size and complexity of equipment. Preliminary measurements in which both octave and equal-mel bands were used yield results that are in substantial agreement with those of previous workers.

* This study was carried out under a contract between the Central Institute for the Deaf and the U. S. Air Force Air Material Command, Contract No. AF 33(038)-18682.
[1] W. H. Rudmose, "Effects of High Altitude On The Human Voice." OSRD Report No. 3106, Harvard University, Cambridge, Massachusetts, January 30, 1944.

F8. Propagation of Sound through Solids. A. LONDON, A. W. ORLACCHIO, R. L. BACH, AND D. EPSTEIN, *National Bureau of Standards, Washington, D. C.*—A method of measuring the dynamic properties of resilient materials under static loads is described. The method is useful over a large part of the audiofrequency range. The experimental set-up consists of an electromagnetic loudspeaker pot and a rigid voice coil which is supported above and below by two disks of the sample material. The motion of the voice coil assembly is determined by an electrostatic variable capacity vibration detector. The ratio of the input to output voltage is measured in both magnitude and phase. The dynamic properties of samples can be determined either by making measurements for several values of the mass of the moving system or by the use of a resonance technique. Results obtained on several samples of rubber and a mechanical spring using both types of determination are presented. Apparatus similar to that described above is used to measure the transmissibility of several commercial shock amounts over a frequency range from 8 to 4500 cps. The results are presented graphically and are compared with results obtained by another group working on the same problem. Theoretical problems concerning low and high pass filtration of plane, compressional elastic waves are discussed for a system consisting of a vibrating driving mass coupled to a compound transmission line terminating in a rigid base.

Session G. Ultrasonics and Underwater Sound

Contributed Papers

G1. Measurement of the Ultrasonic Absorption Coefficient by a Modified Radiation Pressure Method.* F. L. MCNAMARA,† *Massachusetts Institute of Technology, Cambridge, Massachusetts,* AND R. T. BEYER, *Brown University, Providence, Rhode Island.*—A technique reported by Barone and Nuovo[1] has been adapted to the measurement of ultrasonic absorption in liquids. The output of an rf transmitter is 100 percent modulated at an audiofrequency and applied to a crystal. This results in a periodic variation of the radiation pressure in the acoustic beam. A condenser microphone has been constructed, employing a front face consisting of a thin sheet of plastic, coated with silver paint. The microphone responds to the audiofrequency variation radiation pressure, and its output is preamplified and then detected on a harmonic analyzer. The apparatus has been tested in water in the frequency range 9 to 30 mc, and the measured values of the absorption coefficient agree with the accepted values within a few percent. Measurements of the absorption coefficient have been carried out in a number of uni-univalent electrolytic solutions.

* Research supported by the ONR.
† Formerly at Brown University.
[1] A. Barone and M. Nuovo, Ricerca Sci. **21**, 516 (1951).

G2. The Ultrasonic Absorption in Acetate Solutions.* R. E. BARRETT, M. W. DILL, AND R. T. BEYER, *Brown University, Providence, Rhode Island,* AND F. L. MCNAMARA† *Massachusetts Institute of Technology, Cambridge, Massachusetts.*—The measurements of the ultrasonic absorption coefficient in aqueous solutions of sodium acetate, reported previously,[1] have been extended. The results indicate a value of the absorption coefficient below that for pure water at frequencies above 20 mc. Measurements have also been made of the sound velocity and kinematic viscosity of the solution, and the classical absorption coefficient computed. These values for the solution are slightly higher than the corresponding values for water. It appears that the presence of the solute in some way disrupts the structural relaxation which is hypothesized to account for excess absorption in water. Similar measurements are being made in potassium acetate solutions.

* Research supported by the ONR.
† Formerly at Brown University.
[1] R. E. Barrett and R. T. Beyer, Phys. Rev. 84, 1060 (1951).

G3. Self-Excited Hydrodynamic Oscillators.* JOHN BOUYOUCOS, *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—Self-excited sound sources for use in fluids are discussed with principal attention given to the Pohlmann whistle. Although certain applications of this source have been reported in the literature, little has been available concerning its properties. The Pohlmann source employs a fluid jet impinging upon the end of a rectangular steel blade simply supported at points on the nodal lines of its fundamental mode of vibration. It is assumed that the system of vortices characteristic of edge-tone production arise at the blade edge and exert upon it a periodic transverse force. When the period of this force is equal to the period of blade resonance (or is one of its odd subharmonics) the blade is set into strong vibration. The source strength, radiation properties, frequency range, and applications are described.

* This research has been aided by funds made available under a contract with the ONR.

G4. An Experimental Study of Single Bubble Cavitation Noise. MARK HARRISON, *David Taylor Model Basin, Department of the Navy, Washington 7, D. C.*—An experimental study of single bubble cavitation noise has been made. Single bubbles were produced either by a venturi nozzle or by a spark technique. The motion of the bubbles was studied photographically and simultaneously the noise measured. The noise consists principally of a shock wave associated with the collapse of the bubble. There are other sources of noise but they are of minor importance. The pressure *versus* time records permit the spectrum to be easily computed by Fourier transforms. Rayleigh[1] treated the motion of an empty spherical bubble in an incompressible fluid. He showed that when the bubble collapses the radial velocity becomes infinite and an infinite pressure is developed. Incompressibility is clearly an untenable assumption. Also, the thermodynamics of the bubble contents must be considered. It was observed experimentally that the air content of the bubbles is the dominant factor in determining the magnitude of the pressure shock wave. When the air content becomes small compressibility becomes the dominant factor in determining the magnitude of the pressure shock wave. The venturi bubbles and the spark bubbles behave differently as might be expected since the thermodynamics of their contents are different.

[1] Rayleigh, Phil. Mag. 34, 94–98 (1917).

G5. Gaseous Cavitation in Liquids.* M. D. ROSENBERG, *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—A focused standing-wave system of sound waves with a frequency of 60 kc/sec has been used to produce cavitation in gas-saturated liquids. The system consists of magneto-strictive transducers with appropriate paraboloidal and plane reflectors. A thin-walled flask holds the liquids to be studied at the focal point of the paraboloid. The liquid under study is saturated just before measurement with predried air by means of mechanical agitation consisting of 1264 one-inch strokes per minute. A calibrated magnetostrictive probe, $\frac{1}{8}$ inch in diameter is placed at the focal point of the system. The pressure at which cavitation bubbles (gas-filled) occur at the surface of the probe is plotted as a function of viscosity and pulse length. A new theory of sonically induced diffusion appears to offer an explanation for the experimental data.

* This research has been aided by funds made available under a contract with the ONR.

G6. Ultrasonically Induced Cavitation in Water. G. W. WILLARD, *Bell Telephone Laboratories, Murray Hill, New Jersey.*—Using a 2.5-megacycle spherical focusing radiator, cavitation is produced in water at a location remote from any liquid-solid interface. The cavitating region is localized in the high intensity core of the focal region, about one millimeter diameter by 10 millimeters long. A feather-like cavitation burst is sporadically produced within the focal region. High speed camera studies show that the total duration of the burst is less than 3 milliseconds, and that the cavitation at any one point of the burst is completed in a matter of microseconds. The cavitating region propagates along the feather shaped burst from the quill end (nearest the radiator) to the tip end, at a velocity of 5 to 10 meters per second. It is believed that this velocity corresponds to that of the radiation pressure induced streaming velocity of the liquid along the axis, of the focal spot, and that a discrete, traveling, oscillating cavity initiates the surrounding cavitation. These sporadically produced cavitation bursts appear without other effects in degassed water. On the other hand, in aerated water identical appearing bursts produce noncollapsing air bubbles which blow off down stream (because of liquid streaming) providing there is no standing wave pattern present. In the presence of standing waves many of the bubbles are trapped in the standing wave pattern until they grow too large (by accumulation of other bubbles) when they again blow down stream. Slides showing the nature of these phenomena will be exhibited.

G7. Sound Scattering by Fluid Cylinders.* IRA DYER, *Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*—The scattering of plane waves of sound from an infinitely long circular cylinder has been investigated both theoretically and experimentally. Wave motion in the cylinder cannot be neglected because the properties of the fluid in the cylinder are comparable to the properties of the external fluid. A rigorous series solution for the scattered radiation has been obtained, taking into account the possibility of compressibility, density, and attenuation differences between the two fluids. At high frequencies the series solution is difficult to apply because of the many terms that must be included. Consequently, approximate closed-form solutions have been developed which are useful for high frequencies and which agree essentially with the rigorous series solution in the limit of low frequencies. The approximate solutions follow from an integral equation formulation which has application in other coordinate systems and which is similar to the results of some recent work of Montroll and Hart.[1] Measurements have been performed on cylinders containing mixtures of tertiary butyl alcohol and water immersed in water for wavelengths approximately $\frac{1}{4}$ the diameter. The approximate theory predicts the angular positions of the minima of the scattered radiation within experimental error and the magnitude of the maxima of the scattered radiation within a few decibels.

* Portions of this work were submitted in a thesis to the Department of Physics, Massachusetts Institute of Technology, August, 1951, in partial fulfillment of the requirements for the Master of Science degree.
[1] Elliott W. Montroll and Robert W. Hart, J. Appl. Phys. 22, 1278 (1951).

G8. Wave Propagation in Liquid-Filled Cylinders.* R. D. FAY, *Acoustics Laboratory, Massachusetts Institute of Technology.*—Difficulties encountered in obtaining reliable measurements in a water-filled impedance tube over a reasonable range of frequencies have led to an investigation of the propagation of waves in a column of fluid bounded by a cylindrical shell of arbitrary thickness. The investigation has dealt chiefly with the phase velocity of free traveling waves in the shell, since the connection between such waves and the major measurement difficulties has been well established. The relation between these free waves and the dimension of the cylindrical shell will be presented graphically for typical cases.

* This work was supported by the Navy Department under the Bureau of Ships Contract NObsr52060.

G9. Some Design Considerations for High Frequency Anechoic Tanks. M. S. WEINSTEIN, *Naval Ordnance Laboratory, White Oak, Maryland.*—By an extension of the techniques of Lindsay[1] the reflection from a semi-infinite attenuating medium is derived for the case of oblique angles of incidence. The results are applied to the design of a water tank each wall of which is assumed to be covered by a sheet of absorbing material. The optimum physical properties of the absorber required to make the tank anechoic in the megacycle region are then determined theoretically. Experimental measurements at 3.35 megacycles/sec indicate that the properties of tan rho-c rubber are very close to optimum. With a $\frac{1}{4}$-inch-thick sheet backed by aluminum the reflection coefficient is about −30 db at normal incidence and rises to −20 db at an incident angle of 60°. Beyond 60° the rubber is of little value in reducing the reflectivity. The results obtained are in good agreement with those expected from the theoretical treatment when modified for reflections from the back surface and the phase difficulties previously described by the author.[2]

[1] R. B. Lindsay, J. Acoust. Soc. Am. 11, 178 (1939).
[2] M. S. Weinstein, J. Acoust. Soc. Am. 24, 118 (1952).

G10. An Experimental Study of Sound Reflection from a River Bottom. R. J. URICK, *Naval Research Laboratory, Washington 25, D. C.*—Using short pulses of sound in the frequency range 7.5 to 75 kilocycles, the reflection coefficient of a natural bottom has been determined over a wide range of angle of incidence. The structure of the bottom was such that the results are interpretable in terms of the absorption coefficient of a thin overlying layer of mud. These values are believed to represent among the first information extant on the absorption of sound in this frequency range in an undisturbed sediment *in situ*. The reflection and absorption characteristics are compared with existing applicable theory.

Session H. Acoustics in the Radio and Television Industry

Invited Papers

H1. Outline of Typical Sound Broadcasting and TV Broadcasting System. GEORGE NIXON, *NBC.*

H2. Sound and Construction Problem. MICHAEL KODARAS, *Johns-Manville Corporation.*

H3. Microphone Technique—TV. H. M. GURIN, *NBC.*

H4. Audio Design in TV Studio Systems. EMIL T. VINCENT, *ABC.*

H5. CBS TV Studio Intercommunication Facilities. ROBERT MONROE, *CBS.*

H6. Sound Problems Encountered in Field TV Broadcasting. TOM HOWARD, *WPIX.*

Session I. Waves and Vibrations

Contributed Papers

I1. Inharmonicity of Plain Wire Piano Strings. ROBERT W. YOUNG, *U. S. Navy Electronics Laboratory, San Diego 52, California.*—The inharmonicity of plain wire strings *in situ* has been measured in six pianos of various styles and makes. By inharmonicity is meant the departure in frequency from the harmonic modes of vibration expected of an ideal flexible string. It is shown from the theory of stiff strings that the basic inharmonicity in cents (hundredths of a semitone) is given by $3.4\times10^{13}n^2d^2/\nu_0{}^2l^4$, where n is the mode number, d is the diameter of the wire in cm, l is the vibrating length in cm, and ν_0 is the fundamental frequency. A value of $Q/\rho=25.5\times10^{10}$ (cm/sec)^2 was assumed for the steel wire, where Q is Young's modulus and ρ is the density. The observations are entirely compatible with the relationship given. In general terms, the inharmonicity of the plain steel strings is roughly the same in all the pianos tested, being about 1.2 cents for the second mode of vibration of the middle C string. Above this point, every eight semitones it is doubled. Below middle C the inharmonicity is consistently less in large pianos than in small ones.

I2. Axially Symmetrical Vibrations of a Finite Isotropic Disk. R. R. AGGARWAL, *National Research Council, Ottawa, Canada.*—Using an approximate method similar to that of Love,[1] some normal modes of a thick disk have been calculated. The boundary conditions have been exactly satisfied on the flat surfaces and approximately satisfied on the curved surface. It is found that two fundamental frequencies occur for each vibration pattern on the surface. The validity of the boundary conditions is tested by calculating the residual stresses on the curved surface and comparing these with the compressional stress at the center of the disk. Both compressional and shear vibrations will be discussed.

[1] A. E. H. Love, *Mathematical Theory of Elasticity* (1944), pp. 287–292.

I3. Sound Scattering by Thin Elastic Shells.* MIGUEL C. JUNGER, *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—The theory of scattering of plane waves of sound is extended to scatterers in the form of thin elastic shells of cylindrical and spherical shape. As for all elastic scatterers, the scattering action is the resultant of (1) "rigid body scattering," i.e., the scattering which would be present if the scatterer were rigid and immovable; (2) "radiation scattering," which represents the sound radiation from the shell undergoing forced vibrations under the influence of the incident wave pressure and which is determined by the dynamic characteristics of the submerged shell. Contrarily to solid scatterers whose dynamic characteristics are little different *in vacuo* and in the fluid medium, the characteristics of shells are profoundly altered by fluid reaction. When the shell is excited near resonance, the scattering pattern resembles the dynamic response of the shell in that it is highly frequency sensitive.

* This research has been aided by funds made available under a contract with the ONR.

I4. Precise Measurement of the Velocity of Sound.* P. W. SMITH, JR., *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—Precise measurements of the velocity of sound in a gas at low frequencies have been made by a method of detecting the variations in the driving-point impedance caused by changes in the distance from the transducer diaphragm to a reflecting piston. The electrical terminals of the transducer are connected into the feedback circuit of a bridge-stabilized oscillator so that the frequency of oscillation is determined by the position of the piston. Measurements of the position of the piston are made at points for which the frequency is identical. When careful consideration has been given to all the possible sources of error and proper corrections have been applied, the accuracy of the results is comparable with that of the best measurements made by other means. Measurements made in air at 1000 cps yield a velocity, corrected to standard conditions, of 331.46±0.05 m/sec. The analysis of one source of error has been generalized to apply to other systems whose operation depends upon the reaction of the acoustical field upon the transducer. It is shown that recurrent extrema measured in the electrical circuit which result from changes in the position of the reflecting piston will not in general have a period precisely equal to the half-wavelength of sound.

* This research has been aided by funds made available under a contract with the ONR.

I5. Construction of Apparatus for Measuring the Velocity of Sound in Gas Mixtures. JAMES WOODBURN, *Rice Institute, Houston, Texas*.—The present paper deals with the construction of apparatus for measuring the velocity of sound in gas mixtures at maximum pressures of 400 psi and 750°F. Experimental results have been obtained on mixtures of CO_2 and N_2 at a constant mixture pressure and from a temperature range from room temperature to 525°F. The frequency of all measurements has been at 575 kc. A general description of the present apparatus will be presented and also some high pressure gas ultrasonic apparatus in which work is being done at the present on the above gas mixtures. The high pressure apparatus will withstand a maximum pressure of 7000 psi and a maximum temperature of 1000°F.

I6. Absorption of Sound in Argon, Nitrogen, and Oxygen at Low Pressures.* J. G. PARKER† AND R. M. STAVSETH, *Department of Physics, Brown University, Providence, Rhode Island*.—The amplitude absorption coefficient α for pulsed spherical sound waves in argon, nitrogen, and oxygen has been measured over a 1–10 mm Hg range of pressure p and a 60–70 kc range of frequency f for temperatures varying from 20° to 21.5°C, by means of apparatus described previously.[1] For the three gases used, the following experimental values for $p\alpha/f^2\times10^7$ were obtained: 1.86±0.05 (argon), 1.63±0.05 (nitrogen), 1.95±0.05 (oxygen) as compared with the respective classical theoretical values of 1.87, 1.31, and 1.61. Thus the absorption in argon is classical, while for nitrogen and oxygen there are fractional excesses of 0.24±0.04 and 0.21±0.03, respectively. If these excesses are attributed to rotational relaxation and the associated relaxation time τ is calculated for each gas in accordance with the thermal relaxation theory of Herzfeld and Rice,[2] one obtains the values 4.85×10^{-10} and 4.95×10^{-10} second, respectively, for nitrogen and oxygen. Both of these values are significantly smaller than those which have been calculated in a similar manner by previous workers[3] on the basis of data obtained at higher frequencies. We therefore have evidence that the aforementioned theory is unable to describe rotational relaxation processes adequately.

* Work supported in part by ONR.
† Now at the Institute for Cooperative Research, Johns Hopkins University, Baltimore, Maryland.
[1] Parker, Adams, and Stavseth, J. Acoust. Soc. Am. 23, 628A (1951).
[2] Herzfeld and Rice, Phys. Rev. 31, 691 (1928).
[3] W. J. Thaler, J. Acoust. Soc. Am. 24, 15 (1952).

I7. Solutions of the Generalized Eikonal Equation for Moving Fluids.* E. T. KORNHAUSER, *Brown University, Providence, Rhode Island*.—Heller[1] has pointed out that weak acoustic shocks in moving fluids are propagated according to a generalized eikonal equation, $|\nabla\phi|^2=\mu^2[1-(V\cdot\nabla\phi/c_0)]^2$, where c_0 is the reference sound velocity, V the vector velocity of the moving fluid, and μ the refractive index. Such an expression has also been used by Milne[2] to obtain approximate solutions for wave propagation in the atmosphere subject to the effect of wind. This equation may be obtained as a very simple extension of the ordinary eikonal equation. Solutions are exhibited for some simple cases involving point sources or plane waves. Solutions obtained by Milne on the basis of a generalized Snells' law are shown to be incorrect except in the case of a plane wave incident from a homgeneous half-space.

* Supported by ONR contract.
[1] G. S. Heller, Paper No. I9, to be presented at meeting of Acoustical Society of America, May, 1952.
[2] E. A. Milne, Phil. Mag. 42, 96 (1921).

I8. The Attenuation of Repeated Shock Waves.* ISADORE RUDNICK AND ROBERT W. LEONARD, *Department of Physics, University of California, Los Angeles, California*.—The sound waves generated by the siren described in an earlier paper on this program by the same authors develop shock fronts in a short distance of travel and their shape finally approximates the characteristic sawtooth form. The spatial attenuation rates of such waves have been measured as a function of the siren frequency in the range 30–100 cps. A typical datum shows that a 100-cps wave with a pressure ratio across the shock of 1.5 is reduced by a factor of 2 in a travel distance of 55 feet. A first-order theory using the Rankine Hugoniot shock conditions is developed for a sawtooth wave. This gives attenuation rates which are higher than those observed experimentally. For the datum given the ratio of theoretical to observed attenuation rate is 1.5. This discrepancy will be discussed.

* Part of this work was performed under ONR contract N8onr-70502 with Soundrive Engine Company, Los Angeles, California, under the authors' technical direction.

I9. On the Propagation of Acoustic Discontinuities in a Moving Inhomogeneous Fluid.* G. S. HELLER, *Brown University, Providence, Rhode Island*.—Consider a moving surface, on which the time derivatives of velocity and pressure are discontinuous but on which the velocity and pressure themselves are continuous. Such discontinuities may correspond to dissipated shock waves or "weak shocks." Then under the assumption that each moving fluid element undergoes adiabatic changes, it can be shown that the surface is given by the solution of a generalized eikonal equation, which in the case of a fluid at rest becomes the ordinary eikonal equation of ray acoustics. This treatment does not require the usual assumption of infinitesimal amplitudes ordinarily used in acoustics. Conservation laws corresponding to those in ray theory are also derived under the above assumptions.

* Supported by an ONR contract.

I10. Sound Propagation in Granular Media.* R. W. MORSE, *Brown University, Providence, Rhode Island*.—The sound velocity and attenuation in a granular medium such as air- or water-saturated sand are discussed theoretically and conclusions are compared with experiments. A simplified theory based on the gross properties of the porous medium is shown to predict a square-root frequency dependent attenuation coefficient and a nondispersive velocity dependent only on the porosity of the sand and the sound velocity in the fluid (provided the frequency is high enough). Calculated values for the attenuation coefficient agree fairly well with reported measurements in air-sand mixtures.[1] Predicted sound velocities are consistent with geophysical data. Comparisons are also made with results of theories based on viscous-wave scattering by the particles. The scattering theory of Epstein[2] and others, though not intended to be applied to such a close-packed medium as sand, is shown to yield an expression for the attenuation coefficient which is very nearly the same as that given by the gross theory.

* Supported by ONR.
[1] Nyborg, Rudnick, and Schilling, J. Acoust. Soc. Am. 22, 422 (1950).
[2] P. S. Epstein, *Theo. von Karman Anniversary Volume*, p. 162.

I11. Intensity Fluctuations of Radiation Propagated in a Randomly-Inhomogeneous Medium.* DAVID MINTZER, *Physics Department, Brown University, Providence, Rhode Island.*—By considering an approximate solution to the equations of ray propagation, P. G. Bergmann[1] has derived an expression for the fluctuation of the intensity of radiation from a non-directional source, propagated through a medium in which the index of refraction varies randomly with position, subject to the condition that the variations are small compared with unity. It is found that his theoretical results do not give the correct range dependence for the intensity fluctuations. In an effort to remove this discrepancy, the equations have been extended to include the directionality of the source and absorption in the medium. Comparison will be made with experimental results.[2,3]

* Assisted by an ONR contract.
[1] P. G. Bergmann, Phys. Rev. 70, 486 (1946).
[2] M. J. Sheehy, J. Acoust. Soc. Am. 22, 24 (1950).
[3] L. Liebermann, J. Acoust. Soc. Am. 23, 563 (1951).

Session J. Piezo-Electric Transducers and Ultrasonics

Contributed Papers

J1. Theoretical Sensitivity of a Transversely Loaded, Circular Bimorph Transducer. EDWARD G. THURSTON, *Battelle Memorial Institute, Columbus, Ohio.*—With the advent of barium titanate as a piezoelectric material, the construction of transducers whose active elements can be in a wide variety of shapes became possible. The theoretical sensitivity of an interesting structure consisting of a transversely loaded, centrally supported, circular, barium titanate bimorph is calculated using the results of elasticity theory. Some experimental verification is presented.

J2. The Analysis of Magnetostrictive and Piezoelectric Transducers by the Mode Impedance Method.* FRANK J. ROSATO, *Acoustics Research Laboratory, Harvard University, Cambridge, Massachusetts.*—The basis of this method, which is particularly applicable to continuous systems, is as follows: the dynamic configuration of the vibrating element is expressed in terms of the generalized coordinates of the system and the appropriate mode functions. Next, the kinetic and potential energies of the system are expressed in terms of the generalized coordinates. Application of the nonhomogeneous Lagrange equations then leads to the dynamical equations of motion, one in each of the generalized coordinates. For continuous systems, the number of dynamical equations is necessarily infinite. In this theory, the magnetostrictive (or piezoelectric) induced stresses are considered as part of the generalized forces; the remaining generalized forces take into account the reaction of the fluid medium on the vibrating surface and other forces acting on the system. The magnetostrictive (or piezoelectric) equation which relates the total magnetic induction (or total electric polarization) to the external magnetic (or electric) field and the induced strain, is then employed to obtain the electromechanical equations of the transducer. These equations may then be represented by electromechanical networks, consisting of two input electric terminals and an infinite set of output mechanical terminals. The final results may be obtained to any degree of approximation desired.

* This research has been aided by funds made available under a contract with the ONR.

J3. Surface Vibration Patterns of Ultrasonic Radiators. III.* JOHN D. NIXON,† RICHARD A. RHODES II, AND A. O. WILLIAMS, JR., *Physics Department, Brown University, Providence, Rhode Island.*—Previous experimental work[1] has been modified by placing an optically flat partially silvered quartz crystal between two optically flat plates of glass, partially silvered adjacent to the crystal (intervening air space 1 mm). The optical fringes, formed thus, indicate the behavior of both sides of the vibrating crystal. This modification prevents the study of acoustic radiation into liquids, but gives sharp fringes, and eases the problem of collimation and photography Two 18½° X-cut and two X-cut quartz crystals, one of each at 0.5 mc and 1 mc, were investigated by this method and by a capacitance bridge. The 18½° crystals behaved more uniformly, but all displayed several modes corresponding to a particular localized vibration pattern in a small area; the sum of these areas approaches the surface area of the crystal. The phenomenon is tentatively attributed to crystalline inhomogeneity. Attempts to enhance the effect by reducing the acoustic loading through reduction of air pressure gave inconclusive results.

* Work aided by the ONR.
† Now at Narragansett Marine Laboratory, University of Rhode Island.
[1] J. D. Nixon and A. O. Williams, J. Acoust. Soc. Am. 22, 676A (1950); 23, 629A (1951).

J4. Electromechanical Response and Dielectric Loss of Prepolarized Barium Titanate Ceramics under Maintained Electric Bias. HANS G. BAERWALD AND DON A. BERLINCOURT, *The Brush Development Company, Cleveland, Ohio.*—The effect of a maintained aiding direct current bias field on the performance of prepolarized barium titanate ceramics has been investigated with respect to both loss factor and electromechanical response over the temperature range from 25° to 120°C as a function of bias field strength. In addition the effect on the temperature variation of the reversible dielectric constant was studied. The dielectric losses under high ac fields are considerably reduced by the application of bias, and the magnitude of this effect shows a pronounced temperature dependence. Aiding bias also proves beneficial by substantially increasing the electromechanical coupling, and it raises the Curie point by up to about 4°C. Dielectric loss factors were determined semiquantitatively by bridge measurements at moderate ac fields and by means of hysteresis loop areas at higher fields. Both the electrostrictive coefficient u_{31} relating transversal strain to the square of the total charge density and the linear piezoelectric coefficient g_{31} relating the increment of strain to the increment of charge density in prepolarized ceramics have been measured directly. From these results, approximate values of retained polarization referring to various physical conditions have been determined; they range to about 11 microcoulombs per square centimeter.

J5. Some Vibration Patterns of Thick Barium Titanate Disks. E. A. G. SHAW, *Division of Physics, National Research Council, Ottawa, Canada.*—The forms of some resonant vibrations of thick polarized barium titanate disks have been examined by an optical method using multiple beam Fizeau fringes with stroboscopic illumination. The technique permits accurate determination of the distribution of displacement amplitude over the surface of the disk. Only modes having axial symmetry appear to be strongly excited, and more than one strong resonance is observed in a frequency range which should include the principal dilatational thickness mode. Each mode in this region has characteristics generally associated with both axial and radial resonances.

J6. Ultrasonic Propagation in Dry CO_2-Free Air.* C. ENER† AND J. C. HUBBARD, *Catholic University of America, Washington, D. C.*—The ultrasonic properties of dry, CO_2-free air have been measured at 32°C and f/p values ranging from 2 to 125 Mc/atmos. Dispersion of the velocity has been found beginning at 30 Mc/atmos, accompanied by a large increase in absorption such that measurements could not be made above 130 Mc/atmos with the equipment used. Changes in velocity, absorption, and specific heat are interpreted as owing to the slowing of energy exchange between translational and rotational states. The relaxation time derived from the dispersion measurements has been found to be 2.29×10^{-9} sec, corresponding to a midpoint of the dispersion curve at 116 Mc/atmos.

* Supported by the ONR.
† From the University of Istanbul, Turkey. At the Catholic University of America, November, 1949–February, 1951.

J7. Diffraction and Reflection as Sources of Error in Ultrasonic Measurements.* J. C. HUBBARD, *Catholic University of America, Washington, D. C.*—Current practise in ultrasonic intensity measurements and interferometry in gases favors the mounting of a source such as a piezoelectric crystal (1) flush with a plane surface, (2) behind an orifice, or (3) projecting into a chamber. Reflector and source in interferometers are usually mounted in a cylindrical or box-like chamber of greater lateral dimensions than source and reflector. It is well known that diffraction takes place under these conditions. Not much attention has been paid to the reflection of diffracted sound from side walls back into the main beam. Under such conditions measurements of intensity by probes or otherwise are subject to complicated variations with distance from the source and half-wave determinations by any method, especially near the source, show variations from the constancy which can otherwise be obtained. Errors due to these causes may largely be avoided if the measurements can be carried out in a tubular chamber of material having as large a value of ρc as may be obtained, the full cross section of which is covered at one end by the source. In the case of the interferometer the reflector should also completely fill the cross-section of the tube. Reflector and source should be plane and parallel and accurately perpendicular to the axis of the tube. Diffraction will then be practically absent, reflection is largely confined to the surfaces of source and reflector. Shadowgraph and schlieren pictures and numerical data will be presented in support of these statements. These precautions have been taken from the first by the writer and his students.

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AUTHOR INDEX TO ABSTRACTS OF THE NEW YORK MEETING